Rehabilitation studies and recovery of a once lifeless estuary: the Golden Horn

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Abstract Within this study fluctuations in biodiversity of the Golden Horn from past to present are evaluated. Limited studies and observations dating back to 60 years ago pointed out the importance of the Golden Horn as a fishery. Unfortunately, in accordance with increase in unplanned settlements and industry around the Golden Horn in the 1960s, pollution stress became a demanding factor for this unique environment, affecting biodiversity adversely. Preliminary studies in the 1990s indicated survival of only a couple of pollution-resistant species, at the relatively cleaner outer estuary. Following intensification of "still ongoing" rehabilitation studies in 1998, a remarkable day-by-day recovery in marine life has began, in regard to improvements in water quality. Surveys conducted in 2002 using SCUBA, documented the level of diversification of life at the Golden Horn. Extended till Haliç Bridge, all appropriate substratums were intensely covered by macrobenthic forms and particularly filter feeders dominated the plankton-rich ecosystem. Detection of seahorses at the inner-middle parts of the estuary, in addition to numerous fish, invertebrate and macroalgae species, clearly depicted the level of recovery and change in the ecosystem. All results support the existence of a dynamic biological life at the Golden Horn, improving considerably with rehabilitation studies. Achieving the diversity of the 1940s is not possible, since the Black and Marmara seas, highly influencing water quality in the Golden Horn are also suffering from anthropogenic impacts and are far beyond their rich diversity in the 1940s. However, it is obvious that ecosystems should recover when mankind gave a chance to them. Recovery of the recently lifeless Golden Horn in such a short period of time is a very good example.

Keywords Biodiversity; estuary; fauna and flora; Golden Horn; rehabilitation; water quality

Introduction

For centuries, the Golden Horn has been the recreational and trade center of Istanbul; a city having a known history of almost 5,000 years. Increase in settlements and industrial facilities around the Golden Horn since the 1950s were accompanied with severe pollution, particularly from wastewaters of pharmaceutical, detergent, dye and leather industries and domestic discharges. Moreover, dams built on streams considerably blocked freshwater input, while the dry docks of shipyards located at middle parts of the estuary and floating bridges at various points inhibited water circulation greatly (Figure 1). As a consequence of estuarine characteristics and anthropogenic perturbations, a major proportion of the estuary was almost completely filled and the innermost parts were connected to the middle estuary only via a narrow channel in the early 1990s.

The 7.5 km long, 150–900 m wide estuary, located at the south west of the Strait of Istanbul was originally characterized by a two-layered structure similar to the Strait of Istanbul and Sea of Marmara. Saline (~38 psu) Mediterranean waters were covered by less saline Black Sea waters (~18 psu), while salinity dropped to 13–14 psu at the innermost parts, due to freshwater input. However, blocking of the upper layer circulation by floating bridges and dry docks caused formation of a 2–3 m thick, less refreshing third layer, whose character was highly associated with surface discharges of industrial facilities and domestic wastewater (Özsoy *et al.*, 1988). Soon hydrogen sulfide formed at the inner parts and prevailed throughout the year, increasing its magnitude in warmer periods

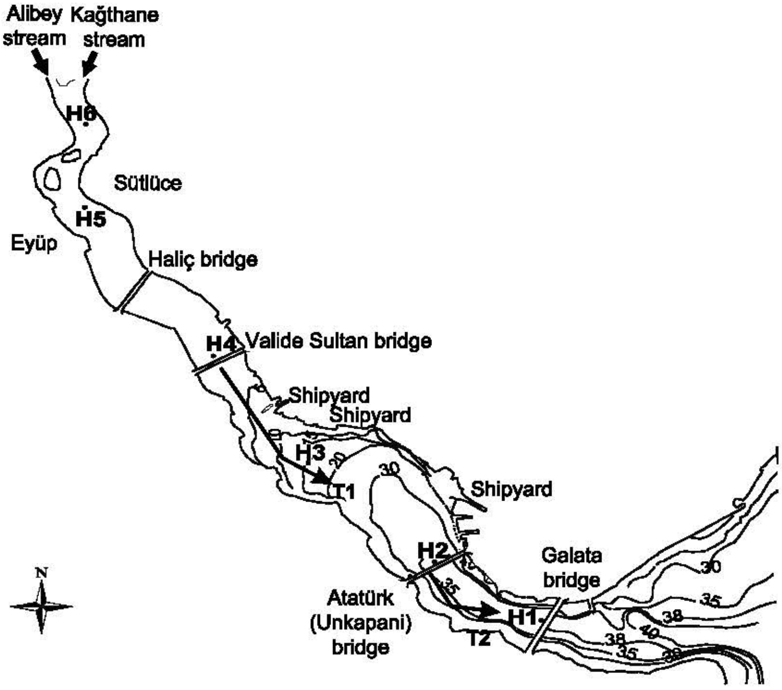

Figure 1 Map of Golden estuary. Arrows indicate horizontal ichthyoplankton net casts

of the year (Kıratlı and Balkıs, 2001). The devastation of the Golden Horn had drastically affected its ecosystem. Severe pollution limited marine life to the surroundings of Galata Bridge, while more inner parts were almost lifeless (Güvengiriş, 1977).

Within the framework of rehabilitation studies started in 1996, an important fraction of surface discharges were gradually taken under control and connected to collector systems. The North collector was linked to Baltalimanı Deep Discharge Facility, while the collector system at the south of Golden Horn has ended at the Ahırkapı Deep Discharge Facility. The most important, $4.25 \times 10^6 m^3$ anoxic sediment filling the inner estuary was pumped to an ex stone quarry and 4–5 m depth was gained at this region. Following the semi-opening of the floating bridge located at the inner estuary, freshwater was released from the closest dam for rapid oxidization of the entire water column, particularly of the anoxic inner parts. The response of the Golden Horn ecosystem to rehabilitation efforts was very quick and life incredibly diversified at the Golden Horn. This paper deals with past and present state of marine life in the Golden Horn.

Material and methods

Water samples for nutrient, chlorophyll a, dissolved oxygen, phytoplankton and fecal coliform analyses for the 1998–2002 period were collected monthly by 51 Niskin bottles from various points and depths at the estuary. All sampling procedures and analyses were detailed in reports of the Institute, submitted to the General Directorate of Istanbul Water and Sewerage Administration (e.g. Sur *et al.*, 2003). Macrozoobenthos samples were collected using a Van Veen grab ($0.1 m^2$ area). Ichtyoplankton samples were collected by 5 or 10 minute horizontal tows of a 500 μm Nansen net between Unkapanı and Galata bridges starting from 1999, after water quality at the upper layer became appropriate for horizontal net tows. Following the semi opening of the floating bridge and release of freshwater in June 2000, a second horizontal tow was started between Valide Sultan and

Unkapanı bridges. Additionally at three stations, a 200 μm Nansen net was vertically hauled from 10 (Camialtı) or 20 (Galata and Unkapani) metres. Results of ichthyoplankton analyses were given as individuals in $10^2 m^2$ according to (FAO, 1974). A similar methodology has also been utilized for the base study prior to the onset of rehabilitation studies in 1996.

Results and discussion

Water quality

Studies performed two decades ago pointed out devastation of the Golden Horn ecosystem (Saydam *et al.*, 1986). Following the onset of rehabilitation studies at the estuary, the dissolved oxygen (DO) concentrations have risen $\sim 3\,mg.l^{-1}$ between Galata and Unkapanı and H_2S at the upper layer around Balat-Eyüp has disappeared in the second half of 1998, while following 2000, it is very seldom detected at the innermost parts, particularly in warmer periods of the year. Total suspended sediment (TSS) values were decreased from $80\,mg.l^{-1}$ to $10\,mg.l^{-1}$ in 2000 at Kasımpaşa, however they remained around $25\,mg.l^{-1}$ at the more inner parts due to high phytoplankton densities and influxes particularly originating from rainfall (Kıratlı and Balkıs, 2001). The decline in TSS was accompanied by a clear increase in Secchi depths. Excluding periods of high phytoplankton development, Secchi depth has risen from 20 cm to 4 m in three years. Excessive nutrient concentrations in 1998 were pointing out intense pollution. Following the connection of numerous discharges to the collector system, semi-opening of Valide Sultan Bridge (inhibiting upper layer circulation considerably) and release of freshwater form a dam located on the stream for rapid renewal of water body, nutrient concentrations at the outer estuary approached the concentrations of the Strait of Istanbul. Meanwhile, a remarkable decrease was monitored at the innermost regions when compared to 1998, despite of weak circulation and ongoing inputs from the Alibey and Kağıthane streams (Okuş *et al.*, 2001). For instance at the outer estuary, NO_2 values decreased form $5\,\mu mol\,l^{-1}$ to $<1\,\mu mol\,l^{-1}$; $NO_2 + NO_3$ concentrations from $18\,\mu mol\,l^{-1}$ to $<5\,\mu mol\,l^{-1}$ and SiO_2 from $\sim 300\,\mu mol\,l^{-1}$ to $<50\,\mu mol\,l^{-1}$ (Okuş *et al.*, 2001). Chlorophyll a values clearly depicted a level of recovery at the Golden Horn ecosystem, reflecting alterations from anoxic conditions to a eutrophic environment. Heavily polluted upper layers, where only a few or no phytoplankton biomass exist, began to face dense and frequent phytoplankton blooms with chlorophyll a values approaching $500\,\mu g.l^{-1}$ (Okuş *et al.*, 2001). In 2000 chlorophyll a concentrations were generally below $10\,\mu g.l^{-1}$ at the outer estuary and around $50\,\mu g.l^{-1}$ at more inner parts, displaying clear seasonal patterns. The level of change can be best followed from the bacteriological data (Figure 2). High bacterial counts of 1998, approaching 10^7 CFU.100 ml^{-1}, gradually decreased during the rehabilitation studies. In 2000 fecal

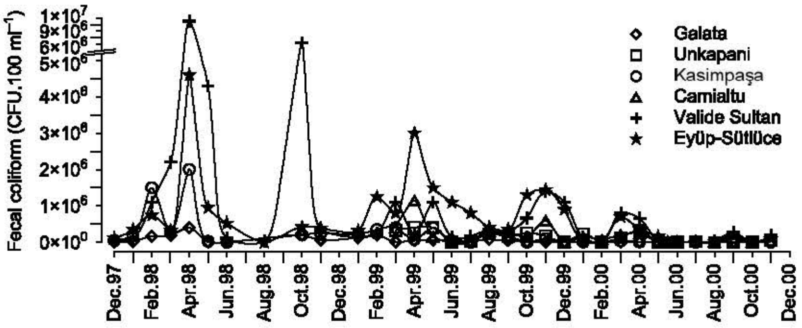

Figure 2 Spatiotemporal fluctuations in fecal coliform values (Aslan *et al.*, 2001)

coliform values were around 500–1,000 CFU.100 ml^{-1} between Galata and Kasımpaşa and below 5,000 CFU.100 ml^{-1} at Valide Sultan Bridge and Eyüp though, during rainy periods, values rapidly increased, as a consequence of increase in discharges (Aslan *et al.*, 2001).

Phytoplankton

Plankton studies performed before 1996 clearly demonstrated that pelagic life was very limited. Saydam *et al.* (1986) stated that phytoplankton distribution was very weak or almost no plankton existed at upper layers in 1985. Uysal (1986) could not even sample uppers layers for phytoplankton studies, while he identified 29 diatom species at 10, 20 and 30 m samples, highly influenced by the Strait current system. In 1995 Taş and Okuş (2003) determined 24 phytoplankton species (16 diatoms and 8 dinoflagellates) and reported a great decrease in both phytoplankton abundance and species number towards the middle parts of the estuary. More inner parts than Valide Sultan Bridge were completely filled by sediment and anoxic conditions did not affect phytoplankton development. Plankton studies dating later than 1998 clearly reflected the changing ecosystem of the Golden Horn. Phytoplankton species number increased from 44 species in 1998 to 60 in 1999, 81 in 2000 and finally to 92 in 2001 (Taş, 2003).

Macroalgae

One of the earliest records of macroflora at the Golden Horn dated back to the studies of Fitsch (1899), who reported 3 species from Chlorophycea (*Enteromorpha compressa*, *Cladophora crystallina* (*Conferva crystallina*), *C. tenerrima*), 1 species from Pheaophycea (*Ectocarpus siliculosus*) and 4 species from Rhodophyceae (*Chondriopsis tenuissima*, *Alsidium subtile*, *Polysiphonia sanguinea*, *Cermamium diaphanum*), reflecting the eutrophic status of the Golden Horn even at the beginning of 1900s. In 1990 the level of eutrophication limited diversification and distribution of macroalgae greatly and only four species resistant to eutrophication survived at the spray zone; *Enteromorpha intestinalis* var. *tubulosa*, *E. intestinalis* var. *intestinalis*, *E. compressa* and *Ulotrix flaxsa* from Chlorophyceae (Aydın and Yüksek, 1990). Species at the mediolittoral zone, on the other hand, completely lost their pigmentation and no macroalgae distribution was detected at lower depths. No algae species either at the spray zone or mediolittoral were detected after Eyüp-Sütlüce. During a study prior to the onset of rehabilitation studies, distribution of only 2 species from Chlorophycea (*Enteromorpha intestinalis* var. *tubulosa*, *E. intestinalis* var. *intestinalis*, *E. compressa*) at the spray zone was reported (Okuş *et al.*, 2001). During a coastal vegetation survey in 2000, Erdal (2000) sampled 1 species from Cyanophycea, 6 species from Chlorophyceae and 1 species from Rhodophyceae. More important, Erdal reported distribution of 1 species from Cyanophyceae and 3 from Chlorophyceae at the innermost regions of the estuary (from Eyüp to Alibey stream), where no species existed in the 1990s. Observations performed in 2001 clearly depicted diversification of macroalgae species in the Golden Horn and 1 species from Cyanophyceae (*Oscilatoria* sp.), 7 species from Chlorophyceae (*Ulva lactuca*, *E. intastinalis*, *E. compressa*, *Chalodophora porilifera*, *Chaetomorpha* sp. *Bryopsis* sp., *Ulotrix flacca*) and 1 from Rhodophyceae (*Ceramium rubrum*) were detected. SCUBA dives in 2002 showed that distribution of macroalgae species was not limited to the surface or spray zone. Species such as *Ulva lactuca*, *Entramorpha intestinalis*, *E. compressa*, *Ceramium rubrum* were monitored till 20–30 m, successfully distributed over dense *Mytilus galloprovincialis* facies, where only anoxic mud consisted until recently (Demo Production, 2002).

Macrozoobenthos

Prior to the rehabilitation studies, species identified were usually from Polychaeta, highly tolerant to organic pollution (Ünsal, 1988). Ünsal detected 5 species around Galata Bridge with a diversity of 2.02 (H'), towards the inner parts the number of species decreased to 2 and diversity to 0.11. The dominant species around Galata Bridge was *Polidora ciliata* (% 54.7) while *Capitella capitata* (% 91.7) was dominant between Kasımpaşa–Sütlüce. Diversity and distribution of species clearly reflected the level of organic pollution at the estuary, particularly at the inner parts. A base study for planning of rehabilitation studies showed that some polychaetes were present between algae located in the spray zone or mediolittoral while no macrobenthic life was detected in grab samples taken from the anoxic sediment (Okuş *et al.*, 1996). Studies conducted in 2000 pointed out dense Crustacea and Polychaeta communities inside macroalgae distributed along the coasts of the Golden Horn (e.g. *Jassa falcata*, *Maera grossimana*, *Gammarus* sp., *Caprella acanthifera*, *Idotea baltica*, *Semibalanus* sp., *Hesione panterina*, *Polydora* sp.) (Erdal, 2000). Macrobenthic life particularly increased around Galata Bridge in 2001. *Mytillus galloprovincialis* from Bivalvia; *Ampelisca* sp., *Jassa* sp., *Maera* sp., *Erichthonius* sp., *Liocarcinus* sp., *Chthamalus* sp. from Crustacea and *Polycirus* sp., *Nereis* sp., *Eunice* sp. from Polychaeta were widely distributed. Dense *Mytillus galloprovincialis* facies extended till Eyüp–Sütlüce. During this period Secchi depth increased to 4 m from 0.1 m. Grab samples of recently anoxic Camialtı, bear dense *Hinia* sp. (Gastropoda) and *Pagurus* sp. (Crustacea) populations. Decapoda, Echinodermata and Tunicata larvae detected in plankton net samples in 1999 indicated that larvae drifted to the estuary by currents, could settle in the region, if optimum conditions are achieved (Yüksek *et al.*, 2001). SCUBA dives performed at 10 points in 2002 showed that wide *Mytillus galloprovincialis* beds were populated densely by *Balanus* sp., *Liocarcinus depurator* (Crustacea), *Asterias rubens* (Echinodermata) and *Ciyona* sp. (Tunicata) populations between 10–34 m depth contour (DEMO Productions, 2002). Dives at Ayvansaray–Sütlüce (4 m), where water exchange could be maintained through a very thin stream due to sedimentation very recently, showed that the sand substratum was populated by tunicates, *Crangon* sp. (Crustacea) and a characteristic brackish water bivalve *Cerastoderma glaucum*, thus clearly depicted the level of recovery and fluctuation in the ecosystem and water quality of the Golden Horn.

Ichthyoplankton (Fish egg and larvae)

No historical data exist on distribution of fish larvae and eggs in the Golden Horn. However the significant alterations in the ecosystem of the Golden Horn, made ichthyoplankton surveys obligatory to understanding the importance of the estuary in fisheries, since brackish waters are known to be very favorable regions for development of fish egg and larvae worldwide. Following the onset of rehabilitation studies and recovery at the upper layer, the first ichthyoplankton samplings have been started in 1999 and all eggs and larvae collected appeared to be dead before sampling. However, ichthyoplankton rapidly diversified in the estuary after semi opening of the floating bridge and "flushing" of the estuary by freshwater supplied from the closest dam. By the end of 1999, eggs and larvae belonging to 16 species were determined, 11 alive during sampling and 5 dead (European pilchard, European sprat, Brown comber, Red mullet and European seabass). This number increased to 24 in 2000 and alive specimens belonging to all 24 species were recorded. In 2001 27 species and in 2002 28 species were determined alive. The eggs of some certain species, such as European anchovy (*Engraulis encrasicolus*), European sprat (*Sprattus sprattus*), Black scorpionfish (*Scorpaena porcus*), Mediterranean horse mackerel (*Trachurus mediterraneus*), Whiting (*Merlangius merlangus*), Shore rockling (*Gaidropsarus mediterraneus*), *Symphodus* sp., appeared to be in early stages of their embryological development, thus indicating that these species are local for the estuary. The most frequently determined species in the first two years were; in spring, larvae of European seabass (*Dicentrarchus labrax*); in summer, European anchovy (*Engraulis encrasicolus*) eggs and larvae, Golden grey mullet (*Liza aurata*) larvae, Mediterranean horse mackerel (*Trachurus mediterraneus*) eggs, Black scorpionfish (*Scorpaena porcus*) eggs and Common sole (*Solea solea*) eggs; in autumn, Shore rockling (*Gaidropsarus mediterraneus*) egg and larvae and in winter, European sprat egg and larvae. However in winter 2002 most frequently determined species changed and Shore rockling appeared as the most frequent species, while abundance of larvae and eggs of European sprat regressed. In summer of 2002 wrasses (*Symphodus* sp.) dominated ichthyoplankton. There is a marked seasonality in ichthyoplankton species number (Figure 3d) and a more diverse community characterized summer–early autumn. Number of species generally increased rapidly in June and minimum numbers are detected in spring. Excluding the November 2001–January 2002 period, fish egg and larvae densities were always higher along the Transect-I where seasonal fluctuations are also better discriminated (Figure 3a, c). Alterations in mortality of fish eggs clearly reflect the recovery of the pelagic ecosystem. The linear fit demonstrated a continuous decrease in the 4 year period and mortality rates decreased from 100% in 1999 to ~40% in 2002 (Figure 3b). Mortality rates were slightly higher at Transect-II than Transect-I. High mortality rates in summer might be attributed to dense phytoplankton blooms, while mortalities in autumn might be due to rapidly changing environmental conditions.

Fish diversity

Güvengiriş (1977) described the old Golden Horn as a rich ecosystem, where people caught Common two-banded seabream (*Diplodus vulgaris*), Blotched picarel (*Spicara maena*) and Mediterranean horse mackerel from the coast by dip nets, crowded dolphin groups enter and valuable fishes such as Atlantic bonito (*Sarda sarda*), Northern bluefin tuna (*Thunnus thynnus*), Bluefish (*Pomatomus saltatrix*) were caught. Even the streams feeding the estuary were rich in European Chub (*Leuciscus cephalus*) and Rudd

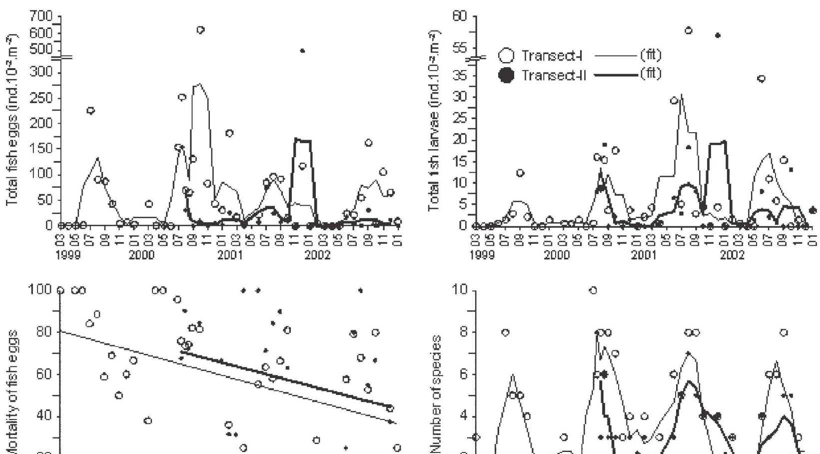

Figure 3 Variations in ichthyoplankton components of Golden Horn during the recovery of the estuary. Fits are 3 point running means for total fish eggs, larvae and species numbers and linear fit for mortality of fish eggs

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(*Scardinius erythrophthalmus*). Unfortunately in 1996, fish distribution was limited to the outermost region (around Galata Bridge) and only fishes such as mackerel, sprat and mullet were caught (Okuş *et al.*, 1996). Nowadays, the fish community of the Golden Horn, is once again, significantly diversified. Between Galata and Unkapanı bridges, angling has become a popular activity and fishes such as Golden grey mullet, Flathead mullet, Thicklip grey mullet, European seabass, European sprat, European anchovy, Black scorpionfish, Mediterranean horse mackerel, Blotched picarel, Brown meagre, Red mullet, Flounder, Bluefish, Atlantic bonito are caught. Mugil, European seabass and Bluefish have even penetrated to more inner parts of the estuary. Although freshwater species were very frequent in streams feeding the estuary in 1940s, nowadays they are seldom recorded at the Golden Horn, as a consequence of dams built on the streams. In May 2000, following the release of water from Alibey Stream, large quantities of dead Rudd were seen around Sünnet Köprüsü, indicating persistence of these species in the dam reservoir. Existence of 35 species in Golden Horn was detected in 2002, for feeding and/or reproduction purposes. Among these 35 species, egg and/or larvae belonging to 32 were determined (Table 1). SCUBA dives showed that demersal fishes were widely distributed in the Golden Horn, a good indicator of the current status of life in the Golden Horn and level of recovery of the ecosystem after the rehabilitation studies.

Table 1 Fish species identified at Golden Horn in 1999–2002 period

	Ichthyoplankton				Adults sampled (Galata-Unkapanı)
	1999	2000	2001	2002	
Sardina pilchardus (Walbaum, 1792))	*	*	*	*	*
Sprattus sprattus (Linnaeus, 1758)	*	*	*	*	*
Engraulis encrasicolus (Linnaeus, 1758)	*	*	*	*	*
Atherina sp		*		*	*
Dicentrarchus labrax (Linnaeus, 1758)	*	*	*	*	*
Liza auratus (Linnaeus, 1758)	*	*	*	*	*
Mugil labrousus (Risso, 1827)	*	*		*	*
Mugil cephalus (Linnaeus, 1758)	*	*	*	*	*
Mugil so-iuy (Basilewsky, 1855)		*		*	*
Gaidropsarus mediterraneus (Linnaeus, 1758)	*	*	*	*	*
Merlangius merlangus (Linnaeus, 1758)		*	*	*	*
Trachurus meditterraneus (Steindachner, 1868)	*	*	*	*	*
Mullus barbatus Linnaeus, 1758		*	*	*	*
Serranus hepatus (Linnaeus, 1758)	*	*	*	*	*
Trigla sp.		*	*	*	*
Scorpaena porcus (Linnaeus, 1758)	*	*	*	*	*
Microchirus variegatus (Donovan, 1808)		*	*	*	*
Buglasidium luteum (Risso, 1810)		*	*		*
Solea solea (Linnaeus, 1758)	*	*	*	*	*
Platichthyes flesus (Linnaeus, 1758)	*	*	*	*	*
Callionymus sp.					*
Uranuscopus scaber Linnaeus, 1758		*	*	*	*
Belenius sp.	*	*	*	*	*
Gobius sp.	*	*	*	*	*
Ctenolabrus rupestris (Linnaeus, 1758)			*	*	*
Spicara maena (Linnaeus, 1758)	*	*	*		*
Symphodus tinca (Linnaeus, 1758)			*	*	*
Scianea umbra (Linnaeus, 1758)			*		*
Pomatomus saltator (Linnaeus, 1758)				*	*
Sarda sarda (Bloch, 1793)			*		*
Diplodus annularis (Linnaeus, 1758)			*	*	*
Hippocampus guttulatus (Cuvier 1829)			*	*	*
Sygnathus acus (Linnaeus, 1758)					*
Gynammodytes cicerelus (Rafinesque, 1810)				*	
Suqualis acantias (Linnaeus, 1758)					*

Conclusion

The Golden Horn is among the most important ecosystems in Istanbul, and is strictly to be protected. Unfortunately, the importance and fragility of this unique environment was not recognized until just prior to complete destruction. Development of industrial facilities and settlements around the Golden Horn, as major sources of this devastation, are probably the most important mistakes for the region. Actually, the Golden Horn should be protected as a whole with its historical heritage and natural resources. As of today, the Golden Horn can be described as an estuary with new species contributing to its biota every year and serving mankind as a recreational area with its history and nature, within the historical peninsula.

Achieving the biodiversity of the 1940s in the Golden Horn is not feasible, since the Black and Marmara seas and streams feeding the estuary are far beyond their original diversity in the 1940s, all now suffering from anthropogenic perturbations. However, it is obvious that life will continue to diversify at the Golden Horn, as long as rehabilitation studies continue and/or authorities keep the conditions in a steady state. Rehabilitation studies in the Golden Horn attracted a considerable public audience, who witnessed the terrible condition of the Golden Horn prior to the onset of rehabilitation studies. However one must be reluctant to make strict assumptions such as "Golden Horn is saved" or "the recovery remained very superficial", since there are still lots of steps to be taken for rehabilitation of the estuary. The least but the most important, the semiopened floating Valide Sultan Bridge must be completely removed from the estuary or modified to operate on stakes to enhance water circulation at the inner parts. The sedimentation at the inner parts due to silt transferred by streams must be prevented. The present state of the estuary and level of recovery achieved are tremendous improvements for the region, however continuity of these efforts is equally important, since conditions could rapidly change and anoxic conditions could once again prevail at the region.

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