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Changes in biodiversity of the extremely polluted Golden Horn Estuary following the improvements in water quality

Ahsen Yüksek, Erdoğan Okuş †, İ. Noyan Yilmaz *, Aslı Aslan-Yilmaz, Seyfettin Taş

Institute of Marine Sciences and Management, Istanbul University, Muskule Sok., No. 1, 34470 Vefa, Istanbul, Turkey

Abstract

Long-term biological data supported by physicochemical parameters were evaluated to investigate the biodiversity of the Golden Horn Estuary from the past to the present. Limited observations dating back to 60 years ago indicated the existence of a diverse community in this small estuary. Unfortunately, in parallel with the increase in unplanned settlements and industry around the Golden Horn, pollution stress increased since the 1960s. Preliminary studies in the 1990s indicated survival of only a couple of pollution-resistant species, in the relatively cleaner lower estuary. Following the intensification of rehabilitation studies in 1998 and particularly after the opening of the floating bridge at the mid estuary; a remarkable day-by-day recovery in marine life has begun with the improving water quality. Nutrient concentrations decreased markedly; while water clarity significantly increased. Fecal coliform values decreased 10^3 fold. Phytoplankton composition changed and dense blooms of eukaryotic phytoplankters frequently occurred. Hydrogen sulfide almost completely disappeared even during the warmest periods of the year and dissolved oxygen concentrations increased. All results clearly depicted that the Golden Horn ecosystem shifted to eutrophic conditions from an anoxic environment. SCUBA dives in 2002, documented the level of diversification of life in the Golden Horn. All appropriate substratums were intensely covered by macrobenthic forms until the Halic Bridge and filter feeders dominated the plankton-rich ecosystem. Achieving the diversity of 1940s is not possible since the Black and Marmara seas, influencing water quality of the Golden Horn, are also suffering from anthropogenic impacts and are far less diverse than their rich diversity in 1940s. However, the Golden Horn is a good example that even the most polluted ecosystems can recover when appropriate measures are taken.

Keywords: Biodiversity; Ichthyoplankton; Macroalgae, benthos; Phytoplankton; Water quality; Rehabilitation

1. Introduction

Estuaries are transition zones from the freshwater to the sea, supporting a diverse range of biota and serving as habitat, breeding grounds or nursery areas for many species (Ketchum, 1983). Conditions in estuaries are highly variable. As a result of rainfall, overland runoff and meteorological conditions salinity fluctuates in a wider range. In addition, anthropogenic effects are stronger at the estuaries since water circulation is much more limited than the coastal ecosystem. Biological studies implemented into monitoring programs in estuaries provide reliable information on anthropogenic impacts and effectiveness of environmental protection measures. Moreover, long-term biological data can be used to monitor the stability of environmental conditions and assess water quality in respect to ecological, economical and political implications.

The Golden Horn has long been important to the civilizations of Istanbul, and its ecosystem faced pollution over centuries. Documents show that the regulations concerning the control of pollution around Golden Horn date back to the Byzantine period. Sultan Mehmet the Conqueror prepared a decree to prevent the filling and pollution of the

* Corresponding author. Fax: +90 212 526 8433.
E-mail address: noyan@istanbul.edu.tr (İ. Noyan Yilmaz).

† Professor Erdoğan Okuş passed away in April 9, 2006 following a tragic accident while participating in the Water Quality Monitoring studies at the Black Sea, where he had great contributions to the efforts against the pollution of the basin. He was a frontier in many aspects of marine ecology in Turkey and his very early loss (44) will be mourned by his many colleagues and students. As his assistants and colleagues we will do our very best to continue his brilliant vision on marine sciences.

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estuary in the 1450s (Eroğlu et al., 2001). On the other hand, the turning point for the Golden Horn was 1950s. The increase in settlements and industrial facilities around the Golden Horn since the 1950s caused severe pollution, particularly from wastewaters of pharmaceutical, detergent, dye and leather industries and domestic discharges. The 7.5 km long, 900 m (max) wide estuary, located at the south west of the Strait of Istanbul, was originally characterized by a two-layered structure similar to the neighboring Strait of Istanbul, whose upper layer has ~20 PSU and lower layer ~38 PSU. The estuary received freshwater from two streams discharging to the uppermost part. Kor (1963) calculated the flow rates of these streams as 3×10^5 m^3 day^{-1}. Following the construction of a series of dams on these streams, freshwater influx considerably decreased and rain and coastal inputs became the main sources of freshwater in the Golden Horn (Sur et al., 2002). The maximum depth of the estuary was around 40 m at the lower parts while the depth rapidly decreases to 15 m in mid-estuary and to 4–5 m in the upper parts. However as a consequence of estuarine characteristics and anthropogenic impacts, a major proportion of the estuary was almost completely filled with sediment and upper parts have been connected to the middle estuary only through a narrow channel since the early 1990s. In addition hydrogen sulfide formed at upper parts and prevailed throughout the year, increasing in warmer periods of the year (Kıratlı and Balkıs, 2001). The devastation of Golden Horn had drastically affected its ecosystem. Severe pollution limited aquatic life to the surrounding of Galata Bridge, while more upper parts were almost lifeless (Güvengiriş, 1977).

Within the framework of rehabilitation studies started in 1990, an important part of the surface discharges were gradually taken under control and connected to collector systems. The north collector was linked to Cendere Pump Station and Baltalimanı Deep Discharge Facility, while a collector system at the south of the Golden Horn has ended at Ahırkapı Deep Discharge Facility (Fig. 1). The most important, 4.25×10^6 m^3 anoxic sediment filling the upper estuary was pumped to a disused stone quarry, and 4–5 m depth was gained at this region. The industrial facilities and buildings at the coasts of the estuary were expropriated and flattened. The shipyard facilities were limited and the dry docks were moved out from the estuary to enhance upper layer circulation. Following the semi-opening of the floating bridge (Valide Sultan Bridge) located at the upper estuary, freshwater was released from a dam into Alibey Stream due to maintenance studies. This resulted in rapid oxygenation of the entire water column, particularly in the anoxic upper parts. The response of the Golden Horn ecosystem to the latest achievements in rehabilitation efforts was very quick and diversified.

Even though the Golden Horn was located in the middle of the most populated city of Turkey (over 12 million), environmental studies on this estuary remained very superficial and only a few studies were performed addressing specific topics (e.g. Tuncer et al., 2001; Altunkaynak et al., 2005). This paper deals with past and present state

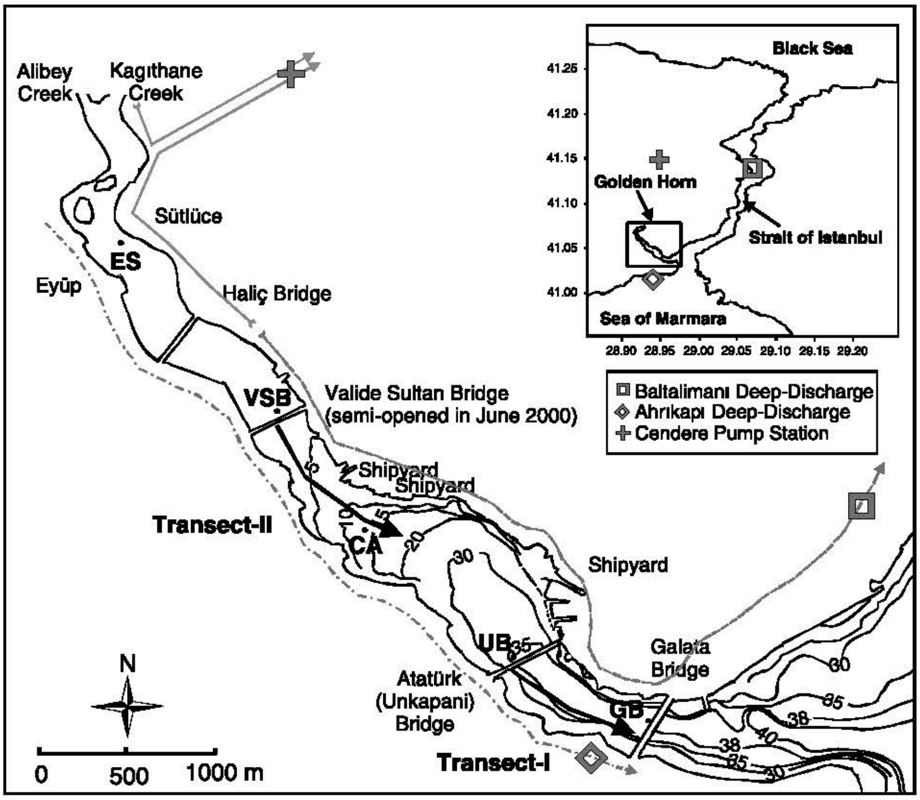

Fig. 1. Map of Golden Estuary. Oceanographic stations (●) and horizontal Ichthyoplankton net tows (arrows).

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of marine life in this fragile estuary, integrating macro- and microbiology and water quality parameters.

2. Materials and methods

2.1. Seawater analysis

Water samples were collected vertically from five stations throughout the estuary using 5 l Niskin bottles. Samples for nutrient analysis were pre-filtered through 5 μm syringe filters (Sartorius 17594). Nitrite was analyzed onboard by colorimetric method (Parsons et al., 1984) while samples were deep-frozen for other nutrient analyses. $NO_2 + NO_3$ were detected by cadmium reduction method on a Skalar autoanalyser. PO_4 and SiO_2 were detected spectrophotometrically following Parsons et al. (1984). For chlorophyll a analysis, depending on the turbidity, 250–1000 ml of seawater was filtered through 0.45 μm cellulose nitrate membrane filters (Sartorius 11306) and deep-frozen. Chlorophyll a analyses were performed by acetone extraction method (Parsons et al., 1984). Fecal coliform analyses were carried out onboard by membrane filtration technique (APHA, 1999). Subsamples were filtered aseptically through 0.45 μm sterile membrane filters and incubated for 24 h at 44.5 ± 0.1 °C on *m*-FC medium (Sartorius 14068-50-N). Dissolved oxygen (winkler method) and total suspended sediments (TSS) were measured following APHA (1999).

2.2. Phytoplankton

In 1995 phytoplankton sampling was not possible at Eyüp–Sütlüce (ES), since the region was almost completely filled by sediment, except a very narrow channel enabling a weak water flow. Therefore phytoplankton samples were collected from the Valide Sultan Bridge (VSB) and Galata Bridge (GB) by filtering 50 l surface water through a modified Hensen net (55 μm mesh, 0.25 m diameter) (Fig. 1). Samples were washed gently and fixed by adding borax buffered formaldehyde solution to a final concentration of 4%. In 1998–2001 periods phytoplankton was sampled from ES and GB by 5 l Niskin bottles. One litre seawater was transferred to PVC bottles and 5 ml of 40% borax buffered formaldehyde solution was added (Throndsen, 1978). At the laboratory, samples were left for sedimentation and concentrated to 100 ml by siphoning the excessive water through a 55 μm mesh. Quantitative analyses were performed under a compound microscope using Sedgwick–Rafter counting cell (Guillard, 1978).

2.3. Ichthyoplankton

Samples were collected by 5 or 10 min horizontal tows of a 500 μm Nansen net between Unkapanı and Galata bridges starting from 1999, when water quality at the upper layer became appropriate for horizontal net tows. Following the semi-opening of the floating bridge in June 2000, a second horizontal tow was started between VSB and Unkapanı Bridge (UB). Additionally at three stations a 200 μm Nansen net was vertically hauled from 10 m (CA) or 20 m (GB and UB) (Fig. 1).

2.4. Macrobenthos

Samples were collected in August 1996 and November 2001 using a Van Veen grab (0.1 m^2 area) and taxa remaining on 500 μm mesh were qualitatively evaluated. During a coastal vegetation survey in 2000, macrobenthic species in algal mats were identified. In addition SCUBA dives were carried out within the frame work of a documentary film in 2002 (*Living Golden Horn*, Demo Productions). The dive team led by Dr. Okuş performed approximately 30 dives at 10 points, extending to 40 m. Species were identified in situ and further through examination of video recordings.

3. Results and discussion

3.1. Water quality

Studies performed two decades ago illustrated the devastation of the Golden Horn ecosystem (Saydam et al., 1986). A third layer at the upper 2–3 m was highly associated with precipitation and domestic and industrial discharges (Sur et al., 2002). Following the onset of rehabilitation studies, the surface dissolved oxygen (DO) concentrations have raised significantly throughout the estuary. Minimum values were ~3 mg l^{-1} in 1998 at GB and rose to ~5 mg l^{-1} in 2000. The heavy H_2S formation detected at the onset of the study disappeared in the following years and maximum DO reached hyper-saturation values after the partial opening of the bridge at the innermost parts (Kıratlı and Balkıs, 2001), as a result of increased primary production. Total suspended sediment (TSS) values decreased from 80 mg l^{-1} to 10 mg l^{-1} in 2000 at mid-estuary, but remained around 25 mg l^{-1} in more upper parts due to high phytoplankton densities and influxes, particularly those 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, clarity has risen from 0.1 m to

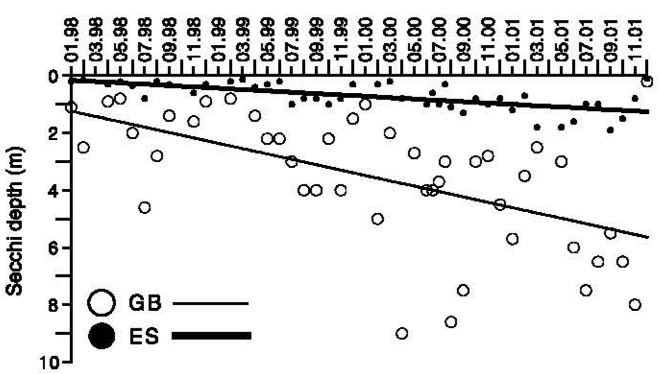

Fig. 2. Secchi disc depth at upper (ES) and lower estuary (GB). Solid lines are linear fits.

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4.0 m in 3 years (Fig. 2). The estuaries are characterized by turbid waters and therefore low clarity should be interpreted as being natural. However the remarkable improvement in the clarity of water in a small temporal scale and quick response of biota indicates that previous high turbidity in the Golden Horn was primarily due to pollution and limited circulation.

Excessive nutrient concentrations throughout the estuary in 1998 were indications of intense pollution. Following the connection of numerous discharges to the collector system, the semi-opening of Valide Sultan Bridge (VSB) and release of freshwater from a dam located on the Alibey Creek resulted in rapid renewal of the water body and the nutrient concentrations at the lower estuary approached the concentrations of the Strait of Istanbul (Fig. 3). The highest surface inorganic phosphate (PO_4) value was 10.36 μM in 1998 at the entrance of the estuary and decreased to 1.12 μM in 2001. The decrease was more striking at the innermost parts, highest PO_4 was 55.35 μM in 1998 and decreased to 12.58 μM in 2001. Silicate (SiO_2) concentrations decreased ~10 folds at the outer part, while the inner part concentration decreased ~16 folds at the first sampling following the semi-opening the bridge. Nitrite (NO_2) displayed slighter decrease compared to phosphate and silicate. A remarkable decrease was monitored at uppermost regions when compared to 1998, despite weak circulation and ongoing inputs from the Alibey and Kağıthane creeks. Although seasonal fluctuations were detected, $NO_3 + NO_2$ concentrations increased 2 folds in the period after May 2000 at the entire estuary (Okuş et al., 2004).

The level of change in the water quality can be best followed from the bacteriological data. High bacterial counts of 1998 approaching 10^7 CFU 100 ml^{-1} gradually decreased during the rehabilitation studies (Fig. 4). Bacteriological values decreased to 10^3 CFU 100 ml^{-1} by the end of 2001, with the exceptions in rainy periods and therefore it is can be concluded that rainfall became the dominant factor influencing the water quality within the estuary following the rehabilitation studies (Aslan-Yılmaz et al., 2004).

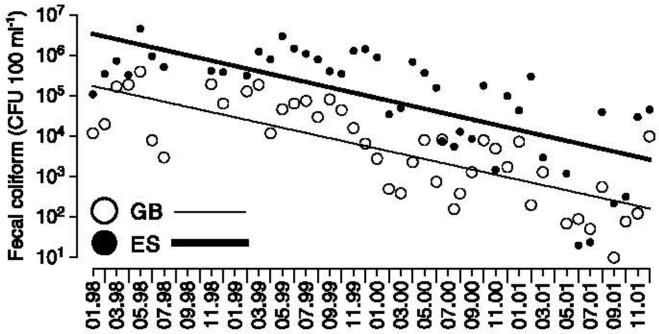

Fig. 4. Surface fecal coliform at upper (ES) and lower estuary (GB). Solid lines are linear fits.

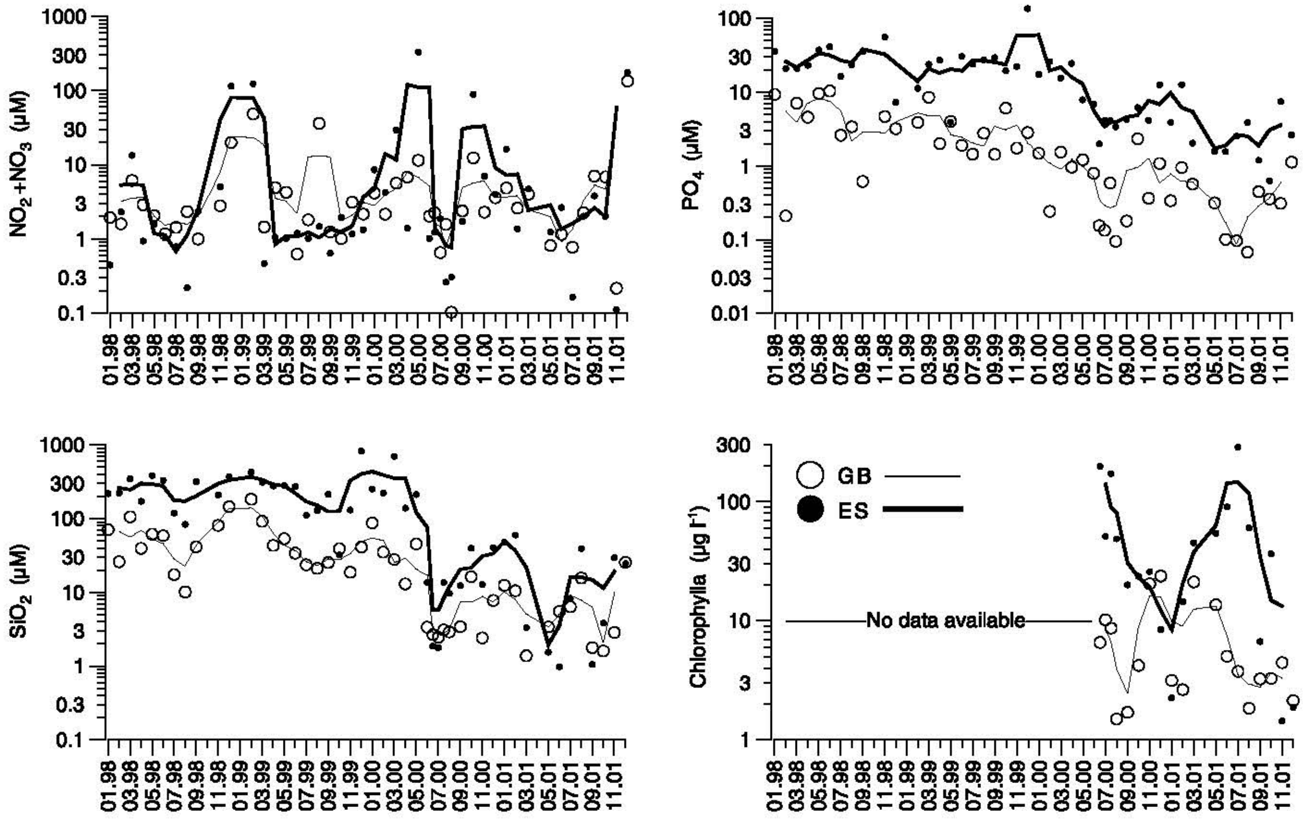

Fig. 3. Distribution of nutrients at upper (ES) and lower estuary (GB). Solid lines are 3 point running means.

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3.2. Phytoplankton

Phytoplankton studies performed before 1996 clearly demonstrated that pelagic life was very limited. Phytoplankton distribution was very weak and almost no plankton existed in the upper layer in 1986 (Saydam et al., 1986). Uysal (1987) could not even sample upper layer for phytoplankton studies, while he identified 29 diatom species at 10, 20 and 30 m samples. Those depths were highly influenced by the Strait's current system. In 1995, 24 phytoplankton species (16 diatoms and eight dinoflagellates) were identified in the upper layer (Taş and Okuş, 2003). The highest phytoplankton density was detected in July 1995 as 3.62×10^4 cells l^{-1}, dominated by the diatom *Leptocylindrus minumus.* A great decrease in both phytoplankton abundance and species number towards the middle parts of the estuary was distinguished (Fig. 5). Areas higher than VSB were completely filled by sediment, and anoxic conditions did not allow phytoplankton development. Plankton studies later than 1998 clearly reflected the changing ecosystem of the Golden Horn. The number of phytoplankton species increased from 44 species in 1998 to 60 in 1999, 81 in 2000 and finally to 92 in 2001 (Taş, 2003). Prior to the semi-opening of VSB phytoplankton was seldom detected in the upper parts and *Microcystis* sp. (Cyanobacteria) blooms were frequently determined. Following the opening of the bridge, eukaryotic photosynthetic organisms dominated the plankton and succession of different species was observed in very small temporal scales (Table 1). The heavily polluted upper layer, where only a few or no phytoplankters exists, began to show dense and frequent phytoplankton blooms (Fig. 5) with chlorophyll *a* surpassing 300 $\mu g\, l^{-1}$ (Fig. 3). In 2000 chlorophyll *a* concentrations were generally below 10 $\mu g\, l^{-1}$ at lower estuary and around 50 $\mu g\, l^{-1}$ at more upper parts, displaying clear seasonal patterns (Fig. 3). Regression lines indicate statistically significant trends of increasing abundance over the time period at both upper and lower estuaries (Fig. 5). In addition to the abundance, the opening of VSB was also the turning point for species number (Fig. 5), particularly the alteration in the upper estuary was tremendous. Changes in the species composition, total abundance and dominant species of phytoplankton clearly showed that the phytoplankton community once affected from pollution, now benefits from nutrient enrichment and increased clarity of water and the Golden Horn ecosystem shifted from anoxic conditions to a eutrophic environment.

3.3. Macroalgae

One of the earliest records of macroflora in the Golden Horn dates back to the studies of Fritsch (1899), who reported three species from Chlorophycea (*Enteromorpha compressa, Cladophora crystallina, C. tenerrima*), one species from Pheaophycea (*Ectocarpus siliculosus*) and four species from Rhodophyceae (*Chondriopsis tenuissima, Alsidium subtile, Polysiphonia sanguinea, Ceramium diaphanum*), pointing out to a eutrophic estuary a century ago. In 1987–88 the level of pollution limited diversification and distribution of macroalgae greatly and only five species resistant to pollution survived at the spray zone (Aydın and Yüksek, 1990) (Table 2). Species in the mediolittoral zone, on the other hand, completely lost their pigmentation and no macroalgae distribution was detected at lower depths. No algae species neither at the spray zone nor mediolittoral were detected after Eyüp–Sütlüce (ES). During a study prior to the onset of rehabilitation studies, distribution of only three species from Chlorophycea in the spray zone were reported (Okuş et al., 1996) (Table 2). Following the rehabilitation studies one species from Cyanophycea, six species from Chlorophyceae and one species from Rhodophyceae were sampled during a coastal vegetation survey in 2000 (Table 2). More importantly, the distribution of one species of Cyanophyceae and three of Chlorophyceae in the uppermost regions of the estuary (Erdal, 2001), where no species existed in the 1990s, were reported. Studies in 2001 pointed to the diversification of macroalgae species in Golden Horn and one species of Cyanophyceae, seven species of Chlorophyceae and one

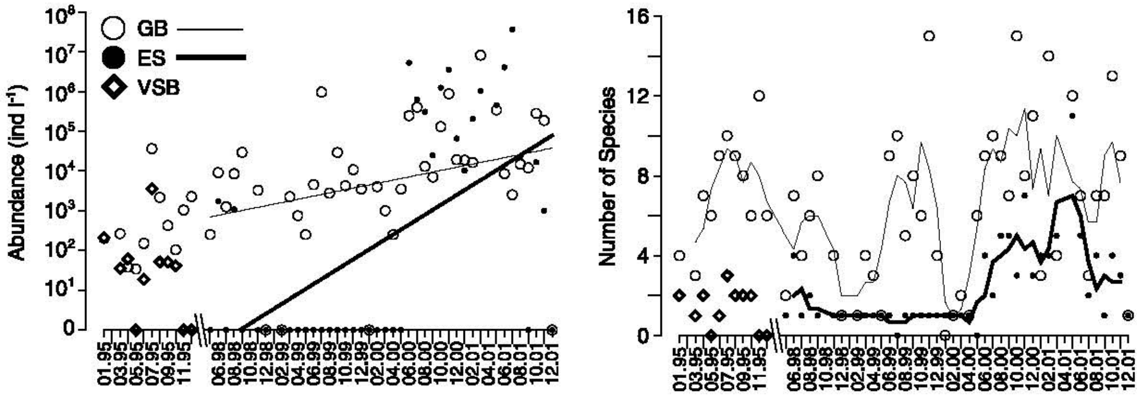

Fig. 5. Variations in abundance and species number of phytoplankton at upper (VSB, ES) and lower (GB) estuary. Solid lines are linear fit for abundance and 3 point running means for the species number.

Table 1
Major phytoplankton blooms in 1998–2001 period

Date	Species	Group	Abundance (10^6 cells l^{-1})	
			ES	GB
13.07.1999	*Skeletonema costatum* (Greville) P.T. Cleve	Bacillariophyceae	0	0.96
Semi-opening of the Valide Sultan Bridge (June 2000)				
23.06.2000	*Skeletonema costatum* (Greville) P.T. Cleve	Bacillariophyceae	5.00	0.24
26.07.2000	*Prorocentrum minimum* (Pavillard) Schiller	Dinophyceae	40.00	0.68
24.10.2000	*Eutreptiella* sp.	Euglenophyceae	1.24	0.10
14.11.2000	*Skeletonema costatum* (Greville) P.T. Cleve	Bacillariophyceae	3.50	0.86
28.03.2001	*Skeletonema costatum* (Greville) P.T. Cleve	Bacillariophyceae	0.96	8.12
20.06.2001	*Thalassiosira allenii* Takano	Bacillariophyceae	4.00	0
10.07.2001	*Prorocentrum minimum* (Pavillard) Schiller	Dinophyceae	36.00	0

Table 2
Macroalgae species identified in the Golden Horn

	1899[a]	1987–88[b]	1996[c]	2000[d]
Cyanophyceae				
Trichodesmium erythraeum Ehrenberg ex Gomont				+
Chlorophycea				
Bryopsis sp.				+
Chaetomorpha sp.				+
Cladophora crystalline (Roth) Kützing	+			
Cladophora prolifera (Roth) Kützing		+		+
Cladophora vagabunda (Linnaeus) Hoek	+			
Enteromorpha compressa (Linnaeus) Nees	+	+	+	+
Enteromorpha intestinalis var. *intestinalis* (Linnaeus) Hamel		+	+	+
Enteromorpha intestinalis var. *tubulosa* Kützing		+	+	
Ulothrix flacca (Dillwyn) Thuret		+		+
Ulva lactuca Linnaeus				+
Pheaophycea				
Ectocarpus siliculosus (Dillwyn) Lyngbye	+			
Dictyota dichotoma (Hudson) Lamouroux				+
Pylaiella littoralis (Linnaeus) Kjellman				+
Rhodophyceae				
Alsidium subtile Kützing	+			
Ceramium diaphanum (Lightfoot) Roth	+			
Ceramium rubrum Agardh				+
Chondriopsis tenuissima (Goodenough and Woodward) Agardh	+			
Laurencia obtuse (Hudson) Lamouroux				+
Polysiphonia sanguinea (Agardh) Zanardini	+			
Porphyra leucosticta Thuret				+

[a] Fritsch (1899).
[b] Aydın and Yüksek (1990).
[c] Okuş et al. (1996).
[d] Erdal (2001).

of Rhodophyceae was determined (Table 2). SCUBA dives performed in 2002 showed that distribution of macroalgae species was not limited to the surface or spray zone. Species such as *Ulva lactuca*, *E. intestinalis*, *E. compressa*, *Ceramium rubrum* were monitored until 20 m, widely distributed over dense *Mytilus galloprovincialis* facies, an area that was almost lifeless recently due to pollution and high turbidity. Large scale development of macroalgal mats in eutrophic environments is reported to have a negative impact on species assemblages (Raffaelli, 2000) however present data showed that those mats sheltered many invertebrate species.

3.4. Macrozoobenthos

Prior to the rehabilitation studies species identified, limited studies were usually from Polychaeta, highly tolerant to organic pollution. Ünsal (1988) detected five species around Galata Bridge, while towards the upper parts the number of species decreased to two. The dominant species around GB was *Polidora ciliata* (54.7%) while *Capitella capitata* (91.7%) was dominant between UB–ES. Distributions of species clearly reflected the level of organic pollution at the estuary, particularly in the upper parts. A study for the 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 2001 indicated dense crustacean and polychaet communities among macroalgae distributed along the coasts of Golden Horn (e.g. *Jassa marmorata*, *Maera grossimana*, *Gammarus* sp., *Caprella acanthifera*, *Idotea baltica*, *Balanus* sp., *Hesione panterina*, *Polydora* sp.) (Erdal, 2001). Macrobenthic life particularly increased around Galata Bridge in 2001. *Mytillus galloprovincialis* from Bivalvia; *Ampelisca diadema*, *Jassa* sp., *Maera* sp, *Erichthonius* sp., *Liocarcinus* sp., *Chthamalus* sp. from Crustacea and *Polycirus* sp., *Nereis* sp., *Eunice* sp. from Polychaeta were frequently determined. Dense *M. galloprovincialis* facies extended as far as ES. In general, filter feeders dominated macrozoobenthos at the plankton-rich ecosystem. Grab samples of recently anoxic CA, 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 and could settle in the region if optimum conditions were achieved. SCUBA dives performed at 10 points in 2002 showed that wide *M. galloprovincialis* beds were densely populated by *Balanus* sp., *Liocarcinus depurator* (Crustacea), *Asterias rubens* (Echinodermata) and *Ciona* sp. (Tunicata) populations between 10 and 34 m depth contour. Dives at Ayvansaray–Sütlüce (4 m), where water exchange was maintained through a very thin stream due to very recent sedimentation, showed that the mud/sand substratum was populated by *Ciona* sp. (Tunicata), *Crangon crangon* (Crustacea) and a characteristic brackish water bivalve *Cerastoderma glaucum*.

3.5. Ichthyoplankton (Fish egg and larvae)

Brackish waters are known to be very favorable regions for development of fish egg and larvae worldwide, supporting a diverse range of marine fishes (e.g. Wallace et al., 1984). Although no historical data exist on distribution of fish larvae and eggs in the Golden Horn, the significant alterations in the ecosystem made ichthyoplankton surveys an obligatory measure to understand the importance of the estuary in fisheries. In addition, mortality rates in sensitive life stages are good indicators of water quality. Following the onset of rehabilitation studies, first ichthyoplankton samplings was started in 1999 and all eggs and larvae collected appeared to be dead before sampling. However, ichthyoplankton rapidly diversified in the estuary parallel to the recovery of the upper layer. By the end of 1999, eggs and larvae belonging to 16 species were determined, 11 alive during sampling and five dead (Table 3). This number increased to 24 in 2000 and living specimens belonging to all 24 species were recorded. In 2001, 27 species and in 2002, 28 species were determined to be alive. The eggs of *Engraulis encrasicolus*, *Sprattus sprattus*, *Scorpaena porcus*, *Trachurus mediterraneus*, *Merlangius merlangus*, *Gaidropsarus mediterraneus*, *Symphodus* sp. were in the early stages of their embryological development, thus indicating that these species are local for the estuary. A marked seasonality can be distinguished in the number of ichthyoplankton species (Fig. 6) and a more diverse community characterized the summer–early autumn time period. The number of species generally increased rapidly in June and minimum numbers were detected in spring. Excluding November 2001–January 2002 period, fish egg and larvae densities were always higher along the Transect-I where seasonal fluctuations are better discriminated (Fig. 6). Alterations in mortality of fish eggs clearly reflect the recovery of pelagic ecosystem. Mortality rates decreased from 100% in 1999 to ~40% in 2002 (Fig. 6). Mortality rates were higher at Transect-II than Transect-I. This pattern is supported by other water quality and biota results, indicating that pollution stress is higher in the mid estuary than lower parts of the Golden Horn.

3.6. Fish

Although high mobility of fish limited the usage in pollution monitoring, the group is included in monitoring studies as a result of the commercial and public interest. Güvengiriş (1977) described the historic Golden Horn as a rich ecosystem, where valuable fish such as *Sarda sarda*, *Thunnus thynnus*, *Pomatomus saltatrix* were caught. Even the creeks feeding the estuary were rich in *Leuciscus cephalus* and *Scardinius erythrophthalmus*. Unfortunately, in 1996 fish distribution was limited to the lowermost region (around Galata Bridge) and only fish such as mackerel, sprat and mullet were caught (Okuş et al., 1996). Nowadays the fish community of the Golden Horn, is once again significantly diverse. Between Galata and Unkapanı bridges angling became a popular recreational activity and many fish species penetrated to more upper parts of the estuary. Although freshwater species were very frequent in creeks feeding the estuary in the 1940s, nowadays they are seldom recorded in the Golden Horn, as a consequence of dams built on the creeks. In May 2000, following the release of water from Alibey Creek, many dead *S. erythrophthalmus* were seen in the uppermost parts, indicating persistence of these species in the dam reservoir. Existence of 35 species in the 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 3). Detection of top predators such as *Squalas acus* in the Golden Horn ecosystem points to a well functioning food chain. SCUBA dives showed that demersal fish were widely distributed in the Golden Horn, another indicator of the level of recovery in the ecosystem following the rehabilitation studies.

The Golden Horn is among the most important ecosystems in Turkey, and it is also unique by being connected to a highly stratified water system with high current velocities in the Strait of Istanbul. Unfortunately, importance and fragility of this unique environment was recognized just

Table 3
Larval and adult fish species identified in the Golden Horn in 1999–2002 period

	Ichthyoplankton				Adults sampled
	1999	2000	2001	2002	
Squalus acantias Linnaeus					+
Atherina sp.		+		+	+
Blennius ocellatus Gilchrist and Thompson	+	+	+	+	+
Buglasidium luteum (Risso)		+	+		+
Callionymus sp.					+
Ctenolabrus rupestris (Linnaeus)			+	+	+
Dicentrarchus labrax (Linnaeus)	o	+	+	+	+
Diplodus annularis (Linnaeus)			+	+	+
Engraulis encrasicolus (Linnaeus)	+	+	+	+	+
Gaidropsarus mediterraneus (Linnaeus)	+	+	+	+	+
Gobius sp.	+	+	+	+	+
Gynammodytes cicerelus (Rafinesque)				+	
Hippocampus guttulatus Cuvier			+	+	+
Liza auratus (Linnaeus)	+	+	+	+	+
Merlangius merlangus (Linnaeus)		+	+	+	+
Microchirus variegatus (Donovan)		+	+	+	+
Mugil cephalus Linnaeus	+	+	+	+	+
Mugil labrosus Risso	o	+		+	+
Mugil so-iuy Basilewsky		+		+	+
Mullus barbatus Linnaeus		+	+	+	+
Platichthyes flesus (Linnaeus)	+	+	+	+	+
Pomatomus saltator (Linnaeus)				+	+
Sarda sarda (Bloch)			+		+
Sardina pilchardus (Walbaum)	o	+	+	+	+
Scianea umbra (Linnaeus)			+		+
Scorpaena porcus Linnaeus	+	o	+	+	+
Serranus hepatus (Linnaeus)	o	+	+	+	+
Solea solea (Linnaeus)	+	+	+	+	+
Spicara maena (Linnaeus)	+	+	+		+
Sprattus sprattus (Linnaeus)	o	+	+	+	+
Symphodus tinca (Linnaeus)			+	+	+
Syngnathus acus Linnaeus					+
Trachurus meditterraneus (Steindachner)	+	+	+	+	+
Trigla sp.		+	+	+	+
Uranuscopus scaber Linnaeus		+	+	+	+

(+) Sampled alive; (o) Sampled dead.

prior to complete destruction from development of industrial facilities and settlements around the Golden. The level of pollution in the estuary was so severe that in the 1980s authorities even considered filling the estuary to overcome the effects of pollution. 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.

Achieving the biodiversity of the 1940s in the Golden Horn is not possible, since the Black and Marmara seas and creeks feeding the estuary are themselves far beyond their original diversity, all suffering from anthropogenic perturbations. However, it is obvious that life will continue to diversify in the Golden Horn, as long as rehabilitation studies continue and/or authorities keep the conditions in a steady state. The recovery process of the Golden Horn is a very good example that even the most polluted ecosystems may recover if rational measures are taken. Even though rehabilitation studies began in 1990, the observable improvements in the water quality for the public were maintained a decade later. In the recovery processes, the dynamics of the neighboring Strait of Istanbul was also very important. Higher nutrient concentrations and primary production in Golden Horn than in the Strait of Istanbul is a consequence of estuarine characteristics, and impacts of high productivity on biodiversity should be considered carefully.

Rehabilitation studies in the Golden Horn attracted a considerable public audience, which had witnessed the terrible condition of the Golden Horn prior to the onset of rehabilitation studies. However, there are still a lot of steps to be taken for the estuary. The smallest but most important detail, the semi-opened floating Valide Sultan Bridge must be completely removed from the estuary or modified to operate on stakes to enhance water circulation in the upper parts. The sedimentation in the upper parts due to silt transferred by creeks must be prevented. The present state of the estuary and level of recovery achieved are tremendous improvements for the region; however continuity

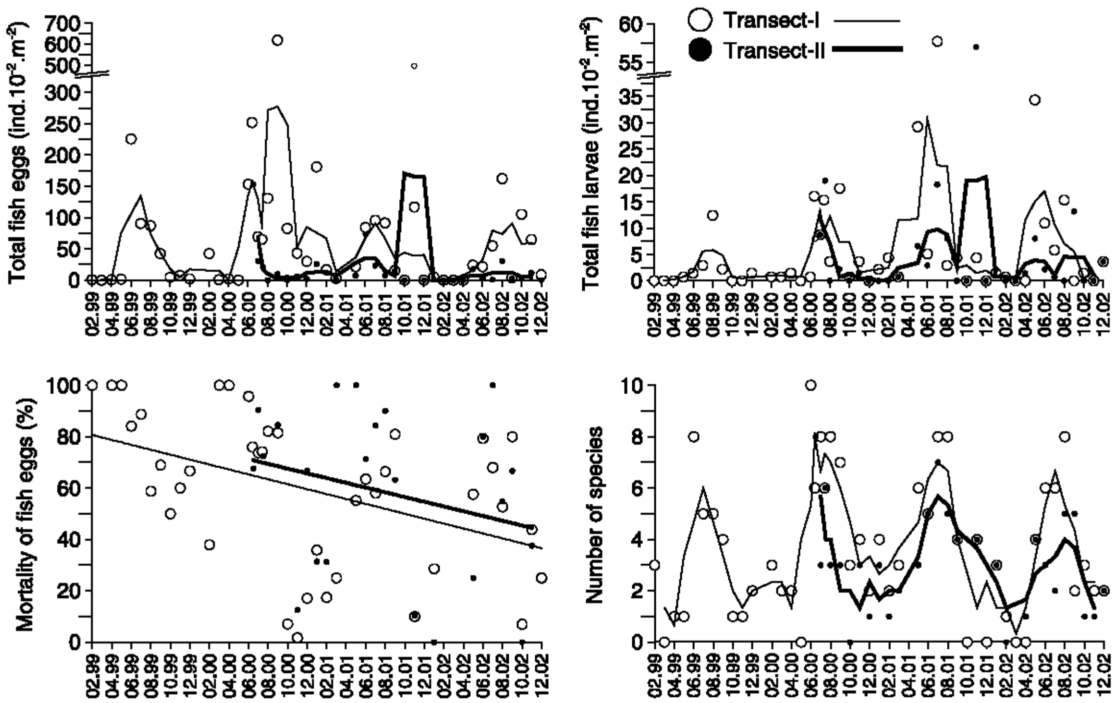

Fig. 6. Fluctuations in Ichthyoplankton of Golden Horn. Solid lines are 3 point running means for total fish eggs, larvae and species numbers and linear fit for mortality of fish eggs.

of these efforts is equally important, since conditions could rapidly change and anoxic conditions should once again prevail at the region.

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