INTRODUCTION TO GEOGRAPHICAL, HISTORICAL AND SCIENTIFIC IMPORTANCE OF THE TURKISH STRAITS SYSTEM

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1. Geography

We refer to the region extending from the Aegean Sea to the Black Sea as the "Turkish Straits System" (TSS). The TSS is unique in its geographical features, connecting two large marine basins and medium sized inter-continental water body of the Marmara Sea by means of the Dardanelles and Bosphorus Straits, which are among the few narrowest and longest straits in the European-Mediterranean region (Figure 1).

Figure 1. Narrow straits in Europe. Of the 12 narrowest sea straits in Europe, the Turkish Straits System (#12) is one of the most unique physical / ecological characteristics, and a historical role with great socio-economic implications.

The TSS (Figure 2) covers the Sea of Marmara (surface area 11,500 km2), the Dardanelles Strait (length 75 km, min. width 1.3 km) and the Bosphorus Strait (length 35 km, min. width 0.7 km). The Marmara Sea is a deep basin adjoining continental shelves. The deeper part has three elongated depressions (max. depth 1350 m) separated by sills (depth ~600 m).

Figure 2. Geography of the Turkish Straits System

Figure 3. An old geographical map of the TSS issued by the Turkish Republic after ending the Ottoman rule and before the acceptance of the modern Turkish scripture. (1927, TBMM Kütüphanesi Açık Erişim Koleksiyonu http://acikerisim.tbmm.gov.tr:8080/xmlui/handle/11543/2012).

The TSS, a natural wonder and a lively marine habitat of the old world, has seen many ages of human influence and civilizations since the beginning of history serving as a main passageway between the continents of Europe and Asia / Africa, and between Mediterranean and Black Seas and their hinterlands. It has seen development of great cultures as well as conflicts, and continued to serve as a sea of intense natural, cultural and economic activity since the last century (Figures 3 and 4), though what is now threatening the TSS are the risks of unprecedented environmental degradation, navigation accidents, pollution and earthquakes unless we can protect it from further damage.

Figure 4. An old geographical map of the Bosphorus issued by the Turkish Republic after ending the Ottoman rule and before the acceptance of the modern Turkish scripture. (TBMM Kütüphanesi Açık Erişim Koleksiyonu http://acikerisim. tbmm.gov.tr:8080/xmlui/handle/11543/1200).

The most critical element of the TSS controlling the exchanges between the Black Sea and the Mediterranean is the Bosphorus, because of the narrow geometry of the Strait and its topographical features establishing the first order physical constraints. The

Bosphorus of course is also the most beautiful and naturally exquisite part of the whole domain attracting the admiration of humanity, subject of the historical attraction of Venice which modeled itself after İstanbul, a part of the natural and cultural heritage and one that is also most fragile, increasingly in need of urgent environmental protection that arise from uncontrolled population growth, industrial and socio-economic pressures. The TSS also has been the center of historical conflicts in the past, presently secured and protected from international political pressures by the Montreaux Convention of 1936 that established navigation rules and rights of passage in a peaceful and just way.

The Dardanelles and Bosphorus Straits are shallow waterways having complex topography. The Dardanelles (Figure 5a) extends from the Aegean Sea to the Marmara Sea, with two strong right angle turns at the narrows of the Nara Pass (26º 22.5' E). A deep channel of 75 m depth runs through the Strait and later turns east (26º 45' E) along the southern part of the widening strait where it joins the western depression of Marmara Sea.

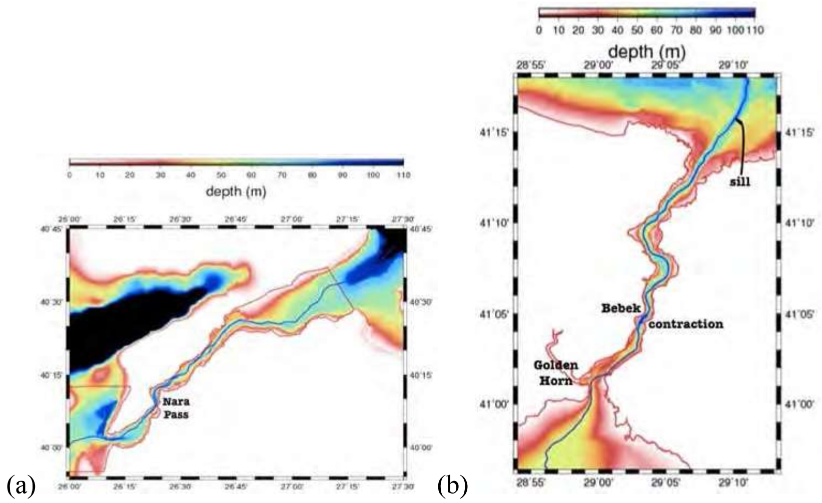

Figure 5. Location and bottom topography maps for the (a) Turkish Straits System (TSS) including the (b) Dardanelles and (c) Bosphorus Straits. The blue line denotes the thalweg along the strait channels.

The Bosphorus (Figure 5b) starts from the Marmara Sea with a deep channel rising north and past the junction with the Golden Horn estuary (41° 01.5' N) where it meets with the complex southern sill of 30 m depth flanked by deeper channels of 40 m on its two sides (41° 02' N). The deep channel then meets the contraction (41° 04.5' N) at the deepest (110 m) and narrowest section of the Strait, coinciding with right angle turns of the channel. From here towards north, the channel first has a straight section, then swings first to the northeast, then to the northwest and once more to the northeast, past a few shallow banks and headlands before the exit to the Black Sea, where the thalweg depth is

75m. A shallow cut canyon then extends northeast from the Strait, and later swings to the northwest across the Black Sea shelf. Shortly after exit into the Black Sea, a shallow area elevated to 60 m depth inside the canyon (41° 16' N) constitutes the northern sill of the Bosphorus.

The TSS has its own local dynamics, becomes influenced by the adjacent seas, and also regulates what happens in the adjacent seas, by controlling the currents passing through it in both directions.

2. Recognition of the TSS in the 'Old World'

The key geographical role of the TSS at the confluence of the European, Asian, African continent, has attracted the first civilizations, especially the seafaring ones living on the coasts of the 'Old World'. Trade along the ancient 'Silk Road' and across the sea linked civilizations of three continents and two seas converging upon the essential meeting point of the Turkish Straits. The historical venue of İstanbul (Constantinopolis) served civilizations and east-west transfers of knowledge and cultures throughout history, and especially during the Eastern Roman (Byzantian) and Ottoman Empires, which in total lasted for about two millennia, till the beginning of the 20th century. The cultural tradition, knowledge, resources and material wealth of the east was on high demand of the west throughout the middle ages, motivating the Crusades in the 11th to 13th centuries and notably Marco Polo in the 13th century. The conquest of İstanbul in mid 15th century had a major impact on the west, starting the search for alternative sea routes that would re-connect with the Silk Road. Instead, Christopher Columbus landed on America, taking advantage of a good knowledge on winds and currents in his travels within the Mediterranean. The search for the control of trade routes motivated the development of naval powers and eventually the scientific discoveries that followed up.

From the 15th century onwards, isolario (island books) became common, reciting geographical maps, pictures, stories about Mediterranean locations based on travelers' accounts (Harley and Woodward, 1987). To a great extent based on the much earlier stories of Anaplous Bosporou of Dionysios of Byzantion (5th century AD), the isolario of Gilles (1561) gives an account of the Bosphorus.

One of the fine details about Bosphorus currents noted by Polybios (203-120 BC) and Pliny the elder (23-79 AD) and also re-discovered by Gilles (1561) was the interception the surface currents by the protrusion of Seraglio Point (Byzantium) which then diverted the currents towards the Golden Horn (Keras), forming a local recirculation cell southward of Beşiktaş filling the Golden Horn, which is well-known today. The entrapment of bonito schools coming from the Black Sea and very easily fished in this small estuary for millennia gave support to the strong local seafood economy and exports of dried salted fish and fish sauce, historically known to be a major source of income for

İstanbul since ancient times (Bekker-Nielsen 2005; Bursa 2010; Tekin 2010; Thompson 2010).

The recirculating currents could lead the fish into the Golden Horn in the past when there was no obstruction at its mouth. The construction of Galata Bridge in 1875, resting on pontoons preventing free circulation of the surface waters and heavy pollution in the 20th century had barred fish from entering the Golden Horn until the recent environmental recovery programs starting in the late 1980's that brought additional flushing of the estuary by pumping water into it and also the final replacement of the old bridge in 1994. In addition to the recirculating currents south of Beşiktaş, Gilles (1561) has noticed other areas of recirculating currents in the many bends and turns of the Bosphorus, referring to them with their historical names. These recirculating currents are well known today, and demonstrated by our measurement programs, near Çengelköy, Bebek Akıntıburnu, Yeniköy, Çubuklu, Beykoz, Umuryeri and Büyükdere. Ships challenging the mainstream currents are often caught up in these zones of rapid change in currents at the various bends and narrows, resulting in the many ship accidents that occur in the strait. In addition to the recirculations and eddies, the transient reversal in direction of the surface currents known as "Orkoz" during southwesterly winds (”lodos”) of approaching storms increases pollution and creates havoc in the Bosphorus.

The seasonal spawning migrations of some fish between the Black and the Mediterranean Seas are adapted to the fast currents and stratified waters of the Bosphorus. Until the later part of the last century, the fish were so plentiful that ancient methods of fishing were efficiently used on the shores of the Bosphorus. For instance, simple nets lowered from the elevated wooden 'dalyan' structures, often inhabited by entire fishing families, described in Anaplous Bosporou of Dionysios, and 'ığrıp' nets encircling fish schools and hauled by people at the coast were quite sufficient to catch plenty of fish at any time (Ertan 2010).

Gilles (1561) also noted the reversal of currents with depth in the Bosphorus. The drift towards the Black Sea of fishing nets submerged in the deeper waters of the Bosphorus was already well-known by fishermen and recorded much earlier by Procopius in the 6th century (Gill 1982; Deacon 1982; Korfmann and Neumann 1993), until the 17th century when significant advances were made by Marsili (1681) in understanding of the essential physics.

3. First in ocean science: Ferdinando Luigi Marsili (1658-1730)

During 1679-1680 Luigi Ferdinando Marsili (1658-1730), made the first quantitative measurements of sea-water density en route to İstanbul from Venice, followed up by other measurements in the Bosphorus during his residence in İstanbul. These measurements, interpreted with the help of a laboratory 'fluid dynamics' experiment he performed later in Rome, proved the existence of a counter-current transporting Mediterranean water below the surface current of Black Sea water (Marsili, 1681). Marsili's inquiry identified the hydrostatic pressure difference, proportional to water densities of the adjacent seas, as the main agent driving the strait exchange flows. The experimental verification of a theory by Marsili, following the "scientific method" of Galileo, in fact was the start of ocean science in the waters of the Bosphorus (Defant 1961; Soffientino and Pilson 2005; Pinardi 2009; Pinardi *et al.* 2016).

4. Early developments in the last century

Further exploration in the region in the late 19th and early 20th centuries (Makarov 1885; Shpindler 1896; Nielsen 1912; Möller 1928) led to further understanding of the regional seas and the role of Turkish Straits System within the marine environment. The exchange flow of counter-currents in the upper and lower layers of the Bosphorus Strait explained for the first time by Marsili have since been verified by instrumental measurements, first carried out in 1918 and 1921 and reported by Merz, and Möller (1928), Möller (1928) and interpreted by Defant (1961) in his pivotal book on physical oceanography.

Local development of marine science that would create first interests on marine science in Turkey had to wait until the 1930's till after the founding of the Turkish Republic in 1923 by the Anatolian Revolution that ended the Ottoman rule. During the earlier period of 1940-1970 however, there were not enough qualified scientists. Ulyott and Ilgaz (1944) and Pektaş (1953, 1956) carried out few measurements in the Bosphorus, with the limited means available to them at the time, facing the task to rediscover and demonstrate what was already known about the exchange flows. However, these measurements were quite insufficient to create a healthy physical understanding of the Bosphorus flows.

Because of the lack of evidence that needed to rest on observations, it was vainly discussed whether there was an underflow in the Bosphorus, and if it existed, whether or not it reached the Black Sea. In fact, it is surprising that even the earlier measurements of Merz, and Möller (1928), Möller (1928) did not seem to improve this understanding and the controversy about the existence of an undercurrent continued till the later part of the 20th century. The basic facts about the exchange flows of the Bosphorus exchange flows established by Alfred Merz and three centuries earlier by Marsili (1681) were still questioned at this time because new observations could not be made with the required accuracy and detailed coverage.

5. The present state of TSS research

By the 1980's technically gifted people such as engineers made new studies approaching the problems of the TSS. However, as experts in hydrodynamics, Çeçen *et al.* (1981) and Bayazıt and Sümer (1982) made new studies including mathematical formulations that acknowledged but failed to detect the outflow of the Mediterranean water into the Black Sea, because there was insufficient knowledge of the narrow canyon and northern sill topography leading into the Black Sea and insufficient sampling to locate its position. It was therefore argued whether the lower layer flow was continuous or perhaps intercepted during some time.

Modern oceanographic research unfortunately had yet to wait until the 1980s, when an active scientific research agenda and research programs including extensive measurement campaigns in the Turkish seas were created for the first time, both at national level and through international scientific collaboration. The first studies were performed by the only group of physical oceanographers at the Institute of Marine Sciences of the Middle East Technical University, established at the end of the 1970's. International scientific research programs such as the Physical Oceanography of the Eastern Mediterranean (POEM) program, followed later by a similar series of programs such as CoMSBlack and NATO programs in the Black Sea immensely elevated the level of scientific understanding of the regional seas.

During this new period, the first studies by Gunnerson and Özturgut (1974), Tolmazin (1985), Latif *et al.* (1991) and Yüce *et al.* (1996) have revealed further facts both about the functioning of the Bosphorus and about the exit conditions, to permanently settle the question of the outflow of the "Mediterranean Effluent" to the Black Sea.

The knowledge base on the Turkish Straits System existing at the time was extensively reviewed by Ünlüata *et al.* (1990) who also presented results of the first studies, including an assessment of fluxes through the TSS. Continued surveys with plenty of observations by oceanographers in the last decades including better and more accurate measurements and synergetic interpretation of results once again revealed fine details of the flow and the underlying physics (e.g. Ünlüata *et al.* 1990; Gregg *et al.* 1999; Özsoy *et al.* 2001; Gregg and Özsoy 2002; Tutsak 2012).

Short reviews on the TSS and its role in coupling two larger Seas have been provided by Beşiktepe *et al.* (1993, 1994, 2000) and Schroeder *et al.* (2012), while other details such as its influence on the Black Sea and the Mediterranean Sea can be found in reviews by Özsoy and Ünlüata (1997, 1998) and Jordà *et al.* (2016). Particular information based on experimental studies of the Bosphorus Strait and its exit regions can be found in the works by Ünlüata *et al.* (1990), Latif *et al.* (1991), Özsoy *et al.* (1995, 1996, 1998, 2001), Gregg *et al.* (1999), Gregg and Özsoy (1999, 2002), and the more recent works by Jarosz *et al.* (2011a,b, 2012, 2013), Book *et al.* (2014) and Dorrell *et al.* (2016). Measurements in the Bosphorus and Dardanelles Straits and their exit regions have revealed rapid currents and hydraulic controls with high shear and turbulence zones involving many different time-scales of motion in the TSS, ranging from inertial, semi-diurnal, diurnal to several day periods influenced by the adjacent basins.

The northern sill outside the Bosphorus standing at 60m depth in the canyon cutting across the Black Sea shelf, as well as the contraction in the southern Bosphorus are understood to be the main geometrical constrictions in the path of the flow where hydraulic controls are expected (Latif *et al.* 1990, Dorrell *et al.* 2016) and verified by model results (Sözer 2013; Sözer and Özsoy 2016) to be responsible in establishing a maximal exchange regime as predicted by Farmer and Armi (1986). A single contraction at the Nara Pass subjects the flow in the Dardanelles Strait to sub-maximal hydraulic control (Latif *et al.* 1990; Ünlüata *et al.* 1990).

6. The road forward

As indicated by the above review on the state of matters regarding the TSS, it is very evident to scientists that great new efforts are needed to fully understand the very complex nature of the TSS, both from the physical, ecological and socio-economics points of view. Despite recent scientific developments we are still at the beginning, and our pace may still be too slow in countering or preventing the environmental damage to this precious system that is a heritage of all humanity.

Today, the old world centered on the Mediterranean and Black Seas region is the common heritage of all peoples living around the Seas of the Old World. The shared civilization and culture of the Mediterranean (e.g. Braudel 1996) are integral parts of today's world, as it has been for the ancient world. Therefore, it is necessary to assimilate all that is brought to us from previous civilizations, preserve the environment and to extend knowledge across the region whether it originates from the east or the west in order to peacefully share and protect this unique habitat, while advancing the science that would hopefully ensure the survival of the heritage. Oceanography, a modern science often claimed to have developed after the world wars, but now understood to have had precursors of development since the middle ages, not always given recognition in those times, but since then have promised to be a pillar of civilization in the modern world.

As we have touched upon some features of the high energy environment of the Turkish Straits, a unique passage that connects and regulates contrasting ecosystems both on land and at sea, it is essential that we poise to think to do what science would dictate on the projected 'Canal İstanbul' craze that potentially endangers these precious ecosystems, in direct contrast with international agreements such as the Montreaux, Barcelona and Bucharest Conventions. Such drastic intervention would threaten the environment that supports liveliness of the millions of people living on the already over-populated coasts and emerging mega-cities in the region. Danger of imminent collapse of the ecosystems, which already has greatly deteriorated in the last century and already defying a healthy understanding of their survival in the present age of anthropogenic climate change, can only be stopped by conscientious efforts based on scientific research results.

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