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Allochthonous and vagrant ichthyofauna in Hellenic marine and estuarine waters

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Abstract

A review of the non-indigenous ichthyofauna occurring in the Hellenic marine and estuarine waters is presented, including Atlantic origin colonizers, aquaculture introduced and Lessepsian alien species. 34 non-native species have been registered. The majority of allochthonous fish are Lessepsian immigrants, which represent approximately 80% of the ascertained non-native ichthyofauna in Hellenic waters; their establishment, spread, habitat, abundance and interaction with indigenous fish are discussed.

Keywords: Allochthonous fish species; Alien fish species; Greece; Ionian; Aegean; Mediterranean; Lessepsian migration.

Introduction

The Mediterranean is one of the most important enclosed seas in the world with a large shipping circulation but narrow communication with two oceans by the Gibraltar strait (Atlantic Ocean) and by the man-made Suez Canal (Indian Ocean through the Red Sea). It also has a free water exchange with its annexed Black Sea through the Dardanelles, the Sea of Marmara and the Bosporus, all of which, that in spite of marked particularities are in reality annexed parts of the Mediterranean. This whole frame of marine and brackish waters conveys a large variety of biota, which enter the Mediterranean continuously and include organisms frequently described as ‘allochthonous’, ‘exotic’, ‘alien’, ‘introduced’ by man or ‘vagrant visitors’. According to dependable ecological parameters they have settled in the Mediterranean for a few or a large number of years, temporarily or permanently, with large or scarce populations, following their ecological requirements and the short or long term environmental oscillations. Therefore, the Mediterranean is by far the major recipient of exotic species and vagrant visitors like macrophytes, invertebrates and fish. Apart from the rather free energetic movement through the above passages, ships' ballast, fouling, clinging of ship hulls and aquaculture are also important vectors of non-indigenous marine species. Since the last glacial period, it seems the Mediterranean has presented a continuous exchange of fauna with the Atlantic and the Black Sea. During the last 150 years since the opening of the Suez Canal, it has been presenting many Indo-Pacific species, which migrate through it. The rate of this so-called Lessepsian migration has increased in the last decades, with ecological and economic impacts, mainly in the Levantine basin.

The Mediterranean Ichthyofauna

In a rather simplified scheme, which could also be adapted and used for the Hellenic seas, recent Mediterranean ichthyofauna is composed of four main groups of species: (1) endemic (QUIGNARD & TOMASINI, 2000), (2) Atlantic, Boreal and Tropical (sensu TORTONESE, 1960, 1964, 1967, 1970; WHITEHEAD *et al.,* 1984-86). These Atlanto-Mediterranean species occur or not in the Mediterranean according to environmental factors, many of which oscillate significantly depending on long or short term climatic changes. Altogether these species are called 'autochthonous'. Several such species, with rare or periodic appearance, could be described as 'vagrant' or 'visitors' but not 'alien' or 'exotic', even if they are only present in limited concentration and many of them are, in fact, detected with difficulty. Others could also be called 'new colonizers', particularly when their spread is favoured by special circumstances such as the tendency towards a change in temperature and current regime in the NE Atlantic. (3) Introduced by man (sensu HUNTER & GIBBS, 2006) mainly for aquaculture or aquarium purposes, and which escape into the wild or are carelessly released. This is a rather obscure phenomenon and actually there is no or only very little elementary knowledge of its impact on the natural environment and genetic compatibility after mating with closely-related wild species. In this category should also be included the release with the ballast water of various taxa, many of which maybe 'exotic', and (4) the Lessepsian or Erythrean, of Red Sea origin immigrants, which are real 'exotic' or 'alien' species. In several cases, when a population explosion has occurred, these last could be characterized as really 'invasive' (HUNTER & GIBBS, 2006), as in the case of the recent colonizer *Fistularia commersonii* in many areas of the Eastern Mediterranean.

Greek Allochthonous fish species

Among a number of about 500 native marine fish species in the Hellenic waters, 34 allochthonous have been registered, while seven others are not yet confirmed for various reasons (Table 1). Among the last, six species belong to the category of introduced for aquaculture and their presence in nature is based on unverified observation of free swimming specimens or unidentified samples, strongly suggesting careless release or escape from fish farms. From the remainder, the majority (27 species plus one uncertain, i.e. 79.4%) originate from the Indo-Pacific Ocean and the Red Sea having penetrated into the Mediterranean via the Suez Canal. Among the other seven species, four are usually

Table 1
List of allochthonous fishes in Hellenic waters.
O: Origin (IP: Indo-Pacific, A: Atlantic, Aq: aquaculture). ES: Establishment success (E: Established, S: Stocking, C: Casual, Q: Questionable), FR: Region of first record.
BP: Benthopelagic, P: pelagic, D: demersal, RA: reef associated, DW: deep waters, EP: epipelagic, TE: temperate, ST: subtropical, T: tropical, F: fish, BI: benthic invertebrates, I: invertebrates, C: crustaceans, Z: zooplankton, M: molluscs, GA: green algae, Ph: phytoplankton, P: plankton, O: omnivorous, H: herbivorous.

Fish	O	ES	FR	References*	World range**	Ecology**	Climate**	Food**
Acipenser güldenstädtii	Aq	C	Evros estuaries	[1]	Black and Caspian seas estuaries and rivers	BP, sandy and muddy	TE	F, BI
Acipenser stellatus[1]	Aq	C	Evros estuaries	[1]	Black & Caspian seas drainage, native in Evros	BP, sandy and muddy	TE	F, BI
Acipenser sturio[1]	Aq	Q	Evros estuaries	[1]	European estuaries, native in Evros	BP, sandy and muddy	TE	F, BI
Alepes djedaba[2]	IP	C	Aegean Sea	[2]	Indo-Pacific, Red Sea, E. Africa	P, inshore	ST	C, F
Anguilla japonica ?	Aq	Q	Ionian Sea	Present work	Pacific	D, estuaries	ST	F, C, insect
Apogon pharaonis	IP	E	Rhodes	[3]	Indo-Pacific. Red Sea, E. Africa coasts to Australia	D, nocturnal, rocky	T	Z
Atherinomorus lacunosus	IP	C	Rhodes	[4] [5]	Wide Indo-Pacific, Red Sea	RA, coastal, lagoons	ST	Z
Callionymus filamentosus	IP	C	Rhodes	[6]	Indo-Pacific, Red Sea	B, sandy and muddy	ST	BI
Enchelycore anatina	A	C	Elafonissos	[7]	Eastern Atlantic	D, pelagic eggs	ST	F, C
Etrumeus teres	IP	E	Rhodes, Cyclades	[6] [8]	Red Sea to E. Africa, Indian Ocean to Australia	P, inshore	ST	Z
Fistularia commersonii	IP	E	Rhodes	[9]	Wide Indo-Pacific, Central and South America	RA	T	F, C, M
Gaidropsarus granti	A	Q	Rhodes	[10]	Atlantic	DW	T	Palaemonid prawns
Hemiramphus far	IP	E	Rhodes	[11] [12] [13]	Wide Indo-Pacific, Red Sea	EP, inshore	ST	Z, GA, Ph
Huso huso	Aq	S	Evros estuaries	[1]	Black and Caspian seas drainage	BP	TE	F
Iniistius pavo	IP	C	Rhodes	[14]	Wide Indo-Pacific, Red Sea included, and E. Pacific	RA	T	M, C
Lagocephalus sceleratus	IP	E	Rhodes	[14]	Indo-Pacific	B (mainly), on sandy	T	BI
Lagocephalus spadiceus	IP	E	Samos	[15]	Wide Indo-Pacific, Red Sea	BP	ST	BI
Lagocephalus suezensis	IP	E	Rhodes	[6]	Red Sea endemic	B, sandy and muddy	TE	BI
Leiognathus klunzingeri	IP	E	Rhodes	[16]	Red Sea	D	T	BI
Liza carinata ?	Aq	Q	Amvrakikos	Present work	Western Indian, Red Sea	Coastal and brackish water	T	BI, P
Liza haematocheila	Aq	E	Thracian Sea	[17]	Far eastern Asia from Russia to China	Coastal, estuaries, freshwater	TE	O

(continued)

Table 1 (continued)

Fish	O	ES	FR	References*	World range**	Ecology**	Climate**	Food**
Micropterus salmoides	Aq	Q	Ionian Sea	Present work	North America	Freshwater (rivers and Atlantic drainages)	TE	F, BI
Pagrus major ?	Aq	Q	?	Present work	Northwest Pacific	D, oceanodromous	ST	BI
Parexocoetus mento	IP	E	Rhodes	[16]	Wide Indo-Pacific from Red Sea to Fiji	EP, inshore	T	Z
Pempheris vanicolensis	IP	E	Kastellorizon	[18]	Wide Indo-Pacific, Red Sea	Daytime in caves, night inshore pelagic	T	PC
Petroscirtes ancylodon	IP	C	Rhodes	[6]	Red Sea to Arabian Gulf	D, sandy shore	T	BI
Pteragogus pelycus	IP	E	Symi	[19]	Red Sea to E. Africa	D, coastal with sea grass	ST	BI
Sargocentron rubrum	IP	E	Rhodes	[20]	Indo-Pacific (E. Africa to Samoa and Japan)	Nocturnal, daytime in caves	ST	F, BI
Saurida undosquamis	IP	E	Naxos	[21]	Indo-Pacific to Australia and S. Japan	D, sandy or muddy	ST	F, C, BI
Seriola fasciata	A	C	Rhodes	[14]	Easterna and Western Atlantic	Young EP, adult BP	ST	F, M
Siganus luridus	IP	E	Tilos	[22]	Red Sea, E. Africa to Arabian Gulf	RA, rocky or hard with vegetation	ST	H
Siganus rivulatus	IP	E	Rhodes	[23]	Red Sea and Gulf of Aden	RA, sandy, with algae and seagrass	ST	H
Sphoeroides pachygaster	A	E	Rhodes	[24]	Atlantic, Indian oceans	D, muddy, sandy and rocky bottoms	ST	M
Sphyraena chrysotaenia (pinguis)	IP	E	Rhodes	[19]	Indo-Pacific to China and N. Australia	BP, coastal	ST	F, C
Sphyraena flavicauda (obtusata)	IP	C	Rhodes	[6]	Wide Indo-Pacific, Red Sea, E. Africa	EP, inshore	T	F, I
Stephanolepis diaspros	IP	E	Rhodes	[11] [12] [13]	Red Sea to the Arabian Gulf	D, rocky substrate with vegetation.	T	BI
Torquigener flavimaculosus	IP	C	Rhodes	[25]	Red Sea, Arabian Gulf, E. Africa, Seychelles	RA, shallow sandy shores with seagrass	T	BI
Tylerius spinosissimus	IP	C	Rhodes	[6]	Indo-West Pacific, Southeast Atlantic	DW	T	
Tylosyrus crocodilus	IP	C	Chalkidiki	[26]	Wide Indo-Pacific	EP, coastal	T	F
Upeneus moluccensis	IP	E	Rhodes	[27] [28]	Indo-Pacific	B, sandy or muddy	ST	BI, F
Upeneus pori	IP	C	Rhodes	[6]	Red Sea, Gulf of Oman	B, sandy and muddy	ST	BI

(1): As the species is considered as rare or extinct from its native range in Evros drainage, the new records maybe concern specimens from stocking (see KOUTRAKIS & ECONOMIDIS, 2006).
(2): The occurrence of *Alepes djedaba* in Greek waters is to be ascertained.
* [1] KOUTRAKIS & ECONOMIDIS, 2006; [2] BINI, 1960; [3] CORSINI FOKA *et al.,* 2004; [4] QUIGNARD & PRAS, 1986; [5] CORSINI, 2004, new data; [6] CORSINI *et al.,* 2005; [7] GOLANI *et al.,* 2002; [8] KALLIANIOTIS & LEKKAS, 2005; [9] CORSINI *et al.,* 2002; [10] ZACHARIOU-MAMALINGA, 1999; [11] TORTONESE, 1946, [12] TORTONESE, 1947a; [13] TORTONESE, 1947 b; [14] CORSINI *et al.,* 2006; [15] ANANIADIS, 1952; [16] KOSSWIG, 1950; [17] KOUTRAKIS & ECONOMIDIS, 2000; [18] PAPACONSTANTINOU & CARAGITSOU, 1987; [19] CORSINI & ECONOMIDIS, 1999; [20] LASKARIDIS, 1948a; [21] ONDRIAS, 1971; [22] KAVALAKIS, 1968; [23] BRUNELLI & BINI, 1934; [24] ZACHARIOU-MAMALINGA & CORSINI, 1994; [25] CORSINI FOKA *et al,* 2006; [26] SINIS, 2005; [27] SERBETIS, 1947; [28] LASKARIDIS, 1948b.
** Based on: GOLANI *et al.,* 2006 on-line; FROESE & PAULY, 2006

considered to originate from the Atlantic Ocean and three, two sturgeons and one mullet, come from aquaculture either from stocking or escape.

All these allochthonous species can be classified in three main groups according to their origin: (a) Atlantic, (b) Aquaculture and (c) Indo-Pacific. The first group of species could eventually be included more easily in the indigenous Mediterranean species, according to the above expressed points. The list of species coming from aquaculture is expected to gradually increase, as the number of aquaculture installations is increasing in the Hellenic seas and in the neighbouring areas as well. The Indo-Pacific group includes the majority of allochthonous species, which are real alien species in the Mediterranean as they have penetrated an area out of their original distribution. It is worth noting that the majority of these species have quite a slow process of spread and settlement, underlining their thermophilous and stenohaline, tropical or sub-tropical, character. In the Mediterranean such environmental conditions are current in the eastern basin, mainly along the Asian coasts. In the Aegean Sea a closely related situation occurs in the SE corner around the Dodecanese continental plateau. There is evidence that the contribution of the Indo-Pacific alien species to the Aegean Sea fish species composition and ecosystem structure, is gradually accelerating, as many populations of these species have already constructed commercial stocks, as did long ago the *Upeneus* and *Siganus* species in the Dodecanese islands and more recently *Fistularia commersonii* (CORSINI *et al.,* 2002; KALOGIROU *et al.,* 2007) and *Etrumeus teres* in the Cyclades (KALLIANIOTIS & LEKKAS, 2005) and in the Dodecanese as well (CORSINI-FOKA, unpubl. data).

Atlantic vagrant and new colonizer

As aforementioned, the vagrant or visitor and the new colonizer fish species of Atlantic origin are not easy to enumerate because their flux has been continuing for more than 10,000 years. Various attempts, however, have been made at standardization of their origin and at the calculation of the number of Mediterranean fish species (TORTONESE, 1938, 1963, 1970, 1975, 1982; QUIGNARD & TOMASINI, 2000). Furthermore, as research in various part of the Mediterranean becomes more intensive, many new species are registered each year, mainly in the western part of the sea, which is closest to the Atlantic. This could also be attributed to other reasons, such as the warming trend of the Mediterranean, the expansion of maritime traffic, etc. (GOLANI *et al.,* 2002) or combination of all these reasons. There is widespread discussion regarding the exact number of Atlantic vagrant and new colonizer fish species (QUIGNARD & TOMASINI, 2000). Recent estimations (up to 2006) have considered those species entering through the Gibraltar straits and crossing into the Mediterranean to be over 30 (GOLANI *et al.,* 2006 on-line; REINA-HERVÁS *et al.,* 2004), also reaching the Aegean (ERYILMAZ *et al.,* 2003; CORSINI *et al.,* 2006) and the Adriatic Sea as with the recently recorded *Cyclopterus lumpus* (DULČIČ & GOLANI, 2006). Some of them, particularly *Sphoeroides pachygaster, Seriola fasciata* and *Seriola carpenteri* have achieved significant biomass (ANDALORO, 2001; ANDALORO *et al.,* 2005).

Three such species have been recorded in the Aegean: *Sphoeroides pachygaster,* a species well established throughout the Mediterranean, *Enchelycore anatina* and *Seriola fasciata,* while the consideration of *Gaidropsarus granti* as a non-indigenous Atlantic colonizer is questionable (Table 1).

The regular or rare appearance of Atlantic species in the Mediterranean is a more complicated phenomenon, depending mainly on hydro-climatic long-term changes and short-term trophic relations among species. In a very preliminary and simplified approach, when North Atlantic waters become warmer, there is an access of temperate, even sub-tropical, species into the Mediterranean. On contrary, when Atlantic waters become colder, northern species enter and colonize the Mediterranean. This play seems to have taken place repeatedly during the glacier period dominating in the northern hemisphere of the planet during the last one million years. The inter-glacier period favours the first while the glacier the second movement (see also QUIGNARD & TOMASINI, 2000). Actually, there is a rather clear range of these warm water or 'thermophilous' and cold water or 'psychrophilous' fish fauna in the Mediterranean, as the first is distributed in the south mainly along the African and Asian coasts, while the second is restricted to the European coasts in areas where cold water dominates (North Adriatic, North Aegean, Black Sea, etc.), following the actual temperature and current regime.

Active movement according to trophic availability concerns the errant large pelagic species such as sharks, various scombrids, tetrapterids, swordfish, etc. Several such species are season regular or rare vagrant visitors. In some other cases, such as the sea lamprey *(Petromyzon marinus),* a parasitic mode of life forces it to move far away from its normal distribution. Therefore, the recording of this last species in the North Aegean Sea (ECONOMIDIS *et al.,* 1999), where there are no spawning grounds for permanent settlement, could be qualified as accidental and the species as 'vagrant' and not as exotic or as alien, because the area is within its large range. A similar example would be any species of remoras, accompanying large marine animals, such as the *Remilegia australis* (= *Remora australis*), noticed long ago in Hellenic waters (TORTONESE, 1946, 1947a), and which, according to GOLANI *et al.* (2002), although very rare could be considered a Mediterranean resident.

In several other cases, such as the Atlantic muraenid *Enchelycore anatina,* spread from the Atlantic to the Mediterranean, where there are only two records one of which being from Elafonissos (Peloponnesus coasts) (GOLANI *et al.,* 2002), could be explained by passive dissemination of the leptocephali larvae and/or via transport in ship ballast.

Aquaculture introduced

Uncontrolled and/or collapsed aquacultures are responsible for the releasing of specimens into nature from their reared stocks. Some few cases have already been reported in the Greek seas by pictured and/or preserved specimen, but information has not been yet published. One of these may concern some mullet specimens, apparently *Liza carinata,* captured in western Greek estuaries (Table 1). Such a species was introduced long ago as fry from Egypt to a fish farm near Arta (river Arachthos estuary in the Amvrakikos Gulf), which subsequently closed down (unpublished data). However, *Liza carinata* is listed among Indo-Pacific aliens

(GOLANI *et al.,* 2002), since it has also been recorded in the Levantine basin, including the Turkish Mediterranean and Aegean coasts (TORCU & MATER, 2000; ZAITSEV & ÖZTÜRK, 2001; BILECENOGLU *et al.,* 2002). Consequently, its occurrence could be also due to the expansion of this lessepsian immigrant distribution from the Eastern Mediterranean to the Ionian Greek waters previously mentioned.

It is known that around Greek and other European estuaries, among captured growing European eel *(Anguilla anguilla)* there also are some specimens of the elvers of the Japanese eel *(Anguilla japonica),* species largely used in fish farms, which have escaped from eel farms (unpublished data). Another case concerns the largemouth bass *(Micropterus salmoides)* that was observed in 2003 and photographed near the estuaries of the stream Lessini, flowing directly into the Ionian Sea (unpublished data) (Table 1). Recent records concerning several species of sturgeons such as *Acipenser güldenständi, Huso huso* or various rearing hybrids, as well as *Acipenser sturio,* captured in the Thracian Sea, near the Evros estuaries or in the river itself, strongly suggest that they originate from the release of fry or escapees from hatcheries lying in the Evros river catchment of Bulgaria and/or of Turkey, as there are no such installations in the Hellenic part of the river (KOUTRAKIS & ECONOMIDIS, 2006). Therefore, some previous records of *Acipenser stellatus* (ECONOMIDIS *et al.,* 2000) maybe have had the same origin. Furthermore, there is unverified information that certain alien fish species (for instance *Pagrus major*) or even fry of native Mediterranean fish, such as *Dicentrarchus labrax* and *Sparus auratus,* originating from distant areas (i.e. Spain), are used widely in marine Greek fish farms. Consequently, very often these species of different genetic stocks are released or escape as fry or adults into the wild. But there is a confirmed record of the Indo-Pacific native mullet, *Liza haematocheilus* (*Mugil soiuy*), which was reared in Black Sea cage fish farms. Many of these farms collapsed in the nineties and specimens were carelessly released in the Azov and Black Sea areas (STARUSHENKO & KAZANSKY, 1996). Soon after, the species was observed in the Turkish Aegean Sea (Gulf of Smyrna: KAYA *et al.,* 1998) and in the Thracian Sea (KOUTRAKIS & ECONOMIDIS, 2000) (see also HARRISON, 2004). Actually, it forms fished population in various Thracian and Macedonia lagoons and it is captured and appears frequently in the fish markets of North Greece. (After MINOS *et al.,* 2007 and in press).

Lessepsian Aliens

The movement of various marine organisms from the Red Sea to the Mediterranean via the Suez Canal was named Lessepsian migration by POR (1969), a term widely used in literature thereafter; it is very often also called Erythrean migration. According to GALIL & ZENETOS (2002), the Eastern Mediterranean, open to Atlantic, Pontic and Erythrean biota, is particularly prone to invasion. Concerning fish, the Lessepsian species in the Mediterranean are real alien species because they belong to another ecological status (thermophilous) and to a different bio-geographical zone (Indo-Pacific), and the Mediterranean is out of their native distribution.

In recent years intensive research has brought to light more alien species which might have been present in low densities and thus escaped our attention (CORSINI & ECONOMIDIS, 1999). The immigration of such alien species is far from ceasing after approaching a standard level, since in practice the flux of invaders is continuous (STREFTARIS *et al.,* 2005). The dynamics of invasions and extension of the distribution of alien species obviously need a continuous update and a monitoring procedure (GOLANI *et al.,* 2004; ZENETOS *et al.,* 2005; PANCUCCI-PAPADOPOULOU *et al.,* 2005a, b).

Establishment. According to the more recent inventories the Lessepsian fish migrants in the Mediterranean are one Elasmobranchii species and more than 60 Teleostei species (GOLANI *et al.,* 2006 on-line; GOKOGLU *et al.,* 2003; CORSINI *et al.,* 2005; AKYOL *et al.,* 2005; CORSINI *et al.,* 2006; BILECENOGLU & KAYA, 2006; ÇINAR *et al.,* 2006; GOLANI, 2006; ERYLMAZ & DALYAN, 2006; GOLANI & SONIN, 2006). Once arrived in the Mediterranean Sea through the Suez Canal, these species move either westwards to the African

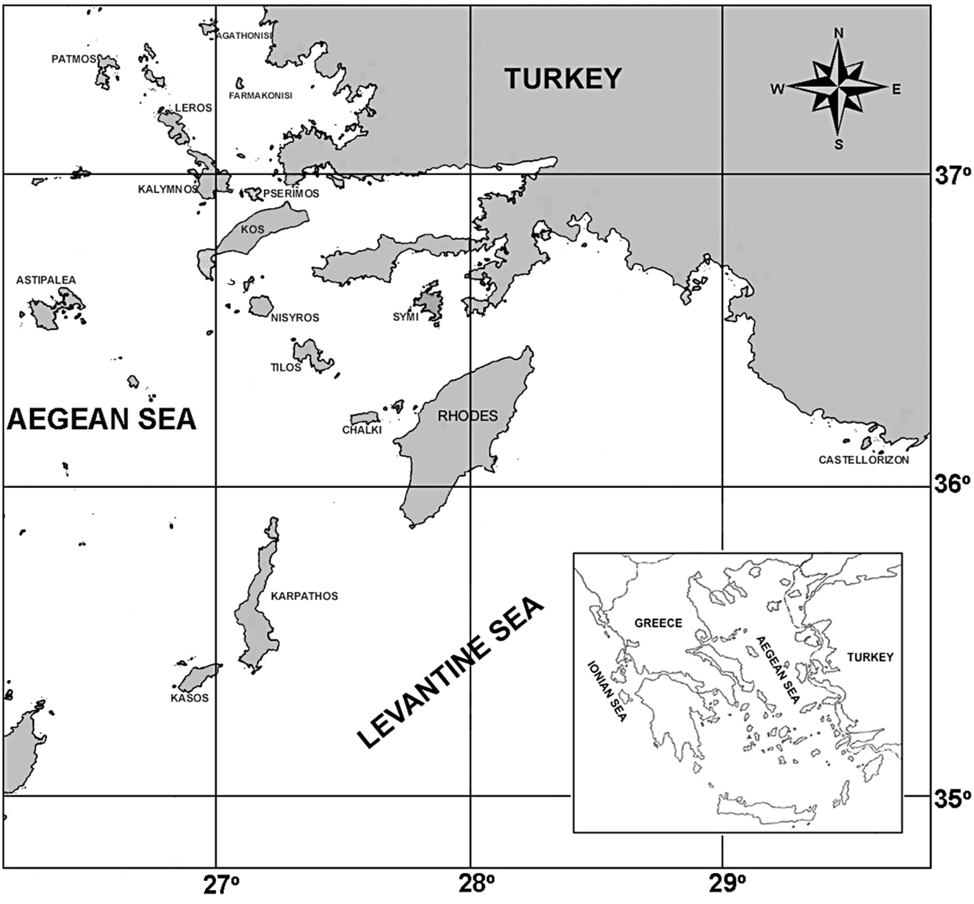

Fig. 1: The Dodecanese islands and the Hellenic Seas.

coasts or usually eastwards first and then northwards, following mainly the Asiatic continental shelf. They normally establish, fast or slow, dense or scarce populations, in the Levantine Sea where they influence or even modify essentially the composition and the structure of the local marine ecosystems. The common way for further colonization of the Mediterranean is mainly by using the South coast of Turkey and its narrow continental shelf. Besides, the water masses around the Dodecanese Islands form the most important gates for entering and establishing in the Aegean Sea and the main pathway of spread within the Mediterranean (PANCUCCI-PAPADOPOULOU *et al.,* 2005a, b) (Fig. 1). A number of 28 Lessepsian immigrant fish species has entered Greek waters (Table 1). Three additional ones have been reported from the SE Aegean Sea, along the Turkish coasts, *Scomberomorus commerson* (BUHAN *et al.,* 1997) and *Oxyurichthys petersi* (AKYOL *et al.,* 2006) in Gokova Bay and *Sillago sihama* in Datça peninsula (BILECENOGLU, 2004). Older records of Lessepsian fish in Hellenic waters amounted to thirteen species until 1990 (PAPACONSTANTINOU, 1987, 1990; also References in Table 1). An evident increase in records has been observed in the last decade, when 15 other such species were added. A similar picture is presented by the Erythrean crustaceans, which suddenly occurred in the SE Aegean in the past decade and, according to GALIL & KEVREKIDIS (2002), this may be due to the more extensive inflow of the Asia Minor Current in the area.

CORSINI & ECONOMIDIS (1999) mention that several Lessepsian species were reported in the Dodecanese almost simultaneously as along the coasts of Israel. Such are the cases of *Siganus rivulatus, Upeneus moluccensis, Sargocentron rubrum, Pteragogus pelycus and Fistularia commersonii.* On the contrary, as for example the cases of *Sphyraena chrysotaenia, Apogon pharaonis, Etrumeus teres* and some others, the advance along the Anatolian coasts was gradual and the immigrants reached this area after a relatively long time, depending on biotic and abiotic factors (GOLANI, 1998a; CORSINI & ECONOMIDIS, 1999; CORSINI *et al.,* 2002, 2005; CORSINI FOKA *et al.,* 2004) (Table 1). There is a direct relation between the environmental conditions and the speed of spread and adaptation of the new settler. In fact, species have to face a combination of unfavourable ecological conditions (water temperature, substratum, currents, trophic conditions etc.) when following the narrow continental shelf of the South Anatolian coast as the main way for westward spread, as the majority of species are coastal. Consequently, once they reach the continental shelf of the Dodecanese islands, they do not usually advance any further; some of them are also commercially exploited.

On the other hand, a large number of Lessepsian immigrants, being quite common in the Levantine, have not been recorded in the SE Aegean Sea. This different trend could be owing to many biotic and/or abiotic factors as, for example, the temperature regime and the thermal tolerance of the colonizing species, food availability, competition with indigenous species, local pathogens and the suitable substrate (GOLANI, 1998a). The extension of the spawning season, the aggressive behaviour of the new species, their food preferences, could also be added. Colonizers may also occupy free niches already existing or created by over-fishing of local species. All these, like many other factors, need a more accurate survey to obtain a complete view of the real situation.

In comparison, along the Turkish territorial waters of the Aegean and the East Mediterranean, 38 species of teleosts of Red Sea origin have been recorded (GOLANI *et al.,* 2006 on-line; BILECENOGLU *et al.,* 2002; ÇINAR *et al.,* 2005, 2006; BILECENOGLU & KAYA, 2006).

A number of 25 species is common in the Hellenic and the Turkish waters.

It is obvious that several fish species already detected and established along the Levantine Turkish coasts can be expected also in Hellenic waters, especially *Dussumieria elopsoides, Herklotsichthys punctatus, Pelates quadrilineatus, Cynoglossus sinusarabici, Liza carinata.*

Spreading. Lessepsian migrant species once having reached the Dodecanese continental shelf seem to have difficulties in further spread to the rest of the Aegean Sea, mainly to the north, or in continuing their expansion to all the Mediterranean. Among the above 28 Lessepsian fish species (Table 1), only nine have been recorded further north than the Dodecanese plateau, five before the last decade and the other four during the last seven years (Table 2). The recording of the *Tylosurus crocodilus* in the Chalkidiki peninsula, based on a dead fish found on Gerakini beach (SINIS, 2005), needs a special mention as it is a recording which merits further investigation. This is a first recording in the Mediterranean and its derivation as a rejected specimen from undelivered foreign stock should also be considered.

Spreading to the south, central or western Greek waters of the Aegean and the Ionian seas seems to have the same low success, as only fourteen and six species respectively followed these routes (Table 2).

This statement shows that some abiotic (water temperature, salinity, current regime, size of continental shelf, etc.) and/or biotic factors (food quality and quantity, spawning facilities, etc.) are impeding the spread of Erythrean fish.

In general, the species which have spread out of the Dodecanese 'refuge' (Table 2) have a wide native distribution area (Table 1). Although tropical or subtropical fish, they are able to colonize temperate regions quite easily, the water temperature not prohibiting their spread.

Although the Cretan continental shelf lies in the south Aegean Sea in a rather warm water zone, colonization by Lessepsian immigrants presents some interesting particularities. Since these species are regarded as thermophilous, it would be expected that they would settle more easily in the coastal waters of Crete. However, unfavourable factors obviously seem to be an interdiction for their large scale settlement there as only eleven fish species were recorded, two before 2002, *Stephanolepis diaspros* and *Saurida undosquamis,* and another nine in the last four years: *Siganus luridus, Fistularia commersonii, Siganus rivulatus, Pempheris vanicolensis, Sargocentron rubrum* and recently, *Lagocephalus sceleratus, Etrumeus teres, Upeneus moluccensis* and *Pteragogus pelycus* (Table 2). These new records are the result of recent more intensive local investigations, but still the number of the species remains low. This phenomenon could be attributed to the fact that although the continental shelf of Crete is accessible to Lessepsian immigrants through the Kasos-Karpathos corridor, its colonization shows a rather slow progress mainly because it is very narrow and delimited by exceptionally deep waters, thus isolating the coastal zone of Crete.

Several of the Erythrean fish are still not only distributed in the Levant Basin, since the populations of at least nine of them already established in the eastern Mediterranean, both along the Asiatic and African coasts as well as the Greek seas, have expanded westward. According to GOLANI *et al.* (2002, 2004), in some cases they have reached the Central Mediterranean, such as *Siganus luridus, Siganus rivulatus, Stephanolepis diaspros. Siganus luridus* has enlarged its distribution to the southern coasts of Sicily (AZZURRO & ANDALORO, 2004) and the northern coasts of Sicily in the Tyrrhenian sea (CASTRIOTA & ANDALORO, 2005), as have also *Stephanolepis diaspros,* which has reached the Palermo coasts (CATALANO & ZAVA, 1993), *Sphyraena chrysotaenia* which has been reported from Malta (LANFRANCO, 1993), *Parexocoetus mento* and *Fistularia commersonii* from Tunisia (BEN SOUSSI *et al.,* 2004), the last species also from southern Sicily (AZZURRO *et al.,* 2004), the SW shore of Sicily (MILAZZO *et al.,* 2006) and Central Tyrrhenian waters (MICARELLI *et al.,* 2006; PAIS *et al.,*

Table 2
Spreading of Lessepsian fishes in the Aegean and Ionian seas, out of the Dodecanese continental shelf.

Species	North Aegean	South Central Aegean	Ionian Sea	References*
Etrumeus teres		+		[1] [2]
Fistularia commersonii	+	+		[3] [4] [5]
Lagocepalus sceleratus	+	+		[6] [2] [17]
Lagocephalus spadiceus		+		[7]
Leiognathus klunzingeri	+	+		[3]
Parexocoetus mento		+	+	[3]
Pempheris vanicolensis		+		[5]
Saurida undosquamis	+	+	+	[8][9] [3] [10]
Siganus luridus	+	+	+	[9] [3] [5]
Siganus rivulatus	+	+	+	[11] [3] [5]
Stephanolepis diaspros		+	+	[3] [12]
Tylosurus crocodilus	+			[13]
Upeneus moluccensis	+	+	+	[14] [15] [3] [16]
Pteragogus pelycus		+		[18]
Sargocentron rubrum		+		[19]

* [1] Cyclades, Crete, KALLIANIOTIS & LEKKAS, 2005; [2] Crete, KASAPIDIS *et al.,* 2007; [3] GOLANI *et al.,* 2006 on-line; [4] Chalkidiki, KARACHLE *et al.,* 2004; [5] Crete, TINGILIS *et al.,* 2003; [6] Izmir, BILECENOGLU *et al.,* 2006; [7] Samos, ANANIADIS, 1952; [8] ZAITSEV & ÖZTÜRK, 2001; [9] ONDRIAS, 1971; [10] Crete, TSIMENIDIS *et al.,* 1991; [11] Izmir, GELDIAY, 1969; [12] Crete, ECONOMIDIS & BAUCHOT, 1976; [13] Thermaikos, SINIS, 2005; [14] Kusadasi, KAYA *et al.,* 1999; [15] Patraikos, KASPIRIS, 1976; [16] various areas, PERISTERAKI *et al.,* 2006; [17] Lesvos, KOUTSOUMBA, D., 2007 (pers. comm.); [18] Crete, STERIOTI, A., 2005 (pers. comm.); [19] Crete, TINGILIS, G., 2003 (pers. comm.).

2007). Some Lessepsian fish are furthrmore colonizing the coasts of the Adriatic Sea, like *Siganus rivulatus, Stephanolepis diaspros, Sphyraena chrysotaenia, Saurida undosquamis, Parexocoetus mento, Leiognathus klunzingeri* and *Hemiramphus far* (DULČIČ *et al.,* 2003).

In conclusion the westward spread of Lessepsian species will proceed slowly, but may accelerate if the increase in water temperature continues. A rearrangement of the ecosystem structure is already appearing in the eastern basin and this could be an important factor for fishery management.

Habitat. At present most Erythrean Indo-Pacific alien invertebrates occupy the Mediterranean littoral and infralittoral zones to a depth of approximately 50m, and are hardly ever found in deeper waters (GALIL & ZENETOS, 2002). This is also true for the Lessepsian fish species, which are in the majority coastal species dwelling in rather shallow, sandy or muddy habitats (GOLANI, 1993) or rocky shores, often covered by sea-grass.

In Rhodes and other Dodecanese coastal areas the majority of Erythrean fish are collected by trawlers at depths of up to 50m, more frequently on sandy-muddy bottoms covered by well-developed Chlorophyceae beds (*Caulerpa prolifera* and *Caulerpa racemosa*) and Phanerogames prairies, mainly *Posidonia oceanica* and *Halophila stipulacea* (CORSINI & ECONOMIDIS, 1999; CORSINI *et al.,* 2005, 2006). Other species are encountered on sandy-rocky bottoms, such as *Pempheris vanicolensis, Sargocentron rubrum* and schools of juvenile *Shyraena chrysotaenia* or in very shallow sandy areas, as for *Iniistius pavo.* On the other hand, as assessed by CORSINI *et al.* (2005), *Tylerius spinosissimus* was collected at a lower depth than those it is found in in its original tropical waters, but deeper than that usual for Lessepsian migrant fish in the SE Aegean Sea. This probably shows that there may be several unexplored niches suitable for the new colonizers. The first finding of this young pufferfish in Rhodes, far from the Suez Canal, indicates that a certain population of the species is already established in the eastern Mediterranean, especially closer to the Suez Canal areas; its spread follows quite unusual paths, as observed in the case of *Tetrosomus gibbosus* (SPANIER & GOREN, 1988). However, the possibility that other vectors (ship ballast, aquaculture or aquaria purposes transport), different from the natural pathway, may be responsible for the introduction of such Indo-Pacific species as the spiny blaasop *Tylerius spinosissimus* should not be undervalued, in common with other taxa also introduced in this way into Hellenic waters (PANCUCCI-PAPADOPOULOU *et al.,* 2006).

Abundance and interactions. The abundance of some Lessepsian immigrant fish has assumed economic importance in the south-eastern Levantine and Anatolian fisheries (GUCU *et al.,* 1994; TORCU & MATER, 2000; GOLANI *et al.,* 2002; ÇICEK & ASVAR, 2003; HARMELIN-VIVIEN *et al.,* 2005), while other Erythtrean invaders are considered as economic burden by GOREN & GALIL (2005).

Populations of Lessepsian fish throughout the coastal waters of the Dodecanese continental shelf generally correspond to species that have been previously established there and they have been large enough to be detectable (CORSINI *et al.,* 2005). This is confirmed by the fact that such various species have normally been present in fishery activities from their first recording in the region until today (CORSINI FOKA *et al.,* 2004). Among the established species listed in Table 1, the majority are caught regularly, but these species cannot be considered abundant. They are: *Hemiramphus far, Stephanolepis diaspros, Upeneus moluccensis, Sargocentron rubrum, Saurida undosquamis, Atherinomorus lacunosus, Pempheris vanicolensis, Pteragogus pelycus* and *Apogon pharaonis.* On the contrary, some other successfully established species are common and have acquired a commercial importance, i.e. *Siganus luridus, S. rivulatus* and *Sphyraena chrysotaenia;* the latter is normally confused with the two indigenous species *S. sphyhraena* and *S. viridensis* coexisting in the same coastal area (CORSINI & ECONOMIDIS, 1999), and also with the new Erythrean colonizer *S. flavicauda.* The quickly increasing population of the recent colonizer *Etrumeus teres* is already contributing to fishery in the Dodecanese (CORSINI-FOKA, unpubl. data) and in the Cyclades Islands (KALLIANIOTIS & LEKKAS, 2005), as also has been observed in Israel, Cyprus and Turkey (GOLANI *et al.,* 2002, ÇICEK & AVSAR, 2003).

Local indigenous fish, especially small-sized and fry, are subjected to a remarkable predation pressure. This fact presents the other side of the coin, perhaps suggesting that several invaders and native species are in competition. Consequently, the impact on the local exploited populations by Lessepsian immigrants seems to be serious and accelerated in some cases. Thus a more detailed approach on this matter is needed.

The permanent establishment of a Lessepsian species in the area, and consequently how harmful this would be for the native fish, is related to its reproductive success. In many cases such a successful breeding, in combination with food availability and other favourable environmental factors, leads to a population explosion. Such a case of population explosion was observed in the area during the 1940's for *Upeneus moluccensis* (LASKARIDIS, 1948a), followed by a dramatic crash shortly after, so that nowadays this species is rarely found in the area (CORSINI & ECONOMIDIS, 1999).

Several Erythrean invaders may have found vacant ecological niches and obviously they do not compete with local native species. Thus, *Siganus luridus* and *S. rivulatus* were well established in the entire Levantine basin initially and then invaded the Central Mediterranean, due to the presence of few herbivorous competitors and/or abundant available food. Furthermore, *Upeneus moluccensis* is present but it does not dominate *Mullus barbatus. Apogon pharaonis* is regularly caught in trawl nets, as well as its indigenous counterpart *Apogon imberbis,* while *Pteragogus pelycus* occurs with other labrid species of similar size (for example *Symphodus* sp., *Coris julis, Thalassoma pavo*). Schools of Sphyraenidae are also noted, both belonging to the indigenous species *Sphyraena sphyraena* and *S. viridensis* but also to the Lessepsian *S. chrysotaenia* and *S. flavicauda* (see above). *Saurida undosquamis* is very rare compared to *Synodus saurus.* On the other hand, no local fish species disappeared in the Rhodes marine area as assessed for the rest of the Eastern Mediterranean (GOLANI, 1998b).

Fistularia invasion. In terms of impact, the recent invader, blue cornetfish, *Fistularia commersonii,* caught normally by trawl-nets up to 50-60m, has developed an important population and is considered one of the worst invasive fish species in the Mediterranean Sea (PANCUCCI-PAPADOPOULOU *et al.,* 2005b; STREFTARIS & ZENETOU, 2006). This species presents a very fast expansion along the coasts of the Levantine basin (GOLANI, 2000; CORSINI *et al.,* 2002) and recently up to the north Aegean Sea (Chalkidiki peninsula), to the northern coasts of Crete and westward to the Central Mediterranean and Tyrrhenian Sea (GOLANI *et al.,* 2006 on-line; Table 2; ICES, 2006; PAIS *et al.,* 2007). The phenomenon is alarming because this fish reproduces and grows very rapidly, reaching a remarkably large size. Since its first appearance in the Rhodes marine area in 2001, the blue cornetfish occurs at a number of 5 to 20 specimens occasionally in a catch of any trawl net operation, mainly at a depth of 20-25 m, but also in the very shallow waters of beaches and harbours (KALOGIROU *et al.,* 2007).

Additionally, the species presents an extreme feeding activity and a clear aggressive behaviour when in schools. As a free-swimming carnivore, it is merely dwelling over reefs and sea-grass beds. As it has no or little commercial value, it is subjected to a very low fishing pressure, being more a 'by catch' fish than a target. Consequently, it is free to form large populations, which seriously affect economically and ecologically important native species not only in the limited area of the SE Aegean Sea, but in all occupied new habitats, as in the South Aegean Sea (unpublished data). It mainly feeds on fish fry, gobiids and several exploited populations of economically valuable native fish, namely *Spicara smaris, Mullus* spp. and *Boops boops* (CORSINI *et al.,* 2002; KALOGIROU *et al.,* 2007). Anatomical features of mouth and feeding behaviour observed in nature and food items found in stomach content reveal that *Fistularia commersonii* should not be ranked in the highest trophic levels. Various sized individuals of the species could be seen rather as an easy prey-fish for any energetic predator, if it accepts and/or appreciates them.

Inventorying Lessepsian migrants. Lessepsian alien fish species occurring in Greek waters belong to 20 families. The non-indigenous species have added seven families to the Hellenic ichthyofauna: Siganidae, Hemiramphidae, Fistularidae, Holocentridae, Leiognathidae, Pempheridae, Monacanthidae, while other aliens increased the species number of five already well-represented families (ECONOMIDIS, 1973; WHITEHEAD *et al.,* 1984-1986; BAUCHOT, 1987; PAPAKONSTANTINOU, 1988) (Fig. 2). The remaining aliens increased the species number in families represented by one or two species, with the exception of the Tetraodontidae, which needs particular attention. Until 1994, only the autochthonous *Lagocephalus lagocephalus,* the Lessepsian *Lagocephalus spadiceus* and *Sphoeroides pachygaster* from the Atlantic were known in the area. A rapid increase of records in the last two years added four more Indo-Pacific tetraodontid species: *Tylerius spinosissimus, Lagocephalus suezensis, Lagocephalus sceleratus and Torquigener flavimaculosus* (Table 1). Among these last alien tetraodontid colonizers, the population of the large sized *L. sceleratus,* which is not marketable since it may cause food poisoning, is increasing rapidly (AKYOL

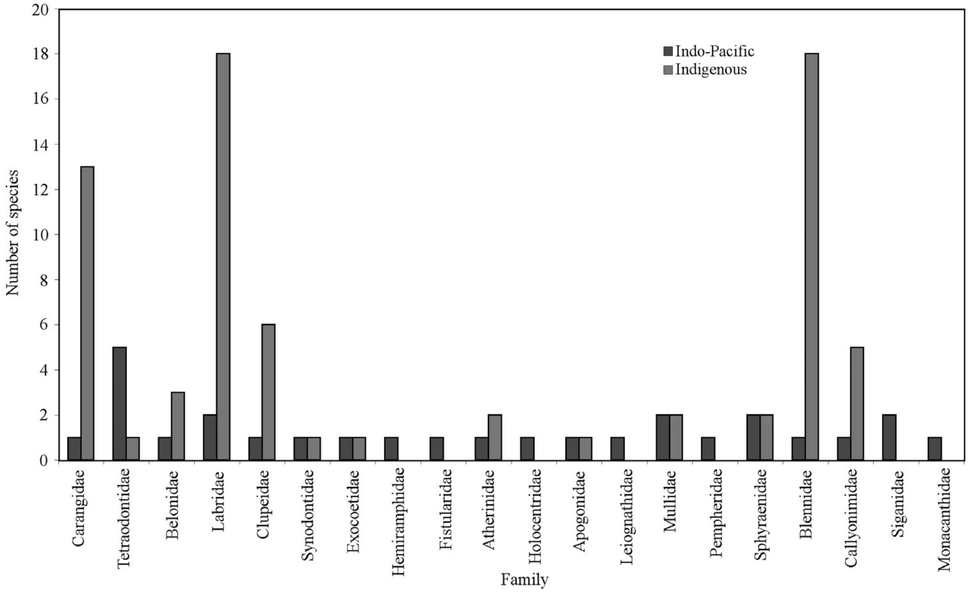

Fig. 2: Number of Lessepsian fish species and families added to the Hellenic ichthyofauna.

et al., 2005; GOLANI & LEVY, 2005; CORSINI *et al.,* 2006; BILECENOGLU *et al.,* 2006; KASAPIDIS *et al.,* 2007) as *L. suezensis* as well. This fact is also sustained by very recent unpublished data which show the presence of a large number of juveniles of these two species in fishery activities along the coasts of Rhodes Island.

Conclusions

Almost the entirety of alien fish species introduced for aquaculture and their presence in nature is based on unverified observations of free-swimming specimens which strongly suggest careless release or escape from fish farms. The list of species is expected to gradually increase, as the number of aquaculture installations in the Hellenic seas and in the neighbouring areas has been increasing. Apparently, no serious precautions are undertaken in order to avoid any accidental escape from farm stocks.

Concerning Lessepsian aliens, the presence of other species may be ascertained only through a comprehensive and regular study along the coasts, also including habitats fished infrequently, where a species at a low density population although it is a regular inhabitant may be undetected, (GOLANI *et al.,* 2002), or habitats are not exploited because their resources are considered as having minimal or zero commercial value or they are unreachable by usual fishing methods, however, they may be important as nursery grounds and biodiversity reservoirs.

Taking into account the increased interest of the scientific community in Lessepsian colonization, a higher rate of invasion of the Levantine coasts by tropical fish species and their successful acclimatization is evident, confirming that 'the littoral and infralittoral biota of the Levantine Sea is undergoing a profound change due to the influx of Erythrean invaders' (GALIL & ZENETOS, 2002), and furthermore giving support to the indication of a tropicalization of the area (BIANCHI & MORRI, 2003). In the long run, this phenomenon will little by little increase the complexity of the entire eastern Mediterranean ecosystem and will most probably lead to a new equilibrium, which should be characterized by a higher productivity and stability.

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