

Loss or gain? Invasive aliens and biodiversity in the Mediterranean Sea

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Abstract

More than 500 alien species were listed from the Mediterranean Sea. Though no extinction of a native species is known, sudden decline in abundance, and even local extirpations, concurrent with proliferation of aliens, had been recorded. Examination of the profound ecological impacts of some of the most conspicuous invasive alien species underscores their role, among multiple anthropogenic stressors, in altering the infralittoral communities. Local population losses and niche contraction of native species may not induce immediate extirpation, but they augur reduction of genetic diversity, loss of functions, processes, and habitat structure, increase the risk of decline and extinction, and lead to biotic homogenization. The relevant environmental policy and management framework is discussed. © 2006 Elsevier Ltd. All rights reserved.

1. Introduction

Invasive alien species are increasingly seen by scientists and policy makers as a major threat: “Invasions ... are now widely recognized as one of the most significant components of global change, with far reaching and often harmful effects on biodiversity” (www.eupolitix.com). The “Jakarta Mandate on Marine and Coastal Biological Diversity”, adopted by the Parties to the “Convention on Biological Diversity” (CBD), cites “invasion of exotic species” as one of the five main categories of the anthropogenic impact on marine and coastal biota (www.biodiv.org). Marine invasions are recognized as imperiling global “biodiversity, marine industries (including fishing and tourism) and human health” (Bax et al., 2003). Biodiversity in this context is understood as more than the number of species in an area, it is a conglomeration including genetic variability, species interactions and ecosystem processes. The CBD defines biodiversity as “the variability among living organisms from all sources... and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.” (www.biodiv.org). However, it has been suggested recently that whereas invasive species are indeed “altering many

communities and ecosystems... Evidence supporting a general and primary role for invasive aliens in extinctions remains limited.” (Gurevitch and Padilla, 2004).

Alien macrophytes, invertebrates and fish – over 500 species have been recorded thus far – are prominent in most coastal habitats in the Mediterranean (Galil, in press). It is assumed this is only a partial inventory, as our ignorance of the marine biota leads to “massive underreporting and thus understatement of ... the altered distributions of nonindigenous species” (Carlton, 2000); a distinct size bias is apparent in the Mediterranean records, and data is entirely absent for many of the small-sized invertebrate taxa. With few exceptions, the ecological impact of invasive alien species on the native Mediterranean biota is poorly known (Zibrowius, 1992; Boudouresque, 2004), though it is believed that keystone invasive species may cause major shifts in community composition. In this paper, the reports on the ecological impacts of invasive marine alien species in the Mediterranean are reviewed, and biodiversity loss is discussed.

2. Impacts of invasive alien species

The loss of marine biodiversity in the Mediterranean is of major concern, though no extinction of native species has been recorded (Boudouresque, 2004). Little is known

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about the kaleidoscopic inter-relationships of native and alien biota in the Mediterranean Sea, hindering thorough evaluation and direct tests of competition leading to niche limitation, displacement or extirpation (local extinction). The documented instances of sudden concurrent changes in abundance, where populations of native Mediterranean species appear to have been wholly outcompeted or partially displaced from their habitat space by an alien, could be part of a profound anthropogenic alteration of the marine ecosystem through habitat destruction, pollution, and rising Mediterranean sea-water temperature. Thus, it remains difficult to disentangle potential confounding factors in evaluation impacts of many (if not most) invasions.

Still, a handful of Mediterranean invasive aliens have drawn the attention of scientists, management, and media, for the conspicuous impacts on the native biota attributed to them. Perhaps the most notorious and the best studied invasive species in the Mediterranean are a pair of coenocytic chlorophytes: *Caulerpa taxifolia* (Vahl) C. Agardh (A.K.A. “the killer Alga”, Meinesz et al., 2002), and *Caulerpa racemosa* var. *cylindracea* (Sonder) Verlaque, Huisman and Boudouresque (Verlaque et al., 2004). Other studies traced the impacts of invasive aliens that entered the Mediterranean from the Red Sea through the Suez Canal (Por, 1978; Golani, 1998; Galil, 2000, 2006; Goren and Galil, 2005). Below, I highlight a few of the discernible and sometimes dramatic changes in native biota associated with alien species in the Mediterranean Sea.

2.1. *Caulerpa taxifolia*

An invasive strain of a tropical green alga, *Caulerpa taxifolia* (Vahl) C. Agardh, widely available through the aquarium trade, was unintentionally introduced into the Mediterranean in 1984, by the Musée Océanographique de Monaco with aquaria outflow (Jousson et al., 1998). Within 15 years the invasive alga spread to Spain, France, Italy, Croatia and Tunisia (Meinesz et al., 2001).

This alga’s rapid spread, high growth rate, and its ability to form dense meadows (up to 14,000 blades per m²) on various infralittoral bottom types, especially in areas plagued by higher nutrient loads, led to formation of homogenized microhabitats and replacement of native algal species (Verlaque and Fritayre, 1994; Boudouresque et al., 1995; Harmelin-Vivien et al., 1999). *Caulerpa taxifolia* is associated with reduction of species richness of native hard substrate algae by 25–55% (Verlaque and Fritayre, 1994), and, under certain conditions, outcompetes *Cymodocea nodosa* (Ucria) Ascherson and *Posidonia oceanica* L. Dellile (Villèle and Verlaque, 1995; Ceccherelli and Cinelli, 1999). Since the seagrass meadows are immensely important ecologically, any changes in their architecture, density, and quality would be reflected in the food web they support and in the highly-diverse biota for which they serve as spawning ground and nursery. The alga’s dense clumps of rhizomes and stolons form an obstruction to fish feeding on benthic invertebrates, indeed, total species richness,

density and biomass of fish assemblages are significantly lower in *C. taxifolia*-invaded *Posidonia* beds (Francour et al., 1995; Harmelin-Vivien et al., 1999; Levi and Francour, 2004). Moreover, the most potent of the suite of repellent endotoxins protecting *C. taxifolia* against epiphytes and herbivores, caulerpenyne, is toxic for molluscs, sea urchins, herbivorous fish, at least during summer and autumn when metabolite-production peaks, and capable of decimating microscopic organisms (Ruitton and Boudouresque, 1994; Lemée et al., 1996; Amade and Lemée, 1998). The diminution in the structural complexity of the invaded habitat, together with the replacement of the rich native biota with the *C. taxifolia* species-poor community, result in a dramatic reduction in the richness and diversity of the affected littoral, and constitutes “a real threat for the balance of the marine coastal biodiversity” (Longpierre et al., 2005).

2.2. *Caulerpa racemosa* var. *cylindracea*

The extremely invasive variety, endemic to southwestern Australia, was discovered in the Mediterranean in 1990, and has since spread from Cyprus to Spain and even into the Canary Islands (Verlaque et al., 2003, 2004).

Caulerpa racemosa var. *cylindracea* (Sonder) (Verlaque et al., 2003), is known to attain total coverage in certain areas within six months of entry, its fast growing stolons allowing it to overgrow other macroalgae, mainly turf and encrusting species, and to curtail species number, percent cover and diversity of the macroalgal community. This feat is achieved even in highly diverse, native macroalgal assemblages with dense coverage (Piazzi et al., 2001, 2003). Off Cyprus, where *C. racemosa* var. *cylindracea* was first sighted in 1991, it replaced within six years the dominant *P. oceanica* community, “forming extensive mats” (Argyrou et al., 1999). The drastic change in the composition of the phytobenthos brought about a modification of the macrobenthos: a proliferation of polychaetes, bivalves and echinoderms and a reduction in the numbers of gastropods and crustaceans, and though the total number of species increased, it was mainly due to the greater number of polychaete species. A study of meiofauna in a dead mat of *P. oceanica* invaded by *C. racemosa* var. *cylindracea* revealed an increase in meiofaunal average density but a significant decrease of diversity, and profound change in the crustacean assemblage, where harpacticoid copepods proliferate at the expense of ostracods, cumaceans, isopods, amphipods and tanaidaceans (Carriglio et al., 2003).

2.3. *The rabbitfish*

The two species of siganid fish, *Siganus rivulatus* (Forskål, 1775) and *S. luridus* (Rüppell, 1828), that entered the Mediterranean from the Red Sea through the Suez Canal, were first recorded off the coast of Israel in 1924 (Steinitz, 1927) and 1955 (Ben-Tuvia, 1964), respectively.

Both species are found as far west as the southern Adriatic Sea, Sicily and Tunisia (Ktari-Chakroun and Bahloul, 1971; Ktari and Ktari, 1974; Dulčić and Pallaoro, 2004; Azzurro and Andaloro, 2004). The schooling, herbivorous fishes, able to settle in a range of habitats, form thriving populations in the Levant Sea where “. . . million of young abound over rocky outcropping grazing on the relatively abundant early summer algal cover” (George and Athanassiou, 1967). The siganids comprise 80% of the abundance of the herbivorous fish in shallow coastal sites in Lebanon (Bariche et al., 2004) and one third of the fish biomass in rocky habitats along the Israeli coast (Goren and Galil, 2001). The multitubulous siganids have replaced native herbivorous fish: “. . . along the Libyan coast, *S. rivulatus* seems to outcompete *Boops boops*, reducing the abundance of the latter, since both species feed upon algae. . . . Quite likely, the same is true for the S.E. Aegean Sea” (Papaconstantinou, 1987). Along the Lebanese coast, 40 years ago it was yet unclear “whether or not *Siganus rivulatus* displaces *Boops salpa*” [= *Sarpa salpa* (Linnaeus, 1758)], that had been abundant in trawl catches early in the 20th century (Gravel, 1931; George and Athanassiou, 1967). It has since replaced the native herbivorous *Sarpa* (Bariche et al., 2004).

Prior to the arrival of the siganids in the Mediterranean, there were few herbivorous fish and invertebrates and their role in the food web off the Levantine rocky habitats had been negligible. The algal contribution to the web was mainly through the decomposers (bacteria, fungi, and protozoans) that in turn constituted the main source of food for the upper level of consumers. The siganids brought on fundamental changes that “normalized” the food web: by increasing the rate by which large amounts of algal material were recycled, these fish apparently accelerated the transfer of energy from the producer to the consumer levels (in hours through the fish gastrointestinal system rather than weeks or months of decomposition), and by serving as major item of prey (up to 70%) for larger infralittoral predators such as groupers (Aronov, 2002; Goren and Galil, 2005). Their grazing pressure on the intertidal rocky algae may have benefited the proliferation of an alien Erythrean mussel by providing suitable substrate for its settlement (see below). A comprehensive study of the algal vegetation and the ecology of the fish community off a vermetid reef, south of Haifa Bay, Israel, provided an opportunity to compare the diets of *S. rivulatus* and *S. luridus* collected at the site with the composition of the local algal community, and examine the importance of algal spatial variability and seasonality in the dietary choices of both siganid fish. An analysis of the siganids’ gut contents, in conjunction with the spatial and seasonal composition of the local algal community, showed that their diet has a significant impact on the structure of the local algal community: it seems that by feeding selectively they have nearly eradicated some of their favorite algae locally (Lundberg et al., 2004). The siganids, successful Erythrean invasive aliens, have altered the community structure and the native food web along the Levantine rocky infralittoral.

2.4. The pharaonic mussel

A small Erythrean mytilid mussel, *Brachidontes pharaonis* (Fischer P., 1870), is one of the earliest Erythrean invaders to enter the Mediterranean, already present in 1876 near the northern entrance of the Suez Canal (Pallary, 1912). Common in the Levant Sea, where it settles in dense clusters on midlittoral and infralittoral rocks, piers and debris, it has spread as far west as Sicily, probably in ship fouling, where it is found in high-salinity, high temperature environments (Barash and Danin, 1992; Rilov et al., 2004; Di Geronimo, 1971; Pirro de et al., 2004).

In the early 1970s *B. pharaonis* was “c. 250 times rarer” than the native mytilid *Mytilaster minimus* (Poli, 1795), that formed dense ‘*Mytilaster* beds’ on intertidal rocky ledges along the Israeli coastline, with up to 26 specimens per cm² (at Palmahim; Safriel et al., 1980, Table 4). Studies conducted in the late 1970s along the Israeli coastline, while *B. pharaonis* was still relatively rare, predicted it would neither establish dense populations nor outcompete the native *Mytilaster minimus*: “*B. variabilis* [*pharaonis*] never forms ‘beds’ in the eastern Mediterranean, and is singly or in small groups dispersed within *M. minimus*”, and “. . . it did not displace *M. minimus*” (Safriel et al., 1980, p. 39, 59). The relative rarity of *B. pharaonis* was attributed to the invader’s low intrinsic rate of increase relative to that of the native species, and to strong density-independent mortality generated by exposure to either high wave action or sedimentation. By the end of the 1980s, following a series of experiments, it was determined that *Brachidontes* interferes with recruitment of *Mytilaster*, and detrimentally affects its survival and growth, yet the researchers maintained the Erythrean mytilid was not likely to outcompete the native species: “The two species can coexist, both locally and regionally” (Safriel and Sasson-Frosting, 1988, p. 225). A survey conducted in some of the same sites in the late 1990s have shown a rapid shift in dominance, with some dense populations of up to 300 specimens per 100 cm² on rocky platforms “where mussel beds were absent in the past” (Rilov et al., 2004, p. 347). More recently “the same rocks are . . . completely covered with the Eritrean *B. pharaonis*, while *M. minimus* is only rarely encountered.” (Mienis, 2003, p. 15). The establishment of massive beds of *Brachidontes* has had significant effects on the biota of the hard substrate intertidal. The displacement of the native mussel by the larger, thicker-shelled Erythrean alien appears to have changed predation patterns so that the population of the native whelk, *Stramonita haemastoma* (Linnaeus, 1758), that was found to preferentially prey on *Brachidontes*, increased greatly (Rilov et al., 2002).

2.5. The Erythrean limpet

An Erythrean limpet, *Cellana rota* (Gmelin, 1791), commonly found in the Red Sea and Suez Canal (Tillier and Bavay, 1905; Sharabati, 1984), was first collected in the

Mediterranean in 1961 (Christiaens, 1967). By 2000, *C. rota* spread along the southeastern Levantine coast, occupying the more protected (i.e., less wave-exposed) sites in the intertidal zone, whereas the native Mediterranean limpet, *Patella caerulea* Linnaeus, 1758, inhabited rocks exposed to the surf. A recent survey along the Mediterranean coast of Israel found that alien limpet dominates the upper rocky littoral and has been replacing the native limpet when “a few years ago *Patella caerulea* was the only limpet inhabiting the same rocks at that locality [Ashdod]” (Mienis, 2002, p. 275). Along the southern coast of Israel it has already completely replaced the native limpet, along the central coast it “has taken possession of 40–50% of the available space”. (Mienis, 2003, p. 15).

2.6. The killifish

The Erythrean alien killifish, *Aphanius dispar* (Rüppell, 1829), is markedly euryhaline, occurring in freshwater, and in a range of salinities up to 4 times as high as seawater (Lotan, 1982), whereas its peri-Mediterranean endemic congener, *A. fasciatus* (Nardo, 1827), occurs mostly in brackish lagoons (Maltagliati, 1999). Norman (1927, p. 386) suspected the species interbred: “Both species occur together in Ismailia Lagoon, and I have found it difficult to identify certain specimens from this locality with one species or the other; these examples may perhaps represent hybrids”; and so did (Tortonese, 1954, p. 2), who examined the killifish populations of the Timsah and Bitter lakes in 1944–1945: “Their [*A. fasciatus* and *A. dispar*] hybridization does not appear unlike”. Indeed, of the 4600 killifish collected, between 1973 and 1975, in the hypersaline Bardawil Lagoon on the Mediterranean coast of Sinai, Egypt, 45% were identified as *A. dispar*, 17% as *A. fasciatus*, and 38% were found to be hybrids (Lotan and Ben Tuvia, 1996). Naturally occurring hybrids of the two killifish species were described as “... common, and in some localities (Ashdod Harbour [southern coast of Israel], parts of Bardawil Lagune etc.), these populations comprise mostly hybrids” (Goren and Rychwalsky, 1978, p. 261). Villwock (1985, 1987) too described hybrids from Bardawil Lagoon and al-Qanatir, Egypt. The first Erythrean killifish was collected off Tel Aviv, Israel, in the winter of 1943/44 (Mendelssohn, 1947). The last specimens of the native killifish, *A. fasciatus*, along the Israeli Mediterranean coast were collected on August 13, 1976 (M. Goren, pers. comm.; preserved in the National Collections, Tel Aviv University, access number 6319). Within a generation an endemic genotype appears to be locally lost through hybridization, and *A. dispar* and its hybrids replaced *A. fasciatus* along the Mediterranean coast of Israel (Goren and Galil, 2005).

2.7. Penaeid prawns

Eight species of Erythrean alien penaeid prawns are recorded in the Mediterranean, two reaching as far west as Tunisia (www.ciesm.org). The Erythrean prawns, in par-

ticular *Marsupenaeus japonicus* (Bate, 1888) *Metapenaeus monoceros* (Fabricius, 1798) and *Penaeus semisulcatus* de Haan, 1844, are highly prized and are considered a boon to the Levantine fisheries. They compose most of the prawn catch off the Mediterranean coast of Egypt and in the Nile delta lagoons (Dowidar and Ramadan, 1976; Bishara, 1976). Off the Israeli coast a small fleet of coastal “mini” trawlers has specialized in shrimping, bringing in a quarter of the total trawl catch volume and a third of the trawl gross income (Pisanty and Grofit, 1991; Galil, 1993; Snovskiy and Shapiro, 1999). However, that boon came at the expense of the native penaeid prawn, *Melicertus kerathurus* (Forskål, 1775). The native prawn was commonly caught by trawlers along the Israeli coastal shelf on sandy or sandy mud bottoms, and supported a commercial fishery throughout the 1950s (Holthuis and Gottlieb, 1958). It has since nearly disappeared, and its habitat overrun by the Erythrean penaeid prawns. Geldiay and Kocatas (1972), reported that off the southern coast of Turkey, too, it has been replaced by *M. japonicus* in fisheries catches. d’Udekem d’Acoz (1999) reported that *M. japonicus* “has almost evicted the native *P. kerathurus* from the easternmost part of the Mediterranean”. The rapid advent of *M. monoceros* into the Gulf of Gabes, Tunisia, has raised concerns over the fate of *M. kerathurus* fisheries there (Chaouachi et al., 1998).

2.8. The goatfish and the lizardfish

The Erythrean goldband goatfish, *Upeneus moluccensis* (Bleeker, 1855), was first recorded in the Levant in the 1930s, and has since established populations from Rhodes to Libya (www.ciesm.org). By the late 1940s it made up 10–15% of the total mullid catches off the Israeli coast (Wirszubski, 1953). Following the exceptionally warm winter of 1954–1955, its percentages increased to 83% of the catch, replacing the native red mullet, *Mullus barbatus* (Linnaeus, 1758), in the commercial fisheries (Perlmutter, 1956). Both mullid species have a similar diet, and occupy muddy bottoms shallower than 75 m, but whereas the red mullet spawns from April to June with a peak in May, the goldband goatfish spawns from June to September (Wirszubski, 1953). The considerably higher water temperatures may have resulted in poor survival of the red mullet spawn; that year an unusually large year class of the goldband goatfish survived. In previous years, the young red mullets would settle to the bottom during July through September, where they have had a distinct size advantage over the later-spawned goldband goatfish. The failure of the 1955 red mullet year class may have left their niche only partly occupied, to the advantage of the Erythrean species, and the unusually warm waters enhanced the latter species’ survival rate (Oren). The native mullet has ever since been displaced into deeper, cooler waters: 87% of the mullid catch off the Israeli coast consisted of alien mullids at depth of 20 m, 50% at 55 m, but only 20% in waters deeper than 70 m (Golani and Ben Tuvia, 1995). This phenomenon is not

limited to the SE Levant: the goldband goatfish constituted a significant fraction of the trawl catches in the Bay of Mersin, Turkey, by 1952 (Gottlieb, 1957), concurrent with decline in the numbers of the previously common native mullet (Oren, 1957a).

The Erythrean lizardfish, *Saurida undosquamis* (Richardson, 1848), was first recorded from the Mediterranean coast of Israel in 1952 (Ben-Tuvia, 1953), and has since spread in the entire eastern Mediterranean, from Albania to Libya (Galil, in press, www.ciesm.org). The “abrupt rise in catch of the lizard fish *Saurida undosquamis*, taken by otter trawlers with the usual gear on the regular fishing grounds” (Oren, 1957, p. 1) was attributed to a rise of 1–1.5 °C in sea temperature during the winter months of 1955 (Ben Yami, 1955; Chervinsky, 1959). In 1955–1956 the lizardfish became commercially important, constituting for a few years over half of the total catch on the shallow shelf opposite El-Arish (Gorgy, 1966), up to one fifth of the total annual trawl catch along the Mediterranean coast of Israel, and an important staple of the coastal fishery in the area stretching from Damietta eastward to Port Said (El-Zarka and Koura, 1965). By the mid 1960s it formed the main catch of trawlers off Mersin (Ben-Tuvia, 1966), and accounted for 2/3 of the fish landing biomass in the fall months in the 1980s (Gücü and Bingel, 1994). This sudden increase came at the expense of the native hake, *Merluccius merluccius* (Linnaeus, 1758), it too was displaced into deeper waters (Ben Yami and Glaser, 1974). Since the mid 1980s the lizardfish’s share in catches has declined, and that of the hake augmented.

2.9. *et cetera, et cetera*

The Indo West Pacific fissiparous starfish *Asterina burtoni* Gray, 1840, was first collected in the Mediterranean in 1955, and within a decade formed large populations along the Levant coastline (Tortonese, 1966; Achituv, 1969, 1973; Achituv and Sher, 1991; Karako et al., 2002). Its proliferation was believed to be linked with the concurrent decline in the population of the native congener, *Asterina gibbosa* (Pennant, 1777). Within a decade of its first record in Haifa Bay, Israel, the Erythrean Spiny oyster, *Spondylus spinosus* Schreibers, 1793, has completely out-competed the native congener *S. gaederopus* Linnaeus, 1758 (Mienis et al., 1993). Similarly, the Erythrean jewel box oyster *Chama pacifica* Broderip, 1834, outnumbered its native congener, *C. gryphoides* Linnaeus, 1758: “The local *S. gaederopus* and *C. gryphoides* are hardly even encountered as epibionts on the new immigrant species.” (Mienis, 2003, p. 15). The native Mediterranean cerithiid gastropods, *Cerithium vulgatum* Bruguière, 1792 and *C. lividulum* Risso, 1826, respectively common and abundant in shallow water along the coast of Israel until the 1970s, were supplanted by the Erythrean cerithiids *Cerithium scabridum* Philippi, 1848 and *Rhinoclavis kochi* (Philippi, 1848) (Mienis, 2003, p. 15). The population of the Erythrean narrow-barred mackerel, *Scomberomorus commerson* Lacepède,

1800, has greatly increased in the 1980s, coincidentally with the decline of the one-time common native meager, *Argyrosomus regius* (Asso, 1801), to the point where the latter is rarely encountered along the Israeli coast; the Erythrean dragonet, *Callionymus filamentosus* Valenciennes, 1837, replaced the native callionymids *C. pusillus* Delaroche, 1809, and *C. risso* LeSueur, 1814, along the Levantine upper shelf (Golani, 1998). The Erythrean snapping shrimps *Alpheus inopinatus* Holthuis and Gottlieb, 1958, and *A. audouini* Coutière, 1905, are more common in the south-eastern Levantine rocky littoral than the native *A. dentipes* Guérin-Méneville, 1832, and on the muddy bottoms *A. rapacida* de Man, 1908, is much more common than the native *A. glaber* (Olivi, 1792) (Lewinsohn and Galil, 1982; Galil, 1986).

3. Loss or gain?

Confronted by adversity, a common reaction is seeking refuge in denial. Faced with the preponderance of Erythrean biota in the Southeastern Mediterranean, the risks of invasion were initially dismissed – “Other than *Asterina gibbosa* there is no known case in which a Lessepsian migrant species has completely replaced a local one” (Por, 1978, p. 149), or entirely denied “The Lessepsian migrants may be considered, in a figurative sense “welcome guests” in the impoverished, subtropical cul-de-sac” (Por, 1978, p. 123), even, to have “biologically enriched” the sea (Tortonese, 1973, p. 327). Indeed, the “vacant niche” hypothesis, postulating that the eastern Mediterranean, and particularly the Levant Sea, are “biologically under-exploited by marine life. . . a sort of ecological vacuum where many ecological niches are available” is still current (Oliverio and Taviani, 2003, p. 314). *Mare Mediterraneo felix* – gaining eight alien penaeid prawn species but losing, locally, but a single native one (www.ciesm.org/atlas). One may, or may not, take comfort from the predication that invasions may promote increases in biodiversity locally “. . . because we are introducing new species to areas faster than those new species exterminate natives” (Rosenzweig, 2001, p. 365). Yet biodiversity is not a simple arithmetic. Local population losses and niche contraction may not induce immediate extirpation, but they augur reduction of genetic diversity, loss of functions, processes, and habitat structure, increase the risk of decline and extinction, and lead to biotic homogenization (Olden and LeRoy Poff, 2003; Ruiz, pers. com.).

Studies in the Mediterranean have documented domination of invasive aliens and degradation or loss of local native biodiversity (see above). However, concurrent alien invasion and decimation of native population, though suggesting competitive dominance, do not in themselves imply causation (Ruiz et al., 1999), and high abundance of alien species could be explained as the consequence of native species loss caused by of multiple drivers (Didham et al., 2005). It had been suggested that in reality most invasive aliens serve neither as drivers of ecological change, nor as

mere "... passengers of more fundamental environmental change that is most limiting to native..." (MacDougall and Turkington, 2005, p. 43), but are part and parcel of a synergetic complex of drivers where "habitat disturbance frequently increases the impacts of invasive species" (Didham et al., 2005, p. 472). Multiple stressors – pollution, eutrophication, destruction and fragmentation of habitats, fisheries overexploitation, climate change – are implicated in a web of linkages that caused the pre-introduction decline in the richness and diversity of the native Mediterranean littoral ecosystem and thus to its domination by invasive aliens (Bianchi and Morri, 2000; Occhipinti-Ambrogi and Savini, 2003; Galil, 2006).

In many of the examples described above the changes that had occurred are probably irreversible: despite the return to normal sea water temperature after 1954/5, the invasive goatfish and lizardfish, and other Erythrean aliens, remained dominant in the southern Levant Sea. Similarly, the Erythrean aliens established in the southeastern Aegean Sea during the eastern Mediterranean Transient, have not receded since its decline (Galil and Kevrekidis, 2002; Kumulu et al., 2002; Bilecenoglu et al., 2002; Corsini; Yokes and Galil, 2004; Yokes and Rudman, 2004; Katagan et al., 2004). It is unmistakably plain that the myopic prognostications holding to an "optimistical view on the effects of invasion" (Tortonese, 1973, p. 328) were wrong. It seems that the establishment of alien biota, and the concurrent adverse changes in the native communities, are part of a catastrophic anthropogenic ecosystem shift in the Mediterranean Sea.

4. Ou Allons Nous?

The Conference of Parties to the Convention on Biological Diversity called upon governments to act 'to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species' (CBD 1992, Article 8h), but preventing alien species introductions is a task which needs scientific, administrative and political coordination at the regional, if not international, level. The results thus far have been disheartening.

The International Maritime Organization (IMO) and the shipping industry have concentrated their attention on ways to provide a uniform international instrument to regulate ballast water management, since ballast-mediated bioinvasions have caused significant economic and environmental losses. The International Convention on the Control and Management of Ships Ballast Water and Sediments, a potentially significant environmental achievement, was adopted by a Diplomatic Conference in 2004. To enter into force the convention should be ratified by 30 States, representing 35% of world merchant shipping tonnage. As of now only 6 countries have signed the Convention (www.imo.org).

The past decade saw rapid growth in mariculture in the Mediterranean. However, the Mediterranean countries have not developed the comprehensive legal and institutional sys-

tems that are capable of responding effectively to the introduction of alien species for use in mariculture. Though legislation on introduction and transfers of alien species exists in some countries, in practice the administrative measures to control the deliberate importation of alien and limit their dispersal are still rudimentary and an effective policy of prevention is hardly enforced (Occhipinti-Ambrogi, 2002). Key industry groups, governmental bodies, and even local environmental groups have a poor appreciation of the magnitude of the problem. As a consequence, too often, responses are insufficient, late and ineffective.

The unabated influx of the Erythrean biota is rooted in the continuous enlargement of the Suez Canal that has altered its hydrography and hydrology, and enhanced its potential as a "corridor" allowing ever greater numbers of organisms through. At the time of writing the Suez Canal Authority is expanding the channel further to accommodate Ultra Large Crude Carriers. As in the past, this present enlargement is carried out with no thought to the impacts arising from the invasion of species. Egypt is a Party to the United Nation Convention on the Law of the Seas (UNCLOS, 1982), where Article 196 states that Parties should take measures "to prevent, reduce and control pollution of the marine environment resulting from ... the intentional or accidental introduction of species alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto." Egypt is also a signatory of the CBD, and as such is required to prevent the introduction of, control or eradicate alien species which threaten ecosystems, habitats or species (Article 8(h)), and ensure that the environmental consequences of their policies that are likely to have significant adverse effects on biological diversity are taken into account (Article 14.1). Hewitt et al. (2006, p. 302) suggest inserting an environmental barrier such as a high-salinity lock in the Suez Canal, since a salinity barrier "reduces the likelihood of species migrations through canals" and "The Suez Canal also had, for nearly a century, a natural salinity barrier in the form of the high salinity Bitter Lakes. The magnitude of Erythrean inva[sion] is directly related to the decline in salinity in the Bitter Lakes". In an era of high environmental concern the silence of marine scientists regarding the main means of introduction of alien biota into the Mediterranean Sea is as disturbing as the lack of political will to confront the blatant disregard of international agreements.

The peri-Mediterranean countries possess a valuable instrument were they ready to tackle marine bioinvasions. The Barcelona Convention (1976) and its relevant protocols, initially aimed at reducing pollution, has been updated with the adoption of new protocols. The Protocol concerning Specially Protected Areas (SPA), that had been adopted in 1982 and came into force in 1986, prohibits 'the introduction of exotic species' (Article 7e). In 2003 the Mediterranean Action Plan (MAP), United Nations Environment Programme (UNEP), drafted an 'Action Plan concerning species introductions and invasive species in

the Mediterranean Sea' (UNEP(DEC)MED WG.232/6). In 2005, the Regional Activity Centre for Specially Protected Areas (RAC/SPA) convened a meeting of scientists to identify the most important taxonomic and geographic data gaps concerning Mediterranean alien biota, and to propose guidelines for the prevention of biodiversity loss caused by vessel and mariculture-introduced alien species. These are meant to assist the Contracting Parties to the Barcelona Convention in implementing the SPA protocol (Barcelona, 1995) that calls on them to take "... all appropriate measures to regulate the intentional or non-intentional introduction of non-indigenous ... into the wild and prohibit those that may have harmful impacts on the ecosystems, habitats or species". The desired goal would be the creation of a new Protocol specifically aimed at preventing further loss of biological diversity due to the deleterious effects of the intentional and unintentional introductions of alien invasive biota in the Mediterranean.

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References

- Achituv, Y., 1969. Studies on the reproduction and distribution of *Asterina burtoni* Gray and *A. wega* Perrier (Asteroidea) in the Red Sea and the eastern Mediterranean. *Isr. J. Zool.* 18, 329–342.
- Achituv, Y., Sher, E., 1991. Sexual reproduction and fission in the sea star *Asterina burtoni* from the Mediterranean coast of Israel. *Bull. Mar. Sci.* 48, 670–678.
- Amade, P., Lemée, R., 1998. Chemical defense of the Mediterranean alga *Caulerpa taxifolia* variations in caulerpenyne production. *Aquat. Toxicol.* 43, 287–300.
- Argyrou, M., Demetropoulos, M., Hadjichristophorou, M., 1999. The impact of *Caulerpa racemosa* on the macrobenthic communities in the coastal waters of Cyprus. In: Proceedings of the Workshop on Invasive *Caulerpa* Species in the Mediterranean, Heraklion, Crete, Greece. MAP technical report series 125, 139–158.
- Aronov, A., 2002. Comparative study of the ecology of three groupers (Epinephelidae, Serranidae) at the shallow rocky habitats of the Israeli Mediterranean coast. M.Sc. Thesis, Tel Aviv University, Tel Aviv, Israel, 90 pp. [Hebrew].
- Azzurro, E., Andaloro, F., 2004. A new settled population of the lessepsian migrant *Siganus luridus* (Pisces: Siganidae) in Linosa Island – Sicily Strait. *J. Mar. Biol. UK* 84, 819–821.
- Barash, A., Danin, Z., 1992. Fauna Palaestina: Mollusca I. Annotated list of Mediterranean molluscs of Israel and Sinai. The Israel Academy of Sciences and Humanities, Jerusalem. 405 pp.
- Bariche, M., Letourneur, Y., Harmelin-Vivien, M., 2004. Temporal fluctuations and settlement patterns of native and Lessepsian herbivorous fishes on the Lebanese coast (eastern Mediterranean). *Environ. Biol. Fishes* 70, 81–90.
- Bax, N., Williamson, A., Aguero, M., Gonzalez, E., Geeves, W., 2003. Marine invasive alien species: a threat to global biodiversity. *Mar. Policy* 27, 313–323.
- Ben-Tuvia, A., 1953. New Erythrean fishes from the Mediterranean coast of Israel. *Nature* 172, 464–465.
- Ben-Tuvia, A., 1964. Two siganid fishes of Red Sea origin in the eastern Mediterranean. *Bull. Sea Fisheries Res. Sta., Haifa* 37, 1–9.
- Ben Tuvia, A., 1966. Red Sea fishes recently found in the Mediterranean. *Copeia* 2, 254–275.
- Ben Yami, M., 1955. 1954–1955: over-fishing or bad season? *Fisher. Bull., Haifa*, 6, 10–14 [Hebrew].
- Ben Yami, M., Glaser, T., 1974. The invasion of *Saurida undosquamis* (Richardson) into the Levant Basin – an example of biological effect of interoceanic canals. *Fish. Bull. Wash. DC* 72, 359–373.
- Bianchi, C.N., Morri, C., 2000. Marine biodiversity in the Mediterranean Sea: situations, problems and prospects for future research. *Mar. Poll. Bull.* 40, 367–376.
- Bilecenoglu, M., Taşkavak, E., Kunt, K.B., 2002. Range extension of three lessepsian migrant fish (*Fistularia commersoni*, *Sphyræna flavicauda*, *Lagocephalus suezensis*) in the Mediterranean Sea. *J. Mar. Biol. Ass. UK* 82, 525–526.
- Bishara, N., 1976. Contributions to the biology of penaeid prawns in Lake Manzalah, Egypt I. Growth studies and length-weight relationship. *Aquaculture* 8, 337–349.
- Boudouresque, C.F., 2004. Marine biodiversity in the Mediterranean: status of species, populations, and communities. *Sci. Rep. Port-Cros nat. Park, France* 20, 97–146.
- Boudouresque, C.F., Meinesz, A., Ribera, M.A., Ballesteros, E., 1995. Spread of the green alga *Caulerpa taxifolia* (Caulerpales, Chlorophyta) in the Mediterranean: possible consequences of a major ecological event. *Science* 59 (Suppl.), 21–29.
- Carlton, J.T., 2000. Global change and biological invasions in the oceans. In: Mooney, H.A., Hobbs, R.J. (Eds.), *Invasive Species in a Changing World*. Island Press, Washington DC, Covelo, California, pp. 31–53.
- Carriglio, D., Sandulli, R., Deastis, S., Gall D'Addabbo, M., Grimaldi de Zio, S., 2003. *Caulerpa racemosa* spread effects on the meiofauna of the Gulf of Taranto. *Biol. Mar. Medit.* 10, 509–511.
- Ceccherelli, G., Cinelli, F., 1999. Effects of *Posidonia oceanica* canopy on *Caulerpa taxifolia* size in a north-western Mediterranean bay. *J. Exp. Mar. Biol. Ecol.* 240, 19–36.
- Chaouachi, B., Dos Santos, A., Ben Hassine, O.K., 1998. Occurrence of the shrimp *Metapenaeus monoceros* (Fabricius, 1798) in the Gulf of Gabes: a first record for Tunisian coasts. IV International Crustacean Congress, Amsterdam [Abst].
- Chervinsky, J., 1959. A systematic and biological comparison between the lizardfish (*Saurida grandisquamis*) from the Mediterranean and the Red Sea. *Fisher. Bull., Haifa*, 19, 10–14 [English Abstract].
- Christiaens, J., 1967. Présence de la Pattele *Cellana rota* Gmelin en Méditerranée orientale. *Bull. Mus. Nat. Hist. Nat. Paris* 38, 903.
- Corsini, M., Kondilatos, G., 2006. On the occurrence of two brachyurans, *Myra subgranulata* and *Herbestia condyliata*, on Rhodes Island (SE Aegean Sea). *Crustaceana* 79, 167–174.
- Corsini, M., Kondilatos, G., Economidis, P.S., 2002. Lessepsian migrant *Fistularia commersonii* from the Rhodes marine area. *J. Fish Biol.* 61, 1061–1062.
- Didham, R.K., Tylianakis, J.M., Hutchinson, M.A., Ewers, R.M., Gemmill, N.J., 2005. Are invasive species the drivers of ecological change. *Trends Ecol. Evol.* 20, 470–474.
- Di Geronimo, I., 1971. Prima segnalazione sulle coste italiane di *Brachiodontes variabilis* Krauss. *Boll. Sedute Accad. Gioenia Sci. Nat. Catania* 10, 847–852.
- Dowidar, N.M., Ramadan, Sh.E., 1976. Family Penaeidae from the Mediterranean waters of Egypt. *Thalassia Jugosl.* 8, 121–126.
- Dulčić, J., Pallaoro, A., 2004. First record of the marbled spinefoot *Siganus rivulatus* (Pisces: Siganidae) in the Adriatic Sea. *J. Mar. Biol. Ass. UK* 84, 1087–1088.

- El-Zarka, S. El-Din, Koura, R., 1965. Seasonal fluctuations in production of the principal edible fish in the Mediterranean Sea off the United Arab Republic. *Proc. G.F.C.M.* 8, 227–259.
- Francour, P., Harmelin-Vivien, M., Harmelin, J.-G., Duclerc, J., 1995. Impact of *Caulerpa taxifolia* colonization on the littoral ichthyofauna of north-western Mediterranean: preliminary results. *Hydrobiologia*, 345–353.
- Galil, B.S., 1986. Red Sea decapods along the Mediterranean coast of Israel: ecology and distribution. In: Dubinsky, Z., Steinberger, Y. (Eds.), *Environmental Quality and Ecosystem Stability*, vol. IIIA/B. Ramat Gan, Bar-Ilan University Press 179–183 pp.
- Galil, B.S., 1993. Lessepsian migration: New findings on the foremost anthropogenic change in the Levant Basin fauna. In: Della Croce NFR (Ed) *Symposium Mediterranean Seas 2000* 307–318 pp.
- Galil, B.S., 2000. A sea under siege – alien species in the Mediterranean. *Biol. Inv.* 2, 77–186.
- Galil, B.S., 2006. The marine caravan – the Suez Canal and the Erythrean invasion. In: Gollasch, S., Galil, B.S., Cohen, A.N. (Eds.), *Bridging Divides: Maritime Canals as Invasion Corridors*. *Monographiae Biologicae* 83. Springer, pp. 207–300.
- Galil, B.S., in press. Alien species in the Mediterranean Sea – which, when, where, why? *Hydrobiologia*.
- Galil, B.S., Kevrekidis, K., 2002. Exotic decapods and a stomatopod off Rhodes Island (Greece) and the eastern Mediterranean Transient. *Crustaceana* 75, 925–930.
- Geldiay, A., Kocatas, A., 1972. A report on the occurrence of Penaeidae (Decapoda, Crustacea) along the coast of Turkey from eastern Mediterranean to the vicinity of Izmir, as a result of migration and its factors. 17^e Congrès International de Zoologie (Monte Carlo, 1972). 7 pp.
- George, C.J., Athanassiou, V., 1967. A two year study of the fishes appearing in the seine fishery of St George Bay, Lebanon. *Ann. Mus. Civ. Storia Nat. Geneva* 79, 32–44.
- Golani, D., 1998. Impact of Red Sea fish migrants through the Suez Canal on the aquatic environment of the Eastern Mediterranean. In: J. Albert, M. Bernhardsson, R. Kenna (Eds.), *Transformations of Middle Eastern Natural Environments: Legacies and Lessons*. Yale University Conference. Yale Univ. Sch. Environ. Stud. Bull. 103, 375–387.
- Golani, D., Ben Tuvia, A., 1995. Lessepsian migration and the Mediterranean fisheries of Israel. In: Armantrout, N.B. (Ed.), *Condition of the World's Aquatic Habitats*. Proceedings of the World Fisheries Congress. Theme 1. Science Publishers, Lebanon, New Hampshire, pp. 279–289.
- Goren, M., Galil, B.S., 2001. Fish biodiversity and dynamics in the vermetid reef of Shiqmona (Israel). *Mar. Ecol.* 22, 369–378.
- Goren, M., Galil, B.S., 2005. A review of changes in the fish assemblages of Levantine Inland and marine ecosystems following the introduction of non-native fishes. *J. Appl. Ichthyol.* 21, 364–370.
- Goren, M., Rychwalsky, E.M., 1978. Hybrids of *Aphanius dispar* and *Aphanius mento*, (Cyprinodontidae: Pisces). *Zool. J. Linn. Soc. London* 63, 259–264.
- Gorgy, S., 1966. Les pêcheries et le milieu marin dans le secteur Méditerranéen de la République Arabe Unie. *Rev. Trav. Inst. Pêches marit.* 30, 25–92.
- Gottlieb, E., 1957. Age and growth studies of the yellow-striped mullet (*Upeneus moluccensis*). *Fisher. Bull.*, Haifa 11, 13–20, English Abstract.
- Gruvel, A., 1931. *Les Etats de Syrie. Richesses marines et fluviales, exportation actuelle – Avenir*. Société d'Édition Géographiques, Maritimes et Coloniales, Paris. 453 pp.
- Gücü, A.C., Bingel, F., 1994. Trawlable species assemblages on the continental shelf on the Northeastern Levant Sea (Mediterranean) with an emphasis on Lessepsian migration. *Acta Adriat.* 35, 83–100.
- Gurevitch, J., Padilla, D.K., 2004. Are invasive species a major cause of extinctions? *Trends Ecol. Evol.* 19, 470–474.
- Harmelin-Vivien, M., Francour, P., Harmelin, J.-G., 1999. Impact of *Caulerpa taxifolia* on Mediterranean fish assemblages: a six year study. In: *Proceedings of the Workshop on Invasive Caulerpa in the Mediterranean*; MAP Tech. Rep. Ser. 125, 127–138. Athens: UNEP.
- Hewitt, C., Minchin, D., Olenin, S., Gollasch, S., 2006. Canals, invasion corridors and Introductions. In: Gollasch, S., Galil, B.S., Cohen, A.N. (Eds.), *Bridging Divides: Maritime Canals as Invasion Corridors*. *Monographiae Biologicae* 83. Springer, pp. 301–306.
- Holthuis, L.B., Gottlieb, E., 1958. An annotated list of the Decapod Crustacea of the Mediterranean coast of Israel, with an appendix listing the Decapoda of the Eastern Mediterranean. *Bull. Res. Coun. Israel* 7B, 1–126.
- Jousson, O., Pawlowski, J., Zaninetti, L., Meinesz, A., Boudouresque, C.F., 1998. Molecular evidence for the aquarium origin of the green alga *Caulerpa taxifolia* introduced to the Mediterranean Sea. *Mar. Ecol. Prog. Ser.* 172, 275–280.
- Karako, S., Achituv, Y., Perl-Treves, R., Katcoff, D., 2002. *Asterina burtoni* (Asteroidea: Echinodermata) in the Mediterranean and the Red Sea: does asexual reproduction facilitate colonization? *Mar. Ecol. Prog. Ser.* 234, 139–145.
- Katagan, T., Kocatas, A., Zengin, M., Ates, A., 2004. An Indo-Pacific stomatopod from the Sea of Marmara: *Erugosquilla massavensis* (Kossmann, 1880). *Crustaceana* 77, 381–383.
- Ktari, F., Ktari, M.H., 1974. Présence dans le golfe de Gabes de *Siganus luridus* (Rüppell, 1829) et de *Siganus riulatus* (Forsskal, 1775) (Poissons, siganides) parasites par *Pseudohaliotrematoides polymorphus*. *Bull. Inst. Natl. Sci. Tech. Océanogr. Pêche Salammbô* 3, 95–98.
- Ktari-Chakroun, F., Bahloul, M., 1971. Capture de *Siganus luridus* (Rüppell) dans le golfe de Tunis. *Bull. Inst. Natl. Sci. Tech. Océanogr. Pêche Salammbô*, 2, 49–52.
- Kumulu, M., Erolodogan, O.T., Aktas, M., Gocer, M., 2002. A new shrimp record for the Turkish Seas: *Melicertus hathor* (Burkenroad, 1959) (Penaeidae: Crustacea). *Isr. J. Zool.* 48, 246–247.
- Lemée, R., Boudouresque, C.F., Gobert, J., Malestroit, P., Mari, X., Meinesz, A., Menager, V., Ruitton, S., 1996. Feeding behaviour of *Paracentrotus lividus* in the presence of *Caulerpa taxifolia* introduced in the Mediterranean Sea. *Oceanol. Acta* 19, 245–253.
- Levi, F., Francour, P., 2004. Behavioural response of *Mullus surmuletus* to habitat modification by the invasive macroalga *Caulerpa taxifolia*. *J. Fish. Biol.* 64, 55–64.
- Lewinsohn, Ch., Galil, B.S., 1982. Notes on species of *Alpheus* (Crustacea, Decapoda) from the Mediterranean coast of Israel. *Quad. Lab. Tecno. Pesca, Ancona* 3, 207–210.
- Longpierre, S., Robert, A., Levi, F., Francour, P., 2005. How an invasive alga species (*Caulerpa taxifolia*) induces changes in foraging strategies of the benthivorous fish *Mullus surmuletus* in coastal Mediterranean ecosystems. *Biodivers. Conserv.* 14, 365–376.
- Lotan, R., Ben Tuvia, A., 1996. Distribution and reproduction of killifish *Aphanius dispar* and *A. fasciatus* and their hybrids in the Bardawil Lagoon on the Mediterranean coast of Sinai. *Egypt. Isr. J. Zool.* 42, 203–213.
- Lundberg, B., Ogorek, R., Galil, B.S., Goren, M., 2004. Dietary choices of siganid fish at Shiqmona reef, Israel. *Isr. J. Zool.* 50, 39–53.
- MacDougall, A.S., Turkington, R., 2005. Are invasive species the drivers or passengers of change in degraded ecosystems? *Ecology* 86, 42–55.
- Maltagliati, F., 1999. Genetic divergence in natural populations of the Mediterranean brackish-water killifish *Aphanius fasciatus*. *Mar. Ecol. Prog. Ser.* 179, 155–166.
- Meinesz, A., Belsher, T., Thibaut, T., Antolic, B., Ben Mustapha, K., Boudouresque, C.F., Chiaverini, D., Cinelli, F., Cottalorda, J.M., Djellouli, A., El Abed, A., Orestano, C., Grau, A.M., Ivesa, M., Jaklin, A., Langar, H., Massuti-Pascual, E., Peirano, A., Tunesi, L., de Vaugelas, J., Zavodnik, N., Zuljevic, A., 2001. The introduced green alga *Caulerpa taxifolia* continues to spread in the Mediterranean. *Biol. Inv.* 3, 201–210.
- Meinesz, A., Simberloff, D., Quammen, D., 2002. *Killer Algae*. University of Chicago Press, pp. 360.
- Mendelssohn, H., 1947. A new locality for *Cyprinodon dispar* Rueppel. *Nature* 160, 123.

- Mienis, H., 2002. Is the Lessepsian migrant *Cellana rota* replacing native limpets along the Mediterranean coast of Israel? *Conchologists' Newslett* 163, 275–276.
- Mienis, H., 2003. Native marine molluscs replaced by Lessepsian migrants. *Tentacle* 11, 15–16.
- Mienis, H.K., Galili, E., Rapoport, J., 1993. The Spiny Oyster, *Spondylus spinosus*, a well-established Indo-Pacific bivalve in the Eastern Mediterranean off Israel (Mollusca, Bivalvia, Spondylidae). *Zool. Middle East* 9, 83–91.
- Norman, J.R., 1927. XXV. Report on the Fishes. In: Cambridge Expedition to the Suez Canal, 1924. *Trans. Zool. Soc. London* 3, 375–390.
- Occhipinti-Ambrogi, A., 2002. Current status of aquatic introductions in Italy. *Invasive Aquatic Species of Europe, Distribution, Impacts and Management*. Kluwer, Dordrecht, pp. 311–324.
- Occhipinti-Ambrogi, A., Savini, D., 2003. Biological invasions as a component of global change in stressed marine ecosystems. *Mar. Poll. Bull.* 46, 542–551.
- Olden, J.D., LeRoy Poff, N., 2003. Towards a mechanistic understanding and prediction of biotic homogenization. *Am. Nat.* 162, 442–460.
- Oliverio, M., Taviani, M., 2003. The Eastern Mediterranean Sea: tropical invasions and niche opportunities in a “Godot Basin”. *Biogeographia* 24, 313–327.
- Oren, O.H., 1957a. Changes in the temperature of the eastern Mediterranean Sea in relation to the catch of the Israel trawl fishery during the years 1954–1956. *Fisher. Bull.*, Haifa, 12, 4–6 [Hebrew].
- Oren, O.H., 1957b. Changes in the temperature of the eastern Mediterranean Sea in relation to the catch of the Israel trawl fishery during the years 1954–1955 and 1955–1956. *Bull. Inst. Océanogr. (Monaco)* 1102, 1–13.
- Pallary, P., 1912. Catalogue des mollusques du littoral méditerranéen de l’Égypte. *Mém. Inst. Égypte* 7, 69–207.
- Papaconstantinou, C., 1987. Distribution of the Lessepsian fish migrants in the Aegean Sea. *Biol. Gallo-hell.* 13, 15–20.
- Perlmutter, A., 1956. Sea fisheries. Report to the government of Israel. Technical Assistance Program USOM Agricultural Report No. 13, 58 pp.
- Piazzi, L., Ceccherelli, G., Cinelli, F., 2001. Threat to macroalgal diversity: effects of the introduced alga *Caulerpa racemosa* in the Mediterranean. *Mar. Ecol. Prog. Ser.* 210, 149–159.
- Piazzi, L., Balata, D., Cecchi, E., Cinelli, F., 2003. Co-occurrence of *Caulerpa taxifolia* and *C. racemosa* in the Mediterranean Sea: interspecific interactions and influence on native macroalgal assemblages. *Crypt. Alg.* 24, 233–243.
- Pirro de, M., Sarà G., Mazzola A., Chelazzi G., 2004. Metabolic response of a new Lessepsian *Brachidontes pharaonis* (Bivalvia, Mytilidae) in the Mediterranean: effect of water temperature and salinity. In: Casagrandi R. Melià P (Eds.) *Ecologia. Atti del XIII Congresso della Società Italiana di Ecologia*. <http://www.xiiicongresso.societaitalianaecologia.org>.
- Pisanty, S., Grofit, E., 1991. Limiting effort in the Israeli trawl fishery. *Fish. Fishbreed. Isr.* 24, 100–133, English Abstract.
- Por, F.D., 1978. Lessepsian Migration – the influx of Red Sea Biota into the Mediterranean by way of the Suez Canal. In: *Ecological Studies*, 23. Springer, Springer-Verlag, Berlin-Heidelberg-New York, pp. 228.
- Rilov, G., Gasith, A., Benayahu, Y., 2002. Effect of an exotic prey on the feeding pattern of a predatory snail. *Mar. Environ. Res.* 54, 85–98.
- Rilov, G., Benayahu, Y., Gasith, A., 2004. Prolonged lag in population outbreak of an invasive mussel: a shifting-habitat model. *Biol. Inv.* 6, 347–364.
- Rosenzweig, M., 2001. The four questions: what does the introduction of exotic species do to diversity? *Evol. Ecol. Res.* 3, 361–367.
- Ruitton, S., Boudouresque, C.F., 1994. Impact de *Caulerpa taxifolia* sur une population de l’oursin *Paracentrotus lividus* à Roquebrune-Cap Martin (Alpes Maritimes, France). In: Boudouresque, C.F., Meinesz, A., Gravez, V. (Eds.), *First International Workshop on Caulerpa taxifolia*. pp. 371–378. GIS Posidonie, Marseille.
- Ruiz, G.M., Fofonoff, P.F., Hines, A.H., Grosholz, E.D., 1999. Nonindigenous species as stressors in estuarine and marine communities: assessing invasion impacts and interactions. *Limnol. Oceanogr.* 44, 950–972.
- Safriel, U.N., Sasson-Frosting, Z., 1988. Can colonizing mussel outcompete indigenous mussel? *J. Exp. Mar. Biol. Ecol.* 117, 211–226.
- Safriel, U.N., Gilboa, A., Felsenburg, T., 1980. Distribution of rocky intertidal mussels in the Red Sea coasts of Sinai, the Suez Canal, and the Mediterranean coast of Israel, with special reference to recent colonizer. *J. Biogeogr.* 7, 39–62.
- Sharabati, D., 1984. *Red Sea Shells*. 128 pp. KPI, London, Boston, Melbourne, Henley.
- Snovsky, Z., Shapiro, J., 1999. The fisheries and Aquaculture of Israel 1997 in figures. Ministry of Agriculture, Department of Fisheries, xii+42 pp.
- Steinitz, W., 1927. Beiträge zur Kenntnis der Küstenfauna Palästinas. I. *Publ. Staz. Zool. Napoli* 8, 331–353.
- Tillier, J.B., Bavay, A., 1905. Les mollusques testacés du Canal de Suez. *Bull. Soc. Zool. Fr.* 30, 170–181.
- Tortonese, E., 1954. Some field-notes on the fauna of the Suez Canal (Timsah and Bitter lakes). *Istanb. Univ. Fen. Fak. Hidrobiol.* 1, 1–6.
- Tortonese, E., 1966. Echinoderms from the coast of Lebanon. *Misc. pap. Nat. sci. Am. Uni. Beirut* 5, 2–5.
- Tortonese, E., 1973. Facts and perspectives related to the spreading of Red Sea organisms into the eastern Mediterranean. *Annali del Museo Civico di Storia Naturale di Genova* 79, 322–329.
- Udekem d’Acoz C. d’, 1999. Inventaire et distribution des crustacés décapodes de l’Atlantique nord-oriental, de la Méditerranée et des eaux continentales adjacentes au nord de 25°N. *Patrimoines naturels (M.N.H.N./S.P.N.)* 40, i–x, 1–383.
- Verlaque, M., Fritayre, P., 1994. Modification des communautés algales méditerranéennes en présence de l’algue envahissante *Caulerpa taxifolia* (Vahl) C. Agardh. *Oceanologia acta* 17, 659–672.
- Verlaque, M., Durand, C., Huisman, J.M., Boudouresque, C.F., Le Parco, Y., 2003. On the identity and origin of the Mediterranean invasive *Caulerpa racemosa* (Caulerpales, Chlorophyta). *Eur. J. Phycol.* 38, 325–339.
- de Villèle, X., Verlaque, M., 1995. Changes and degradation in a *Posidonia oceanica* bed invaded by the introduced tropical alga *Caulerpa taxifolia* in the north western Mediterranean. *Bot. Mar.* 38, 79–87.
- Verlaque, M., Afonso-Carrillo, J., Candelaria Gil-Rodríguez, M., Durand, C., Boudouresque, C.F., Le Parco, Y., 2004. Blitzkrieg in a marine invasion: *Caulerpa racemosa* var *cylindracea* (Bryopsidales, Chlorophyta) reaches the Canary Islands. *Biol. Inv.* 6, 269–281.
- Villwock, W., 1985. Contribution on natural hybrids between two valid species of *Aphanius* (Pisces: Cyprinodontidae) from the Bardawil-Lagoon, North Sinai, Egypt. *Rapp. Comm. Int. Mer. Médit.* 29, 57–63.
- Villwock, W., 1987. Further contributions on natural hybrids between two valid species of *Aphanius*, *Aphanius dispar dispar* (Rüppell) and *Aphanius fasciatus* (Valenciennes), (Pisces: Cyprinodontidae) from the Bardawil-Lagoon, North Sinai, and al-Qanatir, west of the Suez Canal, Egypt. In: Krupp, F., Schneider, W., Kinzelbach, R. (Eds.) *Proc. Symp. Fauna Zoogeogr. Middle East*.
- Wirzubski, A., 1953. On the biology and biotope of the red mullet, *Mullus barbatus* L. *Bull. Sea Fish. Res. Sta. Caesarea* 7, 1–20.
- Yokes, B., Galil, B.S., 2004. New record of alien decapods from the southwestern coast of Turkey. *Rapp. Comm. Int. Mer. Médit.* 37, 556.
- Yokes, B., Rudman, W.B., 2004. Lessepsian opisthobranchs from southwestern coast of Turkey; five new records for Mediterranean. *Rapp. Comm. Int. Mer. Médit.* 37, 557.
- Zibrowius, H., 1992. Ongoing modification of the Mediterranean marine fauna and flora by the establishment of exotic species. *Mésogée* 51, 83–107.