The price of change: the economic impacts of alien species and jellyfish outbreaks in the Mediterranean Sea

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ABSTRACT
The economic impacts of invasive alien species and jellyfish outbreaks in the Mediterranean are reviewed. Some Erythrean aliens have been exploited commercially almost as soon as they entered the Levant and today they form an important part of the region’s fishery resources. Other Erythrean aliens are noxious and venomous and pose severe health hazards and economic losses. In the western and central basins of the Mediterranean indigenous jellyfish outbreaks have detrimental impacts on fishery resources and ecosystem functioning, cause health hazards and costly damages to tourism. Multiple anthropogenic stressors destabilize and disrupt the native Mediterranean littoral ecosystem. Virtually every anthropogenic activity harms the sea in some degree. Those activities represent market failures because consumers do not pay for the current and future costs of their actions – in effect grazing on the Mediterranean commons. We need to correct this failure by ensuring that society is confronted with a market price for harming the sea.

INTRODUCTION
Coastal marine systems are among the most ecologically and socio-economically vital. Marine habitats from the intertidal to the continental shelf break are estimated to provide valuable ecosystem goods (e.g. food and raw materials) and services (e.g. disturbance regulation and nutrient cycling). But those marine ecosystems, along with the goods and services they provide, are threatened by multiple anthropogenic stressors – pollution, eutrophication, destruction and fragmentation of habitats, overfishing, introduction of alien species and climate change. These stressors, which are only a fraction of the magnitude of predicted changes in the coming centuries, have already triggered significant responses in the Mediterranean Sea. As these changes continue, we risk serious degradation of marine and coastal ecosystems, with far-reaching consequences for human health and welfare.

Evidence is accumulating that some recent changes in biodiversity patterns in the Mediterranean littoral are linked to direct drivers such as climate change and invasive species (Bianchi and Morri, 2003; Galil, 2007; 2008a,b). By the middle of the century, climate change and invasive species may be the dominant direct drivers of biodiversity loss and increased risk of extinction for many species, especially those already at risk due to low population numbers, restricted or patchy habitats, and limited climatic ranges. Both processes – global warming and the influx of thermophilic aliens – may impact the already teetering fisheries, mariculture, and tourism through proliferation of alien parasitic, noxious and poisonous species, displacement of commercially-important native species,
or through alteration of the food web and by causing phase shift in coastal ecosystems and changing seascape patterns.

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). Alien macrophytes, invertebrates and fish – nearly 600 species have been recorded thus far – are prominent in a number of Mediterranean coastal habitats (Galil, 2008b). In this paper, the reports on the economic impacts of invasive alien species and jellyfish outbreaks in the Mediterranean are reviewed.

**INVASIVE ALIEN SPECIES**

Some Erythrean aliens have been exploited commercially almost as soon as they entered the Levant and their economic importance have been long acknowledged: “… les passages définitifs de ces espèces à travers la totalité du Canal présentent un résultat économique [sic] également très important….. pour les marchés palestiniens et syriens, un appoint non négligeable et particulièrement intéressant, par consequent, pour l’ensemble des populations de ces deux Pays“ (Gravel, 1936: 228, 229).

An early Erythrean invader, the swimming crab *Portunus pelagicus* was on sale already by the early 1900s in the fish market of Haifa (Fox, 1924; Calman, 1927); during the British Mandate the fishermen of Haifa and Acre sold 20 tons of the crab annually (Perlmuter, 1956). By mid-century the Erythrean fishes were an important part of the Levantine fisheries. Insofar as the Israeli fishing grounds were concerned, the bulk of the trawler catch from 1950 to 1955 was comprised of three species – the native red bream *Pagellus erythrinus* (Linnaeus, 1758), the hake *Merluccius merluccius*, and the Erythrean yellow striped mullet *Upeneus moluccensis*. The latter were fished commercially in the early 1940s only along the southern coast of Israel. By 1946-1947 they were found all along the coast (Gottlieb, 1957), and by the late 1940s constituted an estimated 10-15% of the total mullid catch (Wirszubski, 1953). In 1955 Israeli fishermen noticed greater numbers of the yellow striped mullet, and data assembled by the Sea Fisheries Research Station, Haifa, indicated that their percentage in the mullid catch rose to 20%, and to over 83% in early 1956 (Oren, 1957a,b), so as to be considered “the most important commercial fish in the Israel trawl catches“ (Gottlieb, 1957: 20). Since the total mullid catch had remained constant, the yellow striped mullet had in the early 1950s “almost completely replaced the Mediterranean species, the red mullet, *Mullus barbatus* in the trawl catch” (Perlmuter, 1956: 4). In 1955, another Erythrean alien, the lizardfish *Saurida undosquamis* became an important part of the trawl catch (Oren, 1957b). In 1953 it was first recorded from the Mediterranean coast of Israel (Ben Tuvia, 1953a,b) as much rarer than the native Mediterranean lizardfish *Synodus saurus* (Linnaeus, 1758). Within two years commercial catches increased steadily: in November and December 1955, 22 and 27.5 tons respectively were taken, swelling to 40 and 46.8 tons in January and February 1956 respectively, to a total of 266.5 tons for 1956 – that is, 20% of the total annual trawl catch (Oren, 1957a,b). The sudden increase in the populations of the lizardfish, the yellow striped mullet, the red soldierfish, and Erythrean penaeids was attributed to a rise of 1-1.5°C in sea temperature during the winter months of 1955 (Ben Yami, 1955; Chervinsky, 1959).

Examination of the Israeli fisheries statistics since the mid 1980s underscores the growing prominence of the Erythrean aliens. The Erythrean conch, *Conomurex persicus* Swainson, 1821, and on occasion the Erythrean spiny oyster, are served in seafood restaurants in Israel. Erythrean penaeid prawns make up most of the shrimp catches along the SE Levantine coasts. The Erythrean prawns, in particular *Marsupenaeus japonicus* (Bate, 1888) *Metapenaeus monoceros* (Fabricius, 1798) and *Penaeus semisulcatus* de Haan, 1844, are highly prized. Beginning in the 1970s a shrimp fishery developed off the Sinai coast, and since the mid 1980s off the Israeli coast where 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; Snovsky and Shapiro, 1997).
1999). Off the southeastern coast of Turkey the Erythrean prawns *M. japonicus* and *Penaeus semisulcatus* are the most important species in the landings (Duruer *et al.*, 2008), together with four other Erythrean decapod crustaceans. In southern Lebanon Erythrean aliens constitute 37% in weight of the total landings of the artisanal fishery (Carpentieri *et al.*, 2008). Nearly half of the trawl catches along the Israeli coast consist of Erythrean fish (Golani and Ben Tuvia, 1995). The dominant fishes in the inshore fisheries (trammel-netting and hook-and-lining) are the rabbit fish *Siganus rivulatus* and *S. luridus*, the obtuse barracuda *Sphyraena chrysotaenia* Klunzinger, 1884, and the Erythrean jack, *Alepes djedaba* (Forsskål, 1775). The above species, together with *Silago sihama* (Forsskål, 1775) and *Scromeromorus commerson*, two species that underwent population explosion in the early 1980s, are common in purse-seine landings. The annual catch of the Erythrean lizardfish which reached 400 tons in 1960 soon after its arrival (see above), declined to 100 tons in the mid 1960s, but has since increased, and catch fluctuations are correlated with CPUE. Catch statistics for mulldis do not distinguish between the natives, *M. barbatus* and *M. surmuletus* Linnaeus, 1758, and the Erythrean aliens *Upeneus moluccensis* and *U. pori*, but a study of the frequency of the latter in trawl catches conducted in the mid 1980s showed they formed 87% of the mullid catch off the coast of Israel at depths of 20 m, and 50% at 55 m, whereas the native mulldis are more abundant in deeper waters (Golani and Ben Tuvia, 1995). The percentage of the Erythrean mulldis in the total mullid catch has been increasing steadily, from 30% in 1980, 42% in 1984, to 47% in 1989 (Golani and Ben Tuvia, 1995). Similarly, catch statistics of sphyraenids do not separate the Red Sea obtuse barracuda from the native Mediterranean species *S. sphyraena* (Linnaeus, 1758) and *S. viridensis* Cuvier, 1829. However, examination of the landed catch showed that the Erythrean barracuda had outnumbered the native sphyraenids in inshore trawl and purse-seine catches (Grofit, 1987). In addition, two of the four species of Erythrean clupeids that established populations in the Levant – *Dussariumia elapsoides* Bleeker, 1849, and *Herklotsichthys punctatus* (Rüppell, 1837) – are of importance in the inshore-pelagic fishery. The increasing exploitation of Erythrean aliens meant the shifting of the trawling grounds nearshore since their densest populations occur at depths up to 50 m. Between 1980 and 1986 the Israeli trawlers doubled their activity (measured as fishing hours) in shallow waters (Pisanty and Grofit, 1991). The shoreward displacement of the fishing grounds coupled with the inexorable gain of Erythrean aliens raise the ratio of alien to native taxa in the Levantine trawl landings.

But together with the commercially exploitable species, the Erythrean invasion swept ashore the scyphozoan jellyfish, *Rhopilema nomadica* Galil, 1990. Each summer since the mid 1980s huge swarms of the Erythrean jellyfish have appeared along the Levantine coast. These planktotrophic swarms, some stretching 100 km long, must play havoc with the limited resources of this oligotrophic sea, and when the shoals draw nearer shore, they adversely affect tourism, fisheries and coastal installations. As early as the summer of 1987 severe jellyfish envenomations requiring hospitalization had been reported in the medical literature: 30 patients, mainly children, suffering various degrees of painful injuries to different parts of their bodies were treated that summer in the emergency ward of the Soroka Medical Center Beersheva, Israel, alone (Benmeir *et al.*, 1990). The annual swarming brings each year reports of envenomation victims suffering burning sensation, erythema, papulovesicular and urticaria-like eruptions that may last weeks and even months after the event (Silfen *et al.*, 2003; Yoffe and Baruchin, 2004; Sendovski *et al.*, 2005). Local municipalities report a decrease in holiday makers frequenting the beaches because of the public’s concern over the painful stings inflicted by the jellyfish. The local newspapers and TV news report during the summer months the presence of jellyfish along the beaches. Coastal trawling and purse-seine fishing are disrupted for the duration of the swarming due to net clogging and inability to sort yield “It is not uncommon that fishermen, especially purse seines, discard entire hauls due to the overwhelming presence of poisonous medusae in their nets” (Golani and Ben Tuvia, 1995: 287). Jellyfish-blocked water intake pipes pose a threat to the cooling systems of port-bound vessels and coastal power plants: in the summer of 2001 Israel Electric removed tons of jellyfish from its seawater intake pipes at its two largest power plants, at estimated costs of 50,000 US$ (M. Cohen, pers. comm.).

The recent spread of the silver stripe blaasop *Lagocephalus sceleratus* (Gmelin, 1789), and the striped catfish *Plotosus lineatus* (Thunberg, 1787) pose severe health hazards. The blaasop’s internal organs, and in particular the gonads during the spawning season, contain a strong paralytic
neurotoxin. In the Suez City, on the Red Sea, eight fatalities from tetrodoxin poisoning associated with eating the fish have been described recently (Zaki, 2004). Several cases of poisoning were reported from Israel, but none proved fatal (Eisenman et al., 2008). Injuries caused by the barbed and venomous first dorsal spine and pectoral spines of the striped catfish may produce pain levels requiring hospitalization – injuries have been reported by local professional and amateur fishermen.

**MASSIVE JELLYFISH OUTBREAKS**

Periodic increases of indigenous jellyfish outbreaks have long been noted in the Mediterranean: the penultimate bloom of *Pelagia noctiluca* lasting a decade (1976-1986) (UNEP, 1991; CIESM, 2001). Studies of the phenomenon suggested that various anthropogenic perturbations – eutrophication, overfishing, global warming and the increase of man-made marine hard substrates – may have contributed to the proliferation of jellyfish populations in recent decades (Goy et al., 1989; CIESM, 2001). Jellyfish are both predators and competitors of fishery resources, and outbreaks are often accompanied by a decline in fishery resources. Modelling has suggested that the increased competition for zooplankton during a jellyfish outbreak may possibly lead to a negative impact upon small pelagic fish and their predators, and result in disruption of the pelagic trophic pathway and a reduction in pelagic fishery resources (Jiang et al., 2008). Boero et al. (2008) recently proposed that the removal of top predators and the formation of oligotrophic temperature-stable watermasses may cause the suppression of the high energy fish and mammal-dominated food web and the re-emergence of medusozooan-dominated food web. Though experts agree that jellyfish outbreaks have detrimental impacts on fishery resources and ecosystem functioning, no data are available on the cost to fisheries of jellyfish outbreaks in the Mediterranean.

Whatever the cause, the recurrent massive jellyfish outbreaks that have appeared along the shores of the Mediterranean have been amply documented as causing health hazards and costly damages to tourism.

Back in 2006, 21,000 people had been stung by *Pelagia noctiluca* on the beaches of Catalonia, 11,571 people were attended by health authorities in Valencia, while on a single day in August, 400 bathers were treated at a beach in Málaga (The Daily Telegraph, 9 August 2006; <www.iberianature.com>). Some of the country’s most popular holiday destinations are affected including the Costa del Sol, Costa Blanca and the Balearic Islands. The warm salty lagoons near the fashionable Murcian resort of La Manga, Mar Menor, are so infested with *Cortylorhiza tuberculata*, that 1,000 tonnes had to be carted away. In Italy that year, large groups of jellyfish have appeared at beaches in the northern region of Liguria, at resorts around the Sicilian city of Messina and in parts of the Adriatic Sea near Trieste.

In the summer of 2007 The Associated Press reported that at least 30,000 people had been stung by jellyfish off Spain. The Sunday Times (June 24, 2007) reported that from the Costa del Sol to the French Riviera, an infestation of jellyfish was forcing seaside resorts to set up defences, repel the invaders and protect the tourist industry. Spain has launched a national “jellyfish plan” to tackle the menace. The numbers of lifeguards and first aid staff have been increased, and a leaflet created to warn tourists of the danger (<www.environmentalgraffiti.com/ecology/>, 8 August 2007). The Environmental Ministry has organised a network of recruits among fishermen and pleasure craft operators to inform the coastguard of jellyfish sightings as well as a “spotter plane”. More than a dozen boats normally used for scooping up rubbish at sea will be deployed to suck jellyfish into their holds. The city of Cannes on the Côte d’Azur, shoveled over 11 million tons of jellyfish off its beaches and invested nearly $50,000 in floaters and netting to create jellyfish-free zones the size of Olympic swimming pools at two of its most popular beaches (<www.travelmole.com>, 26 June 2007; <www.time.com>, 21 July 2008). Fearful of the effect on the tourist trade, Monaco too installed booms and nets on several beaches. Marine biologists disdain the use of fixed nets or barriers around swimming areas as the waves could amputate the tentacles of an ensnared jellyfish and carry the venom-filled extremities toward swimmers. Stray tentacles and even dead jellyfish can still be dangerous. In Antibes, a 30ft catamaran which has been described as a “jellyfish hoover” patrolled the coastline, ready to suck up any jellyfish.
This past summer was no better. As thousands of tourists headed to the Mediterranean, beaches were plagued by jellyfish, whose burning stings have sent holiday-makers shorewards. Schools of jellyfish flooded the northern shores of Greece. The jellyfish were observed on the beaches of the Chalkidiki, Pieria, Kavala and Xanthi areas, as well as in the northern part of the Aegean Sea, near the islands of Limnos and Agios Efstratios (<www.BalkanTravellers.com>). French emergency services received more than 500 calls in a single day along a 10-mile stretch of coast from Nice to Cannes (<www.independent.co.uk/environment/nature/>, 24 July 2008). As well as the Côte d’Azur, the coast of Liguria on the west coast of Italy, the Costa Smeralda in Sardinia, parts of the Adriatic coast of Italy, and much of the southern coastline of Spain have been hit. Prodded by Spain’s mighty tourist industry, the environmental authorities are expected to support major anti-jellyfish measures from year-round monitoring to jellyfish hunting boats, though the Environmental minister, Cristina Narbona, admitted that even with preventive measures in place “we cannot guarantee in any way the complete absence of these organisms in bathing areas” (<www.independent.co.uk/environment/nature/>, 16 February 2008), and may have to resort to closing beaches.

This is the eighth consecutive year that ever larger populations of jellyfish have appeared off the coasts of Spain, France, Italy and Greece - a trend, experts say, that may or may not reverse itself and may reflect a regime shift resulting from domination of jellyfish over rivals in the food chain (<www.time.com>, 21 July 2008).

CONCLUSION

Multiple anthropogenic stressors – pollution, eutrophication, destruction and fragmentation of habitats, fisheries overexploitation, rising temperatures – are implicated in a web of linkages that cause the decline in the richness and diversity of the native Mediterranean littoral ecosystem, destabilize and disrupt its communities.

The economics of the ecosystem change in the Mediterranean is straightforward. Virtually every activity in the peri-Mediterranean littoral and in the sea itself harms the sea in some degree. Those activities represent economic and social consequences not accounted for by the workings of the market. They are market failures because consumers do not pay for the current and future costs of their actions. Economic participants – governments, producers, consumers – need to face realistic prices for harming the sea if their decisions about consumption, investment, and innovation are to be appropriate. Raising the price of “harm” has the primary purpose of providing strong incentives to reduce it. Those who harm the sea are enjoying an economic subsidy – in effect, grazing on the Mediterranean commons and not paying for the costs of their activities. We need to correct this failure by ensuring that society is confronted with a market price for harming the sea.