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Alien Marine Species in the Mediterranean - the 100 'Worst Invasives' and their Impact

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Abstract

A number of marine alien species have been described as invasive or locally invasive in the Mediterranean because of their proliferation, and/or their geographical spread and/or impact on native populations. Based on that information and on the documented impact they have on the biodiversity and socioeconomics of the basin, a preliminary list of the 100 'worst' Invasive Alien Species (IAS) in the Mediterranean has been produced and presented in this work along with details on their impact. Emphasis is given to their impact on socioeconomics (fisheries/aquaculture, health & sanitation, infrastructure & building), documented for 43 species. Such selection of the 'worst' IAS was difficult and controversial and is expected to attract much attention and scientific criticism since not only can the documentation of the impact of IAS be controversial, but also their inventory can be biased towards the effort and resources devoted to the study of the impact of certain species/taxonomic groups. Thus, while marine plants (phytobenthos and phytoplankton) are fairly well studied, less attention has been paid to the impact of vertebrates and even less to invertebrates. Nevertheless, the list highlights the need for continued research on the issue (monitoring aliens and their impact for an integrated ecosystem based management approach over the entire area). The preliminary list can provide the basis for selecting indicator species within the Mediterranean and thus be the common ground to build cooperation about IAS within countries in the region.

Keywords: Worst Invasive Alien Species; Mediterranean; Impact; Biodiversity; Socioeconomics.

Introduction

A number of definitions have been applied to describe the term Invasive Alien Species (IAS); in many of them the term invasive is associated with established species which are agents of change and threaten native biological diversity (IUCN, 2002), or with species that threaten the diversity or abundance of native species, the ecological stability of infested ecosystems, economic activities dependent on these ecosystems and/or human health (EPA, 2001).

Biological invasions in marine habitats represent a recognized worldwide threat to the integrity of native communities, to economy and even to human health. Invasive species are believed to accelerate the decline of native populations already under environmental stress, leading to population losses and extinctions on a local scale (RICCIARDI, 2004), but not globally (GUREVITCH

& PADILLA, 2004). The extent of the impact has been so severe that invasive species are regarded as the second biggest cause of biodiversity loss after habitat destruction (BREITHAUPT, 2003), constituting one of the four greatest threats to the world's oceans on local, regional and global scales (IMO 2000-2004). This 'biological pollution' (CARLTON & GELLER, 1993) can be detrimental to the host ecosystem since unlike other forms of marine pollution where ameliorative action can be taken and their effects can be reversed, their impact is more often irreversible (CARLTON, 1989).

In general, however, the impact of most invasive species remains unknown, and the predictability of their direct and indirect effects remains uncertain (RUIZ *et al.*, 1997). In most regional European Seas the alterations of marine ecosystems due to new introductions and the associated socioeconomic impacts have been poorly studied with few well-documented cases reported and rarely quantified (LEPPAKOSKI *et al.*, 2002).

Among invasive alien species, the 'worst' invasive species have been the focus of many environmental programs and initiatives. A list of '100 of the World's 'Worst IAS' has been compiled by IUCN/GISP, whereas a list of the worst IAS threatening biodiversity in Europe has been endorsed by the SEBI2010 Working Group 5[1]. However, both lists are very generic, covering all environments (terrestrial, freshwater, marine) at global or Pan-European scale and the contribution of marine species is underestimated.

The aim of this work is to give an overview of the situation in the Mediterranean by presenting a list of the 'worst' invasive marine species which will be the common ground to build cooperation about IAS within countries in the region. Moreover, it will give an idea of what priorities may be needed for the different countries in developing control programs, and starting environmental monitoring of IAS species.

Methods

Selecting 'worst' invasive species is a difficult task and will be surely criticised by scientists. Since no objective criteria are available at the moment, the choice of 'worst' invasive species is subjective. Depending on personal interest some species will be favoured over others. For a rapid assessment of this indicator, a preliminary list of 'worst IAS' of the Mediterranean by taxonomic groups was compiled through a literature search.

The criteria used for selecting the 'worst invasive species' in the Mediterranean were based on the criteria used by the IUCN/GISP for the list '100 of the World's Worst Invasive Alien Species' and endorsed by the SEBI2010 Working Group 5. In this task, we have included species that have either a documented impact and/or possess the potential to cause serious negative impacts on biological diversity and socio-economy. Thus, as 'worst IAS' have been defined invasive species that have an impact on:

Biodiversity

In general alien species pose a threat to biodiversity by impacting on:

- Native species
- Ecosystems either directly (affecting hydrology, nutrient cycling, and other processes, mainly by the so-called 'ecosystem engineers'), or indirectly by changing the whole ecosystem structure and functioning (introduced species often consume or prey on native ones, overgrow them, compete with them, attack them, or hybridise with them).
- Unique biodiversity of endemic species, isolated (pristine) ecosystems and conservation areas

[1] As part of the SEBI2010 process (Streamlining European 2010 Biodiversity Indicators http://biodiversity-chm.eea.eu.int/information/indicator/F1090245995) the Expert group 5 on 'Trends in invasive alien species' is developing a list of 'Worst invasive species threatening biodiversity in Europe'.

Socio-economics

New incursions of marine alien species continue and some existing species are extending their range. By doing so, they can be detrimentally affect the socioeconomic values of an area by impacting on fisheries & aquaculture, health & sanitation, and infrastructure & building.

- *Fisheries & Aquaculture*: Alien species, including imported livestock pests, reduce yields drastically, either directly (e.g. pests) or indirectly (e.g. clogging of nets). IAS may also greatly increase the effort required to clean fishing gear and aquaculture.
- *Health & Sanitation*: The unintentional introduction of toxic species, parasites and pathogens has an impact on both the ecosystem and human health,
- *Infrastructure & Building*: Alien species may induce habitat modification and alteration of physical conditions. They may also cause fouling (for example may clog water pipes and/or foul propellers), and may become navigational hazards.

In general, it does not seem a great problem to separate biodiversity and economic impact, although they sometimes go hand in hand. Nevertheless, in lists of 'worst' aliens there are some 'pest' species with a negative economic impact or which affect human or animal health, but without a known ecological impact so far. In the preliminary list of 'worst IAS' of the Mediterranean presented in this paper however, the impact has been clearly indicated on the two major categories: biodiversity and socioeconomics, with special attention to the latter and its subdivisions (fisheries & aquaculture (F), health & sanitation (H), and infrastructure & building (I)).

Results

1. Records of 'Worst Invasive' Alien Species

A number of alien species have been described as invasive or locally invasive by different authors in different parts of the Mediterranean because of their proliferation, and/or their geographical spread and/or impact on native populations. ZENETOS *et al.,* (2005) presented some of the 'worst' IAS per eco-functional/taxonomic group. Table 1 summarises the top '100 Worst IAS' based on the documented impact they have on biodiversity and socioeconomic values. By definition all introduced species have an impact on biodiversity (SEBI2010: WG5). However, only those having a serious impact are selected for our preliminary list. The literature upon the attributions of a species on the list is given below (brief notes on their geographical distribution in ZENETOS *et al.,* (2005)). Details of their impact are presented in the relevant sections that follow.

1.1. Plants

Many authors have provided lists of invasive macrophytes in the Mediterranean. WALLENTINUS (2002) for example has provided a different perspective in which 25 macroalgae are considered as invasive and nine as highly invasive. The current list is based on the list of invasive species produced by BOUDOURESQUE & VERLAQUE (2002b) and references therein and on the list of invasive or potentially invasive exotic macroalgae which according to a screening protocol, defined in the ALIENS project, is based on species with: a) large and fast spread in Europe (e.g. *Heterosiphonia japonica*); b) invasive behaviour in Europe (e.g. *Sargassum muticum*); c) high impact on recipient assemblages and/or human activities (e.g. *Caulerpa* spp.) (VERLAQUE *et al.,* 2005).

Microscopic algal species (phytoplankton) responsible for the occurrence of Harmful Algal Blooms have been regarded as invasive by many authors. For details see section 3.2 'Impact on health'.

1.2. Vertebrates

Fish: Among the alien fish eighteen species are characterised as successful invaders and of economic importance and twelve as very common or prevalent but of no economic importance due to their small size (GOLANI *et al.*, 2002). However the term invasive is not used when describing the impact of alien fish species due to the lack of reliable information on distribution and abundance prior to the opening of Suez Canal (GOLANI, 1998). The 'Worst Fish IAS' found in Table 1 are based on the works of GOLANI *et al.*, (2002; 2006); GOREN & GALIL, (2005), HARMELIN-VIVIEN *et al.*, (2005).

1.3. Invertebrates

Mollusca: Many authors have provided lists of invasive molluscs in the Mediterranean. The selected species in Table 1 are based on lists of invasive species produced by OCCHIPINTI AMBROGI (2002a,b), ZIBROWIUS (2002), GOFAS & ZENETOS (2003), ZENETOS *et al.*, (2003) and individual species reported in BLANCHARD (1996) and HOPPE (2002).

Polychaeta: Alien polychaetes have been reported as invasive throughout the Mediterranean by KOÇAK *et al.*, (1999), ZIBROWIUS (2002), ÇINAR *et al.*, (2005), ÇINAR (2006).

Crustacea: our list has been compiled based on the alien crustaceans that have been reported as very abundant with recorded impact on biodiversity and the socioeconomic values of the area by GALIL 1986, GALIL *et al.*, (2002 & 2006), ZIBROWIUS (2002), THESSALOU-LEGAKI *et al.*, (2006).

Other invertebrates: When assessing the scale and impact of ship-transported alien fauna in the Mediterranean, invertebrate species have been regarded as invasive primarily based on their spread by ZIBROWIUS (2002), and individual species were also regarded as such by GALIL *et al.*, (1990), OCCHIPINTI AMBROGI (2000a,b), GALIL & ZENETOS (2002), HYAMS *et al.*, (2002), MERIÇ *et al.*, (2002), YOKES & MERIÇ (2004).

Table 1
The '100 Worst Invasive Species' in the Mediterranean
F:Fisheries/Aquaculture - H: Health & Sanitation - I: Infrastructure & Building.

Species Latin name	Common name	Biodiversity	Socio-economy			SEBI 2010
PLANTS			**F**	**H**	**I**	
PHYTOBENTHOS						
Acrothamnion preissii	A red alga	+	+			+
Antithamnion nipponicum	A red alga	+	+		+	
Asparagopsis armata	Harpoon weed	+	+			+
Asparagopsis taxiformis	Limu kohu	+				+
Bonnemaisonia hamifera	A red alga	+				
Caulerpa racemosa	Grape caulerpa	+	+			+
Caulerpa taxifolia	Killer alga	+	+			+
Codium fragile	Dead man's finger	+	+		+	+
Colpomenia peregrina	A brown alga	+	+			
Desmarestia viridis	A brown alga	+	+		+	
Grateloupia turuturu	A red alga	+	+			
Halophila stipulacea	A sea grass	+				+
Heterosiphonia japonica	A red alga	+	+			
Lophocladia lallemandii	A red alga	+				
Polysiphonia morrowii	A red alga	+	+			+
Sargassum muticum	Jap weed	+	+		+	+

Continued

Table 1 (Continued)

Species Latin name	Common name	Biodiver-sity	Socio-economy			SEBI 2010
			F	H	I	
Stypopodium schimperi	A brown alga	+			+	+
Undaria pinnatifida	Wakeme, Asian kelp	+	+		+	+
Womersleyella setacea	A red alga	+	+			+
PHYTOPLANKTON						
Alexandrium catenella	A dinoflagellate	+	+	+		+
Alexandrium taylori	A dinoflagellate	+	+			
Coolia monotis	A dinoflagellate	+	+	+		
Ostreopsis ovata	A dinoflagellate	+	+	+		
VERTEBRATES						
FISH						
Alepes djedaba	Shrimp scad	+				
Callionymus filamentosus	Dragonet	+				
Dussumieria elopsoides	Slender rainbow sardine	+				
Lagocephalus sceleratus	Elongated pufferfish	+		+		
Fistularia commersonii	Bluespotted cornetfish	+				+
Herklotsichthys punctatus	Spotted herring	+				
Pempheris vanicolensis	Vanikoro sweeper	+				
Plotosus lineatus	Eel catfish	+		+		
Sargocentron rubrum	Redcoat	+				
Saurida undosquamis	Brushtooth lizard fish	+				+
Scomberomorus commerson	Narrowbarred Spanish mackerel	+				
Seriola fasciata	Lesser amberjack	+		+		+
Siganus luridus	Dusky spine foot	+		+		+
Siganus rivulatus	Marbel spine foot	+		+		+
Sillago sihama	Silver sillago	+				
Sphoeroides pachygaster	Blunthead puffer	+	+	+		+
Sphyraena chrysotaenia	Yellow stripe barracuda	+				
Upeneus moluccensis	Goldband goatfish	+				
Upeneus pori	Por's goatfish	+				
INVERTEBRATES						
MOLLUSCA						
Anadara demiri	Arc shell	+				+
Anadara inaequivalvis	Arc shell	+				+
Brachidontes pharaonis	Variable mussel	+			+	
Bursatella leachi	Ragged sea hare	+				
Chama pacifica	Large Pacific Chama	+				+
Cerithium scabridum	A gastropod	+				
Crassostrea gigas	Pacific giant oyster	+			+	
Crepidula aculeata	Spiny Slippersnail	+				
Crepidula fornicata	Slipper limpet	+	+			+

Continued

Table 1 (Continued)

Species Latin name	Common name	Biodiver-sity	Socio-economy			SEBI 2010
			F	H	I	
Musculista senhousia	Green bugmussel	+				+
Mya arenaria	Soft shell clam	+				+
Pinctada radiata	Pearl oyster	+				+
Rapana venosa	Veined rapa whelk	+	+			+
Rhinoclavis kochi	A gastropod	+				
Ruditapes philippinarum	Manila clam	+	+		+	+
Spondylus spinosus	Shiro-toge-umi-giku	+				+
Strombus persicus	Persian Conch	+				
Teredo navalis	Shipworm	+				+
Xenostrobus securis	Little Brown Mussel	+				+
POLYCHAETA						
Branchiomma luctuosum	Tube worm	+				
Ficopomatus enigmaticus	Australian tube worm	+			+	+
Hydroides dianthus	Tube worm	+			+	
Hydroides dirampha	Tube worm	+			+	
Hydroides elegans	Tube worm	+			+	
Hydroides heterocerus	Tube worm	+				
Hydroides homoceros	Tube worm	+				
Hydroides minax	Tube worm	+				
Hydroides operculatus	Tube worm	+			+	
Hydroides branchyacanthus	Tube worm	+				
Leonnates persicus	Mud worm	+				
Polydora cornuta	Mud worm	+	+			+
Pomatoleios kraussii	Tube worm	+			+	
Pseudonereis anomala	Mud worm	+				
Spirobranchus tetraceros	Tube worm	+				
Spirorbis marioni	Tube worm	+			+	+
Streblospio gynobranchiata	Mud worm	+				
CRUSTACEA						
Callinectes sapidus	Blue crab	+	+			
Charybdis longicollis	Swimming crab	+	+			
Charybdis helleri	Spiny hands	+				
Dyspanopaeus sayi		+				
Erugosquilla massavensis	Mantis shrimp	+				
Elasmopus pectenicrus	An amphipod					
Eriocheir sinensis	Chinese mitten crab	+	+		+	+
Marsupenaeus japonicus	Tiger prawn Karuma	+				+
Melicertus hathor	A shrimp	+				
Metapenaeus monoceros	Speckled shrimp	+				
Metapenaeus stebbingi	Penegrine shrimp	+				
Mytilicola orientalis	Red worm	+	+			

Continued

Table 1 (Continued)

Species Latin name	Common name	Biodiversity	Socio-economy F	H	I	SEBI 2010
Penaeus semisulcatus	Green tiger prawn	+				
Percnon gibbesi	Nimble spray crab	+				+
Portunus pelagicus	Blue swimming crab	+				
OTHER INVERTEBRATES						
Amphistegina lobifera	A foraminiferan	+				
Amphisorus hemprichii	A foraminiferan	+				
Asterina burtoni	A starfish	+				
Microcosmus exasperatus	An ascidian	+				+
Oculina patagonica	A stony coral	+				
Rhopilema nomadica	A jelly fish	+	+	+	+	+
Tricellaria inopinata	A bryozoan	+				+

2. Impact on biodiversity

2.1 Plants

Caulerpa species

Caulerpaceae - *Caulerpa taxifolia* and *Caulerpa racemosa* var. *cylindracea* - are perhaps the most notorious invaders in the Mediterranean; in many cases their invasive spread has radically altered the structure and function of native ecosystems causing a decrease in biodiversity and representing a very serious ecological problem in the Mediterranean (GRAVEZ *et al.*, 2001). They are considered particularly invasive since they are good colonisers of unvegetated sediments, have wide tolerance of stress and are unaffected by nutrient and light limitation. In other words, they possess a high capacity for vegetative growth and population persistence (WILLIAMS, 1990; MEINESZ *et al.*, 1995; CHISHOLM *et al.*, 1996; DELGADO *et al.*, 1996; CECCHERELLI & CINELLI, 1999a; PIAZZI & CINELLI, 1999; WILLIAMS & GROSHOLSZ, 2002).

The mechanisms, by which *Caulerpa* spp. might affect native vegetation, especially the seagrasses, are still unclear (CECCHERELLI & CINELLI, 1997). A correlation with sediment environment has been suggested as extremely high sulfate reduction rates, and sulfide concentrations in colonised sediments have been reported (HOLMER *et al.*, 2004). Despite the abundant scientific reports available no efforts have yet been made to elucidate the role of ecosystem biodiversity in the susceptibility of Mediterranean macrophyte assemblages to impacts by invasive *Caulerpa* species (MARBÀ *et al.*, 2005).

Caulerpa racemosa var. *cylindracea*

Thirteen years after the first record in the early 1990's of the invasive variety of *C. racemosa* var. *cylindracea* (for identification see VERLAQUE *et al.*, 2003), nearly the entire Mediterranean basin was reported colonized, reaching as far as the Canary Islands; by 2005 it has colonised the coasts of 11 nations (Albania, Croatia, Cyprus, France, Greece, Italy, Libya, Malta, Spain, Tunisia and Turkey, and all major Mediterranean islands), growing on all kind of substrata, both in polluted and unpolluted areas, between 0 and 70 m depth, demonstrating an excessive rate of proliferation (VERLAQUE *et al.*, 2000, 2003, 2004; PIAZZI *et al.*, 2001a, 2005; BOUDOURESQUE & VERLAQUE, 2002b; MEINESZ *et al.*, 2003; RUITTON *et al.*, 2005).

The invasive ability and strong competitive characteristics of *C. racemosa* have been demonstrated in many works (CECCHERELLI & CINELLI 1997; PIAZZI *et al.*, 1997, 2001a; PIAZZI & CINELLI, 1999; CECCHERELLI *et al.,* 2000; CECCHERELLI & CAMPO, 2002). First indications of the impacts suggested alarming changes in community structure both on phytobenthos as well as on zoobenthos (see below). However, when examining the impact on the zoobenthos in Cyprus, ARGYROU *et al.,* (1999) demonstrated contradictory effects (decreased abundance of gastropods and crustaceans, but increased abundance of polychaetes, bivalves and echinoderms).

Experimental work (PIAZZI *et al.,* 2001a; PIAZZI & CINELLI, 2003; BALATA *et al.,* 2004) has shown that *C. racemosa* var. *cylindracea* invasions have a great impact on Mediterranean macroalgal assemblages on dead mattes of *Posidonia oceanica* and rocky bottoms, with greater impact on the former. Within 6 months the alga had completely overgrown the substrata and had impoverished the algal assemblages by reducing the species cover, number of species and diversity (affecting primarily turf and encrusting species, compared to erect species); the impact was so extensive that the algal assemblage did not seem to recover even when *C. racemosa* diminished following a seasonal cycle.

Interestingly, whereas the dead matte of *P. oceanica* appears to be the most favorable substratum for colonization, no colonization has been observed on dense meadows in many other Mediterranean regions; dense *P. oceanica* meadows seem to prevent *C. racemosa* var. *cylindracea* invasion (PIAZZI & CINELLI, 1999, 2003; CECCHERELLI *et al.,* 2000; PIAZZI *et al.,* 2001a, 2005; RUITTON *et al.,* 2005). Nevertheless other studies have demonstrated some changes in the vegetative cycle and production of *P. oceanica* (DUMAY *et al.,* 2002).

Contrasting results have emerged when the impact on other native seagrasses was investigated. Some results suggest reduction in the distribution of *Cymodocea nodosa* as a result of competitive displacement by *C. racemosa*: *C. nodosa* shoot density was reduced even by 50% (CECCHERELLI & CINELLI 1997; CECCHERELLI & CAMPO, 2002). Conversely, a positive influence was found on the *Zostera noltii* shoots (CECCHERELLI & CAMPO, 2002).

Caulerpa taxifolia

The invasive proliferation of *Caulerpa taxifolia,* the 'killer alga' (MEINESZ, 1999), is the most infamous example of the impact of invasive species. In the Mediterranean, the alga is causing a 'major ecological event' (BOUDOURESQUE *et al.,* 1995). Even though *C. taxifolia* is not considered as so invasive as *C. racemosa* var. *cylindracea* (PIAZZI *et al.,* 2001b; BALATA *et al.,* 2004), it has reached high abundances (MEINESZ *et al.,* 1995; CECCHERELLI & CINELLI 1997, 1998). The small colony of 1m^2 (accidentally introduced in 1984 by the Oceanographic Museum of Monaco) had spread to more than 6,000 hectares by 1996 (MEINESZ *et al.,* 1998). It covered more than 13000 hectares along 191 km of coastline in six countries (Monaco, France, Italy, Spain, Croatia and Tunisia) by 2000. The area colonized along the Mediterranean French coast increased from 77.3 km^2 to 122.7 km^2 between 2001 and 2004, and the species is still expanding, out-competing native species and seriously reducing diversity (MEINESZ *et al.,* 2001, 2004). Yacht anchors and fishing gears appear to have carried it over great distances (MADL & YIP 2003).

Caulerpa taxifolia is known to have a major impact on marine ecosystems, which is mainly attributed to a toxic nature (synthesis of terpenoids), an ability to colonize all parts of the littoral zones and all substrata, and a high ecological fitness. The toxic terpenoids synthesized in higher concentrations than in tropical waters (GUERRIERO *et al.,* 1992) inhibit the growth of *Cystoseira barbata* and *Gracilaria bursa-pastoris* (FERRER *et al.,* 1997), and can explain the superior competitiveness of *Caulerpa* against native macroalgae. They also negatively affect several phytoplanktonic organisms (LEMEE *et al.,* 1997). Lastly they protect

C. taxifolia against grazers (RUITTON & BOUDOURESQUE, 1994). *Caulerpa taxifolia* can drastically reduce marine biodiversity (mainly by displacing native algae and altering seagrass beds) (BOUDOURESQUE *et al.*, 1992; VERLAQUE & FRITAYRE, 1994a,b; de VILLELE & VERLAQUE, 1995; CECCHERELLI & CINELLI 1997, 1999a), disturb zoobenthos (BELLAN-SANTINI *et al.*, 1994; HARMELIN-VIVIEN *et al.*, 1996) and modify organic and inorganic components of the sediment (CHISHOLM & MOULIN 2003). The *C. taxifolia* impact differs also according to the sensitivity and susceptibility of macrophyte assemblages (PIAZZI *et al.*, 2001a; VERLAQUE & FRITAYRE, 1994a, b; de VILLELE & VERLAQUE, 1995; BALATA *et al.*, 2004). Dramatic decreases (with impoverishment reaching up to 75%) have been observed in photophilic subtidal assemblages of rocky substrates, which appear particularly vulnerable to invasions (VERLAQUE & FRITAYRE 1994a, b; KLEIN *et al.*, 2005). *Caulerpa taxifolia,* like *C. racemosa*, especially colonizes the *Cymodocea nodosa* meadows and sparse *Posidonia oceanica* beds, causing the decay and regression of seagrasses (MEINESZ & HESSE 1991;, BOUDOURESQUE *et al.*, 1992; MEINESZ *et al.*, 1993; CECCHERELLI & CINELLI, 1997, 1998, 1999a). In invaded *P. oceanica* meadows, the percentage of dead shoots can reach up to 45% and the living shoots possess abnormal yellowish leaves (de VILLELE & VERLAQUE, 1995). Even a facilitative effect of seagrasses on *C. taxifolia* has been demonstrated, which may cause indirect negative effects on seagrasses (CECCHERELLI & CINELLI, 1997, 1998). Invasion appears to be successful when seagrass meadows are already experiencing a decline as a result of deteriorated environmental quality. There are suggestions that *C. taxifolia* is not capable of invading the dense and healthy *P. oceanica* meadows (MARBÀ *et al.*, 1996, 2005; CECCHERELLI & CINELLI, 1999b; JAUBERT *et al.*, 1999; PEIRANO *et al.*, 2005).

Impoverishment has also been reported in faunal assemblages. Polychaeta and mainly amphipod abundance (and to a lesser degree species richness) has been reduced), whereas the molluscan community appears either to be benefited or to be impacted the least (BELLAN-SANTINI *et al.*, 1994, 1996). Decreases have been observed in fish species in number, density and biomass (HARMELIN-VIVIEN *et al.*, 1996; GELIN *et al.*,, 1998; RELINI *et al.*,, 1998) along with an increase in numbers of green forms of labrid fish in populations living within *C taxifolia* meadows (ARIGONI *et al.,* 2002). In contrast, other authors (FRANCOUR *et al.,* 1995; GELIN *et al.,* 1998) have suggested that no simple relation exists between the presence of *C. taxifolia* and fish community.

Sargassum muticum

The macrophyte *Sargassum muticum* reported in the Venice lagoon, Italy (RIBERA SIGUAN, 2002) and the Thau lagoon and other parts of the Languedoc-Roussillon coast, France (BOUDOURESQUE, 1994; VERLAQUE, 2001) is known to have a direct impact on the indigenous floral assemblages. It inhibits their recruitment and growth (CRITCHLEY, 1983), even leading to the eradication of many species e.g. *Cystoseira barbata* in Venice (OCCHIPINTI AMBROGI, 2002b) and in the Thau lagoon (GERBAL *et al.*, 1985; BOUDOURESQUE, 1994). It is also reported to have altered the vegetal landscape of canals in the Venice lagoon, together with other invasive algae (CURIEL *et al.,* 1999), imposing a burden on the economy.

Womersleyella setacea, Acrothamnion preissii

Mediterranean turfs are largely composed of two introduced Rhodophyta: *Acrothamnion preissii,* colonising many parts of the western basin (BOILLOT *et al.,* 1982; CINELLI *et al.,* 1984; FERRER *et al.,* 1994; PIAZZI *et al.,* 1996, 2002), and *Womersleyella setacea* colonising wide zones throughout the Mediterranean Sea (AIROLDI *et al.*,1995; ATHANASIADIS, 1997).

These turfs have an adverse impact on *Posidonia oceanica* meadows in the W. Mediterranean: the diversity of the epiphytic macroalgal community of the rhizomes has been found to decrease as the result of invading filamentous Rhodophyta (PIAZZI & CINELLI, 2000). In a study area in the Ligurian Sea (Italy) both total percentage cover and diversity were found to be lower in invaded areas than in control areas: the invasive Rhodophyta were reported to constitute more than 90% of the epiphyte cover in *P. oceanica* rhizomes and along with *C. racemosa* were discovered to occupy about 50% of macroalgal cover on dead *P. oceanica* mattes, throughout the year (PIAZZI & CINELLI, 2003). Similar high values have been recorded for *Womersleyella setacea* abundance in the area (AIROLDI *et al.*, 1995).

Womersleyella setacea is also known to have an impact on the coralligenous communities, as it has been found to form a monospecific layer covering the coralligenous substrata in the Scandola reserve (Corsica) (RIBERA & BOUDOURESQUE, 1995).

Asparagopsis armata, Codium fragile

These have been reported as forming monospecific coverages, dominating many algal assemblages. *Asparagopsis armata* is known to cover 100 % of the upper infralittoral (0-10 m depth) in winter in the NW Mediterranean and to dominate many infralittoral assemblages in the Marseilles area along with *Codium fragile* (RIBERA & BOUDOURESQUE, 1995). The dense populations of *A. armata* are maintained, probably because the main Mediterranean herbivores, i.e. the sea urchin *Paracentrotus lividus* and the fish *Sarpa salpa*, avoid it (SALA & BOUDOURESQUE, 1997).

Undaria pinnatifida, Desmarestia viridis, Antithamnion nipponicum

Impacts of *Desmarestia viridis, Undaria pinnatıfida,* and *Antithamnion nipponicum* (= *pectinatum*) on coastal lagoon ecosystems have also been reported (CURIEL *et al.*, 1998). Proliferations *of Laminaria japonica* have been reported in the Thau lagoon where its accumulation and decomposition have resulted in anoxia during summer (ANONYMOUS, 1982).

2.2. Vertebrates

Notwithstanding, definite changes in fish communities in the Levantine ecosystem have been attributed to Lessepsian migrants.

According to OREN (1957) populations of red mullet (*Mullus barbatus*) and hake (*Merluccius merluccius*) have been forced to migrate to deeper waters by the aliens *Upeneus moluccensis* and *Saurida undosquamis*, respectively. However GOLANI (1998, and personal communication) argues against the evidence of such displacement as '*it is difficult to determine whether the colonisers displaced the local species or whether the latter occupied the same bathymetric niche prior to its confamiliar colonisation*'. According to GOLANI (1998) there are these two cases that deserve further study. The populations of narrow-barred Spanish mackerel *Scomberomorus commerson* and the dragonet *Callionymus filamentosus* have dramatically increased at a time when the indigenous meager *Argyrosomus regius* (once of the most common commercial species in Israel) and three other confamilial to the C. *filamentosus* species, have almost completely disappeared.

Along the Lebanese rocky coasts, the Lessepsian migrants represent 13% of the species richness and 19% of the total abundance of individuals (HARMELIN-VIVIEN *et al.*, 2005), while almost half of the trawl catches on the Mediterranean coast of Israel consist of alien fish species (GOLANI & BEN TUVIA, 1995). Similarly invading species have been found to comprise 62% of the demersal fish biomass in the Gulf of Iskenderun, Turkey (GÜCÜ & BINGEL, 1994). The invasive fish dominate the structure and function of littoral ecosystems on the Levantine coast, representing 50-90% of the fish biomass (GOREN & GALIL, 2005).

2.3. Invertebrates

In the Mediterranean, fast expanding invaders outcompete local species. This can have a major impact on the ecosystem as many sudden changes in faunal community diversity and structure are attributed to this competition. Another alarming issue is the number of unintentional introductions of pathogens and parasites, with species imported for aquaculture.

Mollusca

In coastal lagoons *Musculista senhousia* has been found to alter native benthic communities (CROOKS, 1998). Enormous proliferations of *Anadara inaequivalvis* in the N. Adriatic (RINALDI, 1985), replacing the native *Cerastoderma glaucum* (OCCHIPINTI AMBROGI, 2000), and of *Mya arenaria* in the Berre lagoon, Marseilles, (ZIBROWIUS, 2002) have been reported. The predatory gastropod *Rapana venosa* was initially regarded to have potential impact on native bivalves and on the environment in the Northern Adriatic (ZENETOS *et al.,* 2003), but no clear cut sign of impacts in the Northern Adriatic Sea has been recorded (OCCHIPINTI AMBROGI 2000, 2001a; SAVINI & OCCHIPINTI AMBROGI, 2006).

Imported mollusca for aquaculture purposes

Imported bivalves for aquaculture purposes (especially oysters and clams) are among the best-known examples of negative impacts of alien species in European seas in general and in Mediterranean in particular as the case of the Venice lagoon has demonstrated. The Manila clam *Ruditapes philippinarum* and the Pacific oyster *Crassostrea gigas* are considered as the most spectacular invasions in the lagoon of Venice (OCCHIPINTI AMBROGI, 2000).

Among alien species in the lagoon, the Manila clam, *Ruditapes philippinarum* is surely the most well-adapted and widespread species. The species was introduced into the lagoon in 1983, to enhance the depressed fisheries and aquaculture activities. At present, Italy is the largest clam producer in Europe, with an estimated production in 1998 of 40 000 MT. The exploitation of the clam banks represents one of the main sources of environmental disturbance in the Venice lagoon. About 600 boats equipped with mechanical dredges, operate without any management strategies, causing heavy stress on benthic communities:a single fishing haul can affect the macrozoobenthos organism density: (PRANOVI *et al.,* 2004) and the whole lagoon ecosystem (PRANOVI *et al.,* 2003; SFRISO *et al.,* 2003).

As for *Crassostrea gigas,* that is also intensely cultivated in the brackish lagoons of Southern France. Collecting methods are not as impacting as in the case of burrowing clams but mostly related to the influence on particulate matter dynamics between the water column and the bottom (OCCHIPINTI AMBROGI, 2000).

Polychaeta

Fouling serpulid worms have become a nuisance in ports and marinas throughout the Mediterranean. *Hydroides elegans, H. dianthus, H. elegans, H. dirampha, Ficopomatus enigmaticus* and *Spirorbis marioni* are known to foul harbours throughout the Mediterranean and are regarded as major foulants on artificial surfaces (KOÇAK *et al.*, 1999; ZIBROWIUS, 2002).

According to a recent study of the Levantine coasts of Turkey '*the alien serpulid species dominated rocks, molluscs* (Brachidontes pharaonis, Thais rugosa and Spondylus gaederopus) *and artificial substrates (i.e. dock's pilings, ropes and tires), comprising more than 95% of the specimens found in these habitats. On the algae such as* Ulva sp. and Cystoseira sp. *sampled in this study, alien species accounted for more than 85% of the specimen' (ÇINAR, 2006).*

The serpulid worm *Hydroides elegans* was found to comprise 65 % of the population in the polluted marinas but was only infrequently found in the non-polluted (KOÇAK *et al.,*, 1999). Similarly spionid worms now constitute the key indicators of polluted areas. According to ÇINAR *et al.,* (2005) in Izmir bay (Turkey) *Streblospio gynobranchiata* and *Polydora cornuta* have replaced dominant indicator species such as *Malacoceros fuliginosus* and *Capitella capitata* reaching maximum densities of 34,270 ind m^{-2} and 3170 ind m^{-2}, respectively, and accounting for more than 60% of total faunal populations in the majority of samples collected in winter. Their impact becomes more significant when considering that they constitute more than 90% of the total individuals and 50% of total biomass at some stations.

Crustacea

GALIL & ZENETOS (2002) while reviewing impacts of exotics on the eastern Mediterranean populations reported the rapid decrease of populations of the prawn *Melicertus kerathurus* and the shrimp *Alpheus dentipes,* attributed to invasive displacement by *Marsupenaeus* (=*Penaeus*) *japonicus.* A fisheries commodity, the shrimp *Squilla mantis* has been displaced into deeper waters by the mantis shrimp *Erugosquilla massavensis.*

The crab *Dyspanopeus sayi* was reported as very abundant in the lagoon of Venice (OCCHIPINTI AMBROGI, 2000) with a potential impact on native crabs (GALIL *et al.,* 2002) but already in 2001 it had almost disappeared in the canal of Venice (OCCHIPINTI AMBROGI, 2001b) and now its presence is limited to the marine sectors of the lagoon near the mouths (MIZZAN *et al.,* 2005).

Other Invertebrates: Echinoderms, Bryozoans, Corals and Foraminifera

The bryozoan *Tricellaria inopinata* was discovered to have a profound impact on the bryozoan community by colonizing all possible hard substrata in the lagoon of Venice and outcompeting the native species in adapting to the altered physical and chemical parameters of the ecosystem. (OCCHIPINTI AMBROGI, 2000; OCCHIPINTI AMBROGI & SAVINI, 2003). However, the synergy between the invader and the stress already imposed in the ecosystem is not clear (OCCHIPINTI AMBROGI, 2000).

Invasive displacement has also been reported in echinoderms. The sea star *Asterina burtoni* has increased in number in the Eastern Mediterranean, causing a rapid decrease in the population of the native *A. gibbosa* (GALIL & ZENETOS, 2002).

When assessing the scale and impact of ship-transported alien fauna in the Mediterranean, ZIBROWIUS (2002) reported the vast spread of the Scleractinian coral *Oculina patagonica* in Spain, the Ligurian coast of Italy, Alexandria, Lebanon, Israel, Tunisia (recently it was also reported in Greece, SALOMIDI *et al.,* 2006) and the dense populations of the ascidian *Microcosmus exasperatus* in Mediterranean harbours.

The Lessepsian foraminifer *Amphistegina lobifera* appears to be the worst invasive species in Turkey changing all the habitat type and coastal structure (MERIÇ *et al.,* 2002; YOKES & MERIÇ, 2004). It is actually regarded as a *'very good example to show how much a 'harmless' alien species can actually have the potential to destroy an ecosystem'* (YOKES pers. commun.) *A. lobifera* populations in Turkey have expanded to such an unprecedented extent that the dead tests are locally accumulated as a 30-60 cm thick layer on the sea bed [Antalya, Kas, Kekova, Bes Adalar and Uc Adalar] (MERIÇ *et al.,* 2002) reaching densities of more than 350 specimens/g of sediment (YOKES & MERIÇ, 2004) suggesting a deposition rate of 2,5-4 cm/year. In Israel *A. lobifera* appears to be the most abundant of foraminiferans in hard substrata, reaching densities of almost 180 specimens /g (HYAMS *et al.,* 2002). *Amphisorus hemprichii* is also considered invasive in Turkish waters (YOKES pers. commun.) where it has been spreading rapidly in southwestern coasts over the past two years. It has is also been observed in Israel recently (HYAMS *et al.,* 2002).

3. Impact on socio-economic values

3.1 Impact on Fishery/Aquaculture (Including Pests)

Many cases of economic losses to fisheries and aquaculture associated with invasive species have been reported

Caulerpa taxıfolia infestations are also renowned for their negative impact on fishing, both commercial and recreational (e.g.: tourism and SCUBA diving activities). *Womersleyella setacea* clogs up fishing nets in France (VERLAQUE, 1989) and the same happens with *Acrothamnion preissii* and fishing gear in Italy *(*CINELLI *et al.,* 1984) and with *Asparagopsis armata* (M. VERLAQUE pers. commun). Similarly, *Antithamnion nipponicum (=pectinatum), Caulerpa taxifolia, Codium fragile, Colpomenia peregrina, Heterosiphonia japonica, Desmarestia viridis, Grateloupia turuturu, Polysiphonia morrowii, Sargassum muticum* and *Undaria pinnatifida* foul shellfish aquaculture facilities in coastal lagoons and (VERLAQUE, 1994, 2001; CECERE *et al.,* 2000; M. VERLAQUE pers. commun.).

Dinoflagellate blooms of *Alexandrium taylori, Alexandrium catenella, Ostreopsis ovata* and *Coolia monotis* have an impact on the economy by impacting on fisheries (as well as on human health and tourist activities) (see 3.2.).

Displacement of native fish and prawns (due to *Upeneus moluccensis* and *Saurida undosquamis, Erugosquilla massavensis* reported in section 2) has also economic implications, as these animals are fishery commodities which now require more effort for their harvesting. Abundant populations of fish of no economic importance are another example of economic burden to fishermen as fish are caught in fishing gear and have to de discarded, as in the case of *Sphoeroides pachygaster* (GOLANI *et al.,* 2002).

The mollusc *Crepidula fornicata* has been found to compete with commercial shellfish (BLANCHARD, 1996). *Rapana venosa,* being an active predator of epifaunal bivalves, poses a serious threat to cultivated (as well as natural) populations of oysters and mussels (ZENETOS *et al.,* 2003).

Crustaceans have also been regarded as economic pests (GALIL *et al.,* 2002). *Dyspanopeus sayi* reported abundant in the Venice lagoon feeds on bivalves and may affect local clam farming (although its presence is now regarded as limited (OCCHIPINTI AMBROGI, 2001b; MIZZAN *et al.,* 2005)). *Eriocheir sinensis* reported in the Narbonne littoral lagoons is capable of causing considerable damage to fisheries by consuming netted fish and by cutting nets. *Callinectes sapidus* has also been reported to affect nets and netted fish, and finally *Charybdis longicollis* hampers trawl fishermen. The parasitic copepod *Mytilicola orientalis* has been found to infect the indigenous oyster *Ostrea edulis* (STOCK, 1993) as well as the blue mussel, *Mytilus edulis* and is considered a serious pest (HOLMES & MINCHIN, 1995).

The mass swarms of the jellyfish *Rhopilema nomadica* reported along the Levantine coast and as far north as the southeastern coast of Turkey, imposed a financial strain on fisheries (as well as tourism, and coastal installations, see 3.2. and 3.3) (GALIL & ZENETOS, 2002).

3.2 Impact on health

Harmful Algal Blooms (HABs) are increasing both in intensity and frequency in the Mediterranean Sea (GARCÉS *et al.,* 2000; PENNA *et al.,* 2005). HABs pose a significant and expanding threat to marine ecosystems and socioeconomic values (human health, amenities and fishery resources) either as toxin producers (toxic HABs) or as causatives of anoxic conditions (High-Biomass HABs). However, the mechanisms of the insurgence of blooms of toxic strains in resident populations are poorly known, even if it is suspected that long range transport of cysts and propagules with ballast water might be involved.

Recurrent blooms of the non-toxic dinoflagellate *Alexandrium taylori* have been detected in the western Mediterranean (Catalan coast, Balearic Island, Sicily and Italian west coast) over the past 15 years. High biomass blooms during summer have led to deterioration of water quality for recreational uses, and to economic losses for the tourist industry (PENNA *et al.,* 2001; GIACOBBE & YANG, 1999; GARCÉS *et al.,* 1999, 2000; 2002; BASTERRETXEA *et al.,* 2005). Similar surface water discolorations have been observed in the Eastern Mediterranean (Amvrakikos Bay, Greece, STRATEGY Workshop, 2004).

Toxic red tide species are on the rise in many parts of the Mediterranean. A new PSP toxin in the Mediterranean strain of *Alexandrium andersonii,* previously reported as non-toxic, has been detected in Italy (Gulf of Naples) raising concern about potential toxic events (CIMINIELLO *et al.,* 1999). Similar concern has been raised in Alexandria (Egypt) as a result of the detection of *Alexandrium catenella* (MIKHAIL, 2001). *A. catenella* is known to cause toxic events in the western Mediterranean. In spring 1998, the first toxic event was detected, covering 100 km of the Catalan coast (GARCÉS *et al.,* 2000) reccurring in 1999 (VILA *et al.,*, 2001). A bloom observed in 1994 in Valencia was later attributed to this species (GÓMES *et al.,* 1996). The presence of *Gymnodinium catenatum* in the western Mediterranean has also been perceived as a probable 'protagonist of future red tide events' (GÓMEZ & CLAUSTRE, 2001).

Ostreopsis ovata and *Coolia monotis* have been detected in the Tyrrhenian Sea, (Tuscany coast and the islands of Elba, Giannutri, and Giglio), in Sicily, Sardinia and also in the Ionian Sea (*O. ovata* in Bari). The outbreaks of these red tides have been considered responsible for inflammation of the upper respiratory tract and conjunctivitis in swimmers (SIMONI *et al.,* 2003, 2004). Furthermore, shellfish and *Arbacia* sp. mortality has been observed during *Ostreopsis ovata* blooms on Marina di Massa reefs and additional studies have indicated the presence of DSP-like and ciguatoxin-like toxins (SIMONI *et al.,* 2004). Potentially toxic epiphytic assemblages comprising the *Coolia monotis* (and genera *Ostreopsis, Prorocentrum and Amphidinium*) which have impacts not only on molluscs' safety but also on tourist activities as well, were recorded in Greek coastal waters in 2003 (STRATEGY Workshop, 2004).

In general, dinoflagellate blooms (such as those of *Alexandrium taylori, Alexandrium catenella, Ostreopsis ovata* and *Coolia monotis* in addition to their direct impact on human health, impact on tourist activities in the areas where they occur.

The jellyfish *Rhopilema nomadica* reported along the Levantine coast and as far north as the southeastern coast of Turkey, is most certainly a health issue to swimmers in the area, and has an impact on tourism (GALIL & ZENETOS 2002).

Invading fish also constitute a health threat to humans. Following the recent occurrence of *Lagocephalus sceleratus* (Gmelin, 1789) in the Mediterranean Sea, (AKYOL *et al.,* 2005), new findings revealed that the species is now very common along the Levantine coasts of Turkey (BILECENOGLU *et al.,* 2006) and the south Aegean (CORSINI *et al.*, 2006). The species is a potential risk to humans, since it contains tetrodotoxin (TTX) that may be a source of food poisoning. Two cases of poisoning of people who had consumed this fish were reported from Israel and Lebanon (GOLANI *et al.,* 2006).

Plotosus lineatus is notorious for being highly venomous, with venom glands located along the dorsal and pectoral spines (GOLANI, 2002). Several cases of injury were followed by hospitalization in Israel (GOLANI *et al.*, 2006). Other not so severe threats include: *Siganus luridus*, a food fish that is occasionally poisonous (with all spines slightly venomous), with very painful stinging but not lethal; several cases of ciguatera-like effects have been attributed to consumption of *S. luridus* (FISHBASE); *Siganus rivulatus* which has a very painful, but non-lethal, sting: all spines are slightly venomous (FISHBASE); *Seriola fasciata, is* associated with reports of ciguatera poisoning (FISHBASE) and *Sphoeroides pachygaster* which can be poisonous, due to its capacity to produce tetrodotoxin (nevertheless, some puffers are successfully exploited around the world and are highly valued as food).

3.3 Impact on Infrastructure

A financial burden associated with the proliferation of alien species is the mechanical removal of accumulated material on the beaches and the nuisance to tourism, as in the case of the removal of *Codium fragile* from the coasts of Marseille in the1960s (BOUDOURESQUE, 1994) and the *Cladophora* sp. proliferation along the coasts of Cyprus (RIBERA & BOUDOURESQUE, 1995). *Sargassum muticum, Undaria pinnatifida* and *Antithamnion nipponicum (=pectinatum)* are regarded as navigational hazards to the users of the canals along many of the Venice lagoon canals as they alter the sea bed and canal landscape and entangle boats (RIBERA & BOUDOURESQUE, 1995; OCCHIPINTI AMBROGI & SAVINI, 2003). *Stypopodim schimperi* has also been reported to have an impact on infrasructure facilities. The species is large ecosystem engineer and seasonally huge quantities are cast ashore on the Syrian beaches. (M. VERLAQUE pers. commun.).

Fouling serpulid worms have become a nuisance in ports and marinas throughout the Mediterranean. *Hydroides elegans, H. dianthus, H. dirampha, Ficopomatus enigmaticus* and *Spirorbis marioni* are known to foul harbours throughout the Mediterranean and are regarded as major foulants of artificial surfaces (KOÇAK *et al.,* 1999; ZIBROWIUS, 2002). *Ficopomatus enigmaticus* and *H. dianthus* are building extensive reefs in the lagoon of Orbetello (Tuscany, Italy). Both formed layers of 1m thick which covered about 7 % and 1.5% of the lagoon area respectively (BIANCHI & MORRI, 2001).

Pomatoleios kraussii together with an alien bivalve species, *Brachidontes pharaonis*, may form a calcareous belt the thickness of which reaches approximately 3-5 cm. Rocks in 0-1 m depths in Iskenderun harbour were largely covered with this species. In Mersin Bay, the population density of *Hydroides operculatus* was very high. These two species were also observed on hulls of fishing boats in harbours, indicating that they have a potential to cause economic trouble to ship owners and others using sea-water intake pipes (ÇINAR, 2006).

The bivalvia mollusca *Spondylus spinosus, Chama pacifica, Crassostrea gigas,* which live on hard substrata, can thrive in harbour environments. The dense aggregations they form, may act as ‘ecosystem engineers’ generating solid reefs.

Fouling/clogging is also a problem with the mass swarms of the jellyfish *Rhopilema nomadica* reported along the Levantine coast and as far north as the southeastern coast of Turkey where they are reported to have clogged coastal installations (GALIL & ZENETOS, 2002). Finally, the crustacean *Eriocheir sinensis* has a documented impact by damaging river banks through burrowing (GALIL *et al.,* 2006).

Discussion

In the Mediterranean the impact of invasive species on biodiversity (from species to community to ecosystem level) and to a lesser extent on socioeconomic values and health have been partially covered in various syntheses (BOUDOURESQUE, 1994; BOUDOURESQUE & RIBERA, 1994; VERLAQUE, 1994; RIBERA & BOUDOURESQUE, 1995; GOLANI, 1998; GALIL, 2000a&b; OCCHIPINTI AMBROGI, 2000, 2001a, 2002a,b; ZIBROWIUS, 2002; BOUDOURESQUE & VERLAQUE, 2002a; GALIL & ZENETOS, 2002; GO-

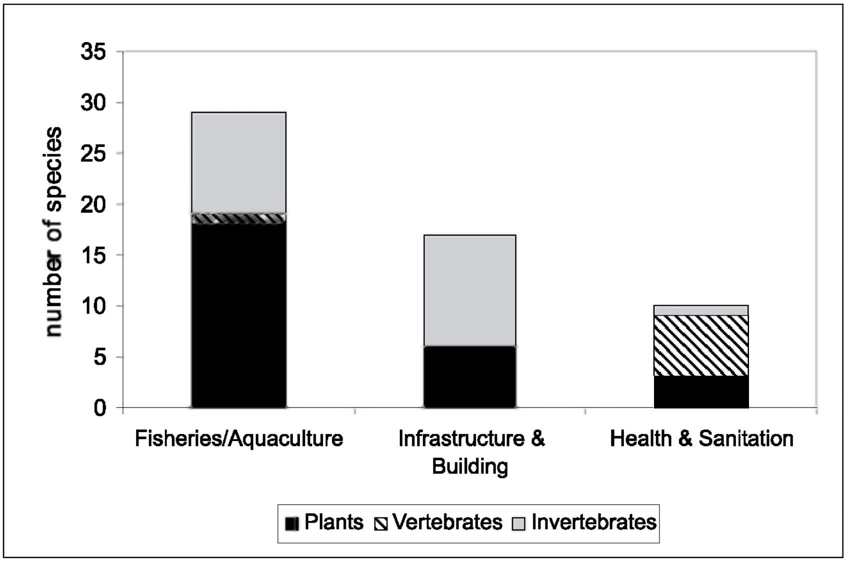

Fig. 1: Numbers of 'worst IAS' impacting on socioeconomy per taxonomic group.

FAS & ZENETOS, 2003; OCCHIPINTI-AMBROGI & SAVINI, 2003; GOREN & GALIL, 2005).

A preliminary list of the 100 'worst IAS' in the Mediterranean by taxonomic groups (Table 1) was compiled through a literature search. All 100 'worst IAS' have an impact on biodiversity (35 documented cases and the rest pose a potential threat) and 43 of them have a documented impact on socio-economic values. Considering that the most recent inventory of marine alien species in the Mediterranean has documented the existence of 745 aliens, out of which 385 are established (ZENETOS *et al.*, 2005), the list of 'worst IAS' is expected to increase

The impact of the 'worst IAS' on socio-economical values is shown graphically in Figure 1.

The Figure however is rather biased towards the effort and resources (both human and financial) devoted to the study of the impact of certain species/taxonomic groups. Thus, although the marine plants (phytobenthos and phytoplankton) are fairly well studied, it has to be noted that taxonomic difficulties often prevent the incontrovertible designation of alien phytoplankton species related to HABs. Less attention has been paid to the impact of vertebrates and even less to invertebrates. Exceptions are the studies on *Ruditapes philippinarum* (review by OCCHIPINTI AMBROGI 2002b) and on polychaetes (ÇINAR, 2006).

Another issue that has to be emphasized is that absence from the list does not imply that a species poses a lesser threat. It must be pointed out that some of the species that have been nominated as among 100 of the 'World's Worst' invaders (ISSG, 2006), although present in the Mediterranean, are not included in our preliminary list of 'worst IAS', mainly because of their sporadic recording and minimal dispersal. These are:

Mnemiopsis leidyi: Known for causing anoxia in bottom-near waters due to massive deposition of dead individuals and serious economic losses due to the imposed decline in fisheries stock, as well as clogging water intakes in the Black Sea. It has recently invaded the Baltic Sea and North Sea (JAVIDPOUR *et al.*, 2006). In the Mediterranean it has been reported in Turkey (UYSAL & MUTLU, 1993) and Greece (SHIGANOVA *et al.,* 2001) in low numbers, where it is not known to have any impact.

Liza haematocheila (Temminck & Schlegel, 1845) [=*Mugil soiuy* Basilewsky, 1855]: One of the six alien species which have a significant impact on the Black Sea ecosystem. Although present in the Mediterranean, no impact has been reported.

***Gambusia affinis*:** potential pest according to FISHBASE. Present in Greece, Italy (1919-21), Spain (1921), Cyprus (1988), Albania, Turkey, Malta, Bosnia, Slovenia, but no impact has been reported.

Abundant populations of alien fish without direct economic use are also not included in the 'worst IAS' despite the fact that they can be considered as pests, an economic burden to fishermen who have to discard them from their gear (GOLANI *et al.,* 2002). These are: Cynoglossus sinusarabici, *Stephanolepis diaspros, Lagocephalus spadiceus* and *Lagocephalus suezensis.*

Bacteria (but also other parasites and disease causing organisms) associated with aquaculture are also not included despite the fact that they are considered a major threat connected with the development of the worldwide transport of marine biota and hence of paramount importance when dealing with alien species. One of the reasons is that with the exception of a few studies (e.g. the parasite *Perkinsus atlanticus* and the bacterium *Photobacterium damselae* subsp. *Piscicida),* there is little data on the Mediterranean alien bacteria/parasites.

The parasite *Perkinsus atlanticus,* first detected in Spain in 1990 (SANTMARTÍ *et al.,* 1995), had been widely distributed along the Catalan coast by 1994, where it has been found in *Ruditapes decussatus* and *Ruditapes philippinarum* in the Ebro river delta (RIERA *et al.,* 1995). It was associated with high mortalities of both bivalve species in 1990 and also of *Ostrea edulis* and *Crassostrea gigas* (SANTMARTÍ *et al.,* 1995).

The bacterium *Photobacterium damselae* subsp. *piscicida* (formerly *Pasteurella piscicida*) reported in the Mediterranean since 1991 (associated with a fish fry imported for aquaculture) has been responsible for fish mortalities due to Pasteurellosis. From 1990 it has caused economic losses in different Mediterranean countries including France, Italy, Spain, Greece, Turkey and Malta (BAKOPOULOS *et al.,*1995, 1997; CANDAN *et al.,* 1996) affecting primarily gilthead sea bream (*Sparus aurata*), seabass (*Dicentrarchus labrax*) and sole (*Solea* spp.).

On the other hand, recent studies have demonstrated a lesser impact of species that had been initially considered to have a serious impact on biodiversity in the Mediterranean (e.g. *Rapana venosa* and *Dyspanopaeus say* in the Venice lagoon: MIZZAN *et al.,* 205; SAVINI, & OCCHIPINTI AMBROGI, 2006).

As pointed out above, selecting the 'worst' IAS is a difficult task that attracts much attention and scientific criticism. The debate is ongoing since even the documentation of the impact of IAS can be controversial, because of the lack of clear evidence on the nature of such impacts and on the interaction between invaders and other anthropogenic stressors that influence such impact (RUIZ *et al.,* 1999). Invasive success (and impact) depends not only on the invaders' competitive advantage over native enemies/competitors, but also on the environmental characteristics of the host ecosystem (primarily species richness and disturbance) and the level of stress already imposed on it (RIBERA & BOUDOURESQUE, 1995; COHEN & CARLTON, 1998; GOODWIN *et al.,* 1999; OCCHIPINTI AMBROGI, 2000; KEANE & CRAWLEY, 2002). These environmental characteristics that render an environment or habitat vulnerable or resistant to biological introductions are the focus of debate. The hypothesis known as Elton's 'biotic resistance hypothesis' (ELTON, 1958), which assumes that a species- rich ecosystem will be more resistant to introductions than a species-poor one, has been verified by several researchers (LOOPE & MUELLER-DOMBOIS, 1989; PIMM, 1989; REJMÀNEK, 1989; SIM-

BERLOFF, 1989; LODGE, 1993).

In the Mediterranean, there is evidence supporting the theory as environments under stress (polluted or physically degraded) appear to be more prone to invasion than pristine sites (RIBERA & BOUDOURESQUE, 1995; KOÇAK *et al.,* 1999; GALIL, 2000b; OCCHIPINTI AMBROGI, 2000; OCCHIPINTI-AMBROGI & SAVINI, 2003; see also references in 2.1 Impact on Biodiversity - *Caulerpa* species). In addition, the fact that environments that are known for their low biodiversity (lagoonal or estuarine habitats and polluted harbours) are recipient areas for IAS related to mariculture and vessel-transported aliens respectively (ZIBROWIUS, 1992), provide further support for this theory. However there are suggestions of the opposite. When examining the frequency of introduced macrophytes in the shallow subtidal macrophytic assemblages along the French Mediterranean coast, no relationship was established between the number of introduced species, the species richness of the host macrophyte assemblages and disturbances (KLEIN *et al.,* 2005).

While recent attention has focused on the adverse impacts of accidentally introduced species, beneficial aspects of introductions are also known, as alien species have become fisheries commodities for the aquaculture and fishing community and industry. Intentionally introduced species have significantly contributed to aquaculture production (FAO DIAS 1998), as well as fisheries (stocking) and recreational angling (MINCHIN & ROSENTHAL, 2002).

A well known example is the successful stocking of the Venice lagoon with the introduction of the oyster *Crassostrea gigas* and the clam *Tapes philippinarum* in order to replace depleted populations of two native species. Both species are fully acclimatised and exploited by fishermen (OCCHIPINTI AMBROGI, 2002a) Similarly, *Marsupenaeus japonicus,* initially imported for aquaculture, has become commercially important in the Aegean Sea and the Central and Western Mediterranean both in aquaculture and in fisheries as wild populations have been established. The species is also exploited by fishermen in the Levantine where it invaded via the Suez Canal (GALIL *et al.,* 2002).

However, considering the high permeability of aquaculture facilities, all introductions for the purpose of aquaculture should be regarded and administered as possible, even probable, introductions into the wild. To reduce environmental and other risks, the ministries responsible and the aquaculture industry need to pursue management practices that prevent escapes and reduce the number of inadvertent releases. Proper decision protocols, containment, contingency planning, and end-user education are proactive means of coping with potentially invasive species (ICES 2005; HEWITT *et al.*, 2006).

Even unintentionally introduced species that have exhibited an invasive character have become locally of commercial importance. Not surprisingly invading prawns make up most of the catches along the coasts of Egypt and Israel (GALIL, 1993).

Examples of alien species that have become fishery resources in the Levantine area are: the gastropod *Strombus persicus;* the prawns *Marsupenaeus japonicus, Metapenaeus monoceros, M stebbingi, Penaeus semisulcatus* and *Melicertus hathor*; the crabs *Portunus pelagicus,* and *Callinectes sapidus* (EEA, 1999; GALIL *et al.,*, 2002, GALIL & ZENETOS, 2002) and species of fish such as the mullids *Upeneus moluccensis* and *U. pori*, the Red sea obtuse barracuda *Sphyranea chrysotaenia*, the clupeids *Dussummieria elopsoides* and *Herklotsichthys puncatus*, the brushtooth lizard fish *Saurida undosquami* as well as the *Etrumeus teres, Hemiramphus far, Atherinomorus lacunosus, Sargocentron rubrum, Sillago sihama, Alepes djedaba, Liza carinata, Gymnammodytes semisquamatus, Siganus luridus, S. rivulatus, Scomberomorus commerson and Solea senegalensis* (GOLANI *et al.*, 2002).

Protection against invasive species has been the focus of many environmental programs, initiatives and policies and strategies. The Bern Convention on the Conservation of European Wildlife and Natural Habitats has developed a European Strategy on Invasive Alien Species, which offers specific advice to countries and international organisations on measures to combat the threat. In February 2004, the International Maritime Organisation (IMO) adopted the International Convention for the Control and Management of Ship's Ballast Water and Sediments. The Convention will in the short term require ships to exchange their ballast water in the open sea. Later, ballast water quality standards will come into force. Ratification is unfortunately only proceeding slowly and it seems unlikely that the Convention will come into force in the near future. The implementation of the EU Marine Strategy Directive, currently under development, should include measures to limit the spread of IAS in European Seas.

The information value of the preliminary list regards not only pressure on biodiversity but is increased through the focus on socio-economic impacts at the species level. As such, it provides the basis to examine the feasibility of endorsing indicator species within the Mediterranean for monitoring aliens and their impact for an integrated ecosystem-based management approach over the entire area. Considering the high number of new introductions in the Mediterranean (ZENETOS *et al.,* 2005), it is inevitable that new invaders with detrimental effects will pop up in the basin. Keeping records up to date is difficult and highlights the need for continuous research on the issue, not only recording the distribution of species but focusing on the impacts of the most invasive ones.

The work will continue under the Integrated Project (IP) SESAME (Southern European Seas: Assessing and Modelling Ecosystem Changes). The list of 'worst IAS' is considered a good management tool in order to assess both the current status of the ecosystem of the region and the impact of climate change and anthropogenic activities. Thus, it is foreseen that individual fact sheets on worst invasive species and their impact on biodiversity and socio-economy will be produced for the Mediterranean and the Black Sea.

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