EXECUTIVE SUMMARY

This synthesis, initiated during the meeting and consolidated thereafter by inputs received from many participants, was prepared and edited by Bella Galil, Greg Ruiz and Frédéric Briand. The editors are especially grateful to Jean-Pierre Dobler, Rick Boelens, Dan Minchin and to the rapporteurs: Lisa Drake, Anna Occhipinti Ambrogi and Tim Wyatt.

1. INTRODUCTION

The workshop was held in Istanbul from 6 to 9 November 2002 in the historic "Pera Palas Hotel". Sixteen scientists from ten countries participated in the meeting at the invitation of CIESM.

The subject does not require a long introduction since the transfer of alien marine species is recognized as one of the greatest threats to the world's ecosystems. Effects range from major shifts in the structure and function of natural communities, disruption of fisheries and aquaculture stocks, and threats to human health. In many geographic regions and habitat types it appears that the rate of new invasions by non-native species is increasing, stimulating both concern and efforts to reduce such transfers which most often result from human activities.

In his welcoming remarks Frédéric Briand, Director General of CIESM, recalled the long interest of the Commission in this issue which has the potential to threaten key aspects of ecosystem form and function as well as local economies of the Mediterranean and Black seas. As emphasized in a series of CIESM publications – most recently and most notably the collection of CIESM Atlases on Exotic Species – never before has man witnessed a change in marine biota as rapid and as pronounced as that under progress in the region. While Erythrean species migrating from the Red Sea through the Suez Canal are presently the major contributors to this process, introductions brought about by shipping deserve increasing attention. This was exemplified by two recent arrivals, the ctenophore *Mnemiopsis leidyi* and the gastropod *Rapana venosa*, transported from distant shores to the Black Sea, and respectively associated with the collapse of regional fisheries and with the destruction of local mussel and oyster beds.

By bringing together experts from a wide range of marine disciplines – biology, shipping and management – the organizers sought to properly characterize the multiple dimensions and interactions (ecological and operational) of ship-borne invasions. Among other objectives the group was encouraged to tackle the issue on a trans-Mediterranean/Black Sea level, transcending traditional national boundaries, and to consider the patterns, processes, and connectivity that emerge on this broad, basin-wide scale. F. Briand then warmly introduced Bella Galil, Chair of the CIESM subcommittee on Marine Ecosystems, also lead author of the recent – and noted – CIESM Atlas of Exotic Crustaceans, who had conceived and developed the theme of the workshop and would serve as its coordinator.

B. Galil pointed out that in the Mediterranean and Black seas ships have carried alien species across long distances ever since the opening of interoceanic maritime routes five centuries ago. While the phenomenon is not new, it is bound to gain in importance due to the fast increase in the size of vessels and in sea trade. Already the rate of detection of introduced species in the Mediterranean has accelerated in recent decades – a trend evident in other marine regions as well. Yet our enumeration of alien species remains much underestimated, and their impact poorly known, for reasons related to the availability of expertise, intensity of collecting efforts and, ultimately, to the size of the organisms.

The Mediterranean and Black seas, with their high-volume shipping routes and local degradation of habitats, are increasingly susceptible to ship-transported bioinvasions. Information about the magnitude and characteristics of vector operation is fragmentary, and a regional synthesis

quantifying current shipping operations and projecting future trends is lacking. In similar fashion, summaries of established invasions are available in some areas, indicating that widespread invasion of the Mediterranean is continuing, but many dimensions about the rate and impact remain poorly resolved – for reasons detailed by various communications in this volume and related to the availability of expertise, intensity of collecting efforts and, ultimately, to the size of the organisms.

Objectives and structure

The multidisciplinary workshop aimed to examine and debate our knowledge of the scale and impact of ship-transported aliens in the Mediterranean and Black seas region. Participants were invited to assess the role of vectors, source and volume of inoculants, environmental factors and anthropogenic activities in invasion patterns and processes. Based upon this foundation, an overall goal was to identify the critical needs and most promising directions for further research, considering a region-wide framework for actions, that would provide the science-based input necessary to guide regional policy and management. The first two days of the workshop were dedicated to the presentations and in-depth discussions (see communications in this volume). In the following days, participants divided into three groups that identified gaps in our knowledge about the role of shipping in bioinvasions and the associated impacts on recipient communities, assessed future trends – notably what is likely to happen in the absence of management intervention – and proposed measures that would substantively advance our understanding of invasion patterns and processes. The preliminary conclusions and recommendations that emerged were debated in plenary sessions, and further consolidated in the aftermath of the workshop by the various sub-groups and their rapporteurs. This executive summary highlights key findings and conclusions.

2. SHIPPING ROUTES AND VECTORS

2.1. Main shipping routes

Over the past half-century shipping has greatly expanded in the region, as measured by the number and the diversity of vessels arriving (see Dobler, Öztürk, this volume), and it is expected to grow much further, three- or four- fold, in the next 20 years. We have focused mainly on commercial shipping, where we have access to some reliable data. We are also much aware of the potential importance of fishing and recreational craft – not quantitatively analysed here – in the secondary dissemination (or spread) of species along the Mediterranean and Black seas shores. Certainly the coasts are dotted with innumerable small ports and marinas, home to busy coastal fisheries and tourist destinations. However, little is known presently about such boat traffic in the region.

The distribution of global sea trade with the Mediterranean region is extensively analysed in Dobler (this volume) according to types of vessels, cargo categories and world regions. This provides the first such basin-wide synthesis. Figure 1 summarizes the main global routes of commercial shipping headed for the Mediterranean area; shown is the percentage of total ship arrivals (over 33,000) recorded in 2001 by origin, as culled from the shipping daily Lloyd's List.

A key point, evident in Figure 1, is that the Mediterranean is connected by considerable sea trade with most global regions. The South Pacific and the North-East Pacific are exceptions, each accounting for less than 1% of the total. It is also worth noting that

• The North-East Atlantic contributes the lion's share (over 55%) of the vessel entries into the Mediterranean/Black seas area. This figure is an underestimate, since commercial vessels heading to the Black Sea (a) from the Baltic via the Russian inland waterways and (b) from the North Sea via the Rhine-Danube Canal have not been taken into consideration, although the volumes involved and the shipping impact on the Black Sea biota are clearly substantial (see Box 1).

• The ratio between temperate-cold source areas *vs* subtropical-tropical source areas is roughly 2/3 : 1/3.

• The tropical/ subtropical source areas are nearly equally distributed between the Atlantic Ocean, Indian Ocean and China Sea.
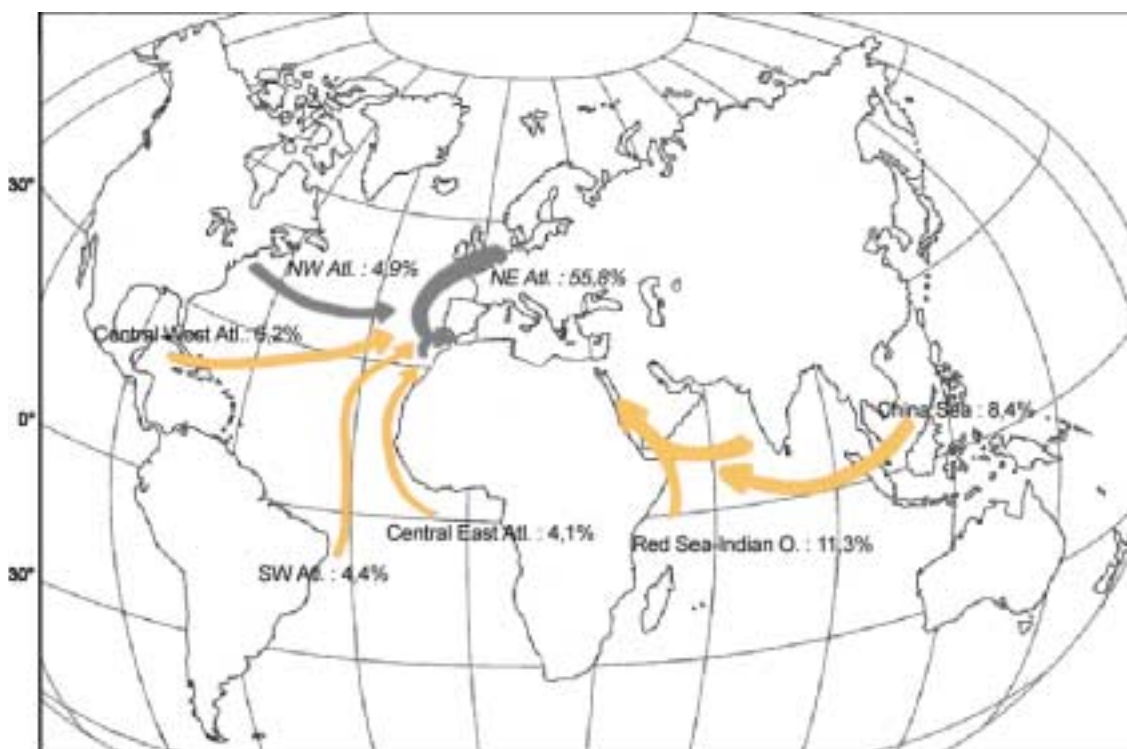
Fig. 1. Main ship movements towards the Mediterranean region (adapted from Dobler, this volume, on the basis of 2001 data).

tropical/subtropical waters

temperate waters

• Some 80% of Mediterranean shipping transits through the Strait of Gibraltar, only 20% through the Suez Canal. The importance of the Suez Canal as a corridor for shipping-transported invertebrates (see section 3.1 below) is unknown. It is impossible to determine how many of the hundreds of Red Sea and Indian Ocean species that have settled in the Mediterranean <www.ciesm.org/atlas> have been ship-borne – rather than migrated – through the canal.

2.2. Vectors of ship-transported invasions

Shipping is one of the major vectors delivering alien species to the Mediterranean and Black seas. Both seas are subject to invasion of ship-borne organisms, whether by fouling, ballast water and sediments, or biofilms. Multiple components of shipping can contribute to invasions. Perhaps the best studied is ships' ballast water, which is known to contain an impressive taxonomic range of organisms, from pathogenic microorganisms (Drake, this volume) to the occasional vertebrate. Hull fouling, the most ancient vector of species introductions in the marine biome, is responsible for many introductions throughout the world. It is still an important mode of macrophyte introductions to the Mediterranean Sea despite the extensive use of anti-fouling paints (Boudouresque, this volume). Least recognized are the impacts of discharging sediment and biofilms found within ballast-water tanks, although these aspects are currently being investigated. Lastly, the effects of recreational boats and fishing vessels on the secondary dispersal of alien organisms through the Basin are mostly unknown.

2.3. Overlapping vectors

Synergies likely exist between the potential aquatic vectors. Commercial shipping, recreational boating, canals and waterways, aquaculture operations, and the release of live aquatic organisms, probably work in concert to increase the potential for alien species to be delivered to new locations. Mediterranean and Black Sea harbours frequently provide a nexus for commercial shipping, fishing boats and recreational vessels, increasing the risk of secondary dissemination. Of particular concern is the proximity of some ports to aquaculture farms. Such overlap renders

aquaculture vulnerable to alien organisms imported through shipping, and it also increases the chances of spread by ships for alien organisms that were initially introduced by aquaculture. Importantly, ship-mediated transfers may enter the food chain through cultured shellfish, or may spread through intentional and unintentional aquaculture introductions. Indeed, the latter appears to have occurred in the lagoon of Venice, Italy, where aquaculture and shipping coexist (Occhipinti, this volume) and in Thau lagoon, France, a heavily invaded, major aquaculture site situated near a port (Zibrowius, this volume).

3. ECOLOGY OF INVASIONS

3.1. Taxonomic and geographic patterns

Table 1 presents, for the first time, a conservative list of ship-borne species introduced in the Mediterranean Sea. Upon analysis of the species biology, certain patterns do emerge :

• The list of ship-borne aliens is dominated by macrophytes, molluscs and crustaceans. Taxonomic groups consisting mostly of small and/or poorly known species are hardly, if at all, represented.

• Clear-cut cases of ship-transported species represent a minority of introductions (less than 30%) in the Mediterranean compared with species introduced by other means (see CIESM Atlases). Boudouresque (this volume) lists 29 ship-transported species out of 90 known introduced macrophytes; the various CIESM Atlases record 14 ship-transported molluscs out of 137 known exotics; 14 decapod crustaceans out of 59 known exotics ... and only one fish[1] out of 91 exotics !

• Of the ship-borne aliens, about 30% of the macrophytes, 38% of the molluscs, and over 55% of the crustaceans originate from temperate to cold-water regions. This is relatively high in a sub-tropical sea such as the Mediterranean, but then over 60% of the incoming vessels sail from North Atlantic ports (see Fig. 1). This suggests that shipping patterns and volumes may be relatively good predictors of invasions compared to environmental similarities between donor and recipient ecosystems.

• Lastly, based on their first Mediterranean record (see CIESM Atlases; and also Boudouresque this volume), it appears that many more species "landed" first in the Western basin and the northern Adriatic than in the Eastern Basin and the Ionian Sea : 25 *vs* 4 macrophytes; 11 *vs* 3 crustaceans; 8 *vs* 6 molluscs.

These data demonstrate clearly the importance of ship-mediated introductions within the Mediterranean Sea, but it is essential to recognize the constraints and possible biases associated with these patterns. Some of these patterns may result from significant biases that exist in the data, as they are uneven in their coverage across taxonomic groups, habitat types, and geographic locations. This is perhaps most striking with respect to size bias, as large organisms are more readily noticed, collected, identified and recognized as non-native, than smaller ones. This reflects to some extent the lack of scrutiny (search effort) and the taxonomic difficulties associated with the latter groups (see Wyatt, this volume; see also Ruiz *et al.*, 2000).

It will be a task for future research and monitoring programs, based on standardized search effort, to determine which of these apparent patterns are robust, and which are artefacts.

In the Black/Azov/Caspian seas complex, it appears that the overwhelming majority of invaders was introduced there by shipping (see list in Öztürk, this volume). Most of these species were transported from distant, temperate to cold, low salinity coastal regions. This is not surprising, given the hydrological characteristics of the host ecosystem.

Many invasive species established elsewhere are capable of survival in the Mediterranean and Black seas, and we should expect some to arrive, settle and develop founder populations locally. It has yet to be determined whether invasion patterns observed for certain taxa and in particular regions of the Mediterranean and Black seas will continue or whether they reflect a research effort

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[1] This is certainly an underestimate, as suggested by recent evidence of secondary transfer in ballast water of at least two Indo-Pacific fishes, *Sargocentron rubrum* and *Abudefduf vaigiensis*, from the Levantine coast to the harbour of Genoa (Lidia Orsi Relini, pers. comm.)

Table 1. Conservative[2] list of species introduced by ships in the Mediterranean Sea.

	Name of species	**Source**
PHYTOPLANKTON	*Alexandrium catenella*	Wyatt, this volume
MACROPHYTES [3]		Boudouresque, this vol.
• **Chromobionta**	*Colpomenia peregrina*	
• **Rhodobionta**	*Acrothamnion preissii, Aglaothamnion feldmanniae, Antithamnion amphigeneum,*	
	Antithamnionella elegans, A. spirographidis, A. sublittoralis, A. ternifolia, Apoglossum gregarium, Asparagopsis armata, A. taxiformis, Bonnemaisonia intricata, Botryocladia madagascariensis, Ceramium strobiliforme, Goniotrichiopsis sublittoralis, Hypnea spinella, H. valentiae, Lophocladia lallemandii, Pleonosporium caribaeum, Plocamium secundatum, Polysiphonia harveyi, Rhodothamniella codicola, Rhodymenia erythraea, Symphyocladia sp., Womersleyella setacea.	
• **Plantae**	*Caulerpa racemosa, Cladophora patentiramea, Codium fragile, Codium taylori*	
CNIDARIANS		
• **Hydroids**	*Clytia hummelincki, Garveia franciscana*	Boero, this volume
• **Scleractinian corals**	*Oculina patagonica*	Zibrowius, this volume
MOLLUSCS		CIESM Atlas, 2003 (Zenetos *et al.*)
• **Gastropods**	*Aeolidiella indica, Conus fumigatus, Crepidula aculeata, Cuthona perca, Polycera hedgpethi, Polycerella emertoni, Thais lacera, T. sacellum*	
• **Bivalves**	*Anadara demiri, A. inaequivalvis, Chlamys lischkei, Mya arenaria, Saccostrea cucullata, Spondylus multisetosus*	
POLYCHAETES	*Ficopomatus enigmaticus, Hydroides dianthus, H. dirampha, H. elegans, Spirorbis marioni*	Zibrowius, this volume
DECAPOD CRUSTACEANS	*Calappa pelii, Callinectes danae, C. sapidus, Dromia spinirostris, Dyspanopeus sayi, Eriocheir sinensis, Hemigrapsus sanguineus, Herbstia nitida, Libinia dubia, Menaethius monoceros, Percnon gibbesi, Rhithropanopeus harrisii, Scyllarus caparti, Thalamita gloriensis*	CIESM Atlas, 2002 (Galil *et al.*)
ISOPODS	*Paradella dianae, Sphaeroma walkeri*	Zibrowius, 1992
AMPHIPODS	*Elasmopus pectenicrus*	Zibrowius, 1992
BRYOZOANS	*Hippopodina feejeensis, Tricellaria inopinata*	Zibrowius, 1992 and Occhipinti, this volume)
ASCIDIANS	*Microcosmus exaperatus*	Zibrowius, this volume
FISHES	*Pinguipes brasilianus*	CIESM Atlas, 2002 (Golani *et al.*)

[2] This is a conservative, non-exhaustive list which mentions only the most likely cases of unintentional introduction via a ship vector. Cases of secondary intra-Mediterranean ship transfers, or of transfers clearly associated with aquaculture shipments, are excluded.

[3] Under Chromobionta, Rhodobionta, and Plantae one finds species of Brown, Red and Green Algae which were formerly classified under Phaeophyceae, Rhodophyceae and Chlorophyceae.

BOX 1

SNAKES AND LADDERS: WATERWAYS AND CANALS AS INVASION CORRIDORS

B.S. Galil and S. Olenin

The technological innovations of the 18th century set in motion processes that led to a proliferation of canals, first in Europe and then worldwide. The invention of the steam engine made possible the industrial revolution with mass production of trade goods it was used to power ships enhancing the role of maritime trade, and in the machinery used in digging the canals that connected most river systems. Besides the 163 km-long Suez Canal which opened a direct route to/from the Indo-Pacific realm,the Mediterranean and Black Seas are now connected, via a dense network of inland waterways across Russia and Europe, with bodies of water as distant as the White Sea and the North Sea.

This cross-continental system of rivers, canals, lakes and inland seas serves a huge number of vessels and a large volume of cargo, providing alien species with many opportunities for shipping-mediated invasion and secondary dispersal. A few indicative figures are telling: though closed to commercial traffic between November and April, the Volga-Don Canal has been traversed by 400.000 ships since its opening 50 years ago; 14,000 commercial vessels transit the Suez Canal annually; the volume of cargo expected to pass through the Mittellandkanal in 2010 is 42 million tons.

There are major aquatic transport routes traversing the continent. One connects the Caspian and Black seas with the northern Baltic Sea through canals linking the Don and Volga rivers with the Neva (Novomariinsky canal); another with the White Sea through the Severo-Dvinsky and the Belomoro-Baltiisky canals. Two routes connect the Black Sea with the western European Atlantic coast – one route meanders through the Dnieper, Vistula, Oder, and the Mittellandkanal to the Rhine; the other through the canals linking the Danube, Rhine, Marne, Loire, and through the Rhone to the Mediterranean Sea. The canalization of European rivers, the concomitant construction of locks and dams, and the prevalent aquatic pollution and eutrophication, tends to harmonize their water quality. The increasing depth and width of the canals, and the creation of reservoirs mean larger volumes of water that buffer temperature and salinity fluctuations, and so provide a more uniform environment.

An invasive organism may be dispersed through the network far and wide: the notorious zebra mussel, formerly a Ponto-Caspian endemic, began its global spread by reaching the Baltic Sea through canals linking the Dnieper with the Vistula and the Neman, and through canals linking the Volga with the Neva, and with the timber trade to western European ports. The mussel has also spread through the central European waterways to the Rhine. Similarly, the Ponto-Caspian water flea, *Cercopagis pengoi*, and the hydrozoan *Cordylophora caspia*, reached the southern Baltic harbours and then spread onward through trans-oceanic shipping. A dozen Ponto-Caspian species have already reached the Rhine delta, either by natural dispersal or through shipping. Since most major European harbours are located in estuaries, world-wide dispersal of Ponto-Caspian invasive organisms is all but assured (Bij de Vaate *et al.*, 2002). The estuarine emplacement of the harbours, between the inland aquatic routes and overseas shipping, hazards frequent inoculations and enables secondary spread of trans-oceanic shipping-mediated inoculations upstream. The Chinese mitten crab, *Eriocheir sinensis*, introduced to Germany in the early 1900s, dispersed in the 1920s and 1930s to many northern and eastern European rivers and estuaries by active migration, in ballast or in of hull fouling. The Atlantic comb jelly, *Mnemiopsis leidyi*, was introduced, probably in ballast water, in the early 1980s in the Black Sea. In November 1999 it was recorded from the Caspian Sea, transported through the Volga-Don Canal. In fifty years, 19 alien species have entered the Caspian Sea through the Volga-Don Canal, in ballast and hull fouling, and established viable local populations (Aladin *et al.*, 2002).

Since shipping is the major vector affecting invasion through the European waterways, and trans-oceanic and continental trade is the single most important determinant, we may be facing a significant increase in bioinvasions. The confluence of the following political and economical events chances a higher potential of inoculation and spread:

• International trade with the eight Baltic and central European countries about to join the EU in 2004 is likely to increase.
• Expansion of Caspian Basin oil production will multiply traffic along the Volga-Don route.
• The Russian Ministry of Transport, the European Bank for Reconstruction and Development and the European Commission have began financing the modernisation of Russia's inland waterways.
• Development of a transportation corridor between the Persian Gulf and the Baltic Sea is expected to increase shipping along the Volga-Baltic waterways.

which is unevenly distributed taxonomically and spatially. Should rates of introduction change for various taxa, we may be unable to recognize them unless we have the proper taxonomic expertise (Wyatt, this volume). At present it is not possible to truly assess the rates of invasions in the absence of standardized, contemporary measures over time. These questions emphasize the need for region-wide collaboration and harmonization of research and recording effort.

3.2. Potential impact

Alien species may elicit a range of ecological, economic, and human health impacts. Although attention to this issue is relatively recent, certain ship-invaders such as the notorious *Mnemiopsis leidyi* and *Rapana venosa* (Öztürk, Kideys, this volume) have had unwelcome ecological and economic effects. Similarly, the introduction of the toxic dinoflagellate *Alexandrium catenella* to Thau Lagoon, France, is of concern for shellfish production, as there are periods when molluscs may be unsuitable for consumption due to the presence of toxins causing paralytic shellfish poisoning. Finally, as documented in Box 2 (L. Drake), available evidence suggests that the transport of the bacterium *Vibrio cholerae* and other species of *Vibrio* by ships' ballast water may pose a serious risk to public health

Despite these few dramatic examples, very little is known about the direct and indirect effects of most non-native species in the Mediterranean and Black seas, as elsewhere in the world. Importantly, the absence of data should not be construed as "no effect" but rather the lack of sufficient examination to date.

3.3. Invasibility of environments and communities

A major goal of invasion biology is to develop reliable predictions, for instance whether or not a given organism, once transported successfully to a new location, is liable to establish a viable population. Resource availability, species richness, presence/absence of natural enemies, life history characteristics of potential invaders, plus the degree of physical compatibility between host and donor environments – all of which vary in time and space – will affect invasion outcomes (e.g., establishment, abundance, impacts, and spread). The chance of establishment will be further enhanced by the abundance and rate of arrival, i.e., the size and frequency of the inoculum of the alien population (see Kolar and Lodge, 2001; Ruiz, this volume). In addition, anthropogenic disturbances, such as dredging, sewage and thermal discharges, contaminant loading, eutrophication, hypoxia, fishing pressure and trawling, may often create "opportunities" for marine invaders.

Finally the hypothesis that regions with low species richness offer less resistance to invasions is considered attractive on several theoretical grounds (see Shea and Chesson, 2002) but participants noted that it is not overwhelmingly supported by empirical evidence. A combination of both disturbance and low species richness may account for the vulnerability of certain habitats, such as polluted harbours, to invasion.

At this stage the predictive capability surrounding invasions remains limited. Invasion ecology is a relatively young science, which has been largely descriptive to this point. General predictions are not yet available to assess the interactive effects of various environmental and biological factors on invasion success, and so the odds of correctly predicting future invaders are not much better than winning at a lottery (see Carlton and Geller, 1993; and Boero, this volume). Though the empirical data base is inadequate, the supply of organisms, as determined largely by operational characteristics of shipping (and additional vectors), is suspected to bear heavily on invasion outcome. There is ample room for, and considerable need of research in this area.

4. PROSPECTIVE TRENDS

In evaluating options for controlling introductions of non-indigenous species into the Mediterranean and Black seas by ships, it is useful to speculate on future scenarios in the absence of any management initiatives. This provides a baseline against which the likely efficacy of specific treatments or other forms of intervention can be judged.

In this discussion we have assumed that the transfer of marine organisms attached to vessel hulls will continue to be retarded by the use of anti-fouling paints and other hull coatings. The relative

efficacy of new coatings to replace those based on tri-butyl tin, which is shortly to be phased out due to environmental concerns, is unknown. Research and development of anti-fouling agents that are environmentally compatible is underway. We are aware that such materials are applied to maintain the speed of vessels and not specifically to prevent transfer of biota, but in the meanwhile the species that constitute hull fouling assemblages should be assessed.

4.1. Shipping increase

It is to be expected that certain trends and developments will continue to influence the transfer and introduction of non-indigenous species into, and between, the Mediterranean and Black seas. Chief among these, the projected increase in the volume of sea borne traffic, both commercial and recreational. As global shipping volume is expected to grow 4-fold in the coming 20 years, the Mediterranean region will share in this trend (see Dobler, this volume). With the rise in living standards in the region, and with the expansion in Caspian oil exports through the Black Sea, changes are expected in shipping patterns and practices. The growth of maritime oil and gas exploration will mean an increase in movements of drilling and production platforms.

The trend in the shipbuilding industry towards construction of ever larger tankers and container vessels entails changes in shipping practices as well, with a system of "hub" ports capable of accommodating high volume mega-vessels, combined with trans-shipping to smaller destination ports. The increase in shipping volume and the construction of mega-vessels provided the impetus for the widening and deepening of the Suez Canal. This project, already underway, will enable passage of larger vessels resulting in shorter distances and voyage durations between the Indian Ocean and the Mediterranean Sea for vessels that otherwise would be required to route around the Cape of Good Hope and enter the Mediterranean Sea through the Strait of Gibraltar. The increasing affluence, leisure and average age of Europeans will probably contribute to the further expansion of tourism along the Mediterranean rim and to the expansion of recreational boating.

4.2. Climate change

Climate change will influence future boundaries of biogeographic regions and thus the ranges of individual species. There are now indications that warm water marine species are extending their ranges and colonizing new regions where they were previously absent. Already most of the alien species in the Mediterranean are thermophilic, originating in the tropical Indo-Pacific or tropical Atlantic. The recent records of tropical Atlantic species in the Mediterranean, mostly shipping- and mariculture-transported, may be indicative of combined anthropogenic and environmental changes. Should global warming affect Mediterranean sea-water temperature, then thermophilic invasive species would gain a distinct advantage over the native biota. Climatic influences on species' introductions and distributions into and within the Mediterranean and Black seas are to be expected, albeit with differing magnitudes and on different time-scales. Some of the more likely developments are as follows : local, regional and larger scale changes to water circulation patterns may modify present species distributions, resulting in shifts in biogeographical zones; increases in sea surface temperatures within the Mediterranean and Black seas are already apparent and may be partly responsible for changes in the range of some species; maritime corridors linking the region to other seas will also be affected by temperature increases; increases in storm frequency and rainfall, and changes in wind speed and direction, may alter salinity and turbidity in shallow environments. The net result of these shifting patterns to invasion outcome is truly complex and difficult to estimate at the present time.

4.3. Trends in legislation

The quality of coastal waters and sediments is expected to improve via new legislation designed to protect aquatic ecosystems, and continuing efforts to improve the implementation of existing measures for the control of shipping-related and land-based impacts on the marine environment. Such improvements may render the environments of certain marine and coastal areas less disturbed, thus in theory (see section 3.3. above) less favourable for the establishment of some alien species.

The European Union Water Framework Directive (EU, 2000), aiming to restore good ecological quality in all transitional (i.e., estuaries, lagoons, tidal inlets, etc.) and coastal waters within one nautical mile seawards of the baseline, is a potentially powerful legislative measure. Special

BOX 2

MICROBIAL INVADERS : FOCUS ON *VIBRIO CHOLERAE*

L. Drake

The bacterium *Vibrio cholerae*, agent of human cholera, has caused seven pandemics since the first documented one in 1817 (Blake, 1994). Today, cases of cholera in developed countries are relatively rare, but epidemics caused by one of two serogroups (O1 or O139) continue to occur in undeveloped countries, sometimes on a seasonal basis. Illness, which carries a mortality rate of about 1%, generally occurs through the ingestion of contaminated water or food and is often associated with poor sanitation.

A considerable body of work regarding the transmission of *V. cholerae* in water has accumulated. In a famous epidemiological study, John Snow showed in 1855 that cholera victims fell ill during an epidemic in London because they drank contaminated water from the Thames River (Brock *et al.*, 1974). Robert Koch later isolated "comma-bacilli" as the cause of human cholera and hypothesized its transmission via the estuarine waters of the Ganges River delta (Koch, 1884). Nearly 100 years later, *V. cholerae* was postulated to be commonly found in coastal waters (Colwell *et al.* 1977), an hypothesis supported by the isolation of *V. cholerae* from various coastal environments, including the East and Gulf coasts of the United States (e.g., Colwell *et al.,* 1981), England, Japan, Australia (Desmarchelier *et al.,* 1995), and Italy (Barbieri *et al.,* 1999).

V. cholerae may maintain its coastal presence in part by adhering to zooplankton, particularly copepods (Nalin, 1976), which often dominate the zooplankton in terms of numbers of organisms. Indeed, marine crustaceans serve as substrates for scores of different types of bacteria, which benefit from such an association by taking up dissolved organic nutrients released from their hosts (as reviewed by Carman and Dobbs, 1997). Such a strategy may help *V. cholerae* survive otherwise inhospitable conditions in the water column. While the relation copepod-*V. cholerae* does not appear obligatory, laboratory experiments demonstrate that *V. cholerae* will attach to copepods when copepods are immersed in water with a high concentration of bacteria (Huq *et al.,* 1983). In field samples, *V. cholerae* have been found as epibionts and endobionts of a variety of organisms, ranging from marine cyanobacteria, microphytes, and macrophytes to crustaceans, oysters, and fish (see review by Islam *et al.*, 1994). On a larger scale, a positive correlation was found between sea surface temperature – a proxy for zooplankton abundance – near Bangladesh and the number of cholera cases reported nearby later (Colwell, 1996; Pascual *et al.* 2000).

In considering ships as a vector for the transport of *V. cholerae*, it is known that bacteria, in general, are abundant in ballast-water samples (Drake *et al.,* 2000, 2001). Specifically, 93% of ships sampled arriving to Chesapeake Bay from foreign ports contained *V. cholerae* O1 and O139 in their ballast water (Ruiz *et al.*, 2000). The presence of *V. cholerae* in ballast water suggests the potential for ships to act as vectors in its geographic translocation. For a microbial invasion to occur, however, the bacterium must survive and reproduce following its discharge into a new environment. In at least one instance, such an invasion has occurred. Cells of toxigenic *V. cholerae* O1 were found in oysters and intestinal contents of fish in Mobile Bay (Alabama, USA) in 1991 (De Paola *et al.*, 1992). The strain of *V. cholerae* was different from strains previously isolated from the Gulf of Mexico but indistinguishable from the strain responsible for a cholera epidemic occurring in Latin America. When the ballast, bilge, and sewage waters of nineteen ships leaving Latin American countries and arriving in Mobile Bay were tested later that year for the cholera bacterium, five contained the epidemic-causing strain (McCarthy *et al.*, 1992). These results suggest that ships were responsible for the introduction of the epidemic-causing strain to the U.S. Gulf Coast.

Given that *V. cholerae* is endemic to the Mediterranean (e.g., Barbieri *et al.*, 1999), one can hypothesize that it is taken up when ballast water is loaded onto ships, transported to subsequent ports of call, and discharged. The risk of invasion of a novel strain of *V. cholerae* around the Mediterranean remains unquantified, although the case history for the U.S. Gulf Coast suggests that such an invasion is possible. Furthermore, given the proximity of some ports to aquaculture facilities (see Occhipinti; Zibrowius, this volume), one can speculate that bacteria – including *V. cholerae* – discharged from ships may be incorporated into shellfish raised for human consumption.

arrangements will be introduced for "heavily modified waterbodies" such as ports and harbours, although strict environmental quality standards will be set for all areas.

The International Maritime Organization (IMO) plans a diplomatic conference in early 2004 to ratify a "ballast water convention" that would achieve a standard approach to ballast water management and would spur research and development of ballast treatment techniques. Meanwhile, another IMO convention, prohibiting the application of TBT-based antifouling paints on ships as of January 2003[4], might conceivably lead to an increase in fouled hulls, and thereby exacerbate the problem of bioinvasions via ship fouling.

5. CONCLUSIONS AND RECOMMENDED ACTIONS

The Mediterranean and Black seas, with their high-volume shipping routes and degraded habitats, are clearly susceptible to ship-transported bioinvasions. Shipping patterns ensure that both seas export as well as import biota. Whereas the science remains incomplete, workshop participants do share the view that enough is known already to say that (a) there are significant risks of invasions and impacts associated with current ship-mediated transfers; and (b) that these risks will rapidly increase, due to the expected growth of shipping activities in the region.

Proactive, precautionary action is warranted, considering the magnitude of effects associated with some invasions and the low capacity to predict the next "high-impact invader". Priority must be given to preventive measures that can be implemented in the near term.

As a start, in order to assess the impact and scale of ship-transported bioinvasions in the Mediterranean and Black seas, a better understanding of the vectors, the pathways, the routes and the species is needed. Only then will decision-makers dispose of rational inputs towards risk assessment and management options.

> **Recommendation:** *To undertake this task, we call for a Mediterranean-wide program, drawing participants from many different countries, which would avoid duplication of efforts and inefficient use of resources.*

5.1. Tracking shipping vectors and pathways

Shipping is considered the largest single vector for the translocation of marine species across the globe. The large number of high-volume vessels passing through the Bosphorus (Öztürk, this volume) is indeed reflected in the number of ship-borne alien species in the Black Sea. In the Mediterranean Sea, more precisely in the eastern Mediterranean Basin where Lessepsian migrants remain largely confined so far, ship-transported aliens lag far behind Erythrean invaders in the number of species introduced. Transport and transplantation of commercially important alien species, mainly shellfish, increase the number of aliens, through intentional and unintentional introductions, though mariculture introductions are mostly restricted to lagunes and estuarine habitats and to their immediate vicinity, as in the Northern Adriatic Sea and the lagoons of southern France (Occhipinti, Boudouresque, this volume). With public attention and scientific research centered on those major vectors, the role of fishing and recreational craft in introducing alien biota and contributing to its secondary spread remains largely unstudied. Monitoring of small craft and marina areas is recommended; an appropriate metric for mapping the incidence of recreational crafts, their ports and marinas, should be developed and standardised (Occhipinti, Minchin, this volume).

> **Recommendation**: *Develop a wide scale program to measure the operational characteristics of shipping associated with species transfers, and how these are changing over time.*

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4 Annex I attached to the Convention states that by an effective date of 1 January 2003, all ships shall not apply or re-apply organotin compounds which act as biocides in anti-fouling systems. By 1 January 2008 (effective date), ships either: (a) shall not bear such compounds on their hulls or external parts or surfaces; or (b) shall bear a coating that forms a barrier to such compounds leaching from the underlying non-compliant anti-fouling systems.

As a first priority, this should focus on commercial shipping, estimating potential transfer associated with ballast tanks and ships' hulls. Ideally, this would be expanded to include examination of fishing vessels and pleasure craft, which we suspect to play an important role in secondary spread within the region. As a final stage, additional analysis of other non-shipping vectors would also be desirable. Below, we outline recommendations for the first two steps, the analysis of commercial vessel traffic and that for other vessels.

5.1.1. Commercial ships

Several characteristics of shipping will influence invasion outcome. These include the frequency of traffic, vessel type, and vessel route(s). Bearing in mind that ballast discharge and hull fouling have been identified as major vectors, the ballast water discharge characteristics (including volume, source, age, and treatment) and the hull characteristics (including surface area and extent of fouling) should be properly surveyed.

> *Recommendation: We stress the necessity of developing a comprehensive database of commercial shipping patterns, including each of these key characteristics associated with species transfer, for the Mediterranean and Black seas (see Dobler, this volume).*

This database should take full advantage of records kept by port authorities on a port-by-port or national level, and against data assembled by the maritime industry. A practical, user-friendly database collating the above information over several years would greatly facilitate estimation of the quantities of ballast water loaded and discharged in each of the region's major ports. It would reveal not only the origin and frequency of delivery of possible inoculants, but also the main routes of primary introductions from outside the region and secondary dissemination within the region.

Beyond a summary of the available data, more precise and comprehensive data should also be collected from vessels arriving to key port systems. This is best done by questionnaire, whereby ships are asked to provide specific information about route, vessel characteristics, and ballast water management and discharge practices. Such an approach has been undertaken now in many countries throughout the world, using a standardized reporting form or questionnaire, providing "fine-grain" information about vessel traffic that is most relevant to species transfer.

Several models already exist for such programs that include ship reporting and organization of data by referencial databases, allowing analysis of ballast water delivery or vessel arrival patterns by ship type, source region, season, and more. The IMO Globallast Program has been facilitating collection of shipping data that include many of these key elements (Raaymakers, this volume). In addition, the Smithsonian Environmental Research Center <http://invasions.si.edu> has developed and implemented a nationwide program for all commercial ship arrivals to U.S. ports, including estimates of ballast water management and estimates of "wetted surface area" for each arriving vessel. Further, for each of these programs, database structures and analytical tools have already been designed that could serve as a useful template for developing a parallel program within the Mediterranean and Black Sea region. It may be useful to organize a workshop to review available tools and develop an implementation plan for such a program in the region.

5.1.2. Fishing vessels, recreational craft and other marine vectors

In addition to commercial vessels, significant attention should be given to other types of marine transport that clearly transfer non-native organisms into and within the Mediterranean/Black Sea region, including fishing vessels, recreational boats, barges, floating docks and platforms. Military vessels should also be given some consideration, as they may behave in appreciably different or unique ways (e.g., frequent visits to one region for one time period, followed by sometimes abrupt shifts in traffic patterns to other regions).

It may be difficult to develop a comprehensive and coordinated reporting systems for these alternate vessel types and transports, similar to that suggested for commercial vessels (above), because relatively few established tracking systems (or models for such systems) already exist.

> *Recommendation: Initial efforts should focus on "pilot studies" to develop the capacity and methodology needed to adequately evaluate such traffic, focusing on characteristics that are known to influence species transfer.*

5.2. Measuring broad invasion patterns

Despite clear evidence of invasions accumulating in the Mediterranean and Black seas, there remain many significant gaps in information that limit our ability to (a) examine patterns of invasion in space and time and (b) develop predictive tools for invasion science and invasion management.

> ***Recommendation***: *Implement a regional program of surveys that employ standardized biological and environmental measures, replicated over time.*

This should be implemented across a network of monitoring sites, taking full advantage of the distributed research laboratories throughout the region. Only this approach will provide the necessary tracking system to understand invasion patterns, including their relationships with vector activity and factors that influence invisibility. CIESM should serve as a catalyst to develop such a program, using its unique connections with the research community on all shores of the region, and pursuing its current high-profile role on this issue.

There are several models available for tracking and evaluating invasion patterns. For example, standardized survey programs have been implemented in Australia and the U.S.A., including database management tools for sharing information via the World Wide Web (e.g., see Ruiz and Hewitt, 2002). To initiate such a program, it would be desirable that a core group develop and advance key elements toward implementation. Within this context, significant thought should be given to (a) research design, (b) taxonomic expertise, (c) voucher collections, (d) data management and analysis, and (e) public access.

5.3. Early Warning System

Ship's ballast water and sediments serve as a significant mechanism for the spread of many non-native organisms. The ecological, economic, and human health impacts of most invasions remain unknown – ranging from barely noticeable to disastrous – and difficult to predict. However, the potential consequences of organisms that infect humans – including toxic dinoflagellates, parasitic protists and pathogens – are much better resolved. Their omnipresence in the sea means that they invariably occur in ballast water and sediments. For example, the bacterium *Vibrio cholerae*, agent of human cholera, is present in the Mediterranean and may be dispersed with loaded ballast (see Box 2). Moreover, many shellfish farms are located in the vicinity of ports and the 'health hazard' in such cases may be even higher. A regional sampling program targeting human pathogens and cysts of toxic dinoflagellates in discharged ballast, and in water and sediments in commercial ports, should form the core of an "early warning system", alerting policy makers and management.

> ***Recommendation***: *Establish an early detection system, aimed at detecting non-native species likely to have significant impacts. Priority should be placed upon those organisms that pose significant risks to human health and commercial shellfish, or those with demonstrated negative impacts in other global regions.*

Such a system shall include a suite of indicators targeting the more high-risk practices and areas. Focusing on the early detection of arrival of alien species, which implies the regular monitoring of selected coastal localities and the development of better taxonomic expertise, will be helpful.

To be effective, a regional system of cooperating institutions shall adopt common methodologies, standards and data collecting/recording protocols. The resulting data should be disseminated rapidly within the network.

5.4. Assessing/reducing the risk of bioinvasions

This is a longer-term proposition. Some 12,000 species have been identified from the Mediterranean and Black seas. Extrapolating from the data currently available, one may estimate that at least 1,000 marine species of alien origin have been introduced in the region in recent decades. While scientific surveys and sampling programs continue to uncover additional species, many of the high-abundance invaders are assumed – for lack of evidence – to neither constitute an ecological nuisance, nor to have an economic impact. But if we exclude the "health hazard" cohort of pathogens, toxic species and parasites, at the present stage of knowledge we have almost no way of identifying which alien species, once established, will cause adverse environmental and economic effects.

It will be helpful to evaluate the cost of marine bioinvasions in the Mediterranean and the Black Sea, at least in cases where societal, health, economic or recreational impairment have been reported, and for "health hazard" scenarios. These evaluations will be useful in assessing the cost of taking no action to prevent, reduce and control ship-transported alien species.

Open ocean exchange of ballast water – the replacement of coastal water with mid-oceanic water – is at present the single most widely recommended procedure for reducing the risk of ballast-mediated bioinvasions. However, there are serious reservations concerning the practicality, safety and efficiency of this technique (Boelens, this volume). Research is underway worldwide to find more efficient treatment technologies that are environmentally benign and cost-effective.

> *Recommendation: We call for a continually-updated, centralized compilation of the records of alien species in the region. The regularly updated digital data base maintained by CIESM on its website <www.ciesm.org/atlas> is an essential reference on invasive Mediterranean biota, which should be fully supported. With improved monitoring worldwide of ship-transported biota it may be possible in the mid-term to assemble lists of "high probability" invasive species that are likely to arrive in the Mediterranean and Black seas, or to be disseminated from the region.*

5.5. Directions for further research

As suggested above, a priority for researchers will be to test the robustness of emerging invasion patterns at the scale of the entire Basin, and to revise current paradigms of biogeographic theory accordingly. The extent to which habitat susceptibility to ship-borne invasions is determined by disturbance level, species richness, trophic complexity of the recipient community, by compatibility between source and sink environments, and by shipping intensity and opportunities, should be thoroughly investigated in a standardized, reliable fashion. A first step will be to test for correlations and associations between the data sets that result from (a) tracking ship patterns and (b) measuring patterns of invasion, with associated environmental data (see Ruiz and Carlton, 2003). Further exploration using manipulative experiments can also provide valuable insights.

The ecosystem response to these invasions is also a fertile and important ground for research, with such priorities as investigating the changes in foodweb structure and in ecosystem functioning caused by alien species, the economic impact of high-risk invaders (predators, pathogens, etc), and the possible synergy of multiple introductions. In addition invasions offer unparalleled insights into the functional interactions of ecological communities, creating uncontrolled "natural" experiments which should be systematically contrasted and compared.

We further recommend that regular surveys give special attention to port-proximal micro-environments such as aquaculture facilities and power plant' cooling ponds, which may create new opportunities for non-native species to establish a foothold in the region.

Recognizing that the cessation of use of TBT antifoulants may enhance dispersal through hull fouling, we strongly recommend region-wide port surveys specifically targeted and designed to provide cost-effective baseline data of alien fouling biota.

In addition to basin-wide efforts, significant opportunities for coordination and collaboration with research activities outside of the region – both with respect to analysis of shipping patterns and invasion patterns – do exist. They should be explored actively.

Analysis of shipping patterns
in the Mediterranean and Black seas

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Face to the current absence, incompleteness and/or inaccessibility of published statistical information on the multifarious shipments loaded and unloaded in the more than 150 commercial ports of the Mediterranean/Black seas region and on the corresponding shipping routes origin and destination matrices, this paper mostly focuses on the ship movements originating from the rest of the world that are directed towards the Mediterranean Basin. When marine bio-invasions in the region are considered as shipping-related, it means that they have been triggered by such movements. However, intra-Mediterranean/Black seas ship's movements are also an important vector for the further regional dissemination of invading species. Finally, the considered geographical area may also be a source for marine bio-invasion, as the maritime transport "corridors" linking the Mediterranean sea with the rest of the oceanic sphere work both ways.

PART PLAYED BY THE REGION ON THE GLOBAL SEA-BORNE TRADE STAGE

The last available set of global detailed origin/destination matrices of the main cargo categories dates from the year 1985 and was based on a Pilot study undertaken by the UNO Statistical Office. Since this time, the lack of funds – and also, alas, lack of interest of member-states for maritime activities – has prevented the UNO Statistical Office to update such matrices. The 1985 Mediterranean region data are presented in Table 1.

Obviously, the volumes of cargoes loaded and unloaded in, or transiting by, the Mediterranean Basin are different today than in 1985. Nowadays according to the last available estimate in 2001, world sea-borne trade reaches 5,500 millions tons, a value which is 77% higher than the corresponding 1985 figure shown in Table 1. However, the structure of the global maritime transport – i.e. its distribution by cargo categories and world major economic areas – is rather rigid, even over a long period such as 1985-2001. Therefore, the following comments based on Table 1 will give a rough preliminary estimate of the part played today by Mediterranean countries in the world sea-borne trade.

1) In 1985 the Mediterranean ports overall cargo trade represented 21.1%, and transiting cargoes 9.9%, of the world total. Thus, the part played by the Mediterranean Sea in the global maritime transport shipments can be estimated at the time to about 30%.

2) The geographical distribution of the total Mediterranean 1985 sea-borne trade was as follows: 26.5% was inter-Mediterranean, a nearly equal share of 27.1% corresponded to cargoes loaded in Mediterranean ports for non-Mediterranean destinations. The balance of 46.4%, not far from half of the total, corresponded to shipments originating from the rest of the world and unloaded in Mediterranean ports. Of course, it is the latter that interest us

Table 1 . Distribution by major cargo categories and main origin/destination of the Mediterranean sea-borne trade in 1985 (figures in millions tonnes).

| Main cargo categories | Mediterranean ports sea-borne trade | | | | World sea-borne trade | | Mediterranean Transit sea-borne trade | | |
| | With the rest of the World | | | | | | from/to W. of Gibraltar | | |
	Inter Med.	from Med.	to Med.	Total	% Med.	Total	Black Sea	E. of Suez	Total
Crude oil	102.51	62.40	98.41	263.37	28	972,22	9,05	12.00	21,05
Oil refined products	20,16	27.61	37.40	82.17	24	341.87	4.68	16.55	21.23
Liquefied gas (LNG/LPG)	6.17	4.77	3.19	14.03	23	39.89	-	0.42	0.42
Liquid chemicals	4.00	5.15	6.27	15.42	19	82.76	1.74	10.10	11.84
Sub-total liquid bulk cargoes	*132.74*	*99.98*	*142.27*	*374.99*	*26*	*1,473.74*	*15.47*	*39.07*	*54,54*
Iron ore	0.55	1.91	25.92	28.38	9	315.50	0.02	7,66	7.68
Coal	0.04	0.06	41.36	41.46	15	285.17	2,11	27.70	29.81
Grains	1.97	2.38	23.14	27.49	15	188.34	20.26	11.99	32.25
Other dry bulk cargoes	27.43	47.28	51.07	125.78	20	629.27	8.56	49.02	57.58
Sub-total dry bulk cargoes	*29.99*	*51.63*	*141.49*	*233.11*	*16*	*1,418.28*	*30.95*	*96.37*	*127. 32*
Refrigerated goods	0.79	3.92	2.56	7.27	23	32.06	0.10	3.11	3.21
Containairisable cargoes	4.80	16.04	6.95	27.76	22	128.61	0.63	14.68	15.31
Other general cargoes	3.81	5.54	11.38	20.73	16	139.49	0.62	14.37	14.99
Sub-total general cargoes	*9.49*	*25.50*	*20.89*	*55.79*	*19*	*300.16*	*1.35*	*32.16*	*33.51*
TOTAL all cargo categories	**172.13**	**177.11**	**304.65**	**653.65**	**21**	**3,104.18**	**47.77**	**167.60**	**215.37**

primarily here, as the carrying ships will have loaded their ballast water and gathered their most recent hull-fouling species outside the basin. It can be remarked in this context that the ships in transit (not having to load or unload cargo in the Mediterranean ports) do not normally discharge ballast water when crossing the Basin. However, they can carry and release some unwanted species in the fouling attached to their submerged hull and appendices, specially chains and anchors or living in other on-board water reserves and pipes.

3) Analysing cargoes movements does not cover the whole of our problem. Ships entering the Basin in ballast condition to load cargoes in its ports and terminals are among the most likely candidates for the dissemination of alien species. If we consider the general cargo trade, we find that about 20% of the required transport capacity for Mediterranean "exports" is not compensated by that for "imports", which means that many of the corresponding vessels have entered the area fully or partially ballasted with sea-water loaded west of Gibraltar or east of Suez.

4) For liquid and dry bulk cargoes, the two other major aggregated categories, "imports" exceed "exports". However, due to the unit size and technical specific requirements of their respective cargoes, quite an important number of oil, chemical and gas tankers loaded in Mediterranean terminals with shipments intended for the rest of the world may previously have entered the basin with their ballast tanks fully loaded with exogenous water, and, therefore, are possible important vectors of alien species.

5) Under the aegis of EUROSTAT and of its regional "offspring" MEDSTAT, a research effort is currently considered to provide and assemble detailed origin and destination matrix of the Mediterranean sea-borne trade on the base of national ports statistics. This effort should be undertaken with the requirements of scientists and officials in charge of monitoring, controlling and fighting the various shipping-related and port activities-generated marine pollution sources in mind. The importance of having suitable statistical data on ships movements and shipped cargo trade was particularly stressed by the author in the Maritime Transport survey prepared for the "Transboundary Diagnostic Analysis" of the Mediterranean marine pollution sources, edited by the UNEP/MAP coordinating Unit (1997). Therefore, it is hoped that the scientific community will be, in a not too distant future, in a position to dispose for the Mediterranean region of more recent sea-borne trade origin/destination matrices than the ones just presented. A similar effort should be undertaken for the Black, Marmara and Azov seas by the concerned coastal countries.

Shipping movements towards the Mediterranean/Black seas area

In fact, precise data about global shipping movements are already available, but outside of the public domain, being gathered and assembled by a private company from which they can be extracted for a fee, often costly. Most of the users of these data banks belong to the commercial sector: shipping companies, shippers and maritime consultants; they generally require specific data about a ship type and/or a given area for marketing studies. Conversely, the marine scientific community don't seem to have much utilised this source of information.

In preparation of this Workshop, the author approached a colleague, member of the International Maritime Statistics Forum, who is a manager at Lloyd's Maritime Intelligence Unit (LMIU), a London maritime consultancy firm, part of the INFORMA Group which is the publisher of the shipping daily Lloyd's List. The request, that was very kindly granted, was to obtain an extract of their global ship movements data bank in order to sort out the 2001 sailings towards the Mediterranean and Black seas from the rest of the world, and analyse these movements by areas of origin and types of vessel.

The resulting spreadsheet is too cumbersome to be presented here, as it comprises 22 origin areas in columns and 83 Vessel Types in lines. Therefore Table 2 was aggregated to present only nine larger areas and 15 types of ship. The larger origin geographical areas presented are as follows:
- in Table 2-a, one finds west of Gibraltar:
    - North-East Atlantic, combining *Iberian Atlantic, North Africa, North Continental Europe* and *UK/Eire*;
    - North West Atlantic, combining *Canada Great Lakes* and *US Atlantic*;
    - Centre East Atlantic (*West Africa*);
    - Centre West Atlantic, combining *USA Gulf, Caribbean* and *Central America*;
    - South West Atlantic (*South America Atlantic*);
    - South Pacific, combining *South America Pacific* and *Australasia*;
    - North East Pacific (*North America Pacific*).

- in Table 2-b, one finds east of Suez:
    - Red Sea and Indian Ocean, combining *Red Sea, Arabian Gulf, Indian subcontinent and South* and *East Africa*;
    - North West Pacific and China Sea, combining *Far East Asean, Far East China Sea* and *Japan*.

The original LMIU areas that have been aggregated or re-named are printed in italics. There is a peculiarity about *North Africa*: according the LMIU geographical distribution of origins and destinations, ships movements originating from this area towards Mediterranean and Black seas ports include not only those from Moroccan Atlantic ports entering through the Strait of Gibraltar but also from the Egyptian Red Sea ports passing by the Suez Canal. Of course the marine biological particulars of these two zones are very different and it would be advisable if an in-deep study of bio-invasion corridors is undertaken in the future to sort out the corresponding ship movements originating from these two opposite directions.

Other geographical ambiguities arise from the spherical shape of the Earth: ships sailing from the west part of the South Pacific area (i.e. east of Australasia) usually reach the Mediterranean and Black seas by the Suez Canal rather than through the Panama Canal, and then the strait of Gibraltar. The large container vessels employed in "Round of the World" services and calling in Mediterranean ports may came from the US west coast either by Panama or by Suez. However very few of them, if any, do not call at intermediate ports when sailing along the east-west route. Therefore, they are not listed as coming from the North-East Pacific.

For the geographical areas aggregation process required to prepare Table 2, I have tentatively combined waters not too much different in their oceanographic particulars. But, as I am not a marine biologist, I am well aware that these various combinations are open to criticism. For instance, to have placed China Sea and North West Pacific in the same group may seem surprising; but, in fact, there are only 123 ship movements registered from Japan, less than 5% of the

total of this wide area. In order to retain the wealth of detailed information provided by LMIU as regards the 22 areas of origin of the vessels calling at the Mediterranean/Black seas ports, Chart 1 provides the whole geographical distribution of sailings in percentage and Chart 2 presents, for each area, a ship type distribution by tanker, bulkcarrier, other cargo carrying vessels (bulk cargo ships and general cargo ships) and other ships.

As regards ship types, Table 2 allows a more detailed analysis: most of the listed merchant vessels are singled out in the LMIU spreadsheet. However in our table Chemical Tanker also includes Chemical oil tanker; Bulkcarrier also includes Ore, Ore/oil, Bulk/oil and Bulk/container carriers; Container vessel also includes Container reefer; Multipurpose cargo vessel aggregates General Cargo and Part c.c. (Container carrier). The entry "Non specific tanker" means that the information gathered by LMIU does not allow to determine if the considered vessel is carrying crude oil or refined petroleum products.

Table 2-a. Shipping movements towards Mediterranean/Black seas area from the rest of the world - from West of Gibraltar.

Areas of origin	N-E Atl.	N-W Atl.	Ct-E Atl.	Ct-W Atl.	S-W Atl.	South Pac.	N-E Pac.	Total West of Gibraltar
Types of ship								
Crude oil tanker	442	62	168	231	52	2	3	960
Non specific tanker	36	4	5	2	2	0	2	51
Oil product tanker	695	112	105	57	39	2	0	1010
Gas (Lng-Lpg) tanker	999	17	39	155	19	1	0	1230
Chemical tanker	1730	89	55	92	40	13	1	2020
Edible liquid tanker	30	0	2	0	0	0	0	32
Bulkcarrier	2122	427	220	762	734	273	14	4552
Sub-total bulk cargo ships	*6054*	*711*	*594*	*1299*	*886*	*291*	*20*	*9855*
Container vessel	3008	553	270	161	203	1	0	4196
Ro/ro cargo vessel	774	58	88	8	19	0	0	947
Multipurpose cargo vessel	6392	126	151	121	99	12	4	6905
Refrigerated vessel	709	10	124	224	69	4	2	1142
Heavy-lift semi-sub vessel	15	15	2	12	0	0	0	44
Barge carrier	21	2	1	12	0	1	0	37
Vehicule carrier	572	31	10	0	6	1	0	620
Sb-total general cargo ships	*11491*	*795*	*646*	*538*	*396*	*19*	*6*	*13891*
Passenger vessels	221	0	2	0	14	0	0	237
Total transport vessels	***17766***	***1506***	***1242***	***1937***	***1296***	***310***	***26***	***23983***
Other ships	3002	17	16	68	48	3	1	3155
Grand total	**20768**	**1523**	**1258**	**1905**	**1344**	**313**	**27**	**27138**

Table 2-b. Shipping movements towards Mediterranean/Black seas area from East of Suez and totalisation of movements outside the area.

| Areas of origin	Red Sea Indian Ocean	NW Pacific China Sea	Total East of Suez	Total West of Gibraltar	All origin movements Numbers	% per types
Types of ship						
Crude oil tanker	193	14	207	960	1167	3,54
non specific tanker	42	8	50	51	101	0,31
Oil product tanker	187	74	261	1010	1271	3,85
Gas (Lng-Lpg) tanker	173	43	216	1230	1446	4,38
Chemical tanker	147	74	221	2020	2241	6,79
Edible liquid tanker	1	0	1	32	33	0,1
Bulkcarrier	632	622	1254	4552	5806	17,56
Sub-total bulk cargo ships	*1375*	*835*	*2210*	*9855*	*12065*	*36,55*
Container vessel	1012	1225	2237	4196	6433	19,49
Ro/ro cargo vessel	112	16	128	947	1075	3,26
Multipurpose cargo vessel	542	146	688	6905	7593	23
Refrigerated vessel	96	20	116	1142	1258	3,81
Heavy-lift semi-sub vessel	6	4	10	44	54	0,16
Barge carrier	2	12	14	37	51	0,15
Vehicule carrier	97	299	396	620	1016	3,08
Sub-total general cargo ships	*1867*	*1722*	*3193*	*13891*	*17184*	*52,06*
Passenger vessels	35	3	38	237	275	0,83
Total transport vessels	***3180***	***2261***	***5441***	***23983***	***29524***	***89,44***
Other ships	293	136	429	3155	3584	10,56
Grand total	**3473**	**2397**	**5870**	**27138**	**33008**	**100**

Source : LMIU processed by ECOMAR

Chart 1. Total ship movements towards Mediterranean/Black seas region distributed in % by main origin area.
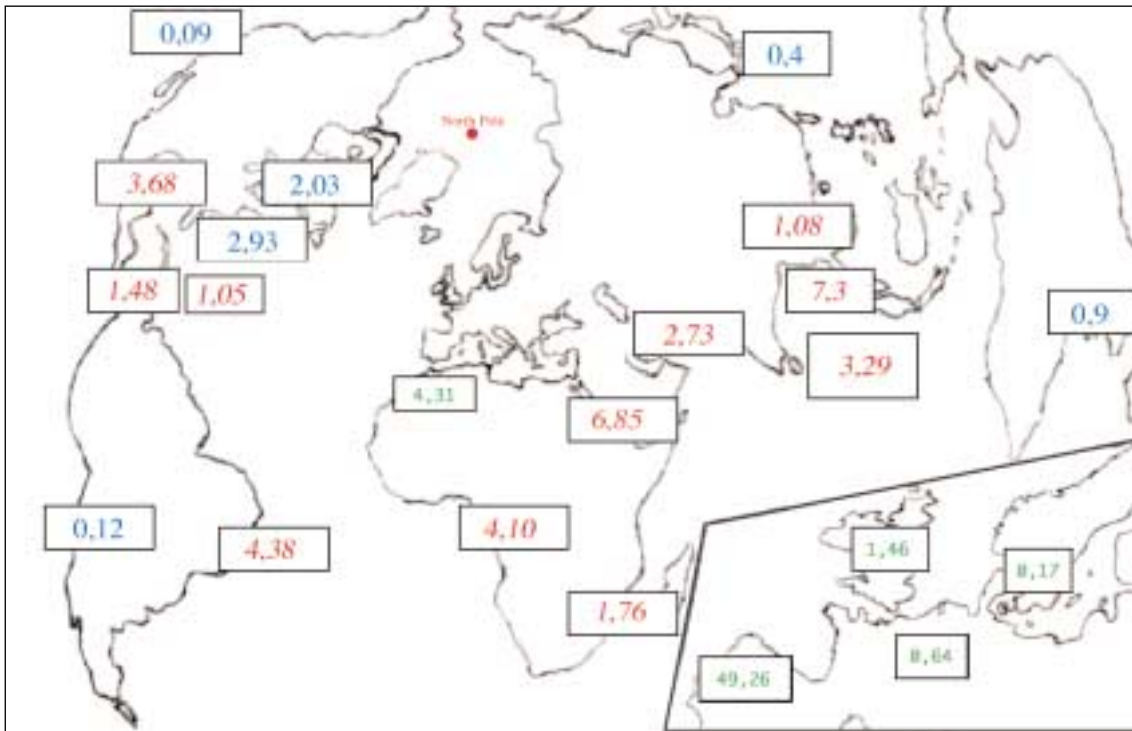
Ships have their last port of call in :
- N-O European and North African waters for 55,84%
- distant temperate waters for 6,47%
- sub-tropical and tropical waters for 37,69%

Chart 2. Numbers of ship movements towards Mediterranean and Black seas area by region of origin in 2001 registered by Lloyd's Maritime Intelligence Unit (LMIU).
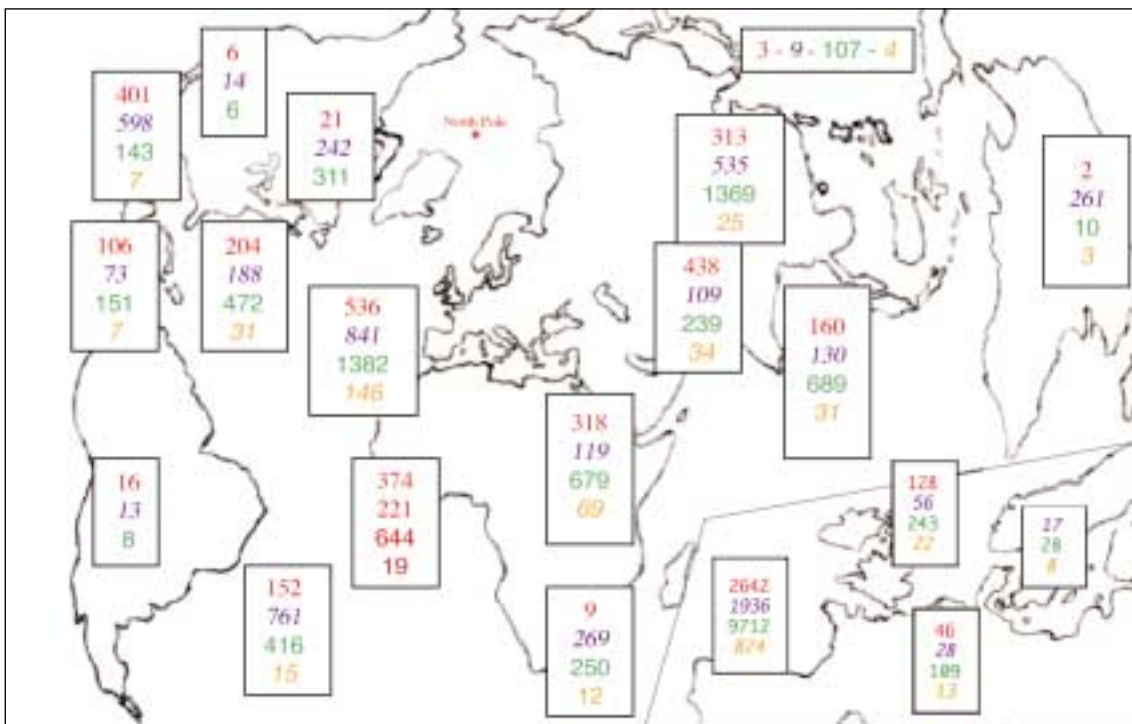
Ship types colour code : tankers; bulkcarriers; other cargo carrying vessels; other ships

Altogether, ships of the above mentioned types and some other form in the table a sub-group called "Transport vessels", comprising all cargo and/or passengers (including car ferries) carrying ships. The "Other ships" sub-group gathers all the types of fishing, service and harbour craft. It should be emphasised that Oil drilling platforms (floating or semi-submersible) are not considered as ships and that their movements towards the Mediterranean/Black seas area from other regions have not been taken into consideration. The same is obviously true for Warships.

What can we learn from Table 2 and from Charts 1 and 2 concerning the origin of the current shipping patterns linking the outside marine world with the Mediterranean/Black seas area ?

1) The concerned ship movements are numerous as they exceed 30,000 for the last year. Of course, in most of the cases the same ship is counted twice or several times, but for our purpose it is the number of actual voyages and not of individual vessels concerned which has to be considered.

2) The sailings of sea/river units towards Black Sea from the Baltic by the Russian inland waterways have not been recorded. The same is true for sailings from the North Sea via the Rhine-Danube Canal. In any case, the Danube was still obstructed in 2001 by the remains of the Novisar bridges destroyed during the Bosnian war.

3) Nearly 80% of these movements came from the West of the Strait of Gibraltar and among them about three-quarter originated in the North-East Atlantic area where the waters already mix naturally with the western Mediterranean ones.

4) More distant sources in western areas are mostly found in tropical zones for 12.7% of movements, when for temperate zones (round North America) the percentage of origins is only 6.3%.

5) Concerning East of Suez origins, after deduction from the total movements of the 123 voyages started in Japan, we can conclude that about 98% of this total have been initiated in tropical waters.

6) When considering the overall picture of the year 2001, it must be emphasized that the voyages initiated in tropical waters represent about a third of the ship movements towards the Mediterranean/Black seas area. This has a particular significance for our subject matter when considering the present warming trend of Mediterranean surface waters.

7) Finally, I will remark that the multifarious movements of ships just transiting through the area from the Strait of Gibraltar to the Suez Canal or in the reverse way, without calling at any port of the region, could not be accounted for in extracting LMIU data due to the structure of their bank. Normally, as previously remarked, a ship in transit does not have to adjust operationally its ballast water volume; however, some accidental releases are likely to happen from time to time. If, in the future, some transiting vessels opt for the "continuous ballast water exchange in open-sea system" recommended in the IMO "Guidelines for ballast-water management", the possible effect of these small but repeated releases from each ship during the Mediterranean Sea crossing should be monitored and, eventually, prohibited, keeping in mind the semi-closed characteristic of this basin.

DISTRIBUTION OF SHIP MOVEMENTS TOWARDS MEDITERRANEAN/BLACK SEAS AREA BY PORT OF DEPARTURE AND ARRIVAL

The ship movements data kindly supplied to the author by LMIU were nor detailed by ports of departure and arrival but only by geographical areas of origin, being understood that they all had the Mediterranean or Black seas for destination. In fact what was taken into consideration was the last port of call outside the area of destination. Therefore no information is available on the port of origin of the voyage, which is often located in another geographical area than the last port of call.

This lack of detailed information concerning the successive ports called at by a vessel during a given voyage is particularly regrettable for ships plying along regular routes which nowadays are principally container and Ro-ro vessels, according to the schedule of cargo lines and consortia. In fact LMIU will provide such information about the ship movements into a given area for any reference period but for a cost which may reach thousands of sterling £ depending on the size of the extraction requested. It is possible, however, to find detailed information about port of departure and/or arrival on the Internet site <http://www.shipguide.com/cgi/esc>, the data bank

of which registers the name and operator of the ships engaged into regular services having called, or intending to call, at a given port of the world during a short period of a few weeks or a month. This site offers the great advantage to be access free. Table 3 has been prepared on the basis of data gathered from this bank for arrivals in the main Mediterranean and Black seas ports during the period September-October 2002.

Table 3. Mediterranean directed cargo liner services analysis by port of origin and destination in September/October 2002, according call data collected on Internet.

Some caution must be expressed concerning the figures presented in Table 3. The more important concerns the frequent occurrence of multi-porting : the same ship calls successively during the same voyage in several Mediterranean ports, and each call is accounted for. This results in inflating the number of calls in the destination area as compared with the number of voyages towards it. Reciprocally, outside this area, such a ship is counted not only at ports of departure but also at the intermediate ports of call.

Nevertheless, such a bias has a technical justification : the sea-water loaded at the port of departure in the ballast tanks of a given cargo liner will not generally be completely discharged at the first port of call. Partial discharges occur in successive ports of call when adjusting ballast to the balance between unloaded/ loaded cargo weight . The best example of regional multi-porting is provided by the service of Troy Shipping Line between New York and the Mediterranean/Black seas area: following a last outside call at Tangiers, the vessels operated by this company visit successively a great number of the ports of the destination area.

Also, it should be emphasised that the type of commercial information gathered from this source cannot be considered as a valid statistical analysis of official port data. The various port listings have to be considered carefully to eliminate double or multi-counting of calls. Due to slot sharing arrangement between container shipping companies, two or more different voyages for different shipping companies or consortia are mentioned when only a single vessel is actually calling. In several occurrences, it has also been found that the same ship is mentioned twice because her scheduled arrival day was modified and a new entry was introduced without suppressing the first one. A serious loophole was found as no voyages were reported during the September/October 2002 reference period for both Venice and Trieste. Consequently the figures presented in Table 3 for these two ports are those displayed on the site for the following November/December two-months period. It was considered that the regular pattern of the cargo liner vessel calls authorizes such a reference period substitution, in order to get an overall regional picture.

Fig. 1. The container ship *Alva Star* grounded at the bottom of a clift of the Greek island of Zakinthos.

Discrepancies have also been found between data of origin considered in an arrival port with corresponding data of destination listed in a departure one. Therefore, despite the fact that the free access to and immediate availability of such information present great advantages, their reliability is somewhat questionable.

As an example, I shall mention the *Alva Star* case: this container ship of the Norasia shipping company engaged in a US West Coast/Far-east/Mediterranean Service is given by the Shipguide data bank consulted on 17/10/02 as having called at Alexandria on the 14 October at the end of her "Mediterranean tour" when in fact this tour was abruptly and unhappily terminated on October 3 when she ran into a 100 m high cliff of the Greek island of Zakinthos (see Fig. 1). Obviously, a lot of further and time-consuming checking processing would be required if such type of commercial information is used for a scientific study of regional ship movements.

Despite these drawbacks in the accuracy of its data base, Table 3 supplies an useful overall view of the current cargo liner shipping pattern along the world maritime routes leading to the Mediterranean Basin, enabling to present the following comments:

1) Among the 38 ports concerned, only nine have registered 30 or more arrivals during the two months observation period:

- five in the North-West Mediterranean Basin:
Barcelona, Marseilles/Fos, Genoa, Naples and Gioia Tauro;
- four in the South-East part of the same basin (when including Adriatic Sea):
Trieste/Montfalcone, Beirut, Damietta and Alexandria.

As shown on Chart 3, the major Italian ports are playing a capital part among the area destinations. No major destination points can be found in the Black Sea region, although the Turkish ports group of Gebze/Gemlik stands just below the defined limit.

2) Only three other ports, Algesiras, Venice and Constanza, have registered more than 10 and less than 30 arrivals during the observation periods. It can be seen on Chart 3 that the

Chart 3. Major Mediterranean ports of call for cargo liner vessels showing voyages distributed by main climatic zones of origin.
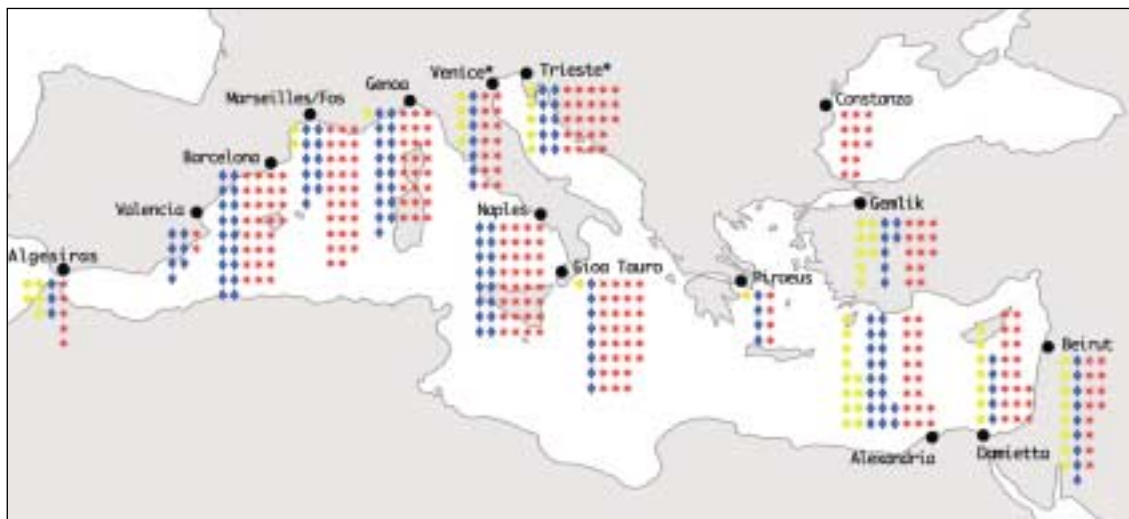
Each point corresponds to a call scheduled during the autumn 2002 observation period of vessels arriving from:
1) NE Europeans waters : yellow
2) Other temperate climate waters : blue
3) Tropical waters : red

* The data were missing for Venice and Trieste when this chart was initially established according to information collected in mid-October on the Internet site ShipGuide.com for the September/October 2002 period. The data inserted later for these two ports correspond to the November/December 2002 period for which the information became available in November.

cargo liner trade is economically concentrated in a few places but geographically spread over the Mediterranean Basin and the adjacent Marmara Sea. Black Sea ports are not much directly served by intercontinental services as their container trade is mainly serviced by feeder vessels after trans-shipments in a Mediterranean terminal.

3) The ports of departure of the service calling at Mediterranean ports are widely spread over the planet. They number 48 but some grouping has allowed to limit to 37 the number of corresponding columns.

4) By far the more important origin of the considered services is the Malay Peninsula with more than 100 departures, about equally divided between Port Keelang and the group formed by the port of Singapore and its nearby and recent rival in Malaysia, Tanjung Pelapas. However, many container ships have called at Port Keelang after having departed from Singapore. Indian Ocean (specially Columbo) and Red Sea ports are also important intermediate call for the lines serving the Mediterranean region. Brazil also plays a non negligible part among tropical origins.

5) Regarding the departure ports located in temperate Atlantic waters, it is worth to underline that those located on the East coast of the USA are a far more important origin for Mediterranean services than the North-West European major "container traffic hubs" such as Bremerhaven, Rotterdam and Felixstove.

6) It is recalled that many of the larger post-panamax* container cargo vessels employed on scheduled lines linking major N-W European and some US West coast ports to ASEAN and Far East ports are crossing the Mediterranean between Gibraltar and the Suez Canal without calling at any port of the Basin. Therefore they have not been taken into consideration for the present analysis although they may be vectors of aliens unwanted marine species, specially among the hull fouling ones.

7) Finally, the liner cargo vessels visiting Mediterranean harbours and having their departure ports on the USA West Pacific coast generally belong to one of the "Round the World services". All have called at one or more intermediate ports located in Asia before reaching the Mediterranean Sea by the Suez Canal. Thus the proportion of temperate climate ballast water loaded before their initial sailing is largely diluted in tropical waters pumped in the China Sea, Indian Ocean and Red Sea along their route so as to adjust the ballast volume to the changes in the cargo weight intermediate. Also the chance to find surviving would-be invaders from the North-West Pacific area in ballast water discharged in a Mediterranean harbour is for most species greatly reduced by the great length of the trip.

CONCLUSION

The overview just presented of the shipping relationships between the Mediterranean/Black seas area and the rest of the world provides only a very preliminary approach to the possible location of the "source" and "sink" areas of ship-transported alien species likely to provoke unwanted or dangerous bio-invasions in the region. Naturally, this area can be as well the source of similarly damaging events in many other parts of the "Seven Seas".

Apart from the geographical aspect of the routes followed and calls effected, technical factors, linked to the type and size of the concerned vessels as well as their operational constraints, must also be considered. At the global level for ballast water, these factors are dealt with within the terms of reference of IMO "Globallast" program. To apply them to the shipping patterns of a given region would require a very detailed cross-analysis of the shipping movements, ships' particulars and shipped cargoes which is not yet possible in the current unsatisfactory context of the maritime statistics.

This is precisely why the author has recommended the building-up of a Mediterranean Maritime Statistics Observatory to agencies such as UNEP/MAP and MEDSTAT.

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*" *post-panamax" refers to vessels too large to cross the Panama canal*

Black Sea - Baltic Sea invasion corridors

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INTRODUCTION

The Black and Baltic seas are geologically-young, brackish seas, that have undergone drastic changes since the end of the Ice Age in size and shape, hydrological and hydrochemical regimes, and connections with neighbouring seas. Their ecosystems are still undergoing changes, due to maturation processes. Consequently, most animal and plant species living in the Baltic and Black seas are postglacial immigrants, many of them living close to their salinity tolerance limits (Leppäkoski and Olenin, 2001; Gomoiu *et al.*, 2002). The process of natural enrichment of their biota with invading species (spontaneously or by means of passive dispersal) from the adjacent, more saline seas still continues.

From a biogeographical point of view, both basins represent isolated "ecological islands", separated from other brackish water bodies by physical and ecological barriers, such as land masses and fully marine waters (Leppäkoski and Olenin, 2000a). These barriers has been breached two hundred years ago, with the construction of the first invasion corridor.

An invasion corridor is defined here as a regular human-mediated connection between isolated biogeographical regions, that cuts through natural environmental barriers and enables transfer of alien species. An invasion corridor may be established in different ways e.g., as high volume overseas shipping, transporting species in ballast tanks or on ship hulls; frequent air or surface transportation of species for stocking, seeds, or as an inland waterway.

This paper is a brief overview of the history and functioning of the inland aquatic invasion corridors between the Baltic and the Black seas, and including the Caspian and the White seas as parts of the Eastern European system of invasion corridors.

The Eastern European system of invasion corridors

Though archeological finds substantiate extensive trade and travel between the Baltic and Black Seas through Eastern Europe since early times, no organisms have been transported as far as we know. Aquatic invasion corridors have been established since the end of the 18th century, when the construction of the waterway system connecting the Baltic Sea and the Ponto-Caspian region (including the Black, Azov and Caspian seas) began (Table 1, Fig. 1). At present, Europe is covered by the ramified net of the waterways linking its western, central and eastern parts and coastal seas into an intercontinental aquatic transportation system. This aquatic web provides the invasion corridors for hundreds of alien species, spreading from previously isolated biogeographical regions either by natural means or assisted by ship traffic or by other human mediated vectors (Jazdzewski and Konopacka, 2002; Minchin and Gollasch, 2002a; Slynko *et al.*, 2002).

Table 1. The elements of the Baltic Sea-Ponto-Caspian invasion corridor system.

Year of opening	Canal (Remote connection)	References
1768	Oginskij Canal: Nemunas - Pripet (Baltic Sea - Black Sea)	Kolupaila, 1953
1775	Bug - Pripet (Baltic Sea - Black Sea)	Jazdzewski and Konopacka, 2002
1810	Mariinskij Waterway: Sheksna - Lake Beloye - Kovzha - Vytegra - Lake Onega - Svir - Lake Ladoga –- Neva (Caspian Sea - Volga - Baltic Sea)	Multimedia Encyclopaedia of Cyril and Mefodij, 2000
1829	Severo-Dvinskiy Waterway: Sheksna - Lake Kubenskoje - Sukhona, Northern Dvina (Caspian Sea - Volga - White Sea)	Multimedia Encyclopaedia of Cyril and Mefodij, 2000
1952	Volga - Don Canal (Caspian Sea – Black Sea)	Multimedia Encyclopaedia of Cyril and Mefodij, 2000

CONNECTION OF THE SOUTH-EASTERN BALTIC COASTAL LAGOONS TO THE RIVER DNIEPR WATERSHED

The first canal linking rivers of the Baltic Sea and Black Sea watersheds, was the Oginskij Canal, named after the Voivode of Vilnius, who built the canal in 1765-1768. The canal is 54 km long, connecting the lake Vygonovskoje with Jaselda, a tributary of the river Pripet, itself a major tributary of the river Dnieper. The Shchara river, originating in lake Vygonovskoje, flows into the river Nemunas (Neman). The canal was built for the rafting of timber from the Belarusian Polesjye to the Baltic Sea ports, Klaipeda (formerly Memel) through the Curonian Lagoon, and Gdansk (Danzig) through East Prussian rivers (Deima, Pregel), small canals and the Vistula lagoon. The Oginskij canal was destroyed during the two World Wars (in 1916 and 1944), then reconstructed (Kolupaila, 1953).

The next invasion corridor appeared within less than one decade with the construction of the canal between the Pripet and the Bug, a tributary of the Vistula (Wisla), connecting the port of Gdansk with the Belarusian Polesjye (Jazdzewski and Konopacka, 2002). Finally, the Vistula and the Nemunas were connected via small tributaries and lakes by the August waterway in 1830 (Kolupaila, 1953).

The introduction of the zebra mussel, *Dreissena polymorpha*, into the Vistula and Curonian coastal lagoons in early 1800s was most likely due to transportation of molluscs attached to the lumber rafts. The zebra mussel was next recorded in London (1824) and Amsterdam (1826), at that time the recipient ports for the Baltic timber trade (Olenin *et al.*, 1999). Only later did the species spread in the inland waters of western and central Europe.

Several other invertebrate species invaded the Baltic Sea coastal regions during the 19th century and early 1900s most likely through the above invasion corridors (Table 2). The hydrozoan *Cordylophora caspia* dwelling on hard substrates; the corophiid amphipod *Chelicorophium (Corophium) curvispinum* attaching its tubes to hard surfaces, including mussel shells; the snail *Litoglyphus naticoides* commonly inhabiting zebra mussel aggregates in the Curonian lagoon, might have used rafts and boats for their travel along canals and rivers (Olenin and Leppäkoski, 1999; Jazdzewski and Konopacka, 2002). In the mid 1990s, two Ponto-Caspian gobiid fishes, *Neogobius gymnotrachelus* and *N. fluviatilis* were found in the Vistula and some of its tributaries, near the Bug-Pripet canal, demonstrating active invasion through that corridor. A cogener, the round goby *Neogobius melanostomus*, was found in the Gulf of Gdansk in the Baltic Sea in 1990. It might have arrived via the Bug-Pripet canal, but also been transported in ballast waters either directly from the Black Sea (ship voyage around Europe) or through the Volga-Baltic Waterway (Jazdzewski and Konopacka, 2002, and references therein). This last is supported by findings of *N. melanostomus* in 1980s-1990s far beyond its historical range in the Caspian and Black seas, in the upper Volga and the Moskva River, a secondary tributary of the upper Volga (Slynko *et al.*, 2002, and references therein).

Fig. 1. Map showing the elements of the Baltic Sea-Ponto-Caspian invasion corridor system.

1 - Oginskij Canal
2 - Bug - Pripet canal
3 - Volga - Baltic Waterway (primarily - Mariinskij Waterway)
4 - Severo-Dvinskiy Waterway
5 - Volga - Don Canal.

Invasions through those corridors are unidirectional: no species from the Baltic Sea is known to have used those canals to enter the Black Sea. Also, neither the Oginskij, nor the Bug-Pripet canals were used for the direct Baltic Sea-Black Sea ship traffic. In these terms they could not be compared with the inner European Russian waterways.

THE CASPIAN SEA-VOLGA-BALTIC INVASION CORRIDOR

The construction of waterways that ultimately would connect the Volga River and the Baltic, White, Caspian, Azov and Black seas began in the time of Peter the Great. Between 1703 and 1718 connections were established between tributaries of the Volga River and rivers falling into Ilmen and Ladoga Lakes and further to the Baltic Sea. However, a navigable link between the Volga River and Baltic and White seas was constructed only at the beginning of the 19th century. This waterway was expanded and improved in 1930-1940s, and was reconstructed and reopened as the Volga-Baltic Waterway (about 1,100 km in length) in 1964. Presently, the cargo turnover through the Caspian-Volga-Baltic route is more than 300 million tons per year (Slynko *et al.*, 2002). This route became also the major invasion corridor along Europe's largest longitudinal river, the Volga River. Unlike the two previous invasion corridors, it is bi-directional, facilitating invasions in both "North-South" and "South-North" directions, and is far more important in species exchange.

Table 2. Ponto-Caspian species which most probably penetrated to the Baltic Sea coastal lagoons and their watershed through the Oginskij and Bug-Pripet canals[1]

Species	Time of introduction	
	Curonian Lagoon	Vistula Lagoon
Zebra mussel *Dreissena polymorpha*	1803	Early 1800s
Athecate hydrozoan *Cordylophora caspia*	Early 1800s	Early 1800s
Snail *Litoglyphus naticoides*	Early 1900s	1870s in Poland
Amphipod *Chelicorophium curvispinum*	1921, in the River Nemunas	Before 1920s in the Vistula River and the Lagoon
Amphipod *Chaetogammarus ischnus*	1960, in the lower Nemunas	1928 in middle and lower Vistula
Round goby *Neogobius melanostomus*	2002[2]	1990[3] in the Gulf of Gdansk, since late 1990s in the Lagoon
Goad goby *N. gymnotrachelus*	-	1995 in the River Bug
Monkey goby *N. fluviatilis*	-	1997 in the Muchawiec River, affluent of Bug

[1] based on: Leppäkoski and Olenin, 2000b; Arbaciauskas, 2002; Jazdzewski and Konopacka, 2002; and references therein;
[2] apparently due to secondary spread from the Polish waters (Yu. Maksimov and T. Zolubas, pers. comm.);
[3] other vectors/invasive corridors may be involved, see text

Recently, Slynko *et al.* (2002) wrote in their comprehensive review: *"The north-south transfer of species in the Volga River basin is not new, but the scale and nature of invasions changed along the Volga-Baltic corridor following transformation of the Volga River from a riverine environment to one of a series of cascading reservoirs. Southward penetration of northern species was facilitated by the formation of a cold-water hypolimnion in the Volga reservoirs. Following reservoir impoundment, 106 invasive species have been found in the Volga River basin, a process that occurred over two different time periods. The first period of invasions occurred between 1940 and 1970, and involved many northern species (77% of total species) moving downstream by passive dispersal. The second period of invasions is still on going and involves invasions by many Ponto-Caspian species (51% of total species) while new invasions by northern species have decreased substantially (7% of total species). The proportion of exotic species (i.e., invaders originating from basins not adjacent to the Volga basin) increased from 7% during the first period to 41% during the second period. Since the late 1970s, water temperatures in the Volga basin have continued to increase and it is postulated that many invasions during the second period are related to global climatic change".*

Analysis of the data presented in the above paper shows two dispersal patterns of alien species along the Ponto-Caspian-Volga-Baltic invasion corridor. The first one ("continuous") suggests gradual semi-natural dispersal of species due to removal of previous physico-chemical barriers and emergence of new suitable habitats, e.g. cold-water hypolimnion or, conversely, areas of thermal pollution from power plants. The second pattern ("discrete") involves ship traffic – ballast water or hulls of "ships of opportunity" – allowing some species to "jump" over the Upper Volga and the Volga-Baltic system of canals and pass directly into the eastern Gulf of Finland, the terminus of this invasion corridor. It is noteworthy that nearly all ship-transported species are of Ponto-Caspian origin. The exception is the Chinese mitten crab, *Eriocheir sinensis*, which was noted during the 1990s in the Volga River delta. In 2001 adult specimens were found for the first time in Cheboksary (Middle Volga) and Rybinsk (Upper Volga) reservoirs, suggesting crab invasions in Volga River reservoirs originating from both southern (River Don and Volga River delta) and northern locations (Gulf of Finland) (Slynko *et al.*, 2002).

The network of Baltic Sea-Black Sea invasion corridors was completed by the Volga-Don Canal, opened in 1952. More than 20 species have been known to pass from the Black Sea into the Caspian Sea, rapidly increasing in abundance and often dominating the coastal plankton and benthos of the Caspian Sea (see Gomoiu *et al.*, 2002 and Aladin *et al.*, 2002 for the most recent reviews). The opposite movement has been disproportionately small: only two Caspian species,

the alga *Ectocarpus caspicus* and crustacean *Shizopera neglecta*, have reached the Black Sea, where they have not flourished (Gomoiu *et al.*, 2002).

Another important intracontinental waterway rapidly becoming a major cross-European "latitudinal" invasion corridor which may facilitate species exchange between the Black Sea and the northwestern Europe, including the Baltic Sea, is the Main-Danube waterway, constructed in 1992 (van der Velde *et al.*, 2002; Nehring, 2002).

ENVIRONMENTAL MATCHING AND CHANGES ALONG THE WATERWAYS RESULT IN FACILITATION OF SPECIES EXCHANGE

The Baltic, Black and Caspian seas provide a broad range of habitats due to various combinations of salinity, temperature, substrate and depth along their environmental gradients (Table 3). These habitat continuums largely coincide, especially in coastal lagoons and river mouths, facilitating the transfer of alien species from one end to another.

Table 3. Physico-geographical characteristics of the Baltic, Black and Caspian seas[*1].

	Baltic Sea	Black Sea[*2]	Caspian Sea
Connection with adjacent seas	Danish Straits	Bosporus Strait	Rivers and canals
Latitude, °N	54 - 66	41 - 46	36 - 47
Major axis length, km	1,300	1,150	1,200
Surface area, 10^3 km^2	412	423	378
Catchment area, 10^3 km^2	1,730	1,860	3,700
Maximum depth, m	459	2,212	1,025
Salinity in central parts (surface), PSU	6-7	17-18	12-13
Temperature in central parts (surface, summer), °C	14-16	22-26	22-28

[*1] *modified from Leppäkoski and Olenin 2000b;* [*2] *excluding the Sea of Azov.*

Another instrumental factor in the spread of the invasive species is the environmental change within the river systems themselves. In the Volga environmental changes include the formation of large lacustrine water bodies along the river channel (water reservoirs) and deceleration of river flow, pronounced thermal stratification of water masses and existence of a cold water hypolimnion, construction of locks and removal of rapids in the Samara Arch, Middle Volga (Slynko *et al.*, 2002).

K. Jadzewski (pers. comm.) suggested that one of the possible reasons behind the recent massive invasion of Ponto-Caspian species in northern, central and western Europe, is the increasing ionic content of large European rivers in recent decades, caused by industrial and agricultural pollution. This rise in the "salinity" of the Dnieper, Vistula, Oder or Danube could reach a "critical point" that permits invasion by oligohaline species (Jazdzewski and Konopacka, 2002). The same factor ("increased mineralisation of water") is mentioned as a possible reason, facilitating the spread of Ponto-Caspian species along the Volga-Baltic invasive corridor (Slynko *et al.*, 2002).

CONCLUDING REMARKS

The role of intracontinental and intercontinental invasion corridors will grow larger in the future, as the inland waterways are increasingly used for international ship traffic. In 2000, a treaty for the construction of the Transport Corridor "North-South" between India, Iran and Russia was undersigned. This corridor is intended to follow the line: European Union - St. Petersburg - Astrakhan - Caspian Sea - Iran - Persian Gulf - India (Tkachenko and Brodin, 2002). Implementation of this project will increase the intensity of shipping and cargo turnover by an order of magnitude. Consequently, the risk of new species introductions will increase if no appropriate measures are taken.

Ship-transported virio- and bacterio- plankton

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The economic and ecological threats posed by non-indigenous invertebrate species transported by ships' ballast water are much better understood and documented than the corresponding epidemiological threats posed by the potential introduction of microorganisms pathogenic to humans, plants, and animals. Research on ballast-water introductions has focused largely on metazoans, with studies of microorganisms limited mostly to those on *Vibrio cholerae* (e.g., McCarthy *et al.*, 1992; Ruiz *et al.*, 2000), dinoflagellates (e.g., Hallegraeff and Bolch, 1991, 1992) and other protists (e.g., Galil and Hülsmann, 1997; Pierce *et al.*, 1997), yet microorganisms are indisputably the most abundant of aquatic organisms. For example, naturally occurring bacteria and viruses in seawater are found in densities on the order of $10^6 - 10^{11}$ l^{-1} (Ducklow and Shiah, 1993; Wommack and Colwell, 2000). Furthermore, the phylogenetic range of microbial taxa detected in ballast-water samples is great (Table 1). Given such high densities and that many microorganisms have high reproductive rates, broad tolerances to physical conditions, and the capability to form resting stages, microorganisms likely are frequent invaders of coastal ecosystems.

Samples of ballast water were collected from vessels arriving to Chesapeake Bay (USA) to determine end-point abundances of microorganisms in ballast water and so gain an understanding of temporal patterns of microorganism delivery. Results from this sampling demonstrate that a variety of microbial groups (bacteria, viruses, and phytoplankton) are indeed abundant in ballast water delivered to Chesapeake Bay (Table 2). The ballast water of the ships sampled was not enriched with bacteria and viruses, was no higher in bacterial productivity, and was impoverished in chlorophyll *a* concentration relative to the Chesapeake Bay water into which it was discharged. Nonetheless, extrapolating from these densities, the number of foreign microorganisms delivered annually to Chesapeake Bay, and by extension, other ports, via ballast-water discharge is enormous.

Work to date has focused principally on quantifying the abundance of major groups of microorganisms in whole-water samples from ballast tanks and holds. However, information on specific microorganisms, particularly human pathogens, has been also collected. Many pathogens have a worldwide distribution in which ballast water could serve as an important vector, as already demonstrated in some instance. *Vibrio cholerae*, the bacterial agent of human cholera (McCarthy *et al.*, 1992; McCarthy and Khambaty, 1994; Ruiz *et al.*, 2000), *Pfiesteria* spp., dinoflagellates implicated in fish kills, *Cryptosporidium* sp., the protozoan cause of human intestinal, tracheal, and pulmonary cryptosporidiosis and *Alexandrium catenella*, a toxic dinoflagellate (Hallegraeff and Bolch, 1991).

A modest sampling program of ships arriving to Chesapeake Bay showed no temporal or spatial pattern in pathogen presence. Ten to twelve ships arriving from foreign ports were tested for the presence of *Pfiesteria piscicida* and *P. shumwayae,* culturable enteric bacteria (*Escherichia coli, Aeromonas* spp., and *Providencia rettgeri*), and enterovirus (the group that includes polioviruses, coxsackieviruses, and echoviruses) (Table 3). Of the ships that contained pathogens, no pattern emerged to link pathogen presence with the last port of call or time of year. When sam-

Table 1. Reports of microorganisms in ships' ballast waters. (Drake *et al.,* 2001).

Group	References
VIRUSES[1]	Ruiz *et al.* (2000); Drake *et al.* (2001)
BACTERIA	Galil and Hülsmann (1997); Ruiz *et al.* (2000); Drake *et al.* (2001)
• Cyanobacteria	Gollasch *et al.* (1998); Smith *et al.* (1999); Gollasch *et al.* (2000); McCarthy and Crowder (2000)
• Purple Bacteria	
Gamma Group	
Vibrio cholerae	McCarthy *et al.* (1992); McCarthy and Khambaty (1994); Ruiz *et al.* (2000)
EUKARYA (protists only)[2,3]	
• Protozoa	
Ciliophora	Carlton (1985); Carlton and Geller (1993); Kelly (1993); Subba Rao *et al.* (1994); Yoshida *et al.* (1996); Chu *et al.* (1997); Galil and Hülsmann (1997); Pierce *et al.* (1997); Macdonald (1998); Smith *et al.* (1999); Lavoie *et al.* (1999); Rigby *et al.* (1999)
Dinozoa	Hallegraeff and Bolch (1991, 1992); Carlton and Geller (1993); Kelly (1993); Subba Rao *et al.* (1994); Gosselin *et al.* (1995); Yoshida *et al.* (1996); Chu *et al.* (1997); Galil and Hülsmann (1997); Gollasch *et al.* (1998); Macdonald (1998); Lavoie *et al.* (1999); Rigby *et al.* (1999); Smith *et al.* (1999); Zhang and Dickman (1999); Gollasch *et al.* (2000); Hamer *et al.* (2000); McCarthy and Crowder (2000)
Euglenozoa	Kelly (1993); Subba Rao *et al.* (1994); Galil and Hülsmann (1997)
Foraminifera	Carlton and Geller (1993); Chu *et al.* (1997); Galil and Hülsmann (1997); Gollasch *et al.* (1998); Macdonald (1998); Lavoie *et al.* (1999); Smith *et al.* (1999); McGann *et al.* (2000)
Heliozoa	Galil and Hülsmann (1997)
Radiozoa	Carlton and Geller (1993); Chu *et al.* (1997); Smith *et al.* (1999)
Rhizopoda	Galil and Hülsmann (1997)
• Chromista	
Bicosoecae	Galil and Hülsmann (1997)
Chrysophyta	Chu *et al.* (1997); Gollasch *et al.* (2000)
Cryptomonada	Galil and Hülsmann (1997)
Diatomae	Hallegraeff and Bolch (1992); Carlton and Geller (1993); Kelly (1993); Subba Rao *et al.* (1994); Yoshida *et al.* (1996); Gollasch *et al.* (1998); Macdonald (1998); Lavoie *et al.* (1999); Rigby *et al.* (1999); Smith *et al.* (1999); Zhang and Dickman (1999); Gollasch *et al.* (2000); McCarthy and Crowder (2000)
Haptomonada	Galil and Hülsmann (1997)
Labyrinthomorpha	Galil and Hülsmann (1997)
Raphidophyta	Yoshida *et al.* (1996)
PLANTAE	
Chlorophyta	Carlton and Geller (1993); Gollasch *et al.* (1998); Macdonald (1998); McCarthy and Crowder (2000)
Prasinophyta	Kelly (1993)
Rhodophyta	Carlton and Geller (1993); Smith *et al.* (1999)
ANIMALIA	
Choanozoa	Galil and Hülsmann (1997)

[1] *category includes virus-like particles.*
[2] *following classification scheme of Corliss (1999).*
[3] *several genera listed by Galil and Hülsmann (1997) were not clearly assignable to the protistan phyla above.*

Table 2. Microbial metrics in ballast water of ships arriving to Chesapeake Bay.

Parameter	Range of values in ballast water 1 (mean)
Bacteria cell concentration	$0.06 - 13 \times 10^9$ L^{-1} $(0.8 \times 10^9$ L$^{-1})$
Virus-like particle concentration	$0.22 - 60 \times 10^9$ L^{-1} $(14 \times 10^9$ L$^{-1})$
Chlorophyll a concentration	$0.0009 - 2.6$ µg L^{-1} $(0.18$ µg L$^{-1})$

1n = 31-58 ships.

ples were collected from eight ships for all analyses, no single ship contained all three types of pathogen. This data set is arguably too small to drive management decisions and further sampling is necessary to support or reject the hypothesis that pathogen arrival is not a function of time of year, source water, or ballast-water history.

The only procedure now in widespread use to reduce the spread of non-indigenous species via ballast-water discharge is open-ocean ballast-water exchange. In this procedure, coastal water in the ballast-water tanks is removed and replaced with oceanic water. In theory, the survival of organisms in exchanged, oceanic water declines when the organisms are discharged into coastal waters, provided there exists a temperature or salinity mismatch between the oceanic and coastal waters.

Sample collection of ballast-water organisms has, with a few exceptions, occurred at the termination of voyages, with little research on the processes leading to end-point conditions. A transoceanic voyage aboard a bulk carrier sailing from Hadera (Israel) to Baltimore (USA) afforded the opportunity to evaluate changes in the microbial community during the crossing and to compare microbial metrics in exchanged and unexchanged ballast-water holds. At the end of sampling (Day 15), all microbial metrics measured – bacteria concentration, virus-like particle density, microbial biomass, and phytoplankton pigment concentration – had decreased 1.6-fold to 34-fold from initial values (Fig. 1).

Considering the decrease in the measured microbial constituents, one has to wonder what happened to the nutrients released by phytoplankton during cell death and lysis (Fig. 1D). It seems that nutrients were not taken up by bacteria and translated into cell growth and division, at least during the course of sampling (Fig. 1A). Several hypotheses were advanced to explain the decrease in microorganisms: uncoupling of the microbial loop, bacteria removal by microzooplankton grazing, and initial respiration of dissolved organic material by bacteria in the beginning of the voyage and a subsequent steady state of low microbial biomass throughout the

Table 3. Pathogen presence in ballast water of ships arriving to Chesapeake Bay[1].

Pathogen	Percentage of ships with pathogen detected (number of ships sampled, percentage of those ships that had exchanged ballast water)	Source of ballast water[2] and time of sampling for pathogen -containing ships
Pfiesteria piscicida and *P. shumwayae*	42% (12, 100%)	UK – EX January 2001 Belgium – EX February 2001 Netherlands – EX March 2001 Netherlands – EX March 2002 Spain – EX December 2000
Enteric bacteria	10% (10, 100%)	Lebanon – EX April 2001
Enterovirus	27% (11, 90%)	Netherlands – EX May 2000 Ireland September 2000 UK – EX June 2001

[1] Dobbs et al., 2003.
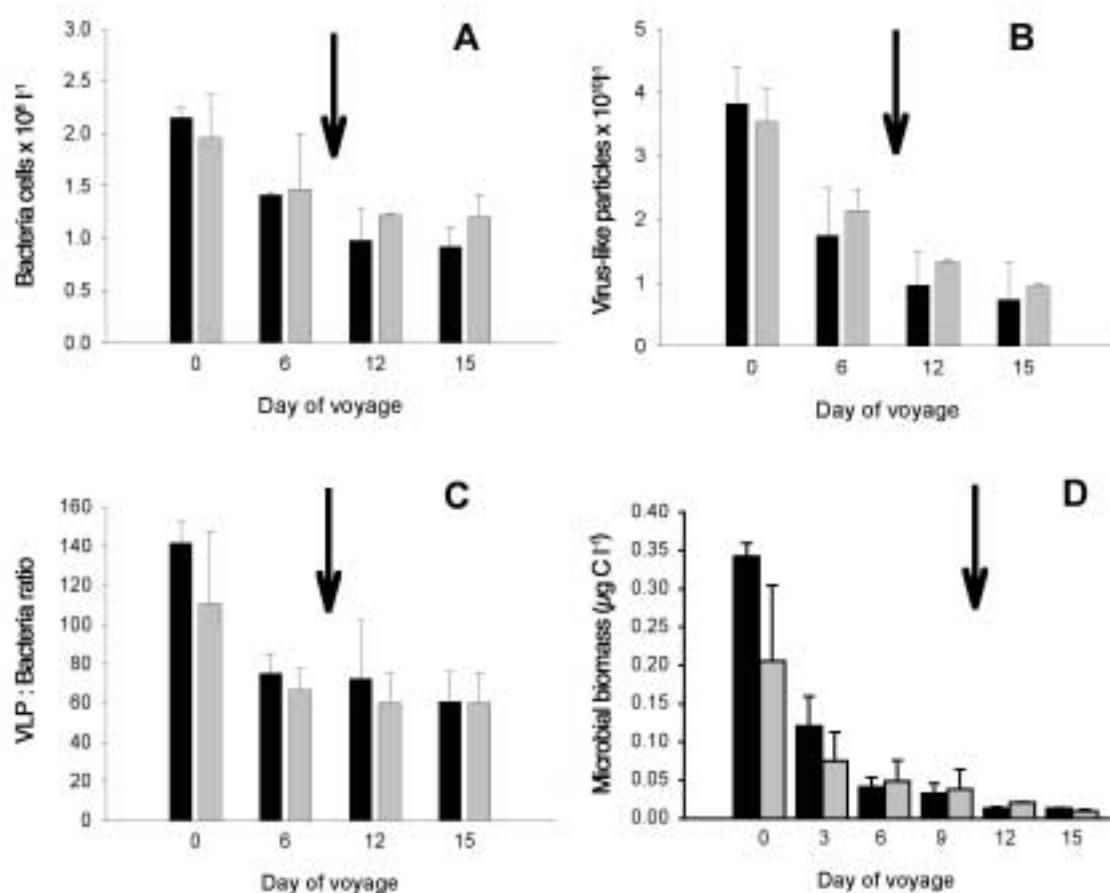*[2] EX = exchanged in the open ocean prior to sampling.*

Fig. 1. Microbial metrics in ballast water. Black bars represent samples from Control Holds; gray bars represent samples from Exchange Holds. (A) Bacteria abundance; (B) virus-like particle (VLP) abundance; (C) microbial biomass; (D) chlorophyll a concentration. In all plots, the arrow indicates Day 10, when Exchange Holds were exchanged in the open ocean. Data are mean values (n = 2, with 3-6 subsamples per replicate); error bars represent one standard deviation. (Drake *et al.*, 2002).

remainder of the voyage (Drake *et al.*, 2002). Another possibility exists: a portion of the phytoplankton was capable of mixotrophy and took up the released nutrients. To fully understand microbial processes during sequestration in ballast-water tanks, future studies should include sampling to determine nutrient concentrations and to estimate protozoan grazing rates and the prevalence of mixotrophy among phytoplankton.

The efficacy of exchanging ballast water in the open ocean to decrease abundances and biomass of microorganisms was evaluated by comparing values in Control and Exchange samples collected on Day 15, the final day of sampling (Fig. 1). For all microbial metrics tested, no significant difference was detected between treatment means. It must be noted, however, that the efficacy of open-ocean exchange in reducing invasion by non-indigenous microorganisms cannot be evaluated solely on microbial abundances and biomass. Future studies should incorporate other analyses to further determine changes in the microbial community, such as microbial diversity.

Data gathered from sampling ballast water at the end points of voyages and during a trans-oceanic voyage suggest that microbial abundances in ballast water decrease over time. Nonetheless, given the great abundances of microorganisms in coastal waters, the number of microorganisms transported globally is staggering. It follows that one must consider the risk presented by ballast-water discharge of microorganisms. The likelihood of microorganisms surviving in a new location fol-

lowing their discharge, a function of their species composition and environmental conditions, is critical to evaluating the risk of microbial invasion. At present, these elements are poorly investigated. Other research areas in the field of ballast microbiology include the potential for lateral gene transfer among microorganisms, the role of tank biofilms in microbial sequestration and release, and the potential transport of antibiotic-resistant bacteria in ballast water and sediment residuals. The ultimate aim of these and other research efforts is to address two essential issues: (1) the survival of non-indigenous microorganisms, including potential pathogens, in receiving waters, and (2) changes that surviving microorganisms may effect in new environments.

Phytoplankton introductions in European coastal waters: why are so few invasions reported?

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INTRODUCTION

Any phytoplankton species successfully introduced into a new area by ballast water has already passed several tests. It has either entered a ship's ballast tanks from the plankton or as a resistant cyst from suspended sediments in its native region, and survived the duration of the voyage in darkness, and subsequent discharge into a new region (Hallegraeff, 1998). These steps comprise the process of hierarchical diffusion (Wyatt, 1995), and apply equally to other vectors such as shellfish shipments. Perhaps the most critical phases are the inoculation process and subsequent neighbourhood diffusion. On arrival, the introduced species may die out. Or it may establish locally and later disperse in the new environment. Terrestrial biologists in treating the matter emphasize the importance of "propagule pressure" (see Ruiz, this volume).

In "Ecological Imperialism", Crosby (1986) attributes the establishment of the neo-Europes, the regions where Europeans have successfully replaced indigenous peoples, to a combination of technology, suitable climate, knowledge of the world's wind systems, the success of Old World cultivars and domestic animals in those regions, and to the pests and diseases, mostly micro-organisms, that travelled with them. The receiving regions were "*on the losing side of the seams of Pangaea". "Chickens met kiwis, cattle met kangaroos, Irish met potatoes, Comanches met horses, Incas met smallpox – all for the first time. The countdown to the extinction of the passenger pigeon and the native peoples of the Greater Antilles and of Tasmania had begun"* (Crosby, 1986). The changes wrought were additional to those caused by human settlement millennia earlier, which had already eliminated 70-80% of large mammals in the Americas and perhaps 90% in Australia, as well as many other vertebrates. Flannery (1994) documents these pre-neo-European changes for the Austronesian region. But extinction is only one side of the coin.

Inclusion of the potato (which originated in South America) in the quotation from Crosby shows that movement across the Pangaean seams has been in both directions, as of course we know very well from food crops or neo-Eucalyptus (which originated in Australia) forests globally. But micro-organisms may have dominated these biotic exchanges. Even without breaching of the seams, changes in the Old World biota have been dramatic both before and since European expansion to other continents, as agriculture and urbanization have accelerated and natural ecosystems have been eroded. Elephants, giraffes, and rhinoceros became extinct in the Nile Valley in the 3rd millennium BC. Lions, leopards, and beavers had disappeared from Greece by

200 BC. Mediaeval maps of large regions of Europe show small scattered settlements surrounded by large areas of forest; modern maps show small scattered woodlands surrounded by large urban conglomerations. The last auroch died in Jaktorova Forest (Poland) in 1627 and the last great auk in Iceland in 1844. A combination of habitat loss and vulnerability accounts for most such losses. Thus in the terrestrial environment, we recognize that human colonization and population growth, and technology, have led to "structural" changes in ecosystems which have favoured the reduction or extinction of native species and the introduction of exotic species.

Can we recognize analogous structural changes in European coastal waters which could have had an impact on pelagic ecosystems? Large vertebrates, especially whales and other mammals, but also birds, turtles, fish, sharks, as well as invertebrates, have been very much reduced in numbers in recent centuries in European waters including the Mediterranean. Many major commercial fisheries are essentially extinct. These losses might be considered analogous to those in terrestrial ecosystems. In addition, there have been exponential increases over recent centuries in at least five factors which might be thought to have effects analogous to agriculture and other cultural trends on land. These are:

i) regulation of runoff by water management for domestic and industrial use and irrigation (following deregulation due to deforestation);

ii) changes in local hydrodynamic regimes stemming from this and from coastal developments, including land reclamation from coastal wetlands, port developments, and seabed mining;

iii) eutrophication;

iv) fisheries activities, including overextraction and seabed destruction by trawling;

v) aquaculture.

Changes expected from i) and ii) include alterations in water column stability and the seasonal timing of trends in mixing and compensation depths. The impacts of these different factors can rarely be isolated, but separately or in combination they are likely to have altered the species composition of local planktonic communities as well as their invasibility by exotic species from other regions. But before examining these factors in more detail, we look at the evidence for introduced phytoplankton species in European waters.

PHYTOPLANKTON CONSIDERED AS INTRODUCTIONS IN EUROPEAN COASTAL WATERS

The following table represents the phytoplankton species currently recognized as introductions in European and Mediterranean coastal waters.

Species	Year, Location	Origin	Spread	Vector	Ecological Effects	References
Thalassiosira punctigera	1978, Plymouth	unknown	Norway 1979	multiple possible vectors	not studied	Hasle, 1990
Thalassiosira tealata	1950, Blakeney, Gloucester	Japan?	Norway 1968	ballast? oysters?	not studied	Rincé and Paulmier, 1986
Odontella sinensis	1889, North Sea	Indian Ocean (Red Sea?)	Baltic	ballast?	prominent in winter spring; effects unknown	Ostenfeld, 1908
Pleurosigma simonsenii	1966, Ushant (Ouessant)	Indian Ocean	Netherlands 1974	ballast?	unstudied	Simonsen, 1974
Coscinodiscus wailesii	1977, Plymouth	Indo-Pacific	Norway 1979	ballast? oysters?	Competes with *nori* culture*	Boalch and Harbour, 1987
Karenia mikimotoi	1966, western Denmark	western Atlantic ?	Western Approaches, Norway	multiple possible vectors	Fish and invertebrate mortalities	Gentien and Arzul, 1990
Alexandrium catenella	1983, Mediterranean	Western Pacific?	?	ballast? oysters?	toxicity; effects unknown	Margalef and Estrada, 1987 Lilly *et al*., 2002

* nori is Japanese for the red alga Porphyra, cultured in Japan, China, and Korea. Growth rates are lowered during C. wailesii *blooms which are thought to compete with it for nutrients (Nagai* et al., *1996).*

We can draw several conclusions from this Table.

Only seven introduced species are recognized in a large region with shipping as heavy as anywhere in the world, and with a high concentration of taxonomic expertise. Although the Lessepsian migration from the Red Sea to the eastern Mediterranean generally refers to fish, molluscs, crustaceans, polychaetes, algae, and other larger organisms – not easily compared to phytoplankton – the number of new species successfully colonizing the Levantine basin via the Suez Canal is of the order of five a year, or two orders of magnitude higher.

No diatom introductions were identified between 1889 and 1950. There were three from 1966 to 1978, which may not be the years they arrived, but if they do, they may correspond to a period identified as a "regime shift" by fisheries biologists, which period witnessed large changes in the pelagic ecosystem at all trophic levels (Southward, 1980). Introductions have been noted mainly in the western Channel and in Norwegian coastal waters, two places where there has been continuous long term expertise in phytoplankton taxonomy.

The Mediterranean provides only one recognized example of a successful phytoplankton introduction, *Alexandrium catenella,* first noted west of the Catalan front in 1983 (Margalef and Estrada, 1987), and later in Thau Lagoon in southern France (Lilly *et al.*, 2002). Local areas such as estuaries and lagoons within regions are thought to be particularly vulnerable to invasion since human activity tends to be concentrated in them (e.g., Ruiz *et al.*, 2000), and may act as foci for local diffusion. Moncheva and Kamburska (this volume) add some phytoplankton species for the Bulgarian coast of the Black Sea.

Our understanding of the history of another dinoflagellate, *Gymnodinium catenatum*, is not clear, and this species can be considered cryptogenic (that is, a species which is neither clearly native nor introduced; Carlton, 1996). This species was first found in Galician waters in 1976 where it caused PSP problems (Estrada *et al.*, 1984), was commonly recorded from 1985 to 1988, but has rarely been found there since 1994, although it is common off central and southern Portugal. It was speculated that it might have been introduced from the southwest Atlantic by Spanish fishing vessels, or from Moroccan waters (Wyatt, 1992). It also now appears to be present in both Mediterranean and Atlantic waters off Morocco.

Is the boom-and-bust appearance (not necessarily followed by extinction) of *G. catenatum* in Galician waters an example of the course well known in some invading species, such as the ctenophore (comb jellyfish) *Mnemiopsis leidyi* in the Black Sea and some Lessepsian migrants in the eastern Mediterranean? Or was this a brief range extension from northwest African coastal waters? The requirements for permanent establishment of dinoflagellates with a dormant cyst stage have been examined numerically by Eilertsen and Wyatt (2000). In that model, tailored for *Alexandrium*, inadequate maintenance of the cyst bank due to reproductive failure and/or overdispersion prevents the seasonal appearance of blooms.

Karenia mikimotoi, a taxonomically "difficult" species formerly confused with *Gyrodinium aureolum* (Hansen *et al.*, 2000), was first reported in Danish waters in 1966. As currently understood (that is, morphologically), this species is very widely distributed (for example, Gulf of Mexico and New Zealand), which raises the question of whether it could have escaped detection in European waters for so long.

In the Black Sea, flagellates have become more abundant both absolutely and relative to diatoms in the last four decades, but diatoms too have increased enormously in abundance, and this despite a 60% decrease in winter silicate concentrations in the surface waters caused by the construction of the Iron Gates dam on the Danube. Between 1960-1970 and 1980-1990, the number of diatom blooms (mainly *Skeletonema costatum, S. subsalsum,* and *Cyclotella caspia*) which have exceeded 5 million cells l^{-1} in Romanian coastal waters increased from 8 to 19 on average each year. In the same period, bloom concentrations of the dinoflagellate *Prorocentrum cordatum* increased about eight-fold, and massive blooms of prymnesiophytes (*Emiliania huxleyi* and *Chromulina* sp.) and a euglenophyte (*Eutreptia lanowii*), not seen there in the 1960s, became prominent components of the phytoplankton.

The change in dominance from diatoms (which require silica to build their frustules) to various flagellated algae (which do not) has led to the suggestion that growth of the latter group is

favoured by anthropogenic eutrophication, since nitrogen but not silica loads are increased. The increases in phytoplankton stock may have been due as much to reduced grazing pressure as to increases in nutrient supplies. In any case the evidence does not allow us to clearly impute the changes to increased eutrophication (Wyatt, 1998), and the increased productivity expected to potentially increase invasibility has not led to the recognition of exotic phytoplankton blooms here.

Moncheva and Kambuzka (this volume) record several phytoplankton species new to their sampling location near Varna. Amongst these are *Alexandrium monilatum, Gyrodinium* cf. *aureolum, G. cornutum, Gymnodinium uberrimum,* and *Rhizosolenia calcar-avis. A. monilatum* is widely known from sites between Chesapeake Bay and Venezuela, and this may be the first European record. Their *G. cf. aureolum*, may be identical with *Karenia mikimotoi* already noted in our table. *G. uberrimum* is a bloom-forming species found in many European and North American lakes, so that its appearance in estuarine areas of the western Black Sea is not unexpected.

Rhizosolenia calcar-avis has a world-wide distribution including the Sea of Azov and the Caspian, where according to T.A. Tatarintseva it may have been introduced from the Mediterranean in the 1930s (other authorities suggest earlier); it is a dominant species there, and also in the Turkish waters of the Black Sea, and off western Crimea (Senichkina, 1995). It is not presently known from the Baltic, but has been found in a sediment core there, and seems to have disappeared from the region along with other warm water species at the end of the Mediaeval warm period around 800 years ago (Andren *et al.*, 2000). Olenin (this volume) implies there may have been transfers of species via eastern European waterways which carried trade between the Vikings and Greeks in the Middle Ages, so we might propose that *Rh. calcar-avis* came by this route rather than from the Mediterranean.

HYPOTHESES

We briefly discuss three hypotheses as to why so few non-indigenous phytoplankton species are currently recognized in European and Mediterranean coastal waters.

• **Many species of phytoplankton were introduced before plankton studies began in Europe.** The prymnesiophyte *Emiliania huxleyi* may have been introduced into the Black Sea by Greek ships during colonization of the region beginning in the early 7th century BC (Jones, 1993). This conclusion is based on accelerator mass spectrometry analysis of subfossil coccoliths. There is also evidence that at least one marine invertebrate, the clam *Mya arenaria*, was introduced to eastern Atlantic shores by Vikings returning from North America in the 10th century (Petersen *et al.*, 1992). Thus, phytoplankton invasions may have commenced centuries or millennia ago, long before the first baseline studies were conducted. Vectors for such introductions would include the bilges of ancient sailing vessels, the cysts and other resting stages of phytoplankton in wet sand ballast, as well as phytoplankton entrained in the once-thick fouling communities of ancient ships. Diatoms and other phytoplankton species first found in Europe in the oldest studies would thus be regarded as "native". We note, as an aside, that many species of attached, benthic diatoms may well have invaded Europe from around the world for centuries, and are now mistaken as "native" species as well.

• **Some marine phytoplankton communities are difficult to invade.** In numbers of individuals and biomass, the plankton of the Black Sea is one to two orders of magnitude higher than in the eastern Mediterranean (Kovalev *et al.*, 2001), but diversity is very much lower. In these respects, the Black Sea more closely resembles northern European waters. The Black Sea has also been marked by a progressive trend towards dominance by gelatinous zooplankton species in recent decades which has not to any significant extent, so far at least, affected the Mediterranean. These general trends might perhaps indicate that the Mediterranean coastal waters are less vulnerable to phytoplankton invasions than other European waters. It is often argued that high diversity in terrestrial systems offers protection against invasion (Tilman, 1999), and there is some experimental evidence for freshwater zooplankton to support the view (Shurin, 2000). Nevertheless, we know of no evidence in marine phytoplankton communities that would suggest they are more or less difficult to invade.

• **Most modern phytoplankton invasions have simply been overlooked.** The apparent paucity of new phytoplankton introductions in the last 100 years may be due almost entirely to the influence of long-standing paradigms in phytoplankton evolutionary biogeography. These paradigms include,

(1) cosmopolitanism in shallow-water, estuarine, harbor-dwelling, lagoonal, and coastal diatoms and dinoflagellates is natural,

(2) species not detected in a given area despite 50 to 100 years of previous investigation were really "always there", but were overlooked for various reasons (historically poor microscopic techniques, undersampling, better sampling techniques, etc.), and, linked with (3),

(3) blooms of species never before found in an area are due to environmental change expressing species that were always there.

For (2) and (3), these paradigms may be invoked even if there are no records whatsoever of such species ever having been present, even though many rare phytoplankton species, often only known from one or two specimens, may have been recorded from the same areas over the past 50 or 100 years. These three aspects of phytoplankton ecology and biogeography would effectively thus block recognition of invasions. For (3) we emphasize that there is a distinction between a vector introducing a species, and what factors cause it to "bloom". Ballast water does not cause harmful algal blooms or toxic phytoplankton blooms, but may well deliver to a new region the species that, under the proper local environmental conditions, would then bloom.

We note that small-bodied species that are believed to be naturally cosmopolitan are often said to be easily transported by wind and water. For virtually all such taxa, however, for which such natural transport mechanisms are invoked, there are no data that demonstrate that wind and water transport shallow-water, estuarine, coastal species across inhospitable ocean basins or between separate oceans. In contrast, we have a long list of well-documented human-mediated transport vectors that have been shown again and again to successfully transport phytoplankton, benthic diatoms, nematodes, rotifers, protozoans, flatworms, and many other microscopic or small taxa, between and across oceans. The great mystery is that we continue to invoke natural mechanisms for which there are no data, and not pay sufficient attention to the dispersal vectors for which there are rich data !

There is a clear relationship between "taxonomic resolution" and biogeographic assumptions. "Taxonomic resolution" can be expressed in a number of ways, such as (1) how easy it is to identify a species by a non-specialist (difficult to easy), (2) the frequency with which one needs to use a microscope to identify a species (always to never), (3) the number of living taxonomists (zero to many) and other measures. If one plots these measures against how widespread a given species (or higher taxonomic level) is believed to be, the relationship between taxonomy and biogeographic perception becomes clear: taxa that are difficult to identify and for which there are relatively fewer taxonomists are believed to be far more cosmopolitan than those that are not. Biogeographic perception thus influences invasion perception: hard-to-identify species that require a microscope for resolution, and for which there are relatively few experts, are almost always seen as cosmopolitan groups with few invasions. For the reverse situation where, for example, shelled molluscs, large crabs, large macroalgae, and so forth, are more easily and accurately identified, and where there are more available experts, high endemism, and many invasions structure the biogeographic perception.

Part of this relationship may also be expressed as the "smalls rule of invasion ecology": the smaller the taxon, the less likely it is to be recognized as introduced (and thus conversely, the more likely considered native). Small species (nematodes, rotifers, protozoans, small flatworms, diatoms, dinoflagellates, tiny filamentous algae, etc.) are rarely if ever reported as invasions, while, in contrast, large-bodied non-native taxa are regularly found and reported.

Thus it may be that the answer to the question posed in our title is that our perceptions are highly coloured by the technical difficulties of accurately describing and identifying phytoplankton species and community composition, that the number of introduced phytoplankton species is much larger than currently recognized, and is almost certainly on the increase. What

we see from macroinvasions all around the world, in response to vastly increased global trade, vastly increased speed of movement of global products, and increased human populations and human movements, is a steep upward slope of invasions that shows no sign of an asymptote.

There is no reason to assume that microinvasions are immune to these same phenomena and processes.

Plankton stowaways in the Black Sea – Impacts on biodiversity and ecosystem health

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INTRODUCTION

The introduction of invasive marine species into new environments in ships' ballast water, attached to ships' hulls, or other vectors, has been identified as one of the four greatest threats to the world's oceans, together with land-based sources of pollution, overexploitation of living marine resources and physical alteration/destruction of marine habitats. Biological invasions as global environmental and economical problems and health threats have been well documented worldwide (Cohen and Carlton, 1998). Zaitsev and Mamaev (1997) list many species of Atlantic and Pacific origin that have been introduced unintentionally to the Black Sea during the 20th century. The invasion of non-indigenous species, together with anthropogenic eutrophication and overfishing emerged as key ecological issues for the Black Sea ecosystem health (Zaitsev and Öztürk, 2001; Kideys *et al.*, 2000). While large-sized non-indigenous species (zoobenthos, fish, ctenophores) have been well reported (Gomoiu, 1988; Gomoiu and Scolka, 1996; Black Sea Red Book, 2000), the information on phytoplankton invasions is fairly poor (Mihnea, 1997; Moncheva *et al.*, 1995; Velikova *et al.*, 1999), a problem of global scale (Wyatt, this volume).

The goal of the present paper is to review plankton species focusing on bloom producing exotic stowaways and to discuss the mechanisms of their deleterious effect for the Black Sea ecosystem health. To assess the impact of exotic invasions on the Black Sea pelagic ecosystem, long-term published and unpublished data, collected under national and international projects, as well as the literature were used.

INVENTORY OF PLANKTON EXOTICS IN THE BLACK SEA

A review of the unpublished data and the published literature revealed an historical trend of exotic species introductions into the Black Sea, with some species transported as early as the mid 18th century and the early 19th century. The number of species, including exotic phyto- and zoo-plankton blooms, recorded in Black Sea increased dramatically during the late 1980s and 1990s (Table 1, Fig. 1).

The list of planktonic aliens represents a high phylogenetic and physiological variability which argues against the proposed "*general rules of successful nonindigenous invaders*" (Ehrlich, 1989). Species such as *Chatonella* sp., *Chrysochromulina* sp., and unidentified microflagellates, are considered as possible exotics, but their identification remains uncertain (Bodeanu *et al.*, 1998; Moncheva and Krastev, 1997). Thus the elaboration of a "black list of plankton invaders" remains a challenge for the Black Sea scientific community.

Population explosions of nonindigenous species manifest irregularity similar to the native species proliferations (Fig. 1, Fig. 2), which together with the uncertainties of species physiological features and cell cycle (Table 1) add to the problem of unpredictability.

Table 1. List of non-indigenous plankton species known in the Black Sea.

Species	First record	Possible origin	Reference	Resting stage	C; R species
Alexandrium monolatum Howell, (F.J. Taylor 1979)	1991	Atlantic Ocean, Gulf of Mexico	Moncheva *et al.* 1995; Moncheva, Krastev,1997	+	R
Gymnodinium uberrimum (Kofoid et Swezy, 1921)	1994, 2000	Fresh waters of Europe	Moncheva *et al.*, 2000; Terenko and Terenko, 2000	+	R
Phaeocystis pouchetii Hariot(Lagerheim, 1893)	1989	Atlantic, Pasific, North Sea	Petrova-Karadjova,1990; Moncheva, 1991	no	C
Mantoniella squamata (Manton and Parke 1960)	early 1980s	Insufficiently known	Mihnea, 1997;	no	C
Pseudosolenia calcar-avis (M. Schultze 1858)	1924	Atlantic and Pacific oceans	Usachev, 1928 (in Zaitsev and Öztürk, 2001)	no	R
Oxyphysis oxytoxoides, Kofoid, 1926	1994	Alaska, California	Moncheva *et. al.*, 1995	?	R
Asterionella japonica Cleve et Moler	1968	Atlantic and Pacific oceans	Senicheva, 1971		
Talassiosira nordenskjoldi Cleve	1986	Northern Atlantic	Shadrin, 2000		
Gymnodinium fuscum Ehr., Stein	1970-1980	Northern Atlantic	Bodeanu, 1997	?	R
Gyrodinium cf aureolum (Gymnodinium cf.mikimotoi Miyake et Kominami ex Oda, 1970) **	2002	Australia, Japan, Denmark	L. Terenko 2002	+	?
Gyrodinium simplex	2002	?	D. Nesterova, (pers.comm.)	?	?
Spatulodinium pseudonoctiluca Poushet, Loeblich, 1969	1995-1996	Mediterranean Atlantic and NE, Japan Sea	Stoyanova, 1999	?	?
Scaphodinium mirabile Margaleff, 1963	1995-1996	Mediterranean	Stoyanova, 1999	?	R
Petaludinium porselio J.M. Cashon, 1969	1995-1996	Mediterranean	Stoyanova, 1999	?	R
Acartia tonsa Dana, 1849	1976 1990	West Atlantic, Indo-Pacific Oceans	Gubanova, A., 1997; Belmonte *et al.*, 1994		
Blackfordia virginica Mayer, 1910	1925	Atlantic coast of North America	Valkanov, 1936		
Mnemiopsis leidyi Agassiz A., 1865	1982	Atlantic coast of North America	Pereladov, 1988		
Beroe ovata Mayer, 1912	1997	Atlantic coast of North America	Konsulov, Kamburska, 1998		

** - toxic ? – no information

IMPACTS OF PLANKTON EXOTICS ON THE BLACK SEA ECOSYSTEM (or Why ignoring the problem of ballast water is equal to a game of ecological roulette)

The biological contamination by exotic species may cause undesirable effects in the host ecosystem, both environmental and socio-economic: as alterations in composition of native populations, gene pool, decrease in fisheries, aquaculture and tourism, problems in water intake pipes of power plants, public health, etc. (Table 2).
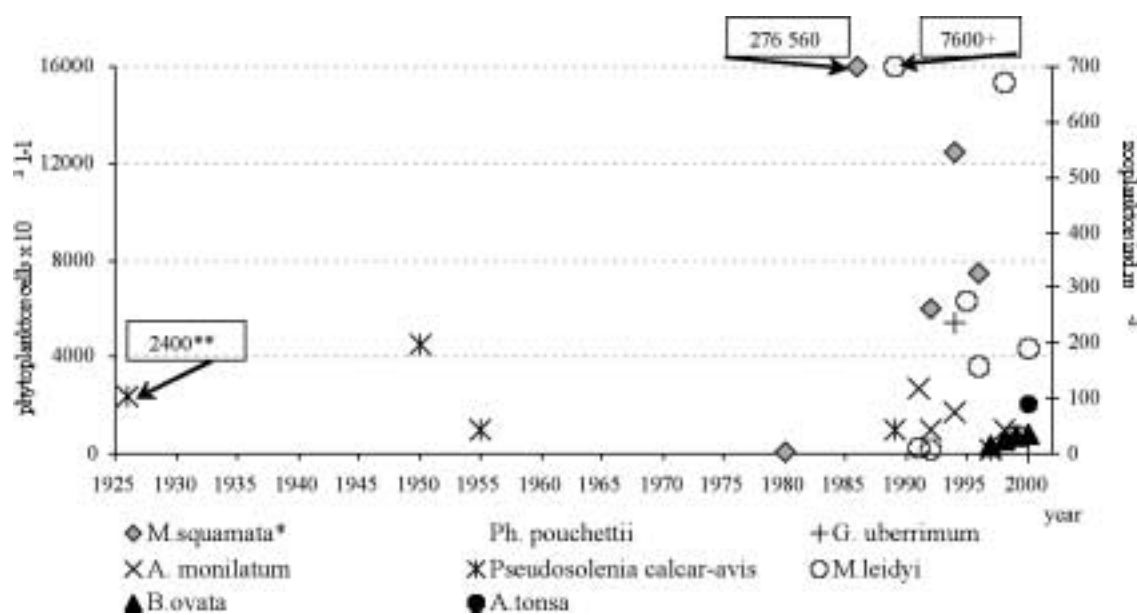
Fig. 1. Blooms of exotic plankton species in Black Sea
(* - data for Romanian coast; **- data for Ukrainian coast; +- ind.m⁻² after Vinogradov et al., 1989)

The possible environmental impacts of exotic species are illustrated by the taxonomic and functional changes in the phytoplankton and zooplankton, and the resulting changes in the food web in the Black Sea. The onset of anthropogenic eutrophication in the 1970s marked the dominance inversion of the major phytoplankton taxa: the opportunistic dinoflagellates dominating the diatoms (7:1) (Moncheva and Krastev, 1997). The blooms of the dinoflagellates *Gymnodinium uberrimum* and *Alexandrium monilatum* (2.7×10^6 cells l⁻¹) supported Bacillariophycea/ Dinophycea biomass at eutrophic levels (0.5 in the 1980s, 0.64 in the 1990s). At the time of their greatest abundance, the exotic dinoflagellates comprised nearly half the abundance and more than 70% of the biomass compared with the dominant native dinoflagellates, and *Phaeocystis pouchettii* more than 50% of the biomass of the native Chrysophyceae (Fig. 2). The invasion of the flagellate *Mantoniella squamata* (276×10^6 cells l⁻¹) resulted in a dramatic shift in the composition and size – spectrum of the phytoplankton associations – since the early 1990s chrysophytes have dominated the communities in summer (more than 60% of total phytoplankton abundance during bloom) and the frequency of 0-1 size class diversity index exceeding 30% (Mihnea, 1997). The prymnesiophyte *Phaeocystis pouchettii* was extremely abundant in the summers of 1989 and 1990 (90×10^6 cells l⁻¹), clogging the gills of fish (Moncheva *et al.*, 1995), and producing discoloration and foaming of the sea and interfering with tourism. *Ph. pouchettii* is reported as toxic to the pelagic copepod *Paracalanus parvus* (Huntley *et al.*, 1986). In the summer and autumn of 1992, 1995, 1997, the diatom *Pseudosolenia calcar-avis* reached densities of
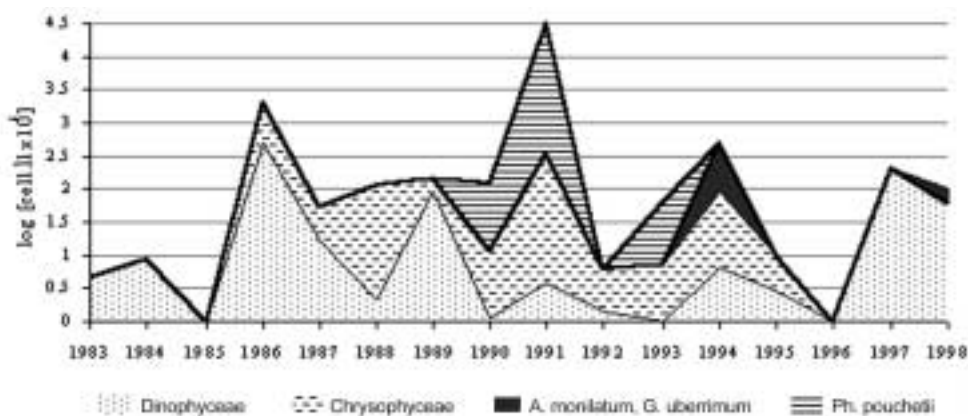

Fig. 2. Long-term variability of Dinophyceae, Chrysophyceae dominant species and exotic species abundance (cumulative abundance [cells.l⁻¹x10⁶] – log scale).

Table 2. Scale of environmental and socio-economic risks

Impacts	Global	Black Sea
Environment		
alteration of taxonomic and functional groups of species	+++	+++
detrimental changes in the food web	+++	+++
changes in habitat	+++	+++
resources competition and limitation	+++	+++
introduction of potentially toxin producing species (harmful algal blooms, seaweeds)	+++	++
introduction of new disease agents or parasites	+++	+
genetic effects on native species (hybridization, change in gene pool, loss of native genotypes)	+++	+
extinction/ reduction of native population size	+++	+++
changes host/ parasite life cycle	++	+?
Socio-economic		
loss in commercial/ recreational species harvest	+++	+++
losses in aquaculture harvest	+++	+?
tourism	+++	+++
losses in shipping (clogging of pipes)	++	+
underwater constructions damage by fouling species	+++	++
increased costs for remediation	+++	+++
threat to underwater cultural heritage	++	+?
human health risk	+++	+?

(+ -low; ++ -medium; +++ -high; ? –lack of data)

200-260 x 10^3 cells l^{-1} or biomass values exceeding 40 g/m^{-3}. Phytoplankton densities over 5 x 10^6 cells l^{-1} and biomass in excess of 30 g/m^{-3} are considered harmful, leading to violations of ecosystem carrying capacity, severe economic losses to aquaculture, fisheries and tourism (Velikova *et al.*, 1999). Red tides of *Gyrodinium aureolum (=Gymnodinium mikimotoi)* forced closing five beaches in Hong Kong in 1998, and were alleged to have killed an estimated 1 500 tons of farmed fish, causing at least $32.3 million in damages. In the same year, between 400 and 500 tons of fish, mostly salmon, had been killed along Norway's southwestern coast, the Danish west coast and the Swedish west coast (Skagerak-Kattegat) by an algal bloom, possibly *Heterosigma* and *Chattonella verrucolusa*.

No cases of phytoplankton toxicity were reported from the Black Sea. However, cases reported from other areas and the hypothesis of "induced toxicity" due to change in nutrients ratios are an alarm bell that the newcomers may act as a "biological time bomb". The changes in the phytoplankton community structure caused by invasions alter the trophic web and modify the native predator-prey interactions, and by a "domino effect" lead to disruption of the marine environment and the economy of the affected areas. Zooplankton communities too underwent changes of their major taxonomic components (copepods and cladocerans) as a result of phytoplankton modifications. In the early 1970s copepods dominated cladocerans, with more than 60% of the biomass and over 70% of abundance, declining in the early 1980s in diversity and abundance. The pattern of oscillations in spring-summer biomass ratio of these taxa generally paralleled phytoplankton alterations (Kamburska *et al.*, 2002).

The arrival of *Mnemiopsis leidyi* in the late 1980s, transported in ballast water from the Atlantic coast of North America, forced further changes in the structure and composition of the plankton (Fig. 3). *Mnemiopsis* biomass in the Black Sea was soon estimated at one billion tons (Vinogradov *et al.*, 1989), and values up to 12 kg/m^{-2} along the Bulgarian shelf in April 1990 (Bogdanova and Konsulov, 1993), a density far higher than in its native habitat.

The *Mnemiopsis* swarms impacted the native zooplankton community, the fisheries and the water quality. Mesozooplankton density, biomass and species composition declined as a result of *Mnemiopsis* predation pressure (50% of its diet is copepods, 30% cladocerans, Tsikhon-Lukanina and Reznischenko, 1991); local extinction of some native pontellid copepods; 45% decrease in cladoceran biomass inshore, and loss of biodiversity (Konsulov and Kamburska, 1998); and a
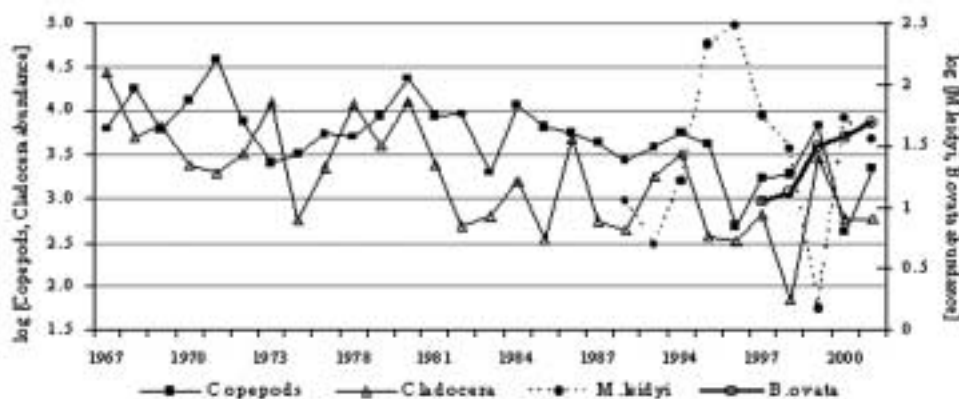
Fig.3. Long-term variability of Copepoda, Cladocera species abundance [inds.m^{-3}] and ctenophore exotics [log scale].

pronounced decrease (about 30%) in zoobenthos due to the grazing on the meroplankton (benthic larvae). *Mnemiopsis* predation on fish eggs and larvae caused loss of up to 70% of total ichthyoplankton in shallow water. The fishery losses attributed to *Mnemiopsis* in the Black Sea was calculated to be about 200 millions USD (Zaitsev and Öztürk, 2001; Kideys, this volume). *Mnemiopsis* produced mucus in the water column and anoxia at the bottom.

Beroe ovata, recently introduced in ballast waters from the Northern Atlantic into the Black Sea (Konsulov and Kamburska, 1998), preys on *Mnemiopsis*. As a result, a decline of *Mnemiopsis* populations was recorded in the autumn month all over the basin (Shiganova *et al.*, 2001a). However, the future of the predator-prey scenario is still a matter of uncertainties and discussion (Kideys, this volume).

The proliferation of alien species is consistent with a global epidemic and worldwide species-spreading phenomenon (Hallegraeff, 1993). The increase in exotic populations in the Black Sea recapitulates the consequences of native blooms, the main vectors being hypoxia/anoxia, and the related mortality of fish and benthos, water discoloration, decrease of water transparency, changes of esthetic appearance of the coastal sea, etc. Ignoring the ballast-mediated introductions is to play an ecological roulette with nature.

CONCLUSIONS

Analysis of the general patterns of environmental impacts in the Black Sea shows:
• change in taxonomic and functional structure of plankton communities;
• outright loss of native species e.g. xenodiversity/native biodiversity shifts;
• change in ecosystem diversity;
• change in basic ecosystem properties and rearrangement of trophic relations – the potentially toxic species may behave as a "biological time-bomb";
• habitat disturbance (increased turbidity, reduced transparency, discoloration, esthetic appearance);
• the presence of exotics is a stressor that could further alter the ecosystem perhaps promoting colonization by other aliens.

UNCERTAINTIES AND GAPS OF KNOWLEDGE

• Do rules exist by which the success or failure of a particular invasion may be predicted ?
• Consensus on taxonomical identification of species (Black list of exotic species);
• Insufficient knowledge of phytoplankton cell cycle, physiology and ecology;
• Lack of knowledge of exotic species/native species modes of interaction.

Assessing scale and impact of ship-transported alien macrophytes in the Mediterranean Sea

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DEFINITIONS

We define an introduced species as a species which fulfils the four following criteria (Carlton, 1985; Boudouresque, 1999a; Boudouresque and Verlaque, 2002). (i) It colonizes a new area where it did not previously occur. (ii) The extension of its range is linked, directly or indirectly, to human activity. (iii) There is geographical discon-tinuity between its native area and the new area (remote dispersal). This means that the occasional advance of a species at the frontiers of its native range (marginal dispersal) is not taken into consideration. Such fluctuations (advances or withdrawals) may be linked to climatic episodes. Thus, the Chlorobionta (Plantae) *Caulerpa prolifera*, which moves northwards from the southern Mediterranean during warm climatic episodes, then southwards during cold episodes, is not an introduced species in the north-western Mediterranean, where it occurs nowadays. (iv) Finally, new generations of the non-native species are born *in situ* without human assistance, thus constituting self-sustaining populations.

A set of criteria (for these criteria, see Boudouresque and Ribera, 1994; Ribera and Boudouresque, 1995), that are rarely all met, offers a basis for assessing the probability (very high, high or medium) that a species has been introduced.

Here, macrophytes are defined as pluricellular species belonging to the following phylums (and kingdoms): Cyanobacteria (Procaryota), Chromobionta (Stramenopiles), Rhodobionta, Chlorobionta and Magnoliophyta (Plantae).

INTRODUCED MACROPHYTES IN THE MEDITERRANEAN

More than 90 taxa of macrophytes can be considered as having been probably introduced into the Mediterranean Sea (Verlaque, 1994; Boudouresque and Ribera, 1995; Verlaque, 2001; Boudouresque and Verlaque, 2002; Ribera-Siguan, 2002), representing 6.5% of its known macrophyte flora (about 1 410 species, according to Ribera *et al.*, 1992; Gallardo *et al.*, 1993; Boudouresque, 1997; Gómez-Garreta *et al.*, 2001). Since the early 20th century, their number has more or less doubled every 20 years (Fig. 1).

The Mediterranean is at world scale the sea which harbours the greatest number of introduced macrophytes. It is also a hot spot for macrophyte species diversity (together with the Japan temperate region and Southern Australia) (Boudouresque, 1995, 1997), a feature which is not consistent with the popular hypothesis that a high species diversity improves resistance to invasion
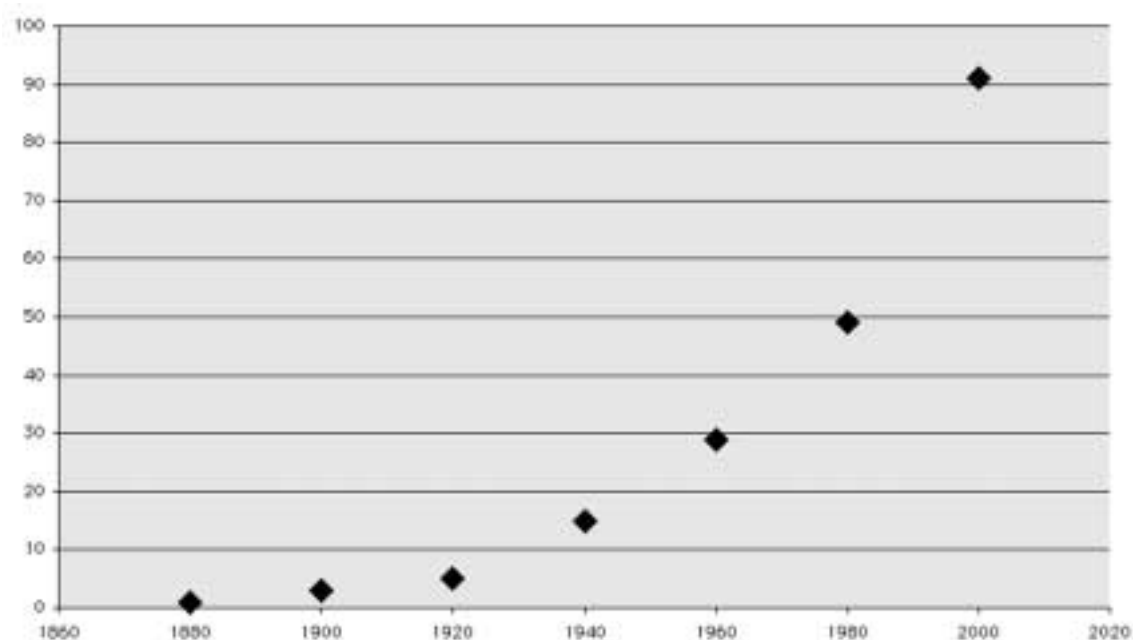
Fig. 1. Change over time in the cumulative number of likely introduced macrophyte taxa in the Mediterranean.

(see Naeem *et al.*, 2000), although locally low diversity habitats (such as lagoons and ports) harbour a higher number of introduced species.

SHIP TRANSPORTED INTRODUCED MACROPHYTES IN THE MEDITERRANEAN

Accidental introduction of species accompanying species bred for aquaculture purposes is the main route of access to the Mediterranean (Table 1): importation of oyster spat (often from Japan and Korea) and transport of living mollusks between aquaculture basins. This is due to the lack of decontamination and quarantine procedures. Another important route is the Suez canal, which makes it possible for Red Sea species to enter the Mediterranean ("Lessepsian aliens"). The other vectors include fouling and clinging (transportation on ships' hulls), ballast waters, fishing bait, escape from aquariums and scientific research (Por, 1978; Meinesz and Hesse, 1991; Spanier and Galil, 1991; Boudouresque and Ribera, 1994; Galil, 1994; Verlaque, 1994; Ribera and Boudouresque, 1995; Jousson *et al.*, 1998; Boudouresque, 1999a; Galil, 2000; Verlaque, 2001; Boudouresque and Verlaque, 2002).

As far as macrophytes probably or possibly introduced into the Mediterranean Sea via ship transport (fouling and ballast waters) are concerned, 29 taxa can be listed from literature data (Table 2). This census is very conservative. Firstly, introduced species which are sibling species of native ones are rarely revealed since they do not attract the attention of collectors and taxonomists. Secondly, many species which are considered as "cosmopolitan", i.e. with a more or less global distribution range, can be actually introduced in most of their present day range area. Such species, that are not demonstrably native or introduced, are named "cryptogenic species" (Carlton, 1996a). In San Francisco Bay, California, estimates of introduced and cryptogenic species are of the order of 211 and 125, respectively (Carlton, 1996a). Molecular analysis may help to unmask sibling and cryptogenic introduced species. In the case of cryptogenic introduced species, non-native populations only possess part of the genetic vari-ability of the species in its original range ("founder effect"). All in all, it is no accident that groups of macrophytes that are extensively involved in fouling, such as Cyanobacteria, Bangiophyceae (Rhodobionta), Ulvaceae (Plantae) and Ectocarpaceae (Chromobionta, Stramenopiles), but of which most species are today cosmopolitan, do not include species assumed to have been introduced. Thirdly, species classified by authors (e.g. Por, 1978; Verlaque, 1994; Ribera and Boudouresque, 1995; Boudouresque, 1999b) within the category of Lessepsian aliens (Table 1) actually constitute a heterogeneous

Table 1. Routes of access to the Mediterranean of probably introduced macrophytes (expressed as a percentage of the total number of introduced taxa). From Boudouresque (1999a), updated.

Routes of access	Percentage
Fouling on ship hulls	24 % [a]
Ballast water	< 1 %
Escape of species bred for aquaculture purposes	-
Accidental introduction of species accompanying living mollusks (aquaculture)	36 %
Fishing bait	2 %
Escape from aquariums	2 %
Suez Canal (Lessepsian aliens)	28 %
Unknown	8 %

[a] *Note that percentages are lower than might be expected by dividing the total number of taxa possibly introduced via a given route (see Table 2) by the total number of introduced taxa, due to the fact that many taxa may have been introduced via several routes.*

Table 2. Taxa of macrophytes probably introduced into the Mediterranean Sea via ship transport.
Probability of introduction: VH = very high, H = high, M = medium. **Probable route** of access to the Mediterranean (primary dispersal) and probable route of dispersal within the Mediterranean (secondary dispersal): AQ = aquarium, BW = ballast water, F = fouling, FN = fishing nets, ND = natural dispersal, S = Suez canal, SA = shellfish aquaculture. **First colonized habitat**: BL = brackish lagoons, H = harbours, Ph = photophilous hard bottom sublittoral communities, PM = Posidonia oceanica meadows, Sc = sciaphilous hard bottom communities (sublittoral or circalittoral).

Taxa	Date of first observation	Probability of introduction	Route of access (primary dispersal)	Route of secondary dispersal	First habitat colonized
Chromobionta (Stramenopiles)					
Colpomenia peregrina	1956	VH	F	SA, ND	Ph
Rhodobionta					
Acrothamnion preissii	1969	VH	F	F, ND	Ph, PM
Aglaothamnion feldmanniae	1976	M	F	F, ND	H
Antithamnion amphigeneum	1989	VH	F	F, ND	Ph
Antithamnionella elegans	1882	VH	F	F	Ph
Antithamnionella spirographidis	1914	H	F	F	H
Antithamnionella sublittoralis [a]	1988	H	F	-	?
Antithamnionella ternifolia	1926	VH	F	-	Ph
Apoglossum gregarium	1997	M	F	F, ND	Sc
Asparagopsis armata	1926	VH	F	F, ND	Ph, Sc
Asparagopsis taxiformis [b]	1939	H	F or S	F, ND	Ph, Sc
Bonnemaisonia intricata	1910	VH	F	F, ND	Sc
Botryocladia madagascariensis	1997	H	F?	F?	Sc
Ceramium strobiliforme	1992	H	F?	F, ND	Sc
Goniotrichiopsis sublittoralis	1989	H	F	-	Sc
Hypnea spinella [c]	1977	H	F?	F, ND	Ph
Hypnea valentiae [d]	1898	H	F or S	F, ND	?
Lophocladia lallemandii	1938	M	F or S	F, ND	Ph
Pleonosporium caribaeum	1974	M	F or SA	F, ND	?
Plocamium secundatum	1991	M	F?	-	Sc
Polysiphonia harveyi	1958	VH	F	F, ND	BL
Rhodothamniella codicola	1952	VH	F or SA	SA	Ph
Rhodymenia erythraea	1948	VH	F or S	-	H
Symphyocladia sp.	1984	VH	F	-	Sc
Womersleyella setacea	1987	VH	F	F or FN	Sc
Plantae					
Caulerpa racemosa ("invasive variety")	1990	VH	AQ or BW	BW, ND	Ph, Sc
Cladophora cf patentiramea	1992	H	F or S	-	Ph
Codium fragile subsp. *tomentosoides*	1950	VH	F or SA	SA	Ph
Codium taylori	1980	M	F?	F	Ph

[a] *According to Athanasiadis (1996), synonym of* Antithamnionella elegans *var.* decussata. [b] *This species may be introduced by fouling on ship's hulls in the western Mediterranean, and a Tethyan relict or a pre-Lessepsian immigrant introduced via waterways built during Pharaonic and Roman times, in the eastern basin (see Por, 1978).* [c] *Synonym of* Hypnea cervicornis. [d] *According to Athanasiadis (1987), the presence of this species in the Mediterranean is doubtful.*

group of species. They may have used a variety of means to cross the Suez isthmus: propagules and cuttings carried by the currents (which usually run from the Red Sea to the Mediterranean), step-by-step colonization of the Suez canal, fouling on ship's hulls and ballast waters. The problem is that current knowledge does not offer an adequate basis for establishing the actual route used by Lessepsian alien macrophytes.

Transportation on the hulls of ships of fixed organisms is certainly the most ancient vector of species introduction in the marine realm. However, prior to the late 19th century, when ship velocity was weak and trans-oceanic canals (Suez and Panama) not already built, travel length and the transit through very cold waters (Cape of Good Hope and Cape Horn) were not propitious to the survival of fouling organisms. It is probably no accident that the introduction into the Mediterranean of steno-thermic macrophytes native to Indo-Pacific temperate areas, such as *Asparagopsis armata* and *Bonnemaisonia intricata*, only started after the construction of these canals. Nowadays, one might suppose that most of the species that were potential candidates (*sensu* Carlton, 1996b) for introduction via fouling on ships' hulls have been already introduced (Ribera and Boudouresque, 1995). In addition, anti-fouling paint now limits this mode of introduction. In the Mediterranean, the relative importance of this vector has actually decreased with time. However, this route of introduction is still actively functioning (Table 3).

Table 3. Change over time in the cumulative number and relative importance (between brackets) of fouling *versus* other vectors for macrophyte taxa probably introduced in the Mediterranean Sea.

Routes of access	1920	1940	1960	1980	2000
Fouling	3.5 (70%)	6.5 (43%)	10.0 (34%)	13.5 (28%)	21.5 (24%)
Accompanying shellfish aquaculture	-	-	-	10.5 (21%)	32.5 (36%)
Suez canal (Lessepsian aliens)	1.0 (20%)	7 (47%)	17.5 (60%)	21.5 (44%)	26.0 (28%)
Other and unknown	0.5 (10%)	1.5 (10%)	1.5 (6%)	3.5 (7%)	11.0 (12%)
Total number of introduced taxa	**5**	**15**	**29**	**49**	**91**

Decimal figures are due to the fact that certain taxa may have been introduced via two possible vectors.

Ballast waters seem to play a minor role as a vector for introduction of macrophytes to the Mediterranean (Tables 1, 2). It is difficult to assess whether or not this is an artefact. However, we note that in ballast waters from ships arriving in Oregon (USA) from Japan after a transoceanic trip of 11-21 days, macrophytes only represented 1% of living propagules (Carlton and Geller, 1993). In Ireland, a single macrophyte species is considered as having possibly been introduced via ballast waters (Minchin and Sheehan, 1996).

It is worth noting that assessing the vector by which a species has been introduced is quite a difficult exercise, so that the possibility of being wrong is considerable. In the case of *Acrothamnion preissi,* for example, the assumption that it entered the Mediterranean via fouling on ship hulls is based upon its first occurrence in the vicinity of port facilities and on its turf growth pattern which makes probable its growth on ship hulls (Cinelli and Sartoni, 1969). In the same way, the turf-like species *Womersleyella setacea* was first discovered in the region of Toulon harbour (France) (Verlaque, 1989, 1994). However, one cannot rule out the possibility that these turf species were present on living material collected in the Indo-Pacific ocean and air-transported to Mediterranean coastal aquariums, for a long time in open circuit with the sea, from which they could have escaped. Similar considerations apply for most of the species listed in Table 2, so that these data must be taken with considerable caution. In addition, the populations of some introduced species may have been founded, simultaneously or successively, by immigrants using different routes (e.g. fouling, ballast waters and aquaculture). This might be the case for *Codium fragile, Colpomenia peregrina and Polysiphonia harveyi.*

As far as the area of origin of introduced taxa via ship transport is concerned, most of them are of Pacific and/or Indian oceans origin (Tables 4 and 5). Changes through time are not significant (H_0, equality of percentages, not rejected; Sokal and Rohlf, 1969). The modest contribution of Atlantic species may be due to (i) the relatively limited range of the temperate zone along the east American coasts (see Lüning, 1990); (ii) the shipping corridors between America and Europe, which either originate in tropical waters (Mediterranean is not a tropical sea, so that it is

not the most propitious host area), or reach northern Europe rather than the Mediterranean (see Carlton, 1996b; Dobler, this volume). However, this may also represent an artefact, due to the fact that species of American origin would have been introduced several centuries ago, a short time after Columbus' voyages, so that today they are not recognized as introduced in Europe (cryptogenic species; see Carlton, 1996a).

Warm biogeographical regions are by far the main donor regions of macrophyte taxa introduced into the Mediterranean via ship transport (Table 6). This is a not unexpected feature, since the Mediterranean is a warm sea (Lüning, 1990). The relative importance of taxa introduced from

Table 4. World distribution of macrophyte taxa probably introduced into the Mediterranean via ship transport.
Type locality: the locality where the taxon was first described (from Guiry and Nic Dhonncha, 2002).
Biogeographical regions: in each ocean, from North to South, C, W, T, W and C = North cold, North warm, tropical, South warm and South cold, respectively. North cold and North warm regions do not exist in the Indian ocean. Delineation of biogeographical regions from Lüning (1990). **World distribution**:
X = probably native, i = probably introduced. Data from Wynne (1985), South and Tittley (1986), Womersley (1987), Adams (1994), Yoshida *et al.* (1995), Silva *et al.* (1996), Van den Heede and Coppejans (1996), Womersley (1996, 1998), Huisman (2000) and McIvor *et al.* (2001), among others.

Taxa	Type locality	Atlantic					Indian			Pacific				
		C	W	T	W	C	T	W	C	C	W	T	W	C
Chromobionta (Stramenopiles)														
Colpomenia peregrina	Britanny (France) a b	i	i	-	-	-	-	X	-	-	X	-	X	X
Rhodobionta														
Acrothamnion preissii	Western Australia	-	-	-	-	-	-	i	-	i	i	-	X	-
Aglaothamnion feldmanniae	Britanny (France)	-	X	-	-	-	-	-	-	-	-	-	-	-
Antithamnion amphigeneum	New South Wales - (Australia)	i	-	-	-	-	-	-	-	-	-	X	-	
Antithamnionella elegans	Italy a	-	X	i	i	-	i	-	-	-	i	i	-	-
Antithamnionella spirographidis	Adriatic Sea (Italy) a	i	i	-	i	-	-	-	-	-	i	-	X	-
Antithamnionella sublittoralis	NE Pacific	-	-	-	-	-	-	-	-	-	X	X	-	-
Antithamnionella ternifolia	Cape Horn	i	i	-	-	X	-	X	-	-	-	-	X	X
Apoglossum gregarium	Gulf of California (Mexico)	-	-	i	-	-	i	-	-	-	X	X	-	-
Asparagopsis armata	Western Australia	-	i	-	-	-	-	-	-	-	-	-	X	X
Asparagopsis taxiformis	Egypt (Medit.) a	-	i	i	i	-	X	X	-	-	I	i	i	i
Bonnemaisonia intricata	Japan	i	i	-	i	-	-	-	-	X	X	-	i	-
Botryocladia madagascariensis	Madagascar	-	-	i	-	-	X	-	-	-	-	-	-	-
Ceramium strobiliforme	Ghana	-	-	X	-	-	-	-	-	-	-	-	-	-
Goniotrichiopsis sublittoralis	California	-	i	-	-	-	-	-	-	X	X	-	-	-
Hypnea spinella	West Indies	-	X	X	X	-	X	-	-	-	i	i	i	-
Hypnea valentiae	Red Sea	-	i	i	-	-	X	-	-	-	X	X	X	-
Lophocladia lallemandii	Red Sea	-	-	-	-	-	X	-	-	-	-	-	-	-
Pleonosporium caribaeum	Virgin Islands a	-	-	i	-	-	X	X	-	i	i	i	i	-
Plocamium secundatum	Cape Horn	-	-	-	-	X	-	-	-	-	-	-	-	X
Polysiphonia harveyi	California a	i	i	-	-	-	-	-	-	X	X	-	-	I
Rhodothamniella codicola	Canary Islands	-	i	-	-	-	-	-	-	-	Xc	-	-	-
Rhodymenia erythraea	Red Sea	-	-	-	-	-	X	-	-	-	-	-	-	-
Symphyocladia sp.	New Zealand d	-	i	-	-	-	i	X	-	-	X	-	-	X
Womersleyella setacea	Hawaiian Islands	-	i	I	I	-	X	-	-	-	-	X	-	-
Plantae														
Caulerpa racemosa ("invasive variety")	Western Australia e	-	-	-	-	-	-	-	-	-	-	-	X	-
Cladophora cf patentiramea	Tahiti	-	-	-	-	-	X	-	-	-	X	X	-	-
Codium fragile subsp. *tomentosoides*	Netherlands a	i	i	-	-	-	-	-	-	-	X	-	i	I
Codium taylori	Florida	-	X	X	X	-	i	-	-	-	-	-	-	-

[a] *The species has been described in a region were it was introduced, before the discovery of its region of origin.* [b] *European populations of* Colpomenia peregrina *were probably introduced from Japan rather than from Southern Pacific.* [c] *The species has not been definitely mentioned from the area, may be because of confusion with* Acrochaetium codii; *however, being a specialized epiphyte of* Codium fragile, *it is likely present there.* [d] *We assume that the species of* Symphyocladia *introduced into the Mediterranean is probably* S. marchantioides, *already introduced to the Azores (see Ardré* et al.*, 1974).* [e] *Unpublished data.*

Table 5. Probable ocean of origin (area where the taxon is native) of the macrophytes introduced into the Mediterranean via ship transport.

Ocean (s) where the introduced taxon is native	Cumulative number of taxa (and percentage)		
	1960	1980	2000
Atlantic ocean	2 (15%)	5 (28%)	7 (24%)
Indian ocean	6 (46%)	8 (44%)	12 (41%)
Pacific ocean	9 (69%)	10 (56%)	19 (66%)
Total number of introduced taxa	13	18	29

Several taxa are probably native to more than one ocean, so that the sum of introduced taxa per ocean is higher than the total number of introduced taxa.

Table 6. Probable biogeographical region of origin (biogeographical region where the taxon is native) of the macrophytes introduced into the Mediterranean via ship transport.

Biogeographical region (s) where the introduced taxon is native	Cumulative number of taxa (and percentage)		
	1960	1980	2000
Northern and/or southern cold region	5 (38%)	5 (28%)	8 (28%)
Northern and/or southern warm region	11 (85%)	16 (89%)	23 (79%)
Tropical region	4 (31%)	7 (39%)	13 (45%)
Total number of introduced taxa	13	18	29

Several taxa are probably native to more than one biogeographical region, so that the sum of introduced taxa per bio-geographical region is higher than the total number of introduced taxa.

tropical regions seems to be on the increase from 1960 to 2000. This would appear to be logical, since Mediterranean waters have experienced a slight but steady warming since the 1960s, in the framework of the present day warm episode: 0.13°C at 800-2000 m depth (Bethoux and Gentili, 1998), 0.7°C at 80 m depth and 1.1°C at the sea surface (Salat and Pascual, 2002; Vargas-Yáñez *et al.*, 2002). However, changes through time are not significant (Table VI; H_0, equality of percentages, not rejected; Sokal and Rohlf, 1969).

MEDITERRANEAN RANGE OF SHIP TRANSPORTED INTRODUCED MACROPHYTES

Two trends are apparent in the Mediterranean distribution of macrophytes introduced via ship transport. Firstly, they are more numerous in the western than in the eastern Mediterranean (Table 7). This does not seems to be an artefact due to differences in scientific knowledge: should Lessepsian aliens be considered, the opposite trend would appear. Secondly, regions which harbour major port facilities (such as Spain, France, western Italy, Sicily and Greece) are more affected than those where there is less shipping (such as Corsica, Sardinia, Morocco and Libya).

Once introduced to the Mediterranean, the speed of range extension is quite contrasting. *Rhodymenia erythraea* was observed in Port-Said harbour (Egypt) by Aleem (1948) and does not seem to have extended its range; in fact, it may even have disappeared. The spread of *Acrothamnion preissii* has been relatively slow. More than three decades after its arrival (near Leghorn, Tuscany, Italy; Cinelli and Sartoni, 1969), it is still localized in the northern part of the western basin (Tyrrhenian Sea, French Riviera and Balearic Islands). In contrast, the spread of the "invasive variety" of *Caulerpa racemosa* has been striking; ten years or so after it was first observed in Libya (Nizamuddin, 1991), it occurs in most of the Mediterranean (Verlaque *et al.*, 2000, Durand *et al.*, 2002).

THE POSSIBLE REASONS FOR SUCCESSFUL INVASIONS

In the Mediterranean, the number of introduced species is higher in habitats which are either under human pressure and disturbed or which harbour a rather low species diversity, such as port and lagoon habitats. However, all corridors converge on such habitats, so that the relation between disturbance or low species diversity and vulnerability to introductions may be just an artefact. Of interest is the fact that, though no species was primarily introduced to Corsica and

Table 7. Mediterranean regions where macrophytes likely introduced by ship have been observed.

Regions: Ad = Adriatic Sea, Ag = Algeria, BI = Balearic Islands, CS = Corsica and Sardinia, Eg = Egypt, F = continental France and Monaco, Gr = Greece, Li = Libya, LS = Cyprus, Syria, Lebanon, Israel and Palestine, Mo = Morocco and African Spanish territories, Si = Sicily and Italian southern Islands, Sp = peninsular Spain, Tn = Tunisia,Tr = Turkey, WI = Western Italy. See Ribera *et al.* (1992) for more details about the geographical delimitation. **Geographical distribution:** X! = the region where the taxon was first recorded (primary introduction), X = presence (secondary introduction), - = not recorded. **Data from:** Ribera *et al.* (1992), Gallardo *et al.* (1993), Verlaque *et al.* (2000), Gómez-Garreta *et al.* (2001), Benhissoune *et al.* (2001, 2002a, 2002b), completed for Rhodobionta other than Ceramiales and updated (from Mayhoub, 1976; Cirik, 1978; Bidoux and Magne, 1989; Perret-Boudouresque and Seridi, 1989; Boudouresque *et al.*, 1990; Cormaci *et al.*, 1992; Aleem, 1993; Ballesteros and Rodríguez-Prieto, 1996; Verlaque and Bernard, 1997; Furnari *et al.*, 1999; Argyrou, 2000; Djellouli, 2000; Turna *et al.*, 2000; Giaccone, 2001; among others).

Taxa	Western							Central					Eastern		
	Sp	BI	F	CS	WI	Ag	Mo	Si	Ad	Gr	Li	Tn	Tr	LS	Eg
Chromobionta (Stramenopiles)															
Colpomenia peregrina	X	-	X	X	X!	X	X	X	-	-	-	-	-	-	-
Rhodobionta															
Acrothamnion preissii	-	X	X	-	X!	-	-	X	-	-	-	-	-	-	-
Aglaothamnion feldmanniae	-	-	X	-	X!	-	-	-	-	-	-	-	-	-	-
Antithamnion amphigeneum	X	-	X	-	X	X!	X	-	-	-	-	-	-	-	-
Antithamnionella elegans	X	X	X	X	X!	X	X	X	X	X	-	X	-	X	X
Antithamnionella spirographidis	X	X	X	X	X	-	X	X	X!	X	-	-	-	-	-
Antithamnionella sublittoralis	-	-	-	-	-	-	-	X!	-	-	-	-	-	-	-
Antithamnionella ternifolia	-	-	X!	-	-	-	-	-	-	-	-	-	-	-	-
Apoglossum gregarium	X	X	X	-	X!	-	-	X	-	-	-	-	-	-	-
Asparagopsis armata	X	X	X!	X	X	X	X	X	X	X	-	-	-	-	-
Asparagopsis taxiformis	-	X	-	-	-	X	-	-	-	-	-	-	-	-	X!
Bonnemaisonia intricata	X	-	-	-	-	X	X	-	X	-	-	X!	-	-	-
Botryocladia madagascariensis	-	-	-	-	-	-	-	X!	X	-	-	-	X	-	-
Ceramium strobiliforme	-	-	-	-	-	-	-	X!	X	-	-	-	-	-	-
Goniotrichopsis sublittoralis	-	-	X!	-	-	-	-	-	-	-	-	-	-	-	-
Hypnea spinella	X!	X	-	X	-	X	-	X	-	X	-	X	X	X	-
Hypnea valentiae	-	-	X	-	-	-	-	-	-	X!	-	-	-	X	X
Lophocladia lallemandii	X	X	-	X	X	X	-	X	X	X!	X	X	X	X	X
Pleonosporium caribaeum	X	-	X!	-	-	-	-	-	-	-	-	-	-	-	-
Plocamium secundatum	-	-	-	-	-	-	-	X!	-	-	-	-	-	-	-
Polysiphonia harveyi	-	-	X!	-	X	-	-	-	-	-	-	-	-	-	-
Rhodothamniella codicola [a]	X?	-	X!	-	-	-	-	X?	-	-	-	X?	-	-	-
Rhodymenia erythraea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X!
Symphyocladia sp.	-	-	-	-	X!	-	-	-	-	-	-	-	-	-	-
Womersleyella setacea	X	X	X!	X	X	-	-	X	X	X	-	-	-	-	-
Plantae															
Caulerpa racemosa ("inv. variety")	-	X	X	X	X	-	-	X	X	X	X!	X	X	X	-
Cladophora cf *patentiramea*	-	-	-	-	-	-	-	-	-	-	-	-	-	X!	-
Codium fragile subsp. *tomentosoides*	X	X	X!	X	-	X	X	X	X	-	-	X	X	-	-
Codium taylori	-	-	-	-	-	X	-	-	-	-	-	-	-	X!	X
Number of introduced taxa	13	11	17	9	13	10	7	16	10	8	2	7	5	7	6
Number of primary introductions	1	-	8	-	6	1	-	4	1	2	1	1	-	2	2

[a] *The Mediterranean distribution of this species, for a long time confused with* R. caespitosa *(as* Acrochaetium codii*), is probably larger (see Bidoux and Magne, 1989).*

Sardinia, nine species were introduced there via secondary routes (Table 7). In addition, pristine habitats of the Corsica Nature Reserve of Scandola are now strongly invaded by *Womersleyella setacea* (unpublished data). In the same way, the number of introduced species via ship transport is higher in the western Mediterranean than in the eastern basin, despite the fact that species diversity is higher in the western basin (Boudouresque, 1995).

Is species diversity higher, equal or lower in donor regions than in the Mediterranean recipient regions ? No general rule can be drawn. Are species which are invasive* in the Mediterranean abundant or rare in the donor areas ? According to available data, *Acrothamnion preissii, Asparagopsis armata, Caulerpa racemosa* "invasive variety" (unpublished data) and *Womersleyella setacea* seem to be rather inconspicuous species in donor areas.

IMPACT OF SHIP TRANSPORTED INTRODUCED MACROPHYTES

It is worth noting that nothing is known about the possible impact of most of the species introduced to the Mediterranean Sea via ship transport. Of the nine taxa of macrophytes considered by Boudouresque and Verlaque (2002) as invasive in the Mediterranean Sea, four taxa were probably or possibly introduced via ship transport, namely *Acrothamnion preissii, Asparagopsis armata, Womersleyella setacea* (Rhodobionta) and the "invasive variety" of *Caulerpa racemosa* (Plantae) (Ribera and Boudouresque, 1995; Boudouresque and Verlaque, 2002; Durand *et al.*, 2002).

Few data are available on the ecological impact of these taxa. In some localities (e.g. the Tuscan Archipelago, western Italy), *Acrothamnion preissii* is dominant on subtidal sea bottoms and often forms dense turf which covers rocks, other macrophytes and seagrasses. Its quantitative dominance is particularly high on *Posidonia oceanica* rhizomes: up to 90% in shallow meadows. Turfs trap sediments, forming a stratum which prevents the development of other macrophyte species and reduces species diversity and equitability (Piazzi *et al.*, 1996; Piazzi and Cinelli, 2000, 2001; Piazzi *et al.*, 2001a). *Womersleyella setacea* often constitutes mixed stands with *Acrothamnion preissii*, e.g. in western Italy, so that it is difficult to distinguish its specific impact. In sites (such as in Corsica, Sardinia and Sithonia Peninsula, Aegean Sea) and in habitats in western Italy where the latter species is not present, the effect of dense carpets of *Womersleyella setacea* appears to be very similar to those of *A. pressii* (Airoldi *et al.*, 1995; Athanasiadis, 1997; Piazzi and Cinelli, 2000; Piazzi and Cinelli, 2001; Piazzi *et al.*, 2001a). *Asparagopsis armata* is strongly avoided by grazers such as the sea-urchin *Paracentrotus lividus* and the fish *Sarpa salpa*, due to toxic secondary metabolites. This may be the reason why locally it constitutes dense stands in the north-western Mediterranean basin (Sala and Boudouresque, 1997). Finally, with rapid horizontal elongation of the stolons (up to 2 cm d-1), *Caulerpa racemosa* ("invasive variety") overgrows native macrophyte species along the Tuscan coast (western Italy). As a consequence, the phytobenthic community structure is deeply changed: species cover, number of species and Shannon-Weaver diversity index greatly decrease. The most affected species are those of the encrusting and turf strata (Table 8) (Ceccherelli *et al.*, 2001; Piazzi *et al.*, 2001b, 2001c).

CONCLUSION

In the Mediterranean, fouling seems to be more important as a vector of macrophyte introduction than ballast waters. Although its relative importance is on the decrease, in contrast with aquaculture, it is still functioning, both as a primary vector (from donor areas to the Mediterranean) and as a secondary vector (within the Mediterranean). The Pacific ocean and

Table 8. Comparison of mean species number and mean Shannon-Weaver diversity index for macrophytes on dead matte of *Posidonia oceanica* and rocky bottoms in control and areas colonized by *Caulerpa racemosa* along the Tuscan coast, western Italy (October, 18 months after the start of the invasion). All differences are significant. Numerical values are taken from the author's figure. From Piazzi *et al.* (2001b).

	Dead *Posidonia oceanica* matte		Rocky bottom	
	Control	Colonized	Control	Colonized
Mean species number	26	14	32	18
Mean diversity index	1.7	0.4	2.2	1.2

* We define as invasive an introduced species which is ecologically and/or economically harmful.
Within recipient ecosystems, this type of species acts as a new key species: it either has a strong impact on native keystone species or it takes their place. (Williamson and Fitter, 1996; Boudouresque and Verlaque, 2002).

warm biogeographical regions are the main donor areas. Through the past 40 years, no significant change was detected in this pattern. There is no clear relationship between the species diversity of donor areas and that of Mediterranean recipient areas, nor between the abundance of the candidate species in the donor area and its invasive success in the Mediterranean.

Assessing scale and impact of ship-transported alien fauna in the Mediterranean ?

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Ship-mediated introductions are well known world-wide for many taxa, but documentation of the phenomenon in the Mediterranean Sea has remained incomplete. Few ship-transported species have a noticeable economic effect in the Mediterranean: fouling serpulid worms are nuisance in ports and marinas, whereas the swimming crab *Callinectes sapidus* is commercially fished. The question mark was placed in the title to call attention to the fact that at present we possess only fragments of the information necessary to tackle the complex task of assessing the scale and impact of ship-transported alien fauna in the Mediterranean. Because ship-mediated introductions have been only incidentally and infrequently documented in the Mediterranean, the number of ship-transported species or their percentage of the total fauna remains uncertain. Consequently, we provide here approximate estimates for some key groups, the more conspicuous cases, and general indications concerning the gaps in our knowledge.

Although the Mediterranean has a long tradition of scientific investigation, regularly-updated, reliable inventories and easily accessible regional faunas are available only for few groups. For most groups only incomplete, outdated and obsolete works are available, resulting in misidentifications or misleading data. Compiled lists of names like ERMS (European Register of Marine Species; Costello *et al.*, 2001) may satisfy bureaucrats but are of little scientific use and cannot palliate the lack of practiced taxonomists and of urgently needed regional faunas (see also Boero, this volume).

Programs and initiatives of regional environmental monitoring, including monitoring of the impact of alien species, are increasing in number, though the number of practicing taxonomists in the region – essential for accomplishing the task – has been in decline since the 1970s. For many invertebrate taxa no specialist has been studying the Mediterranean fauna for a generation, and even at a wider geographical scale it may be difficult to find a competent taxonomist to study them. Whereas the community of Mediterranean phycologists covers the whole diversity and satisfactorily replies to the challenge of assessing the flow of arriving aliens (Boudouresque and Verlaque, 2002; Boudouresque and Verlaque, this volume), the community of invertebrate specialists, faced with a great diversity of complex construction types, is unable to cover the knowledge gaps and to supply the urgently needed precise information. Also, the intentional introduction of species for large-scale aquaculture has been the source of many unintentional introductions. Currently, aquaculture-transported macrophytes are far better documented than the rest of the exotic biota (Verlaque, 2001; Boudouresque and Verlaque, this volume).

Given the decreasing numbers of specialists and the increasing gaps in competence, it is obvious that distinguishing between elements of the indigenous fauna and newcomers from elsewhere is increasingly difficult. With resignation, we have to admit that most newcomers escape our notice, at least until they are present in sizable numbers. We may notice alien species early if these fulfill one or more of the following requisites: belonging to one of the currently investigated taxa – either for their economic value such as fishes, decapod crustaceans and molluscs, or for their aesthetic and interest for collectors and amateurs like molluscs; being of a conspicuous size and shape; and appearing in large enough numbers that impact fisheries, tourism and public health. Experience has shown that for various reasons, arriving exotic species commonly escape immediate detection and are identified only incidentally, or when a special area or habitat are studied. These considerations pertain to the alien fauna that enters the Mediterranean Sea in general.

Navigation has been the oldest way of transferring marine species into the Mediterranean Sea from distant biogeographical provinces (Zibrowius, 1992; Galil, 2000). We presume that this process started with the first transoceanic voyages that followed the discovery of the sea routes to the "East"- and "West"- Indies. The inflow of species from the Red Sea via the Suez Canal – "Lessepsian migration" (Por, 1978) – took a spectacular turn in the second half of the 20th century, following the completion of the high dam at Aswan that reduced Nile water flow into the Mediterranean. The "Lessepsian migration" has been closely watched, because it involves, among other taxa, fish, which, unlike most invertebrates, are of potential commercial value.

Ship-borne biota may arrive as part of the fouling community or in ballast. Fouling communities on ship hulls, constructed of wood or metal, vexed mariners throughout the ages and obliged them to take their vessels on shore for cleaning. Worse, in former times the wood boring fauna could weaken the fabric of the wooden hulls. The solid ballast consisting of stones and sand, carried by vessels till the end of the 1800s may have contained species. The evolving shipping technologies altered the nature and the composition of ship-transported fauna. Though the use of efficient antifoulant paints reduced hull fouling, the ever increasing volume of shipping, together with expanding routes and destinations, the higher speed attained by modern vessels, meaning less time spent between harbours, may give fouling organisms a chance at arriving at some convenient place to colonize. However, the focus of the past 20 years has been the biota transported in ballast water and sediments, especially organisms possibly hazardous to human health (Hallegraeff, 1998; Drake, this volume). Often taken in coastal waters or in harbours, ballast water and sediments contain representatives of most aquatic taxa, from fish to protists. The increase in volume of shipping and speed of vessels means that the Mediterranean Sea will be "enriched" by new arrivals. In addition to the biota transported as hull foulants and in ballast water and sediments, some organisms may arrive in fishing nets, sea chests and in anchor compartments.

The basins in the Mediterranean Sea differ in their salinity, seasonal temperature range, and minimum and maximum temperatures, to refer to few of the physical parameters that can prove critical for an exotic species in matters of surviving and establishing populations. Species of different origins may have a chance in one or the other part of the Mediterranean: (sub)tropical species in the Levantine Sea, temperate species in the northern Adriatic and in the Marmara Sea, etc. Environments already characterized by a less diversified fauna seem to be more receptive to alien species, i.e. estuaries, lagoons, harbours, and the Levant in general, hence the success of the Lessepsian migrants.

Major harbours exposed to a strong inflow of ship-borne aliens, as well as lagoons used for aquaculture and receiving both intentional and unintentional introductions, may serve as foci for secondary ship-mediated dispersal within the Mediterranean. The northern Adriatic lagoons are situated near both large-volume harbours and support intense aquaculture farming. Recent studies have amply demonstrated that the combination of transport vectors results in highly invaded communities (Sacchi *et al.*, 1989; Mizzan, 1999; Occhipinti Ambrogi, 2000a; Occhipinti Ambrogi, this volume). Berre Lagoon, near Marseille on the Mediterranean coast of France, though highly polluted is home to the ship-transported serpulid polychaetes *Hydroides dianthus* and *Ficomomatus enigmaticus*, the crabs *Rhithropanopaeus harrisii* and the extremely abundant bivalve *Mya areanaria;* a single early report of *Callinectes sapidus* was recorded from the lagoon

as well. Thau Lagoon, on the Mediterranean coast of France, is notorious for its many unintentionally introduced aquaculture aliens (Verlaque, 2001), but seems less impacted by ship-borne fauna, although it is connected with the industrial and ferry harbour of Sète. However, no detailed survey of exotic fauna has been conducted there. Similarly, alien species from the Black Sea, where they originally arrived by shipping, may in turn move into the Mediterranean, through natural dispersal, or by secondary ship-transported dispersal. It is often as difficult to identify the original vector as it is to track subsequent dispersal.

The compilation of data on exotic species in the Mediterranean by Zibrowius (1992) covered most taxa and invasion vectors, including shipping. Over the past decade, a wealth of new data became available, mostly concerning Erythrean invaders for the three major groups that are the subject of the first volumes of the "CIESM Atlas of Exotic Species in the Mediterranean". The volumes on fishes (Golani *et al.*, 2002) and crustaceans (essentially decapods; Galil *et al.*, 2002) have been published, the volume on molluscs will soon follow (preliminary version at the CIESM web site <www.ciems.org/Atlas>).

The following paragraphs summarize the extant information on ship-mediated aliens, or highlight the lack of reliable information for some taxa.

Sponges

We lack reliable information on exotic sponges in the Mediterranean (J. Vacelet, pers. comm., 2002). Early references to possibly Lessepsian species, reiterated by Por (1978), did not convince sponge experts. Likewise, there is no evidence of ship-mediated introduction. A singular calcareous sponge, discovered in Thau Lagoon, may be an introduced exotic species (under study by M. Manuel), and in that case probably an unintentional introduction with exotic oysters.

Hydroids

This group comprises hundreds of species (many described independently as the benthic hydroid stage and the pelagic medusa stage; Boero and Bouillon, 1993), some of which are well represented in harbour and ship fouling communities. The world-wide distribution ascribed to many of the species needs verification, but one may wonder if some are ship-mediated introductions (Boero, this volume). Secondary spread by shipping may also have contributed to the present distribution. A stinging lessepsian invader, *Macrorhynchia philippina*, already established in Lebanon, may spread further by shipping.

Scleractinians

Scleractinian corals as shipping-mediated invaders were a surprise, but two cases are now well documented, *Tubastraea* in the tropical west Atlantic and a zooxanthellate, colonial coral tentatively identified as *Oculina patagonica* De Angelis, 1908, in the Mediterranean. Its present Mediterranean distribution may be partly explained by secondary dispersal, probably starting from Spain: many sites along some 1000 km of coastline of Spain from the industrial area of Algeciras (Strait of Gibraltar) to the harbour of Blanes (Catalonia), and including extreme abundance in the harbour of Alicante; 3 localities on the Ligurian coast of Italy; Alexandria (Egypt); along the coasts of Israel (common) and Lebanon (a few localities). Detailed biological and ecological information is now available on this species (Fine *et al.*, 2001), which can multiply asexually, spreading single bailed out polyps (Kramarsky-Winter *et al.*, 1997).

Ctenophores

Mnemiopsis leidyi A. Agassiz, 1865, (or *M. mccradyi* Mayer, 1900) entered in the Mediterranean from the Black Sea, where the species, presumed to have arrived in ballast water, had an immense impact (Kideys, this volume). It has been reported from the Aegean Sea (Tarkan and Kideys, 2001) and from southeastern Turkey (Kideys and Niermann, 1993).

Molluscs

Most of the species of exotic molluscs recorded in the Mediterranean (www.ciesm.org/atlas) are Lessepsian migrants. Some species have been introduced through aquaculture (intentionally or unintentionally), a fewer number may have been ship-borne. The Indian Ocean gastropod *Strombus persicus* Swainson, 1821, very successful in the Levant, is considered a ship-borne

arrival since it is absent from the Red Sea and thus not a Lessepsian migrant *stricto sensu*. The presence of *Rapana venosa* (Valenciennes, 1846) in the northern Adriatic Sea can be explained by secondary dispersal, probably from the Black Sea where it first occurred as a ship-transported exotic species (Zolotarev, 1996). The slipper limpet *Crepidula aculaeta* (Gmelin, 1791) forms a dense population in Alicante harbour, SE Spain (first mention was as *C. calypstraeiformis* in Zibrowius, 1992). *Anadara inaequivalvis* (Brugière, 1789) and *Anadara demiri* (Piani, 1981) proved very successful, respectively in the Adriatic and in the Aegean Sea. *Mya areanaria* Linnaeus, 1758, originates in the western Atlantic, and is present in the Berre lagoon near Marseilles at least since 1990, probably arriving in ballast water. At present it is so common that its shells litter the shore of the lagoon, and live specimens are washed ashore in large quantities following storms (Fig 1). Similarly, in the Black Sea it has been known since the 1960s when it was intentionally introduced for aquaculture purposes (Zenetos *et al.*, 2003).

Fig. 1. Shells of *Mya areanaria* beached at Berre Lagoon, Jaï beach, near Marseilles, February 2002.

Polychaetes

The Mediterranean has been spared thus far an invasion on the order of *Sabella spalanzanii* (Viviani, 1805) in Australia (Andrew and Ward, 1997; Currie *et al.*, 2000).

The polychaete worms of the Mediterranean Sea, with the possible exception of the Serpulidae, are in dire need of a critical, detailed and updated revision. Some taxa described in the eastern Mediterranean are declared Lessepsian migrants when they seem to fit species described in the Indo-Pacific, other recently discovered species may be ship transported – but heed should be taken pending a thorough inventory of the Mediterranean polychaete fauna. Only in the case of few species there may be arguments for ship-mediated introduction, though few more may be among the "cosmopolitan" species in harbour environments.

In the two "calcareous tube worm" families, Serpulidae and Spirorbidae, several species have been recognised to be shipping-transported introductions (data summarised by Zibrowius, 1992). Three alien species of the genus Hydroides had already been present in the Mediterranean harbours' fouling communities as early as the late 19th century, *H. elegans* Haswell, 1883, remaining the most common one. *Ficopomatus enigmaticus* (Fauvel, 1923) is another successful early invader that showed up in the Mediterranean soon after its nearly simultaneous discovery in northern France and southern Britain. *Spirorbis marioni* Caullery and Mesnil, 1997, discovered from Marseilles (not necessarily its point of first arrival) and traced back into the 1970s, is present now in harbours all over the Mediterranean, from the Strait of Gibraltar to Croatia, Turkey, Cyprus and Lebanon. The present distribution of another exotic spirorbid discovered at Marseille requires reinvestigation. Small vessels may be an essential vector of secondary dispersal for these spirorbids.

Balanomorph cirripeds

Barnacles are common components of hull fouling communities, but their status as aliens should be closely examined. A study of the balanid fauna of Roman and Greek harbour structures would be enlightening.

Zibrowius (1992) pointed out that the antipodal *Elminius modestus* Darwin, 1854, so successful on the Atlantic coast of Europe and expected to spread further, was still unknown in the Mediterranean. In the late 1990s this species was found in the Thau Lagoon, where it arrived as a "fellow traveler" of oysters transferred from the Atlantic. The wide-spread and common *Balanus trigonus* Darwin, 1854, has occasionally been considered a rather recent invader of Pacific origin.

Decapod crustaceans

Of ca. 350 decapod species in the Mediterranean, 42 are considered of Erythrean origin (Galil *et al.*, 2002), and 10 are ship-mediated introductions. Among the few successful invaders is the western Atlantic Blue Crab, *Callinectes sapidus* Rathbun, 1896, an eurythermal and euryhaline agressive species with high fecundity that locally attained a certain commercial importance. *Libinia dubia* H. Milne Edwards, 1834, from the western Atlantic, is well established in southern Tunisia. The tropical Atlantic crab *Percnon gibbesi* H. Milne Edwards, 1853, previously known from Madeira, has spread into the southwestern basin and the Strait of Sicily. *Dyspanopaeus sayi* (Smith, 1869) and *Rithropanopaeus harrisii* (Gould, 1841), both originating from the northwestern Atlantic and now well established in lagoons of the northern Adriatic, have probably arrived by ship but unintentional aquaculture-related introduction cannot be excluded, though the arrival of *R. harrissii* in Berre Lagoon where no aquaculture takes place must be ascribed to shipping. *Hemigrapsus sanguineus* (de Haan, 1835), an east-Asian species already successful along the Atlantic coast of France where it arrived with oysters imported for enhancing production, was recently recorded in Croatia. Its presence there may be ascribed to secondary dispersal by shipping in European waters. Secondary intra-Mediterranean dispersal by shipping may also explain the record of *Portunus pelagicus* (Linnaeus, 1758) in eastern Sicily, far away from the Levant Sea it entered in the late 1800s from the Red Sea.

Amphipod crustaceans

Of the approximately 450 Mediterranean amphipod crustaceans recently documented by Ruffo (1982-1998), and Bellan-Santini and Ruffo (1998), few species are presented as Lessepsian invaders, including a species described in the early 20th century from Algeria and species reported from the northwestern Mediterranean and from the lagoon of Venice. The rationale for labelling them Lessepsian lies in their reported occurrence in both the Mediterranean and the Red Sea, or in the Indo-Pacific ocean. Bellan-Santini and Ruffo (1998) and Bellan-Santini (1999) list several other species known for their propensity for passive dispersal and presence in the Mediterranean harbour fouling community, or considered cosmopolitan (verification needed). The underlying suggestion is that ship-transported exotic species may be found in this category. However, their status needs further investigation. *Elasmopus pectenicrus* (Bate, 1862), reported repeatedly from the Levantine Sea and from the Venice lagoon could be an intra-Mediterranean ship-transported exotic.

Echinoderms

Only few Lessepsian echinoderms (one asteroid, three ophiuroids, one holothurian) have been described from the Mediterranean, and those are confined to the southeastern part [early data summarized in Por (1978) and Zibrowius (1992)]. It is suggested that two small sized Lessepsian, *Ophiactis savignyi* (Müller and Troschel, 1842) and *Ophiactis parva* Mortensen, 1926, common along the coast of Lebanon (Stöhr, Zibrowius, Bitar, in preparation), may further disperse by shipping. These cryptic ophioroids hide in crevices and in any kind of shelter, including empty barnacle shells and have already been identified in harbour communities at Beirut (Lebanon) and Famagusta (Cyprus). The northeastern Atlantic asteroid *Asterias rubens* Linnaeus, 1758, has been reported from the Bosphorus (Albayrak, 1996), and the Marmara Sea (B. Yokes, pers. comm., 2002), and may be considered a shipping-mediated invasion. *A. rubens* is a conspicuous macrobenthic species and being voracious should have a detectable impact on benthic communities. Its spread should be monitored, considering the damage wrought by *Asterias amurensis* Lütken, 1871, in South Australia and Tasmania (Buttermore *et al.*, 1994).

Ascidians

Ascidians have been found in harbour and ship-fouling communities around the world (Monniot *et al.*, 1985; Lambert, 2002), and some species occurring in the Mediterranean are doubtlessly ship-borne introductions. Such is the case of an ascidian described by Monniot (1981) as *Microcosmus exasperatus* Heller, 1878 – possibly, in part, *M. squamiger* (A. Ramos, pers. comm., 2002). This species lives in dense populations of agglomerated individuals in Mediterranean harbours and nearby areas.

Fishes

Fifty-seven fish of Indo-Pacific origin in the Mediterranean have been described as Lessepsian migrants (Golani *et al.*, 2002), and their number is ever increasing. Among the records in the *CIESM Atlas* are two exotic species found in Italian waters that may be ship-transported with ballast water. *Pinguipes brasilianus* Cuvier and Valenciennes, 1829, (two records) is a conspicuous shallow water species from the southwestern Atlantic. Ship-mediated fish introduction into the Mediterranean seems surprisingly rare, especially considering the data compiled by Wonham *et al.* (2000). Investigation of small non-commercial fish families (Gobiidae, Blennidae) in Mediterranean harbours and contiguous environments may augment the number.

Conclusive remarks

We lack detailed and reliable information on possible ship-related introductions for most taxa, excluding perhaps fish and some large, conspicuous invertebrates. The reasons are multifarious: lack of awareness of faunal changes due to human activities; lack of meticulous, detailed surveys in bioinvasion-vulnerable environments; lack of updated regional faunas and lack of taxonomic expertise, to a point where many groups lack a regional expert. This is a severe handicap when issues of introduced organisms (including ship-mediated invasions) arise, typically following some damage. "Cosmopolitan" species occurring in harbours and ship-fouling communities deserve special scrutiny. Molecular approaches may provide additional information and contribute to elucidate the origin of the species, and perhaps its paths of dispersal.

At present the number of recorded ship-mediated alien species in the Mediterranean lag far behind the inflow of alien migrants (www.ciesm.org/atlas). From those records it appears that ship-transported alien species tend to inhabit more marginal, unstable or in some way "less saturated" environments, i.e., lagoons and harbours, and many fail to settle the open coastline. These faunistically impoverished environments are in a way comparable to the Black Sea, where ship-transported aliens are more dominant and their impact clearly evident (Kideys, this volume).

Shipping patterns ensure that the Mediterranean Sea both "imports" and "exports" biota, such as the polychaete *Sabella spallanzanii* and the crab *Charybdis helleri*. Facing the ever-increasing shipping volumes and the inherent probability of more faunal exchanges, the Mediterranean scientific community should be aware that lack of taxonomic expertise and attention to meticulous faunal surveys will hamper actions to curb potentially harmful invaders.

Susceptibility to invasion: assessing scale and impact of alien biota in the Northern Adriatic

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INTRODUCTION

The Northern Adriatic Sea offers many cases of mass invasion of non-indigenous species (NIS), more than in any other part of the Italian coastline. Not only the largest populations of NIS are to be found here, the relative importance of those species is high, also in terms of species numbers (Occhipinti Ambrogi, 2002). In the last 30 years, 41 alien species (13 algae, 27 invertebrates, 1 fish) have been recorded in the Northern Adriatic.

Habitats of special interest for bioinvaders are the large semi-enclosed, brackish lagoons, particularly the Lagoon of Venice (Occhipinti Ambrogi, 2000a). The ecological features of the area suggest that it is subjected to considerable stress, both from natural causes (e.g. considerable freshwater runoff) and from human impact (eutrophication and pollution). These, in turn, facilitate the introduction, the establishment and the subsequent spread of NIS.

CASE HISTORIES

The algae *Undaria pinnatifida* and *Sargassum muticum* overgrew large areas in the Lagoon of Venice and have altered the vegetal landscape of many navigable canals and marshes, together with *Desmarestia viridis*, recently found in the Chioggia sector. *Antithamnion pectinatum* and *Polysiphonia morrowii*, that have been repeatedly found in Venice, are known to be potentially invasive (Curiel *et al.*, 1999 and 2001).

The bivalves *Crassostrea gigas* and *Tapes philippinarum* were introduced intentionally for aquaculture in the 1960s and in the 1980s respectively (Ghisotti, 1971a,b; Cesari and Pellizzato, 1985), but have since established large self-sustaining populations in the wild. Many algae and invertebrates may have been introduced unintentionally in shipments of restocking spat.

A bryozoan of Pacific origin, *Tricellaria inopinata,* described from the Lagoon of Venice, is considered highly invasive. Two species of *Anadara (= Scapharca)* are invasive: *A. inaequivalvis* has been known since the 1970s (Ghisotti, 1973), whereas *A. demiri*, was introduced more recently but is fast spreading (Morello and Solustri, 2001 and own observations). The mussels *Xenostrobus securis* and *Musculista senhousia* have built up huge populations in the Po river delta (Turolla, 1999; Mistri, 2002), and the xanthid crab *Dyspanopeus sayi* was the most widespread decapod in the Lagoon of Venice a few years back (Mizzan, 1995), but its populations have been declining recently. The notoriously invasive gastropod *Rapana venosa,* was introduced in the 1970s (Mann *et al.*, 2002) and has since spread along the western coast, but apparently

without severe consequences. A study of the biology of the population living on breakwaters along the Emilia Romagna coast and the surrounding sandy bottoms, collected data on its morphometric parameters, density, and reproduction (Savini and Occhipinti-Ambrogi, in prep.). Only one alien originating form the Indo-Pacific (see Golani *et al.*, 2002) fish species has been recorded, and recorded only once in the area (Parenti and Bressi, 2001).

It is difficult to assess the consequences of NIS on the native biota and the existing ecological equilibria. For instance, the introduction of both *C. gigas* and *T. philippinarum* has followed, rather than caused, the decline of the native populations of *Ostrea adriatica* and *Venerupis aurea*. The impact of massive development of clams is generally regarded as positive (Breber, 2002), but the consequences of bottom disturbance and water turbidity by fishing gears massively used in the Venice Lagoon cannot be overlooked. Mass development and fluctuation of macro-algal populations are the rule inside the lagoons: *Ulva rigida* blooms – and quite possibly toxic phytoplankton blooms (Wyatt, this volume; Honsell *et al.*, 1992; Honsell, 1993) – caused serious problems in Venice well before the Japanese algae were introduced (Sfriso and Marcomini, 1996).

A long-term analysis of the bryozoan community before and after the introduction of *T. inopinata* in the Lagoon of Venice highlighted a progressive homogenisation of the assemblages dominated by the introduced species (Occhipinti-Ambrogi, 2000b).

VECTORS

The main vector for introductions in the Northern Adriatic area is probably aquaculture, through both intentional introductions and accessory species associated with shellfish culture. Maritime traffic as well may have played an important role in the introduction of some species and in the secondary dissemination of others.

Transoceanic cargoes and oil tankers offload in the major ports in the Northern Adriatic : Trieste, Venice, Ravenna and Ancona (Fig.1); no assessment has yet been made, to our knowledge, of the ballast water discharge or of other parameters for estimating the inoculant pressure. The number of regular interoceanic ship lines that use these ports is quite large (Fig. 2), 40% of the lines connect the Adriatic with the Indian Ocean, China Sea and Japan (Fig. 3).

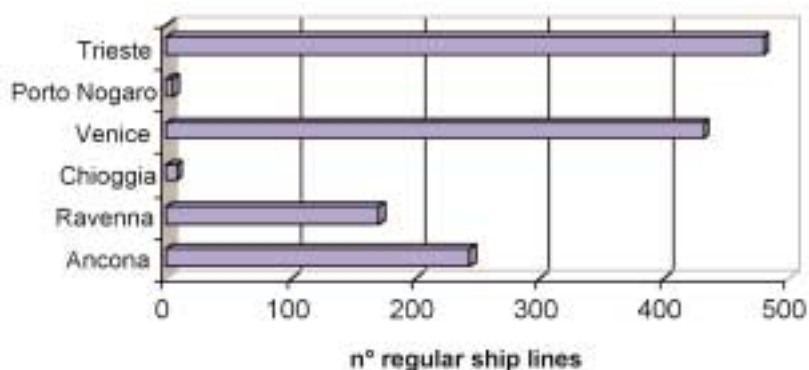Fig. 1. Main ports and localities in the Northern Adriatic Sea.

Fig. 2. Number of regular interoceanic ship lines departing from/arriving to the main ports of the Northern Adriatic.
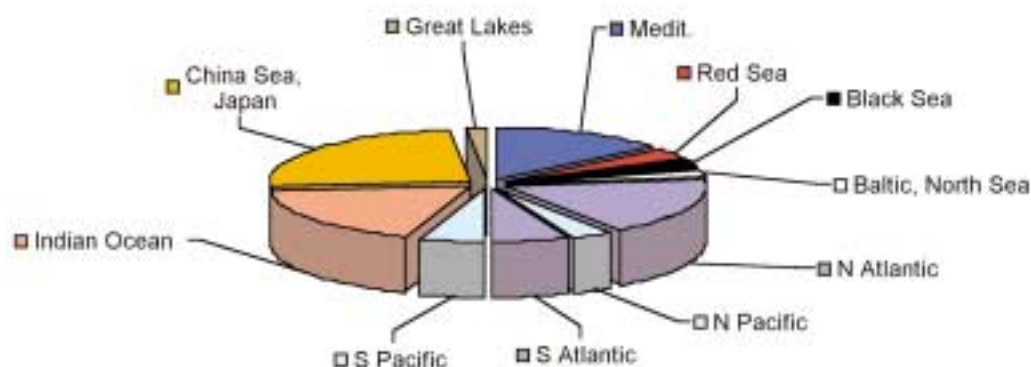

Fig. 3. World distribution of regular ship lines to and from the main ports of the Northern Adriatic (data from "L'Avvisatore marittimo, linee regolari dai porti d'Italia", ed. 2000).

Smaller recreationnal vessels are also very abundant in the Northern Adriatic, with itineraries that include many ports and marinas in the Mediterranean, and smaller vessels may play an important role in the secondary spreading of NIS. Marinas and harbours along the coast offer many landing places (Fig. 4) and provide opportunities for NIS dissemination by recreational vessels through hull fouling, ballast and small spaces on board. The data on boat landing places can be described by the RPCI index (recreational port capability index = n° of landing places per km of coastline). The index values are high in the northernmost part of the Adriatic Sea in comparison with the rest of the Italian coast and neighbouring countries (Fig. 5).

Fisheries operations too may help dissemination of NIS by discarding by-catch at sea, while sorting the commercial products and cleaning the fishing gear or collecting devices.

THE NORTHERN ADRIATIC SEA: A DONOR AREA

The large populations established by many NIS in the Northern Adriatic coast of Italy constitute a large reserve of propagules for further dissemination in the Mediterranean and to transoceanic destinations by maritime traffic. This has to be taken into account in examining the scientific basis of risk management of the possible expansion of some of the demonstrable invasive species in the lagoons or coastal reaches of the Adriatic.

The occurrence of the bryozoan *T. inopinata* in northern European marinas (Dyrynda *et al.*, 2000; De Blauwe and Faasse, 2001) suggests the possibility of long range diffusion of NIS through recreational vessels that are known to travel between the Northern Adriatic and the Atlantic Ocean. Some of the species described – *Anadara, Musculista, Xenostrobus,* algae – have at least some sessile (or fouling) life stage, and could be easily transferred on vessel hulls. The high concentration of NIS propagules in particular areas of the Northern Adriatic suggests a high
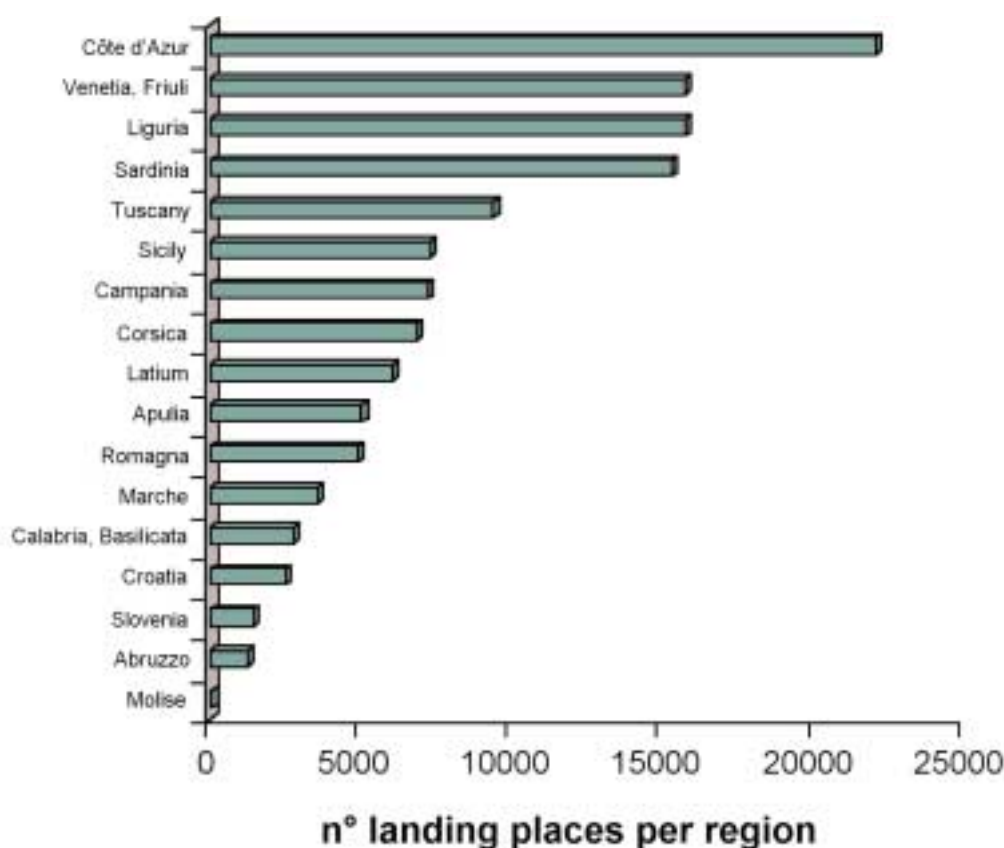
Fig. 4. Number of landing places in recreational marinas of Italian regions and neighbouring countries (Data from "Pagine Azzurre, il Portolano dei Mari d'Italia", ed. Pagine Azzurre, 2000).

probability of being transported by ships through ballast water and boats. For instance, an investigation of the Rapa whelk populations off the town of Cesenatico, on the Emilia Romagna coast (Savini and Occhipinti-Ambrogi, in prep.), examined the two main habitats occupied by the adult snails: sandy bottoms less than 10 m deep and the rocky faces of wave breakers that have been erected since the 1970s parallel to the coast in order to prevent beach erosion. Statistically significant differences in morphometric parameters were found between the two populations; moreover, the observation of shell epibionts and shell erosion strongly suggests that there are two separate groups living on soft and hard bottoms. The average density of Rapa whelks is one individual per one linear meter of wave-breaker. Results from a careful census and an experimental weekly removal of the whelks' egg-cases throughout the reproductive period (May to September), indicate that nearly 90 egg-cases were laid weekly on each linear meter of wave-breaker. A single egg-case contains ~1000 larvae (Mann *et al.*, 2002). If we assume a comparable density and reproductive rate for the entire length of the artificial rocky substrate present from south of the Po River Delta to Ancona (73 km) – a reproductive period lasting 10 weeks; 10% survival rate through hatching and 10% survival at swarming - the number of larvae produced annually along the NW Adriatic coast would be 650 millions. The average density of the sandy bottom whelk population near Cesenatico in the summer 2000 was estimated at 4 individuals per 100 m^2. The calculation is based on findings from commercial squid fisheries, nets of which are favored for egg case deposition by Rapa whelks.

Larval transport with ballast water is more easily accomplished if initial concentrations in areas of ballasting are high. The preliminary estimate of population density and reproductive potential of Rapa whelks, made at a single location of the Emilia Romagna coast, may be used to figure the order of magnitude of risk of possible larval export through ballasting in the Northern Adriatic coastal waters. A standard Risk Assessment (Raaymakers, this volume) would require a lot more information, but this can be viewed as a first step.
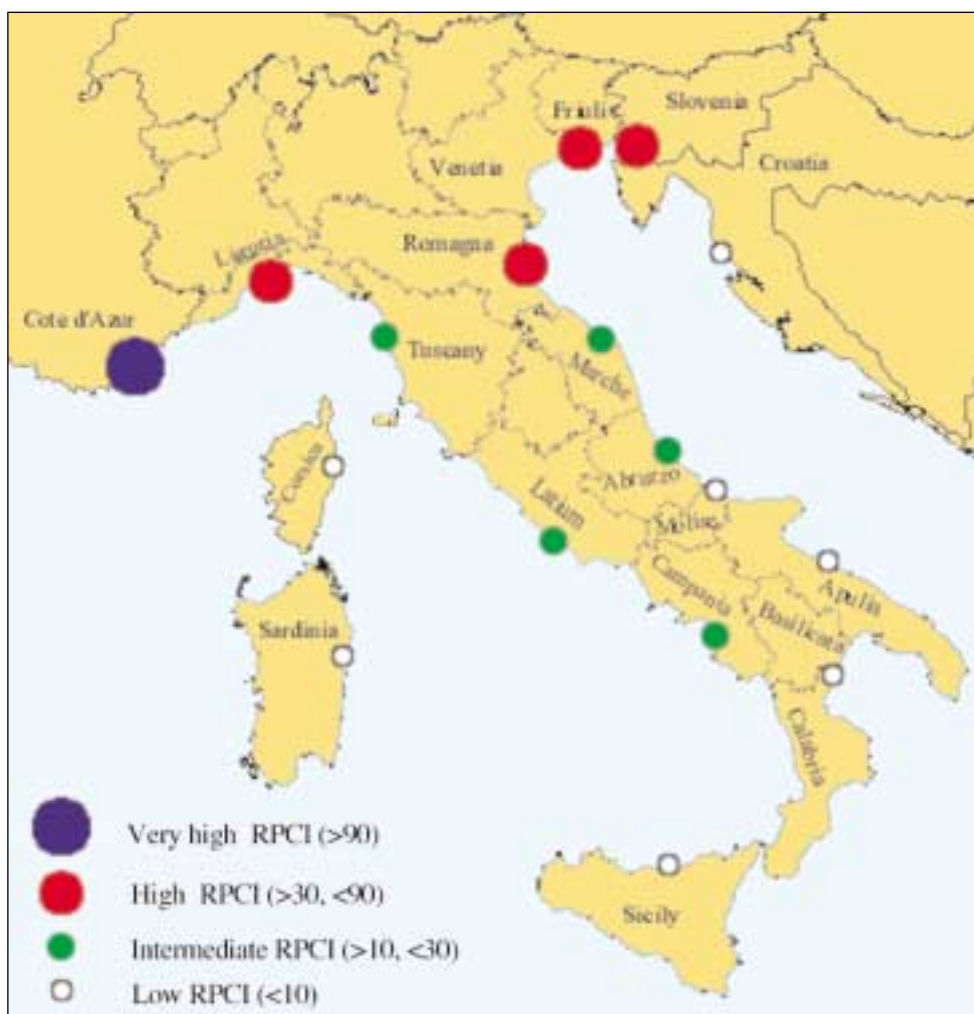
Fig. 5. Recreational Port Capability Index (RPCI = number of landing places per coastal length) of Italian regions and neighbouring countries.

CONCLUSIONS

The Adriatic Sea and its lagoons are inhabited by a large number of NIS, some with large populations, that have arrived from every part of the world ocean.

The factors favouring NIS introduction and mass development in this particular region are: a) the occurrence of intentional introductions and transfers, with the consequent accompanying species, b) large volume of maritime traffic c) environmental stress and high nutrient load of both natural and anthropogenic origin.

The presence of such a large and diverse repository of NIS favours secondary spread within and outside the Mediterranean. The probability of secondary diffusion is enhanced by the presence of numerous commercial ship lines connecting the Adriatic ports with other regions of the world. Moreover the presence of a developed recreational boating fleet suggests a high risk of yet another kind of secondary diffusion (especially at shorter range) of introduced species. The risks are compounded by the phasing out of TBT based antifoulants in the near future (Minchin, this volume).

The risk factors that should be measured and monitored are: a) the source, amount and release location of discharged ballast water; b) a quantification of fouling and other means of transport by recreational boats; c) a comprehensive assessment of the density and reproductive output of some important NIS, such as *Rapana venosa.*

The Ponto-Caspian region: predicting the identity of potential invaders

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More than 50,000 ships passed through the Istanbul Strait in 2000 from the Black Sea to the Mediterranean and back, including 2,500 supertankers more than 200 m long (Öztürk *et al.*, 2001). The shipping volume is expected to increase with increasing production in Central Asian oil fields. Proven oil resources are 6 billion tons, and reserves are estimated at 40 to 200 billion tons. All this oil will be shipped via the Turkish straits.

The number of ships passing the Istanbul Strait has been increasing since 1936 (Fig. 1), when the Montreux Convention regarding the navigation in the strait was signed. Consequently the risk of transporting exotic invaders by ship ballast water and as fouling organisms to the Ponto-Caspian Region has also been increasing as well. Indeed, many of the exotic species that entered the Black Sea after the 1950s have been transported to the Caspian Sea.

Secondary transport of exotic species within the Black Sea, between the Black Sea and the Azov Sea, and between the latter and the Caspian Sea, through the Volga-Don Canal, is highly likely because of the crisscrossing shipping routes and the volume of shipping (Fig. 2). The Volga-Don Canal, which opened in 1952, has been more active since the collapse of the Soviet
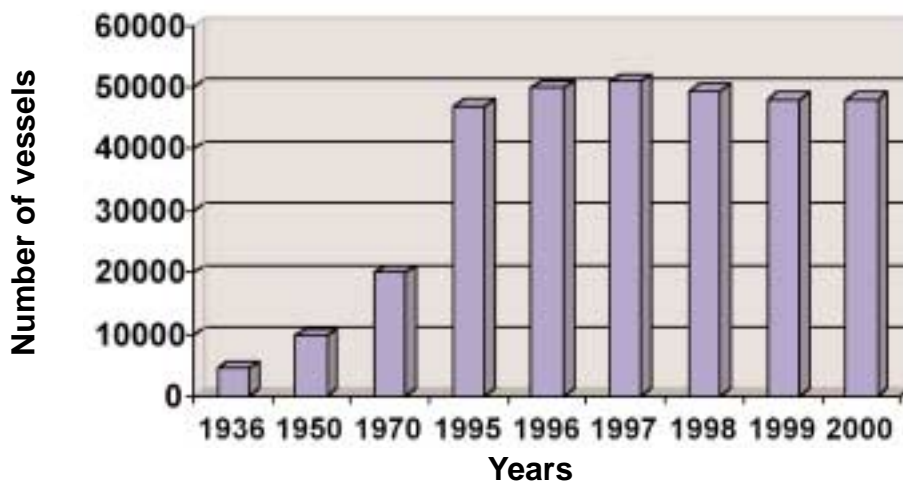

Fig.1. Number of vessels passing the Istanbul Strait.

Fig. 2. The main tanker routes in the Black Sea (Modified from BSEP)

Union because the Caspian states use it for small cargo and fishing vessels originating from the harbors of Baku, Astragan, and others. The shallow Volga-Don Canal does not allow passage of large vessels or tankers.

Twenty-six exotic species have been described from the Black Sea (Zaitsev and Mamaev, 1997). The earliest exotic species is the shipworm *Teredo navalis*, probably introduced into the Black Sea in prehistorical times (Gomoiu and Skolka, 1996). Two exotic species have had significant impact in the Ponto-Caspian Region (see also Kideys, this volume). The veined Rapa whelk, *Rapana venosa*, originally from the Sea of Japan, was introduced into the Black Sea in the 1940s, probably attached to ship hulls. The whelk has successfully colonized and exterminated most oyster and mussel beds in the Black and Azov seas. The large populations spawned an economically important fishery, mainly exported to Far East. The comb jellyfish, *Mnemiopsis leidyi*, which fed mostly on fish eggs and larvae of commercially important pelagic fish species, such as the anchovy and sprat, caused huge economic losses to the Black Sea fisheries (GESAMP, 1997; Öztürk, 1999, 2002).

From the Azov Sea exotic species penetrated the Caspian Sea through the Volga-Don Canal (Volovik, 2000). The geographical isolation of the Caspian Sea is the reason that 88% of its exotic species originate from the Black and Azov seas, or if originating elsewhere, have settled there before settling in the Caspian Sea. These exotic species are distributed predominantly in the central and southern parts of the sea, where the water is more saline and warmer in winter.

The Black, Azov, and Caspian seas are similar in terms of salinity, temperature and dissolved oxygen (Table 1), and their biota is composed of brackish water species and Mediterranean immigrants. The comparable abiotic conditions mean that a successful invader in one sea can easily penetrate the others: thus the comb jellyfish was recorded in the Black Sea in 1982, in the Azov Sea in 1988, and in 1998 in the Caspian Sea (Zaitsev and Öztürk, 2001). The low species diversity is perhaps another factor in the success of exotic species.

Table 1. Abiotic characteristics of the Black, Azov, and Caspian seas.

	Salinity (‰)	Temperature(°C)	Dissolved Oxygen at surface (ml/l)
Black Sea	10-18.3	27-29	5.6-7.4
Azov Sea	10-15	24-25	6-8
Caspian Sea	10-13	22-27	5-9

Of the exotic species in the Black and Azov Seas recorded in the Caspian Sea (Table 2), *Ficopomatus enigmatica* and *Perigonimus megas* are fouling organisms, while *Rhizosolenia calcar-avis, Mnemiopsis leidyi,* and *Rithropanopaeus harrisii tridentatus* are planktonic or have a long planktonic stage. Other exotic species present in the Black and Azov seas may be introduced to the Caspian Sea over time. The invasion of *Mnemiopsis leidyi* and the Black Sea native bivalve *Mytilaster lineatus* has negative consequences in the Caspian Sea (Aladin *et al.*, 2002).

Prediction or identification of potential invaders into the Ponto-Caspian seas is difficult due to our ignorance concerning survival in ballast tanks or fouling communities, as well as the possible origin of the biota in the arriving vessels. However, it can be predicted that macrophytes, invertebrates with a long planktonic stage, and fouling organisms may penetrate the Caspian Sea

Table 2. Distribution of the invasive species in the Black , Azov and Caspian seas possibly introduced in ship ballast water or as fouling (Zaitsev and Oztürk, 2001).

	Black Sea	Azov Sea	Caspian Sea
Plants			
Alexandrium monilatum	+	-	-
Desmarestia viridis	+	-	-
Ectocarpus confervoides	++	++	+
Gymnodinium uberrimum	+	+	-
Mantoniella squamata	+	+	-
Phaeocystis pouchettii	+	-	-
Rhizosolenia calcar-avis	+	+	+
Invertebrates			
Abra ovata	++	++	+
Acartia clause	++	++	+
Acartia tonsa	+	-	-
Anadara inaequivalvis	+	-	-
Aurelia aurita	++	++	+
Balanus eburneus	+	-	+
Balanus improvisus	+	-	+
Barentsia benedeni	++	++	+
Beroe cucumis	+	+	-
Blackfordia virginica	+	-	+
Callinectes sapidus	+	+	-
Conopeum seurati	++	++	+
Corophium volutator	++	++	+
Crassostrea gigas	+	-	-
Doridella obscura	+	+	-
Eriocheir sinensis	+	-	-
Hesionides arenarius	+	-	-
Hypanis colorata	++	++	+
Ficopomatus enigmatica	+	+	+
Mnemiopsis leidyi	+	+	+
Moerizia maeotica	++	++	+
Mya arenaria	+	+	-
Mytilaster lineatus	++	++	+
Nereis diversicolor	++	++	+
Palaemon adspersus	++	++	+
Palaemon elegans	++	++	+
Penilia avirostris	++	++	+
Pentacoelum caspicum	++	++	+
Perigonimus megas	+	+	+
Pleopis polyphemoides	++	++	+
Potamopyrgus jenkinsi	+	-	-
Rapana venosa	+	+	-
Rithropanopaeus harrisii tridentatus	+	+	+
Tenellia adspersa	++	++	+
Teredo navalis	+	+	-
Urnatella gracilis	+	+	-

Notes : ++ Native ,+ Recorded , - Unrecorded

from the Black Sea more easily. Species originating from regions of similar abiotic conditions may colonize in the Ponto-Caspian Region. Also, species lacking predators in the region may have an advantage. Interestingly, the exotic fish species in the region were intentionally introduced, i.e. *Gambusia affinis* and *Mugil soiuy,* and no fish arrived with ballast water. Exotic species enter the Ponto Caspian region through the North Sea-Black Sea-Danube river, Turkish straits and Volga/Don Canal. The "hotspots" for exotic fouling species are the harbours, dockyards and marinas.

The invasive exotics, many of them introduced in ballast water of transoceanic ships, pose a serious threat to the native species of the Black, Azov and Caspian seas, already under threat by pollution and other factors. We believe that an increase in shipping may increase the risk of bio-invasion to the Ponto-Caspian seas. Ballast water management is essential for all vessels, but especially for tankers. We expect that the ballast water Convention will be ratified in 2004 and the non-mandatory Resolution 868 declared mandatory for all vessels.

Assessing extent and impact of ship-transported alien species in the Black Sea

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Enclosed or semi enclosed ecosystems, as the Black Sea, seem particularly sensitive to two modern anthropogenic impacts: eutrophication and biological invasions. Whilst the Black Sea was known as an oligotrophic sea in the 1940s, it became progressively mesotrophic and eutrophic in the 1980s and 1990s. With the increased shipping traffic, the Black Sea has become an important recipient (and donor) region for ship-transported invasive species.

According to Zaitsev and Ozturk (2001), there are 59 species of invasive marine organisms in the Black Sea, not taking into account the temporary planktonic fauna (mostly brought in with the deep current from the Marmara Sea) that may be present in significant numbers (Kovalev *et al.,* 1998a). As seen in Figure 1, the rate of introductions increase, particularly in the last decade.

Many of these introductions, as in the case of several species of copepods (Kovalev *et al.,* 1998a), have gone unnoticed however, the impact of others is unforgettable. Here I present the three most important invasions in the Black Sea: the ctenophores *Beroe ovata* Bruguière, 1789, and *Mnemiopsis leidyi* A.Agassiz 1865, and the gastropod *Rapana venosa* (Valenciennes, 1846) (synonym *R. thomasiana* Crosse, 1861). One might label them "the good, the bad and the ugly".

The original distribution of the veined Rapa whelk, *Rapana venosa* ("the ugly") is the temperate Sea of Japan, Yellow Sea and East China Sea (CIESM Atlas <http://www.ciesm.org/atlas/Rapanavenosa.html>). The whelk was first reported in the Novorossisk Bay in 1946 (Drapkin,
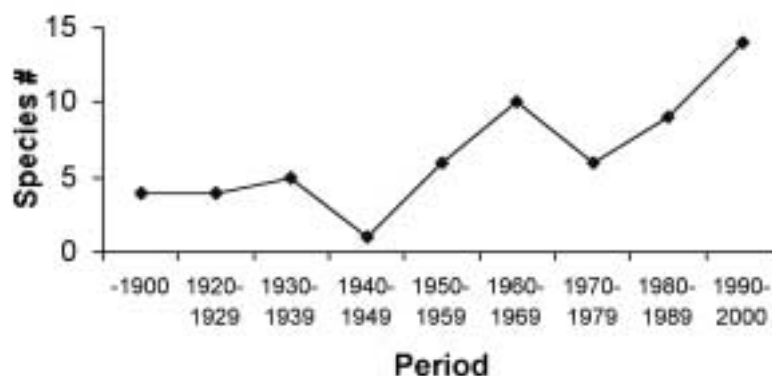

Fig. 1. Number of introduced species in the Black Sea through the 20th century (extracted from Zaitsev and Öztürk, 2001)

1953, cited in Zaitsev and Öztürk, 2001). Its shell is commonly less than 12 cm long in the Black Sea. From June to October it produces egg capsules that are fixed to subtidal hard surfaces (Karayücel *et al.*, 2001). The larvae hatch after 12-17 days and remain 14-17 days in the plankton before settling. It has been speculated that the planktonic larvae have arrived in ballast water, but it is more likely that egg masses have been transported either with the products of marine farming or as fouling on the hull of ships. Adults of *R. venosa* feed mainly on mussels, oysters and other bivalves. It is reported to adversely affect the main native bivalves including the oyster *Ostrea edulis*, the scallop *Pecten ponticus* and the mussel *Mytilus galloprovincialis* in many regions of the Black Sea. It is believed to deplete Gudauta oyster bank on the Caucasus shelf (Chukhchin, 1984, cited in Zaitsev and Öztürk, 2001). The whelk has no predator in the Black Sea. A commercially significant harvest has been developed since 1980s by several riparian nations for export, mainly to Japan and Korea. The Turkish catch was around 10,000 tons (without the shell) in 1988 and 1989, but decreased thereafter below 4,000 tons and in 1995 was only 1,198 tons. Since 1997 the annual catch increased again to around 4,000 tons, valued at around two million US Dollars (Zaitsev and Öztürk, 2001) (Fig. 2). On the Turkish Black Sea coast alone, there are 11 factories processing whelk's meat for export.
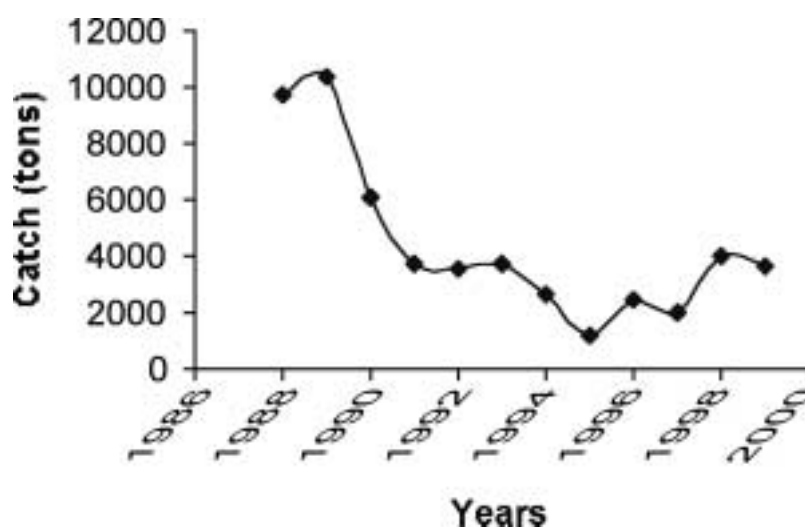

Fig. 2. Catch of the Rapa whelk *Rapana venosa* from Turkish waters (almost all from the Black Sea) (DIE, 1985-99).

The accidental introduction of the ctenophore *Mnemiopsis leidyi* (comb-jelly, "the bad") from the eastern coast of America into the Black Sea via ballast waters in the early 1980s caused unprecedented large-scale ecosystem change. After reaching astounding biomass levels of over 1 kg m^{-2} in the summer of 1989 (Vinogradov *et al.*, 1989), this voracious zooplankton predator devastated the entire basin. Following the ctenophore bloom, sharp decreases were reported by all riparian countries in the landings of the major planktivorous fish (i.e. the anchovy, see Fig. 3) (Kideys, 1994). At the height of *Mnemiopsis* impact, the metrics of landed fish resembled those resulting from overfishing, though fishermen landed fewer fish. The collapse of the pelagic fishery followed a decrease in non-gelatinous zooplankton biomass in all regions (including the deep and eastern Black Sea, Kovalev *et al.*, 1998b) resulting from predation by *Mnemiopsis*. The levels of non-gelatinous zooplankton remained low for several years. A modest increase in non-gelatinous zooplankton was observed in 1994, followed the next year by a secondary increase in *Mnemiopsis* populations. Prior to the mass appearance of *Mnemiopsis*, anchovy was the major consumer of non-gelatinous zooplankton. By feeding on the food, as well as the eggs and larvae, of anchovy, *Mnemiopsis* was responsible for the collapse of the pelagic fisheries (Tsikhon-Lukashina *et al.*, 1991). The economic damage to the Turkish fishery alone is conservatively estimated at several hundred million dollars.

By feeding on herbivorous zooplankton, *Mnemiopsis* brought about an increase in chlorophyll, phytoplankton biomass and primary productivity within the deep basin (Fig. 3). The high-
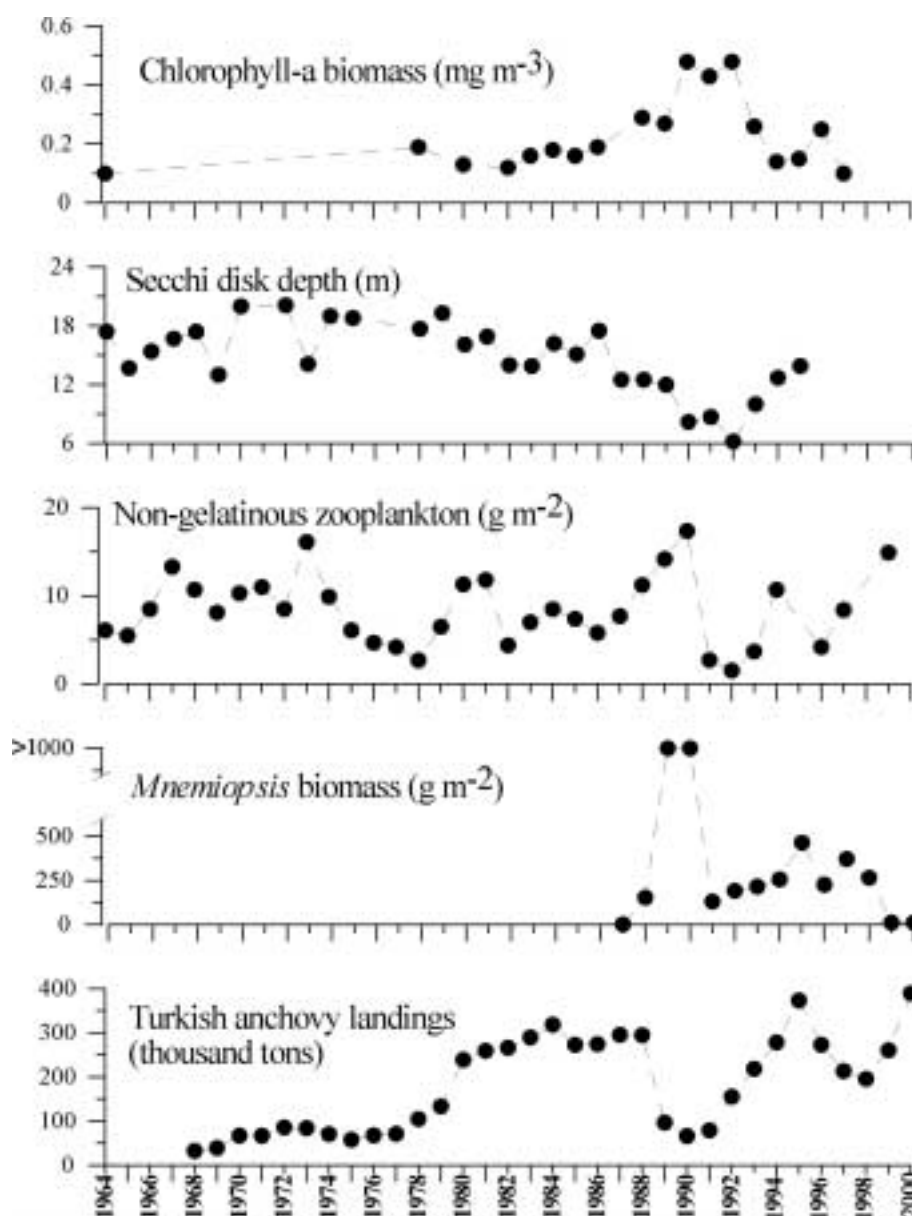
Fig. 3. Long-term variability for several eutrophication indices and the effects of the invading comb-jelly *Mnemiopsis* in the deep and eastern Black Sea (From Kideys, 2002).

est eutrophication indices for all regions of the Black Sea were reached in 1992, following peak biomass of *Mnemiopsis*. The total nutrient input via rivers stabilized or decreased by the mid 1980s. After 1992, eutrophication indices (surface chlorophyll and inorganic phosphate levels, water transparency, non-gelatinous zooplankton biomass and fish landings) improved in the deep and eastern Black Sea, indicating recovery, though *Mnemiopsis* was still present in significant biomass, though at much lower levels than previously (Fig. 3).

The appearance in 1997 of another alien ctenophore, *Beroe ovata* ("the good"), helped the ecosystem to recover further. *B. ovata,* possibly of northwestern Atlantic origin, feeds almost exclusively on *Mnemiopsis* (Finenko *et al.*, 2001). Since its appearance, the year-round abundance of *Mnemiopsis* in most regions has significantly decreased. High biomass levels of Mnemiopsis are now limited to a brief period in late summer (Finenko *et al.*, 2002), due to the effectiveness of its predator. Following the sharp decrease of *Mnemiopsis, Beroe* also almost disappears from the water column, indicating its dependence on *Mnemiopsis*. As a consequence of this biological control, increases were observed in non-gelatinous zooplankton, anchovy landings

(Kideys *et al.*, 2000, Fig. 3), and egg densities of this fish (Kideys *et al.*, 1999), along with increases in the biomass of two native schyphozoans (*Rhizostoma pulmo* and *Aurelia aurita*), particularly in summer 2001 (personal observation).

Eutrophication and invasive species are common problems in many regions of the world. *Mnemiopsis*, and to a certain degree, eutrophication, are present also in the neighbouring Caspian Sea. The Caspian Sea is comparable to the Black Sea in terms of surface area (about 400,000 km^2), low salinity (max. 13-14‰ in the southern part), and large catchment area (about 3.5 million km^2). It is mainly fed by a single large river (the Volga, providing 82% of total riverine inflow), supports a commercial fishery of small pelagic fish (the kilka, *Clupeonella* spp.) and has high endemism (Dumont, 1995). However, unlike the Black Sea, the Caspian Sea is landlocked. This characteristic renders the Caspian Sea even more susceptible to anthropogenic impacts, especially the effects of invasive species. *Mnemiopsis*, transported in ballast waters through the Volga-Don canal during the second half of the 1990s (Ivanov *et al.*, 2000), has already caused significant damage to the zooplankton (Shiganova *et al.*, 2001b) and the valuable kilka stocks (Kideys *et al.*, 2001). Some valuable or endemic species like the white sturgeon (*Huso huso*) and the endemic Caspian seal (*Phoca caspica*) which feed mainly on kilka are, at present, under serious threat due to this invasion. However, the effectiveness of de-eutrophication and biological control measures, even in a relatively large ecosystem as in the Black Sea, and over a comparatively short period, are an encouraging signal for the Caspian Sea and similar aquatic environments suffering from such catastrophic threats.

The invasive species in the Black Sea are instructive illustrations of "non-acceptable", "acceptable" and "desirable" invasions. The subsequent invasion of a successful natural predator of an ecologically or economically damaging invasive species may present a promising venue in dealing successfully with marine invasive species.

Propagule supply as a driver of biological invasions

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INTRODUCTION

The scale and potential impact of biological invasions in marine and estuarine communities has become increasingly clear in the past few decades. Recent analyses have shown that (a) scores to hundreds of non-indigenous species are established in individual bays and estuaries throughout the world and (b) the rate of newly detected invasions is increasing over time (e.g., Cohen and Carlton, 1998: Hewitt *et al.*, 1999; Reise *et al.*, 1999; Ruiz *et al.*, 2000). Colonization of some species has resulted in well known, "high-impact" invasions, having significant ecological, economic, and human health impacts (e.g., Cloern, 1996; Grosholz *et al.*, 2000). Although the effects of most invasions remain unexplored (e.g., Ruiz *et al.*, 1999), there can be no doubt that biological invasions are changing the structure and function of marine communities on a global scale.

Contemporary marine invasions have resulted primarily from human-mediated transfer, both intentional and unintentional, and shipping has been a dominant transfer mechanism. A variety of studies underscore the dominant role of shipping as the source of invasions, resulting from transfer of organisms on ships' hulls and in ballasted materials (e.g., Cohen and Carlton, 1995; Hewitt *et al.*, 1999; Reise *et al.*, 1999, Ruiz *et al.*, 2000). Historically, ships have often contributed the largest cumulative number of invasions to many recipient regions. Furthermore, transfer by ships is frequently driving the overall increase in the rate of invasions over time (e.g., Ruiz *et al.*, 2000).

Human-mediated transfer is a critical first step in the sequence of events that leads to invasions, creating a supply of propagules that breaches historical barriers to dispersal – such as ocean basins and continents. Today, most marine invasions simply would not occur without human activities, and especially shipping, which lead to dispersal.

I wish to examine the relationship between propagule supply and invasion patterns. I focus particular attention on shipping as a dominant transfer mechanism, but the characteristics of propagule supply and their relationships to invasion success are applicable generally to other mechanisms as well. My goal is to examine supply relationships that drive invasion patterns. Here, I wish to (a) outline key elements of propagule supply that may influence invasion patterns, (b) highlight current understanding about relationships between supply and marine invasions, and (c) discuss their relevance to management strategies to reduce invasion risks.

Certainly a wide variety of characteristics in source and recipient communities may influence invasion outcome, independent of transfer mechanisms (e.g., Carlton, 1996b; Vermeij, 1996;

Ruiz *et al.*, 1999, 2000). For example, disturbance regime may greatly influence invasion outcome. Others in this workshop are addressing factors that affect susceptibility to invasion and modify the outcome of propagule supply.

CHARACTERISTICS OF PROPAGULE SUPPLY

In general, an increase in propagule supply is expected to result in an increase in established invasions. However, rather than a single measure, supply consists of a combination of multiple characteristics. Below, I review five key characteristics and their expected influence on invasion outcome, independent of source and recipient environments:

• Density of inoculation. Establishment is expected to be positively associated with the number and density of propagules introduced. Increased density may operate to overcome minimum thresholds for survivorship and reproduction.

• Frequency of inoculation. Establishment is also expected to be positively associated with the frequency of inoculation. Increased frequency of inoculation may increase invasion success by (a) increasing the cumulative local density (as above) or (b) increasing the chances of encountering favorable conditions at the recipient site.

• Duration of inoculation. The longer time period (duration) of continued inoculation is expected to be positively associated with establishment. Increased duration may serve to (a) increase cumulative density or (b) increase the chances of encountering favorable conditions.

• Propagule diversity. Increased species diversity of transferred propagules is expected to increase the number of established invasions. Increased diversity should increase the number of species that (a) possess attributes required for colonization and (b) encounter favorable conditions at the recipient site.

• Propagule condition. Decreased physiological stress, resulting from either food scarcity or environmental stress, should improve chances of establishment.

Theory and laboratory experiments provide strong support for each of these general relationships (see review by Ruiz *et al.*, 2000). However, field demonstrations are much more limited, existing primarily for density and frequency effects on invasion in freshwater and terrestrial systems.

In addition to the individual associations between supply characteristics and invasion establishment, some interactions among supply characteristics may exist that increase invasion opportunities. For example, increased Frequency of Inoculation and Duration of Inoculation should each increase the chances of a high density inoculation, since density is often variable among deliveries (e.g., ballast water discharge events) and may reflect seasonal or long-term changes in abundance at the source regions. Further, both should also result in increased species diversity, which is positively correlated to sampling effort. Importantly, the species pool at source regions may also increase or shift over time, as a result of previous invasions, creating a positive feedback of invasions outlined by Carlton (1996b, 1999).

SUPPLY CHARACTERISTICS AND MARINE INVASIONS: CURRENT UNDERSTANDING

The observed increases in the rate of invasions have been associated, if not causally linked, to an expansion and globalization of trade – and especially shipping. Although globalization is a broad term, with many different meanings, there are particular changes in trade characteristics over time that have likely resulted in more opportunities to transfer more species, at both greater numbers and frequency, and among more regions (Table 1). Increases in each aspect of organism supply should promote an increase in invasions (as above).

There can be no doubt that biotic exchange by trade has increased dramatically over the past decades to centuries, but changes in the relative contribution – as well as cumulative effect – of various trade characteristics on organism transfer per unit time or per recipient region (Table 1) remain poorly quantified. A wealth of data exists to demonstrate the overwhelming numbers and types of organisms that are transferred throughout the world by most trade-related activities. Despite existing analyses that highlight key aspects of transfer mechanisms, we often lack the data needed to estimate changes in the delivery rates of organisms among locations or through time.

Table 1. Temporal changes in trade characteristics and predicted impact on species transfer (from Ruiz and Carlton, 2003).

Trade characteristic	Changes	Predicted impact of change
Frequency of transfer	The amount of traffic for the various modes of transportation (ships, planes, trucks), and therefore frequency of transfer events, has increased over time.	More total organisms are transferred and the frequency of delivery is increased.
Size of transfer	The capacity of each transfer event, or size of shipments, has increased over time. This is perhaps especially true for ships, which have increased in size through time.	More organisms are delivered per transfer event.
Speed of transfer	The speed with which materials are moved among locations has increased over time.	Organisms spend less time in transit. Survivorship and physiological condition of associated organisms is often time-dependent. More organisms are delivered per transfer event and in better condition.
Number of commodities	The total number of different commo-dities traded among locations has increased over time.	Each commodity has a unique set of opportunities for the types organisms that can be transferred, associated directly with the commodity and transfer process (e.g., packaging materials). More species are entrained and trans ferred.
Number of source regions	The total number of different geogra-phic sources of suppliers for commo-dities has increased over time.	Each geographic source represents a unique combination of species composit ion and population densities. More species are entrained and transferred. Number of organisms per species per transfer event more variable, and increased chances of high-density transfer events.
Number of recipient regions	The total number of different geogra-phic regions that receive commo-dities has increased over time.	Each geographic recipient region repre-sents a unique environment, including environmental and biotic conditions. Delivery of organisms to more regions increases the chance of encountering conditions needed for invasion.

The propagule supply by shipping alone, as the major transfer mechanism for marine invasions, is spatially and temporally very dynamic, creating a complex and shifting landscape that is difficult to track. Frequent changes occur in the types, sizes, sources, and destinations of ships. These attributes influence propagule supply characteristics. Furthermore, ships change operating procedures (e.g., type of bottom paints, management of ballast water) among routes and over time, affecting the types and numbers of species transferred. Tracking the multi-dimensional changes in shipping, and their consequences for species transfer and invasions, remains a significant challenge.

For the transfer and invasion of organisms associated with ships, we know:

• concentration of many taxa declines over time during a voyage;

• ballast water exchange further reduces the concentration of many organisms;

• the relative importance of hull fouling to species transfer is unclear;

• many invasions have resulted solely from transfer in ships' ballast water;

• however, many invasions may have resulted from transfer in either ships' ballast water or on ships' hulls.

Although it is evident that ships are an important source of contemporary invasions, the quantitative relationships between propagule supply characteristics and invasion success (e.g., linear, logarithmic, threshold) remain poorly resolved. For single locations (ports), the number of established invasions has often not been measured recently or reliably over time. Moreover, the actual propagule supply characteristics of ships are not known. Thus, it is difficult to estimate the relationship between supply and invasion over time. These gaps also present hurdles to estimating the spatial relationships between supply and invasion.

MANAGEMENT IMPLICATIONS

At the present time, ships are implementing various management practices to reduce the transfer of organisms associated with ballast water. Many ships are now practicing ballast water exchange, flushing their tanks in open ocean to reduce the concentrations of coastal organisms discharged at subsequent ports of call. Studies to date indicate that this practice reduces the concentration of most coastal species, in some cases over 95% (e.g., Taylor *et al.*, 2002; Ruiz *et al.*, unpublished data). Furthermore, additional technologies are being developed and tested to reduce the concentration of various taxa within ballast tanks.

We should expect a reduction in the overall number of ship-mediated invasions as a result of such management actions, but the efficacy of such ballast water treatment measures to reduce invasions is difficult to predict. This depends in large part on the relationship between supply and invasion, which is largely unknown (Ruiz *et al.*, 2000; Ruiz and Carlton, 2003). Further, this also depends upon the relative (but often unknown) importance of transfer by ships' hulls *versus* ships' ballast water (e.g., Cohen and Carlton, 1995; Nehring, 2002; Fofonoff *et al.*, 2003). We should expect both relationships to vary geographically, depending upon the specific shipping traffic (i.e., supply) and the recipient environment.

Certainly management actions, such as ballast water, should proceed to reduce the risk of future invasions. However, uncertainty about the "dose-response" relationship for invasions argues strongly for tracking the effect of management on invasion rates, to further guide and evaluate management actions.

Ship-driven biological invasions in the Mediterranean Sea

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SUMMARY

Human-mediated transport of marine organisms via ships is very efficient and, due to its great maritime traffic, the Mediterranean Sea is particularly exposed to biological invasions through shipping. Invaders can arrive both as fouling on ship hulls and as inhabitants of ballast waters. Not all organisms are able to travel with ships and it might be predicted that, especially for ballast waters, a preadaptation to such environment might be the ability of enter in a resting state, in form of cysts. Many marine organisms can become encysted, from dinoflagellates to copepods and jellyfish. The tropicalisation of the Mediterranean, furthermore, suggests a high probability of invasions by species adapted to warm waters and, thus, of tropical affinity. Strange enough, the most successful invader of a tributary sea of the Mediterranean Sea, the Black Sea, is the ctenophore *Mnemiopsis leydi*, a species that is unable to encyst and that comes from temperate waters ! The scenarios leading to successful invasions are depicted from both an ecological and an evolutionary point of view. The network of conditions ruling the outcome of invasions makes it difficult to predict what species will be successful in a game that resembles a lottery. In this framework, however, tropical species that can become encysted to face adverse conditions do have more tickets !

MEDITERRANEAN INVADED !

In the last decades, biogeographers have noted and recorded the invasion of a host of plant and animal species in the Mediterranean Sea (see CIESM Atlas volumes by Golani *et al.*, 2002 and Galil *et al.*, 2002). The greatest biological invasion that man ever witnessed in recent times is under course, and chances are good that it will continue in the future. Three reasons for this invasion are extrinsic to the features of the Mediterranean and are linked to opportunities provided by human activities:

1. The Suez canal opened a way for Indo Pacific species to get in.
2. Shipping activities transport species in both ballast waters and fouling.
3. Exotic species, used to enhance aquaculture yields, escape from culturing grounds.

Two reasons, however, are intrinsic, being linked to the features of the Mediterranean:
1. Surface water temperature is almost tropical in the summer and temperate in the winter.
2. A recent tendency to global warming is leading to the tropicalisation of the basin.

The history of Mediterranean invasions deals with species that expanded their geographical range, spilling over from nearby regions. The Messinian crisis led to the almost complete drying

up of the Mediterranean Sea, with a mass extinction of its flora and fauna. The natural opening of Gibraltar let Atlantic waters in and, with them, life recolonised the basin. The artificial opening of the Suez Canal allowed the entrance of organisms from the Indo-Pacific region, with a dramatic flux that has been called Lessepsian migration (Por, 1978). In both cases, the source populations (the Atlantic and the Red Sea ones) are in continuous contact with the Mediterranean sink. This pattern poses a series of problems that will not be dealt with here any further. The species that arrive to the Mediterranean while being transported by ships can either be part of the fouling covering the hulls, or be carried into ballast waters. These invading species can arrive from any biogeographical region. The individuals that reach the Mediterranean are the result of episodic events, due to the entrance of a very small sample of the original populations.

These unnatural populations, being formed by very few individuals, should not contain the whole original genetic diversity of their species, and should not have a bright future, being destined to extinction. In spite of this, since most species are rare, as witnessed by every ecological study, it is probable that low numbers of individuals are not always the prelude to extinction, even though endangered species are, by definition, reduced to low numbers of individuals. Since rare species can obviously tolerate being represented by few individuals, rarity does not necessarily anticipate extinction (Boero, 1994).

MIGRATION AND SPECIATION

It is true, however, that the species arriving at a new site often form a small population that, after a short time, becomes extinct. The reason for such collapses is most probably genetic: the low genetic variation allowed by the few founding individuals leads to genetic malfunctions that impair specimens' viability. On the other hand, Mayr's quantum speciation, a speciation model explaining biological diversity on islands, implies that:

1. a few individuals of a species (even just a single pregnant female) accidentally arrive at a place geographically isolated from their original area of distribution;

2. these individuals represent a genetic bottleneck;

3. the subsample of the whole genetic variation of the species has a founder effect on the future offspring of these founding individuals;

4. the most frequent outcome of such events is extinction;

5. in some cases, however, the genetic bottleneck and the founder effect cause a revolution in the genetic make-up of the new population, leading to speciation.

A further refinement, and generalisation, of such speciation model is Carson's (1975) flush and crash model of speciation, implying that:

1. a flushing species is represented by many individuals forming a single population;

2. during a flush, panmixia hurdles evolutionary change: stabilising selection prevails;

3. when environmental conditions change, the genetically homogeneous species (well adapted to face the previous environmental conditions, but not the new ones) goes through a population crash, passing from commonness to rarity;

4. the few remaining individuals are liable to go through the same sequence of events described above for quantum speciation;

5. the new population (species?) deriving from evolutionary change, being adapted to the new environmental conditions, undergoes a new flush: the cycle starts again.

This model probably represents the most common type of speciation, implying that rarity is a necessary condition for the evolution of new species. Both models are evidently applicable to the exotic species that get to a new location, as those reaching the Mediterranean either from Suez or being transported by ships and aquaculture. The best-studied data set of Mediterranean immigrants to date is that of fish (Golani *et al.*, 2002) and decapod crustaceans (Galil *et al.*, 2002). Most species have been recorded just a few times and their destiny is usually local extinction. Some species, however, thrive in the new situation and even replace similar indigenous species. The outcome of biological invasions is often at these two extremes: extinction or overwhelming success.

SUCCESSFUL SHIP-DRIVEN INVADERS

The high rate of immigrant insuccess suggests that many species have the possibility of reaching out their geographic range, but that just a few can build successful populations at the new locations. In other words, the first phase of immigration (arrive at a new place) is seldom followed by a second one (develop a population). A potentially successful invader, thus, should possess a set of attributes:

1. the possibility of "travelling" long distances as a "clandestine" on ships;

2. a propension to pass through genetic bottlenecks, linked, also, to the "luck" of the species in being represented by the "right" founder individuals;

3. a physiological pre-adaptation to the new environmental conditions;

4. a high competitive efficiency, so to outcompete indigenous species with similar ecological requirements;

5. a high rate of reproduction, leading to huge populations in a short time.

Within such a scenario one might be tempted to state that r-strategist, clonal species with high rates of asexual reproduction and able to encyst are the ones that best fit this "identikit". Such species, furthermore, are most favoured if they come from tropical regions, since the Mediterranean Sea is warming up. Tropical dynoflagellates should be among the best potential invaders. Also jellyfish with polyps in their life cycles are perfect invaders. Encystment, in particular, is a very strong advantage in such cases. With encysted stages, in fact, species can survive adverse travelling conditions (either in ballast waters or attached as fouling to the hulls of ships) and, also, can withstand adverse seasonal conditions at the new location. A tropical species not adapted to go through the temperate conditions of the Mediterranean winter, in fact, will be wiped out with the arrival of the first cold season! These requirements are met by many invaders, but not by all. Ctenophores, for instance, are delicate, do not have resting stages and are not clonal. In spite of this, the Black Sea has been invaded by two ctenophore species that most probably arrived by ballast waters (see Kideys, this volume). Furthermore, they are not of tropical affinity!

The warm season in the Mediterranean Sea is usually shorter than the cold one, so that the species of tropical affinity are probably in lower numbers in respect to those adapted to colder climates. The regression of these last species, due to tropicalisation, is freeing ecological space that can be occupied either by the expansion of the geographical or seasonal range of warm-water species, or by the arrival of new species from tropical regions. In other words, the invasions of tropical species might be possible because cold-water species are regressing. Sometimes the causes and the effects are difficult to sort out. It is difficult, for instance, to demonstrate that a new species replaced an indigenous one because it outcompeted it, or that it was the decline of the indigenous species that favoured the establishment of the new one.

PREDICTIVE ECOLOGY AND BIOGEOGRAPHY?

Since ecology is aimed at describing and explaining the distribution and abundance of organisms, ecology and biogeography greatly overlap. Ecology, just like biogeography, is mostly a historical science. History cannot be predicted. History can be described and interpreted and, with the insight gained by such activity, historians can depict scenarios of possible futures, performing very weak, probabilistic predictions. Such predictions are to be based more on thorough knowledge of the natural history of both species and communities than on the precise measurement of few presumably highly informative variables that, then, will be treated by algorithms. Such algorithms, unfortunately, can treat only a limited number of variables for intrinsic reasons: as chaos theory teaches us, complex systems are inherently unpredictable in the medium and long term and, in ecology, the short term is not so informative (Boero, 1996).

We cannot predict what will be the species that will arrive in the Mediterranean area. Nobody would have guessed "North-American Ctenophores" if asked before the arrival of *Mnemiopsis leydi* and *Beroe ovata i*n the Black Sea (see CIESM, 2001). We can, however, recognise trends of change, both in the climate and in the biota. The detection of such trends may allow a set of weak predictions about the future history of the Mediterranean:

1. Persistence of the present tendency towards tropicalisation will cause an increase of the space available to tropical species.
2. Indigenous species of boreal affinity will probably go through negative periods, surviving in deep waters, not affected by surface warming.
3. Indigenous species of tropical affinity will probably go through positive periods, widening their geographical and seasonal ranges of distribution.
4. Some of the exotic species of tropical origin that will reach the basin will have good chances to proliferate.
5. Chances will be lower for the success of alien species adapted to temperate-cold climates.

The use of such predictions for the management of the Mediterranean biota is debatable, as they are not absolute, and leave space to situations that do not obey their forecasts. Understanding change, however, can help us to distinguish modifications that are due to global phenomena (the tropicalisation of the Mediterranean Sea is probably due to global warming) from modifications that are due to local causes (ctenophores arrived in ships). This will suggest completely different ways to cope with change and, also, to try to either remove or favour the causes for its occurrence.

Species recognition and taxnonomic skills are of paramount importance to study biological invasions. For instance, identification of algae at the generic level only, might lead to the impossibility of identifying invaders: if one cannot distinguish the Mediterranean species *Caulerpa prolifera* from the immigrants *Caulerpa taxifolia* and *Caulerpa racemosa*, lumping the three species in the genus *Caulerpa*, how can one be aware that an invasion is under course? This is true in the case of hydroids as well. The Hydrozoa can be transported by ships either as polyps growing on hulls, or as medusae or planulae in ballast waters. Being mostly inconspicuous, the presence of introduced species can be detected only by specialists. The list of Mediterranean Hydromedusan species has been recently updated by Boero and Bouillon (1993) and Boero *et al.* (1997), who almost doubled the list of Picard (1958). It is presently impossible to ascertain the origin of these new records. For two of them, however, there is a good chance that ships might acted as vectors: *Garveia franciscana* (Torrey, 1902) recorded by Morri (1982) from the Venice Lagoon, and *Clytia hummelincki* (Leloup, 1935) recorded by Boero *et al.* (1997). Both species probably arrived as fouling on ships' hulls.

A CASE STUDY IS TELLING US SOMETHING

A possible newcomer into the Mediterranean, for instance, is the hydrozoan *Clytia hummelinki*. The first Mediterranean record of its hydroid is from the coast of Calabria (Ionian coast of Italy) in 1996 (Boero *et al.*, 1997) and, thereafter, the species has been found along the coast of Apulia, living in sea-urchin barrens, near the surface. *Clytia hummelinki* has been recorded both from the tropical Atlantic and the tropical Pacific and it is not clear if it entered the Mediterranean Sea either from Suez or from Gibraltar. There are very few people who are able to recognise such a species and it is probable that it passed overlooked, reaching then the very centre of the Mediterranean, where a specialist detected it. *Clytia hummelinki* produces medusae that can grow rather big, for a hydromedusa, not reaching, however, the evidence of Scyphozoa. The hydroid forms a belt near the surface, and its populations are increasingly thriving, year after year. This means that the hydroid colonies are centres of intense medusa production. These small medusae are not detectable by sight, and are probably confused with the "species" *Clytia hemisphaerica*, a nominal taxon that probably comprises many distinct species. The arrival of a new *Clytia* species, the establishment of successful hydroid populations, and their production of many medusae, might have an impact on fish populations through predation on eggs and larvae. After the case of *Mnemiopsis* in the Black Sea, the importance of gelatinous predators on the size of fish populations does not need further stress. The question is: how many inconspicuous species arrived in the Mediterranean, established successful populations, and passed completely undetected? More: the inconspicuousness of a species is not directly linked to its importance, since it might play an important ecological role in a short time window and in an ecological compartment that is little explored, like the larval ecology of even commercial fish.

FROM QUALITY TO QUANTITY AND BACK

For most groups, we are not equipped to detect qualitative changes requiring high taxonomic espertise. Such changes might lead to quantitative changes so, obviously, we are not producing the right knowledge to interpret change of any sort.

In the last century, ecologists tried hard to get rid of quality, replacing the knowledge of organisms with the knowledge of algorithms while performing mathematical modellings of ecosystem functioning aimed at obtaining precise predictions. The success of this activity is as glorious as the success of predictive economics (another way of predicting history) ! This tragic mistake, that led to the disappearance of taxonomy and natural history, is not to be corrected by an equally tragic one, denying any importance to quantification and mathematical treatment. A balanced compromise is to be reached and, in the light of the present position of the pendulum, it is undeniable that the importance of mathematisation is to be counterbalanced by an equal appreciation of botany and zoology, so to have a more reliable ecology and biogeography. The European Register of Marine Species (Costello *et al.*, 2001) is a list of the species recorded from European waters so far. This basic information, however, requires monographic support to acquire a meaning, so to refer a name to actual specimens.

If the last century was the century of quantity, this new century should become the century of quality. The timely recognition of the importance of biodiversity is calling for a renewed effort in describing (with no inferiority complex) the quality of the present biota, so as to provide proper information leading to a better understanding and, hopefully, a better management of the whole biosphere.

CONCLUSION

The traffic of ships in the Mediterranean is large and increasing. These ships carry organisms in their ballast containers and on their hulls. The mixing of biota is very great and recognition of invaders requires both a thorough knowledge of the local fauna and flora and a global taxonomic expertise. Both types of expertise are lacking for most groups. It is highly probable that future invaders will arrive from tropical regions, since the Mediterranean is going through a period of tropicalisation. It is also highly probable that species with the ability of becoming dormant under adverse conditions will be favoured. The inspection of ballast waters is to be focused on suspended organisms and, also, on resting stages that, in all probability, lie in the dirt on the bottom of ballast containers.

Transport of alien species by ships always occurred, but the change in Mediterranean conditions is probably opening space for species of tropical affinity. A shift in chemico-physical features allows now the preadaptation to Mediterranean conditions by formerly unsuccesful invaders. The scenarios depicted above, however, show that the number of variables, that are to be taken into account to describe the quality and quantity of possible invaders, is so great that it is almost impossible to build up predictive models of this ecological pattern. The probability of success for potential new members of a local fauna can be compared to the probability that players have to win a lottery. In spite of the unpredictability of the outcome of lotteries, it is obvious that the probability of winning is proportional to the number of tickets bought by single players. At present, tropical species with a great propension to become encysted under adverse conditions have more tickets than any other species. In spite of this, a player with a single ticket might still win the lottery.

Options for managing ballast water
to reduce marine species' transfer

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Marine organisms have been transported on ships' hulls and in ballast water for centuries and there is ample evidence to show that many of these have become established well outside their natural ranges. International concern regarding the potential ecological and human health risks of these "invasions" has been increasing over the last 30 years. The current intensive efforts by the International Maritime Organization to broker an intergovernmental agreement to control species transfer in ballast water have exposed the extreme complexity of this issue.

The desire to exercise rigorous control over the introduction of non-indigenous marine organisms is prompted in some countries by clear evidence of the harm that has been caused and in others by fear of the unknown. It would clearly be wrong, for example, not to recognize the ecological impact of the comb jelly *Mnemiopsis leidyi* in the Black Sea (GESAMP, 1997), the replacement of much of the native fauna of San Francisco Bay by introduced species (Cohen and Carlton, 1995) or the potential risks to public health presented by the transfer of pathogens and toxin-producing algae (Casale, 2002). Nevertheless, in many coastal areas there are indications that introduced species have become integrated into local communities without adverse effects. Such differences can influence the stringency of control measures contemplated by national administrations.

It would be difficult to conceive of a simple model that would realistically contrast the environmental and human health costs of marine invasions with the economic costs of preventative measures. Yet this is really the essence of the debate. Without some basis for estimating the costs and benefits of control options, decisions regarding the degree of control required must be arbitrary and may be influenced more by political imperative than, as should be the case, informed risk analysis.

There is no doubt that the control of species introductions is one of the most intractable problems facing environmental managers. The social and economic costs of complete prevention, i.e. absolute control of all potential vectors, are potentially huge and in most jurisdictions unlikely to be politically acceptable. Thus, the only realistic approach is to opt for an affordable degree of risk reduction without any reliable means of predicting how successful the measures might be.

Ballast water is probably the principle vector involved in marine species transfer. As such, it is justifiably the main target of international action to control the extent of marine species introductions. But it is not the only vector (Carlton, 2001). Ship's hulls are also significant vectors and in some areas may equal or exceed ballast water in importance. The release or escape of species imported for aquaculture is another source and so are aquaria, drilling platforms, floating debris,

the opening of canals and transfers resulting from research activities. Clearly, therefore, any programme aimed at reducing the incidence of introductions and their attendant risks should embrace as many of these vectors as possible.

The IMO voluntary guidelines on ballast water management (IMO, 1998), which remain in force pending the planned adoption of a new convention in 2003, recommend that vessels that can do so safely should exchange their ballast water at sea. This was intended as an interim recommendation until such time as more effective forms of treatment could be introduced. Many still question the efficacy of this technique. Recent studies show that there is no correlation between exchange efficiency and biological effectiveness. For example, even where 95% or more of the ballast water is exchanged, biological effectiveness (species removed) may be no better than 60%. Furthermore, the biodiversity of some open-sea areas (e.g. Indonesia) can be even greater than that of coastal sites; such areas are unsuitable for ballast water exchange. In addition, exchange may not be effective against organisms attached to tank walls or contained in sediments at the bottom of tanks. However, few if any existing vessels were designed for ballast water exchange in transit and naval architects have indicated that exchange efficiencies (and probably biological effectiveness) could be vastly improved in newly-designed vessels. Furthermore, unlike many proposed treatment technologies, exchange at sea as a practice is environmentally benign. Thus, in April 2002 participants at the Ballast Water Working Group of IMO's Marine Environment Protection Committee (MEPC) took a sensible step and agreed that exchange at sea should not be rejected as a future control option.

Accordingly, the most recent draft (IMO, 2002a) of a new International Convention for the Control and Management of Ships' Ballast Water and Sediments contains draft standards for the exchange of ballast water by both existing and newly commissioned vessels. Options proposed for existing ships include exchanging ballast water by "*pumping through three times the volume of each ballast tank*" or achieving "*an efficiency of 95% volumetric exchange*".

At the center of the international debate on ballast water management has been the development of one or more ballast water treatment standards. National administrations, equipment manufacturers and the shipping industry are unanimous in their belief that agreement on the quality of ballast water to be achieved is a prerequisite to evaluating treatment technologies and management options. There is general agreement that the optimum standard – 100% kill or removal of all living organisms – is not realistic in the short term and that a standard requiring a substantial reduction (e.g. > 95%) in specified classes (and/or sizes or concentrations) of organisms relative to intake* conditions is the best that can be achieved with available technologies. However, there have been major differences of opinion as how such a standard should be expressed in legal texts and the procedures to be used in calibrating and certifying treatment equipment. In principle, the standard would allow the use of any technologies that can be shown to meet the standard, thereby encouraging research and innovation.

Current proposals (IMO, 2002a) for standards that would apply in the short term are that:
- ships should achieve at least [95%] removal or inactivation of a defined set of taxa; or
- ships should discharge no detectable quantities of viable organisms above [100]µm in size, and no more than [25 viable individuals of zooplankton per litre, 200 viable cells of phytoplankton per ml] smaller than [100]µm in size.

In the longer term, it is proposed that ships should discharge no detectable quantities of viable organisms above [y]µ in size and no other organisms above a concentration of [z].

No technologies are excluded by the wording of these standards. All the standards could be met through the use of sterilization technologies such as heating and dosing with biocides. However, a further regulation requires that treatment systems must be safe for the ship and its crew, environmentally acceptable, practical (i.e. compatible with ship design and operations) and cost-effective as well as biologically effective. Taking into account current difficulties surrounding the use of heat and biocides, it would appear that front runners at the present time would be some form of separation/filtration, possibly linked to UV irradiation.

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* *Opponents of this (intake) approach note that it fails to take account of organism proliferation inside the ballast tanks during transit.*

Whatever treatment technologies are ultimately adopted, it is crucial that all costs – capital, environmental, health, monitoring, enforcement, etc. – are compared with the likely benefits to be achieved (IMO, 2002b). An example of a simple matrix for comparison of the costs and benefits of treatment options is given in Table 1.

Table 1. Example of a matrix for comparing costs and benefits of various ballast water management/treatment options (N.B.: illustrative only).

Management or treatment method	Environ'mtl costs	Human health costs	Capital costs	Operating costs	Monitoring & enforcement costs	[Overall Cost *Note]	[Relative efficacy *Note]
Exchange at sea – Unmodified vessels	X	X	X	X	XX	X	X
Exchange at sea – Purpose built vessels	X	X	XXX	X	XX	XX	XX
Separation/ filtration	XX	X	XX	X	XX	XX	XX
Biocides	XXX	XX	X	XX	XXX	XXX	XXX
Heat	XX	X	XXX	XX	XX	XXX	XXX

XXX : high   XX : medium   X : low
* Note : ranking are hypothetical

It is highly desirable that standards for discharged ballast water promulgated at international level are accepted by all port states. This is possibly the most important factor in persuading the shipping sector to make the necessary investments. However, there are already indications that some countries may not be satisfied with standards that do not eliminate all categories of organisms that in their view present unacceptable risks. This could mean that certain vessels on certain routes may have to be fitted with more specialized equipment. Shipping companies would have less flexibility in the routing of vessels. The question of who should pay the additional costs – the port state or the shipping company – would need to be resolved.

Major technical difficulties surround the testing of equipment in order to demonstrate that it can meet the standard under realistic operating conditions. Prototypes may need to be tested on board vessels, or at selected field sites, as well as in the design/fabrication workshops. There are differences of opinion as to whether filters may be tested using artificial particles (e.g. graded glass beads) or should be fed with water containing living organisms representing specified taxonomic groups. In the latter case, some have suggested that water at certain geographical locations and seasons would be suitable, while others believe that organisms should be batch-cultured for this purpose (a somewhat impractical proposition).

The means of ascertaining compliance with the standard is also problematic. Some feel that confirmation that an approved system fitted to a vessel has been used to treat the ballast water would be sufficient, others feel that port-state authorities should be able to check equipment and/or the biological content of the ballast before discharge. There are many requirements here for methods development and training. Monitoring for compliance purposes needs to be done quickly and efficiently to avoid delays in shipping schedules.

The role of port authorities in the implementation of future ballast water management programmes is critical. Even now, port authorities have a major task in ensuring that vessels have in place a suitable ballast water management plan and that practices in accordance with this plan, including exchanges at sea, are consistent with IMO guidelines. Port authorities also need to facilitate good ballast water management practices, for example through the designation of bal-

last water intake areas where sediment uptake would be reduced and the provision of reception facilities for sediments derived from tank cleaning operations. The adoption of standards requiring on-board treatment systems will clearly add to these tasks and increase the costs of port administration. Where a port-state imposes more stringent standards, enforcement activities may be even more demanding. One option under consideration is to require ballast water from certain vessels (depending on origin) to be discharged to moored or land-based treatment systems where the water could be subject to sterilization procedures. Apart from the infrastructural investments involved, this would require suitable land areas adjacent to ports, dedicated docking facilities and a range of environmental safeguards including monitoring and controlled waste disposal.

Environmental safeguards would include provision for the safe disposal of biological sludges arising from ballast water filtration and, should the use of biocides be permitted, the analysis of ballast water prior to discharge. The use of chemicals is, however, a contentious issue. Apart from heat, which presents a number of engineering challenges, chemical treatment is in principle the strongest contender for ballast water sterilization. Consequently, there are intensive worldwide efforts to develop and promote broad-spectrum biocides that could be used for this purpose. Unfortunately, there has been insufficient attention to the logistical, environmental and human health implications of the frequent use of biocides to treat the huge volumes of seawater involved (See Box 1). Nor have the training, supervisory and regulatory requirements been explored in sufficient detail. The manufacture, transport, storage, dosing, mixing and monitoring of ballast water biocides present a number of technical, environmental and administrative difficulties. Without proper controls, this practice could create more problems than it solves.

Box 1

THE USE OF BIOCIDES TO TREAT BALLAST WATER

Although biocides might provide an effective means of eliminating many or all of the organisms found in ballast water, their use also presents a number of technical and other difficulties. Criteria for the selection and approval of ballast water treatment chemicals should embrace as a minimum:

- kethal exposures (time/concentration curves) for juveniles and adults of species representing major marine taxa;
- toxicity as a function of temperature, salinity and turbidity (organic and clay minerals);
- stability (persistence) and reactivity in seawater;
- log Kow for parent compound and degradation products;
- formulation (solid, liquid, % active ingredient);
- analytical methods applicable to seawater, sediments and tissues;
- acute and chronic mammalian toxicity;
- review of available literature regarding environmental and human health significance.

In addition, protocols governing the use of biocides for the treatment of ballast water should address:

- containerisation (i.e. quantities, container types and designs);
- requirements for storage of chemicals at ports and on vessels;
- equipment and procedures for mixing and/or dosing;
- calibration and verification of equipment performance;
- verification of treatment efficacy;
- on-board health and safety considerations; and
- vontingency plans and procedures for leaks and equipment malfunctions.

Source: IMO 2002b

The mechanisms by which alien species are introduced, become established and dispersed, vary for different sea areas and it is incumbent on local marine biologists to examine these mechanisms and to assess the need for, and likely success of, management interventions. Dialogue between invasion biologists, managers, those familiar with particular vectors and pathways and experts in control technologies is essential to identify the most practical and cost-effective forms of intervention.

It will be clear from this brief discussion of options for ballast water management that an effective strategy for reducing the risks of species' transfer leading to invasions should not depend on a single approach but, rather, a series of complementary actions providing incremental risk reduction (Table 2). National and regional strategies should draw on experience from past invasions and management interventions should be directed at vectors, pathways and organisms that, from detailed analysis, appear to present the greatest risks to the environment, human health or the economy.

Table 2. Hierarchy of management interventions for reducing risk of marine species invasions with particular reference to ship's ballast water.

Level	Focus	Action	IRR* %
1	Target ALL vectors	Give priority to ballast water, ship's hulls and mariculture. Implement IMO *Guidelines for the Control and Management of Ship's Ballast Water*	[~20]
2	Controls over ballast water uptake	Provide source/supply of reduced risk ballast water. Re-use ballast water	
3	Exchange ballast water at sea	Build/refit vessels to optimise efficiency & safety of exchange	
4	Controls over discharge	Provide fixed or floating reception facilities. Provide land-based treatment and/or offshore disposal (barges). Provide jetties that facilitate inter-vessel transfer of ballast water	
5	On-board treatment	Filtration/separation technologies + UV	
6	On-board sterilization	Heat or biocides	[~95]

* Increment Risk Reduction (illustrative only).

For those charged with developing strategies for managing ballast water to reduce the threat of biological invasions, there are clearly a number of caveats that warrant careful consideration. These are summarized in the box 2.

Box 2

PIFALLS TO AVOID IN DEVELOPING BALLAST WATER MANAGEMENT STRATEGIES

- frequent changes in requirements
- progressively more stringent & costly requirements
- massive investments that are ineffective
- multiple standards to satisfy different jurisdictions
- standards leading to net environmental deficit
- compromises in safety of ships and crews
- complex administrative arrangements
- uncertain or inequitable roles of State & industry
- major delays in vessel turn-around
- poor controls over other potential vectors

In summary, coastal state administrations in consultation with scientists, environmental managers, sectoral bodies, port authority and shipping representatives need to evolve pragmatic and cost-effective policies for reducing the incidence of marine species introductions. Such consultations should be informed by reliable data on shipping traffic in and out of ports and up-to-date surveys of the flora and fauna of coastal waters within the jurisdiction. This will help to ensure that management actions are directed at practices, vessels, areas and taxonomic groups that are most influential in facilitating invasions of species that present significant risks to the environment and/or human health.

Shipping : global changes and management of bioinvasions

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Shipping is responsible for the majority of world trade. Although trade has been taking place for many centuries it is only in comparatively recent times that the volume of carried goods, frequency of port visits and trading network have expanded in response to political events, technological advances in handling cargo and more efficient port structure and management (Minchin and Gollasch, 2002a). Accordingly, over the last century aquatic ecosystems in port regions have been greatly altered following habitat modification, dredging, and release of wastes and leachates (Omori *et al.*, 1994). In some cases these changes will have resulted in alterations to the trophic web and shifts in biomass allowing some exotics to become established within partly occupied niches (Olenin and Leppäkoski, 1999). Over the next few decades further changes in trade are to be expected following expansion of the European Union, changes to water quality following the EU Water Framework Directive; and changes in resource management policies (European Union, 2000). Such developments may create new situations favouring invasive species including exchanges with the Ponto-Caspian region (Bij de Vatte *et al.*, 2002).

Management of unwanted species carried in ballast water and its sediments, although discussed for over several decades, has progressed slowly. This is because a practical cost-effective approach needs to be developed (Webster and Raaymakers, 2002) and because the biology of the carried organisms is not well understood. Management of ballast water by complete sterilisation may be difficult to achieve because of the variability of the resistant stages of some taxa. If ballast water management is to be effective it must use methods not only dealing with primary inoculations of exotics but also of their secondary spread over short journeys. Should future ballast water treatments involve chemical sterilisation of biota, detoxification will be necessary for this method to be acceptable.

Hull fouling transmissions have been taking place for some centuries. The use of steel hulls has reduced the spread of boring biota, and yet attaching communities fouling hull surfaces continue to be a problem (Gollasch, 2002). The main purpose of control on modern vessels is not to reduce the transmission of exotics but to reduce fouling so vessels travel more efficiently and use less fuel. However, with more recent knowledge concerning the spread of exotic species it has become an additional priority. For some time the usage of organotin antifouling coatings have been applied and these have considerably reduced fouling biomass. Unfortunately there has been a presumption that such antifouling coatings relate to a low risk of species transmissions resulting in most of the attention being placed on ballast water. Hull fouling is most probably underestimated as a vector. The usage of organotin antifouling coatings by ships has considerably reduced fouling on hulls, yet hulls remain fouled. The phasing out of the usage of TBT over 2003-2008 will mean hulls will become less toxic resulting in less of this substance leaching into

port regions. As organotins have a wide range of impacts on many taxa, the decline of this toxicant will inevitably result in environmental conditions that are less challenging for the establishment of some invaders.

The actual exotic species complement in a port region is almost certainly underestimated (Carlton, 1996; Costello *et al.*, 1996) and the occurrence of exotic microorganisms require serious attention. In the case of species we know to be exotic, we can seldom identify a time or means of arrival and/or determine the number of organisms that created the founder population. Those species that become noticed usually do so either because of their size or the impact that they may have on resources (Bower *et al.*, 1994), the environment (Hallegraeff and Bolch, 1992) or human health (Drake *et al.*, 2001).

We know little about inoculation processes. For hull fouling species shipwrecks in shallow water are a likely means of introduction, with subsequent spread from the wreck. Hull scrapings (e.g. from boatyards) returned to the water could result in some species becoming established. Similarly, in-water hull cleaning using divers and robots could result in the release of viable individuals. Spawning events are a likely means of establishment and biota may be stimulated to spawn following changes of temperature or salinity (Apte *et al.*, 2000; Minchin and Gollasch, 2002b). In particular slow moving vessels, such as barges, are likely to pose a high relative risk for transmission. Specialised craft (i.e. naval vessels) or structures (i.e. oilrigs, floating bridges) may have long stationary periods during which they accumulate significant fouling.

Much of the emphasis has been placed on the management of shipping operations. However, to be effective, ballast water management needs to be guided by science. For example the examination of spatial and seasonal distributions of high risk biota in the plankton in a port region would help in selecting ballasting areas and treatment requirements, thereby reducing overall risk (Minchin, 2000). Alterations in areas where anchoring may be required before port entry may also result in some reduction of risk. In home port regions where knowledge of the biota (both native and exotic) is well understood, these areas should be considered as donor areas. Information on species perceived as being harmful, and the methods currently adopted to manage their impact, should be exchanged with similar information from other biological provinces.

Management needs to involve the public, especially as a means of acquiring information on hitherto unrecorded but expected invasive species to a region. Early detection may lead to controls where otherwise they may not be possible (Field, 1999).

A conceptual approach involving imaginary introduction pathways with different time periods and obstacles, identifying occasions when the population of carried biota is impaired in some way, is proposed as a conceptual aid in assisting the understanding as to how a species may be spread (Fig. 1). Each obstacle may close off the pathway by different amounts and in doing so reduces the abundance of the contained population(s). Long journeys generally have more obstacles than short journeys with greater differences at, and between, the donor and recipient regions. This approach graphically shows the greater opportunities presented by short journeys. For example since aquarium species and stock movements used in aquaculture are moved between suitable regions via short journeys (because these are often carried by planes) this can also favour associated biota. Some of these may be pests or include disease agents. The approach needs to be examined in relation to vector combinations and differently acting vectors, as well as shipping practices, when interpreting risks associated with particular invasion pathways.

The distances between the Mediterranean, Black, Red, Caspian, North European seas and the Atlantic Ocean are comparatively small and consequently management of ballast and hull fouling poses special difficulties, as in preventing secondary spread. Short journeys with few or no challenges, as we have seen, have high risks of transmission (Fig. 2). Some ports regions may pose particularly high risks, such as Piræus, where large numbers of aged merchant vessels remain at anchor for prolonged periods. Should any of these vessels be moved into the Black Sea for any reason, the potential for transferring species is significant. Transmission of species via canal links is already well documented for the Lessepsian biota; similar movements under a wide range of circumstances could enable movements through Europe's inland waterways (Bij de Vaate *et al.*, 2002; Olenin, this volume). The wide diversity of languages within Europe will have
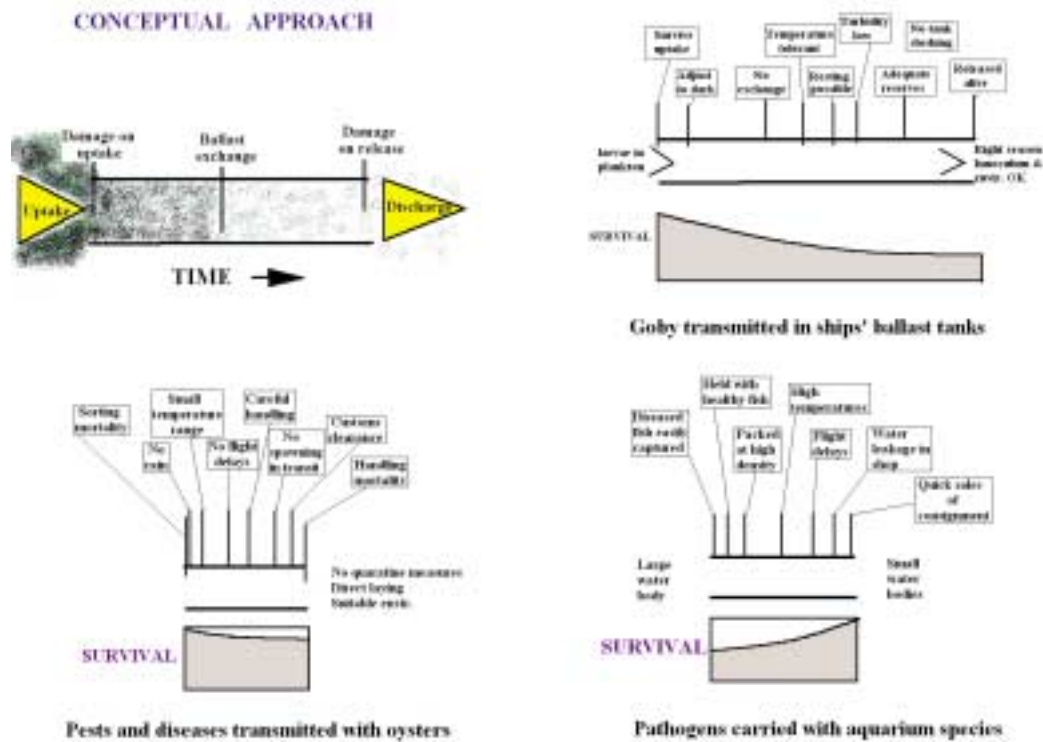
Fig. 1. Hypothetical and conceptual approach for three different vectors bearing different species. The pathway runs from left (the point of uptake) to right (the point of discharge) and the length of the pathway indicates time.

Top left. *Shading illustrates the decline or increase in abundance of a given organism following obstacles.*
**Top right** *indicates some possible mechanisms that may affect the transmission of goby species in ships' ballast water, noted in several exotic species surveys.*
Bottom left: *short transmission of pests and diseases associated with stock movements of oysters.*
Bottom right: *transmission of pathogens associated with aquarium fish transported by plane could result in increases to their populations.*

Fig. 2. Route options to Istanbul from San Francisco (above) and Karachi (middle) including voyages via Cape Agulhas, South Africa and the Suez Canal, Egypt.

Boxes indicate periods when the great majority of specimens in ballast water have expired as determined by sampling (Taylor, 2002). Those routes that do not enter or pass through boxes may have a greater capability of inoculation. Secondary shipping routes carry a high risk (bottom) of spreading species and it may be impractical to undertake many ballast water treatments for such journeys. Estimates of time in days based on direct routes and a ship passage of 20 knots.
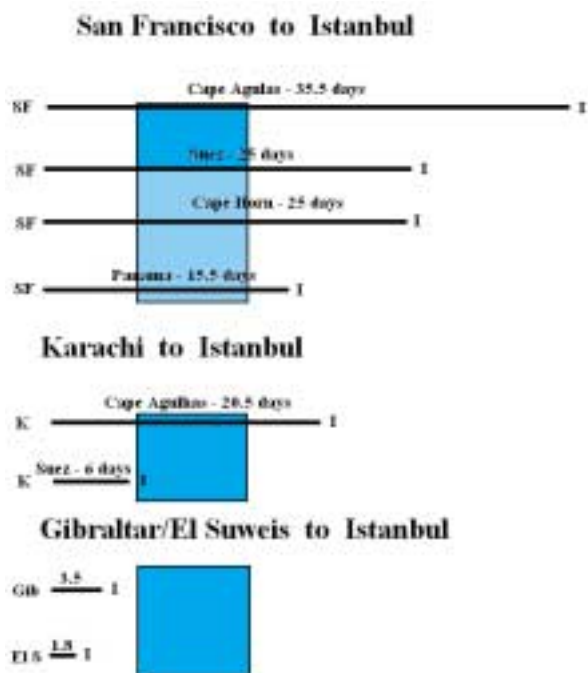
resulted in difficulties in assessing such information and some attempts to draw this together would be worthwhile.

All indications are that in the forthcoming decades there will be further introductions and that shipping will continue to be one of the principal means of spread. Methods used in managing the spread of exotic species need to be practical and cost-effective (Boelens, this volume). There is still much to be learned about the basic biology of species that may be transferred by shipping. In the meantime compilation of the volume of trade and behaviour of the different ship classes entering different regions within the Mediterranean area needs to be urgently compiled, following the innovative path taken by Dobler (this volume). These regions should be separated as far as it is possible according to topographic and oceanographic features. Special measures may be needed where vectors may overlap (marinas in ports) so as to reduce species spread. Some of this can be achieved through public awareness.

Multi-disciplinary approaches are needed involving oceanographers, biologists, microbiologists, ship architects, port authorities, ship owners, regulatory authorities etc., in order that there is a common focus in developing and applying measures to reduce risk. Unless we, as members of the scientific community, fully explain our concerns they are unlikely to understand our approaches. The results of workshops, such as in this *CIESM Monographs*, need to be broadcast as discussion documents. Some conceptual approaches proposed here, together with management of species that have life modes posing a high risk, provide a tangible method to communicate ideas between different professionals.

Harmful aquatic organisms in ships' ballast water
Ballast water risk assessment

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THE ISSUE

The introduction of invasive aquatic species through ships' ballast water and other vectors has been identified as one of the major threats to the world's oceans, relating to bio-diversity and fisheries/food-security. Case studies indicate that the global economic impacts of aquatic bio-invasions are likely to be in the order of tens of billions of US dollars (Raaymakers, 2002). Public health implications are also severe, with thousands of deaths attributed to ballast-mediated organisms and pathogens (Casale, 2002). Addressing this problem is considered by many authorities as perhaps the greatest environmental challenge facing the international maritime industry this century. As highlighted in this volume, enclosed seas such as the Mediterranean are particularly vulnerable to such impacts.

THE RESPONSE

At the national and local levels, individual governments are taking action and the scientific community and industry, including the shipping industry, are undertaking a significant range of activities all aimed at developing solutions. At the international level, governments have responded to this threat by working through the International Maritime Organization (IMO) to:

• adopt Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens (Assembly Resolution A.868(20)), and

• develop a new international legal instrument on ballast water management, to be considered by an IMO Diplomatic Conference in early 2004.

IMO has also joined forces with the Global Environment Facility (GEF), the United Nations Development Programme (UNDP), individual countries and the private sector to implement the Global Ballast Water Management Programme (GloBallast).

The GloBallast Programme is an international technical cooperation programme executed by IMO, with funding provided by the Global Environment Facility (GEF), through the United Nations Development Programme (UNDP), and with support from individual countries and the shipping industry. GloBallast activities commenced in March 2000, with the objectives of assisting developing countries to:

• reduce the transfer of harmful aquatic organisms and pathogens in ships' ballast water,

• implement existing IMO ballast water management Guidelines, and
• prepare for the implementation of a new international ballast water Convention.

The programme is working to achieve these objectives through six initial Demonstration Sites: Sepetiba (Brazil), Dalian (China), Mumbai (India), Khark Island (Iran), Saldanha (South Africa) and Odessa (Ukraine), located in six main developing regions of the world.

At the global level the Programme has established information clearing-house mechanisms, including internet-based networks, directories and databases, has catalysed a more globally coordinated and cooperative research and development effort, is developing modular training packages and is implementing highly successful communication and awareness activities. Activities being carried out at the Demonstration Sites include:
• establishment of national and regional institutional structures;
• communication and awareness activities;
• hazard analysis and risk assessments;
• invasive aquatic species surveys and monitoring and ballast water sampling;
• support for R&D of treatment technologies;
• assistance with national ballast water policies, strategies, legislation and regulations;
• training and technical assistance with implementation of the ballast water guidelines, compliance monitoring and enforcement;
• assistance with developing self-financing and resourcing mechanisms;
• regional replication of the successes at the initial Demonstration Sites and development of cooperative, multi-lateral regional action plans.

RISK ASSESSMENT

The GloBallast approach to risk assessment is to develop a standardised methodology for application on a trial at the six Demonstration Sites, which can then be adopted and adapted at other sites and by other regions, including the Mediterranean.

Risk assessment is a fundamental starting point for any country contemplating implementing management regimes to control the transfer and introduction of harmful aquatic organisms and pathogens in ships' ballast water, whether under the existing IMO ballast water guidelines [A.868(20)] or the forthcoming ballast water Convention.

A port State may wish to apply its regime uniformly to all vessels that call at its ports, or it may wish to assess the relative risk of vessels to valuable resources and apply the regime selectively. Uniform application or the "blanket" approach offers the advantages of simplified administration and no requirement for "judgement calls" to be made. In addition, this approach demands substantially less information management effort. Finally, it offers greater protection from unanticipated bio-invaders, as overall protection is not dependent upon the quality of a decision support system that may not be complete. The primary disadvantage of the blanket approach is additional costs to vessels which otherwise might not need to take action.

Some nations are experimenting with systems to allow more selective applicability of ballast water management requirements, based upon voyage-specific risk assessments. This "selective" approach offers to reduce the numbers of vessels subject to ballast water controls and monitoring. This is especially attractive to nations that wish to reduce introductions of target species only. More rigorous measures can be justified on ships deemed to be of high risk if fewer restrictions are placed on low risk vessels. However, this approach places commensurate information technology and management burdens on the port State and its effectiveness depends on the quality of the information supporting it. The selective approach may also leave the country/port vulnerable to unknown risks from non-target species.

For countries/ ports that choose the selective approach, it is essential to establish an organized means of evaluating the potential risk posed by each arriving vessel, through a Decision Support System (DSS).

QUALITATIVE *VERSUS* QUANTITATIVE

Before a port State decides on whether to adopt the blanket or the selective approach, some form of general risk assessment needs to be carried out for each port under consideration. Ballast water risk assessments can be classified into three categories:

- • qualitative risk identification – this is the simplest approach, and is based on subjective parameters drawn from previous experience and expert opinion, resulting in simple allocation of "low", "medium" and "high" risk;
- • semi-quantitative ranking of risk – this "middle" approach seeks to increase certainty and minimise subjectivity by introducing quantitative data wherever possible;
- • quantitative risk assessment – a full, mathematical analysis of the risk of ballast water introductions, requiring significant inputs of a large variety of data, including on target species, environmental conditions, individual ship and voyage characteristics, management measures applied and evaluation and input of all uncertainties. Such an approach requires a high level of resourcing and sophisticated techniques that are still under development.

GloBallast is undertaking initial, first-pass risk assessments for each of its six Demonstration Sites. To maximise certainty while seeking cost-effectiveness and a simple, widely applicable system, the middle semi-quantitative approach has been selected.

The GloBallast risk assessments are looking at shipping arrival patterns and identifying the source ports from which ballast water is imported. Once these are identified, source port/discharge port environmental comparisons are carried out to give a preliminary indication of overall risk. This will help determine the types of management responses that are required, and provide the foundation blocks for developing more sophisticated ballast water Decision Support Systems.

The risk assessments are being undertaken by international consultancy companies URS Ltd and Meridian Pty Ltd, on contract to the GloBallast PCU. The first country visits, initiated with Ukraine in February 2002, are now nearly completed (January 2003). The consultants are working with, and training country counterparts at each Demonstration Site, as part of the capacity building objectives of the programme. The aim is to establish a fully trained risk assessment team in each country, equipped with the necessary skills, hardware and software to undertake further ballast water risk assessments, both at additional ports within their countries and in their surrounding regions in future.

THE GLOBALLAST RISK ASSESSMENT METHODOLOGY

The GloBallast risk assessment methodology adopts an innovative, modular approach that integrates three computer packages, as shown in Figure 1.

Firstly, a customised and standardised MS Access database is established at the nominated in-country agency for the ongoing entry, management and analysis of the IMO Ballast Water Reporting Forms collected from arriving ships. This database, combined with other shipping records held by the port, is used to identify source and destination ports. The GloBallast Pilot Countries started collecting the Ballast Water Reporting Forms some 12 to 18 months ago. This is a fundamental and essential first basic step for any port State wishing to commence a ballast water management programme.

All coastal and marine resources (biological, social/cultural and commercial) in and around the port that might be impacted by marine bio-invasions are mapped onto ArcView Geographic Information System (GIS), along with map layers of port infrastructure and interactive depictions of the port's de-ballasting/ballasting patterns, including locations, times, frequencies and volumes of discharges and uptakes.

Any high risk species present at the source ports that might pose a threat of introduction to the Demonstration Site, and any high risk species present at the Demonstration Site that might be exported to a destination port, are identified, using all available data sources. These include the biological baseline surveys completed recently at each site under the GloBallast Programme, and
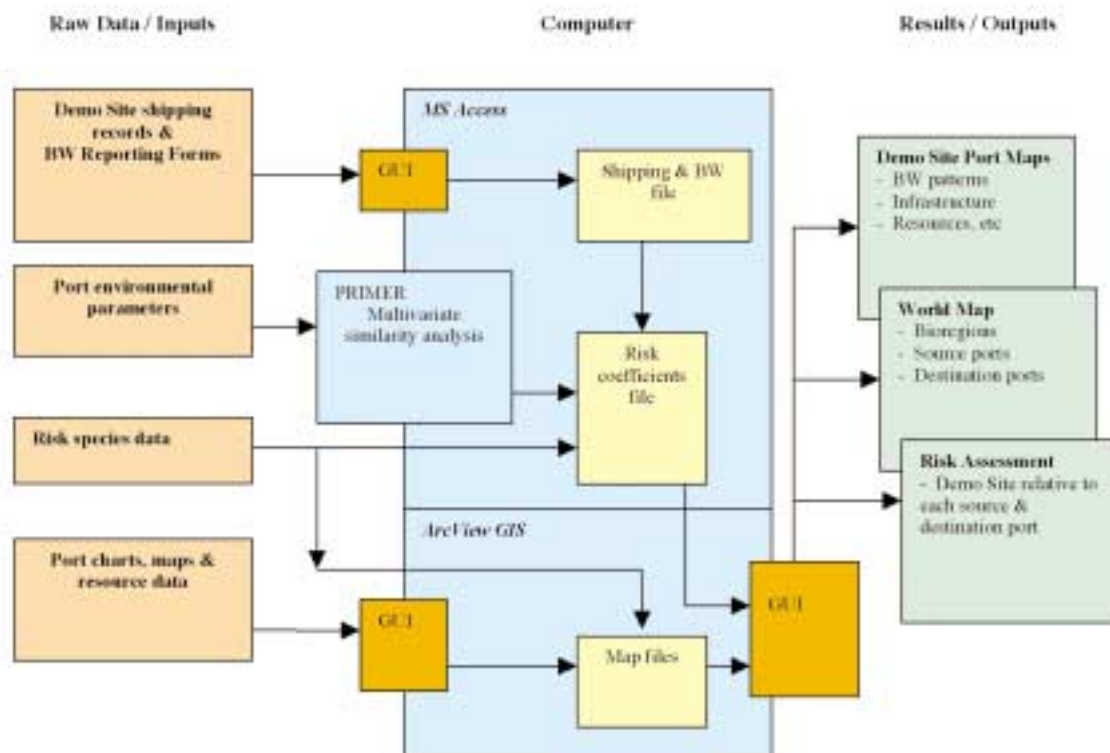
Fig. 1. Schematic of ballast water risk assessment being trailed by the Globallast Programme.
GUI = Graphic User Interface

various databases such as those under development by the Smithsonian Environmental Research Center (SERC), the Australian Centre for Research on Introduced Marine Pests (CRIMP) and the Global Invasive Species Programme (GISP).

Environmental data, including sea temperature, air temperature, salinity, rainfall and tidal regimes, are collected from available sources for both the Demonstration Site and all source and destination ports. They are analysed by PRIMER, a versatile multivariate analysis package, to generate similarity coefficients comparing the Demonstration Site with each of its source ports and destination ports. This environmental matching combined with the risk species analyses provides the underlying basis of the risk assessment, allowing highest and lowest risk ports to be identified.

CALCULATING RISK

The Access database calculates four main coefficients of risk for each BW (ballast water) source port. These are:

C1 - proportion of total BW discharges (= frequency),
C2 - proportion of total discharge volume,
C3 - environmental similarity, and
C4 - proportion of all risk species available (i.e. from all BW source ports *)

C4 is calculated by, firstly, adding up the number of non-indigenous species (NIS) in the source port's bioregion which have no suspected or known harmful status. This number is a measure of the existing weedy species which, although having no recognised harmful status, have proven 'transfer credentials' and so can be assumed to have "ready-to-go-abilities" that allow their transfer to another port, with unknown/unpredictable consequences. This NIS number is then added to:

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* *until many more port surveys are conducted and published.*

(a) the number of suspected harmful species in the same bioregion (these species include natives, as identified by Group C's local scientists). The suspected species are tripled in importance by the weighting factor "w1" (w1 = 3 in the draft project standard); and

(b) the number of known harmful species (i.e. species already listed, declared or otherwise labelled as such by at least one government, reputable scientist, institution or NGO, etc). These known species are multiplied by the larger weighting factor "w2" - which is 10 in the draft project standard (in accordance with the log principle for biological risk).

So the Access database calculates C4 for each source port as follows:

C4 (NIS + [Suspected Harmfuls x w1] + [Known Harmfuls x w2]) / the "total C4 value" *

Therefore C4 is also a measure of relative risk with values between 0-1, because C4 is the proportion of the total risk species potentially available for transfer to the recipient port via its BW importing routes only. Also note that the C4 of a BW source port will be identical to that of any other BW source port which is located in the same bioregion.

The algorithm that calculates C4 discounts any NIS, suspected natives/NIS or known harmful natives/NIS which are also native in the bioregion of the recipient report. Also, the algorithm assumes the recipient port is "uncontaminated" by NIS, even if these are listed as present in its bioregion. Therefore it ignores any NIS that might already be in the recipient port (i.e. any NIS listed for the source port's bioregion).

Apart from the four main coefficients, the Access database also calculates two "risk reduction factors". These are R1 ("BW tank size") and R2 ("BW storage time"). These factors are applied to C2 and C4 respectively (R2 is calculated by subtracting the reported discharge or arrival date from the BW uptake date. If the uptake date is unreported, the standard voyage duration at 14 knots can be used to provide the R2 values). As shown below, the database applies simple risk reduction weighting values, using a log scale which is appropriate for biological risk assessments:

• when R1 (= maximum volume of discharge per tank for each source port) is:
  <100 tonnes   100-500 tonnes   500-1000 tonnes   >1000 tonnes,
then the risk reduction value (w4) is:
  0.4   0.6   0.8   1.0
(i.e. there is no risk reduction for large tanks; >1000 tonnes)

• when R2 (= minimum storage time in BW tank for each source port) is:
  <5 days   5-10 days   10-20 days   20-50 days   >50 days
then the risk reduction weighting value(w5) is:
  1.0   0.8   0.6   0.4   0.2
(i.e. there is no risk reduction for short voyages; <5 days)

• R2 can be deleted from the calculation when only anaerobes/cysts/diseases are being considered.

For scientists who consider that environmental similarity (C3) should be treated as an independent coefficient of risk, then the formula for calculating Relative Overall Risk is:

(1)   ROR = (C1 + [C2 x w4] + C3 + [C4 x w5]) / 4

In this case, ROR is a combined measure of the (proportional) inoculation frequency and inoculation size, the relative similarity of port environmental conditions, and the proportion of all identified risk species which occur inside those bioregions that contain at least one of the source ports. The division by 4 is merely to keep the ROR result within the same 0-1 (proportional) range (i.e. the ROR results can be expressed as simple percentages of the "total risk").

Scientists who recognise/argue that the risk species (C4) are actually the "key stone" of risk measurement may prefer to use Environmental Similarity as a risk reduction factor which influ-

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* the total C4 value is calculated from only the bioregions that contain a BW source port which trades with the recipient port. So the total value is not calculated using every bioregion in the world.

ences the size of C4, rather than using it as an independent coefficient. For this approach, C3 is used as follows:

(2)   ROR = (C1 + [C2 x w4] + [C3 x C4 x w5]) / 3

Thus for a BW source port in a bioregion with a large number of risk species (i.e., a relatively high C4 such as 0.2) but with very dissimilar environmental features (e.g. the C3 is only 0.2), then this C3 will reduce C4 by 80% (i.e. from 0.2 to 0.04). If the BW storage time is short (>5 days), then 0.04 remains unchanged (since w5 = 1). If the storage time is long (e.g. voyage time is always between 10 – 20 days), then the 0.04 value is reduced to 0.024 (due to multiplication with 0.6; see the w5 values in the previous table). Note that the division is now by 3, since there are only three principal coefficients of risk (C1, C2, C4).

This second formula for ROR is more logical, provided that the bioregion database contains a reasonably accurate distribution of all risk species (including native species identified by local experts as potentially harmful if they might establish in other areas).

Scientists who doubt the ability of C4 to provide a reliable picture of potential risk species may prefer to give C3 less influence (on reducing C4), and would rather treat C3 more independently – so as to provide an adjunct measure of the biological risk. This more conservative approach is provided by the first formula for ROR (1).

The more conservative results that are obtained by treating C3 as an independent coefficient [ROR (1)] rather than a risk reduction factor for C4 (ROR (2)), can be seen in the following examples (Table 1).

		FREQ	VOL	ENV	SPECIES
	ROR	C1	C2	C3	C4
ROR (1) = [C1 + C2 + C3 + C4] / 4	0.150	0.1	0.1	0.2	0.2
ROR (2) = [C1 + C2 + (C3 x C4)] / 3	0.080	0.1	0.1	0.2	0.2
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.200	0.2	0.2	0.2	0.2
ROR = [C1 + C2 + (C3 x C4)] / 3	0.147	0.2	0.2	0.2	0.2
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.350	0.5	0.5	0.2	0.2
ROR = [C1 + C2 + (C3 x C4)] / 3	0.347	0.5	0.5	0.2	0.2
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.400	0.6	0.6	0.2	0.2
ROR = [C1 + C2 + (C3 x C4)] / 3	0.413	0.6	0.6	0.2	0.2
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.450	0.7	0.7	0.2	0.2
ROR = [C1 + C2 + (C3 x C4)] / 3	0.480	0.7	0.7	0.2	0.2
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.550	0.9	0.9	0.2	0.2
ROR = [C1 + C2 + (C3 x C4)] / 3	0.613	0.9	0.9	0.2	0.2
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.600	1.0	1.0	0.2	0.2
ROR = [C1 + C2 + (C3 x C4)] / 3	0.680	1.0	1.0	0.2	0.2

The above examples show that, for the typical situation where no single BW source port provides more than 50% of frequency (C1) and volume (C2), the results from ROR (1) are more conservative.

Increasing the importance of C4 [or the C3 x C4 value in the case of ROR (2)] by changing the default value of weighting factor "w3" from 1 to a higher or lower value respectively. The

result of subjectively increasing "w3" from its project standard (1) to 5, can be seen in the following examples (Table 2) [i.e. where C4 has been increased from 0.2 to 1.0 for both ROR(1) and ROR (2)]:

	ROR	FREQ C1	VOL C2	ENV C3	SPECIES C4
ROR = [C1 + C2 + C3 + C4] / 4	0.350	0.1	0.1	0.2	1.0
ROR = [C1 + C2 + (C3 x C4)] / 3	0.133	0.1	0.1	0.2	1.0
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.400	0.2	0.2	0.2	1.0
ROR = [C1 + C2 + (C3 x C4)] / 3	0.200	0.2	0.2	0.2	1.0
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.550	0.5	0.5	0.2	1.0
ROR = [C1 + C2 + (C3 x C4)] / 3	0.400	0.5	0.5	0.2	1.0
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.600	0.6	0.6	0.2	1.0
ROR = [C1 + C2 + (C3 x C4)] / 3	0.467	0.6	0.6	0.2	1.0
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.650	0.7	0.7	0.2	1.0
ROR = [C1 + C2 + (C3 x C4)] / 3	0.533	0.7	0.7	0.2	1.0
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.750	0.9	0.9	0.2	1.0
ROR = [C1 + C2 + (C3 x C4)] / 3	0.667	0.9	0.9	0.2	1.0
	ROR	C1	C2	C3	C4
ROR = [C1 + C2 + C3 + C4] / 4	0.800	1.0	1.0	0.2	1.0
ROR = [C1 + C2 + (C3 x C4)] / 3	0.733	1.0	1.0	0.2	1.0

These examples also show that changing the importance of C4 has more affect in ROR (1) than for ROR (2), because C3 does not influence the size of C4 in the former equation.

Comparing the BWRA Results between different Recipient Ports (= the Demonstration Sites). Because each Recipent Port has a unique set of BW source ports in various bioregions, the results calculated for one demonstration site reflect the relative risks only for that site. If two or more Recipient Ports (= demonstration sites) need to be compared, then the environmental similarity and risk species coefficients (C3, C4) need to be recalculated, using all of the source ports that are exporting BW to one (or more) of the Recipient ports.

PRESENTATION OF OUTPUTS

The overall package is completed through the presentation of results on interactive port and world map layers, using the ArcView GIS. Raw data and inputs are entered and results and outputs are viewed graphically through the Graphic User Interface (GUI), enhancing the user-friendliness and management utility of the system.

WHERE TO FROM HERE?

The approach adopted for the GloBallast risk assessments is not the only one available, but combines the best elements of a semi-quantitative approach to provide an optimum result within the limited available budget. The outputs will include published reports, fully trained risk assessment teams and operational risk assessment systems for use as demonstration tools in each of the six main developing regions of the world. The geographical spread and broad representativeness of the regions mean that the final results will plug a very large gap in the existing global knowledge base. This will place governments, scientists, the shipping industry and the general public in a stronger position to deal with the ballast water "problem" from a more enlightened position.

The GloBallast risk assessment methodology takes a whole-of-port approach comparing the subject-port with all source and destination ports. It provides an integrated information system to manage the port's shipping and Ballast Water Reporting Form data, data on physical and environmental conditions and resources, risk species data and the port-to-port environmental matching and resulting risk co-efficiants. The results will provide an extremely robust foundation to allow port States to clearly identify the risks presented by ballast water introductions, identify high priority areas for action, and decide on whether to apply a blanket or selective ballast water management regime. If a selective regime is adopted, vessel and voyage-specific risk assessment and Decision Support Systems can then be applied, such as those being developed by Det Norsk Veritas in Norway (the EMBLA system), the Australian Quarantine and Inspection Service (the Australian DSS) and Cawthron Institute in New Zealand (the SHIPEXPLORER system). Canada is also developing a ballast water risk assessment and decision support system, and plans to utilize the GloBallast approach and the best elements of the other systems referred above.

The results of the initial GloBallast risk assessments for Dalian, Khark island, Mumbai, Odessa, Saldanha and Sepetiba will be published in early 2003.