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Marine biogeography of the Mediterranean Sea: patterns and dynamics of biodiversity

Aliens - Algal introductions to European shores

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SUMMARY

In recent years European coastal regions have experienced a sudden increase in the number of introduced marine species, both animals and plants. Many of these species spread seemingly unchecked and show a rapid increase of their biomass, which affects whole regional ecosystems. Such species are considered invasive. Increased human activities in the realm of shipping, aquaculture, aquariology, and even scientific research may be culprits.
The European Community project ALIENS currently evaluates such invasive macroalgae and their effects on coastal resources. Findings may assist coastal government agencies in establishing rules and management strategies to avoid future invasions and to mitigate the ill-effects of allochtonous species already established. A consortium of scientists from Spain, United Kingdom, Portugal, France and Italy are currently collaborating through the study of various aspects of these invaders. Research fields include monitoring, experimental ecology, ecophysiology, phylogeography, population genetics and environmental economics. The Laboratories of Benthic Ecology and Marine Botany of the Stazione Zoologica "A. Dohrn" (SZN) at Naples are partners within this international collaboration. Here we describe the general aims of the ALIENS programme and the SZN activities within this project.

INVASIVE MARINE SEAWEEDS

Allochtonous species are organisms that are new in a certain area, where they appear suddenly in consequence of range expansions or introductions. Range expansion consists of dispersal by natural mechanisms into a region where the species did not formerly exist; introduction consists of transportation by human activity (often across natural barriers) (Carlton, 1987). These species may blend in inconspicuously for long time. Unfortunately some can disperse rapidly and severely alter or disrupt local ecosystems, replacing keystone species or affecting the biodiversity otherwise. Such allochtonous species are called

invasive species. According to Williamson and Fitter (1996), about 10% of allochtonous species show such behaviour.

In recent years globalisation of trade, exchange and transports have favoured the spread of marine algae beyond their native biogeographic areas all over the world. Vessels are one of the most important vectors of introduction because of hitchhikers on the hulls (Ribera and Boudouresque, 1995) and in ballast water, mainly for planktonic species and planktonic stages of benthic species (Carlton and Geller, 1993). For macroalgae the main source of introduction is probably aquaculture, both deliberate (aquaculture species, e.g. *Undaria pinnatifida*) and accidental (species hitchhiking with aquaculture species, such as shellfish) (Ribera and Boudouresque, 1995). Aquariology, scientific research and migration through natural (e.g. Gibraltar) or man-built (e.g. Suez) channels could represent other important pathways of introduction.

If these vectors are the culprits, then "developed" regions are more susceptible to invasions than those experiencing little human activity (Ribera and Boudouresque, 1995). The Mediterranean can be considered a developed region due to the extent of human activities. Shipping within the Mediterranean comprises about 30% of the gross global maritime shipments according to Dobler (2002); moreover, in recent years, mariculture has also extended chiefly in coastal lagoons.

Among macro-algae, Boudouresque and Verlaque (2002) listed 85 introduced species in the Mediterranean Sea; 50% of these are found in the Thau Lagoon. With time it is easy to imagine that the effects in hot-spot introduction areas, as the Thau Lagoon can become dramatic. Since the local ecology is often closely connected with the local economy, invasive algae also affect human activities such as aquaculture, tourism and fisheries.

The understanding of this phenomenon requires long-term studies with international and interdisciplinary approaches in order to provide the necessary background for a correct management of the coastal zone.

THE ALIENS PROJECT

The ALIENS project (2002-2005), founded by the European Community, involves 5 different partners: Universidad de Oviedo (Spain), Queen's University of Belfast (United Kingdom), Centro de Ciências do Mar of Faro (Portugal), Université de Marseille (France), and Stazione Zoologica "A. Dohrn" of Naples (Italy).

The research is focused on: (*i*) the understanding of the ecological causes underlying the success of invasive seaweeds along European shores; (*ii*) the estimate of the actual levels of aliens introduction and evaluating ecosystem's susceptibility to future invasions; (*iii*) the assessment of the genetic variability of populations of invasive species and unravelling phylogeographic patterns among them.

The overall aims are to provide an assessment of the probable invasion vectors as well as the information for designing ecologically and economically feasible strategies for the conservation of coastal resources and management of allochtonous introductions.

The research is carried out at seven areas along the European coastline: Northern Ireland, Southern England, The Netherlands, Northern Spain, Southern Portugal, Gulf of Lyon and Gulf of Naples.

In the Gulf of Naples (Fig. 1), two conspicuous invasive species have been recorded in the last decade: the green alga *Caulerpa racemosa* (Forsskål) J. Agardh and the red alga *Asparagopsis taxiformis* (Delile) Trevisan.

C. racemosa (Fig. 2) was reported for the first time in the Mediterranean in 1926 by Hamel. In the Gulf of Naples, it has been observed since 1997 (Buia et al., 2001) and at present it has spread there over a substantial part of the coastline. It only shows rapid growth during summer time on all kinds of substrate, from the surface down to ca. 60 m depth, whereas in the winter it seems to disappear almost completely.

A. taxiformis (Fig. 3), recorded for the first time along Egyptian coast (Delile, 1813), was first observed in the Gulf of Naples in 2000 (personal

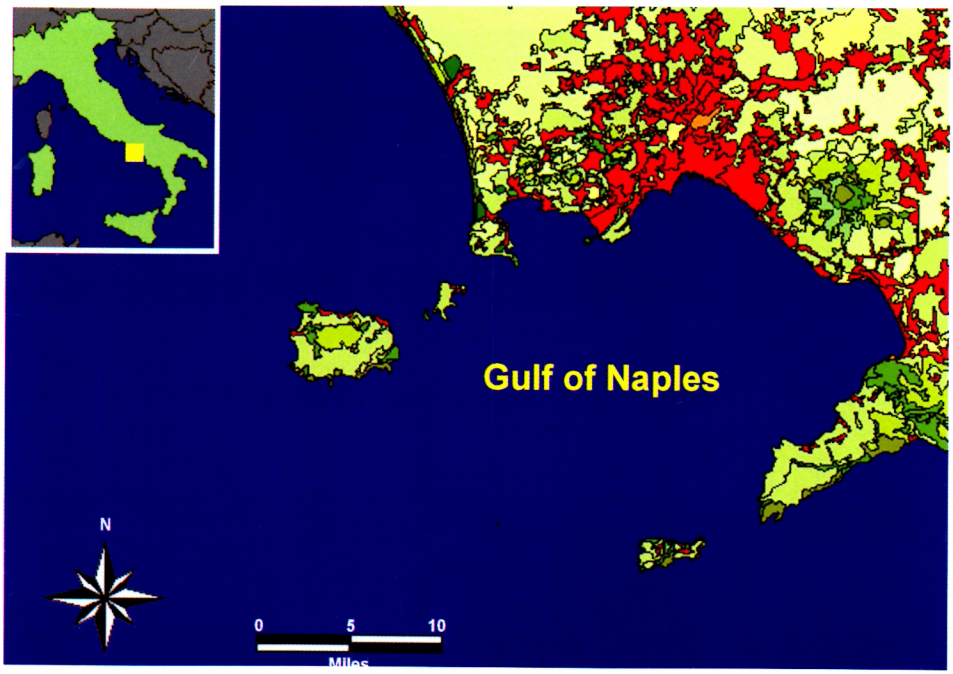

Fig. 1 - Study area (source CORINE-Landuse; graphic elaboration Gianluca Iacono & Luca Tiberti)

Fig. 2 - *Caulerpa racemosa* (Forsskål) J. Agardh (source archives SZN; photo Bruno Iacono)

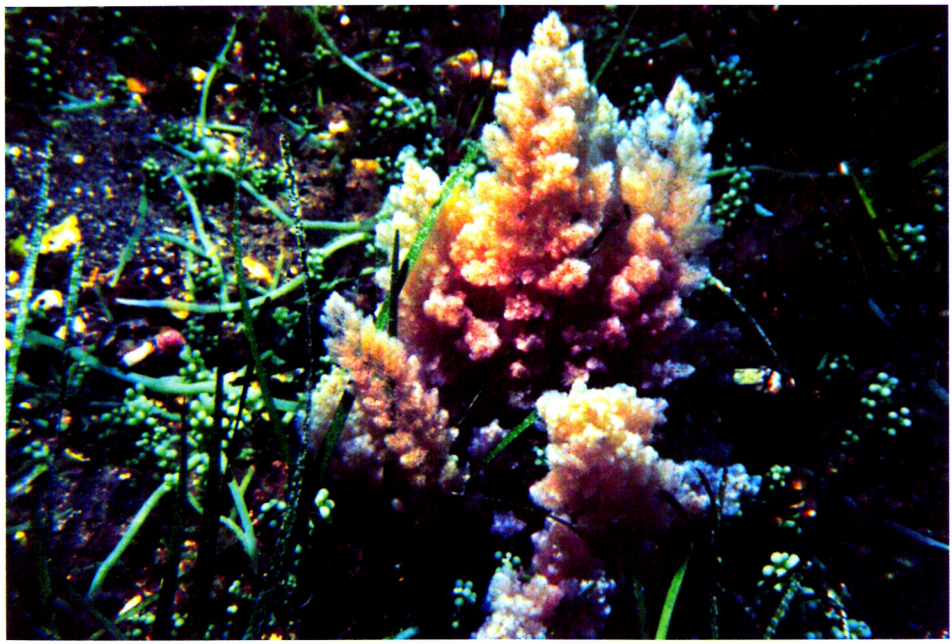

Fig. 3 - *Asparagopsis taxiformis* (Delile) Trevisan (source archives SZN; photo Bruno Iacono)

observation) where it suddenly appeared with an invasive pattern. *A. taxiformis* represents the gametophytic life stage in a heteromorphic diplo-haplontic life cycle; the tetrasporophytic stage is called *Falkenbergia hillebrandii* (Bornet) Falkenberg. Even if both phases are present throughout the year on rocky substrate down to 20 m depth, only the gametophyte forms a continuous belt, more relevant during the cold season.

The Laboratories of Benthic Ecology and Marine Botany of the Stazione Zoologica are involved in the following activities:

(i) *Distribution of invasive species along Neapolitan coastline and description of recipient communities.*

During the summer 2002, a hierarchical sampling was performed in the Gulf of Naples at twelve localities. Of these, six were chosen in impacted areas (farming facilities, harbours, urban zones) and six were selected at relatively undisturbed areas. Each locality comprised a stretch of shoreline of about 0.2-1 Km. At each of these localities, three sites were randomly selected; at each site the sampling was carried out at both 5 and 10 m depths. At each depth 3 quadrats of 50 × 50 cm were examined by means of "visual estimation" of the coverage conspicuous species. In each quadrat a small sample was scraped off (10 × 10 cm) for subsequent floristic examination in the laboratory. Each quadrat was recorded photographically to permit comparison of estimates. Results of this study will be useful to assess spatial distribution and abundance of *C. racemosa*, *A. taxiformis* and, possibly, other undetected invaders. A further aim is to screen the distribution of seaweeds in our region and to generate hypotheses on the effect of the invaders on the local communities.
A check-list of introduced species will be provided in relation to their biogeographical origin. Species will be also ordered according to their spatial distribution, structure of recipient communities, and environmental variables. Habitats with different degrees of human interference will be compared to test the hypothesis that human-impacted environments are more sensitive to aliens invasion than 'natural' ones.

(ii) *Assessment of the impact of invasive species on local communities*
To study the effect of invaders on native communities, manipulative experiments will be performed monthly removing target invasive species (i.e., *C. recemosa* and *A. taxiformis*); percentage coverage of three morphological algal groups (encrusting, turf and erect) will be assessed visually, also in relation to substrate slope.

The aim of the impact assessment and the inventory is to explain how different environments can influence and determine the distribution and settlement of invasive macroalgal species, which are their spread strategies, and their level of interaction with native communities.

(iii) *Ballast water as a vector of introduction of macroalgal allochtonous species*

According to Carlton (1985), seawater discharge from ballast water tanks represents an important introduction vector of allochtonous species in marine ecosystems. In relation to macroalgae a few have probably been transported in this way (*Codium fragile* var. *tomentosoides* and *Sargassum muticum*, Carlton, 1985; Ulotrichales and Rhodopyta, Gollash *et al.*, 2002).

The aim is to detect the survival capacity of propagules or fragments or spores at extreme environmental conditions (light and temperature).

Commercial harbours of Naples and Salerno have been taken into account. Sampling involves several bureaucratic procedures in order to obtain permissions from harbour authorities and shipping agencies. On-board protocol will be standardized. Ballast water samples will be taken in the engine room, extracting water from the ballast pumps. Laboratory procedures will provide water filtration, filters maintainance in climate chambers at controlled conditions, weekly observations of germlings species, algae identification to the lowest taxonomic level possible (from stereomicroscope to DNA-based tools).

A check list of species, according to geographic ballast water origin and algal propagation (propagules, fragments, etc.) will be provided.

(iv) *Ecophysiology of target invasive species*

In order to obtain information on ecophysiological traits of the invasive species, fragments of *C. racemosa* and *A. taxiformis* will be kept in climate chambers at controlled conditions for growth experiments.

Daily growth rates (g fw day^{-1}) and photosynthetic activities (ETRmax and Optimum Quantum Yeld) will be assessed under seven different temperatures (from 6 °C to 30 °C in steps of 4 °C), fixed both daylength (12:12 h LD) and irradiance (60 µmol m^{-2} s^{-1}).

Results will be reflected against annual temperature ranges of the basin in order to predict the limits to the future distribution of the species.

A comparison with native species properties (i.e., *Caulerpa prolifera*) will give evidence supporting their invasive pattern.

(v) *Genetic diversity on regional, pan European and world wide scales by means of cytoplasmic and nuclear molecular markers*

In order to assess phylogeographic patterns and population genetic parameters, specimens of *C. racemosa, A. taxiformis and Asparagopsis armata* are collected at various spatial scales. The basic sampling unit is eight individuals from a quadrate size suited to the size of the thalli. Three replicate sets are collected 5 to 10 m from one another representing a locality. From each locality, 24 specimens are collected randomly and dried in silica gel and one individual is mounted on herbarium paper as voucher specimen. Silica dried samples have been collected from several localities in the Gulf of Naples, at other sites along the Mediterranean coast and on a courser scale from all across the tropics and

subtropics. *A. armata* and *C. racemosa* specimens have been received from other Aliens partners along the Atlantic and Mediterranean European coasts. Silica dried samples and herbarium specimens of *Asparagopsis* spp. have been received from different research groups all over the world.

The taxonomic position of red algae species belonging to the genera *Asparagopsis* will be defined at the molecular level. Independent molecular information obtained from chloroplastic, mitochondrial and nuclear molecular markers will be undertaken to reconstruct phylogenetic and phylogeographic relationships between Mediterranean and extra-Mediterranean populations of *Asparagopsis* spp. The role of cryptic introductions and/or serial introductions from the same source along the Atlantic and Mediterranean European coasts will be evaluated.

Genetic parameters governing introduced populations of the "*Caulerpa racemosa* complex" and *Asparagopsis* spp. will be evaluated using high-resolution micro-satellite markers developed in our lab. A detailed description of levels and patterns of genetic variability, population structure, gene flow and modality of inheritance of genetic characters will be performed. The genetic identification of populations together with the reconstruction of interaction scenarios among them will be the key-point to assess persistence capability and expansion potential of populations belonging to invasive species.

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