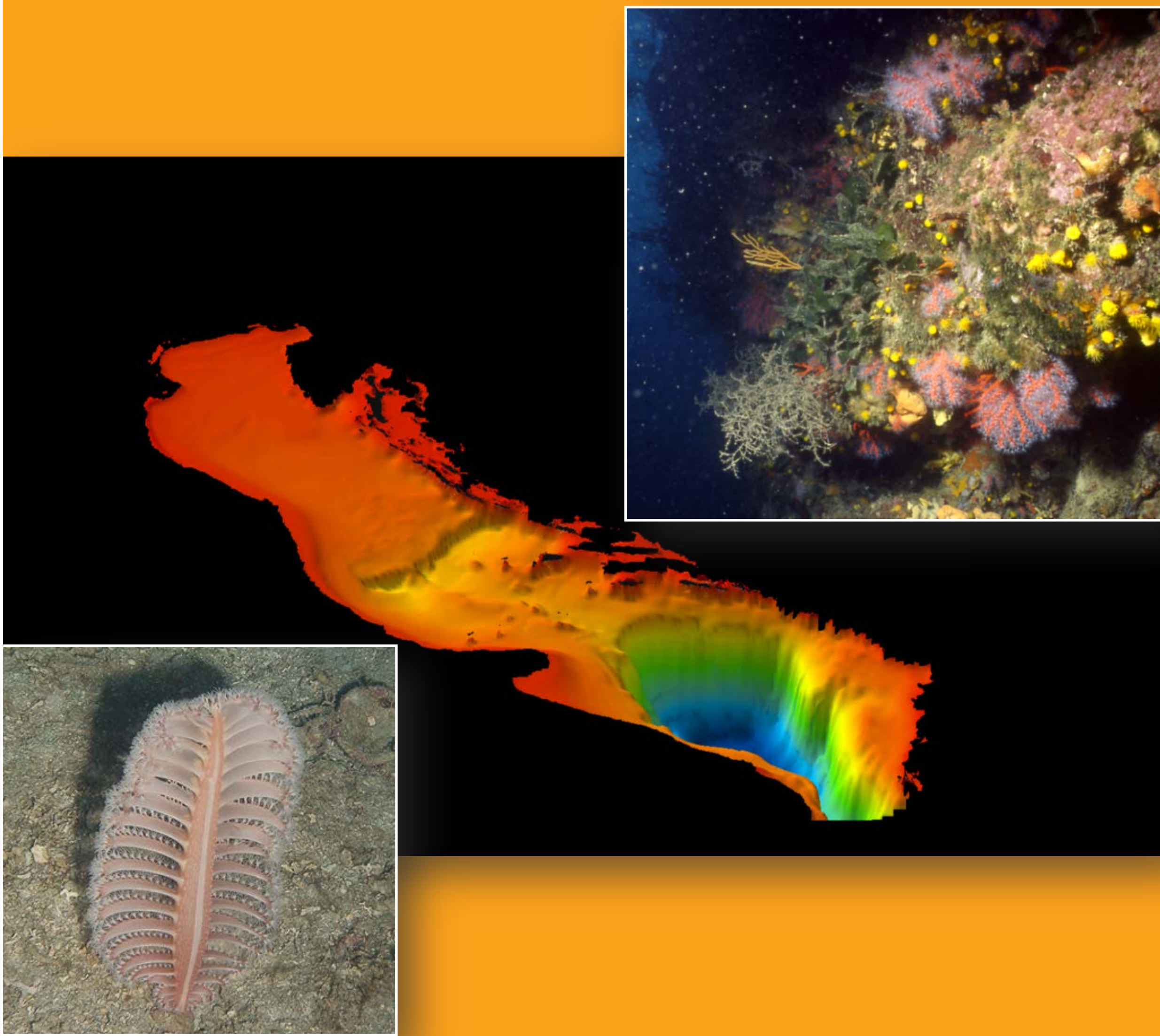
United Nations Environment Programme
Mediterranean Action Plan
Regional Activity Centre For Specially Protected Areas

ADRIATIC SEA

Description of the ecology and identification of the areas that may deserve to be protected



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1 Introduction

1.1 Context of this report

The Mediterranean Sea is subject to tremendous pressure from multiple human uses and climate change. Recent analyses of the cumulative impacts of human activities in the Mediterranean have ranked this hotspot of marine biodiversity among the most heavily impacted marine region worldwide and have characterized this marine region as 'under siege' (Coll et al., 2012; Micheli et al., 2013). Such intense pressure has resulted in major alterations of Mediterranean ecosystems and widespread conflict among marine users. One of the most intensely used and severly degraded regions of the Mediterranean is the Adriatic Sea (Lotze et al., 2006; Micheli et al., 2013).

According to the Regional Activity Centre for Specially Protected Areas (UNEP-MAP-RAC/SPA, 2003, 2008), supported by the European Commission and the Mediterranean Trust Funds, the identification for establishment of Marine Protected Areas in the open seas started in 2008, with the goal of settling these areas with a special ecological value. In 2010 scientific experts and national representatives of the regional centre of the UNEP Mediterranean Action Plan (UNEP/MAP) and Specially Protected Areas (SPA/RAC) identified twelve areas in the Mediterranean, which present specific interest for biodiversity conservation, to build an effective and representative ecological network of protected areas in the Mediterranean Sea (Fig. 1).

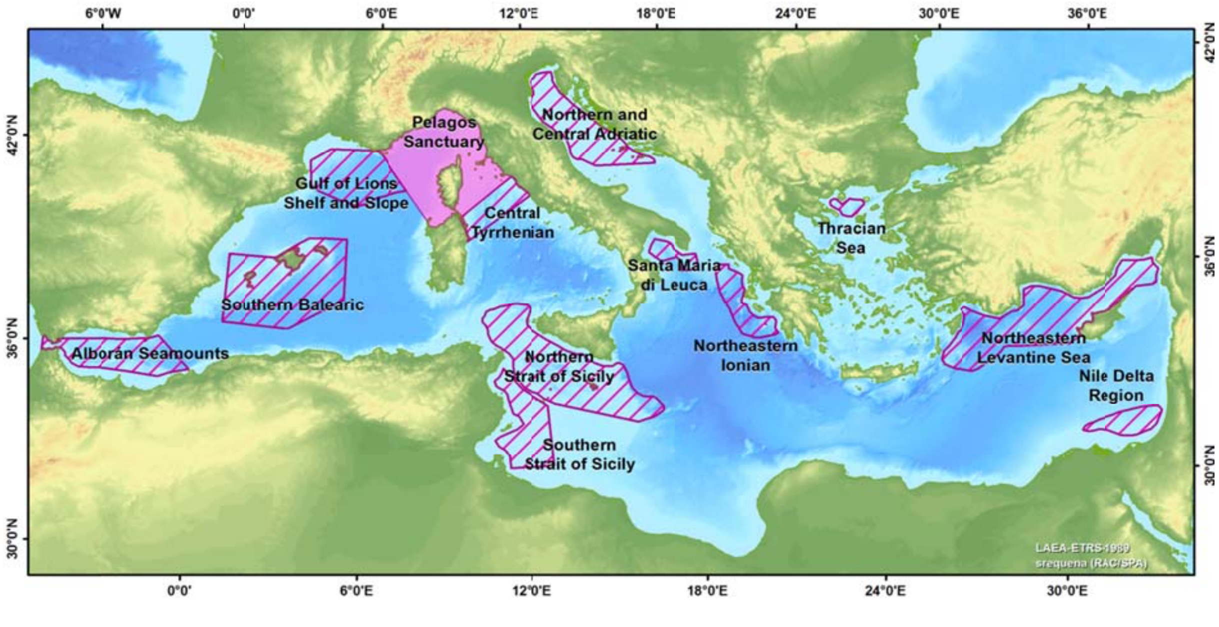

Figure 1. Priority conservation areas selected in the Mediterranean open seas, including the deep sea, that meet the criteria for ecologically or biologically significant marine areas. Extraordinary Meeting of the Focal Points for SPAs (Istanbul, Turkey, 2010). Credit: RAC/SPA-MedABNJ by S.Requena.

The Adriatic Sea has been recently identified by many research institutions and organizations as one of the Mediterranean Sea areas most worth of protection, though which of the zones are more vulnerable or optimal for conservation motivations remains to be identified. The Adriatic basin is probably the most fished area, in relation to its size, by large fleets of trawlers and industrial fishing due to its high productivity and commercial value ([Barausse et al., 2011](); [Libralato et al., 2010](); [Ungaro et al., 1998]()).

The establishment of MPAs in the high seas would allow the protection of highly threatened habitats, which are rarely considered due to their limited access, though crucial for the ecological sustainability of the more coastal environments.

In 2014, the "*Mediterranean regional workshop to facilitate the description of Ecologically or Biologically Significant marine Areas (EBSAs)*" offered the possibility to coordinate a new effort in the definition and justification of EBSAs. In this way, the workshop participants had the opportunity to refine and formalize these areas, wich were adopted at the CBD's COP-12 in 2014 with some modifications (Fig. 2).

The coastal Adriatic basin has historically been intensely researched, especially the Northern basin, but geo-referenced datasets are still poor for the development of adequate management measures. In the last years, several cruises have aimed to identify and characterize the deep and unknown rest of the Adriatic Sea thanks to innovative technology such as ROVs/AUVs and multi-beam technology, though little has been published up to now.

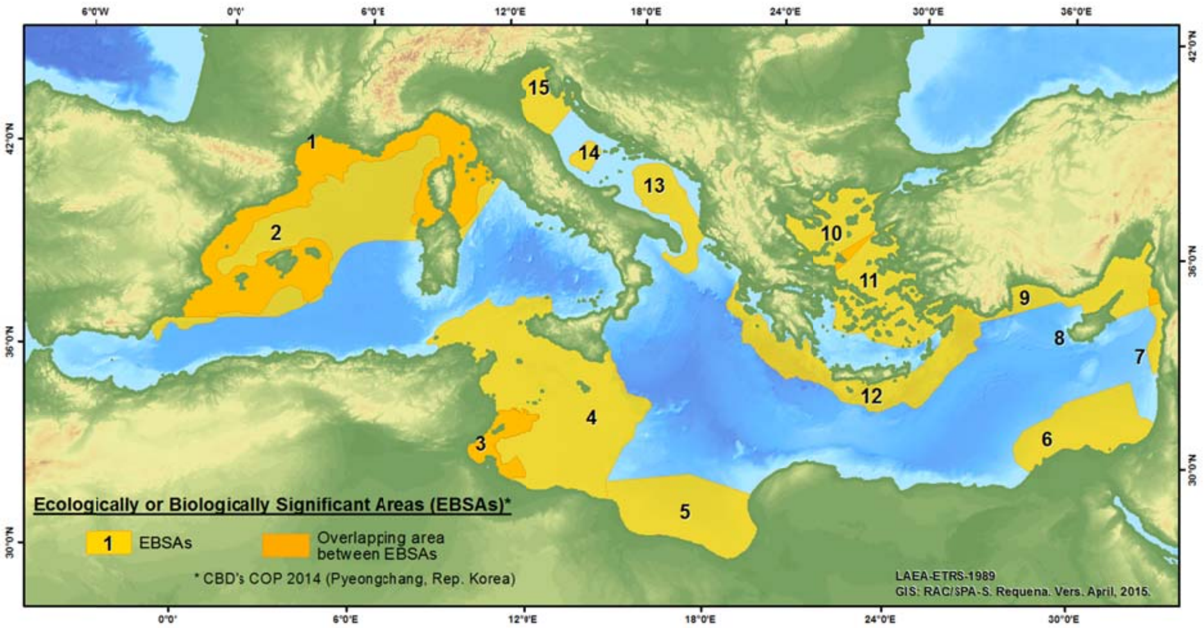

Fig. 2. Areas complying the EBSA criteria in the Mediterranean Sea which were adopted by the CBD at the COP-12 (Oct. 2014). The numbers correspond to the next areas: 1. North-western Mediterranean Pelagic Ecosystems, 2.North-western Mediterranean Benthic Ecosystems, 3.Gulf of Gabes, 4.Sicilian Channel, 5.Gulf of Sirte, 6.Nile Delta Fan, 7.East Levantine Canyons (ELCA), 8.Akamas and Chrysochou Bay, 9.North East Levantine Sea, 10.North Aegean Sea, 11.Central Aegean Sea, 12.Hellenic Trench, 13.South Adriatic Ionian Strait, 14.Jabuka/Pomo Pit, 15.Northern Adriatic. Credit: RAC/SPA-MedABNJ by S.Requena.

Monitoring in the basin is limited, and, for the European Union member States, taking into account the goals of the Good Environmental Status (GES) established in the Marine Strategy Framework Directive (MSFD) is still at its beginning.

This report intends to describe and determine the characteristics for which it is worth considering the protection of the Adriatic Sea despite its important coastal population and multiple human activities and impacts. The Adriatic Sea is surrounded by seven countries that could benefit or be affected by the establishment of large SPAMIs.

For the purposes of this document, the Adriatic region boundaries are those surrounding the Macro Adriatic Region, and include political boundaries at sea of Greece, Albania, Montenegro, Bosnia, Croatia, Slovenia and Italy. Regarding the considered biocoenoses here we focus our synthesis mainly on the open sea, highlighting the main gaps of knowledge still open and that need to be urgently filled to select the main important areas to be included in protection measures.

1.2 Sources of information

Most information used for the purposes of the present report was recovered from publically available literature or from the ongoing research projects within the Adriatic Sea region. Below is a list of the utilized sources:

- ADRIAMED: Scientific cooperation to develop fishing management in the Adriatic Sea (Albania, Croatia, Montenegro, Slovenia, Italy). This project has been ongoing since 1999 with funding from MIPAAF and EC- DGMARE (http://www.faoadriamed.org);
- ADRIPLAN: Funded by the EU, this initiative is aimed at refining and providing recommendations and guidelines on maritime spatial planning in North and South Adriatic Sea. The regions where selected on the scientific knowledge and the availability of authorities (www.adriplan.eu);
- AMER (Adriatic Marine Ecosystem Recovery) project funded by Polytechnic University of Marche to update soft bottoms benthos abundance and distribution to experimentally recover a wide area of Adriatic Sea bottom.
- CAMPs of PAP/RAC Coastal Area Management Programme (CAMP) oriented at the implementation of practical coastal management projects in selected Mediterranean coastal areas, applying the Integrated Coastal Zone Management (ICZM) as a major tool. (http://www.pap-thecoastcentre.org/index.php?lang=en)
- CoCoNet: Design of a MPA network to identify potential or existing small-scale MPAs, which could support wind-farms in the north-western Mediterranean and in the Black Sea. This is a science-based project focused on the distribution of deep and coastal habitats and gathering information to implement MPA networks (http://www.coconet-fp7.eu/index.php/aboutcoconet).
- DEVOTES (Development of strategic indicators and innovative tools for understanding marine biodiversity and assessing Good Environmental Status). http://www.devotes-project.eu/
- MEDISEH (Mediterranean Sensitive Habitat) final report.
- NETCET project: Cofunded by the IPA Adriatic CBC Programme and more specifically within the Priority 2 “Natural and Cultural Resources and Ris Prevention”. The main objective of the NETCET project is to develop common strategies for the conservation of cetaceans and sea turtles in the Adriatic through a pan-Adriatic cooperation. The NETCET project runs from October 2012 to September 2015.
- PEGASO. The main goal of the PEGASO project is to construct a shared Integrated Coastal Zone Management (ICZM) Governance Platform with scientists, users and decision-makers linked with new models of governance. http://www.pegasoproject.eu/
- PERSEUS. Interactions (pressures and components) and possible effects of pressures in the different components in Adriatic Sea. http://www.perseusnet.eu/site/content.php?locale=1&sel=419&artid=364
- POWERED aims to define a set of strategies and shared methods for the development of the off-shore wind energy in all the Countries overlooking the Adriatic Sea. Such energetic choice

could allow a rapid increase of installations, thanks to the reduction of the problems related to landscape topic that are frequently the main obstacles to the creation of wind parks in high density population territories or in areas with high historical or landscape value (http://www.powered-ipa.it/the-powered-project/).

- SHAPE: Shaping a Holistic Approach to Protect the Adriatic Environment between coast and sea SHAPE project aims at the development of a multilevel and cross-sector governance system, based on a holistic approach and on an integrated management of the natural resources, risk's prevention and conflicts resolution among uses and users of the Adriatic coast and sea. Project activities promote the application and the successful implementation of the Integrated Coastal Zone Management Protocol in the Mediterranean and the Roadmap for Maritime Spatial Planning in the Adriatic region (http://www.shape-ipaproject.eu/Default.asp?p=home).
- VECTOR: Aims to improve understanding of how environmental and manmade factors are currently impacting marine ecosystems how they will do so in the future. The project addresses invasives, outbreaks and changes in fisheries distribution and productivity - (http://vector.conismamibi.it).
- Personal unpublished knowledge

1.3 Georeferencing work

The Adriatic Sea, though studied since a long time, has been actually investigated at the scale of the whole basin only in a few occasions and, moreover, those studies dealt with sectorial aspects, not including complex arrays of parameters or thematic layers. Therefore, to date, there are only few papers in the literature that refers to the whole basin or, in the case of regional studies, to a complete array of environmental variables. In addition, most of the studies undertaken in the Adriatic Sea are typically coastal and, most of the time, not fully geo-referred and mapped. This major flaw makes extremely difficult to determine the exact position of a certain biocoenosis or to identify the patterns in the distributions of communities.

Such an inherent gap of knowledge has stimulated us to search for the available information from any possible source (including grey literature) in order to map to the best detail possible the information about the studied area and its habitats and assemblages. Wherever the information available in the literature was referred to spatially scattered data, polygons were created in the designed area. The data set collected to date is currently and constantly under updating.

When possible, data available only in textual, tabular or printed formats were georeferred and digitalised taking into account their associated uncertainty and the original nominal scale. All georeferenced or mapped data were organised and stored in proper GIS formats (raster and/or vector), for further mapping and spatial analyses.

1.4 Further considerations

Because many research projects are currently underway, including efforts to compile and analyse available regional information (e.g. as part of the Medtrends, Adriplan and CoCoNet projects), the available information is rapidly changing. A major future research need is to combine and synthesize the products of these multiple ongoing projects.

2 International Regulations and Conservations Framework

As a preliminary note, it is important to remind that the Adriatic and Ionian Seas link politically the territories of seven countries: four EU Member States (Greece, Italy, Slovenia, and Croatia), one candidate country (Montenegro) and two potential candidate countries (Albania and Bosnia-Herzegovina). Serbia, also an EU candidate country, though without a coastline is one of the eight members of the Adriatic and Ionian Initiative. Both the Adriatic and the Ionian regions are characterized by rich biodiversity. The Adriatic Sea hosts nearly half (49%) of the recorded Mediterranean marine species and it is rich in endemic flora and fauna. The biodiversity of the Adriatic and the Ionian Seas is relatively high and several marine protected areas have been established.

The Council of Europe founded in 1947, launched in 1998 the EMERALD Network, which has the main scope to conserve wild flora and fauna and their natural habitats. The EMERALD Network works under the Convention on the Conservation of European Wildlife and Natural Habitats or Bern Convention that came into force on 1 June 1982. The Council of Europe cannot make binding laws, differently from the European Union, which is also a Contracting Party to the Bern Convention. In order to fulfil its obligations arising from the Convention, which addresses a particular importance on the need to protect endangered natural habitats and endangered vulnerable species, including migratory species, the EU developed the Habitats Directive in 1992, leading to the NATURA 2000 network. The EMERALD Network represents the extension to non-EU countries of the same principles of NATURA 2000.

The EU Water Framework Directive (2000/60/EC) main objective is the protection of water bodies also ground- and surface water and national regulations. Member states had to adopt management plans in order to achieve the ‘good state’ demanded by the EU.

On 17 June 2014, the European Commission has launched the EU Strategy for the Adriatic and Ionian Region. The strategy considers the 'blue growth', land-sea transport, energy connectivity, protecting the marine environment and promoting sustainable tourism sectors that are bound to play a crucial role in creating jobs and boosting economic growth in the region. The starting point for this is the Maritime Strategy for the Adriatic and Ionian Seas, adopted by the Commission on 30 November 2012 and now incorporated into the Strategy.

The Marine Strategy Framework Directive 2008/56/EC is the first EU legislative instrument related to the protection of marine biodiversity and aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. The Directive integrates the concepts of environmental protection and sustainable use.

The fragmentary political conditions (e.g., not all countries are framed into the European regulations) of the different countries facing or with interests in the Adriatic basin, the conservation and protection laws differ in several aspects. In Montenegro the coastal area is relatively small, with a surface of around 1,500 km^2, total length of the coastline of 300 km, and less then 150 km of above ground distance. Montenegro has adopted National Strategy for Sustainable Development in 2007, signed Barcelona Convention Protocol in January 2008.

In Albania biodiversity conservation is regulated through the Law on wild fauna protection including provisions for important habitats for birds in general and migratory birds in particular. Species listed in the Red List of Albania's wild Flora and Fauna, according to different IUCN threat categories, are under special protection and cannot be included in the list of huntable species in the Republic of Albania. The first MPA in Albania was designated in April 2010 as the "Karaburuni peninsula - Sazani island" Marine National Park covering an area of 12.428 hectares. There are four Ramsar sites of wetlands of international importance especially as waterfowl habitats: Karavasta lagoon, Butrinti wetland complex, Shkodra Lake and Buna river wetland complex, and Prespa Lakes area, the latest designation in July 2013.

Bosnia-Herzegovina has a total length of of the coasts of 25.6 km. This is the only way out to the sea of Bosnia and Herzegovina. Neum - Klek Bay and Mali Ston Bay seabed is generally muddy and is considered an almost intact area, with important and sensitive habitats, the presence of 176 fish species and of several invertebrate species. For the naturalness and the potential for life development of these areas, they are suggested as potential areas meeting EBSA criteria. There are also some land habitats recognized as valuable to be included into the NATURA 2000 network.

Hereafter we present the EU instruments that are applicable to Italy, Slovenia, Croatia and Greece.

2.1 NATURA 2000 network: Habitats Directive (92/43/EEC) and Birds Directive (79/409/CEE, 2009/147/CE)

The European Commission considers the NATURA 2000 network as the "*centrepiece of EU nature and biodiversity policy*" and has reunited in the Directive 2009/147/EC, both the Habitat Directive (**92/43/CEE**) and the Birds Directive (79/409/CEE and **2009/147/CE**) aiming to conserve and assure the survival of threatened habitats and species. The NATURA 2000 network, concerning terrestrial and marine environments, focuses on the future sustainable management of protected areas and on the establishment of protected areas as part of its obligations for the UN Convention of Biological Diversity.

The NATURA 2000 network includes thousands of areas, in their great majority terrestrial. Regarding the Adriatic Sea, the NATURA 2000 network is fully linked to coastal areas within the first 10 nautical miles from land. As for NATURA 2000, in part of the eastern and on the southeastern shelf of the Adriatic after 2012 there are no sites enlisted, due to their recent adhesion to the Belgrade convention of conservation and to other non-European legislations. The EMERALD Network is conceptually similar to the NATURA 2000 network and works as an extension to non-EU countries of NATURA 2000.

2.2 Sites of Community Interest (SCI), Special Protection Areas for birds (SPA-IBA), Special Areas of Conservation (SAC-ZSP), EMERALD Sites

The protection and conservation of natural areas is regulated by the Directive 92/43/EEC, for which each member state (EU only) provides and establishes areas aimed to restore and guarantee the best conservation status of the wild flora and fauna as well as the their habitats (Fig. 3). These areas have to be delimited geographically, based on the ecological necessities of the species that have been declared as of community interest and evaluated and managed as important sites.

The Bird Directive establishes that the designation of the areas important for birds are based on the number and occupied surface of bird individuals and communities as well as for the groups migrating in the area. Bird conservation areas in the Adriatic include Special Protection Areas for birds (SPA-IBA) and Ramsar Sites, which concern either migrating stops, nesting zones or accumulation sites for feeding. An **Important Bird and Biodiversity Area** (**IBA**) is an area recognized as being globally important habitat for the conservation of birds populations. These zones are all-terrestrial and include mostly wetlands, rivers, ponds and lagoons. There is no sort of protection and regulation of the migration routes, for passerines and not.

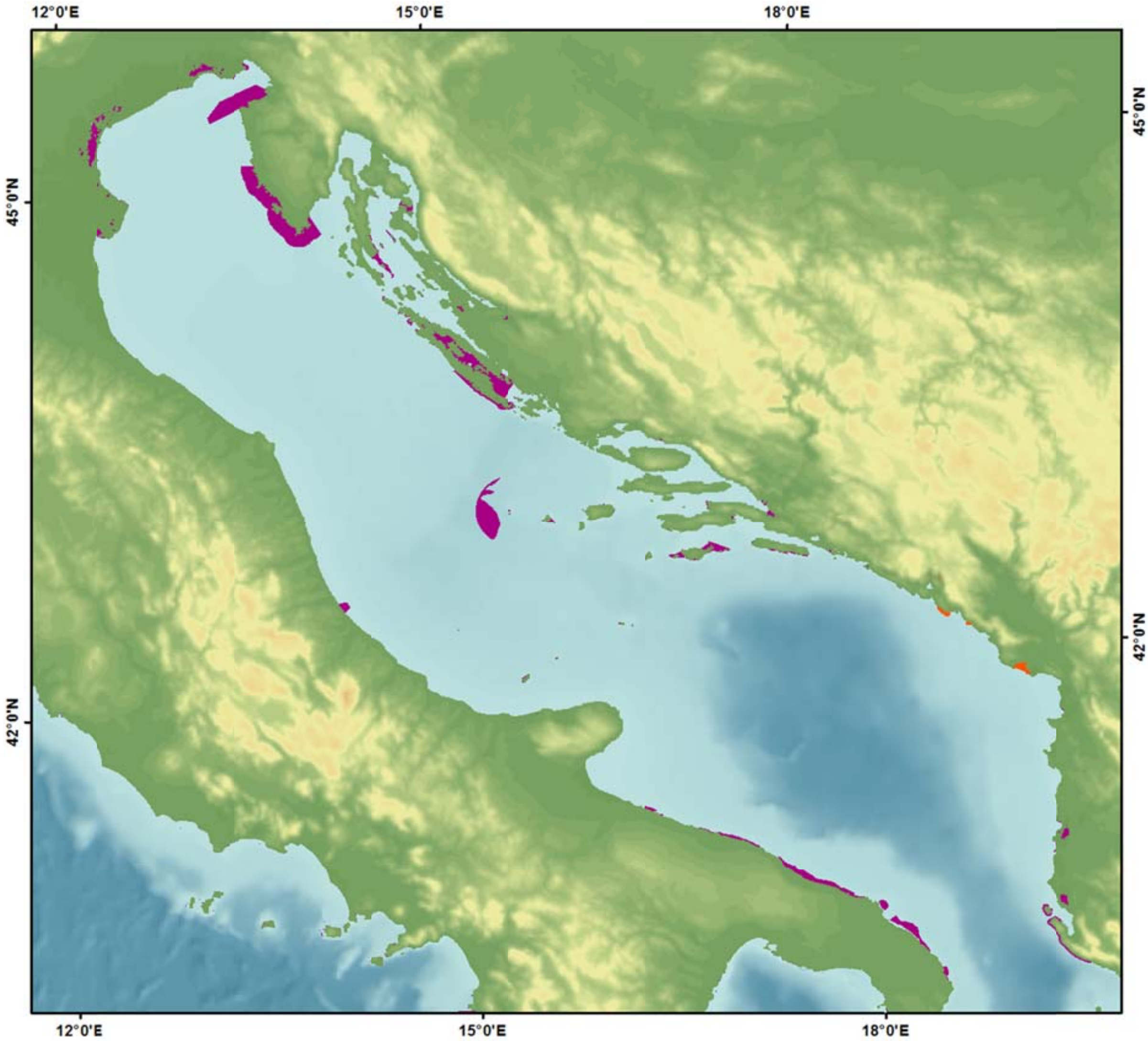

Fig. 3. Marine areas included in Adriatic NATURA 2000 (purple) and EMERALD (orange) networks. Source: http://www.eea.europa.eu/data-and-maps/data. Credit: RAC/SPA-MedABNJ by S.Requena.

The Natura 2000 network includes two types of figures: **Sites of Community Importance** (SCIs) under the Habitats Directive (92/43/EC), and **Special Protection Areas** (SPAs) under the Birds Directive (2009/147/EC). SPAs are classified for rare and vulnerable birds (as listed on Annex I of the Directive), and for regularly occurring migratory species.

SCIs have been adopted by the European Commission but not yet formally designated by the government of each country. They are proposed to the Commission by the State Members and once approved, they can be designated as **Special Areas of Conservation (SACs)** by the State Member. SACs are sites that have been adopted by the European Commission and formally designated by the government of each country in whose territory the site lies. **Candidate SACs (cSACs)** are sites that have been submitted to the European Commission, but not yet formally adopted.

The aim of Natura 2000 is to preserve the natural values triggering the designation of these sites while keeping human activities in a sustainable way.

Several SCIs are present in the Adriatic Sea (Fig. 4), along Italian, Slovenian and Greek coasts. They are all coastal and aimed to protect coralligenous formations, *seagrass* meadows and maerl beds; some of the SPAs coincide with and SCIs, which are automatically included in NATURE 2000.

On the Eastern-Balkan shore of the Adriatic, countries that are not (yet) part of EU have the EMERALD process elucidated in the Bern Convention of Conservation. EMERALD sites are mostly terrestrial at the moment, but there is a high intent of enlarging horizons and surface of protected areas in these countries. The east shores of the Adriatic countries that are not part of EU are working into their programmed goals also on behalf of international collaboration agreements (International Adriatic-Cross borders IPA, ADRIAPAN, ADRIPAN and many others).

The development of a well designed network of coastal protected areas will create a solid background to effective corridors for connectivity (Marti-Puig et al., 2013). Recent molecular data collected on several species, from planktonic jellyfish and pelagic fishes to benthic organisms clearly evidence the presence of an unexpected segregation between the studied populations in the Mediterranean (Aglieri et al., 2014; Costantini et al., 2011; Gkafas et al., 2013). Circulation, current flows, thermocline, and life histories seem to be the main factors that best represent the nature of barriers to gene flow. For species with a sedentary adult phase and a dispersive larval phase, the effectiveness of MPA networks for population persistence depends on connectivity through larval dispersal. Climate change will probably decrease connectivity considering the reduction of pelagic larval duration following sea temperature rise (Andrello et al., 2013) and this aspect needs to be duly took into consideration for future plans of management of Adriatic protected areas

In this regard, we stress here that the geomorphology of the Adriatic Sea, the small distance between the two opposite coasts of the basin offer altogether the actual opportunity to develop a system of small coastal protected areas that could increase their connectivity, especially in the case that a wide off-shore (corridor) conservation area will be also established.

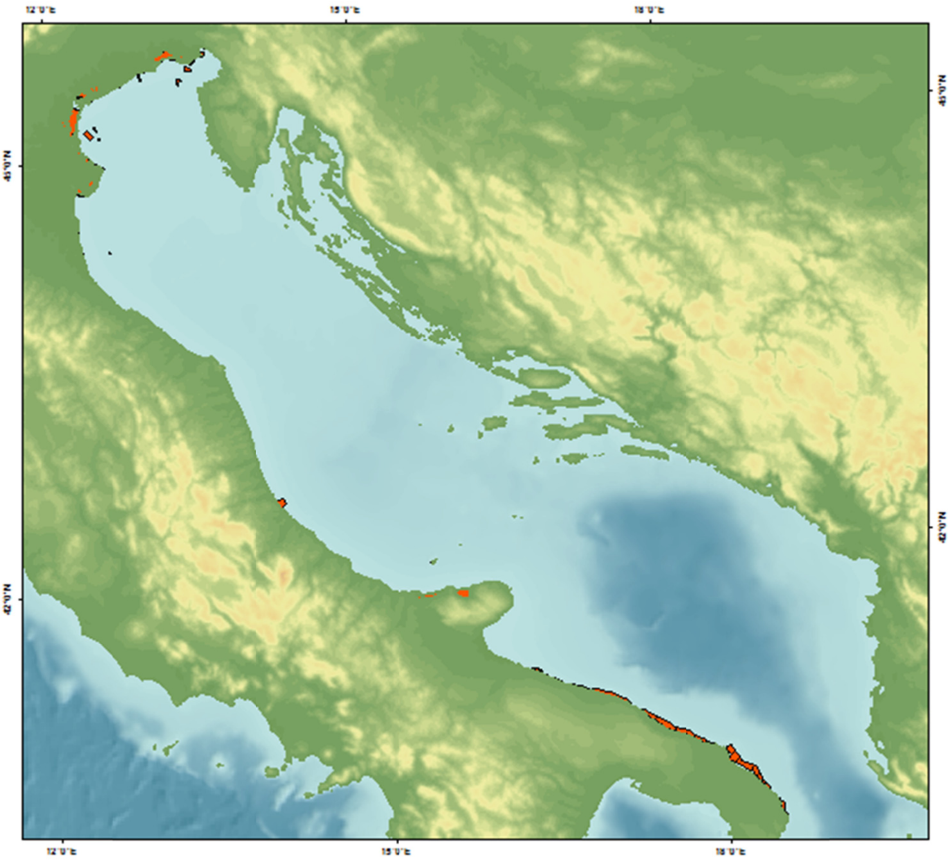

Fig. 4. Italian Site of Community Interests proposed in 2014 (orange). The shapefile of all sites are available at http://www.minambiente.it/pagina/schede-e-cartografie).

2.3 Conservation of the network NATURA 2000, monitoring and surveillance

EU Member states design responsible administrators to achieve and evaluate the conservation purposes of the designated NATURA 2000 network areas. These administrators should be actively involved in the sustainable management of the areas, by creating plans and statutory or any measure necessary for the fulfilment of the conservation and/or restoration of the area (Fraschetti et al., 2005). In addition, each member state is obliged to periodically inform of the achievements and managements results. Therefore, the member states are obliged to take the necessary steps and decision to avoid the depletion, disturbance, deterioration or destruction of the conserved areas; being enabled to infer in the guarding of the possible disturbances created outside the conservation zone but that could negatively affect the areas under protection.

While there is no Adriatic agreement on protection of biodiversity in the basin there are multiple initiatives, such as the Adriatic-Ionian (established in May 2000) as a platform for cross-border/international between Albania, Croatia, Greece, Italy, Montenegro, and Slovenia.

2.4 ADRIAPAN network of Adriatic Marine Protected or to be protected areas

Adriapan is a network of marine protected areas located around the Adriatic Sea (Tab. 1) and its main mission is to facilitate the communication and the development of international projects among MPAs with the hope to achieve a shared vision in conservation strategies.

The map below (Fig. 5) shows the AdriaPAN members in 2013, involved directly or indirectly in the Adriatic aimed to conserve and/or protect the fauna and flora as well as the habitats where they are present.

Fig. 5. Adriapan network (www.adriapan.org)

Tab.1. List of members of the Adriapan network

Western Network	Eastern Network
Marine Protected Area Isole Tremiti	Miramare Marine Protected Area
MPA Torre del Cerrano	Wetland Narta Lagoon
Marine Oasis of Caorle – Tegnùe of P.to Falconera	Important Landscape Dugi otok Island
National Park of Gargano	Important Landscape Lopar
Regional Park of Conero	National Park Brijuni
Regional Park Delta del Po Emilia Romagna	National Park Kornati
Regional Park Delta del Po Veneto	National Park Mljet
Regional Park Monte San Bartolo	Important Landscape Šibenik Chanel - Harbour
Marine Natural Reserve of Torre Guaceto	Nature Park Strunjan
Natural Reserve Punta Aderci	Nature Park Telašćica
Regional Natural Reserve Calanchi di Atri	Nature Park Lastovsko otočje
Regional Natural Reserve Grotta delle Farfalle	Special Marine Reserve Mali Ston bay and Malo More
Regional Natural Reserve Lecceta Torino di Sangro	Significant Landscape Žut – Sit Archipelago
Regional Natural Reserve Sentina	Special reserve Cres Island
Natural Reserve Ripa Bianca di Jesi	Special reserve Kolanjsko blato - Blato Rogoza
Natural Reserve S.Giovanni in Venere	Special reserve Neretva River Delta
State Natural Reserve Le Cesine	Special reserve Prvić
Biological Protection Zone Tegnùe di Chioggia	Special reserve Veliko i Malo blato
	Significant Landscape Badija Island
	Significant Landscape River Krka
	Significant Landscape Saplunara Island
	Special Reserve Island Mrkan, Bobara and Supetar

PART I. CHRACTERISATION

3 Abiotic characterisation

3.1 Geological setting

The Adriatic Sea is a mostly shallow, semi-enclosed and elongated basin located in the Mediterranean Sea between the Italian and the Balkan peninsulas. It is over 800 km long and around 150–200 km wide, with major axis in the northwest–southeast direction. It can be divided into three sections, with increasing depth from north to south, with different characteristics, different widths and topographic gradients (Trincardi et al., 1996).

The northern section, occupying the flooded seaward extension of the Po Plain and reaching an average bottom depth of about 35 m, is the most extensive continental shelf of the entire Mediterranean Sea. It gently slopes part in south-eastern direction down to around 100 m depth to a line between Pescara and Sibenik, where a slope leads to the central basin at depths of 140-150 m (Trincardi et al., 1996; van Straaten, 1970). The northern part of the basin is, by convention, bounded to the south by the transect approximately at 43.5°N.

The central Adriatic is up to 50 km wide, it shows an average depth of 130-150 m, but is also characterized by the presence of the Pomo Depression forming the “Meso-Adriatic Trench" (Trincardi et al., 1996; van Straaten, 1970). The depressions, known by Italians as Pomo Pit and by Croatians as Jabuka Pit (in both languages the term means “apple”) is a complex transverse depression, reaching the depth of 240-270 m (van Straaten, 1970). South of the depression is the morphological elevation known as Palagruza sill, oriented in a northeast – southwest direction and formed during the Quaternary. This represents the shelf break for the Adriatic Sea. The Jabuka Pit represents one of the most productive areas for fish and it is known as an important spawning and nursery area for commercially valuable fish. This area lies in the deepest zones of the central Adriatic, between Italy and Croatia, which are the main countries that exploit it. It is influenced by the Mid Gyre that determines the circulation of the waters, contributing to the well-known dense waters together with the seasons and the entering waters from the Ionian.

This is also a key area for cetaceans, sea turtles and probably birds feeding during migration due to its high productivity. The Jabuka Pit has not been exhaustively studied up to date with regards to its benthic community, but it is presumed that the composition of the bottom should be relatively complex to provide refuge to juvenile fish and invertebrates (Silva et al., 2014). Spawning of hake in the central Adriatic occurs throughout the year with two peaks: in the winter, in deeper waters down to 200 m in the Jabuka Pit, and, in the summer, in shallower waters (Jukic-Peladic and Vrgoc, 1998).

The central Adriatic is separated from the southern area by a line, from the Gargano Peninsula to the Croatian coast.

The southern area shows a wide depression 1218 -1225 m deep and contains a comparatively large bathyal basin, by shelf surfaces of varying width; the continental shelf is wider in the Manfredonia Gulf (ca. 70–80 km), it becomes narrower further to the south (less than 30–40 km) and it is limited by the Ionian Sea, in the Otranto Channel, 800 metres deep and 72 kilometers wide, where important water exchanges take place (Artegiani et al., 1997a, b; Ponti and Mescalchin, 2008; Trincardi et al., 1996; van Straaten, 1970).

3.2 Origin

According to geophysical and geological information, the Adriatic Sea and the Po Valley are associated with a tectonic microplate—identified as the Apulian or Adriatic Plate—that separated from the African Plate during the Mesozoic era (~220 million years ago). Approximately 70 million years ago (Cretaceous period) the Adriatic basin was wider both eastwards, reaching the Dinaric Alps, and westwards, reaching the Alps and Apennines, all originated by compressive forces between the African and the European blocks. The genesis of the Alps and the Apennines chains influenced the morphology and sedimentology of the basin. The geomorphology of the western part of the Adriatic is characterized by low, sediment-loaded coasts, which originate from strong Pleistocene to Holocene river discharge (Fig. 6).

The Eastern Adriatic coast (EAC) is predetermined by its karstic nature (lithologic composition, tectonic fabric, and active tectonics) and is the result of the sediment budget, coastal processes, climate, relative sea level, and human activities. The present EAC structure started to develop almost 240 million years ago, during the Middle Triassic, with the sedimentation on the Adria microplate (Vlahović et al., 2002; Vlahović et al., 2005).

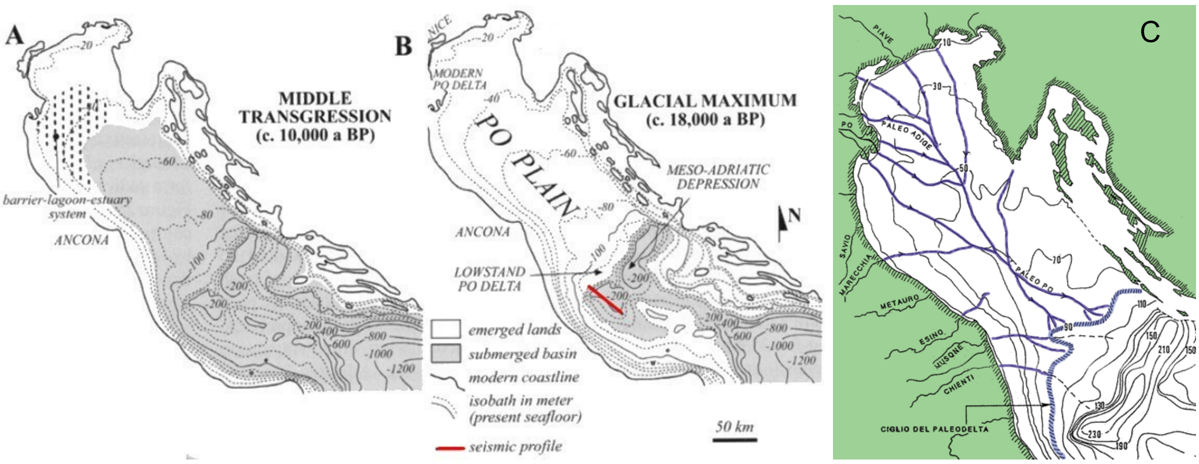

Fig. 6. A and B show two main phases of the Adriatic marine transgression (McKinney, 2007). C evidence the position of the Po river paleo-delta, at the present isobath of 90m (Ricci-Lucchi, 1992 mod.).

During the Mesozoic and Early Paleogene, the deposition of shallow water carbonates resulted in a thick (up to 8 km) carbonate (limestones and dolomites) succession (Vlahović et al., 2005).

The present-day tectonic frame in the eastern Adriatic region initiated in the Miocene to Early Pliocene (Korbar, 2009). The complex carbonate structures could have been significantly karstified since the Miocene (Mocochain et al., 2009). The recent EAC has been shaped by the last (Late Pleistocene–Holocene) sea-level rise, when the folded, faulted, and karstified relief was partially submerged (Benac and Juračić, 1998; Surić et al., 2005).

Also along the Montenegro/Northern Albanian Continental Margin peculiar morphologies of the bottom are reported, likely due to tectonic compressive deformations. They may be the result of sedimentary processes, such as progradation at river outflows, erosion, and reworking of sediments by longshore currents and seismic shaking.

The Late Quaternary sea-level changes affected the presence of seabed forms, diagnostic of erosion or depositional processes, such us large dunes, sediment ridge sand sediment waves (Del Bianco et al., 2014). This reconstruction is similar to the formation and drowning of the elongated dunes observed on the North Adriatic shelf in 24 m water depth, offshore the Venice Lagoon (Correggiari et al., 1996).

The subsidence and the deposition from rivers originated assemble of huge amounts of terrigen sediment and debr is. Moreover, the Adriatic Sea level underwent considerable changes: during the Pliocene waters level was about higher respect to the present, while during the maximum glacial period (Pleistocene 18000 years ago) it was 90-100 m lower respect to the present level (fig. 6). Therefore the Adriatic Sea was widespread during the Pliocene, but with scarce deposition because of lacks of large rivers, receiving turbidities only from the north, that rapidly filled the entire basin. In contrast, during Pleistocene there was a great input of fluvial sediments into the basin, the entire continental shelve was emerged and subjected to erosion by rivers and a large delta modeled the northern side of the middle Pomo Adriatic depression. Around 12.000 – 8.500 years ago increases in sea levels occurred, the extensive plain was quickly flooded and all previously deposited sediments were submerged and re-deposited onshore or along the new coast lines (Trincardi et al., 1996; van Straaten, 1970).

The last strong variation in sea level occurred over the past 100 years, with eustatic rise of several centimetres of sea-level worldwide (Shennan and Woodworth, 1992), while thermal expansion of deep water masses caused rapid sea-level rise in the Mediterranean Sea of 10-20 mm per year from 1993 to 1999, varying from a minimum of 5 mm to a maximum of 20 mm in Otranto Strait and north of the Adriatic Sea respectively (Cazenave et al., 2001). The present water level variations are due to both regional and local causes. At Venice, the mean elevation of 1 m and “acqua alta” events, are related to interactions of tides, winds and atmospheric pressure in the north Adriatic (Bargagli et al., 2002).

3.3 General geomorphology

The Adriatic basin shows three main sub-basins (Fig. 7), with a wide heterogeneity of bottom sediments. Its margin shows a mud-dominated regressive wedge influenced by fluvial supply and marine processes, known as clinoform, including a continuous belt of deltaic and shallow marine deposits of up to 35 m thickness (Tesi et al., 2007).

The Adriatic seabed sediments are predominantly sandy–muddy (Brambati and Venzo, 1967; Brambati et al., 1983), while the main clastic sources are located along the western side (Tesi et al., 2007). While the Italian coast has sedimentary tracts, the Balkan coast is rugged and rocky, separated at the northernmost point of the Adriatic, by Monfalcone that marks the abrupt change between the Italian coast to the southwest and the Balkan one southeast (McKinney, 2007). The Balkan coast from Istrian Peninsula to Albania, delimits the seaward edge of the Karst Plateau, consisting of carbonate rocks and numerous carbonate islands offshore (McKinney, 2007). The western coast is largely sedimentary and tends to be alluvial or terraced, it is low and mostly sandy, while the eastern coast is generally high and rocky. The Italian coast from Monfalcone to Rimini is bordered by sedimentary plains, consists of deltas, sand beaches and barrier islands and is dominated by longshore transport (Colantoni et al., 1997; Simeoni and Bondesan, 1997). From Rimini to the Gargano Peninsula the coast consists of beaches and short sections where rocks form promontories, while from Gargano Peninsula to Otranto, the coast is dominated by rocks (McKinney, 2007). It is highly indented with pronounced erosion due to karstification. This process results in sinkholes, towers, caves, and a complex subsurface drainage system. The similar situation is on the eastern coast, which is predominantly karstic. The Croatian coast is one of the most indented in the Adriatic as well as in the Mediterranean (with the mainland coastline of 1.777 km) and with 1.246 islands, islets, and rocks (with additional 4.398 km of coastline; Duplančić Leder et al., 2004). The rows of island chains are parallel to the coastline and this is known worldwide as a Dalmatian type coast (Fairbridge, 1968).

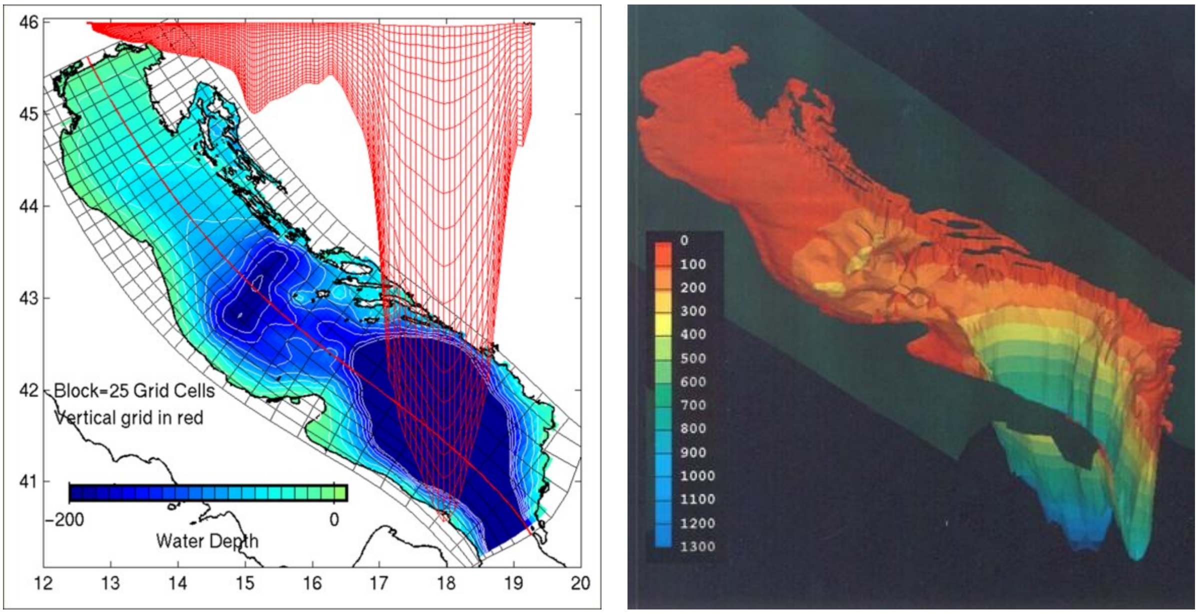

Fig. 7. A) Red transect down center of Adriatic illustrates the vertical resolution (credit: http://www.myroms.org/cstms/wiki/index.php/Sediment_dispersal_in_the_northwestern_Adriatic_Sea). B) Bathymetry of the Adriatic Sea (credit: http://engineering.dartmouth.edu/adriatic/index.html).

4 River Discharge

The numerous rivers discharging into the basin plus underground freshwater seeping into the sea along the eastern coast affect both the sedimentation and the circulation of the coasts. This effect is particulary evident in the northern basin with the Po River and in the southern basin with Neretva river and a group of Albanian rivers (Brambati et al., 1983), delivering more sediment than the Po River (Simeoni et al., 1997). Sedimentation consists of clastic materials, sandy-clay, coming from Po River and from input by Apennine rivers, Veneto, Friuli and from Istrian localities. The highest area of inflow of fresh water of the entire northern and middle regions of the Adriatic is between the Po and the Isonzo rivers, where roughly 40% of riverine water enters into the Adriatic Sea, while between Trieste and Dubrovnik, the main flows of fresh water are subterranean, through the porous carbonate rock at the edge of the Karst Plateau (Poulain and Raicich, 2001). There are a few karstic and therefore oligotrophic rivers that discharge into the Adriatic on its eastern coast like rivers Zrmanja, Krka, Cetina and Neretva. Following Cozzi et al. (2012) Isonzo River, with a length of 136 km, a drainage basin of 3.452 km^2 and an average flow of 82 m^3 s^{-1}, is the major source of land-borne nutrients in the Gulf of Trieste, mainly due to nitrate coming from cropping areas of Venezia-Giulia plain. The second tributary in the gulf, the Timavo River has an average flow of 27 m^3 s^{-1} and a total length of 89 km. Its terminal portion runs for about 40 km through an unexplored path under the Karst Plateau. Its freshwater load generates a plume that mixes with that of Isonzo River affecting phytoplankton dynamics, especially in late winter and autumn (Malej et al., 1995).

The balance of water depending on total input and evaporation results in an excess of water of 90-150 km^3 per year that is exported in the Mediterranean basin through the Otranto Strait (McKinney, 2007). Most of the river input in the Adriatic Sea comes from the Po river and the Italian coasts. The Po River, 673 km long, is the largest Italian river and supplies over the 11 % of the total freshwater flow,into the Mediterranean, the 28% into the entire Adriatic Sea and 50% into its northern part (Degobbis et al., 1986). Both rivers and submarine springs along the Balkan or Dalmatian coasts together contribute another 29% of freshwater flows to the Adriatic basin. This high input not only determines the low salinity and the dense water but also models the coast, conferring in average low slopes and high sedimentary ranges on the Italian coasts and mainly steep rocky coast on the western coast. The Po river terrigenous supply is composed of 77% of pelitic fraction and 23% of sand (Colantoni et al., 1979). These materials have turbiditic character. The littoral environment, influenced also by tidal currents, is a highly energetic environment which does not allow sedimentation of pelitic matter retained in suspension and it is therefore characterized by an exclusive presence of sand representing sedimentation of coarse terrigenous supply by rivers (Brambati et al., 1983). The floor of the Po Plain and the northern Adriatic Sea is constituted of a single flooded sedimentary plain, with a continuous and gentle slope from the Po Plain into the sea that permits lateral large movement of the coastline (McKinney, 2007).

The Po River flowing west to east across Italy's north is the largest contributor of sediments to the basin. At present, 4.2 x 10^7 tons of sediment per year are flushed in the Adriatic Sea by Italian rivers, above all by Po River (Buljan and Zore-Armanda, 1976; Trincardi et al., 1994).

Subsidence of deposited fine-grained sediments occurs in the coasts comprising the Isonzo River and the Po Delta, caused by compaction and de-watering of muds and tectonic movements of the area between Apennines and Alps (McKinney, 2007). The interaction of sea level changes and sediment supply or removal cause variations of sedimentary shorelines along the northwestern Adriatic coast. Two thousand years ago, the sedimentary coasts were prograding due to sediment transported by Po River that built protruding delta, at 70 m yr^{-1} from seventeenth to twentieth centuries due to deforestation of the Po plain and the construction of levees (Colantoni et al., 1979; Oldfield et al., 2003). During the latter half of twentieth century the reduction of sediment supply caused by sediment traps of hydroelectric dams and dredging of sand from riverbeds induced a shift to retreating shorelines (Colantoni et al., 1979; Simeoni and Bondesan, 1997).

The flow, together with the biotic and abiotic entrances in the basin constitutes the river input, one of the key elements that determines the division in sub-basins: north, central and south vs. the north eastern shelf. The inputs coming from the river, when coming in contact with the salty water and the currents coming from the Otranto Strait, create gyres and shape the geological structures, move the sediments to and from the coastal areas (definitive in well natural and un-natural erosion processes), producing deposits and sink zones that determine utterly the local conditions. The influence of the river input, does not only remain local but spread along the whole basin by the transport and primary production it generates. The Italian coast is the most riverine coast compared to the eastern shelf up to Albania, where the river discharge increases (Fig. 8). The eastern shelf, compared to the western is less influenced by the river input, thus more oligotrophic and with a sort of current *di se,* due to the high abundance of inlets and islands.

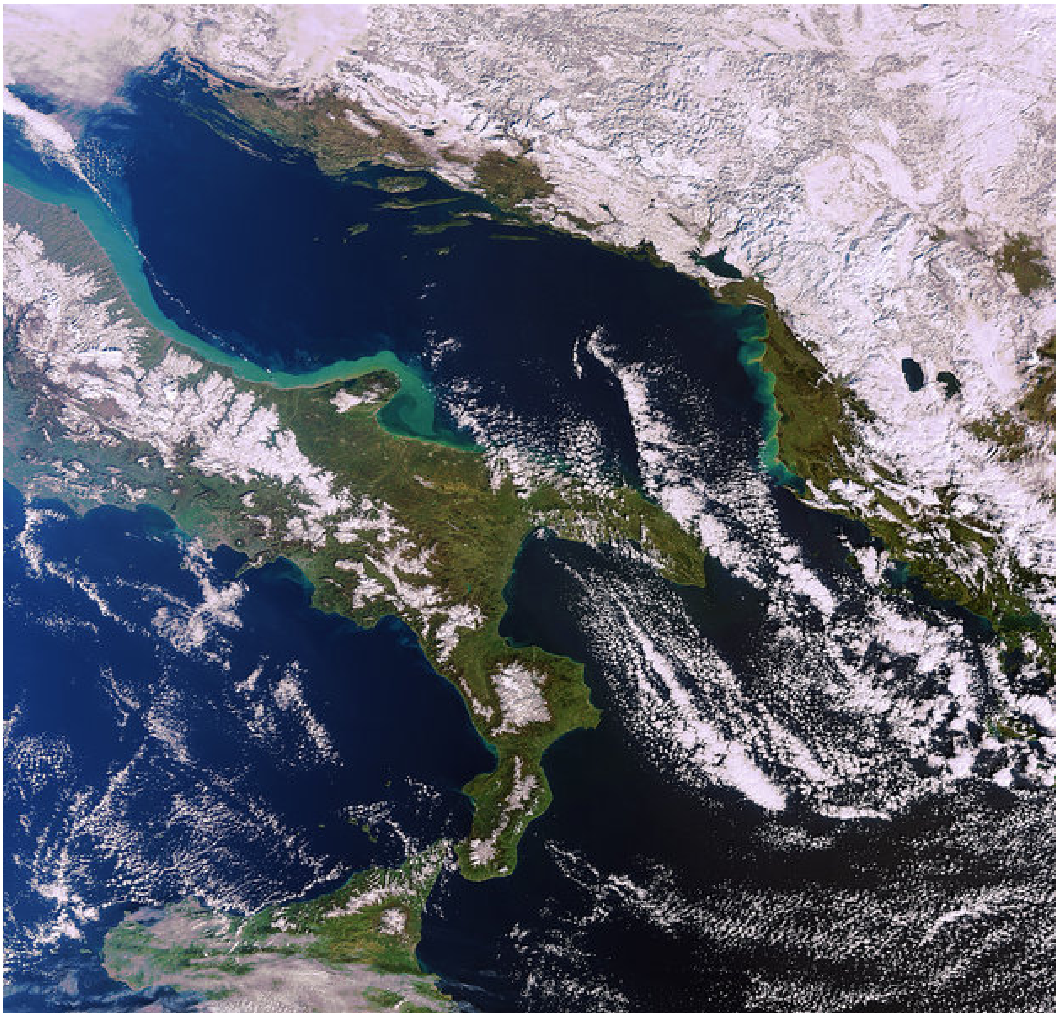

Fig. 8. Satellite imaging to evidence the river outputs and effects among the coastline; transport of sediment is intense up to 5nm from the coastline but still evident at points at the 12nm limit. ESA image 18/02/2011 10:38 am

4.1 Sedimentation processes in the Adriatic

In the Adriatic Sea sediment accumulated during the last transgression, the post-glacial sea-level rise which started around 18 ka BP. This process led to the formation of a continuous sediment body in the centre of the basin and two ones separated by a distance of more than

150 km, comprising preserved barrier-lagoon deposits (Correggiari et al., 1996; Trincardi et al., 1994; Cattaneo and Trincardi, 1999). These two sediment bodies are separated by a time interval of nearly 5000 years.

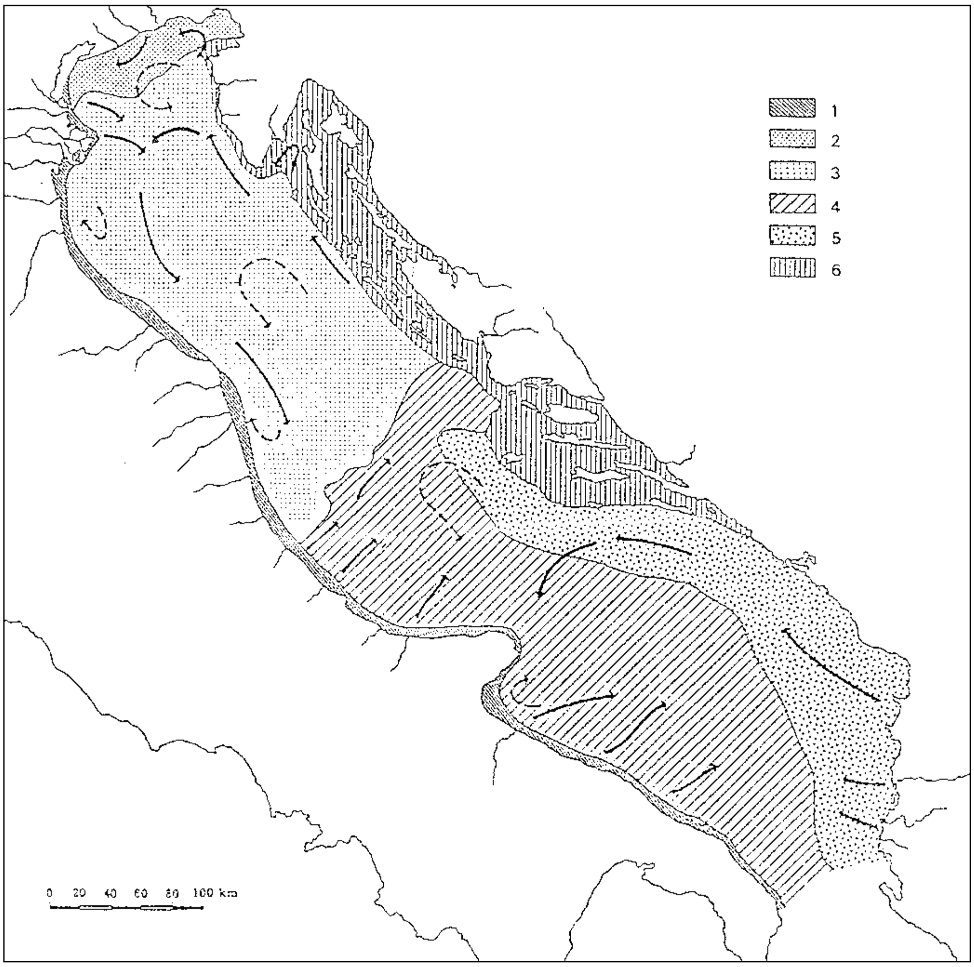

Fig. 9. Sedimentary provinces and main directions of sediment transport: 1) Coastal province; 2) Veneto province; 3) Po province; 4) South-Augitica province; 5) Albanian province; 6) Istria-Dalmatia province (from Colantoni, 1986; mod.).

As a result of the present-day surface counter clockwise circulation pattern (Artegiani et al., 1997a; Orlić et al., 1992), a fine-grained sediment wedge is formed, which consists of Po and the Apennine derived sediments that are dispersed southward (Fig. 9) and deposited in a narrow band along the Italian coast down to the Gulf of Manfredonia, in the area south of the Gargano Promontory (Cattaneo et al., 2003).

The river input in sediments and debris change along the coasts, showing how the Adriatic can be considered separated in diverse provinces based on sediment features, where diverse grain size dependent benthic communities may develop. The differences in sedimentation rates, determine the type of communities present. It is not rare to see flakes of organic matter deposited, disturbed, transported and re-deposited on different areas, where they accumulate in higher or lower layers depending on the grain size or the bottom type.

5 Oceanographic Features

The Adriatic Sea, with its surface of about 138.600 km^2 and its overall depth of 240 m, comprises a volume of roughly 35000 km^3, occupied for a 5% by the northern region, for 15% by the middle one, while the southern region occupies 80% of the total volume, with an area of 57000 km^2 and an average depth of 450 m (Buljan and Zore-Armanda, 1976; Zore-Armanda et al., 1983). The Adriatic supplies up to one-third of the freshwater flow received by the entire Mediterranean. It is estimated that the Adriatic's entire volume is exchanged into the Mediterranean Sea through the Strait of Otranto every three to four years, a very short period and likely due to the combined contribution of rivers and submarine groundwater discharge (Franić, 2005). A duration of 150–168 days is estimated as the residence time in the Adriatic Sea for a drifting particles (Poulain and Hariri, 2013).

There are three principal water masses in the Adriatic Sea: the Adriatic Surface Water (AdSW), the Levantine Intermediate Water (LIW) and the Adriatic Deep Water (AdDW) (every sub-basin has its own characteristic deep water).

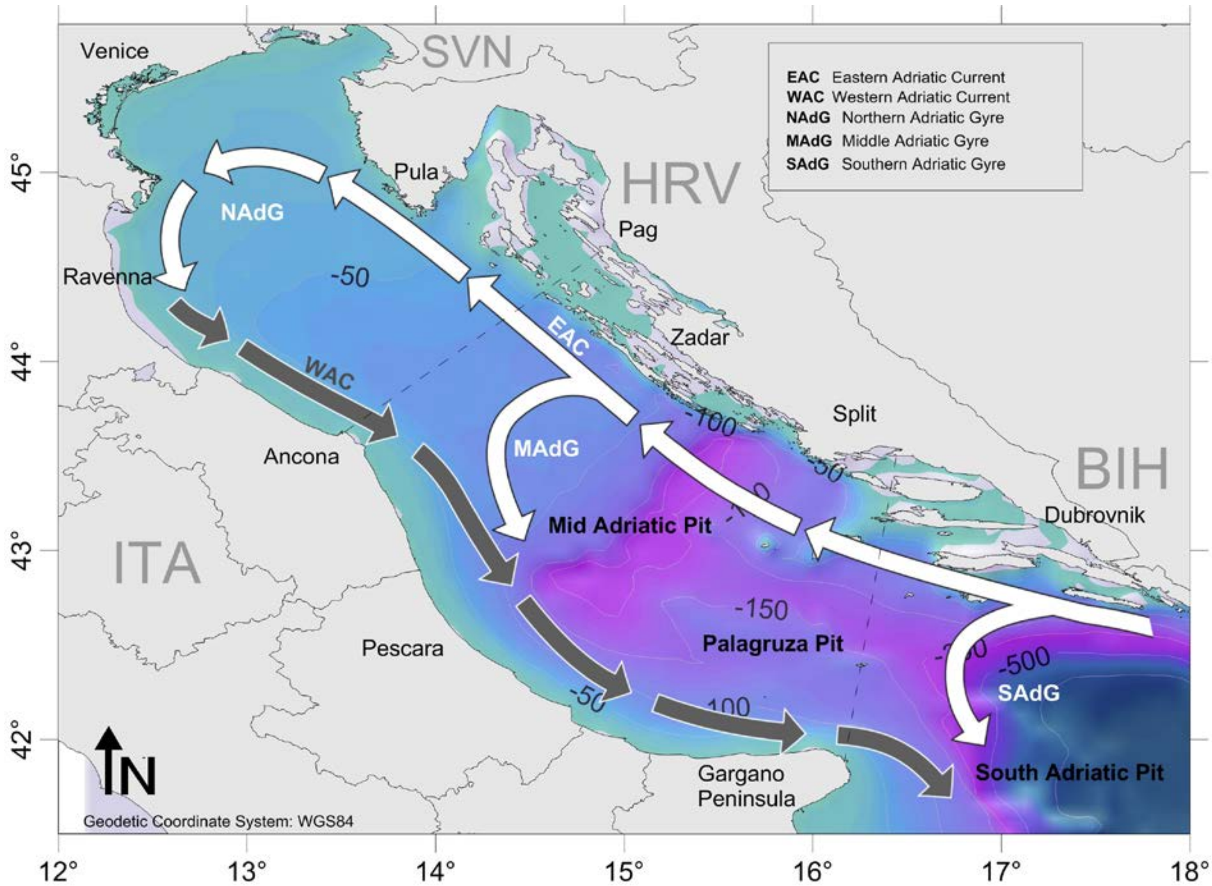

Fig. 10. The typical three paths followed by the main seasonal Adriatic currents.

The basin is characterised by the sinking of colder and heavier waters during the winter, by a relevant surface warming during the summer season and heavy rainfalls and river runoff (in particular by the Po River) during spring and autumn (Artegiani et al., 1997a; Cushman-Roisin et al., 2001).

The circulation is mostly counterclockwise or cyclonic, with up to three closed cells (in the southern, middle and northern basin respectively; Fig. 10). Both intensity and location of the costal currents (Western Adriatic and Eastern Adriatic Current) and of the gyres above the Middle and South Adriatic Pits have significant seasonal variations (Cushman-Roisin et al., 2001). The typical winds Bora and Scirocco blow along the eastern coast of the Adriatic Sea, prevailing during the colder part of the year and their role is fundamental to trigger and regulate water masses circulation. Annual wind show a NNW-SSE directionality in the south Adriatic Basin while an omnidirectional behaviour may be observed at higher latitudes. Near coastal line, winds show more irregular occurrences due to interactions with the local geomorphology. During the warmer seasons, sea and land breezes are rather frequent (Pandžić and Likso, 2005).

The overall Adriatic thermohaline circulation arises from the opposite effects of the thermal and haline forcing. The reciprocal variability of heat and water fluxes may be responsible for the variability of local circulation features. The Western Adriatic Current is due to the lower density of coastal waters than offshore waters (controlled to a large extend by the runoff of the Po and other Italian's rivers). These waters are exchanged through the Strait of Otranto and replaced by others warmer water masses producing the Eastern Adriatic Current.

The deep waters of the Adriatic can be separated into two categories: the first, clearly formed in the northern Adriatic region, cool and relatively less saline, found in the northern and middle Adriatic, and the second of much higher temperature and salinity, in the southern Adriatic (Artegiani et al., 1997a). Deep-waters production in the Adriatic sea is an important process affecting water-mass characteristic (Cushman-Roisin et al., 2001) of a large portion of Eastern Mediterranean and plays a crucial role in the complex and climate-sensitive thermohaline system of the Eastern Mediterranean (Gačić et al., 2010). The necessary conditions to the production of the deep waters are generally met in the Adriatic sea, even if the Adriatic Sea is extremely sensitive to interannual variations with some winters rich in their production and other hardly forming any (Cushman-Roisin et al., 2001).

Both surface salinity and temperature fields show large-scale patchiness during the spring–summer seasons. The salt balance of the surface layer is clearly affected by freshwater river runoff and the maximum values of salinity are found in winter (37,40 psu mean density of the basin), while minimum values occur in summer (36,79 psu mean density of the basin). The surface temperature has a clear seasonal cycle with maximum values of temperature during summer and maximum mixed layer depths during winter (Artegiani et al., 1997a, b). The interaction between processes in the shallower and deeper parts of the basin remains largely unexplored. Joint shallow-deep studies are essential for an understanding of the contribution of the North Adriatic Dense Waters in ventilating the bottom layer of the South Adriatic Pit, or to explain differences between Adriatic shelf areas, which results in diverse open-sea/coastal-zone interactions.

6 Hydrology and hydrodynamics

The Adriatic basin is enclosed by two mountain ranges the Apennines on the western shore and the Dinaric Alps on the eastern shore, becoming this way the most continental basin in the Mediterranean after the Black Sea. There are clear differences amongst the North, the South and the Central areas in terms of seabed morphology and thus of the communities associated.

The circulation of Adriatic surface water is affected by the inflow of freshwater from point sources, particularly the Po River, the inflow of Mediterranean water through the Otranto Strait and wind shear (Artegiani et al., 1997b; Cavaleri et al., 1997). An average rate of 1,600 m^3 sec^{-1} of water are flowed in the Adriatic by the Po River, generating a high and dynamically unstable wedge (Raicich, 1994) and a current that arcs southward towards Italian coasts, is deflected to the right to the Otranto Strait and produce an overall cyclonic flow. Surface circulation is driven by the inflow of fresh water from the Po River and of the Mediterranean water through the Otranto Strait and secondary rivers (McKinney, 2007) and variability is related also to winds effects. The overall basin-wide flow is broken up into three cyclonic gyres by coastal configurations, characterizing three well-separated ecological entities, the more shallow northern shelf platform, the middle Adriatic depression and the deep southern basin. Located at the northern Adriatic shelf, the northern gyre is known to be cyclonic and seasonally varying in strength, with intensified jets along the western Adriatic coastlines (Artegiani et al., 1997b). The middle Adriatic gyre located over the middle Adriatic depression, variable in position during summer season, is more pronounced in summer and autumn. The southern Adriatic cyclonic gyre, permanently located over the southern basin, persists throughout the year and is observed in all seasons (Malanotte-Rizzoli and Bergamasco, 1983; Mosetti and Lavenia, 1969; Zorè, 1962; Russo and Artegiani, 1996) (Fig. 11).

Subsurface circulation is influenced by seasonality, with isolation of the north area from the rest of Adriatic, due to summer thermocline at 10-30 m depth with surface temperature of 22-25°C (Buljan and Zore-Armanda, 1976). The absence of thermocline in winter cause instability of the water column across most of the northern Adriatic, that produce a slow flows of dense and cold water mixing with waters towards south areas and influences deep-water circulation (McKinney, 2007). The Adriatic Sea is the major source of the densest water in the Eastern Mediterranean, the Eastern Mediterranean Deep Water.

Four water masses circulate through the southern Otranto Strait: the Adriatic surface water (ASW), the Ionan surface water (ISW), the Levantine intermediate waters from the eastern Mediterranean (LIW - a warm and highly saline current on the eastern slope of the Otranto Strait from 250 to 500 m depth) and the Adriatic deep water (ADW - a high density, low temperature and low salinity current on the western slope) (McKinney, 2007). These deep-water currents vary depending on discharging of rivers, mainly Po River and atmospheric events (Manca et al., 2002; Poulain et al., 1996).

The northern basin is therefore highly influenced by the Po river (and near minor rivers) discharge and by meteorology events; the freshwater determines a lower salinity in the whole basin, mainly in the vicinity of Po Delta, but also induces elevated primary production that determine high abundance of fish and as a consequence highly exploited fishing zones (Fortibuoni et al., 2010; Fouzai et al., 2012; Libralato et al., 2010; Sabbatini et al., 2012).

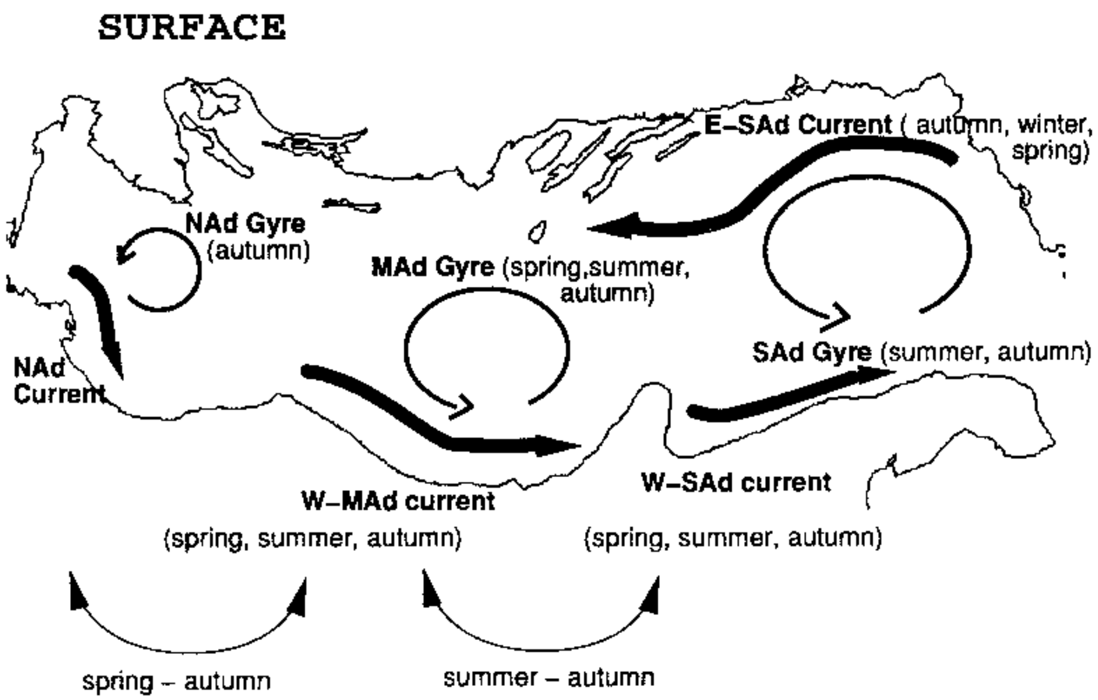

Fig. 11. Main current models of the Adriatic Sea basin. (Source: *Artegiani et al., 1997a*).

Water movement affects both sedimentological and oceanographic processes. Sediments are mixed by thermohaline currents (coming from Ionian sea) and by micro-tidal regime of the Adriatic. Deposit of sediments after the Po floods (Fox et al., 2004) are subsequently remobilized by waves to form density flows (Traykovski et al., 2007). The sediments then travel southward, follow the surface circulation characterised by cyclonic movement and wind patterns generate a southward flow along the eastern Italian shore (Western Adriatic Coastal Current, WACC, (Tesi et al., 2007; Zavatarelli et al., 2002). There are therefore two transports pathways bringing sediments on the Adriatic shelf: in shallow water sediments are transported almost completely along shelf by the WACC, while in deeper water transport is driven by both along- and off-shelf transport due to Ekman veering (Fain et al., 2007; Tesi et al., 2007).

The seaward limit of littoral sand defines the extension and depth of the most dynamic zone of the submarine beach until the depth of 5-7 m and the distribution patterns of sediment exhibit a progressive decrease in sand components and progressive increase in pelitic components. The increase of pelitic sediment testifies to the gradual decrease of energetic influence of wave motion and the progressive increase of other dynamic factors controlling transport and sedimentation processes, such as fluvial currents and marine diffusion (Brambati et al., 1983). At the mouth of rivers the presence of a more or less extended area of pelitic deposition defines the zones of maximum accumulation of fine material of fluvial origin, which laterally decrease in pelite contents and define dispersion of fine material. Finally the continental slope is characterized by the presence of pelitic fraction increasing progressively with depth (Brambati et al., 1983). Seafloor sediment consists of relict Pleistocene sand covered by Holocene mud (Pigorini, 1967; Goff et al., 2006). Recent sands are restricted to the small coastal zone. In between the recent coastal sands and shelfal relict sands, a so-called prolittoral mud belt is developed where most of the recent terrigenous muds are deposited (Ponti and Mescalchin, 2008).

6.1 Other recent geological processes in the Adriatic

In the northwestern Adriatic Sea there are local isolated hard substrata mainly originated by consolidation of relict sands. Carbonate cementation of relict sands are formed by seeps of gas, CO_2 and methane, derived from organic material decomposition within sediments or by fresh water percolation. Pinnacles of indurated sands are common scattered through the northern Adriatic Sea, surrounded by less coherent sands (Conti et al., 2002). Later, calcareous organisms have grown over these crusts, generating coralligenous banks up to 4 m height (Ponti et al., 2011).

Pockmarks discovered in deep bottoms, are roughly conical depressions in the seafloor (King and MacLean, 1970), originated from escape of natural gases and interstitial water from unconsolidated sediment (Hovland and Judd, 1988; Judd and Hovland, 1992). They are related to the hydraulic activity of the seafloor, determining surface fluid flow manifestations and whereas unit-pockmarcks represent cyclic pore-water seepage, normal-pockmarks are formed from periodic or intermittent eruptions/bursts of gas in periods of slow and cyclic pore-water seepage, resulting from the active pumping by the trapped under-ground gas (Cathles et al., 2010; Hovland et al., 2010).

In the central Adriatic Sea there are pockmarks in three distinct areas (Fig. 12): the northern area of Bonaccia gas field at a depth of 80-90 m, emanating seapages "from erosional depression up to a few hundred metres wide and a few metres deep", ascribed to violent gas eruptions related to large gas structures at 30 m depth below seabed (Stefanon, 1981), while two areas of both seabed and buried pockmarks are present in the Jabuka or Pomo Trough, of 30-500 m across and 1-6 m in depth, up to 10 per km^2, at a depth of 182-251 m (Curzi and Veggiani, 1985). These structures were formed by biogenic gas easily migrated because of differential subsidence in the zone, resulting in a collapse of the seabed sediment after escapes of gases, related to seismic activity of the area (Stefanon, 1981).

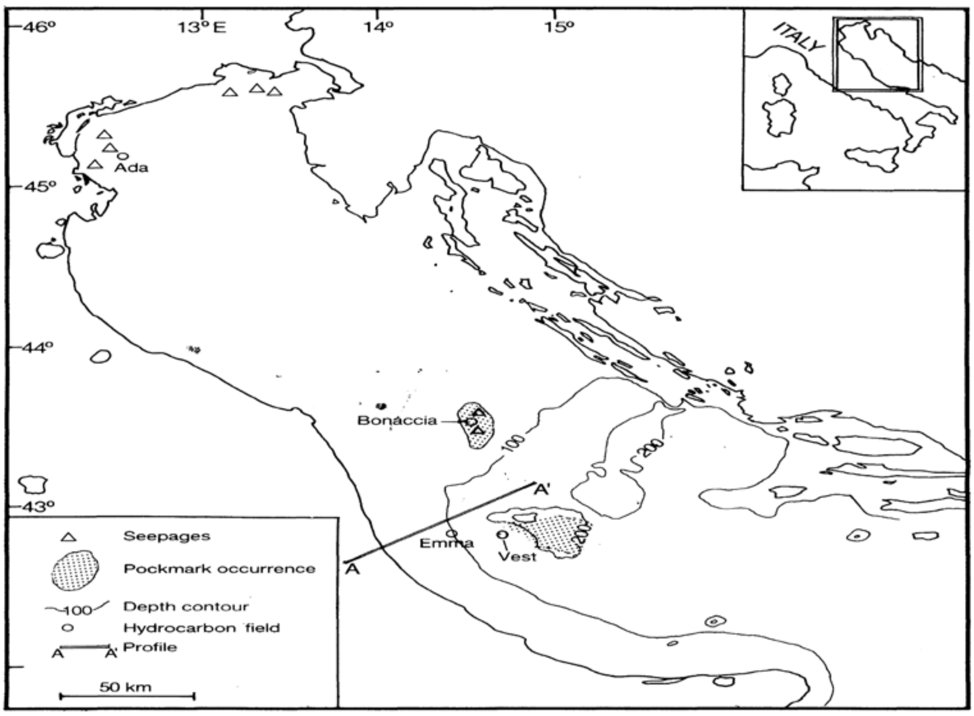

Fig.12. Map of the Adriatic Sea pockmarks (Hovland and Judd, 1988).

PART II. Biological Description of the Study Area

7 Adriatic benthic communities

7.1 Soft bottoms

Adriatic benthic communties have been studied from historical time. Up to the end of the 1967, most of the studies were focused on the phytal biocenoses (Giordani Soika, 1955, 1956, 1959; Huvé et al., 1963; Riedl, 1963; Sarà, 1961; Scaccini, 1967; Vatova, 1935, 1936, 1943, 1946, 1949, 1958, 1960). Since 1968, researches started to include also aphytal and deep communities. Gamulin-Brida (1974) reviewed exhaustively the knowledge of that time applying the biocenotic approach proposed by Pérès and Picard (1964) (Fig. 13). Vatova's and more recent data for the northern Adriatic Sea were reviewed by McKinney (2007) that highlighted the higher biomass of endobenthos extended from the Po Delta northeastward toward the northern tip of the Istrian Peninsula. Wide benthic surveys in the northern Adriatic soft bottoms were carried out in the '60s and '90s and compared with those of Vatova in the '30s by Scardi et al. (2000). The same communities observed in the '30s were still present in the '90s, but a reduced spatial heterogeneity (i.e. a reduction in diversity from local to medium scale) was obtained thirty years later, which could be related to the increased trawling fishing pressure and variation in sedimentation patterns (Scardi et al., 2000).

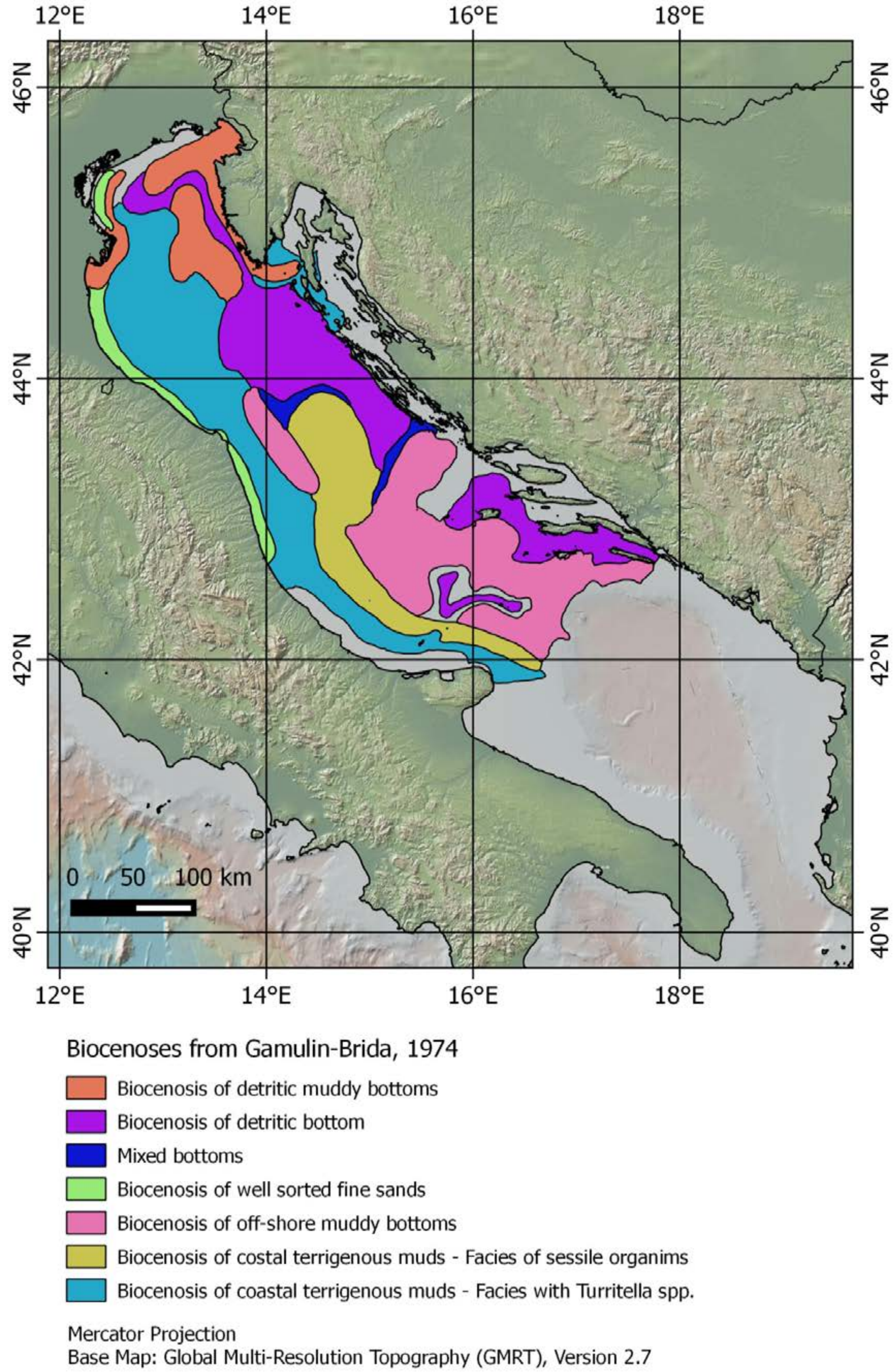

Fig. 13. Adriatic biocenoses adapted from Gamulin-Brida (1974).

Soft bottom biocenoses distribution appeared largely dependent by sediment properties, both regarding their granulometries (Gray, 1974) and their mineralogical features (Cerrano et al., 1999). In turn, they vary according to present and past sedimentation regimes. Western biocenoses tend to be arranged in zones parallel to the coastline, from sandy beaches over to subtidal shallow fine sands, and then to offshore muddy bottoms. Shallow inshore sandy bottoms are often dominated by the suspension-feeding bivalve *Lentidium mediterraneum*, which seasonaly can reach 300,000 ind. m^{-2}.

Close to main river mouths, coastal muddy bottoms affect benthic assemblages. In particular, in shallow muddy-sandy bottoms within few kilometers from the Po River Delta, benthic fauna is dominated by polychaetes and bivalves with relatively low species diversity (Ambrogi et al., 1990; Ambrogi et al., 1985).

Coastal muddy bottoms, 4-5 km offshore the Delta and on 20-21 m depth, showed great abundance of dominant, opportunistic species such as the bivalve *Corbula gibba* (Simonini et al., 2004) typical of unstable sea bottoms with a high rate of sedimentation (Pérès and Picard, 1964) and organic enrichment and anoxic condition (Diaz and Rosenberg, 1995).

Samples collected during summer 1985 at 14-15 m depth offshore of Ravenna revealed a dramatic increase of *C. gibba* in this area, compared to Vatova's findings in the '30s (Crema et al., 1991). This change in the benthic assemblages could be a result of long-term eutrophication and consequent frequent anoxic events (Crema et al., 1991) and/or episodic Po river flow peaks (Occhipinti-Ambrogi et al., 2005). Conversely, in subsequent years characterised by rather steady hydrographic conditions and low river discharge (1997-2000), the amphipod *Ampelisca diadema* replaced *C. gibba* as the dominant species, especially during summer (Occhipinti-Ambrogi et al., 2005). This burrowing amphipod seems to have a relevant role in helping sea-bottom oxygenation and nitrification processes, modifying the substrate and makes it suitable for other species (Occhipinti-Ambrogi et al., 2005).

Far from the rivers outflows, in the middle of the northern Adriatic Sea, the benthic assemblages are influenced by the presence of relict sands (Simonini et al., 2007).

Eastern benthic assemblages, in the area of the Gulf of Trieste, are characterized by deposit-feeding endobenthic bivalves and polychaetes, mud-grazing gastropods, burrowing echinoids and holothurians. With exception of water-sediment interface, sediment below 20 m depth can be often anoxic and bioturbation increment availability of nutrients, oxygen and dissolved organic matter (Faganeli et al., 1991). Several kilometres south to the Gulf of Trieste, the coast is dominated by epibenthic suspension-feeders, ophiuroids, sponges and ascidians (Vatova, 1935, 1949). The area north to Istria is characterized by the so-called *Ophiotrix-Reniera-Microcosmus* (ORM) community, based on the presence of ophiuroid *Ophiothrix* spp., the demosponge *Reniera* spp. and the ascidian *Microcosmus* spp. This community has been involved in several episodes of anoxic crisis in the last years and its distribution is now under regression. Gastropod shells after the death of inhabitant gastropod are quite common and serve as substratum for epibiotic organisms and support a wide hermit crab assemblage. The offshore of the Istrian coast is characterized by progressively muddier sediments. Along the eastern coasts the presence of the fan shell *Pinna nobilis* can be locally very abundant. This species is among the few marine invertebrates taken in account by the Habitat Directive (Annex IV).

Central and southern Adriatic soft bottoms are less investigated and a unified framework of the benthic assemblages is still not available. Anyway, a map describing the main habitats is available from fishermen reports and even if it needs to be adequately validated helps figuring out the heterogeneity of the area (Fig. 14).

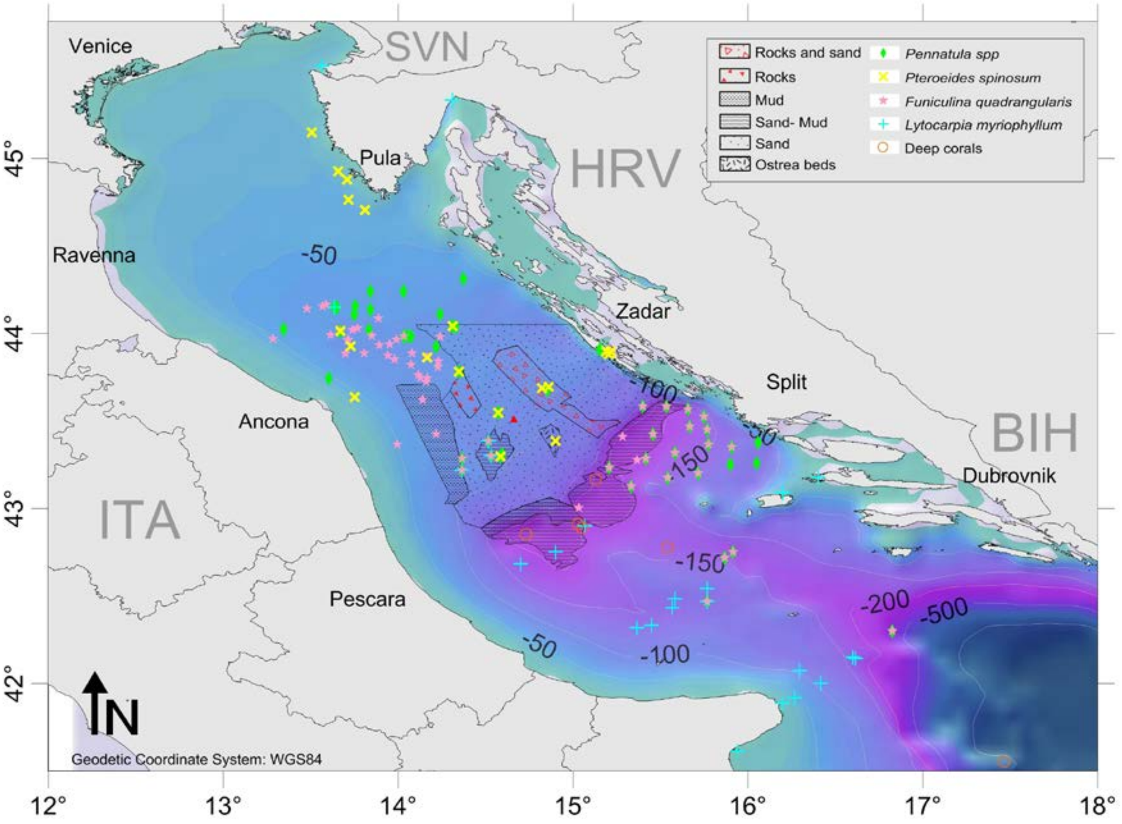

Fig. 14. Main habitats and facies recorded by fishermen in the central Adriatic

7.2 Hard bottoms

Most of the eastern coasts are represented by rocky shores. The prevailing lithologies are calcareous. Benthic assemblages starting from the shore are characterised by photophilic algae, often including *Cystoseira* spp. belts, and sea urchin barrens. Near the rocky shores, especially in shallow bays, there are plenty of seagrass meadows, while deeper subtidal rocky cliffs have peculiar coralligenous habitats. The presence of calcareous substrates allows a wide distribution of the mussel date *Lithophaga lithophaga*. Even if included in the Habitat Directive (Annex IV), this long living species is illegally fished and commercially exploited. Its collection can permanently affect rocky shallow water communities, leading to extensive barrens (Devescovi et al., 2005; Fanelli et al., 1994).

Isolated coralligenous banks in the North-western Adriatic Sea were firstly mentioned in the 18th century (Olivi et al., 1792); to date, their benthic assemblages has been analysed only in few locations (Brunetti, 1994; Gabriele et al., 1999; Mizzan, 2000; Molin et al., 2003; Soresi et al., 2004). An approximate checklist of the benthic organisms living on these outcrops can be found in Casellato and Stefanon (2008) while a photocatalog and distribution maps of the most relevant epibenthic species can be found in Ponti and Mescalchin (2008). Recent studies have allowed to outline the richness and spatial and temporal variability of epibenthic assemblages, including several new records for the northern Adriatic Sea (Curiel et al., 2012; Ponti et al., 2011; Ponti et al., 2014a). The dominant reef-forming organisms were the encrusting calcareous algae (*Lithophyllum incrustans*, *Lithothamnion* spp. and *Peyssonnelia* spp.), while the main bioeroders were boring sponges (*Cliona viridis*, *C. celata*, *C. thoosina*, *C. rhodensis*, *Piona vastifica*) and the bivalve *Rocellaria dubia*. Assemblages on reefs closer to the coast were dominated by algal turfs and boring sponges, while offshore they were generally characterised by the richest and most diverse communities. Composition of the assemblages varied thorough years and among sites. Spatial heterogeneity, at local and regional scale, prevailed over temporal variation. This variability was related both to the geo-morphological features of the outcrops and to environmental variables (Curiel et al., 2012; Ponti et al., 2011; Ponti et al., 2014a).

The above-mentioned pockmarks in offshore deep bottoms host peculiar assemblages. Gases and mineralized water seep nourish seabed sediments and water above them, causing precipitation of nodules, crusts and slabs, that provide hard substrates for sessile organisms (Hovland et al., 1985) (Fig. 15). According to a 'hydraulic theory', nutrients coming from the extra energy percolating upwards as light hydrocarbons (methane, ethane, and propane) (Hovland, 1990) support chemoautotrophs and methanotrophs bacteria (Jensen et al., 2008; Penn et al., 2006; Yakimov et al., 2006) and probably stimulate the growth and biodiversity of benthic organisms (Hovland et al., 2010).

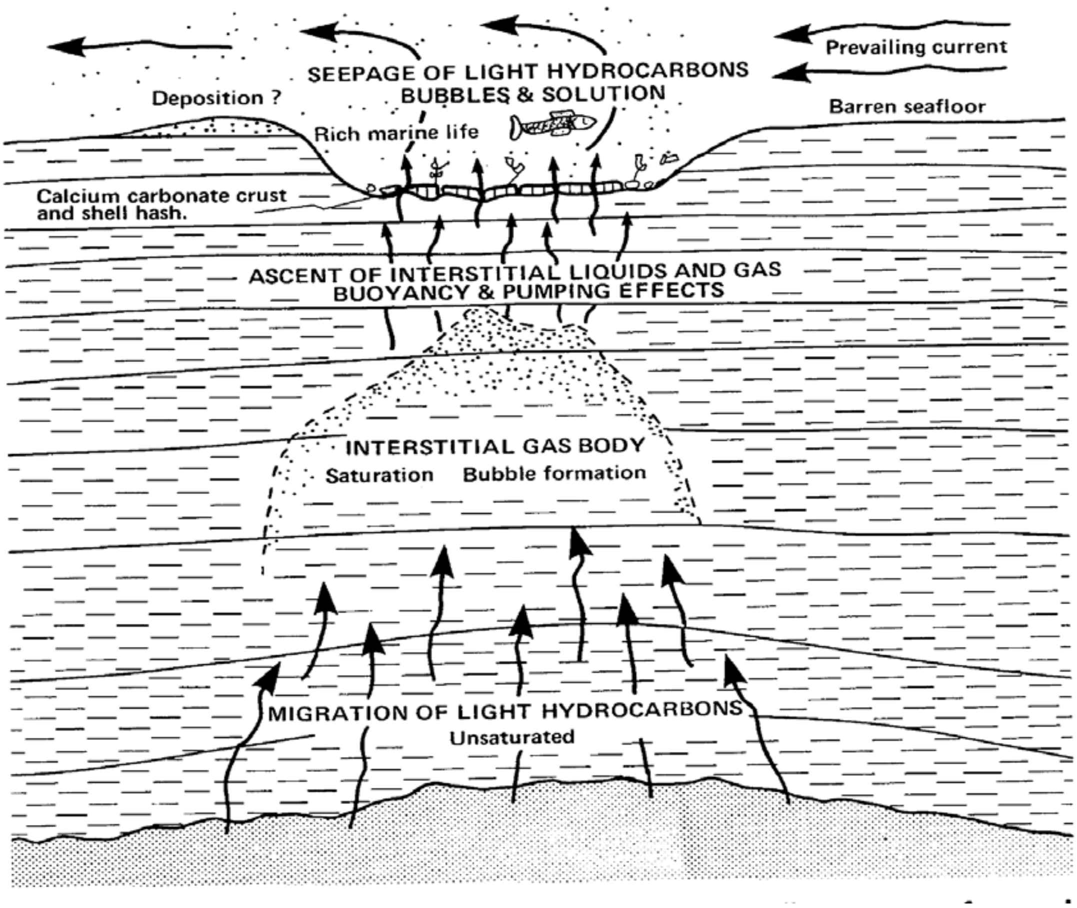

Fig. 15. Biological importance of pockmarks (from: Hovland and Judd, 1988).

7.3 List of Adriatic biocenosis

The classification of Adriatic benthic marine habitats follows the typologies proposed by RAC/SPA for the Mediterranean region. It is important to know that the tentative to include a community into a definited biocoenoses it is not always easy and can lead to misinterpretations. Anyway, in order to outline the work, a list of the recognised biocenosis is reported below, using the referring code select by RAC/SPA and the respectively identifications codes utilised by the EUR 27 (Interpretation Manual of European Union Habitats, 2007, based on the European Union Habitat Directive) and CORINE for biocenosis classification.

The wider biocenoses in the Adriatic Sea are the biocenosis characteristics of the circalittoral. Costal and offshore muddy bottoms host sponges, soft corals, sea pens, and ascidians in addition to a rich infauna. Offshore bottoms are usually viewed as receiving compartment, dependent on primary production in the water column. Benthic compartment regulates mineralization affecting pelagic production. This point is here underlined to support the idea to address conservation measures paying particular attention to sea floor integrity.

I. SUPRALITTORAL:

I.2. SANDS

I. 2. 1 Biocenosis of supralittoral sands

Reference codes for identification: **EUR 27**: 1140 (mudflats and sandflats not covered by seawater at low tide); **CORINE**: 14

I. 2. 1. 3 Facies of quickly-drying wracks

I. 2. 1. 5. Facies of phanerogams which have been washed ashore (upper part)

I. 3. STONES AND PEBBLES

I. 3. 1. Biocenosis of slowly drying wracks

Reference codes for identification: **EUR 27**: 1140; **CORINE**: 14

I. 4. HARD BEDS AND ROCKS

I. 4. 1. Biocenosis of supralittoral rock

Reference codes for identification: **EUR 27**: 1170; **CORINE**: 11.24

I. 4. 1. 1. Association with *Entophysalis deusta* and *Verrucaria amphibian*

I. 4. 1. 2. Pools with variable salinity (mediolittoral enclave)

II. MEDIOLITTORAL

II. 1. MUDS, SANDY MUDS AND SANDS

Reference codes for identification: **EUR 27**: 1140 ; **CORINE**: 14

II. 1. 1. Biocenosis of muddy sands and muds

II. 1. 1. 1. Association with halophytes

II.. 1. 1. 2. Facies of saltworks

II. 2. SAND

Reference codes for identification: **EUR 27**: 1140; **CORINE**: 14

II. 2. 1. Biocenosis of mediolittoral sands

II. 2. 1. 1 Facies with *Ophelia* sp.

II. 3. STONES AND PEBBLES

Reference codes for identification: **EUR 27**: 1140; **CORINE**: 14

II. 3. 1. Biocenosis of mediolittoral coarse detritic bottoms

Reference codes for identification

EUR 15 1140; **CORINE** 14

I. 3.1.1. Facies of banks of dead leaves of *Posidonia oceanica* and other phanerogams

II. 4. HARD BEDS AND ROCKS

II. 4.1 Biocenosis of the upper mediolittoral rock

Reference codes for identification: **EUR 27**: 1140; **CORINE**: 14

II. 4. 1. 1. Association with *Bangia atropurpurea*

II. 4. 1. 2. Association with *Porphyra leucosticta*

II. 4. 1. 3. Association with Nemalion helminthoides and Rissoella verruculosa

II. 4. 1. 4. Association with *Lithophyllum papillosum* and *Polysiphonia* spp.

II. 4. 2. Biocenosis of the lower mediolittoral rock

Reference codes for identification: **EUR 27**: 1170; **CORINE** 1124-1125

II. 4. 2. 1. Association with *Lithophyllum lichenoides* (= Entablure with *L. tortuosum*)

II. 4. 2. 2. Association with *Lithophyllum byssoides*

II. 4. 2. 3. Association with *Tenarea undulosa* (= *Tenarea tortuosa*)

II. 4. 2. 4. Association with *Ceramium ciliatum* and *Corallina elongata*.

II. 4. 2. 6. Association with Enteromorpha compressa (=Ulva compressa)

II. 4. 2. 7. Association with *Fucus virsoides*

II. 4. 2. 8. Neogoniolithon brassica-florida concretion

II. 4. 2. 9. Association with *Gelidium* spp

The code 1170 identify the generic habitats classified as reefs. In the Adriatic Sea a peculiar importance must be recognized to the biogenic reefs built by the polychete *Sabellaria spinulosa.*

II. 4. 3. Mediolittoral caves

Reference codes for identification: **EUR 27**: 8330; **CORINE** 11.294

II. 4. 3. 1. Association with Phymatolithon lenormandii and Hildenbrandia rubra

III. INFRALITTORAL

III. 1. SANDY MUDS, SANDS, GRAVELS AND ROCKS IN EURYHALINE AND EURYTHERMAL ENVIRONMENT

III. 1. 1. Euryhaline and eurythermal biocenosis

Reference codes for identification: **EUR 27**: 1150; **CORINE** 21

III. 1. 1. 1. Association with *Ruppia cirrhosa* and/or *Ruppia maritima*

III. 1. 1. 2. Facies with *Ficopomatus enigmaticus*

III. 1. 1. 3. Association with *Potamogeton pectinatus*

III. 1. 1. 4. Association with *Zostera noltii* in euryhaline and eurythermal environment

III. 1. 1. 5. Association with *Zostera marina* in euryhaline and eurythermal environment

III. 1. 1. 6. Association with *Gracilaria* spp.

III. 1. 1. 7. Association with Chaetomorpha linum and Valonia aegagropila

III. 1. 1. 8. Association with *Halopithys incurva*

III. 1. 1. 9. Association with *Ulva laetevirens* and *Enteromorpha linza*

III. 1. 1. 10. Association with *Cystoseira barbata*

III. 1. 1. 11. Association with *Lamprothamnium papulosum*

III. 1. 1. 12. Association with Cladophora echinus and Rytiphloea tinctoria

III. 2. FINE SANDS WITH MORE OR LESS MUD

III. 2. 1. Biocenosis of fine sands in very shallow waters

Reference codes for identification: **EUR 27**: 1140; **CORINE**: 11.22

III. 2. 1. 1. Facies with *Lentidium mediterraneum*

III. 2. 2. Biocenosis of well sorted fine sands

Reference codes for identification: **EUR 27**: 1110, 1160 if in Large shallow inlets and bays; **CORINE**: 11.22

III. 2. 2. 1. Association with *Cymodocea nodosa* on well sorted fine sands

III. 2. 3. Biocenosis of superficial muddy sands in sheltered waters

Reference codes for identification: **EUR 27**: 1160; **CORINE**: 11.22

III. 2. 3. 1. Facies with Callianassa tyrrhena and Kellia corbuloides

III. 2. 3. 2. Facies with fresh water resurgences with *Cerastoderma glaucum*, and *Cyathura carinata*

III. 2. 3. 3. Facies with *Loripes lacteus* and *Tapes* spp.

III. 2. 3. 4. Association with *Cymodocea nodosa* on superficial muddy sands in sheltered waters

III. 2. 3. 5. Association with *Zostera noltii* on superficial muddy sands in sheltered waters

III. 2. 3. 6. Association with *Caulerpa prolifera* on superficial muddy sands in sheltered waters

III. 2. 3. 7. Facies of hydrothermal oozes with *Cyclope neritea* and nematodes

III. 3. COARSE SANDS WITH MORE OR LESS MUD

III. 3. 2. Biocenosis of coarse sands and fine gravels under the influence of bottom currents (also found in the Circalittoral)

Reference codes for identification: **EUR 27**: 1110; **CORINE** 11.22

III. 3. 2. 1. Maërl facies (= Association with *Lithothamnion corallioides* and *Phymatolithon calcareum*) (can also be found as facies of the biocenosis of coastal detritic)

III. 3. 2. 2. Association with rhodolithes

III. 4. STONES AND PEBBLES

III. 4. 1. Biocenosis of infralittoral pebbles

Reference codes for identification: **EUR 27**: 1110; **CORINE**: 11.22

III. 4. 1. 1. Facies with *Gouania wildenowi*

III. 5. POSIDONIA OCEANICA MEADOWS

III. 5. 1. *Posidonia oceanica* meadows (= Association with *Posidonia oceanica*)

Reference codes for identification: **EUR 27**: 1120; **CORINE** 1134

III. 5. 1. 1. Ecomorphosis of stripped meadows

III. 5. 1. 2. Ecomorphosis of « barrier reef » meadows

III. 5. 1. 3. Facies of dead « mattes » of *Posidonia oceanica* without much epiflora

III. 5. 1. 4. Association with *Caulerpa prolifera*.

III. 6. HARD BEDS AND ROCKS

III. 6. 1. Biocenosis of infralittoral algae

Reference codes for identification: **EUR 27**: 1170; **CORINE** 11.24-11.25

III. 6. 1. 1. Overgrazed facies with encrusting algae and sea urchins

III. 6. 1. 2. Association with *Cystoseira amentacea* (var. *amentacea*, var. *stricta*, var. *spicata*)

III. 6. 1. 4. Facies with *Mytilus galloprovincialis*

III. 6. 1. 5. Association with Corallina elongata and Herposiphonia secunda

III. 6. 1. 6. Association with *Corallina officinalis*

III. 6. 1. 7. Association with Codium vermilara and Rhodymenia ardissonei

III. 6. 1. 8. Association with *Dasycladus vermicularis*

III. 6. 1. 9. Association with *Alsidium helminthochorton*

III. 6. 1. 11. Association with *Gelidium spinosum* v. *hystrix*

III. 6. 1. 13. Association with *Ceramium rubrum*

III. 6. 1. 14. Facies with *Cladocora caespitosa*

III. 6. 1. 16. Association with *Cystoseira crinita*

III. 6. 1. 17. Association with *Cystoseira crinitophylla*

III. 6. 1. 19. Association with *Cystoseira spinosa*

III. 6. 1. 20. Association with *Sargassum vulgare*

III. 6. 1. 21. Association with *Dictyopteris polypodioides*

III. 6. 1. 22. Association with *Colpomenia sinuosa*

III. 6. 1. 23. Association with Stypocaulon scoparium (=Halopteris scoparia)

III. 6. 1. 24. Association with *Trichosolen myura* and *Liagora farinosa*

III. 6. 1. 25. Association with *Cystoseira compressa*

III. 6. 1. 26. Association with Pterocladiella capillacea and Ulva laetevirens

III. 6. 1. 27. Facies with large hydrozoan

III. 6. 1. 29. Association with *Schottera nicaeensis*

III. 6. 1. 30. Association with Rhodymenia ardissonei and Rhodophyllis divaricata

III. 6. 1. 31. Facies with *Astroides calycularis*

III. 6. 1. 32. Association with Flabellia petiolata and Peyssonnelia squamaria

III. 6. 1. 33. Association with Halymenia floresia and Halarachnion ligulatum

III. 6. 1. 34. Association with *Peyssonnelia rubra* and *Peyssonnelia* spp.

III. 6. 1. 35. Facies and association of Coralligenous biocenosis (in enclave)

IV CIRCALITORAL:

IV. 1. MUDS

IV. 1. 1. Biocenosis of costal terrigenous muds

IV. 1. 1. 1. Facies of soft muds with *Turritella tricarinata communis*

IV. 1. 1. 2. Facies of sticky muds with *Virgularia mirabilis* and *Pennatula phosphorea*

IV. 1. 1. 3. Facies of sticky muds with *Alcyonium palmatum* and *Stichopus regalis*

IV. 2. SANDS

IV. 2. 1. Biocenosis of the muddy detritic bottom

IV. 2. 1. 1. Facies with Ophiothrix quinquemaculata

IV. 2. 2. Biocenosis of the costal detritic bottom

Reference codes for identification: **EUR 27**: 1110; **CORINE** 11.22

IV. 2. 2. 1. Association with rhodolithes

IV. 2. 2. 2. Maërl facies (Lithothamnion coralloides and Phymatolithon calcareum)

IV. 2. 2. 3. Association with *Peyssonnelia rosa-marina*

IV. 2. 2. 4. Association with *Arthrocladia villosa*

IV. 2. 2. 5. Association with *Osmundaria volubilis*

IV. 2. 2. 6. Association with *Kallymenia patens*

IV. 2. 2. 7. Association with *Laminaria rodriguezii* on detritic

IV. 2. 2. 8. Facies a Ophiura texturata (=Ophiura ophiura)

IV. 2. 2. 9. Facies with Synascidies

IV. 2. 2. 10. Facies with large Bryozoa

IV. 2. 3. Biocenosis of shelf-edge detritic bottom

IV. 2. 3. 1. Facies with *Neolampas rostellata*

IV. 2. 3. 2. Facies with *Leptometra phalangium*

III. 6. 1. 27. Facies with large Hydrozoa: (Facies *Lytocarpia myriophyllum*)

IV. 3. HARD BEDS AND ROCKS

IV. 3. 1. Coralligenous biocenosis

Reference codes for identification: **EUR 27** 1170; **CORINE** 11251

IV. 3. 1. 1. Association with *Cystoseira zosteroides*

IV. 3. 1. 2. Association with *Cystoseira usneoides*

IV. 3. 1. 3. Association with *Cystoseira dubia*

IV. 3. 1. 4. Association with *Cystoseira corniculata*

IV. 3. 1. 5. Association with *Sargassum* spp. (indigenous)

IV. 3. 1. 6. Association with *Mesophyllum lichenoides*

IV. 3. 1. 7. Association with Lithophyllum stictaeforme and Halimeda tuna

IV. 3. 1. 9. Association with *Rodriguezella strafforelloi*

IV. 3. 1. 10. Facies with *Eunicella cavolinii*

IV. 3. 1. 11. Facies with *Eunicella singularis*

IV. 3. 1. 12. Facies with Lophogorgia ceratophyta (=Leptogorgia sarmentosa)

IV. 3. 1. 13. Facies with *Paramuricea clavata*

IV. 3. 1. 14. Facies with *Parazoanthus axinellae*

IV. 3. 1. 15. Coralligenous platforms

IV. 3. 2. Semi-dark caves (also in enclave in upper stages)

Reference code for identification: **EUR 27** 8330; **CORINE** 1126

IV. 3. 2. 1. Facies with *Parazoanthus axinellae*

IV. 3. 2. 2. Facies with *Corallium rubrum*

IV. 3. 2. 3. Facies with *Leptopsammia pruvoti*

IV. 3. 3. Biocenosis of the shelf-edge rock

V. BATHYAL:

V. 1. MUDS

V. 1. 1. Biocenosis of bathyal muds

V. 1. 1. 1. Facies of sandy muds with *Thenea muricata*

V. 1. 1. 2. Facies of fluid muds with *Brissopsis lyrifera*

V. 1. 1. 3. Facies of soft muds with Funiculina quadrangularis and Aporrhais serresianus

V. 1. 1. 4. Facies of compact mud with *Isidella elongata*

V. 1. 1. 5. Facies with *Pheronema grayi*

V. 2. SANDS

V. 2. 1. Biocenosis of bathyal detritic sands

V. 3. HARD BEDS AND ROCKS

V. 3. 1. Biocenoses of deep sea corals

V. 3. 2. Caves and ducts in total darkness (in enclave in the upper stages)

Reference codes for identification: **EUR 27** 8330

7.4 A.- Adriatic biocenoses of the circalittoral zone

To focus the report on the open sea, here we introduce some general descriptions mainly regarding the circalittoral biocoenoses. Some facies at the moment are not listed in the official reference list of marine habitat types (UNEP-MAP.RAC/SPA 2006), EU NIS and Habitat Directive, asking for an update of these tools.

7.5 Circalittoral sands

(RAC/SPA Reference code for identification: IV. 2.)

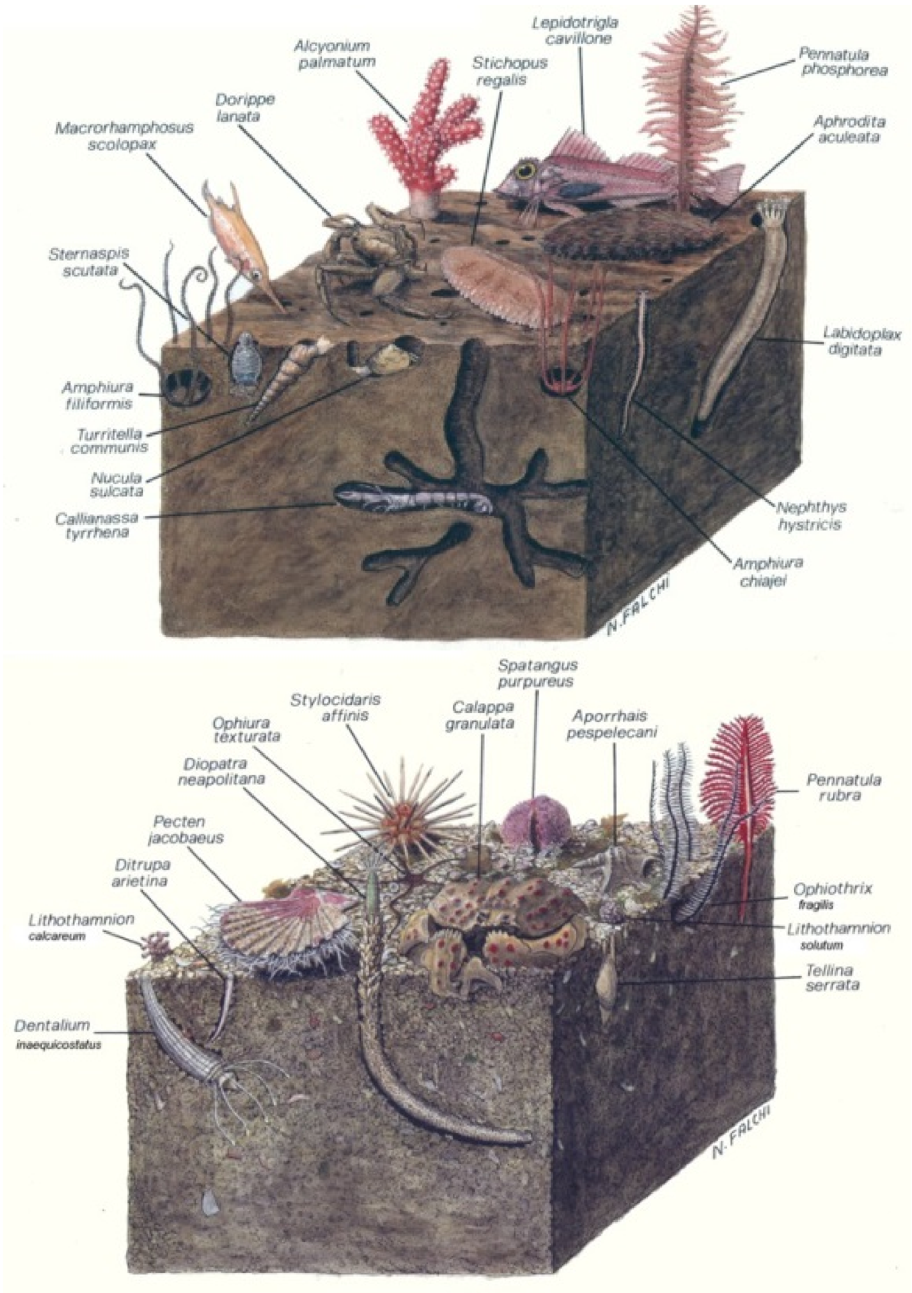

Fig. 16. Schemes representing some of the circalittoral communities found in sandy and muddy bottoms of the Adriatic (from BiologiaMarinaEU.com).

IV. 2. 1. Biocenosis of the muddy detritic bottoms

IV. 2. 1. 1. Facies with Ophiothrix quinquemaculata

It corresponds to the zoocenosis *Schizaster chiajei pelagica* of Vatova

7.5.1 IV. 2. 2. Biocenosis of the coastal detritic bottom

Along the Croatian coast, beside this circalittoral biocoenosis there are infralittoral detritic bottoms but they are not listed in any classification. They are also widely distributed and often present in "large shallow inlets and bays (NATURA 2000 cod. 1160)". Circalittoral coastal detritic bottoms (Fig. 16) are widely distributed along the coast and around islands in the eastern part of the Adriatic Sea (Bakran-Petricioli et al., 2011). It hosts a large number of different *facies*. In the Adriatic Sea, the following facies and associations are well represented:

IV. 2. 2. 1. Association with rhodolithes

IV. 2. 2. 2. Maërl facies

Adriatic distribution: This facies develops near coralligenous biocenoses and in the areas where stronger currents are present on the sea bottom (Gamulin-Brida, 1974). Actually, the knowledge about the distribution of maërl bottoms along the Adriatic coasts is still rather fragmentary (Fig. 17 and 23). In the northern Adriatic Sea several "spots" of coralligenous-maërl are known. In this area, an effort has been carried out to map peculiar formations called "*tegnùe*" containing extraordinary zoobenthic assemblages (Casellato and Stefanon, 2008). Very few data refer to maërl. Some information about maërl is available for Albania while no information is officially available for Montenegro, even though there are internal reports referring to the presence of bioconstructions. Available information still mostly applies to shallow waters from 20 to 30 meters depth. Data on deeper areas are still too scarce and this gap of information should be filled through systematic surveys. Recent predictive models suggest its distribution in seveal areas in the North Adriatic Sea and in the northern side of the Gargano Peninsula (Martin et al., 2014).

Maërl beds are formed by dense population of red calcareous algae not attached to the bottom; the most characteristic species are *Lithothamnion coralloides* and *Phymatolithon calcareum*. They are typically located on sea bottoms with stronger laminar and irregular currents, on depths between 20-90 m in the western basin and between 90-120 m in the southern and eastern basin of the Mediterranean Sea.

This habitat is subject to significant stress related mainly to trawling activities and increased sedimentation/eutrophication due to e.g mariculture.

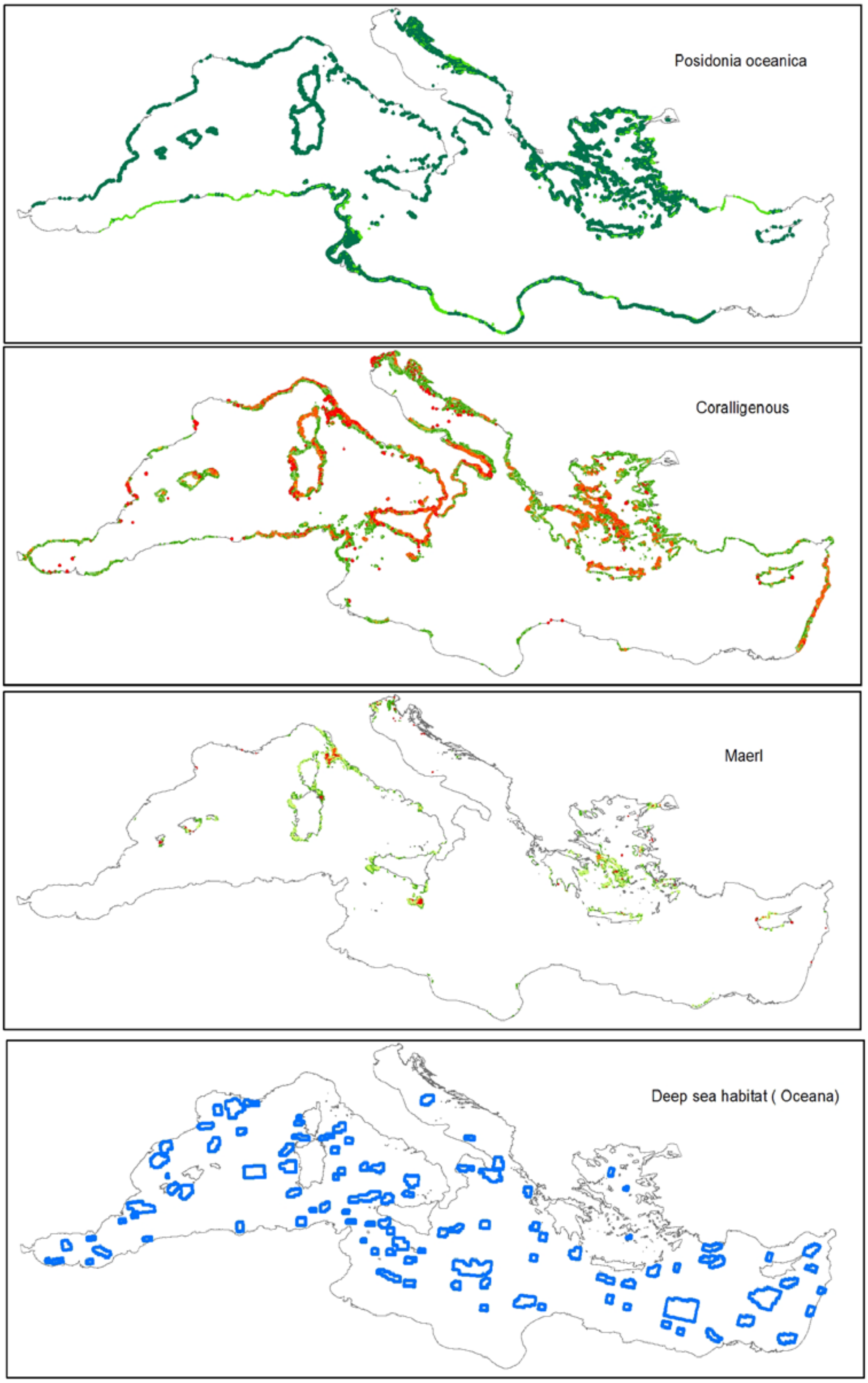

Fig. 17. *Posidonia oceanica*, Coralligenous, Maerl and deep sea habitat maps (Giannoulaki et al., 2013; Martin et al., 2014, www.coconet-fp7.eu).

Ecological r ole: Mäerl beds ar e bi odiversity ' hot-spots' as t hey enha nce bi ological and functional diversity of coastal sediments. In favourable conditions, they can cover large areas and they produce a kind of microscopic forest that hosts a very diverse community of algae and animals. The maërl has a very slow growth rate and it is supposed that living maërl bed could be 50 -70 years old. Maërl beds represent an important habitat that hosts a high number of species of interest to the professional fishing such as *Scorpaena notata*, *S. scrofa*, *Trigloporus lastoviza*, *Trigla lucerna*, *Pagellus erythrinus*.

Sensitivity to human activities: Limited knowledge exists on the effects of threats on bioconstructors. As this habitat is particularly sensitive to be buried under the mud and the activity of bottom trawls, it can be assumed that in the areas without the pressure of these two factors, the environment is still in good condition. The lack of historical trend and the inadequate data about the synergistic relationships among the various threats for this type of habitat, largely prevent the planning of mitigation interventions.

Protection: The principal species forming maërl community are included in Annex V of the Habitats Directive 92/43. This habitat is also protected by regulation (EC) 1967/2006.

IV. 2. 2. 3. Association with *Peyssonnelia rosa-marina* (Rodophyta, Peyssoneliales)

This association is noted for the Adriatic Sea in the north sector near Rovinj and in the central Adriatic near Vis and Biševo islands (Gamulin-Brida, 1974). However, no recent researches esist and the actual distribution in the Adriatic Sea is not known.

IV. 2. 2. 5. Association with *Osmundaria volubilis* (Rodophyta, Ceramiales)

In accordance with Pérès and Picard (1964), this association is characteristic for the transparent waters of the oriental Mediterranean Sea. Gamulin-Brida (1974) claimed that this association is quite abundant in the Adriatic Sea and that it occupies a great surface both in the central and south basin, and also in the northern part. The association is indeed widely distributed in the eastern side of the Adriatic Sea (Bakran-Petricioli, personal observation) but no systematic research was done so far on its abundancy.

IV. 2. 2. 7. Association with *Laminaria rodriguezii* on detritic

Respect the frequent findings reported during survyes conducted in the past (1948-1949 Hvar expedition) in the areas of Jabuka Pits and Palagruža Island, this species is now completely disappeared in Jabuka Pit, most probably due to intensive trawling, and in the area of Palagruža Island it is exceptionally rare (Žuljević et al., 2011).

IV. 2. 2. 8. Facies with *Ophiura texturata* (Echinodermata, Ophiurida)

According to Gamulin-Brida (1974) this facies is widely developed in the Adriatic Sea (e.g. in Vis Channel), in particular near biocenosis with high quantities of bivalves, because *O. texturata* feeds of bivalve larvae. However, systematic research is needed to evaluate distribution, abundance and state of this facies. *Ophiura texturata* is no longer valid name for the species, the valid name is now *Ophiura ophiura* (Linnaeus, 1758) (Stöhr, 2014).

IV. 2. 2. 10. Facies with large Bryozoa

Adriatic distribution: This habitat has been recorded in one site (near Tremiti Island) in the Italian side of the Adriatic Sea (Relini and Giaccone, 2009) and it has also been recorded in Lastovo Archipelago Natural Park on the Croatian side (Bakran-Petricioli et al., 2011), on depths around 50 m (Fig. 18). More research is needed to evaluate the presence of this facies in other Adriatic areas. Some recent works reported the presence on offshore grounds of big quantities of the bryozoa *Amathia semiconvoluta* (Grati et al., 2013).

The basic composition of the biotic assemblage is not different from that shared by all other facies of the biocenosis of costal detritic bottoms. It is characterised by the luxuriance of erect and calcified bryozoans which belong to different species in different situation; only *Tubicellepora incrasstata* seems to be a nearly constant element (Relini and Giaccone, 2009).

Fig.18. Known locations of the large bryozoa in the Italian and Croatian Adriatic (Relini & Giaccone, 2009; Bakran-Petricioli et al., 2011).

Ecological role: Bryozoans may constitute the first nuclei of a bioconcretioning activity, together with calcareous red algae (rhodolites). Soft or mobile bottoms are generally considered as habitats of lower bryozoan diversity. However, if strong and steady bottom currents are present, any small particle of rock or dead shell may be an excellent solid substratum for the bryozoan colony. Bryozoans that are also important habitat structuring elements belong to the least known phyla in the Adriatic Sea. The list of Bryozoans with 184 species was published in 2004 (Novosel et al., 2004) but today up to 263 species are registered Among Bryozoa *Hornera lichenoides* is the only strictly protected species but this is an Atlantic species. *Hornera frondiculata* is present in the Adriatic but it is not legally protected.

Sensitivity to human activities: this habitat is sensitive to several disturbances such as siltation, spilling and dumping and trawling activities. As it has been little studied, and only a small number of sites are reported so far for the Adriatic Sea (Grati et al., 2013; Relini and Giaccone, 2009; Bakran-Petricioli et al., 2011), it is impossible to assess its conservation status. Due to possible threats, it could range from potentially good (around small islands, in some MPAs) to critical (in highly anthropised coastal areas owing to mud accumulation and solid waste disposal or in high seas due to bottom fishing). In recent years some Italian fishing vessels have started to exploit adult sole with gill nets on offshore grounds where the seabed is untrawlable because of the presence of mega-epifaunal communities dominated by holoturians (*Holothuria forskali* and *Stichopus regalis*) and the bryozoan *Amathia semiconvoluta* (Grati et al., 2013). The impact of this practice on the community could be deleterious.

Protection: No regulation actually protects this habitat in Italy but it is in principle protected in Croatia on the level of whole biocoenosis of coastal detritic bottom (Official Gazette 119/2009).

7.5.2 IV. 2. 5. Biocoenosis of detritic bottoms of the open Adriatic

This is a specific Adriatic biocoenosis and it is widely distributed in the open areas of the Adriatic on sandy detritic bottoms (relict sands). According to Gamulin-Brida (1974) this biocoenosis have two facies: IV. 2. 5. 1. Facies with *Atrina pectinata* (widely distributed in the north and middle open Adriatic on detritic bottoms) and facies IV. 2. 5. 2. Facies with *Lytocarpia myriophyllum*. This biocoenosis is not listed among the Mediterranean benthic marine biocenoses (Bellan-Santini et al., 2002) but we consider it should be added (Gamulin-Brida, 1974; Bakran-Petricioli, 2011).

IV. 2. 5. 2. Facies with *Lytocarpia myriophyllum*

Adriatic distribution: *L. myriophyllum* (Fig. 19) was recorded from historical time in the Adriatic basin. It was recorded along Piran, Slovenia (Heller, 1868); Vis, Hvar and Ragusa (Dubrovnik), Croatia (Carus, 1884); Quarnero Croatia (Broch, 1911; Marktanner-Turneretscher, 1890); Brindisi, Manfredonia, Vieste, Apulian coasts (Marano et al., 1989).

Gamulin-Brida (1974), describing the biocenosis of the Adriatic Sea, reported that *L. myriophyllum* facies was particularly developed near Maslinica, going south western of the Šolta Island. Recently this facies has been described offshore the Gargano Promontory (Giannoulaki et al., 2013). This latter habitat represents a nursery for European hake.

L. myriophyllum facies is typical of the sandy-muddy bottoms belonging to the biocenosis of the sandy-detritic bottoms (DL=detritici del largo). In this facies, the sessile endo- and epi-fauna and vagile fauna are very rich. Several sponge species and numerous species of other groups like crustaceans, molluscs and polychaetes are common (Gamulin-Brida, 1974). These bottoms host rich fish communities, but because the presence of abundant sessile fauna this bottoms are less exploited as fishing grounds. However, growing demand for fish threats this habitat.

L. myriophyllum, as well as many other species on deep soft bottoms, are threatened by trawling in many areas of the Mediterranean Sea. Considering Italian waters, no data are available on the effects of physical disturbance of bottom fishing on *L. myriophyllum*, but the species is likely extremely vulnerable to this destructive fishing method.

Ecological role: *Lytocarpia myriophyllum* is the largest leptomedusan hydroid of the Mediterranean Sea, with colonies up to 1 m high. Its ecology is unknown. It creates wide forests on soft bottoms stabilizing sediments, providing refuge and food for several other associated organisms and could be defined both a habitat former and an ecosystem engineer (Cerrano et al., 2015; Di Camillo et al., 2013).

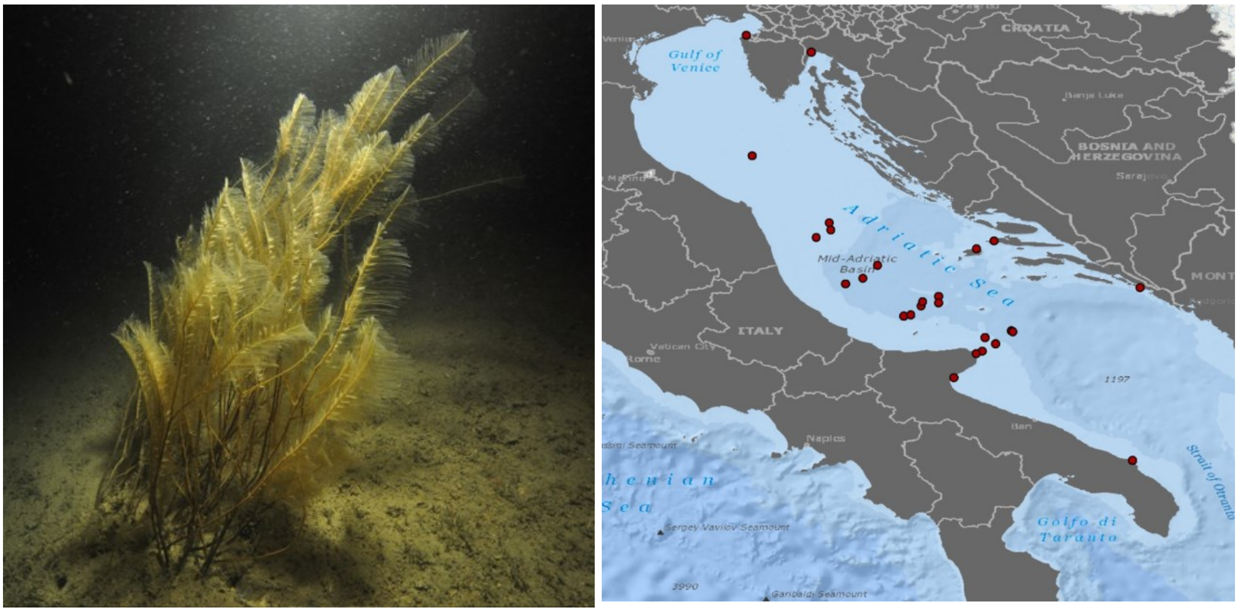

Fig.19. Top: Colonies of the hydrozoan *L. myriophyllum*; Bottom: known distribution of *L. myriophyllum* in the Adriatic Sea (Di Camillo et al., 2013).

7.6 Circalittoral muds

(RAC/SPA Reference code for identification: IV. 1.)

7.6.1 IV. 1. 1. Biocenosis of costal terrigenous muds (VTC)

This biocenosis is widely distributed next to the rocky and detrital bottoms along the oriental coasts, whereas the occidental and the majority of the north Adriatic are mainly sandy and the biocoenosis encompasses smaller areas. The coastal terrigenous muds (Vase Terrigène Côtière VTC) are present in areas where the hydrodynamic regime allows the deposition of very fine particles. Along the occidental coasts it streatches parallel to the sandy belt and somewhere it reaches the coast (e.g. north of Pescara). The VTC biocoenosis occupies a narrow strip parallel to the coast in the southern and in the northern Adriatic Sea and the central part of the channels between islands on the eastern side of the Adriatic.

IV. 1. 1. 1. Facies with *Turritella tricarinata communis* (Mollusca, Gastropoda).

Gamulin-Brida (1974) noted that in some areas this gastropod was so abundant that it represented about 95% of the total macrobenthos abundance. This facies has not been systematically researched in recent years (Fig. 20).

Fig. 20. *Turritella tricarinata* facies from the deep muddy bottoms (from www.marlin.com)

IV. 1. 1. 2. Facies with Virgularia mirabilis and Pennatula phosphorea (Cnidaria, Octocorallia).

Adriatic distribution: This facies is distributed in areas of muddy bottoms with lower sedimentation rates in respect to bottoms covered with *Turritella* facies. In the Adriatic Sea, *Virgularia mirabilis* is distributed along the entire occidental coast, with a range depth of about 5-139 m (Salvati et al., 2014) It is also recorded along some of the Croatian islands and in Albania (Fig. 21).

The Adriatic species belonging to the genus *Pennatula* are *P. phosphorea* and *P. rubra.* These species are distributed along coasts and on deep soft bottoms of the basin (depth range between 19 -280 m). In particular, they were recorded mainly in the central and southern Adriatic Sea.

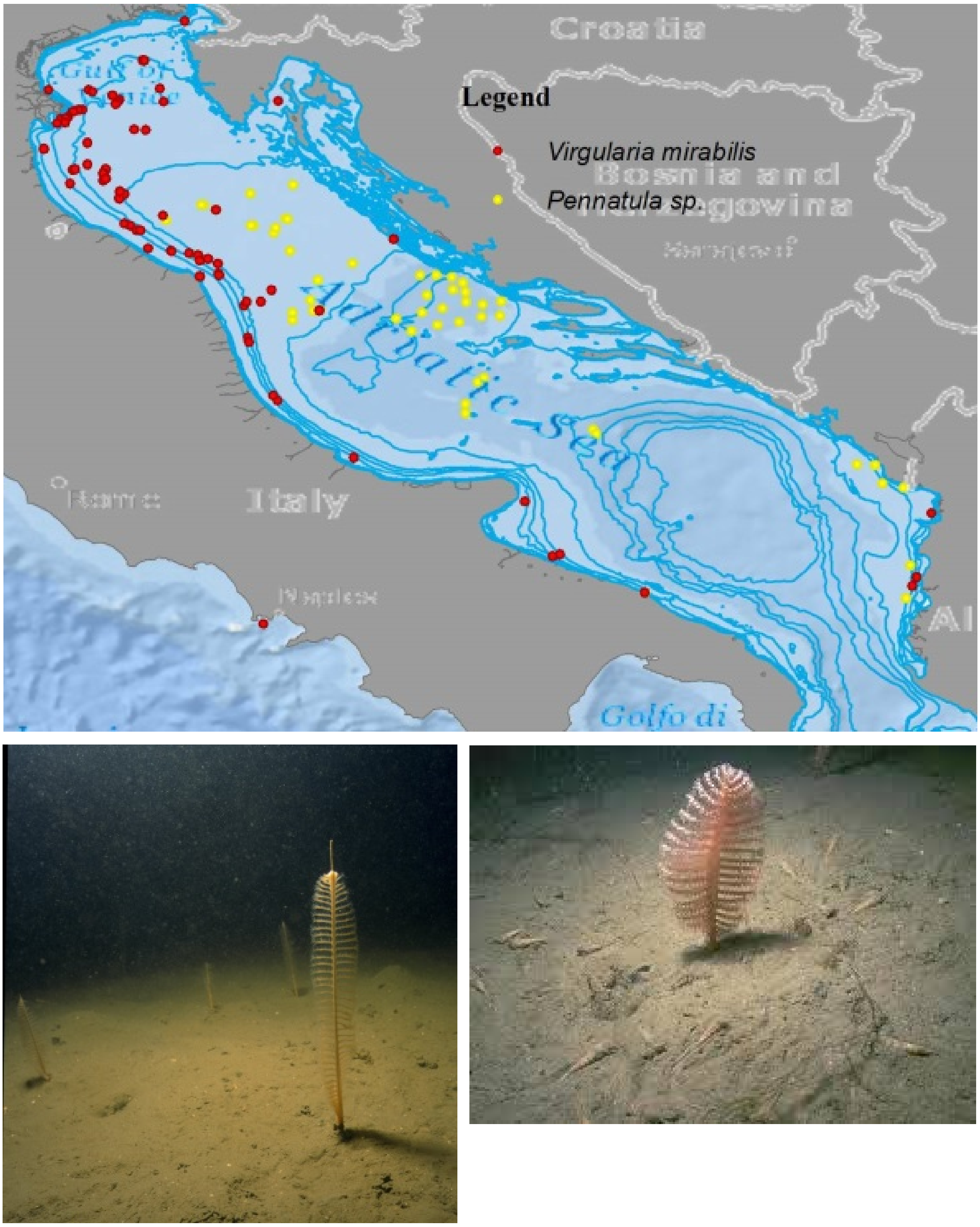

Fig. 21. *Virgularia mirabilis* in their natural environment, (SAMS.com) (left); *Pennatula phosphorea* and *Turritella trincarinata* surrounding facies, (Naturamediterraneo.com9 (right). Top map: Adriatic distribution of *Virgularia* (red dots) and *Pennatula* (yellow dots) facies (Bastari et al., 2013).

IV. 1. 1. 3. Facies of sticky muds with *Alcyonium palmatum* (Cnidaria, Octocorallia) and *Parastichopus regalis* (Echinodermata, Holothuroidea).

Adriatic distribution: this is the most widely distributed facies of the Adriatic VTC biocoenoses (Gamulin-Brida, 1974). It is frequent along the eastern, central and southern coasts; in the western part of the Adriatic basin, these facies extends parallel to the *Turritella* facies (Fig. 22).

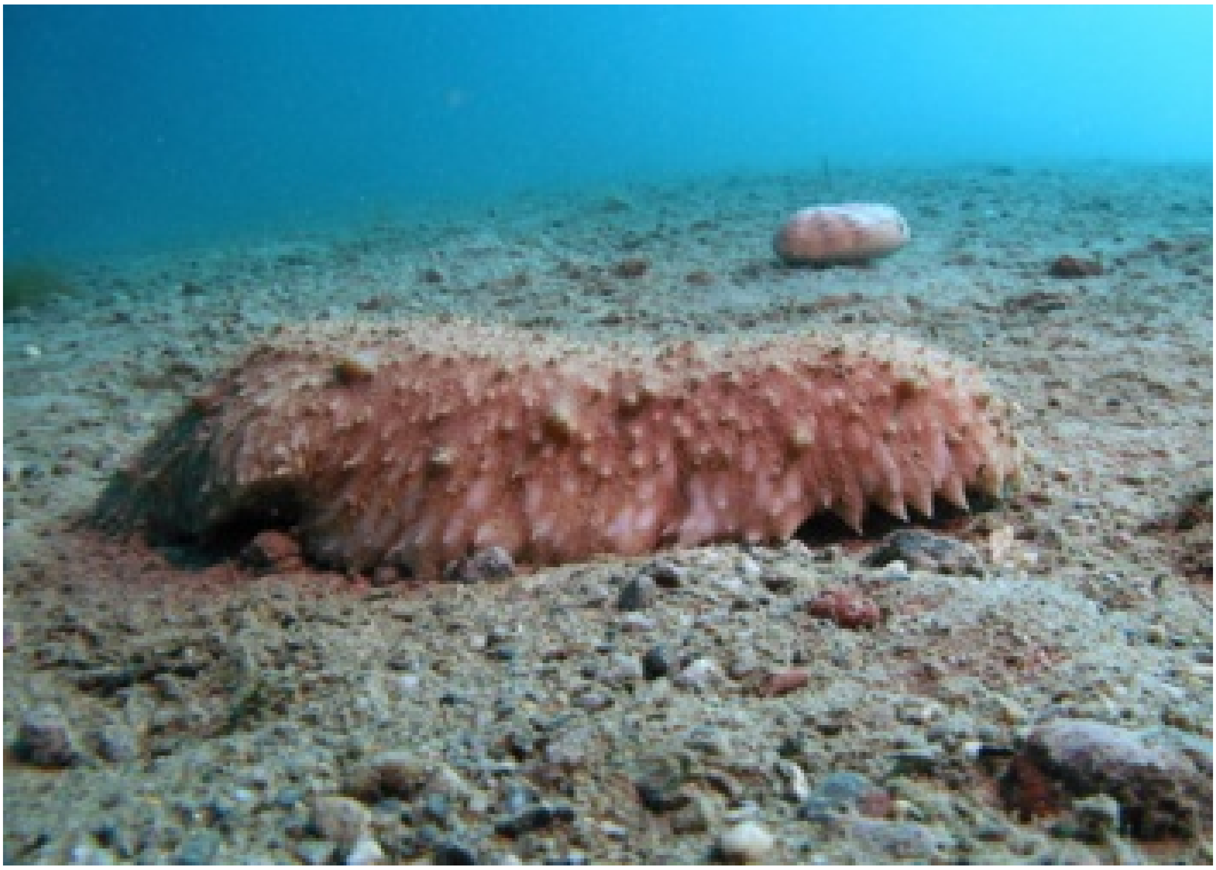

Fig. 22. *Parastichopus regalis* facies. These animals define widely distributed facies often present in combination with other described facies of biocoenoses of costal terrigenous muds like *Turritella tricarinata* and *Alcyonium palamatum.* (foto www.naturamediterranea.com)

7.7 Circalittoral hard bottoms

(RAC/SPA Reference code for identification: IV. 3.)

7.7.1 IV. 3. 1. Coralligenous domain

The Mediterranean coralligenous is a highly heterogeneous bioconstruction that hosts an estimated number of 1,666 species of algae, invertebrates and fish (Ballesteros, 2006). This habitat results in a spatially complex structure, characterized by holes and cavities supporting different microhabitats (Pica et al., 2014). Considering the living organisms able to exploit these microhabitats, the key role of sponges has been only recently highlighted (Bertolino et al., 2013; Calcinai et al., 2015). Because of its great biodiversity the coralligenous is as a whole considered a Zone of Special Conservation (92/43/CE Habitat Directive, habitat code 1170: Reefs, coralligenous assemblage).

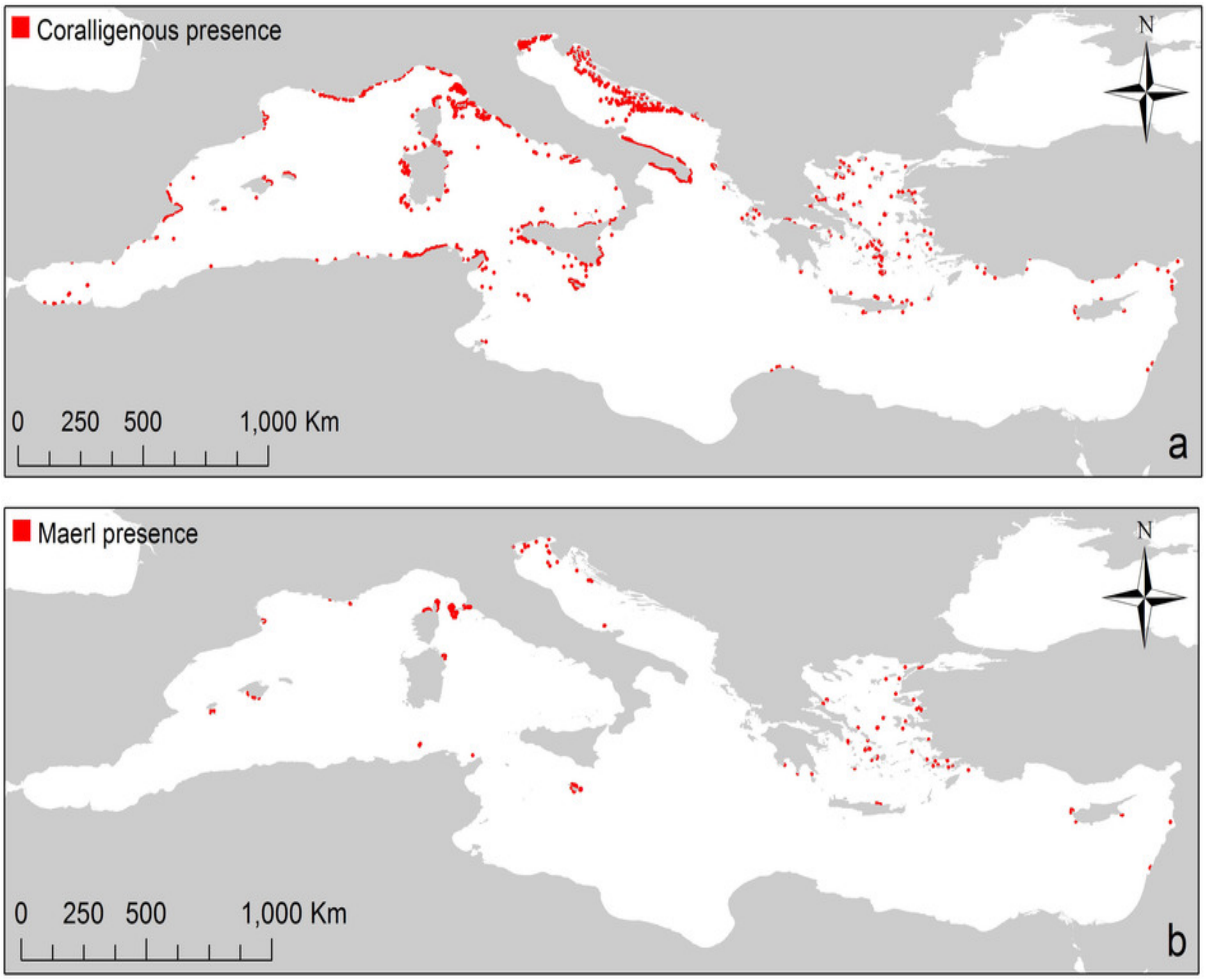

Fig.23 Model of coralligenous and maerl distribution in the Mediterranean Sea. from Martin et al., 2014.

Coralligenous assemblages depend on a fragile equilibrium between bioconstruction, mainly due to coralline algae, and bioerosion, mainly due to sponges and bivalves (Cerrano et al., 2001). Dim-light, narrow thermal oscillations and low water turbidity are among the main environmental conditions determining the coralligenous growth. Coralligenous assemblages cover hard surfaces of the lower limit of submerged slopes. These assemblages develop mainly in the circalittoral, where the photophilous algae disappear, as on slopes, and on flat seabeds (Fig. 24).

Fig. 24. Coralligenous rim with sponges, hydrozoans (*Eudendrium glomeratum*), *Corallium rubrum*, *Leptopsammia pruvoti* that are common in dim-light hard bottom areas.

The coralligenous on the flat seabed is called platform coralligenous (*coralligène de plateau*), and it only includes formations lying on calcareous concretions of biological origin (e.g. rodoliths), which, in turn, lie on mobile seabeds.

Coralligenous concretions are threatened by anthropogenic pressure (Deter et al., 2012) that could cause a rapid loss of biodiversity (Ponti et al., 2014b) hence, it is urgent to develop and support research on this habitat. This is particulary important for the Adriatic Sea.

In the Adriatic Sea, the coralligenous biocenosis is widely distributed along its eastern side, especially in Croatia (Gamulin-Brida, 1974; 1965). Garrabou et al. (2014), stated that the habitat is insufficiently studied and there are no precise historical as well as recent data on its distribution and status. There is a total lack of cartography of coralligenous bottoms all over the Adriatic Sea. Limited information is available only from protected areas (National and Nature parks) and sporadic studies of benthos (Kipson et al., 2009; Kružić, 2007b; Zavodnik et al., 2005; Garrabou et al., 2014 and references herein). Few data are available for Albania and for Montenegro (Fraschetti et al., 2011). Recently, Kipson (Kipson, 2013; Kipson et al., 2014; 2015) undertook systematic research of this habitat along the Croatian coast, especially the facies with gorgonians.

Coralligenous distribution is well known along the Italian coasts of the Adriatic Sea (Fig. 17 and 23). In the northern basin the distribution of several of the so call *tegnùe*, *trezze*, *presure* or *grebeni*, that are submerged rocky substrates of biogenic concretions irregularly scattered in the sandy or muddy seabed, has been mapped the distribution of several of the so call *tegnùe*, *trezze*, *presure* or *grebeni*, that are submerged rocky substrates of biogenic concretions irregularly scattered in the sandy or muddy seabed (Curiel et al., 2012; Ponti et al., 2011; Ponti et al., 2014a). Local names come from fishermen and are related to the capacity of the rocks of withhold and break fishing nets. Fishermen generally avoid these areas but they well know that these bottoms are important for fish (Fig. 25). These formations contain extraordinary zoobenthic assemblages (Casellato and Stefanon, 2008; Curiel et al., 2012; Ponti and Mescalchin, 2008; Ponti et al., 2011) and their age is estimated in 3-4.000 years. Despite many studies, the distribution and magnitude of these outcrops are still only partially known.

Even along the Apulian coasts there are several evidences of the presence of bioconstructions (http://www.biomapping.it/index/). In Martin et al. (2014) a predictive model on the distribution of the coralligenous habitat in the Mediterranean is provided, together with maerl. According to this predictive model the most important areas in the Adriatic Sea for coralligenous habitats are the eastern coast and the Apulian coast. In the eastern side the coralligenous develops mainly along vertical cliffs while along Apulian coasts its structure is more related to platforms and its distribution is shallow.

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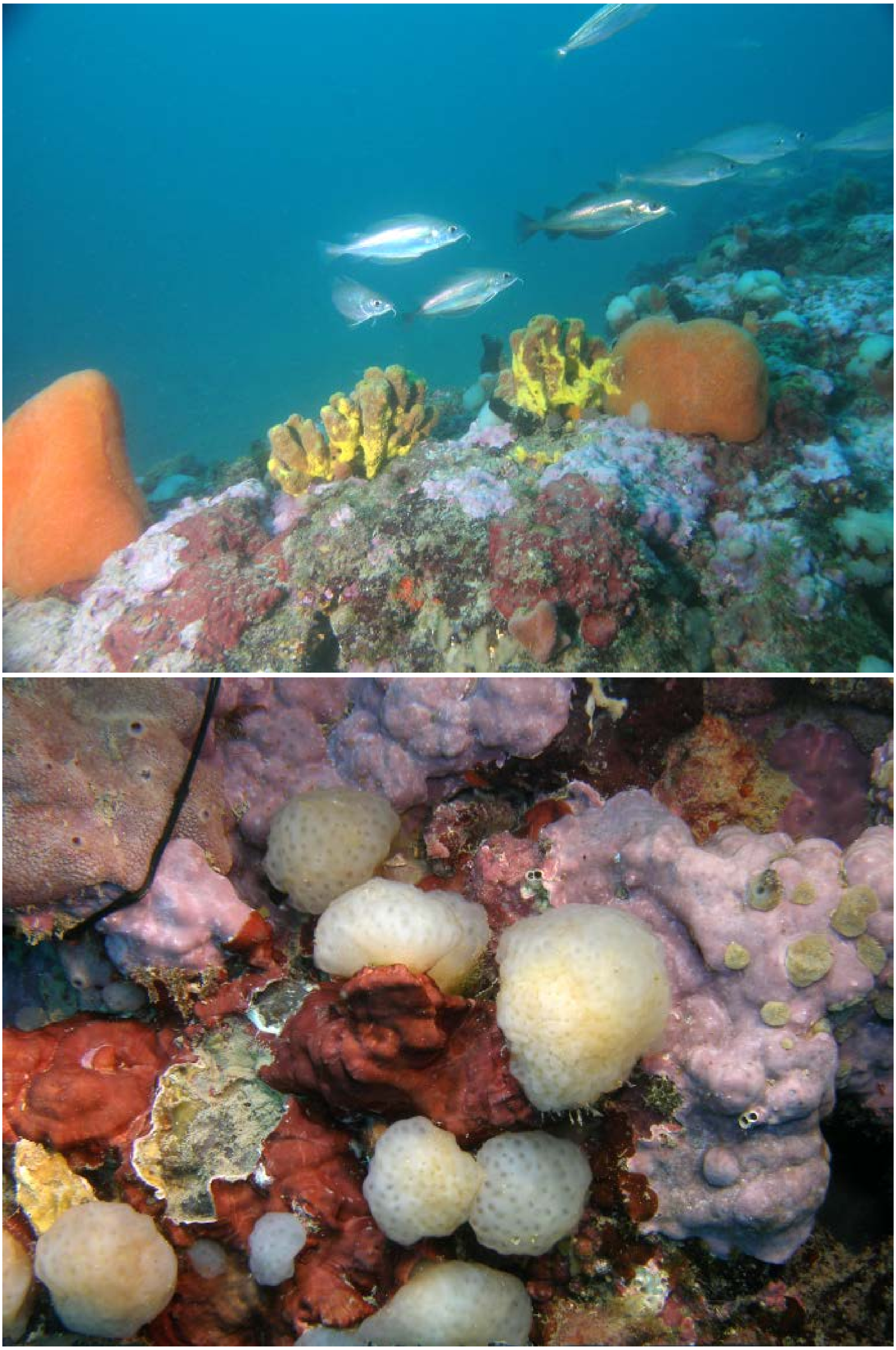

Fig. 25. Coralligenous environment and example of benthic assemblages on rocky outcrops 7-10 nm offshore of Venice and Chioggia (Courtesy Massimo Ponti).

Almost all the facies and association known for the coralligenous biocenosis of the Mediterranean Sea are also present also in the Adriatic Sea.

IV. 3. 1. 1. Association with *Cystoseira zosteroides*

IV. 3. 1. 2. Association with *Cystoseira usneoides*

IV. 3. 1. 3. Association with *Cystoseira dubia*

IV. 3. 1. 4. Association with *Cystoseira corniculata*

IV. 3. 1. 5. Association with *Sargassum* spp. (indigenous)

IV. 3. 1. 6. Association with *Mesophyllum lichenoides*

IV. 3. 1. 7. Association with Lithophyllum stictaeforme and Halimeda tuna

IV. 3. 1. 9. Association with *Rodriguezella strafforelloi*

IV. 3. 1. 10. Facies with *Eunicella cavolini*

IV. 3. 1. 11. Facies with *Eunicella singularis*

IV. 3. 1. 12. Facies with Lophogorgia ceratophyta (=Leptogorgia sarmentosa (Esper, 1789))

IV. 3. 1. 13. Facies with *Paramuricea clavata*

IV. 3. 1. 14. Facies with *Parazoanthus axinellae*

IV. 3. 1. 15. Coralligenous platforms

7.7.2 IV. 3. 2. Semi-dark caves (also in enclave in upper stages) (GSO)

Biocoenosis of semi dark caves is present in the front part of marine caves and it is characterized by high species diversity and biomass, dominated by massive sponges, cnidarians (class Anthozoa) and branched bryozoans. Usually the phylum Porifera is the most dominant group in this biocoenosis, and the poriferan species diversity in the Adriatic caves ranks among the highest in the Mediterranean (Radolović et al., 2015). The eastern karstic part of the Adriatic coasts abounds with marine caves (Surić and Juračić, 2010; Soresi et al., 2004) and that results with a great diversity of submerged karst habitats, such as completely or partially submerged pits, caves and submarine passages (Bakran-Petricioli and Petricioli, 2008; Bakran-Petricioli et al., 2011). The similar situation is with karstic Apulian coast. Two distinctive biocoenoses could be recognized within marine caves Pérès and Picard, 1964: the biocoenosis of semi-dark caves (biocénose des grottes semi-obscures, GSO) and the biocoenosis of caves and ducts in total darkness (biocénose des grottes et boyaux à obscurité totale, GO). Completely dark caves, especially those that trap cold seawater, can be considered extensions of the bathyal zone. They are often inhabited by deep sea organisms (Bakran-Petricioli et al., 2007). Therefore marine caves, although only point habitats, play an important role in connectivity patterns between hard bottom deep sea habitats and littoral biocoenoses.

IV. 3. 2. 1. Facies with *Parazoanthus axinellae*

IV. 3. 2. 2. Facies with *Corallium rubrum*

IV. 3. 2. 3. Facies with *Leptopsammia pruvoti*

7.8 B.- Bathyal zone

7.9 V. 1. Bathyal muds

(RAC/SPA Reference code for identification: V. 1.)

7.9.1 V. 1. 1. Biocenosis of bathyal muds

Deep-water species are usually slow growing with a low reproductive capacity and are adapted to live in an ecosystem of low energy turnover. Thus, they are highly vulnerable to exploitation (Merret and Haedrich, 1997). Some species living both in the Adriatic bathyal horizon and the Thyrrenian one are generally smaller in the Adriatic Sea (Bombace and Froglia, 1973).

V. 1. 1. 1. Facies of sandy muds with Thenea muricata (Porifera, Demospongiae)

This species of demosponge shapes grounds that are characterized by continuous water flows. It can uptake particles in the range of 3-10 µm.

V. 1. 1. 2. Facies of fluid muds with Brissopsis lyrifera (Echinodermata, Echinoidea)

Brissopsis lyrifera is a deposit feeders that lives completely burried in the sediment and can co-occur on some soft bottom areas with *Amphiura* spp.

7.10 V. 3. Bathyal hard bottoms

(RAC/SPA Reference code for identification: V. 3.)

7.10.1 V. 3. 1. Biocenoses of deep sea corals

This biocenosis is built by the so called white corals or cold-water corals (CWC), which basically include two major ramified forms: *Lophelia pertusa* and *Madrepora oculata*, which are relicts of the cold fauna of the Quaternary. The peculiar geomorpholgy of the central and southern deep basins of the Adriatic Sea are supporting the survivor of a wide coverage of CWCs (Savini et al., 2014). This biocoenosis (Fig. 26) develops complex 3D habitat providing shelter, enhanced food supply, spawning sites and nursery areas for many associated species and are of key importance as as attractors and refuge for deep-sea fish fauna (D'Onghia et al., 2012).

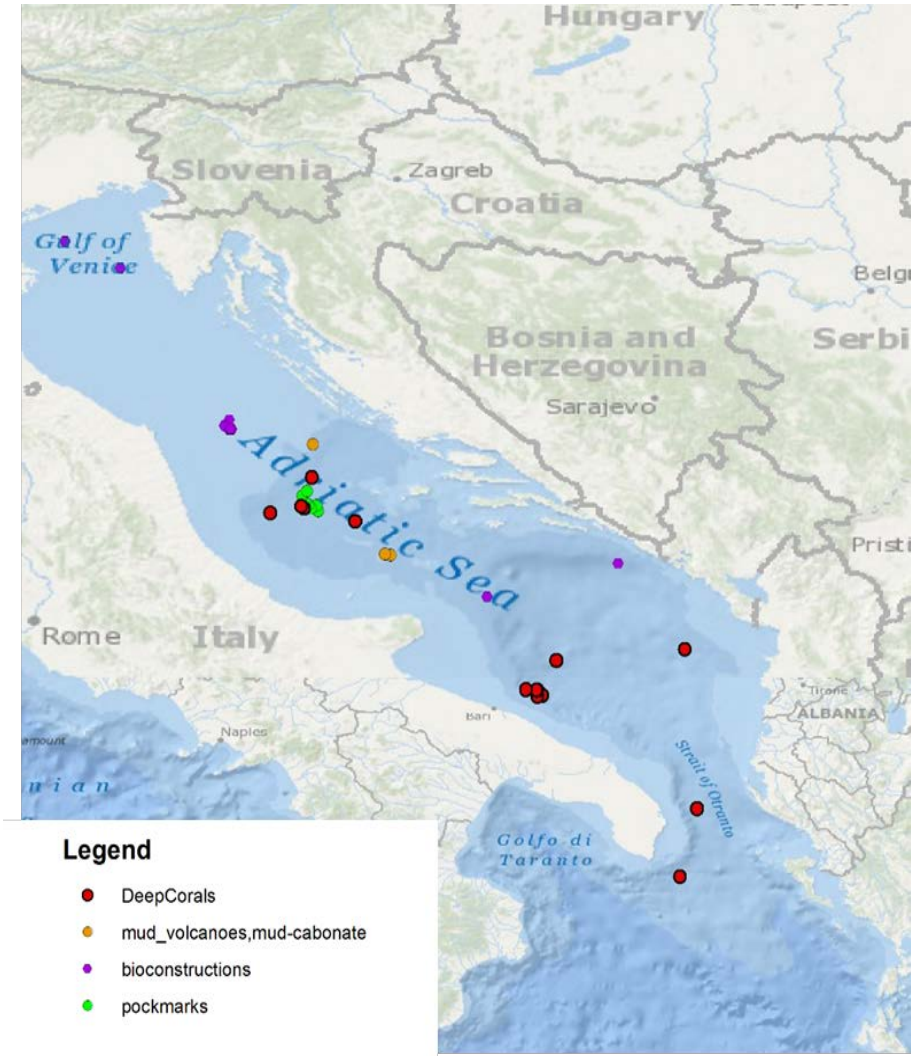

Fig. 26. Distribution of deep water corals and other deep relevant structures in the Adriatic Sea (from: Angeletti et al., 2014; Freiwald et al., 2009; Geletti et al., 2008; Tursi et al., 2004).

8 Benthic communities: conservation and threats

Sediment composition is one of the important factors that regulate the distribution and composition of soft bottom communities (Cerrano et al., 1999; Dame, 2012). As described in Part II, most of the benthic communities are related to the characteristics of sediment (both physical and chemical) and their organic enrichment. Detritic bottoms, and the deep zones like Jabuka Pit are of extreme relevance for the Adriatic biodiversity and functioning.

Besides communities of Pennatulaceans and bi valves, which are the main habitat forming species in these type of bottoms we can easily find *facies* of hydroids, echinoderms, gastropods and holothurians that create great mats of populations in deep dark areas and play an important role in the ecology of this basin. Besides the detritic bottom communities, where a cement factory and plastic polymer factory, there are several zones where we can admire well developed and healthy coralligenous habitats as well as maerls and other hard bottom communities. The shallow coastal areas, in the eastern and southern basins are covered by phanerogames and pre-coralligenous habitats while the southern Adriatic-Ionic show deep peculiar and important white-coral *facies* (Mastrototaro et al., 2010).

Sand and mud habitats account for approximately 70% of the marine sea floor, and the importance of the soft-sediment benthos is increasingly recognized for its contribution to the productivity of overlying waters and to global elemental budgets (Snelgrove, 1997; Thrush and Dayton, 2002). The North Adriatic Sea can be considered the largest shelf area of the Mediterranean (Ott, 1992): due to its shallowness the basin shows a temperate climate with very low winter temperature (about 7° C) and vertical stratification in summer. The conspicuous fresh water inputs make the basin among the most productive of the Mediterranean (Ott, 1992). The Northern Adriatic Sea has been repeatedly affected over the last four decades by bottom anoxia and benthic mortalities coupled with marine snow development (Danovaro et al., 2009). Many of the outbreaks occurred in the northern sector of the basin were due to its shallowness, high water temperature, low winds and stable sea that drive water stratification and prevent pollutant dispersion (Justić, 1991; Pearson and Rosenberg, 1978). These disturbances, along with benthic fisheries, have a major impact on the macro-epibenthic community.

The sessile benthic communities are threatened by any sort of activity or process involving the use and alteration of the bottom substrate. In the Adriatic Sea, considering the massive fleets of trawlers, intense dredging events to nourish beaches and ports, the anchoring of the fleets and the cruising boats, the installation of underwater structures like gas or oil ducts, mining concessions, added to the pollutants these activities carry, added to the waste and discards (solid or liquid) from land, which tend to settle on the bottom by sedimentation, and probably more threats that are not listed here but could have great effects on the benthic communities define that the Adriatic benthic communities are highly threatened and are in need of protection. Eventual large protected areas, could avoid the intensification of the anthropogenic impacts in the Adriatic and prevent future damages to the benthic communities that are already threatened.

Within the Adriatic, indeed, we find endemic species, vulnerable habitats, threatened species, red list endangered species, protected habitats and a complete variety of communities worthwhile protecting as they are the base of the future generation and a crucial in ecosystem services.Historical reports on fishing activities, between the two World Wars, (Paolucci, 1913; Pasquini, 1926) wrote of a wide area in the central Adriatic in which dragging nets were not possible due to the high abundances of sponges (mainly belonging to the genus *Geodia*), pennatulacea, fan shells, holoturians, crinoids etc, evidencing a completely different structure of benthic communities in respect what we know nowdays. The massive sponge *Geodia* is typically present in the bycatch of the Atlantic trawlers. In the Mediterranean Sea it is now considered endangered and listed among SPAMI species. The impact of fishery on benthic habitats is clearly perceived by fishermen, which notice impressive changes expecially after the 80s, in particular regarding sponges (EVOMED, 2011).

Lotze et al. (2006) analyzed historical data to show the consequences of several human impacts on coastal waters worldwide, including the North Adriatic Sea. Severe shifts in species composition and diversity are occurring in the basin, with cascade effects on the entire food web (Giani et al., 2012; Lotze et al., 2006). In particular, the common sea pens *Funiculina quadrangularis*, *Virgularia mirabilis*, *Pennatula rubra* and *Ptereoides spinosum* share the same habitat with some of the most commercial value species (e.g. *Nephrops norvegicus*). They could be very useful indicator of the quality of sand-mud habitats and associated communities. A more detailed knowledge of sea pens distribution and their related community could be important in order to contribute to develop spatial (GIS) management measures to protect the last habitats structured by their presence (Fig. 27).

Along the eastern side of the Adriatic coast there are several populations of mesophotic corals such as *Savalia savaglia* and *Anthipatella subpinnata*. These long living species play a key role both under a structural and functional point of view, being true ecosystem engineers (Cerrano et al., 2010).

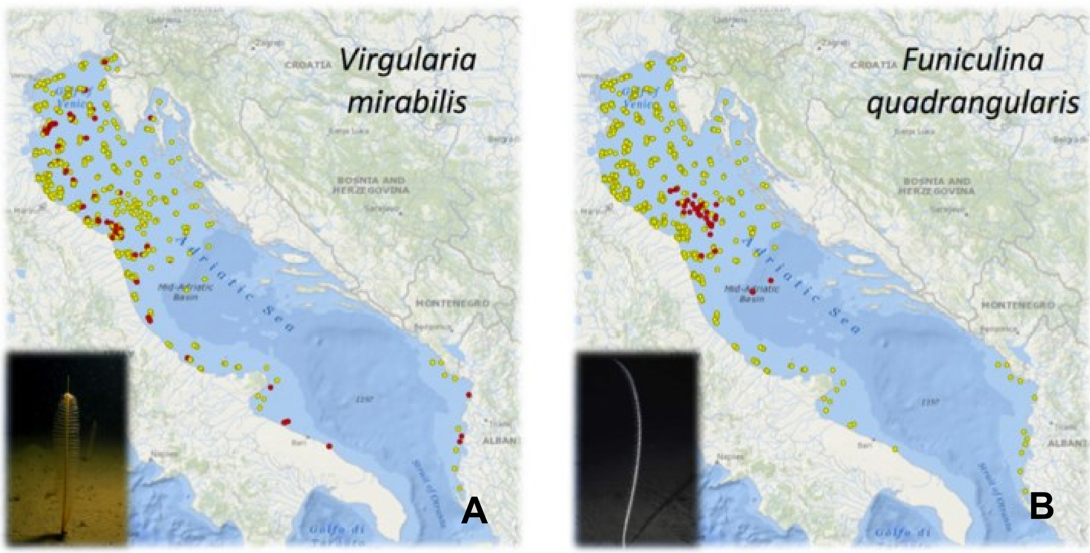

Fig. 27. From A to D: distribution maps of the main Adriatic sea-pens (Gamulin-Brida, 1965; Kružić, 2007a; Martinelli et al., 2013). Red dots indicate presence of the specie where yellow dots are absences.

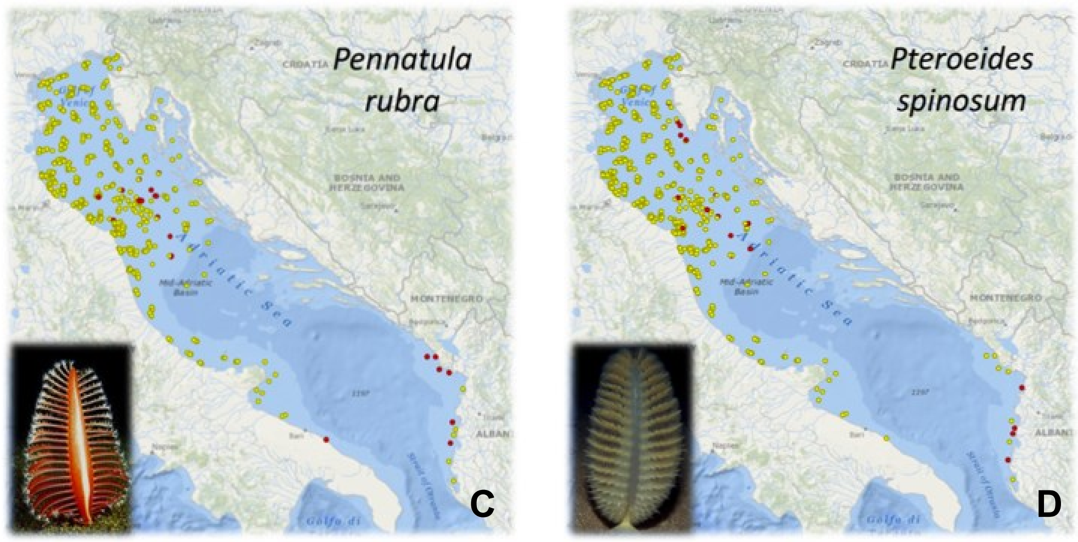

Fig. 27 (cont). From A to D: distribution maps of the main Adriatic sea-pens (Gamulin-Brida, 1965; Kružić, 2007a; Martinelli et al., 2013). Red dots indicate presence of the specie where yellow dots are absences.

9 Vertebrates

9.1 Seaturtles

Today, most sea turtle populations worldwide are depleted, declining, or locally extinct and all species are endangered.

The northern Adriatic Sea contains important foraging and overwintering habitat for the loggerhead turtle, *Caretta caretta*. In the late nineteenth century, sea turtles were common in the Adriatic Sea, and Adriatic fishermen often caught loggerhead turtles, with individuals larger than 100 kg.

In the twentieth century, sharp declines in sea turtles were observed due to by-catch and destruction of breeding sites.

In the 1990s, incidental catches of at least 2,500 turtles per year were estimated for the eastern Adriatic Sea and surveys identified 166 observations of 1,286 turtles including loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), and green turtles (*Chelonia mydas*). Recent global analyses have reported high sea turtle bycatch in the Adriatic Sea (Lewison et al., 2004; 2014). The high level of fishing interaction in the north Adriatic Sea, especially the north–east part is worrisome and requires urgent and effective countermeasures (Casale et al., 2004). Lower winter temperatures affect seasonal migrations of both adult and juvenile loggerheads frequenting the two northernmost parts of the basin, i.e. the Ligurian and the northern Adriatic Sea (Luschi and Casale, 2014).

9.2 Seabirds

The distribution of pelagic sea birds, including the rare European storm petrel, in the Adriatic has been mapped by Carboneras and Requena (2010). Because of the shallow depth of the large portions of the Adriatic, procellariiforms are scarce, and only *Puffinus yelkouan* uses these productive waters to feed on clupeids and other small fish (Carboneras and Requena, 2010). The report identified the Gulf of Venice and the central Adriatic as areas of specifc ornithological importance. The Gulf of Venice "comprises wetlands and river mouths that support large numbers of tern and gull species, including *Larus melanocephalus*. Offshore, the area is home to regular aggregations of *Puffinus yelkouan*. Shags *Phalacrocorax a. desmarestii* are present along the coast of Slovenia and Croatia." In the central Adriatic, "a few thousand *Calonectris d. diomedea* and smaller numbers of *Puffinus yelkouan* nest on the islands of this coast. *Phalacrocorax a. desmarestii* and *Larus audouinii* are present on the coast and *Larus melanocephalus* nest on the coastal salt pans and frequent the offshore waters."

9.3 Sea mammals

Eight species of cetaceans are present, with different densities, throughout the Adriatic Sea. These include the common bottlenose dolphin, *Tursiops truncatus*, the short-beaked common dolphin, *Delphinus delphis,* the striped dolphin, *Stenella coeruleoalba*, the fin whale (*Balaenoptera physalus*), the sperm whale (*Physeter macrocephalus*), the long-finned pilot whale (*Globicephala melas*), the Risso's dolphin (*Grampus griseus*) and the Cuvier's beaked whale (*Ziphius cavirostris*). Additionally, two species considered visitors to the Mediterranean Sea, the false killer whale (*Pseudorca crassidens*) and the humpback whale (*Megaptera novaeangliae*), have been recorded with solitary individuals in the Adriatic Sea (UNEP-MAP-RAC/SPA 2015).

Only the common bottlenose dolphin *Tursiops truncatus* is considered regularly present in the entire Adriatic Sea. Bottlenose dolphins (*Tursiops truncatus*) have been abundantly reported in the northern Adriatic in historical times, but today's numbers are also low due to the shift of the ecosystem functioning towards lower trophic level (Boero, 2014), inadequate for the survival of any marine mammal species. The hypothesis is that human impact on the dolphin population in the north western Adriatic sea has kept in danger these mammals and depleted them by 40% to 70 % in almost 90 years (Simeoni, 2013). In the eastern Adriatic Sea *T. truncatus* is still the most common species of marine mammals. In the northern Adriatic Sea, short-beaked dolphins (*Delphinus delphis*) have progressively declined during the twentieth century and are largely absent today, due to systematic culling campaigns, direct and by-catch in fisheries from the 1850s to 1960s, and habitat degradation in recent decades. *Stenella coeruleoalba* is still frequent in the Adriatic Sea.

Striped dolphins (*Stenella coeruleoalba*) can be found in the middle of the Adriatic. Aerial surveys documented the presence of fin whales (*Balaenoptera physalus*), particularly around the Palagruza archipelago. Cuvier's beaked whales (*Ziphius cavirostris*) and Risso's dolphins (*Grampus griseus*) are found on the edges of the Southern Adriatic Pit (Fortuna et al., 2010). The monk seal *Monachus monachus* (Aguilar and Lowry, 2013) seems widening its distribution from the Turkey and Greece coasts towards the the northern Adriatic Sea

(Gomerčić et al., 2011). The complex morphology of eastern coasts is likely facilitating the re-colonization but conflicts with fishermen could be locally still important.

9.4 Fisheries

The Adriatic Sea is one of the largest areas of occurrence of demersal and small pelagic shared stocks in the Mediterranean. The main small pelagic species are sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*), horse mackerel (*Trachurus spp.*) and mackerel (*Scomber* spp.). Two kind of fishing gears are currently used to catch the small pelagic species: in the northern and central areas the Italian fleet use mostly the “volante” a mid-water pelagic trawl net towed by two vessels.

In the Northern sector, with a wide continental shelf from 10-50 m depth, the dominant fish species in terms of biomass are poor cod (*Trisopterus minutus*), various species of triglids as the red mullet *M. barbatus*, various species of flatfishes as the sole *Solea solea*, gobies and pandoras (*Pagellus* spp.). In the central Adriatic Sea, from 50 to 100 m depth, the diversity increases, finding also anglerfish (*Lophius* spp.), European hake (*Merluccius merluccius*), greater forkbeard (*Phycis blennoides*) and red bandfish (*Cepola rubescens*) and from 100 to 200 m depth blue whiting (*Micromesistius poutassou*).

The continental shelf of the Adriatic Sea is also rich in invertebrate fauna, in particular mollusks and crustaceans. Among bivalaves, the scallops *Pecten jacobaeus* and *Chlamys opercularis;* among cephalopods the cuttlefish (both *Sepia officinalis* and *S. elegans*), octopuses (*Eledone moschata, E. cirrhosa* and *Octopus vulgaris*), squids (*Loligo vulgaris* and *Alloteuthis media*); amog crustaceans, the mantis shrimps (*Squilla mantis*), shrimps (*Solenocera membranacea* and *Parapenaeus longirostris*), Norway lobster (*Nephrops norvegicus*). The highest densities of *N. norvegicus* are in other areas deeper than 100 meters, in particular in the Pomo Pit. Low densities but bigger size/faster growing individuals are found in Central Northern Adriatic, in muddy bottom shallower than 100 m depth. Demersal invertebrates and triglids are fished with classical bottom trawls, while another bottom gear, the « rapido » is used for the demersal fishery. This gear is a dredge composed by an anterior rigid metallic framework, a wooden table acting as depressor and maintaining the mouth in close contact with the sea bottom, and a series of iron teeth that penetrate in the sediment. Bottom trawls and rapido trawls induce severe sub-lethal and lethal damages on non-target species.

Impact of reduced prey availability due to overfishing, habitat degradation and by catch are the main sources of concern for large marine vertebrates including Cetaceans, marine turtles and cartilaginous fish. The most important change respect the past is the decline of Chondrichthyes, large demersals and large-sized species (Ferretti et al., 2008). Thanks to a detailed survey performed by questionnaires, Fortibuoni et al. (2010) demonstrated that some species, such as the angel shark, *Squatina squatina*, the tope shark, *Galeorhinus galeus*, and the sturgeon, *Acipenser sturio*, which are now considered extirpated, were common until 1950. The total disappearance of fish taxa that were considered common in the past have can have important effect on the equilibrium of trophic webs. Also *Anguilla anguilla* can be considered an example of affected species. In present days it is definitively absent from coastal areas where, 50-60 years ago, it was hand fished in the intertidal, among small boulders in some zone of the north-center Adriatic Sea.

[Ferretti et al. (2008)](#) combined and standardized catches from five international trawl surveys conducted in the Adriatic Sea between 1948 and 2005, and used life histories, fish-market and effort data, and historical information to evaluate long term patterns of change in abundance and diversity of sharks and rays in the Adriatic sea. They revealed a generally depleted elasmobranch community. Since 1948, catches have declined by 92%, 26 species were not detected at all (though these occurred in earlier periods) and 11 species have disappeared during the last 57 years. However, analyses revealed a strong gradient of fishing intensity decreasing from the Italian to the Croatian side, and, consequently, the persistence of a more abundant and diverse elasmobranch community in the eastern Adriatic. The situation is similar in the upper Adriatic Sea. Analyses suggest a spillover of mobile sharks and rays (spurdogs, smoothounds and mesopelagic rays) from the least exploited Istria to other areas of the upper Adriatic. Moreover, in the territorial water of Croatia, they observed the persistence of several sedentary elasmobranchs (e. g. small spotted catsharks, and brown or thornback skates) whose small home ranges prevented their exposure to high exploitation levels in the Italian waters.

Regarding other target species, especially demersal ones, the trend is generally negative ([Mazzoldi et al., 2014](#)), but also several pelagic resources looks under overexploitation (Fig. 28). The reports produced by the Mediterranaen trawl surveys (MEDITS) provide detailed maps regarding abundance distribution and the localization of the main nursery areas ([Piccinetti et al., 2012](#)).

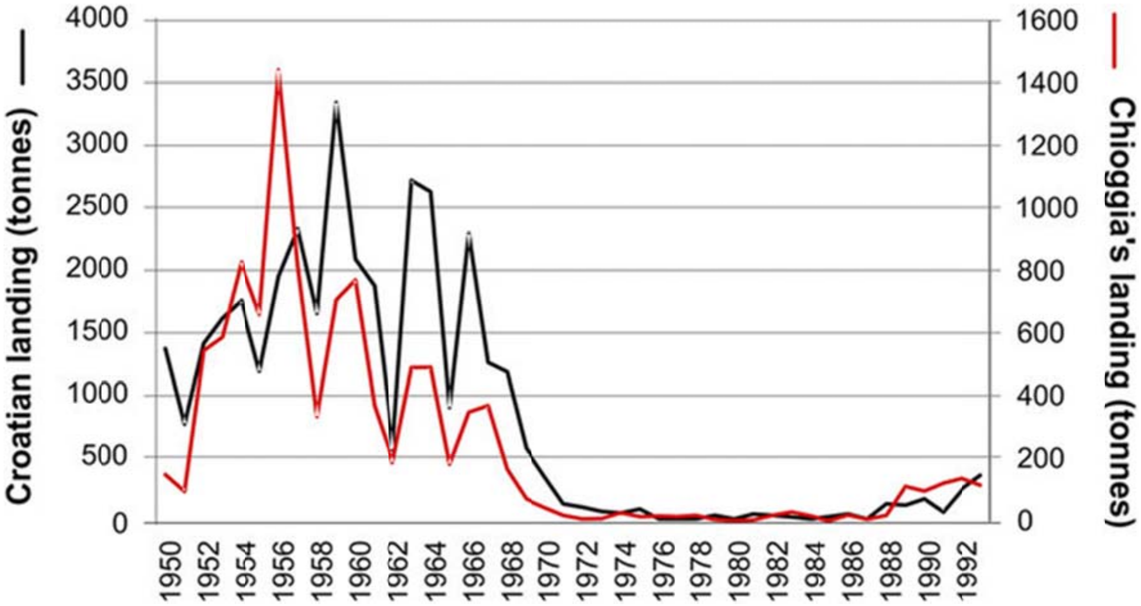

Fig. 28. Annual (1950–1992) landing of *Scomber scombrus* of the Croatian (black line) and the Chioggia's (red line) fleets (from: [Mazzoldi et al., 2014](#)).

10 Anthropogenic pressures

The Mediterranean ecosystems have been threatened by historical and current pressures, which have led to major shifts in marine ecosystems and widespread conflict among marine users. Because of such intense pressure from multiple uses and stressors (Fig. 29), the Mediterranean is characterized as a sea "under siege" (Coll et al., 2012), and here, as in other intensely used ocean areas, an ecosystem based management (EBM) approach has been recommended as a better management alternative to sectoral management (Crowder and Norse, 2008).

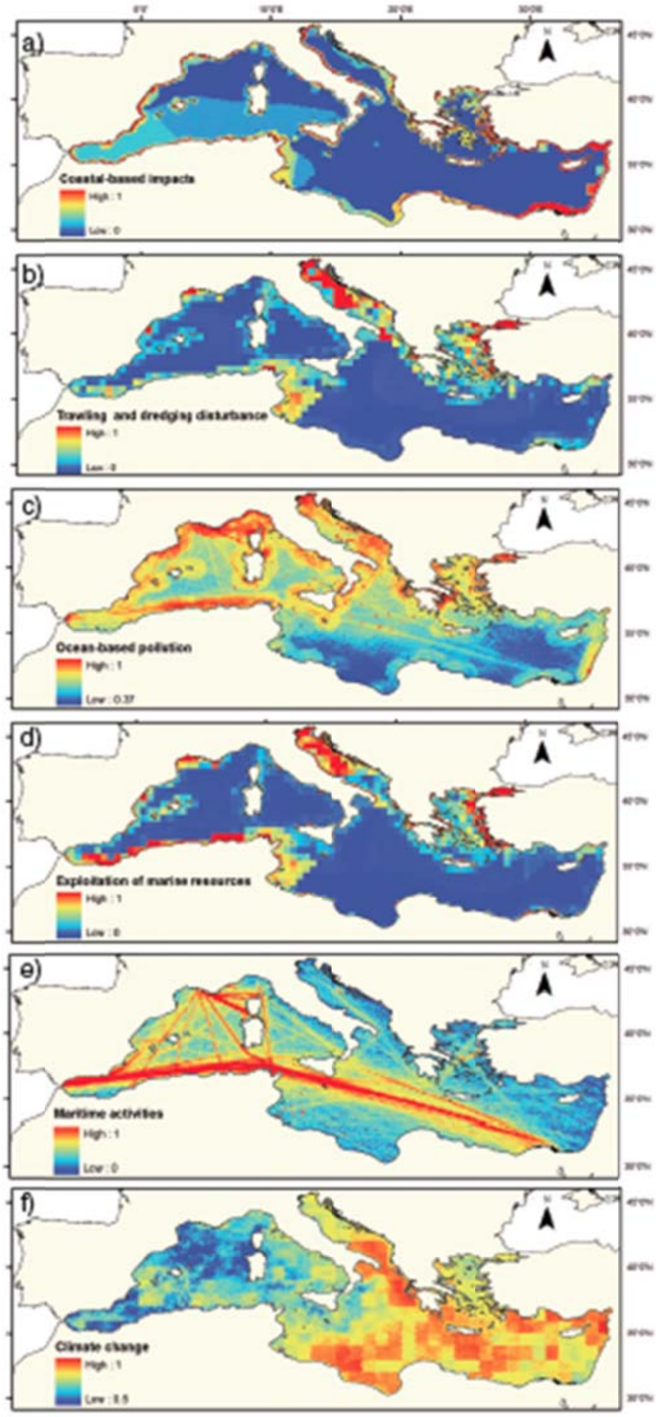

Fig. 29. Human threats with potential impact on marine biodiversity in the Mediterranean Sea: (a) coastal-based impacts,(b) trawling and dredging disturbance, (c) ocean-based pollution, (d) exploitation of marine resources, (e) maritime activities, and (f) climate change impact (from Coll et al., 2012).

Recent analyses of cumulative human impacts have highlighted the Adriatic as one of the most impacted regions within the Mediterranean Sea, both in nearshore and offshore benthic and pelagic habitats (Coll et al., 2012; Micheli et al., 2013). The highest impacts are found in offshore central Adriatic areas, although areas of relatively high impact also exist in the northern and southern basins (Fig. 30 and 31).

The spatial distribution of cumulative human pressure is similar among different components of marine biodiversity. Climatic stressors (Rivetti et al., 2014), demersal fishing, hypoxia and pollution from land-based activities are major contributors to high cumulative impacts to the Adriatic Sea (Micheli et al., 2013).

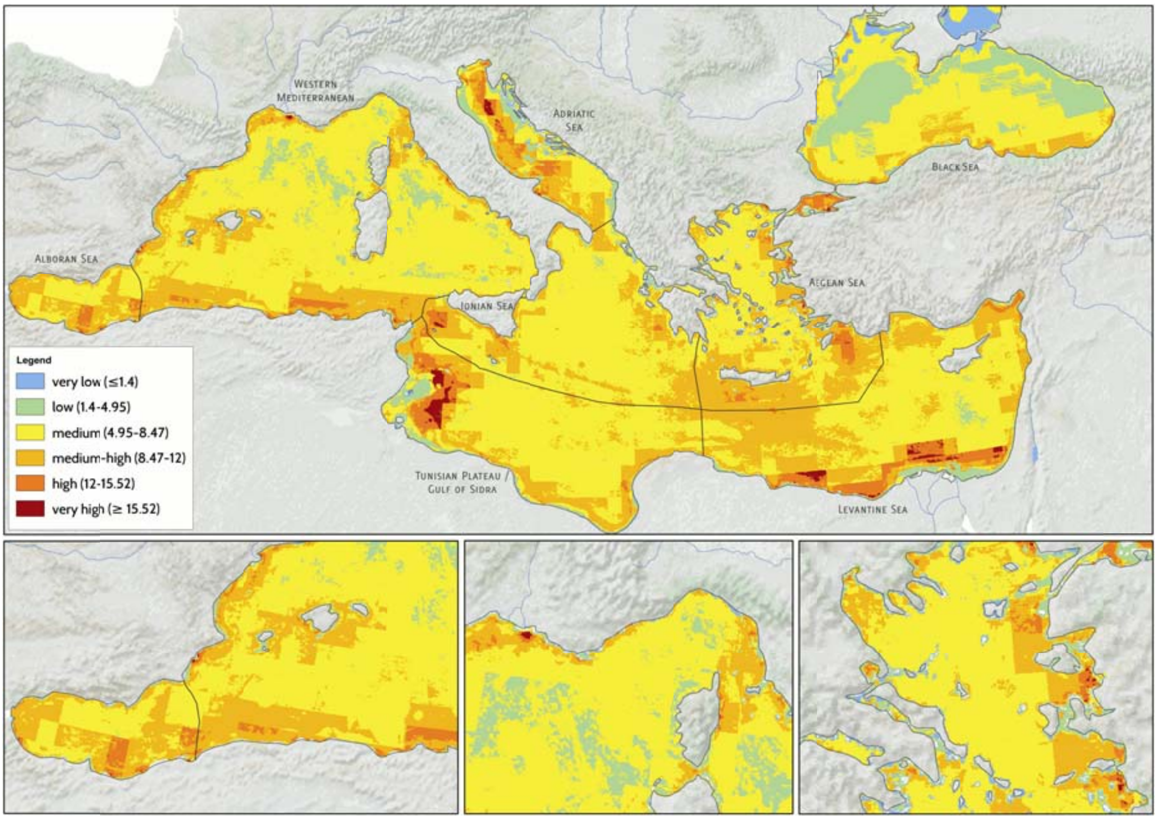

Fig. 30. Spatial distribution of cumulative impacts to marine ecosystems of the Mediterranean and Black Sea. Inserts at the bottom show larger views of the Alboran (left), Northern Tyrrhenian (center), and Aegean Sea (right). Colors correspond to different impact categories, from very low to very high cumulative impact (Micheli et al., 2013).

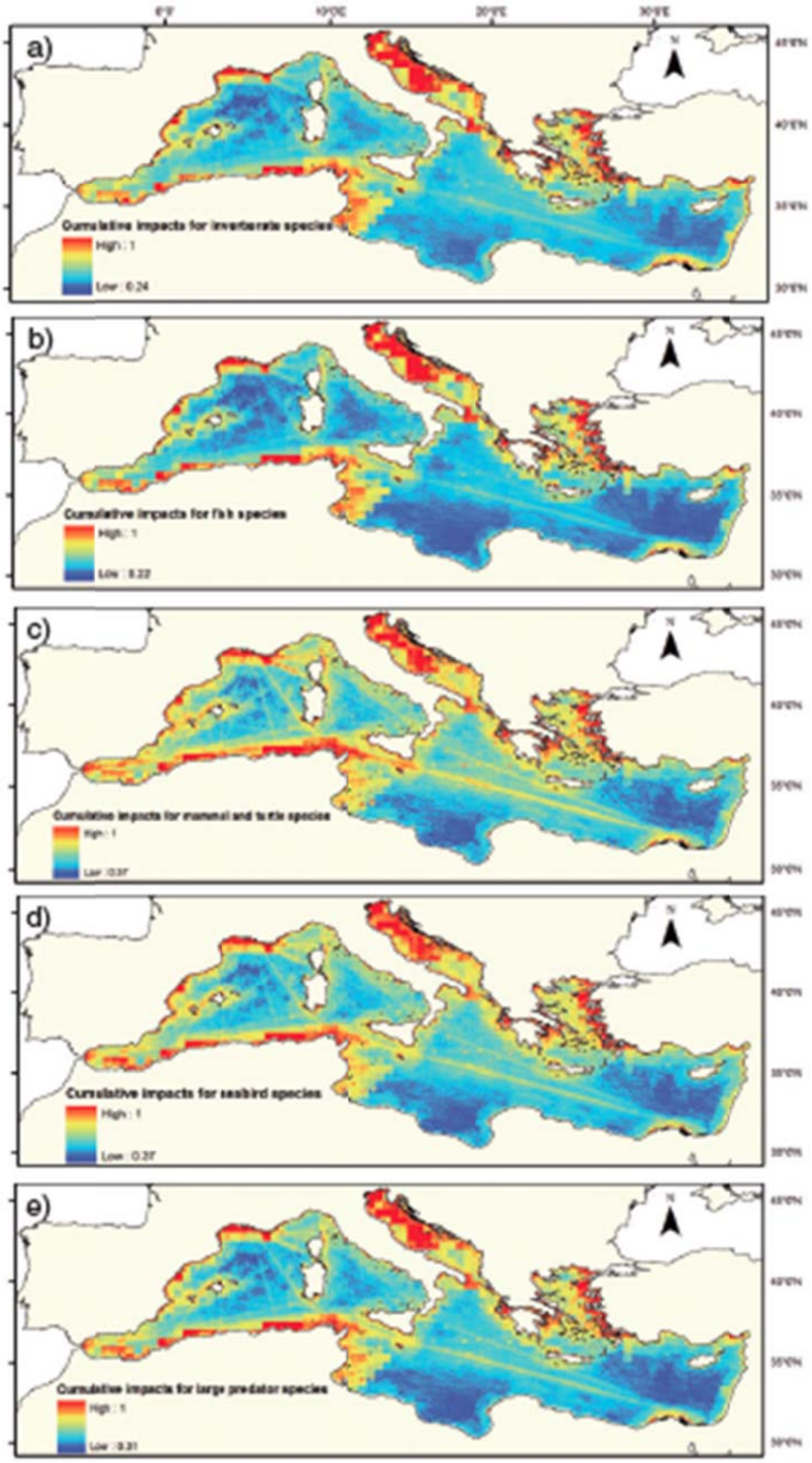

Fig. 31. Areas of cumulative threats (expressed as relative values between 0 and 1) with potential impact on marine biodiversity in the Mediterranean Sea: (a) commercial or well-documented invertebrate species, (b) fish species, (c) marine mammals and turtles, (d) sea birds, and (e) large predators (including large fishes, mammals, turtles and seabirds) (from Coll et al., 2012).

Because of the reduced dimension of the basin and its hydrology, the Adriatic Sea responds more quickly to climatic anomalies and other environmental stresses, hence it is a good model to study the effects of climate change on the benthic communities. Climate change triggered deep modifications expecially in the northern basin, with several documented cases of hypoxia and of dystrophy leading to mucilage outbreaks.

The eastern Adriatic coast is experiencing increasing problems due climate change as the introduction of new species that include aliens (due to aquaculture activities and shipping) and thermophilic species from other Mediterranean subregions that are extending their geographic range (Pecarevic et al., 2013). These dynamics are enhanced by frequent massive mortality episodes (Di Camillo et al., 2013).

The incoming of non indigenus species (NIS) such as the toxic benthic microalga *Ostreopsis ovata* is affecting benthic communities including bivalves, gastropods, cirripeds, echinoderms and fishes, causing diseases or mass mortalities where massive *Ostreopsis* blooms occur (Gorbi et al., 2013).

Increased human activities and the continuous coastal development are quickly affecting the Adriatic Sea biodiversity with evident negative effects in ecosystem functioning. Along the coastline, untreated waste water and solid waste can cause faecal coliforms contamination in adjacent waters, fertiliser run-off from agricultural activities, invasive species from ballast waters, and pollution from oil and gas exploration further worsen the situation (Fig. 32).

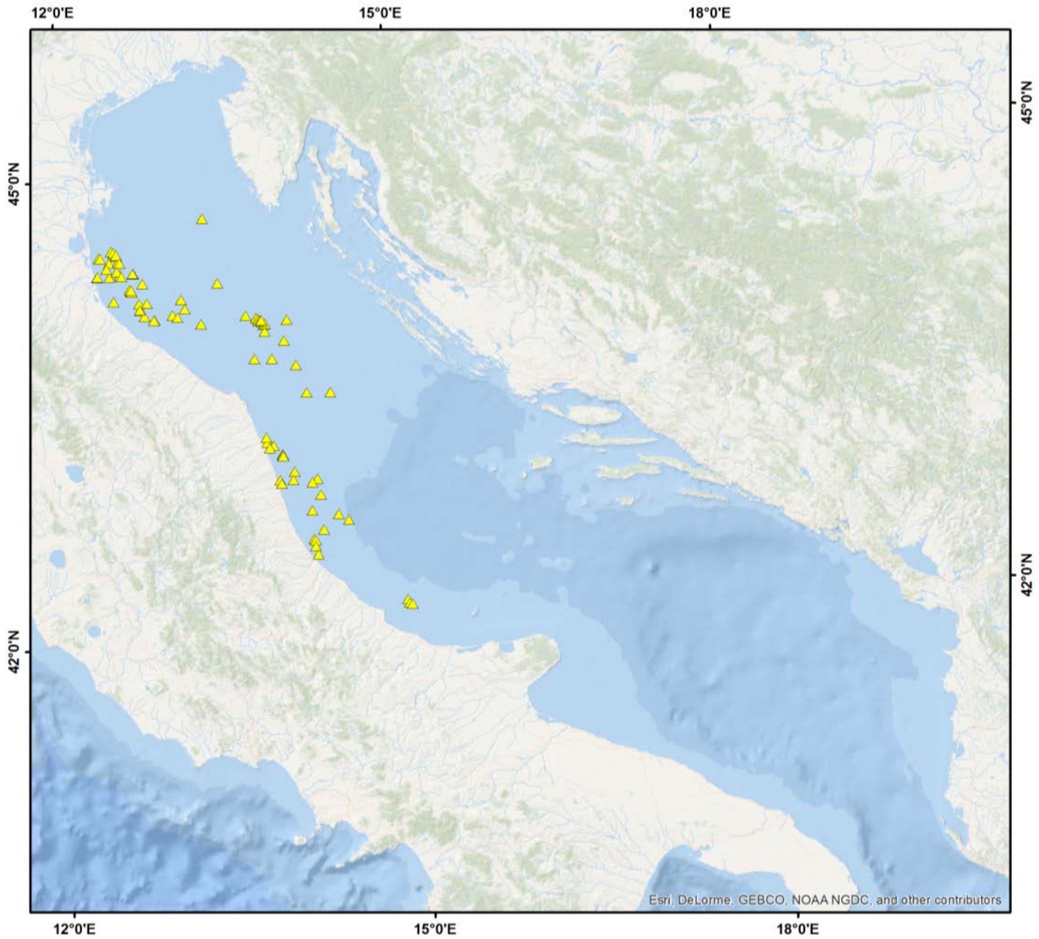

Fig. 32. Distribution of Italian platforms for gas extraction (source: http://unmig.sviluppoeconomico.gov.it)

Although gas and oil extraction are a source of pollution, monitoring of fouling organisms on gas platforms on the Croatian side of the Adriatic since 2002 showed that well maintained gas platforms do not have an evident negative environmental impact (Bakran-Petricioli et al., 2014). They can be seen even as artificial reefs harbouring complex fouling community with accompanying fish assemblages, which find here protection from overfishing in the surrounding areas. A notable impact comes from seismic activities aimed at understanding the geology and hydrocarbon beds on the sea bottom. Further, testing and wells drilling, rigs construction and their operation, additional drilling during operational lifetime in order to stop decline in the oil production are additional sources of significant noise pollution. Depending on the extracting methodology, particularly during secondary and tertiary recovery, a number of different chemical compounds used for extraction together with hydrocarbons could end up in the environment.

In the Gargano area and Tremiti Islands there are chemical residuals from the 2nd World War. A very polluted region is located in Kaštela Bay north of Split, where a cement factory and plastic polymer factory, active between 1950 and 1990 as well as other heavy industry, led to the accumulation of inorganic mercury and other heavy metals (Kljaković-Gašpić et al., 2006).

Martime transports are another important pressure that need to be considered and planned for the near future as strongly reccommended by the Marine Spatial Planning Directive (2014/89/UE). The activities connected with the maritime transport are responsible for underwater acoustic pollution, water polution, marine litter production (including plastics), and air pollution (Carić, 2010). Marine traffic also increases the transport and introduction of invasive species.

PART III.

11 Synthesis of the ecosystem functioning of the Adriatic

There is wide scientific evidence of the increased spread and intensity of eutrophication in several areas of the Mediterranean endangering the natural equilibrium of the basin. The Adriatic Sea mirrors a situation more worrying for the entire Mediterranean. As described in the various parts of this report, the Adriatic is a complex unit and highly diverse in production, biodiversity and ecological regions. Rivers bring to the Adriatic fresh water and sediments that determine the high productivity of the basin in terms of energy availability by nutrients, primary production, secondary production and biomass. The currents created by the characteristic gyres and the Levantine currents entry mix and distribute the all the energy produced in the basin. The Adriatic is considered the most productive area of the Mediterranean, probably one of the most exploited areas in it and, at the same time, with a high diversity determined by high variety of ecosystems in a small area. The biodiversity present in the basin is represented in a higher percentage by sand and muddy bottoms, with scattered hard bottom communities that serve as nurseries and refuges (Coll et al., 2010).

Adriatic biodiversity has a crucial role in direct ecosystem services, that, when overexploited, sacrifice the whole ecosystem, from the smallest participant to the largest, and from the bottom to the top of food webs. The case of the Adriatic and its intense usage in time and the natural characteristics of the basin, have shown how communities can adapt or perish in a relative quick time, for example to be used as a case study for the effects on the climate change consequences as it cools and warms quicker than other Mediterranean basins.

On the other hand, the particular characteristics of the basin and the communities, forging the high biodiversity levels, have proven certain reluctance to "naturally arrived" invasive species. Altogether, the Adriatic coasts have been populated for centuries and this small basin has accumulated, and efficiently tempted to reclaim, all the waste of the various industrial revolutions, the oil spills, the climate changes, and still can be considered a meso-oligotrophic sea. It suffers of overexploitation, severe coastal erosion on the western shelf, methane and petrol derivate extraction, intense naval activity and all the productivity it enhances can also be negative, as there are local zones with continuous or punctual hypoxia events or algal blooms including some from potentially toxic microalgae.

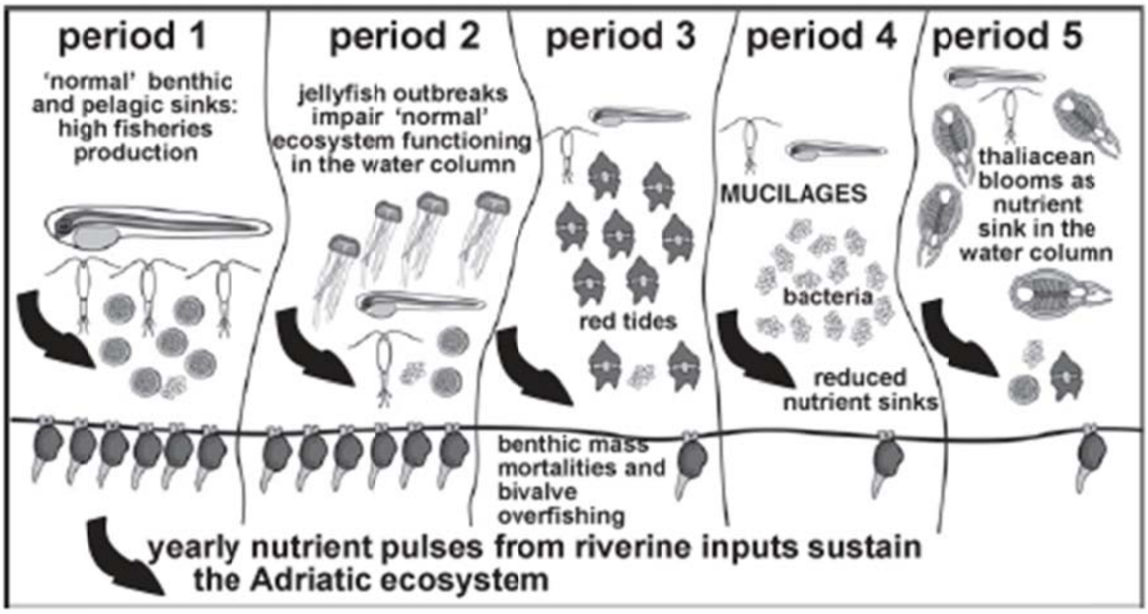

Fig. 33. Historical ecology of the Adriatic Sea. Period 1: Nutrients feed diatom production that, in turn, sustains zoobenthic filter feeders and zooplankton, that in turn sustain nekton. In this period the Adriatic fisheries yields are very high. Period 2: Several years of outbreaks of *Pelagia noctiluca* likely impact the communities in the water column, removing zooplankton and fish larvae. Period 3: The decrease of pelagic nutrient sinks, due to *Pelagia* outbreaks, leaves open corridors for opportunistic dinoflagellates, leading to toxic algae blooms in the water column and to benthic mass mortalities. The decrease in fisheries yields leads to increased fishery efforts (for instance with hydraulic dredges). Both pelagic and benthic nutrient sinks are limited. Period 4: In the absence of relevant nutrient sinks, nutrient pulses are exploited by bacteria and microalgae that trigger production of mucilages as a side effect of their metabolism. Period 5: Blooms of pelagic tunicates filter phytoplankton (including bacteria) and restore, albeit temporarily, the pelagic nutrient sinks (From Boero and Bonsdorff, 2007).

Predicting the consequences of species loss is critically important, given present threats to biological diversity such as habitat destruction, overharvesting and climate change (Ponti et al., 2014b). Several empirical studies have reported decreased ecosystem performance (for example, primary productivity) coincident with decreased biodiversity, although the relative influence of biotic effects and confounding abiotic factors has been vigorously debated. The North-central Adriatic basin could be considered, in some way, as a large marine lake, where all the changes in one remote part of the basin occur they are quickly felt in the whole ecosystem. Phytoplankton has generally three main periods of growth: February, April and July. In a nutrient-enriched system, the dominant taxon are diatoms (both micro- and nanoplankton fractions), over most of the year. Dinoflagellates can be recorded mainly in June–July, after the spring bloom of diatoms, when there is a low concentration of nutrients. This is why dinoflagellates have lower nutritional requirements (Aubry et al., 2004).

The Jabuka Pit, or Pomo Pit, is one of the deepest areas of the north and central Adriatic Sea. Here it is possible to find peculiar environmental conditions, supporting a very productive area regarding commercial fishing activities. This high productivity explain why this area is considered also an important cetaceans route, a turtle foraging area and migration zone, a fish spawning and nursery zones, a seep area for deposits with high hydrodynamisms that makes recirculate the waters, thus a key zone to identify as open and deep sea zone to protect. The Jabuka Pits are important nursery area for commercial species and area for european hake spawning.

In the whole Adriatic basin, physical disturbance caused by bottom trawling can be classified as one of the most important sources of human induced disturbance to soft-sediment benthic communities and habitats. The long-lasting effects of trawling on benthic communities negatively affect their structure and function, compromising, reproduction and/or recruitment for several commercial species. This situation is asking for an urgent identification of Essential Fish Habitats (EFH). The identification of spawing areas and recruitment areas for small pelagics cannot be the only pathway to follow addressing the main conservation measures for Adriatic Sea. Fishing activities and climate change are enhancing the loss of ecosystem complexity, decreasing the distribution and the abundance of many species. Considering benthic species this loss affect mainy filter feeders such as sponges, gogonians and bivlaves (Cerrano and Bavestrello, 2008; Di Camillo et al., 2013; Garrabou et al., 2009), compromising the resilience of whole basin. The presence of a wide belt of suspension feeders (e.g. *Chamelea galina*) all around the Adriatic sandy coasts suggests also an importat role in term of filtration activity and nutrients production played by this functional group, a service now strongly altered and compromised by trawling and hydraulic dredge overfishing. In such environments the effect of suspension feeders is not only a simple consumption of suspended matter but also a stimulatory feed-back effect to water column producer by nutrient regeneration from the faeces and pseudofaeces as demonstrated by Doering et al., 1986 and Lohrer et al., 2004. Reductions in density of a single key species may have lasting consequences for important bentho-pelagic processes, biogeochemical equilibria and indicators of ecosystem performance such as primary and secondary production.

The importance of these dynamics increases considernig that, over the large shallow continental shelf areas of the northern Adriatic, the formation of the densest water of the whole Mediterranean is recorded. Their formation rate varies on an interannual timescale as a function of winter air–sea fluxes (Manca et al., 2002; Vilibić, 2003). These water masses sink to the bottom, flows southwards as a bottom density-driven current contribute to the formation of the deep waters in the eastern Mediterranean.

The deep water outflow from the Adriatic represents a key component for the Ionian and eastern Mediterranean deep circulation (Ovchinnikov et al., 1985), so that modifications in the properties of Adriatic deep waters can influence the whole eastern Mediterranean

11.1 Primary production and nutrient patterns in the Adriatic Sea

The Adriatic basin is considered a highly productive sea; where the central western coasts are hyper-productive and the southern coasts are more oligotrophic. The distinction on the levels of primary production is due mainly to river inputs and the continuous mixing of the waters.

Eastern areas of the northern Adriatic Sea are oligotrophic, while the western ones are mesotrophic, with eutrophic zones off and south of the Po Delta.

The north-western Adriatic waters offshore the coast are less productive than onshore coast and productivity of the onshore zone decreases southward away from the Po Rivers' nutrient influx with seasonal variability of the trophic state in relation to rate of discharge of the Po River (Vollenweider et al., 1998).

The northern Adriatic is divided into two subregions: the shallow northern Adriatic, with high surface concentration of nutrients, decreasing downward to 5-10 m depths and increasing concentration below 10 m (Zavatarelli et al., 1998) and the deep northern Adriatic, respectively northwest and southeast of the 40 m isobaths (northwest of a line from Rimini to Rovinj). The influx of low-density waters of Italian Rivers causes the high concentration of nutrients in the sea surface, but not of deeper areas of the northern Adriatic. The largest sources of inorganic nitrogen are Italians rivers, mainly the Po River (Degobbis and Gilmartin, 1990; Gilmartin and Revelante, 1991). Higher-nutrient waters are then swept southward along the Italian coast during the winter by the Adriatic-wide circulation system (Artegiani et al., 1997b; Degobbis et al., 2000), with a less effective transport during spring-summer (Brana and Krajcar, 1995; Krajcar, 2003). Late spread of of low-salinity and nutrient rich waters in summer and autumn, may lead to benthic anoxia (Hrs-Brenko et al., 1994; Justić, 1991; Stachowitsch, 1984, 1991).

The cyclonic flow remove riverine nutrients in an east-west gradient, leaving the northern Adriatic at oligotrophic levels (Harding et al., 1999). From the eutrophic area of the Po River, nutrient rich waters spread east to the Istrian coast because of a vertical stratification of the water column and a well-developed pycnocline, due to high temperature and low salinity of surficial waters of dilution of discharge of Po flow (Degobbis, 1989).

Together with nitrogen, the principal limiting nutrient in the northern Adriatic during late winter-spring blooms is phosphorous, particularly where sea and fresh waters mix (Chiaudani et al., 1980; Zavatarelli et al., 2000; Zoppini et al., 1995), whereas silicate, despite its twice concentration of nitrogen in the Northern Adriatic, could become at times a limiting nutrient for diatom growth (Zavatarelli et al., 2000).

Being difficult to quantify the freshwater contribution form the complex Croatian karst systems, it is assumed that the Albanian rivers introduce the highest inputs after the Po River into the basin. Due to nutrient and organic matter inflow of the Po River, the Northern Adriatic shows nutrient levels higher than other major regions of the Mediterranean Sea (Pettine et al., 1998; Zoppini et al., 1995; Viličić et al., 2011). The northeastern, middle and south Adriatic regions are instead more oligotrophic, with similar levels of nutrients and productivity, with a west to east gradient to the Otranto Strait (Zavatarelli et al., 2000). Therefore, while diatoms are the dominant microplankon component in the nutrient-enriched northern Adriatic, the middle and southern oligotrophic offshore waters are dominated by dinoflagellates (Fonda Umani, 1996). Blooms occur with winter overturn and highest river discharge (Revelante and Gilmartin, 1983). Algal blooms can also occur with red tides and with mucilage phenomenon. Red tides are due to high concentration of dinoflagellates in coastal areas, especially within Po plume, caused by nutrient loads, inefficient grazing, spring warming and freshwater flows (Sellner and Fonda -Umani, 1999). Apparently favoured by high N/P ratio, mucilage proliferation events (or “marine snow” at small scale), known as “sea blooms” or “dirty sea”, produce creamy to gelatinous masses in the water column, caused by polysaccharide-rich exudates from diatoms that entrap suspended organic and inorganic matter and bacteria that release dissolved organic carbon back into water column (Degobbis, 1999; Herndl and Peduzzi, 1988). In between the second half of the last century and till 2007 the frequency and extension of mucilage events in the Adriatic Sea have increased a lot in concurrence with seawater warming (Danovaro et al., 2009).

Seasonal variations in planktonic availability affect distribution, abundance and growth of all direct and indirect consumers, both in the water column and in benthic ecosystems. Besides the primary production, *Cystoseira* spp., *Posidonia* and other phanerogames contribute the elevated primary productions, though only in selected sectors of the basin (namely the eastern coasts and the southern basin). This high production translates at times in large algal blooms, including some toxic events, during the whole year that deposit on the bottom creating a sort of mat and high turbidity during most of the year. In fact, most of the benthic community are filter feeders that are constantly active. On the other hand, this great production may translate in local severe or less severe hypoxia events, that together with the increasing farming can get to be almost constant in the northern area. Benthic hypoxia and complete anoxia can occur in large areas of the northern Adriatic due to falling to low level of bottom oxygen (Degobbis et al., 2000). Bottom oxygen saturation decrease caused by low photosynthetic rate in bottom waters, particle setting decay through the pycnocline and benthic organisms respiration, in Po outflow western regions is lower than in eastern areas of Adriatic (Smodlaka, 1986). However, bottom anoxias with benthic mortalities – but in much smaller and enclosed areas - were also recorded along the eastern Adriatic coast: in the estuarine part of the River Krka (e.g. Legović et al., 1991) and in the marine lake Zmajevo Oko near Rogoznica (Baric et al., 2007). Nevertheless, the eastern shelf is generally less productive, and together with a rocky environment confers a much diverse and complex, benthic community. The high productivity of this basin creates the ideal conditions for nursing and spawning of a variety of species, which in the early stages feed on the large amount of suspended matter.

11.2 Zooplankton patterns in the Adriatic Sea

In the Adriatic plankton, phytoplankton and primary production is predominant. Feeding on phytoplankton, zooplankton shows the highest biomass and species richness of the Mediterranean basin, in the Adriatic Sea (Kovalev et al., 1999), especially in the north-west side due to discharge of Po river. Po River inputs in the northern Adriatic influences proliferation of zooplankton within summer and in stratification of water column during autumn. Both the eutrophic western and the oligotrophic eastern north Adriatic are dominated by copepod nauplii, followed by ciliates (McKinney, 2007), strongly influenced by Po River discharge, while lowest biomass are recorded in the eastern oligotrophic side of Adriatic (Gotsis-Skretas et al., 2000). The grazing by the zooplankton in the basin is not enough to control the primary production and its biomass, leading to possible disequilibria shifting in eutrophication events. Zooplankton follows, in less degree the fluctuation of phytoplankton and nutrient availability, thus not being restricted in N or P (Fig. 34). The fluctuations are seasonal and determine three groups of communities the oceanic, the coastal and the inshore zones (Baranović et al., 1993; Fonda Umani, 1996). Water masses are clearly connected between the North Atlantic and Eastern Mediterranean affecting the southern Adriatic dynamics. Considering also the warmer Mediterranean waters, these synergies facilitate the incoming of non indigenous species, raising concerns over dramatic changes in the marine biodiversity of the Adriatic at a different trophic level (Batistić et al., 2014).

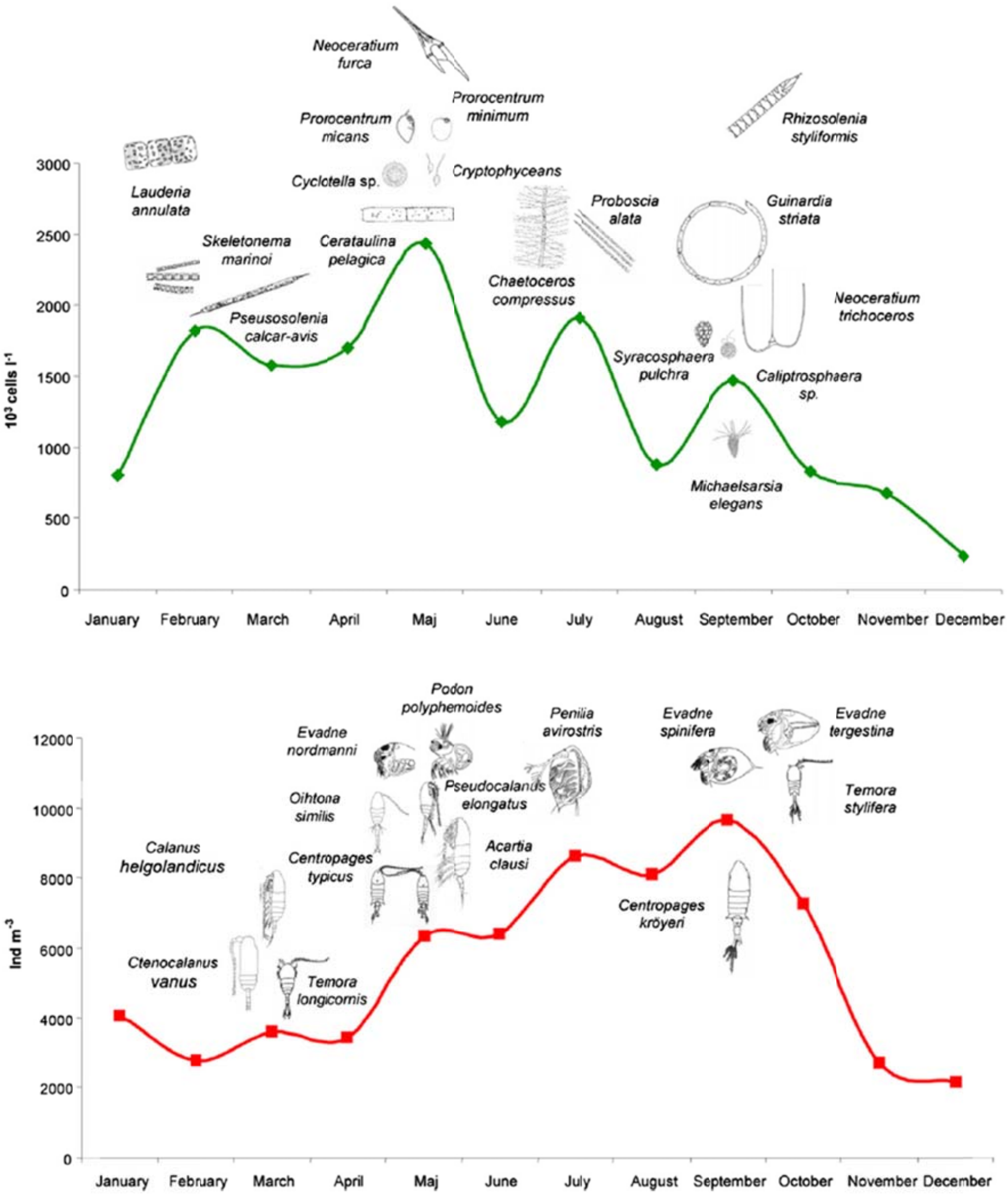

Fig. 34. Example of phytoplankton and mesozooplankton seasonal trends in the northern Adriatic Sea. The monthly values represent the mean abundance obtained from the whole dataset (from 1977 to 2006 for the phytoplankton and from 1986 to 2006 for the mesozooplankton). The main blooming taxa are depicted (from: Aubry et al. (2012). Drawings from Avancini et al. (2006a); Avancini et al., 2006b)).

The phytoplankton community structure is not only influenced by the spatial and temporal variations of abiotic parameters but is regulated by an endogenous clock and phenology. Seasonal trends of species may vary from year to year, but the annual cycles are recognisable with a high degree of reliability. Regarding the mesozooplankton, occupying higher levels in the trophic chain, the sensitiveness to environmental constraints such as climatic-oceanographic and anthropogenic changes is higher in respect the one of phytoplankton (Aubry et al., 2012).

12 Conclusions

The protection of high seas is more difficult then protection of coastal areas due to their limited accessibility, but it is crucial for their ecological sustainability. Filling the gap existing on the knowledge of the Adriatic seafloor in the open sea, respect to the coastal areas, more intensively explored and described, could support the achieving of the Good Environmental Status (GES) established in the Marine Strategy Framework Directive (MSFD) by European Union, especially regading sea floor integrity.

The "*Mediterranean regional workshop to facilitate the description of Ecologically or Biologically Significant marine Areas (EBSAs)*" introduced in 2014 the definition of these areas. A guidance of criteria for selecting areas, including open waters and deep-sea habitats has been provided in order to establish representative MPA networks, although the majority of areas comprise connections to terrestrial areas and low focus is given to open and deep waters, especially outside the national jurisdiction. The Mediterreanean Sea is comprised for the selection of sites of Community Importance (SIC) defined by EU (EEA 2010) and high seas areas are considered in the Protocol for Specially Protected Areas and Biological Diversity in the Mediterranean (SPA/BD Protocol) defined by the Barcelona Convention. Areas containing sites of Specially Protected Areas of Mediterranean Importance (SPAMIs) were designated as Ecologically or Biologically Significant Areas (EBSA), creating a list approved at the Extraordinary Meeting of the Focal Points for Specially Protected Areas (UNEP(DEPI)/MED WG. 348/5, June 2010). The Northern and the upper part of the central area of Adriatic Sea has been included (UNEP MAP RAC/SPA, 2010b) and identified as a priority conservation open sea areas, because of its high productivity and high level of degradation that suggest a need of restoration efforts, but no consideration was given to all the area comprised between this region and the Ionian Sea. Within this latter a vulnerable area of demersal habitat has been identified as priority for the management of fisheries resources (UNEP MAP/RAC SPA 2010a) and a more wide area was identified as Mediterranean Marine Peace Park (CIESM Workshp 41, 2010), whose purpose was to harmonised measures of protection, going beyond national jurisdiction and promoting the cooperation among countries. Up today fisheries restricted areas do not contemplate this region, but it is reported among high sea areas requiring protection in the Greenpeace proposal of 2006 and comprises sites included in the Oeana MedNet proposal according to CBD requests, to develop a high seas network of MPAs and protect vulnerable areas.

12.1 Identification of the priority target areas

The Adriatic Sea can be separated in a northern, a central and a southern sub-basin, characterized by different average depths and different features between the eastern and the western coasts. Based on the existing knowledge related to the open sea, it is possible to distinguish three key areas.

The Northern basin has numerous and diversified kind of exploitations that act on an area characterized by a high richness of benthic habitats. Its low average depth (35 m) and volume amplify the negative effects of these pressures but enhances the processes of mineralization of organic matter in the sediment and nutrient redistribution into the water column (Giordani et al., 1992). This basin is characterized by soft bottom and relict sands, with mainly biocoenosis of costal terrigenous muds, detritic, muddy bottom, with facies of *Atrina pectinata* and *Lytocarpia myriophyllum.* The area is of high interstest also because of the presence of foraging habitat for the loggerhead turtle, *Caretta caretta*, whales and dolphins (*Delphinus delphis* and *Tursiops truncatus)*.

Ecologically and Biologically Significant Areas Criteria[1]	Score
Uniqueness or rarity	HIGH
Special importance for life history stages of species	HIGH
Importance of threatenes, endangered or declining species and/or habitats	HIGH
Vulnerability, Fragility, Sensitivity or Slow Recovery	HIGH
Biological productivity	HIGH
Biological diversity	MEDIUM
Naturalness	LOW
Cultural representativeness	MEDIUM
Representativity	MEDIUM

The Central Adriatic Sea (average depth 150 m) has also high anthropic pressures and a very high diversity of habitats. It comprises both a shelf and an open sea ecosystem, which are closely connected. Here is possible to find a very good level of representativeness of Adriatic marine habitats (*sensu* Stevens, 2002).

The Central Adriatic open sea reaches an average depth of 130-150 m and 240-270 m at the Pomo Pits depressions. Pockmarcks are also present. The main biocoenoses are those of terrigenous muds, mixed bottom and offshore muddy. Biocoenoses of the circalitoral and bathyal muds and sands, with *Lytocarpia myriophyllum, Pennatula rubra and Pennatula phoshorea* are present. Deep-sea corals are also recorded. For the open sea of the central area only scattered informations are available.

Ecologically and Biologically Significant Areas Criteria[1]	Score
Uniqueness or rarity	HIGH
Special importance for life history stages of species	VERY HIGH
Importance of threatenes, endangered or declining species and/or habitats	VERY HIGH
Vulnerability, Fragility, Sensitivity or Slow Recovery	HIGH
Biological productivity	VERY HIGH
Biological diversity	HIGH
Naturalness	LOW
Representativity	HIGH

[1] CBD scientific criteria for ecologically or biologically significant areas (EBSAs) (annex I, decision IX/20), COP 9 (2008). https://www.cbd.int/decision/cop/default.shtml?id=11663

The Southern basin has a medium-high level of fruition respect the North and Central ones and it is characterized mainly by deep habitats. It contains a large bathyal basin and comprises a wide depression reaching around 1200 m depth. The open sea area is dominated by biocoenoses of offshore muddy bottoms and of detritic ones. Biocoenoses of bathyal muds and of deep sea white corals are present on hard substrata, with impressive colonies of *Lophelia prolifera* and *Madrepora oculata.*

Ecologically and Biologically Significant Areas Criteria2	Score
Uniqueness or rarity	VERY HIGH
Special importance for life history stages of species	HIGH
Importance of threatenes, endangered or declining species and/or habitats	MEDIUM
Vulnerability, Fragility, Sensitivity or Slow Recovery	HIGH
Biological productivity	HIGH
Biological diversity	HIGH
Naturalness	MEDIUM
Representativity	MEDIUM

Each area has thus ecological peculiarities and is prone to different intensities of human pressures and different levels of resilience and vulnerability. These three sub-basins and their ecosystems are also connected by the southward coastal current flowing along the western coast of the basin, affecting the large scale distribution of the ecological and biogeochemical properties of each sub-basin. Moreover, despite its limited geographical dimensions, the Adriatic Sea hosts key seasonal interacting processes that influence the whole Mediterranean Sea. Over the large shallow continental shelf areas of the northern Adriatic, the formation of the densest water of the whole Mediterranean is recorded. Formation rates vary on an interannual timescale as a function of winter air–sea fluxes (Manca et al., 2002; Vilibić, 2003). These water masses sink to the bottom, flow southwards as a bottom density-driven current and eventually spills over the Otranto Strait, contributing to the formation of the deep waters in the eastern Mediterranean. As the deep water outflow from the Adriatic represents a key component for the Ionian and eastern Mediterranean deep circulation (Ovchinnikov et al., 1985), modifications in the properties of Adriatic deep waters influence the whole eastern Mediterranean.

The Adriatic marine habitats are clearly facing major impacts from overfishing, pollution and maritime uses still poorly managed at the national and international level. Historical data demonstrate that the Adriatic ecosystems have changed dramatically over the last 30 years, loosing many key components critical to ecosystem functioning, without any sign of recovery (Boero and Bonsdroff, 2007).

Based on these considerations we therefore underline open sea areas in the three basins Northern, Central, Southern of the Adriatic Sea, as priority target ones. The highest level of fruitions on the Northern area, highly rich of benthic habitats, the deep sea characteristics of the Southern one and the very high diversity of habitats of the Central one, suggest the importance of protection efforts in each open areas of the three basins for joining the goal of an effective action on biodiversity of all the Adriatic Sea. The Central open sea area cover the representativity of the full range of biotic and habitat diversity of both the Northern and Southern ones, whose

[2] CBD scientific criteria for ecologically or biologically significant areas (EBSAs) (annex I, decision IX/20), COP 9 (2008). https://www.cbd.int/decision/cop/default.shtml?id=11663

connectivity through the open sea of the Central one could represent a key linkage and reserve for both of them. The Central open sea area shows features, as species, habitats and ecological processes occurring in both the other two ones and its involving in protection measures could improve the ecological viability and integrity of features of both the other two. All these criteria are evidenced in the scientific guidance for selecting areas defined to establish a representative network of MPAs including open and deep sea waters (UNEP/CBD/EWS.MPA/1/2-2007; UNEP/CBD/COP/DEC/IX/20-2008 and UNEP/CBD/BCS&IMA/1/2-2009).

The identification of open seas areas in all the three region of the Adriatic basin as prioprity target ones for protection actions could improve the efforts invested and bridge the gap previously underlined.

This review shows there is good general knowledge of the water dynamics of the Adriatic Sea and extensive information on the geology of this basin, but also important gaps regarding the distribution, abundance and function of benthic organisms and the habitat they form in the open sea, limiting the possibility to achieve management decisions adequately supported by scientific evidence. Despite such gaps, enough information exists to identify areas exposed to high levels of human pressure, and inform spatial management of this crucial and highly impacted sea as mandated by the EU Marine Strategy Framework Directive, Strategy for the Adriatic and Ionian Regions, and the UNEP EBSAs process.

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