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TESI DI DOTTORATO

# Ecological effects of offshore artificial structures at sea on macrobenthic and fish assemblages (NW Adriatic Sea)

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# EXTENDED ABSTRACT

The extraction of natural gas represents one of the most relevant and concerning anthropogenic stressors affecting the NW Adriatic Sea, as oil and gas platforms are widely considered one of the main threats for marine environments and maritime navigation (Liu *et al*., 2016).

Indeed, this basin is subjected to intense (and possibly increasing) drilling activities, carried out with offshore oil and gas platforms, whose number represents ca. 90% of the structures located in the Italian Seas (OGP, 2005; Maggi *et al.,* 2007; Manoukian *et al.,* 2010). Moreover, drilling activities in the Adriatic Sea last since the early 60s and, over the next few decades, their decommissioning will be inevitable, as the existing field infrastructures at sea are approaching the end of their productive life. It has been estimated that in the period 2013-2020 an average of 38 platforms per year will be removed in Europe, with the majority of them being located along the Italian coasts of the Adriatic Sea (Scottish Enterprise, 2013).

On the one hand, decommissioning of offshore oil and gas platforms could be highly desirable in order to restore the marine environment. A key issue within the decommissioning challenge of offshore platforms is to assess the most ecologically sustainable practices of decommissioning in order to preserve ecosystems functions under a reasonable economical effort. On the other hand, it must be considered that, since these structures exist at sea since a long time, they could have become part of the marine ecosystem. In this regard, for instance, fishing is prohibited for a radius of 500 m around each structure. These off-limit zones, if adequately expanded, could represent opportunities for larval recruitment and increased biomass, in a similar manner as for no-take zones of marine protected areas (Lester *et al*., 2009; Kark *et al.,* 2015; Pondella *et al.,* 2015). Such refuge and spillover effects are likely also enhanced by the FAD (*Fish Aggregating Device*) nature of offshores structures (Love *et al.,* 2003). This suggests that reclaiming offshore platforms while keeping them (or at least their submerged part) in place instead of decommissioning, could be an after-life ecologically sustainable option. Nevertheless, to approach this goal, it is of primary importance accumulating science-based knowledge of the potential effects of offshore platforms on hosting ecosystems and their neighboring.

In order to achieve this objective, my PhD thesis has been built upon four main interrelated chapters, each of them with specific targets.

Specifically, I tested the following four (null) hypotheses:

**i) the quantity and biochemical composition of organic matter in the sediment do not vary at increasing distance from offshore artificial structures**. To test this hypothesis, sediment samples have been collected by box-corer at 0, 30 and 120 m from two offshore structures (one subsea well-site and one four-leg platform) and analyzed in terms of phytopigment, protein, carbohydrate, lipid and biopolymeric organic carbon contents, used here as descriptors of the benthic trophic status (Pusceddu *et al*., 2009);

**ii) the abundance and biodiversity of macro-benthic communities do not vary at increasing distance from offshore artificial structures**. To test this hypothesis, the spatial distribution of macro-zoobenthic communities living around offshore artificial structures has been investigated through bi-annual surveys conducted for two years at 0, 30, 60, 120 and 1000 m distance from one subsea well-site, one four-leg platform and one one-leg platform.

**iii) the abundance, biomass and biodiversity of fish assemblages close to offshore platforms do not differ from those in open waters**. To test this hypothesis, monthly campaigns during two consecutive years were conducted using either hydroacoustic techniques (through Multibeam Echosounder) or fishing surveys (through trammel net) at one well-site, one four-leg platform and one one-leg platform.

**iv) the diet of two commercial demersal fish (namely *Scorpaena notata* and *Scorpaena porcus*) do not vary among specimens collected close to the offshore structures or in open waters.** To test this hypothesis, gut contents of the two species were analysed and compared to assess the “trophic” attraction of the structures and to determine the trophic relationships among those ecologically and commercially important species.

The results evidenced that the presence of offshore artificial structures had only a very limited influence on organic matter (OM) contents in the sediment, whereas it apparently influenced OM biochemical composition of sediments surrounding the four-leg platform. More specifically, chlorophyll-a and phaeopigment sedimentary contents (representing the most labile fractions of OM) significantly increased with increasing distance from the platform. This result could be related to the higher abundance of filter feeder organisms living on the platform legs able to intercept labile particles (Punzo *et al.,* 2015) suggesting that offshore platforms with a multifaceted architecture (like the four-leg platform under scrutiny in this study) can mirror, at a much larger spatial scale, the ecosystem engineering behaviour of branched corals living in incoherent sediments (Cerrano *et al*., 2010; Bianchelli *et al.,* 2013).

Both univariate and multivariate analyses showed different spatial patterns and temporal changes of macrozoobenthic communities surrounding the artificial structures. This result, on the one hand, suggested that the observed variations in the stock and composition of macrobenthic communities with increasing distance from the structures could be related, to a certain extent, to the different shape and dimension of the structures themselves. Nevertheless, given also the different position at sea, these differences could be also due to the different environmental conditions encountered around the three different structures. For instance, the development of bivalve mounds (mainly composed by *Mytilus galloprovincialis* and *Neopycnodonte cochlear*) occurring on the submerged part of the two offshore platforms, but not in well-site, suggested that different size and building architecture of different structures (i.e., platform vs. well-site) can attract different "fouling" organisms. These, in turn, providing different secondary substrates for different colonizing associated faunas, could sustain increased levels of biodiversity.

Using the results gathered from both hydroacoustic and fishing surveys around the three submerged structures, it has been reported that the abundance and biomass of fish close to the structures are higher than those in the open sea. Fish abundance in the surroundings of the four-leg platform was higher than those surrounding the two other structures, again likely because of the different building architecture of the investigated structures. This result allowed me to infer that the magnitude of the attraction exerted by submerged structures on fish assemblages is related to the dimension and volume occupied by the structure itself. The results of this study confirmed the 'FAD' nature of the three types of artificial structures and allowed me also to hypothesize that such attractiveness is related to the different growth patterns of attracted fish, in turn related to the higher food availability encountered in the proximity of the structures. This latter hypothesis is also supported by the results of the diet analysis of *S. porcus* and *S. notata*. Indeed, the results showed that the bases of artificial structures, involving numerous crossbeams and large interstitial spaces, which altogether increase the overall habitat complexity, can offer shelter and increase prey availability for both species, though with some differences between them. In fact, the diet composition of specimens caught close to offshore artificial structures was significantly different from that of specimens living in their natural habitat, even if more clearly for *S. notata* than for *S. porcus*. As a corollary result of the diet analysis, it was evidenced that, although both species mainly prefer crustaceans prey, the differences in their diets suggest no interspecific competition relationships between the two congeneric species.

Overall the results of my thesis highlighted the aggregation effect of the artificial structures under scrutiny on both the fish and macrobenthic assemblages. The higher abundance and biomass of fish close to the structures could be explained by several factors, which include, among the others, the thigmotropic effect exerted by the submerged parts of the structures, the increased availability of food, and the decreased risk of predation in the vicinity of the platforms compared to the open sea (Bohnsack *et al*., 1991). The exclusive presence or the higher abundance of several species with high affinity to hard substrates, such as the crustaceans *Palinurus elephas* and *Homarus gammarus*, the benthic fish *Mullus surmuletus*, *S. porcus*, and the necto-benthic *Diplodus vulgaris*, *Sparus aurata*, *Spondilyosoma cantharus*, *Dentex dentex* and *Dicentrarchus labrax* close to the structures confirmed the 'fish aggregating device' nature of these structures (Hastings *et al*., 1976; Love *et al.,* 2005). The results of this study evidenced also that the magnitude of the attraction is related to the dimension, volume and building architecture of the structures (Bombace *et al.,* 1994).

Similar results emerged also for the macro-benthic communities, highlighting that the dimension and the complexity of offshore structures have different influences on the benthic communities and that these features of the structures can also affect the amplitude and the timing required to reach a new diversified and stable community. An initial and localized effect (up to a maximum of 60 m distance from the structure), consisting in the defaunation and/or in a low diversity, occurred at both the well-site and the four-leg platform, with a faster recovery in the former. A longer-term effect, directly linked to the physical presence of the structures, consisted in the development of shells mounds, which occurred at the two platforms from the third sampling survey onward. Both mobile and sessile species are attracted by the shells mounds and use them as food source or as substrate, with a consequent enrichment of the community living close to the structures (Manoukian *et al*., 2010).

In the light of the findings reported here, and in view of the upcoming platform's decommissioning programme, I conclude that a case-by-case evaluation of decommissioning options should be recommended, in addition with before-after environmental impact assessments, in order to avoid any secondary effect on the actually established fish and benthic communities.

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# 1. GENERAL INTRODUCTION

## 1.1. ARTIFICIAL STRUCTURES IN THE MARINE ENVIRONMENT

### 1.1.1. DEFINITION

Marine artificial structures can be broadly defined as human-made engineering facilities constructed and installed for a variety of functions and in a variety of water depths and environments. They are basically built to exploit various marine living and non-living resources (Li and Li, 2008), to control erosion, to deter trawling in coastal areas, to promote marine life in areas with a generally featureless bottom (Bombace *et al.*, 2000; Relini, 2000; Fabi *et al.*, 2011) in coastal or open sea areas.

In consideration of these purposes, in the last decades artificial structures have reached a strong importance in the marine environment, accounting the deployment of a huge amount of different substrates, such as shipwrecks, coastal defense structures, artificial reefs, oil and gas platforms, fish farms, and renewable energy devices like offshore wind farms (Zintzen *et al.*, 2008; OSPAR Commission, 2009a; Moffat *et al.*, 2010; Coates *et al.*, 2014).

Generally, the marine structures can be divided into two main different types: fixed (or immobile) and floating (or mobile) structures. The formers are at least partially submerged and fixed on the seabed on a long-term basis by using piles or the gravity of structure itself and include: gravity type breakwater, gravity type pier, groin, seawall, gravity concrete platform, jacket platform, submarine pipeline, submarine tunnel and various types of artificial reefs. Floating structures are defined as those that can float or be moved (Allen, 1953; Crisp, 1958; Foster and Willan, 1979; Carlton and Hodder, 1995; Gollasch and Riemann-Zürneck, 1996; Apte *et al.*, 2000; Mineur *et al.*, 2012), such as buoys, floating pontoons, floating type breakwater, floating pier, jack-up drilling platform, bottom-supported platform, semi-submersible platform and various type of specially designed boats, etc.

Another distinction within artificial structures is based on their location in the marine environment, distinguishing them into coastal, offshore and deep ocean structures.

### 1.1.2. TYPES AND MATERIALS

Worldwide, a diverse array of man-made structures can be identified according to their main function. The most important artificial structures (Figure 1.1) can be summarized as follow:

- Offshore gas and oil platforms or oil rigs to drill wells, to extract and process oil and natural gas, or to temporarily store product until it can be brought to shore for refining and marketing.
- Wind turbines or airfoil-powered generators used to convert kinetic energy from the wind into electrical power. Arrays of large turbines, known as windfarms, are becoming an increasingly important source of renewable energy and are used by many countries both as part of a strategy to reduce their reliance on fossil fuels and to attain the EU target of 20% of energy generation from renewables by 2020 (Directive 2009/28/EC). For these reasons, it is likely that in the next 10 years a rapid expansion of the windfarm development will occur (Ashley *et al*., 2014).
- Artificial reef to protect spawning and nursery areas from illegal trawling (Bombace *et al.*, 2000; Relini, 2000); to attract and aggregate reef dwelling fish and to improve commercial fishing (Bombace *et al*., 1994); to redirect the excess nutrients flow into edible biomass through mariculture (Bombace *et al*., 2000); to replace habitat losses caused by human impacts or to mitigate impacts to natural habitats (Fabi *et al*., 2002; Feary *et al*., 2011).
- Artificial structures to act as dive sites for recreational SCUBA organizations (Al-Saffar and Al-Tamimi, 2006; Fabi *et al*., 2011);
- Sea breakwaters and seawall, deployed parallel to the shoreline, and jetties and groynes, running perpendicular to the shoreline, are permanent infrastructures to minimize coastal erosion, protecting the coastlines from erosion and beach nourishment (Cenci *et al*., 2011; Fabi *et al*., 2011; Feary *et al*., 2011). Breakwaters, also called bulkheads, reduce the intensity of wave action in inshore waters and thereby reduce coastal erosion or provide safe harborage. They can be made of small structures designed to protect a gently sloping beach and placed 30 to 100 m offshore in relatively shallow water. The average life span is around 50–100 years for breakwaters and seawalls and 30–40 years for

groynes; therefore they need to be periodically refurbished or rebuilt. Moreover, they strongly alter the natural state of the beach. Their design is influenced by the angle of wave approach and other environmental parameters. Breakwater constructions can be either parallel or perpendicular to the coast, depending on the shoreline requirements.

In relation to their orientation (either seaward or landward) and to the type of material used for their construction, the defense structures may influence the colonization and recruitment of marine organisms (Dafforn *et al*., 2015). In addition, these structures can host communities that are different from those recorded in the natural hard bottom habitats, also harboring a considerable number of non-native species.

Many different materials, shapes and dimensions can been used for the construction of artificial structures.

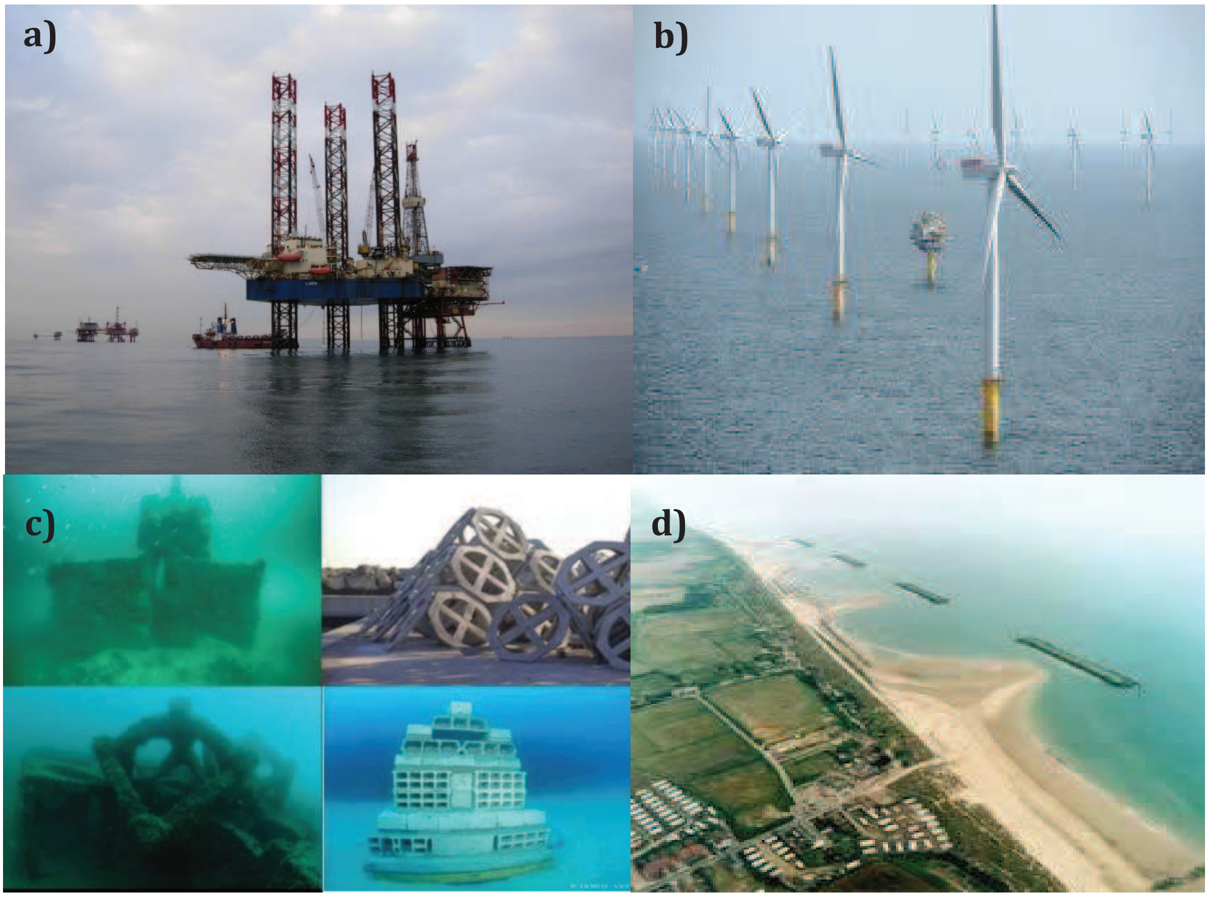

**Figure 1.1** - Artificial structures in the world: a) Gas-oil platforms; b) Windfarms; c) Artificial reefs; d) Sea breakwaters.

Fixed gas and oil platforms are designed for very long-term use; moreover, they designed for installation in the open sea, lakes, gulfs, etc., many kilometers from shorelines. Thus, these structures may be made of steel, reinforced concrete or a combination of both, anchored directly onto the seabed, supporting a deck with space for drilling rigs and facilities to house the workforce (Sadeghi, 2007). The offshore oil and gas platforms are generally made of various grades of steel, from mild steel to high-strength steel, although some of the older structures were made of reinforced concrete. Various types of structures are used, such as steel jacket, concrete caisson, floating steel and even floating concrete. Steel jackets are vertical sections made of tubular steel members, and are usually piled into the seabed.

Primary components of a typical offshore windfarm include several wind turbines located in the water and usually spaced laterally at several (4 to 8) times the rotor diameter and staggered to minimize wave effects. A wind turbine system includes the following components: foundation, the support structure, the transition piece, the tower, the rotor blades and the nacelle. The foundation system and support structure, used to keep the turbine in its proper position and to resist to sea storms can be made using a variety of materials such as reinforced concrete or steel. Support structures connect the transition piece or tower to the foundation at seabed level. In some cases, the foundations serve as support structures as well by extending from the seabed level to above the water level. The transition piece connects the tower to the support structure or foundation. The towers are made of steel plate rolled into conical subsections that are cut and rolled into the right shape, and then welded together. The nacelles contain the key electro-mechanical components of the wind turbine. The rotor blades are made of fiberglass mats impregnated with polyester or carbon fiber composites.

As concerns artificial reefs, in the last 30 years their construction has included both objects that were built for other purposes (*e.g.*, car bodies, vessel wrecks, construction debris), and ad hoc PVC, concrete or sea-friendly cement modules (*e.g.*, Reef Balls™, Tecnoreef® modules; Punzo *et al.*, 2015). However, not all materials were suitable; the pollutant percolating and the paint flaking reduced the number of organisms able of attaching and/or maintaining a permanent foothold on certain material (*e.g.*, fouling organisms; Relini and Orsi Relini, 1971; Relini and Wurtz, 1977;

Relini, 1979; 1983a; 1983b; Manoukian, 2011), or to the destructive action of perforating organisms. Other problems include quick burial of the structures associated with limited supporting surfaces (Faranda *et al.*, 1998; CoNISMa, 1999). Also certain modules specifically designed for artificial reefs did not give satisfactory results. Some artificial structures broke up under the action of the waves or partially sank in the soft sediment bottom (Bombace *et al.*, 2000).

Sea breakwaters and groynes are used to reduce the intensity of wave action in inshore waters, to interrupt water flow and limits the movement of sediment in the beaches are usually made of rock piles or reinforced concrete units and placed in groups. They are often used in tandem with seawalls to reduce coastal erosion. A breakwater structure is designed to absorb the energy of the waves that hit it. The length and elevation of a sea breakwater and the spacing between structures are determined according to local wave energy and beach slope. Sea breakwaters can be permeable, allowing the water to flow through at reduced velocities, or impermeable, blocking and deflecting the current. Permeable sea breakwaters are usually made of large rocks piled, while impermeable ones are constructed using rock, gravel, and gabions.

## 1.2. THE EFFECTS OF ARTIFICIAL STRUCTURES ON THE MARINE ENVIRONMENT

Beyond their main purposes (such as oil and gas extraction, production of energy, coastal protection from erosion, etc.), artificial structures influence the behavior and ecology of aquatic organisms, ranging from small-scale modification of local environments to complex effects due to structures deployed over extensive areas of seafloor (Seaman and Sprague, 1991).

The most important effects exerted by artificial structures on the surrounding environment can be itemized as follows:

- alteration of wave and current patterns mainly by introducing additional friction. This reduces current speeds and breaks up waves, causing deposition of sediments in some areas and scour in others. For this reason the presence of structures induces changes in the surrounding soft bottom, influencing sedimentation rates and benthic communities (Cenci *et al*., 2011);

- reduction of natural mortality of fish by providing refuges from predators;
- provision of new hard substratum for the settlement of a wide variety of epibiota and associated assemblages (Fabi *et al*., 2002; Mineur *et al.,* 2012);
- reduction of fishing mortality because the hard and heavy components of the structures represent a mechanical deterrent against towed gears, namely bottom and pelagic trawling;
- contribution to increase fish biomass: they provide shelters for reproductive specimens and a wide surface for the egg settlement of several species;
- modification of natural dispersal patterns, particularly along formerly exposed sedimentary coastlines, or facilitate the establishment and spread of alien species (Ruiz *et al*., 2009; Bulleri and Chapman, 2010; Mineur *et al*., 2012). In fact, on a regional scale artificial structures can act as stepping stones for the dispersal of the larval stages of nonindigenous species (ICES, 2012; OSPAR Commission, 2009a; Coates *et al.,* 2014);
- in some specific habitats, provision of refuge and foraging areas for various organisms including fish, resting and nesting sites for birds, and haul outs for seals and sea lions (California State Coastal Conservancy, 2010);
- where the structures are placed close to other substrata, interaction with existing natural and/or artificial substrates (Carr and Hixon, 1997; Cenci *et al*., 2011).

Figure 1.2 shows both functions and services provided by the artificial structures and their influences on the natural environment.

The impacts of these structures in coastal waters vary according to the nature of the host habitat (Bulleri and Chapman, 2010). Some Authors (*e.g.*, Thompson *et al*., 2002; Branch *et al*., 2008) consider that the introduction of artificial surfaces on rocky bottoms does not alter the natural habitat, given that the structure and functioning of the assemblages colonizing those structures are similar to those living in the natural rocky substrates. On the contrary, other Authors (*e.g.,* Connell, 2001; Bulleri, 2005; Clynick *et al*., 2008; Lam *et al*., 2009), reported that community composition differs significantly between artificial and natural substrata, independently from the type of seabed. According to these Authors, the unnatural material used to construct the artificial structures (*e.g.*, concrete, plastic or metal) may affect colonization, even if many epibiotic taxa readily colonize unnatural surfaces (Bulleri and Chapman, 2010).

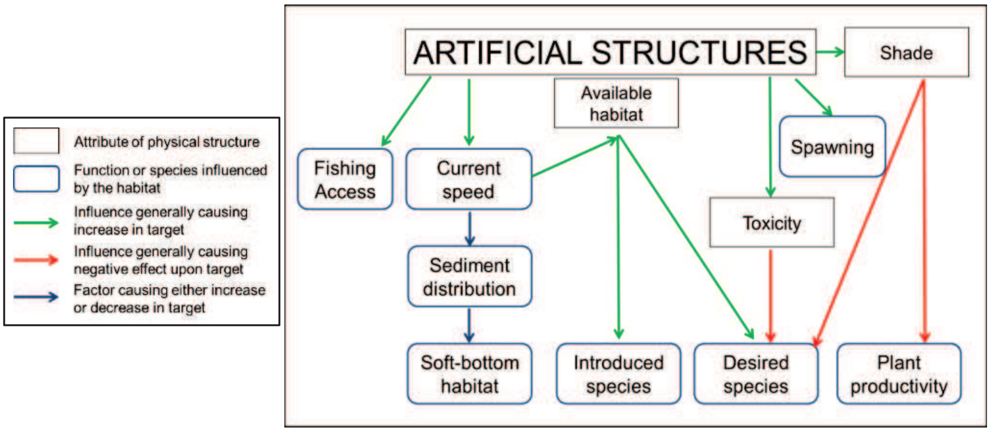

**Figure 1.2** - Functions and services provided by artificial structures and influences on artificial structures (modified from California State Coastal Conservancy, 2010).

Logically the effects of the new structures within the natural soft sediments are more complex, influencing all the organisms living in the surrounding area (Davis *et al*., 1982; Ambrose and Anderson, 1990; Petersen and Malm, 2006; Langhamer, 2010; Coates *et al*., 2014). In marine areas characterized by soft sediments, as the central-northern Adriatic Sea, artificial structures (gas platforms, artificial reefs and groynes) represent something new in a seabed which is flat, sandy or sand-muddy or muddy, thus attracting several species and affecting the surrounding environment. In this case, their deployment introduces species otherwise absent in the area (Airoldi *et al*., 2005).

The comprehension of these interactions is essential in deploying new artificial reefs not only for fishery management but also for planning coastal restoration and maintenance (Cenci *et al*., 2011).

Artificial structures may function purely as fish attractors, hosting individuals, adults and juveniles previously or otherwise inhabiting other hard substrates, or they can act as fish producers, enhancing fish biomass in an area by providing new spaces and refuges and increasing the overall habitat complexity (Cenci *et al*., 2011). For these reasons, two opposing but not mutually exclusive models have been proposed to explain increased abundances: the “attraction hypothesis” and the “production hypothesis”. In the first case, artificial reefs, acting as Fish Aggregating Devices (FADs), purely attract fish from the surroundings due to several factors, such as:

- the thigmotropic tendencies of fish species to move towards structured rather than bare, featureless habitat (Bohnsack, 1989);
- the increased feeding opportunities due to the greater food availability;
- the decreased risk of predation.

In this way, artificial reefs do not significantly increase local populations but concentrate existing individuals into a smaller area of habitat (Brickhill *et al*., 2005).

The production hypothesis suggests that artificial reefs provide additional habitat, increasing the carrying capacity of an area (Bohnsack, 1989). In this case, in fact, as well as to increase the opportunities of finding food and shelters, a large number of juveniles are able to settle, survive to spawn as adults and contribute new individuals to local populations. In this way, the reef supports a net increase of fish abundance because new individuals can be accommodated by new (i.e. artificial reef) habitat (Brickhill *et al*., 2005).

## 1.3. GAS PLATFORMS IN THE WORLD: TYPES AND IMPORTANCE

Offshore platforms are huge steel or concrete structures used for the exploration and extraction of gas from the earth's crust. Different types of offshore oil or gas rigs and platforms are used depending on the offshore oil/gas field water-depth and location. The offshore platforms can be divided in three main categories: fixed platforms, floating production systems, and subsea systems (Figure 1.3).

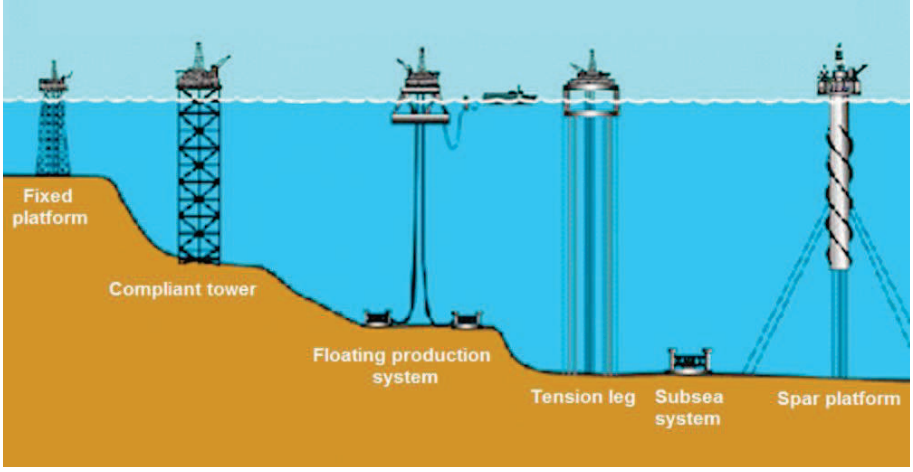

**Figure 1.3 -** Different types of offshore structures (modified from Sadeghi, 2007).

**Fixed platforms**. These structures are anchored directly into the seabed and consist of a tall, steel or concrete structure known as a "jacket" that rises up from the sea surface to support a deck (Figure 1.4). Fixed platforms offer stability but no mobility, and they are designed for very long-term use.

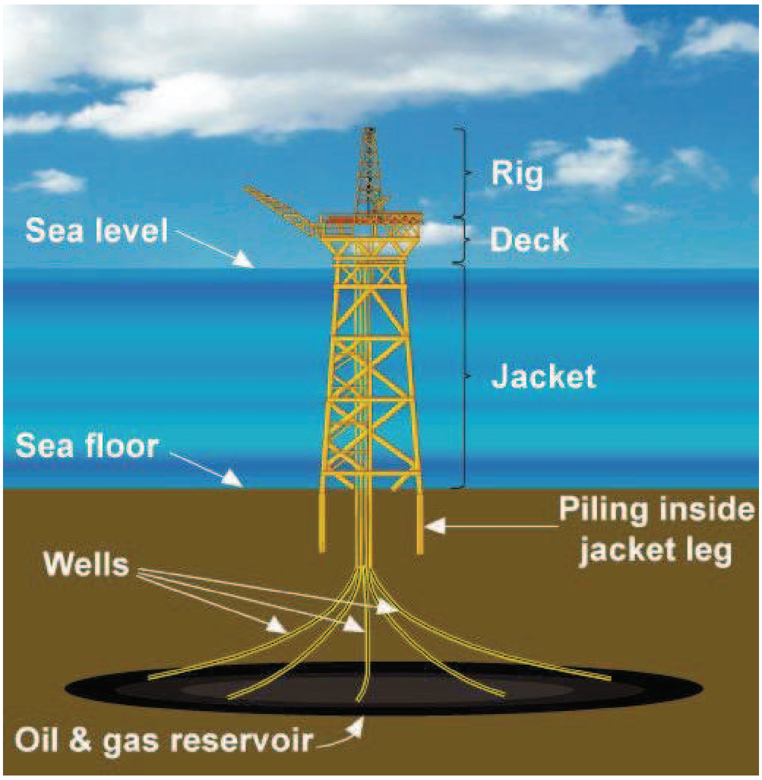

**Figure 1.4** - Scheme of an offshore platform (from http://www.conservation.ca.gov).

Within this category it is possible to distinguish:

- <u>Jacket structure</u> - The steel jacket on a pile foundation is by far the most common kind of offshore structures. It provides the rig's base and holds everything else out of the water, while the drilling modules and crew quarters are located on the surface deck. The steel lattice structure is constructed by tubular members and usually consists of 4 or 8 legs of large diameter, even though also structures with a lower number of legs (1 or 3) exist. The jacket legs are generally designed to diverge from the vertical by a few degrees so that the base of the structure is larger than its top, thus enabling it to transfer loads to the seabed more effectively. The legs are connected one to each other by a series of tubes welded both vertically and horizontally to form a three-dimensional frame structure and their diameters depend on the size and weight of surface facilities and on the depth of the seabed (Pallavicini, 2005).

○ Gravity based structure - Differently from the jackets, these structures do not need foundation piles or anchor, but they are usually placed on the seafloor and held in place by their weight (Figure 1.5) Generally the gravity structures are made of reinforced concrete and the topside is supported by four cylindrical columns of large diameter (Pallavicini, 2005).

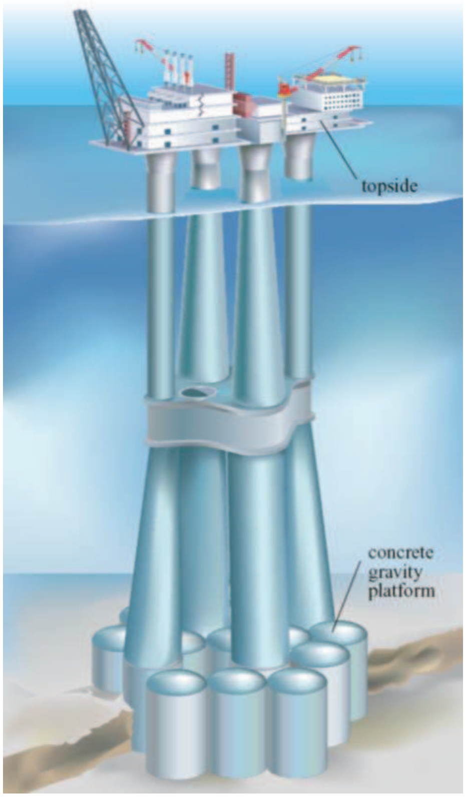

**Figure 1.5** - Gravity based structure (from Pallavicini, 2005).

○ Compliant tower - A compliant is similar to a jacket platform, with a steel framework support structure, but very narrow and with far lower rigidity, and thus with natural oscillation periods much higher than those of conventional rigid platforms, even higher than those of the most powerful waves (Pallavicini, 2005; Figure 1.3). In fact, this structure is designed to flex with the forces of waves, wind and currents. This is possible because its jacket has smaller dimensions than this of a fixed platform and may consists of two or more sections, with the lower part serving as the base for the upper jacket and surface facilities. They are anchored to the seabed and hold most of their equipment above the surface; in addition, they sway with the wind and water almost as if they were floating.

**Floating production systems** - These rigs are buoyant and semisubmersible, floating partly above the surface (Figure 1.3). In some cases wires and ropes are used to connect the rig with a stabilizing anchor, while in others it is "dynamically positioned", using computer-coordinated thrusters to keep it in place. These systems are used in deep water, from 200 to 2000 m depth, and have been widely used in the Gulf of Mexico (Von Aschwege *et al.,* 2007). This category includes the following type of floating structures:

- Semi-submersible - The semi-submersible structures are multi legged floating structures with a large deck interconnected at the sea bottom with horizontal buoyant members called pontoons.
- Tension-leg - These platforms consist of a floating surface structure (hull) with excellent stability, which is held in place by taut, vertical tendons connected to the seafloor (Figure 1.3). The hull is made of steel, and consists of four vertical columns of large diameter (about 20 m), stiffened by internal longitudinal and circumferential ribs. The columns, placed at each corner of the structure, are connected at the top to a structural platform, designed to support treatment facilities and occasionally drilling equipment (Pallavicini, 2005).
- Spar platform - This is a type of floating production system for deep waters. The hull consists of a cylindrical tower structure with diameter of about 25 m and 200-250 m high, which floats in a vertical position using a special arrangement of watertight compartments. The structure is in steel reinforced by circumferential ribs, and by transverse and radial bulkheads (Pallavicini, 2005).

**Subsea system** - A subsea drilling system includes a deep water production module that remains on the sea bottom as well as any transportation lines that channel the hydrocarbon to surface facilities (Figure 1.3). These facilities may be aboard a nearby platform rig, a ship floating overhead, a centralized production hub or even a faraway onshore site.

The offshore oil and gas industry plays a leading role in the marine field extraction activity exceeding 14 billion tons of oil equivalent (Pinder, 2001). For these reasons offshore rigs are among the largest artificial structures in the ocean (Friedlander *et al.,* 2014).

Starting from the late 1940s, when the first well was successfully completed in the Gulf of Mexico (Chakrabarti *et al*., 2005; Trabucco *et al*., 2012), this activity has significantly evolved over time, even if only starting from the 1970s the offshore industry really started booming. In the last decades the number of offshore platforms has increased, reaching more than 9000 platforms and related structures distributed worldwide in the oceans.

This number will likely increase over the coming years, due to the petroleum products demand (Macreadie *et al*., 2011) and to the raise of exploitation and research of not-renewable resources. In fact, even though steps are being taken to encourage the use of alternative renewable energy sources, there are strong financial incentives to search for marine oil and gas and to lease large marine areas for hydrocarbon operations (Kark *et al*., 2015). In addition, most of the undiscovered hydrocarbon reserves are located in deep-sea regions reaching 4000 m depth leading to advanced technological findings in the hydrocarbon industry to venture into new frontiers (Kark *et al*., 2015).

Today the majority of the existing structures (more than 65% of the total) are located along the American coast of the Gulf of Mexico, which represents the most highly exploited continental shelf regions in the world (Montagna *et al*., 2002), having more offshore platforms (about 4,500) than the rest of the world combined. The remainder is concentrated in the North Sea, Middle East, Africa, Australia, Asia and South America (Wilson III and Heath, 2008).

The North Sea has been exploited since the mid 1960s and it hosts more than 1000 oil and gas platforms located offshore all around the North Sea region (Figure 1.6), 600 of which are in the northern part of the basin (Olsgard and Gray, 1995; Jorgensen, 2012; Bergmark and Jorgensen, 2014) in the British and Norwegian sectors (Figure 1.7).

**Figure 1.6** - Location (in red) of the major offshore installations in European country (from www.betterworld-canaan.blogspot.com).

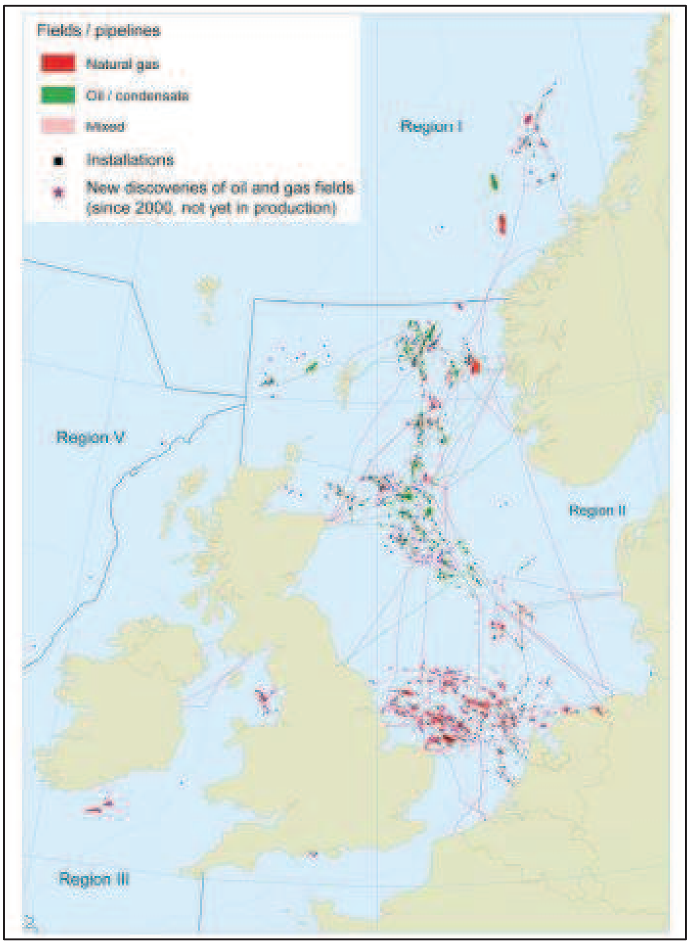

**Figure 1.7** - Offshore oil and gas installations and pipelines in the OSPAR Maritime Area in 2009 (from OSPAR Commission, 2009b).

About 0.4% of world reserves of oil and gas are placed in the Mediterranean basin (Pinder, 2001) and consequently this area will have greater expansion in offshore activities in the coming years (Maksound, 2004; Trabucco *et al*., 2012; Figure 1.8).

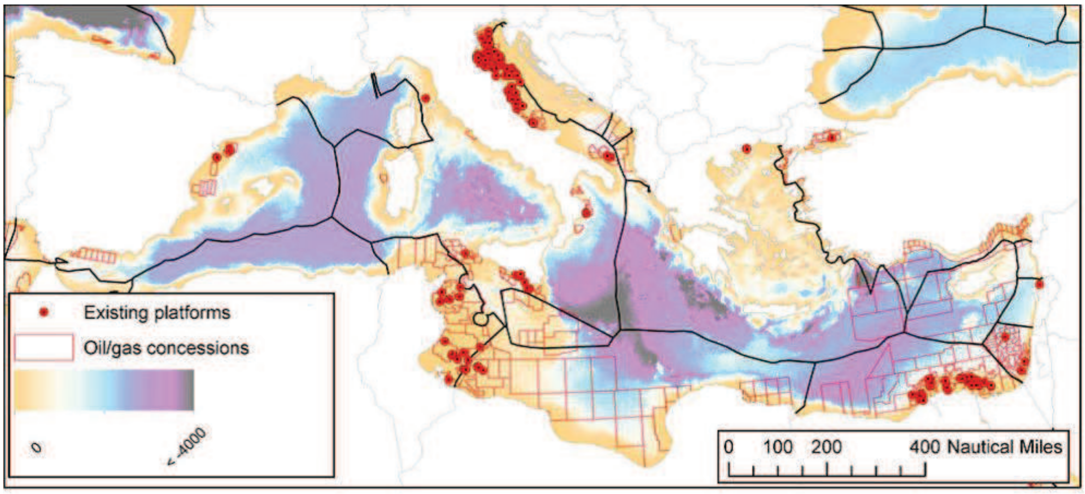

**Figure 1.8** – Location of concessions areas and existing drilling in the Mediterranean Sea (modified from Kark *et al*., 2015)

In addition, in the Mediterranean most countries have decided to grant new licenses for open oil exploitation throughout the whole Basin (Consoli *et al*., 2013). Within the Mediterranean basin, the Italian production of natural gas is one of the largest in the EU (Manoukian *et al*., 2010). In the Italian Seas about 136 platforms and similar structures are actually installed (Ministry Economic Development, DGMRE – Italy; updated 22/12/2014). The majority of these structures (about 88%) is used to extract gas, while only 16 platforms are used for oil extraction, most of them located in the Ionian Sea and Sicily channel. Almost half of the Mediterranean production is provided from offshore reserves located in the Adriatic continental shelf (OGP, 2005). In fact, Adriatic Sea (GSAs 17 and 18; Figure 1.9) hosts numerous oil- and gas-related infrastructures and a dense network of pipelines. The exploitation of gas fields in the Adriatic Sea began in the 1960s and more than 110 offshore gas platforms, representing nearly 90% of the structures located in the Italian Seas (Ministry Economic Development, DGMRE – Italy; updated 22/12/2014; Annex 1.1), have been deployed in this basin since then (Maggi *et al*., 2007; Gorbi *et al*., 2008). The almost totality of these structures are located in the Italian part, while until now Croatia has never exploited its reserves, if not marginally, since that development and production from the gas reservoirs in the Croatian part started regularly only in 1996 (Malvic *et al.,* 2011). However, an intensive program of drilling operations has been recently approved; therefore, it is likely to assume that the number of platforms in the Adriatic Sea is rapidly increasing.

In this basin the positive effects of offshore platform on the marine environment have been recognized through the Ministry Decree of the 16/03/2004, which established the “Zona di Tutela Biologica - ZTB” (Biological Protected Zone) “Barbare”, identified by the following coordinates:

a) lat. 44° 00'00 N - long. 13° 38'50 E
b) lat. 44° 00'00 N - long. 13° 50'00 E
c) lat. 44° 07'00 N - long. 13° 50'00 E
d) lat. 44° 07'00 N - long. 13° 43'00 E

This area of the Adriatic Sea is characterized by a high density of gas platforms (namely Barbara A, B, C, D, E, F, G, H, T, T2, NW) positioned at about 35 nautical miles from the coast, at a depth of about 70 m.

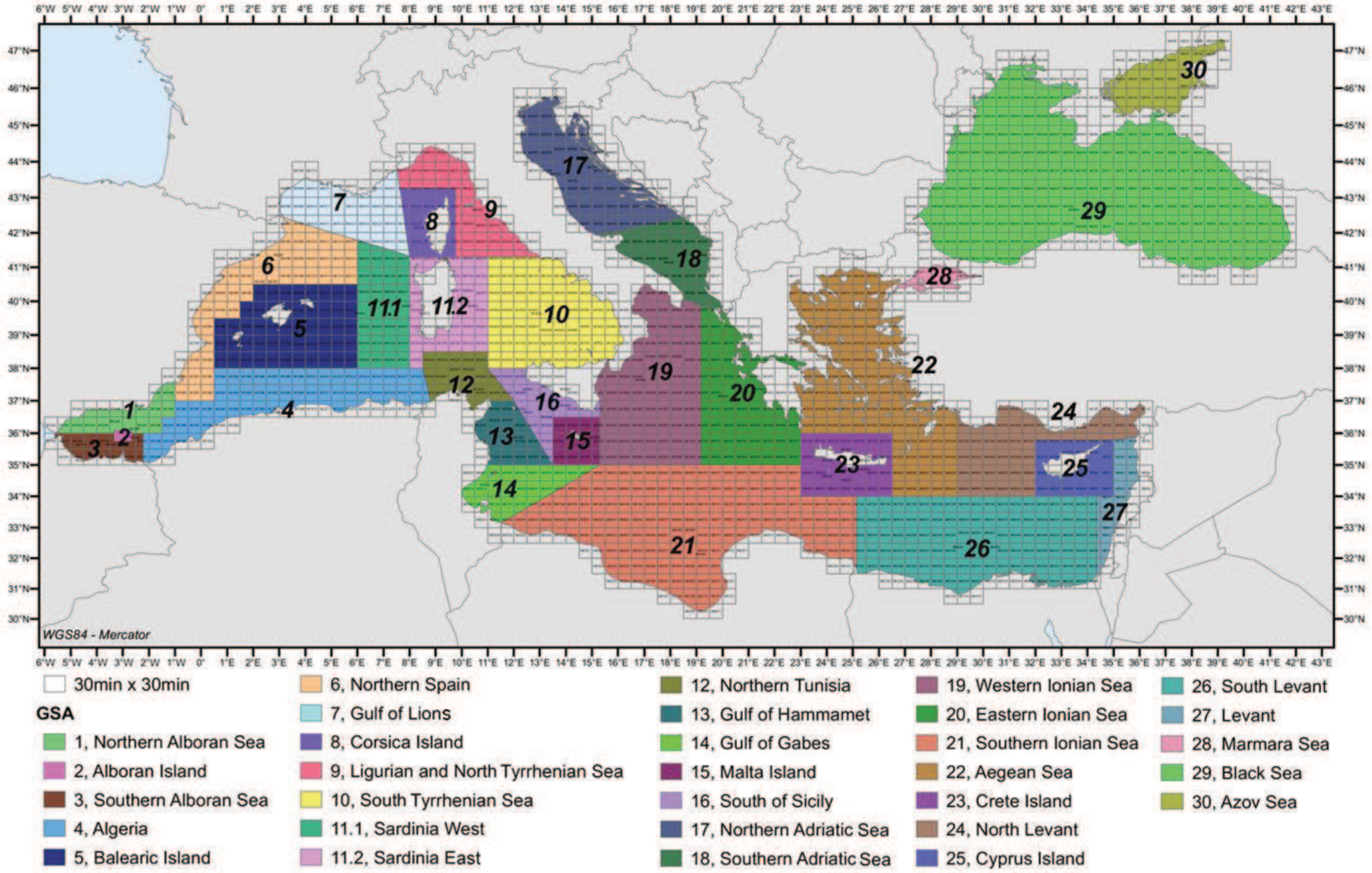

**Figure 1.9 -** Mediterranean and Black Sea Geographical Sub-Areas (GSAs; from www.gfcmonline.org/maps/statisticalgrid).

## 1.4. EFFECTS OF GAS PLATFORMS IN THE ENVIRONMENT

Offshore oil and gas platforms are very heavy and are among the largest and the tallest artificial structures in the marine environment (Page *et al.,* 2006; Sadeghi, 2007). Oil and gas exploration and correlated production operations have the potential for a variety of impacts on the environment depending upon the stage of the process, the nature and sensitivity of the surrounding environment, and pollution prevention, mitigation and control techniques (Elbisy, 2015). The environmental threats posed by offshore oil and natural gas operations draw much public and media attention, and this is well evident after an oil spill (Kark *et al*., 2015). These threats, however, represent just a portion of the environmental risks and impacts associated with these structures. In fact, environmental impact concerns may arise from pressures associated with all stages of oil and gas activities, including initial exploration, production and final decommissioning.

For instance, in the aquatic environment the main pressures include the placement of installations on the seabed, and operational and accidental discharges of drilling fluids, cuttings and produced waters (Manfra and Maggi, 2012; Elbisy, 2015). Even if these structures have been introduced in the marine environment with a different primary purpose, i.e. oil or gas extraction platforms, their architectural complexity and extension along the entire water column let them having relevant ecological effects, which can strongly influence the surrounding environment and communities. Offshore platforms are indeed multifaceted structures, involving numerous crossbeams and large interstitial spaces, which increase overall habitat complexity (Friedlander *et al.,* 2014). Moreover, the legs of platforms, occupying the entire water column, can often act as artificial reefs on continental shelves supporting a hard-bottom fouling community of algae and invertebrates and a pelagic community of herbivorous and carnivorous fish (Page *et al*., 1999; Stanley and Wilson, 2000; Montagna and Kennicutt, 2002; Fabi *et al*., 2004; Scarcella *et al*., 2011a; 2011b). Finally, since extractive platforms are mostly located far from human disturbance, they can represent an observation network for the assessment of biodiversity changes (Consoli *et al.,* 2013).

The main effects induced by these structures are summarized in the following chapters.

### 1.4.1. EFFECTS ON THE WATER COLUMN

The installation and operational of offshore platforms can negatively affect the surrounding environment and more likely the water column. The main impacts affecting the water column arise from the discharges of produced water and accidental spills of oil and chemicals (OSPAR Commission, 2009b). In fact, waste fluids and cuttings generated by drilling operations could cause strong environmental impacts related to drilling mud discharges or hydrocarbon associated waters (Terlizzi *et al*., 2008).

To supervise the effects of petroleum and other waste discharges on marine water quality, the metals and hydrocarbons concentrations in mussel and/or in fish might be taken constantly under control. In North Sea, for example, the effects of waste fluids produced by offshore platforms, which are considered as a priority in the recent years, have been investigated through the study of biological effects in field transplanted mussels and/or fish at known distances from the discharge outlet from an offshore platform. These investigations generally found, within a limited distance from the platform (approximately from 500 to 1000 m), elevated concentrations of chemical bioaccumulation combined with some low level of health effects/biomarker responses (Brooks *et al.*, 2013).

### 1.4.2. EFFECTS ON THE SEA BOTTOM

The installation of a platform may cause a physical impact on the seabed that varies on a case by case basis depending on the particular sensitivities associated in the area. Physical impacts on the sea bottom may occur in connection with deployment of pipelines, cables, bottom rigs, templates, skids, and platforms including platform legs and anchoring (Manfra and Maggi, 2012).

Beyond the direct influence on the communities inhabiting an area, the physical structure of the new substrate may determine some alterations on the environment: changes in local water flows, variations in erosion or sedimentation rate, modification in bottom morphology, variation in grain size and organic content in sediments (Manfra and Maggi, 2012).

The local increase of the current and wave motions cause a fast flow of water that stirs sand particles, picks them up and transports them away from the structure, creating a hole around the structure, in a phenomenon usually called *scour* (Van der Tempel *et al.,* 2004). Usually, around more complex structures with several legs, such as offshore platforms, beyond the local scour around each separate leg it is possible to distinguish also the lowering of a large area surrounding the entire structure (Figure 1.10). This type of scour is called global scour or dishpan scour (Van der Tempel *et al.,* 2004).

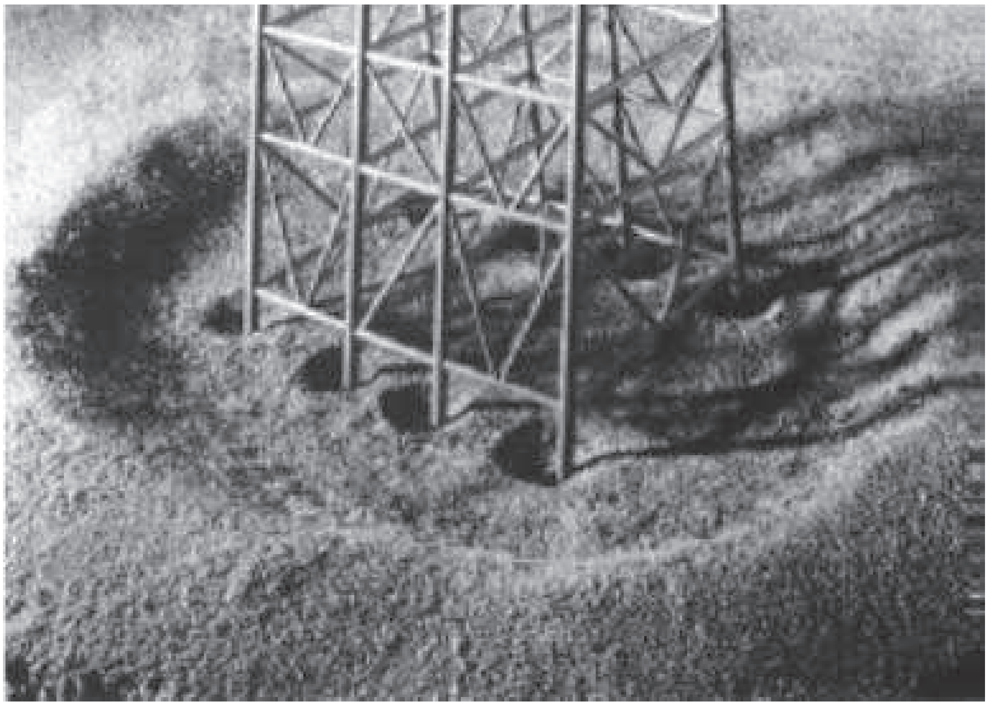

**Figure 1.10** - Local and global scour around a jacket structure (from Van der Tempel *et al.,* 2004).

In addition, offshore platforms may produce seabed disturbance and mobilization of sediment. The volume and distance that suspended sediments disperse depends on particle size, weight and current velocity. However, it is possible that the positioning of the structure results in a temporary increase in turbidity due to the material raised from the bottom (OSPAR Commission, 2009b; Manfra and Maggi, 2012).

Moreover, changes in wave exposure and water circulation due to a new barrier are expected to directly and/or indirectly affect fish assemblage through their effect on benthic cover, particularly for species living in strictly contact with the substratum (Fulton and Bellwood, 2004; Santin and Willis, 2007; Cenci *et al.,* 2011).

Finally, the use of antifouling paints and corrosion protection systems (anodes) containing heavy metals (*e.g*., Zn, Al and Cd) can lead to contamination phenomena in water, sediment and biota (Manfra and Maggi, 2012).

### 1.4.3. EFFECTS ON MACROZOOBENTHIC COMMUNITIES

The installation of new hard structures, including platforms, into the environment generate the potential for the foundations to act as artificial reefs, thereby creating new habitat and giving an opportunity for new benthic species to colonize the former sandy/mudflat areas.

In fact, pipelines, platform legs and subsea templates may provide a habitat for benthic organisms usually associated with hard substrate (OSPAR Commission, 2009b). These new pockets of habitat can then act as stepping stones for colonization, allowing the spread of both existing and new species across the area (Wilson *et al.,* 2010).

Geographical position likely plays an important role in the timing of the effects on benthic communities. In areas of soft sediments, where most pipelines are trenched and buried, the organisms re-colonize within one or two years, while in areas of harder substrates the recovery of benthic communities may take longer, up to 10 years in deeper colder water areas (OSPAR Commission, 2009b).

Physical structure of oil and gas platforms may cause biotic modifications, affecting the benthic community composition and the responses of organisms exposed to eventual contaminations linked to installation phase (Manfra and Maggi, 2012). For these reasons, it is considered counter-intuitive that the oil industry might represent a positive force for conservation of epifauna (Hall, 2001).

The first studies on the impact of oil-related activities on the macrobenthic communities (Addy *et al*., 1984; Davies *et al.,* 1984; Kingston, 1992) carried out in the North Sea highlighted a disturbance localized close to the platform site, with a reduction in macrofauna up to 200 m away from the platform, a peak in opportunistic species from 500 to 1000 m away and subtle effects detectable up to 2 km from the center of the disturbance activity (Hernández Arana *et al.,* 2005). Afterwards, similar studies detected effects on macrofauna assemblages up to 6 km from platforms, suggesting that the local approach to studying oil-related disturbances was no longer suitable (Gray *et al*., 1990; Olsgard and Gray, 1995). In contrast, long-term studies performed in the northern Gulf of Mexico evidenced chronic effects up to 200 m from source of impact (Montagna and Harper, 1996) and up to 800 m from produced water discharge sites (Rabalais *et al.,* 1992). In this area, the presence of a wide zone of offshore oil production potentially contributes to changes in the structure of benthic communities (Vazquez *et al.,* 2000).

Manoukian *et al.* (2010) found two main typologies of effects caused by the installation of 2 gas platforms on soft-bottom benthic communities in Adriatic Sea: 1) a short-term and localized effect, consisting in the defaunation that could be attributed to the drilling operations and installation phase followed by 2) a longer-term effect due to the physical presence of the structure starting after two years from installation and consisting of a mussel mounds development and subsequent macrofauna diversification strictly close to the platform.

Finally, in the Ionian Sea Terlizzi *et al.* (2008) evidenced changes in macrobenthic assemblages with increasing distance from the point of impact only for the deeper platforms. In fact, no significant variations were detected for the platforms located in shallow water. Such findings suggest that deeper water platforms could potentially affect surrounding benthic assemblages at a greater spatial extent than those located in shallow water. This result contrasts with other studies (Ellis *et al*., 1996; Burns *et al.,* 1999), which suggested that platforms might affect adjacent assemblage’s structure more strongly at lower depth since, in deeper water, higher environmental stability and greater potential of dilution and dispersion of pollutants could mitigate their potential impact.

### 1.4.4. EFFECTS ON FOULING COMMUNITIES

Any hard substratum placed in the sea for any time is expected to be colonized by epifauna (Hall, 2001), especially in eutrophic areas, such as the Adriatic Sea. For these reasons, platform structures and related submerged pipelines are known to host extensive fouling communities (Stachowitsch *et al.,* 2002), mainly represented by mussels (Spagnolo *et al.,* 2002; Fabi *et al*., 2005; Spagnolo *et al*., 2006; Trabucco *et al*., 2006; Fabi *et al.,* 2007; Trabucco *et al*., 2008; Spagnolo *et al*., 2009; Manoukian *et al.,* 2010; Gomiero *et al*., 2011), barnacles and bryozoans, but also the deep oyster *Neopycnodonte cochlear* and the deep water coral *Lophelia pertusa* were reported respectively in the Adriatic Sea (unpublished data) and in the North Sea (Bergmark and Jorgensen, 2014).

The complex three-dimensional structures created by the fouling organisms provide a habitat for a highly diverse fauna: mobile species (such as polychaetes, amphipods, tanaidaceans, and isopods) use the living mussels as a food source and the shells of dead specimens as shelter (Kneib and Weeks, 1990; Warburg and Schwartz, 1993), while sessile species settle on the mussel shells utilizing them as substrate (Manoukian *et al*., 2010).

Moreover, bivalves falling from the platform legs form mounds on the seafloor (Figure 1.11), creating a suitable habitat for mobile and sessile invertebrates ecologically linked to hard substrates and leading to an enrichment of the community (Wolfson *et al*., 1979; Thayer *et al*., 1997; Page *et al*., 1999; Bomkamp *et al*., 2004). The shell mound provides hard attachment sites, microhabitats, and food for an assemblage of invertebrate species typically not present on soft bottom (Page *et al*., 1999).

This scenario is common in the northern and central Adriatic Sea, when the formation of mussel mounds and the subsequent enrichment of the benthic community and development of alternative trophic chains are usually found one year from rig construction (Frascari *et al*., 1991; 1992; Spagnolo *et al.,* 2002; Fabi *et al*., 2005; Spagnolo *et al*., 2006; Trabucco *et al*., 2006; Fabi *et al.,* 2007; Trabucco *et al*., 2008; Spagnolo *et al*., 2009; Manoukian *et al.,* 2010; Gomiero *et al*., 2011). Similar findings have been also reported in southern California (Wolfson *et al*., 1979; Love *et al*., 1999; Page *et al*., 1999), where the phenomenon of shell mound formation has been documented at most offshore oil platforms (MEC, 2003; Bomkamp *et al*., 2004), in the southern Arabian Gulf (Stachowitsch *et al*., 2002), and in the south-eastern Australia (Currie and Isaacs, 2005). For example, Wolfson *et al.* (1979) stated unusually high densities of echinoderms (*e.g*., *Pisaster* spp., *Patiria miniata*) feeding on mussels displaced from a structure located in California.

Although oil exploration and production might be a threat to these rich communities, the extent of the risk and the mechanisms of impact remain uncertain.

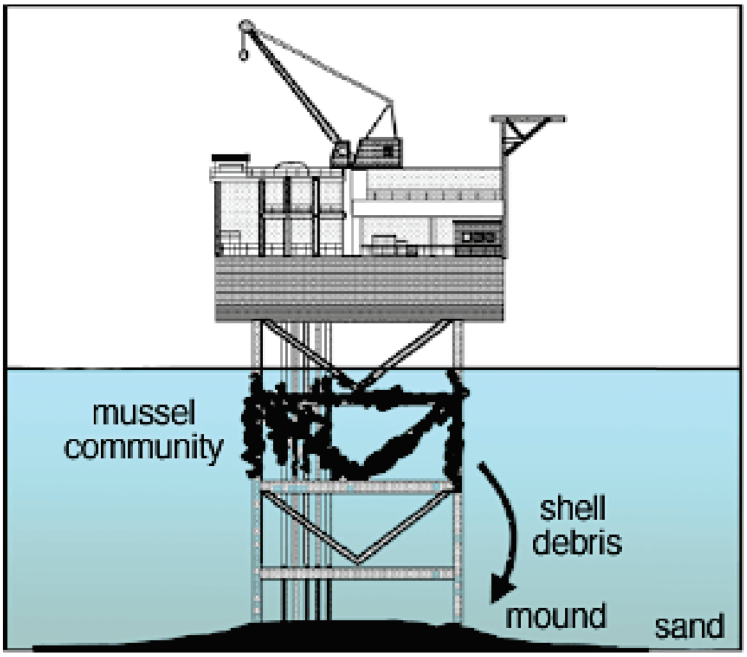

**Figure 1.11** - Schematic illustration of the mussel mounds and other organisms from the structure of an offshore platform (from Bomkamp *et al*., 2004).

### 1.4.5. PLATFORMS AS VECTOR OF BIOFOULING-MEDIATED INVASIONS

As anticipated before (see Chapter 1.4.4), fouling on oil platforms include both sessile and vagile species; it comprehends species typically found on shallow natural reefs and pier pilings (*e.g*., mussels, barnacles, anemones) as well as other species that are relatively rare in the nearshore environment (Page *et al.,* 2006).

Only in the last decade, oil platforms have been considered as important vectors of biofouling-mediated invasions in the marine realm, resulting in a great abundance and diversity of non-indigenous species on platforms (Ferreira *et al.,* 2006; Yeo *et al.,* 2010). For example, Page *et al.* (2006) found three exotic species on oil platforms in California.

In fact, with more than 900 floating oil platforms in service worldwide, most of them represented by jack-up drilling rigs and floating production storage offloading systems, the potential threat is larger than might be expected and cannot be ignored (Yeo *et al.,* 2010).

Offshore oil and gas platforms could facilitate species range expansions and/or the introduction of exotic species into new geographic areas acting as 'stepping stones' of vertical relief and hard substrate habitat across a soft seafloor environment (Gallaway and Lewbel, 1982).

The presence of exotic species on offshore platforms might have several implications. One of these could be in assessing the 'habitat value' of offshore structures and the degree to which they provide the ecological services (*e.g*., biodiversity, habitat, food chain support) of natural inshore reefs. In fact, a high density of an exotic species may reduce the abundance of native species. On the other hand, some exotic species (*e.g*., caprellid amphipods) represent an important prey item in the diet of several reef fishes, thus, their high densities may benefit some fish populations. In addition, the presence of exotic species has implications for platform 'decommissioning' with consequences for policy decisions concerning the fate of these (Page *et al*., 2006).

### 1.4.6. PLATFORMS AS FISHING AGGREGATING DEVICES (FADS)

Pelagic fishes appear to be attracted to artificial structures mostly when the structure extends a considerable distance above the bottom or even reach the surface (Franks, 2000) as oil and gas platforms. For these reasons these structures work as "aggregation points" for large number of fish and their effects are not only confined to benthic and demersal fish but also extend to pelagic fish, functioning as FADs (Franks, 2000). FADs are anchored or drifting objects designated to create artificial habitats and usually float at or near the surface or are suspended in midwater (Figure 1.12). The offshore artificial structure, in fact, can act purely as FADs providing behavioral cues that exploit the thigmotactic tendency of fish species, namely the tendency of fish to move towards structured rather than bare, featureless habitat (Brickhill *et al*., 2005).

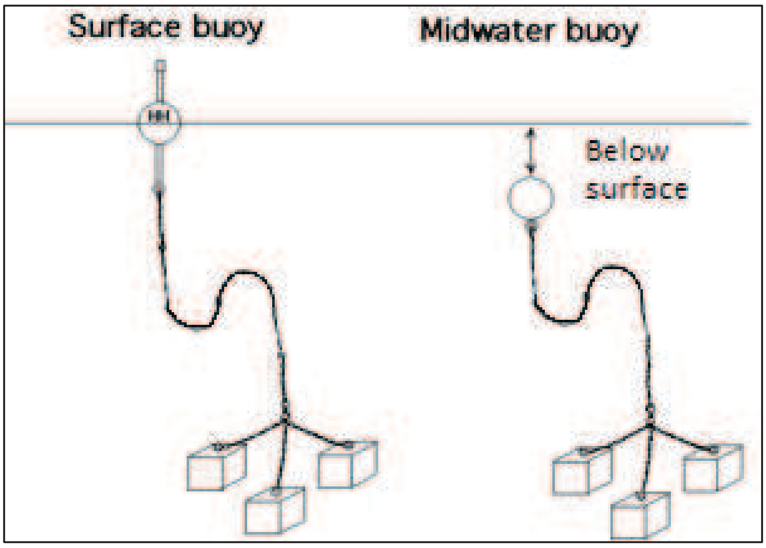

**Figure 1.12** – Different types of FADs (modified from http://www.hawaii.edu/HIMB/FADS/FADFAQ.html).

It has been proposed that North Gulf of Mexico petroleum platforms and FADs may function comparably in their attraction of pelagic fishes, and that platforms provide unique opportunities to study the natural history and behavior of pelagic species (U.S. Minerals Management Service, 1986).

FADs have been shown to attract a wide variety of pelagic species of commercial and recreational fishing importance, such as tuna, marlin, shark, and mackerel, and their use has become the dominant practice in tropical tuna purse seine fishing (Davies *et al*., 2014).

Even though the specific reasons for the attraction of fishes to floating objects are not completely understood, food availability, shelter from predators, spawning substrate, orientation and shadow seem to be the most important factors. In fact, it has been proved that fish move away from direct sunlight (negative phototaxis) in response to the shadow cast by the object and that the shadow associated with the floating object makes local populations of zooplankton more visible to predators (Armstrong and Oliver, 1996). In addition floating objects may provide spatial orientation in the optical void of the pelagic environment and function as schooling companions for pelagic fish species, as suggested by Hunter and Mitchell (1967).

### 1.4.7. EFFECTS ON FISH ASSEMBLAGES

Offshore platforms may enhance fish assemblages inducing a redistribution of the resources and providing suitable conditions for increase of biomass as established by several studies (Hastings *et al.,* 1976; Gallaway *et al.,* 1981; Gerlotto *et al.,* 1989; Stanley and Wilson, 1990; 1991; Scarborough-Bull and Kendall, 1994; Stanley and Wilson, 1996; 1997; 1998; Love *et al.,* 1999; Page *et al.,* 1999; Love *et al.,* 2000; Jørgensen *et al.,* 2002; Løkkeborg *et al.,* 2002). In fact, due to their extension along the entire water column, these structures are effective in aggregating either benthic, demersal and pelagic organisms (Hastings *et al*., 1976; Stanley and Wilson, 1991; Scarborough-Bull and Kendall, 1994; Stanley and Wilson, 1998), providing additional food opportunities and supporting considerable amounts of fish of great importance for recreational and commercial fisheries (Fabi *et al.,* 2002; 2004; Consoli *et al*., 2007; Andaloro *et al*., 2011; Scarcella *et al*., 2011b; Consoli *et al.,* 2013; Friedlander *et al.,* 2014).

It has been stated that small pelagic fish usually stay from near the surface to mid-depth within or up-current from the platforms, while large predatory pelagic species are reported to swim from the surface to mid-depth around the platforms, rarely venturing within them (Hastings *et al*., 1976; Gallaway *et al*., 1981; Stanley and Wilson, 1990; Scarborough-Bull and Kendall, 1994). Nevertheless, some Authors focused on the fact that the big amount of juveniles around the platforms could attract predators, hence reducing survival rates of some species (Love *et al*., 2000). In addition, fish abundance and species composition close to the platforms can change radically in relation with location (*e.g*., bottom type, depth) and time of deployment (Sonnier *et al*., 1976; Putt, 1982; Gerlotto *et al*., 1989; Stanley and Wilson, 1996, 1997; Løkkeborg *et al*., 2002). For example, several studies conducted in the Adriatic Sea pointed out diverse fish species composition and densities at gas platforms placed at different depths, higher abundances at the rigs in respect to the natural sandy-mud habitat and temporal changes of the rig fish assemblages (Fabi *et al*., 2002; 2004; Scarcella *et al*., 2011b).

Annual tracking observations revealed that strong year classes of rockfish may live their entire benthic lives around a single platform, while a pilot study evidenced that young-of-the-year rockfish grew faster at a platform than at a natural outcrop indicating that juvenile fishes at platforms are at least as healthy as those around natural outcrops (Love *et al.,* 2003).

In addition, these structures may provide a spawning substrate suitable for the eggs settlement of several species and may act as shelter from predation for juveniles and spawners (OSPAR Commission, 2009b; Scarcella *et al*., 2011a).

Love *et al.* (2003) demonstrated that many of the rockfishes living at the platform bottom, such as cowcod, bocaccio, flag, greenspotted, and greenblotched rockfishes, dwell in the crevices formed by the bottom-most crossbeam and the seafloor. It is likely that these fishes are resident to the shell mound habitat, together with other benthic species.

Finally, platforms reduce fishing mortality by protecting nearby seabed substrates from bottom and pelagic trawling. In addition, because many of the platforms are largely unfished they have been considered as de facto Marine Protected Areas (Friedlander *et al.,* 2014).

### 1.4.8. EFFECTS ON SEABIRDS

Seabirds are attracted to offshore structures, such as hydrocarbon drilling and production platforms (Wiese *et al.,* 2001; Poot *et al.*, 2008), due to several factors, such as structural stimuli, food concentrations, oceanographic process and lights and flares. In fact, it is known that the lights attract birds and these might cause some mortality in migratory species. The level of impact depends on the location of the platform, the season and the prevailing weather conditions at the time with birds being most frequently attracted during the autumn migration and periods of poor weather (OSPAR Commission, 2009b). Until now this issue has received relatively little attention. Many nocturnally migrating birds die or lose a large amount of their energy reserves during migration as a result of encountering artificial light sources. For example, in the North Sea large amounts of nocturnally migrating birds are attracted to the many offshore platforms (Figure 1.13; Poot et al., 2008).

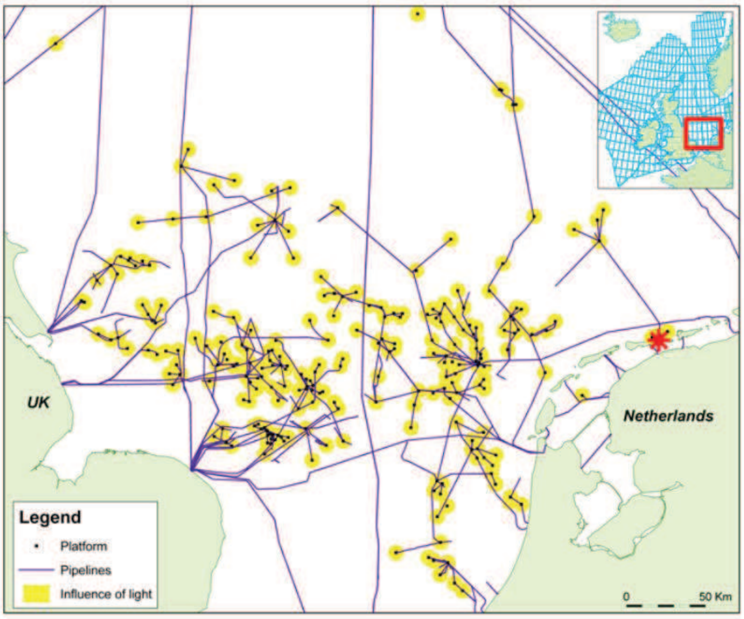

**Figure 1.13** - Map of the southern part of North Sea with existing production platforms in 2007. For each platform, the potential impact zone of 5 km is indicated in yellow (from Poot *et al.*, 2008).

Some experiments carried out manipulating the lighting of a gas-production platform situated 70 km offshore of the Dutch coast highlighted that the artificial lightings attract the birds. In fact, when the lights were switched on, the number of birds on and around the platform quickly increased, while when the lights were switched off, the birds rapidly dispersed from the platform (Poot *et al.,* 2008).

The study strongly evidenced that changing the color (spectral composition) of artificial lights for man-made structures will significantly decrease the number of casualties among nocturnally migrating birds (Poot *et al.,* 2008). In fact, the main conclusion was that birds do respond significantly differently under field conditions to various colors of artificial light, i.e. birds are only disoriented under specific wavelength conditions (Poot *et al.,* 2008). In particular, birds react strongest to white and red light (long wavelength), little to green one (shorter wavelength), while blue light (short wavelength) hardly causes any observable effect on the birds' orientation.

### 1.4.9. EFFECTS ON MARINE MAMMALS

Another important issue to be considered is represented by the fact that many human activities at sea, such as marine dredging construction, drilling and hydrocarbon production, often emit underwater noise, that seems to have some short-term effect on cetacean behavior (Richardson and Würsig, 1997). In particular, one of the major source of underwater anthropogenic noise is caused by seismic operations that are used in offshore exploration for fossil fuel reserves. They involve the use of a noise source, usually an array of air guns, being towed behind a ship and fired at regular intervals producing a high intensity, low frequency noise (20–500 Hz; Fewtrell and McCauley, 2012). This underwater noise can lead to stress, evasive and stranding behavior in marine mammals, but also in turtles, fish and cephalopods (Fewtrell and McCauley, 2012).

Latest studies focused on the use of bubble curtains for noise reduction suggesting that this is a recognized noise reduction/shielding method and that its effectiveness is dependent on bubble size and water depth in addition to water temperature, density and salinity (Kuo and Fulton, 2013).

### 1.4.10. EFFECTS ON AIR QUALITY

Air emissions, including $CO_2$, CO, $NO_x$, $SO_2$, hydrocarbons and particulates, can contribute to local air pollution and greenhouse gases.

Direct effects on air quality are the results of catastrophic events and operational emissions, such as well blowouts with fire, gas well blowouts without fire, venting hydrogen sulfide laden gas, or major oil spills. Air emissions from these events are of a short-term non-routine nature (U.S. Minerals Management Service, 1986).

In particular, during the construction phases, the potential impacts on air quality may result from fuel burning on construction vessel, power generators and helicopters, while during the platform operation phase, the main sources include venting during maintenance operations and the resulting dusts and purging gases, losses from gas processing equipment and maintenance vessels and helicopter flights (Elbisy, 2015).

However, these effects are considered to be minor, as the elevated levels of pollutants will be short term, transient and rapidly dispersed.

### 1.4.11. DECOMMISSIONING ISSUES

Oil and gas platforms are not intended to be permanent. In fact, they have finite economic lives and, when the production ceases, managers must decide what to do with the structure, a process known as decommissioning (Love *et al*., 2003).

More than 7,500 oil and gas platforms will need to be decommissioned in the next few decades around the world, being near the end of their lives, including in the North Sea and the Mediterranean Sea (Love *et al*., 2003; MacReadie *et al.*, 2011; Claisse *et al.,* 2015). In fact, forecasts suggested that in the period 2013-2020 an average of 38 platforms per year will be removed in Europe (Scottish Enterprise, 2013; Figures 1.14 and 1.15), with the majority of activity in the Italian part of the Adriatic Sea, where existing infrastructure consists of old and relatively easy to remove piled assets, such as Porto Corsini, Porto Garibaldi, San Giorgio Mare and Cervia Mare (Annex 1.1).

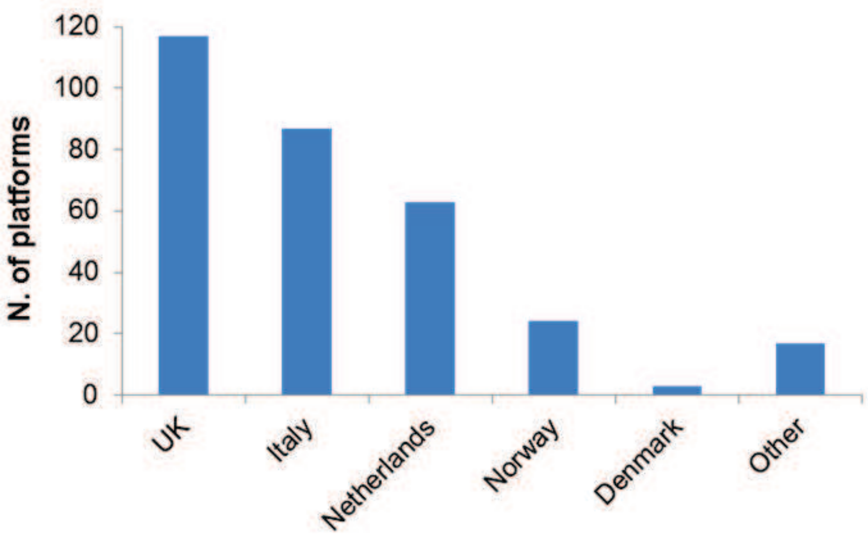

**Figure 1.14** - Platform removals by country in Europe in the period 2013-2020 (data from Scottish Enterprise, 2013).

For all the above mentioned effects of these structures on the marine environment, the decommissioning process is becoming a primary issue for the environmental management of drilling and production activities. For example, in the Gulf of Mexico, due to the presence of coral at some platforms, it has been proposed that 10-20% of the overall number may be qualified for preservation and environmental purpose (Bortone*,* 2014) rather than remove them.

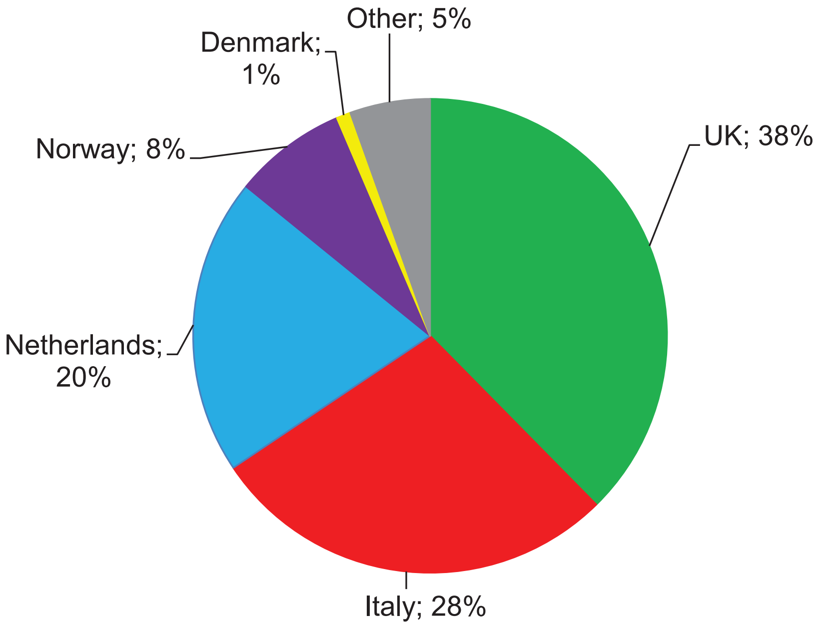

**Figure 1.15** - Europe platform decommissioning forecasted by country in the period 2013-2020 (data from Scottish Enterprise, 2013).

Central to this topic become the cost and the question of who holds the liability (Bernstein *et al.,* 2010). The history of decommissioning goes back as far as the 1960s. Since that time, many advances have been made and the conversion of decommissioned offshore rigs into artificial reefs has been proposed and developed by the former Minerals Management Service in the so called "rigs-to-reefs program" (MacReadie *et al.*, 2011). Rigs-to-reefs (RTR) could be defined as the conversion of obsolete offshore oil and gas platforms into artificial reefs, a common practice in the United States (Gulf of Mexico), Brunei and Malaysia. On the contrary, despite scientific findings of the potential value of rigs-to-reefs in the North Sea, OSPAR Commission, which has jurisdiction over North Sea oil development, has blocked RTR program (Jorgensen, 2012). In the Adriatic Sea the only case study of RTR is represented by the "Paguro" platform, a gas platform that in 1965, following an explosion, sank into the sea in front of Ravenna, 12 miles offshore the coast. In 1995, a Government Decree recognized the area as a ‘Biologically Protected Area’, and the ‘Paguro’ association has had permission to carry out guided tours and scuba diving since 1996.

There are three primary international conventions that apply to the removal of offshore installations (Scottish Enterprise, 2013), including:

- the Geneva Convention on the Continental Shelf, signed on 1958, which states that any installations which are abandoned or disused must be entirely removed;
- the London Dumping Convention (1972);
- the United Nations Convention on the Law of the Sea, the international agreement that resulted from the third United Nations Conference on the Law of the Sea (UNCLOS III), which took place between 1973 and 1982.

In addition, in 1989 the IMO Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone were also drafted by the International Maritime Organization (IMO).

The international obligation to decommissioning is also regulated by OSPAR, which in general prohibits sea dumping of decommissioned structures, allowing for derogation of platforms and jackets weighting more than 10,000 tons.

Decisions about when and how a structure is decommissioned involve issues of environmental protection, safety, cost, and strategic opportunity (Kaiser, 2006).
Platforms usually consist of two parts for decommissioning purposes:

- the topside (the structure visible above the waterline);
- the substructure (the parts between the surface and the seabed, or mudline).

In most cases the topsides, that contain the operational components, are taken to shore for recycling or re-use. The substructure is generally severed about 5 m below the mudline, then removed and brought to shore to sell as scrap for recycling or refurbished for installation in another location.

The decommissioning process can be addressed in many ways, ranging from complete or partial removal, toppling, and leave-in-place (Love *et al.,* 2003; Schroeder and Love, 2004; Figure 1.16), that have been also used in the RTR process, each of them with pro and cons.

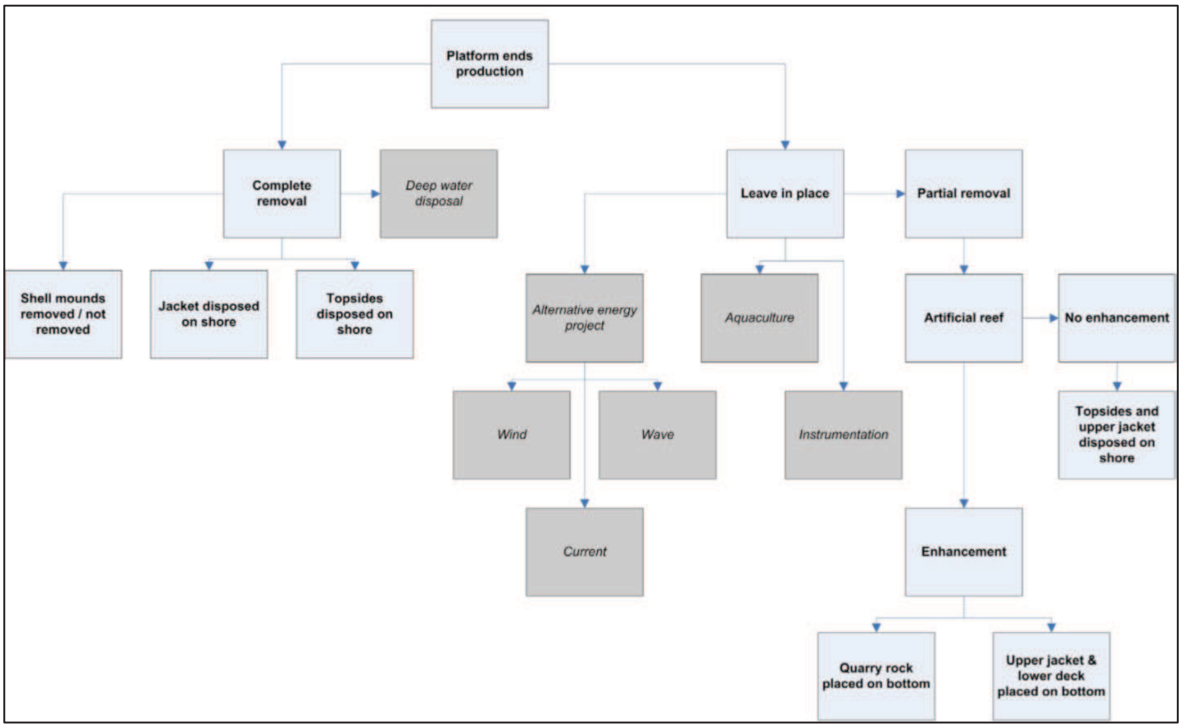

**Figure 1.16** – Overview of decommissioning options (modified from Bernstein *et al*., 2010).

1. <u>Complete Removal or Tow-and-Place</u> – the platform is moved to shore for recycling, reuse, or disposal or it can be towed to another site and reefed (Figure 1.17).

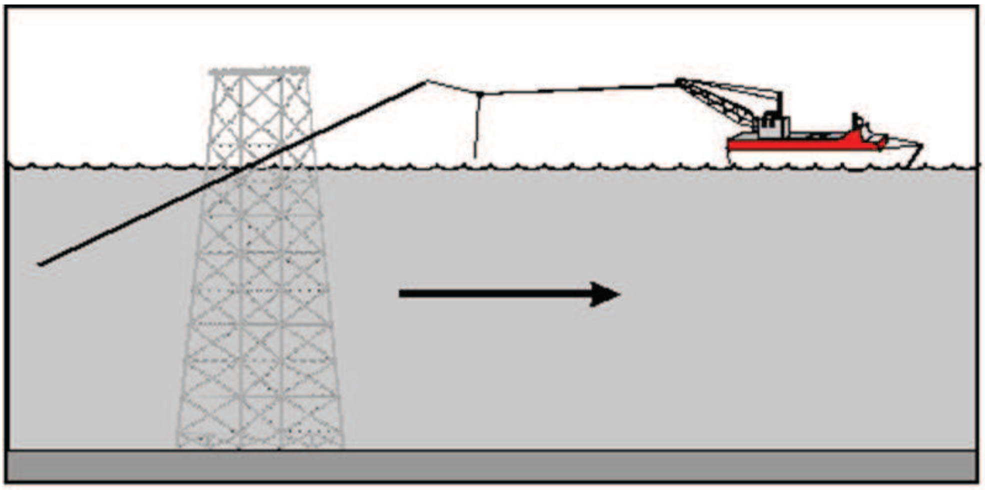

**Figure 1.17 -** Method of rig-to-reef conversion by "tow and place" (from Les Dauterive, 2000).

In the first hypothesis the operations will cause the complete death of all the attached invertebrates. On the contrary, if the platform structure is hauled to a reef area and replaced in the water, some of these animals may survive, depending on water depth and on the time at which the structure is exposed to the air. In addition, the explosives used to separate the conductor and jacket from the seafloor cause the death of many fish (Love *et al.,* 2003).

2. Partial Removal and Toppling – In both situations the topsides are removed. In partial removal (Figure 1.18) the top portion of the submerged platform is severed to a predetermined depth below the sea surface and the remaining structure is left standing, while in toppling (Figure1.19) the base of the structure is severed through explosives in a matter such that it simply falls over. In the U.S. the partial removal option involves removal of the platform structure to 26 m below the water line to maximize safe navigation, reduce the risk of ship strikes and minimize the need for surface buoys or other markings (Bernstein *et al.,* 2010; Claisse *et al*., 2015).

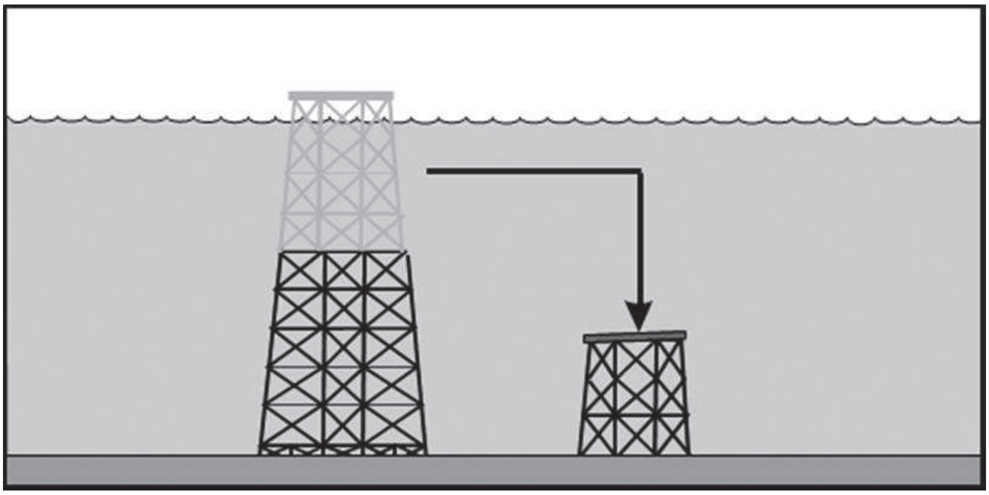

**Figure 1.18 -** Method of rig-to-reef decommissioning by "partial removal" (from Les Dauterive, 2000).

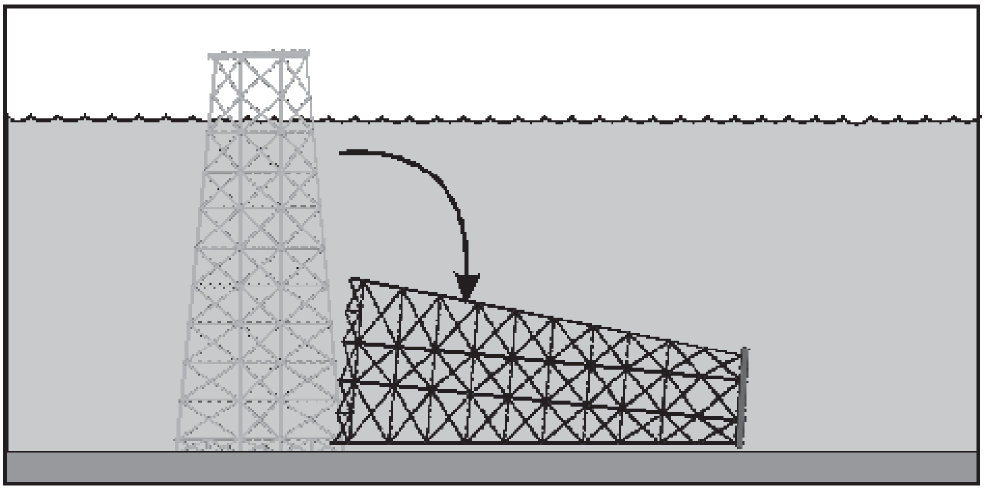

**Figure 1.19-** Method of rig-to-reef decommissioning by "toppling" (from Les Dauterive, 2000).

Partial removal cause the loss of the shell mound community and of fish that live in the top section but the majority of the habitat remains intact (Schroeder and Love, 2004). This is due to the fact that partial removal does not require explosives, and vertebrate and invertebrate assemblages associated with the remaining structure are likely to be minimally affected (Love *et al.,* 2003). Otherwise, toppling cause the elimination of shallow and mid-ocean habitats.

In addition, if the platform is partially removed fishes continue to be protected from fishing gear by the mass of the platform. However, depending on the characteristics of the platform, a toppled structure, with twisted and deformed pilings and beams, will be quickly occupied by other organisms bringing to a more benthic complexity than one that is partially removed (Love *et al.,* 2003).

3. Leave-in-Place - The platform is left in its original location at the time of decommissioning. The topsides would be stripped of oil and gas processing equipment, cleaned, and navigational aids installed. In this case the effects on platform sea life would be minimal (Love *et al.,* 2003).

However, despite the practice of converting obsolete structures to artificial reefs has gathered broad public and private support, the opinions regarding their effects continuous to remain divided.

Decommissioning is a complex and costly engineering undertaking that involves a wide range of legal, environmental, socioeconomic and policy issues. For this reason, the large number of existing decommissioning options has resulted into a series of socio-economic and environmental impacts (both positive and negative), each of which is perceived and evaluated in a different manner by several stakeholders (Bernstein *et al*., 2010).

In the last year, several studies (Bernstein, 2015a; 2015b; Bressler and Bernstein, 2015; Cantle and Bernstein, 2015; Claisse *et al.,* 2015; Henrion *et al*., 2015; Kruse *et al*., 2015; Pondella *et al.,* 2015) have been conducted in California in order to investigate the biological, socioeconomic, and environmental costs and benefits of the most feasible and likely decommissioning options, taking into account the two most feasible options: the complete removal and the partial removal. For example, one of them (Pondella *et al.,* 2015) developed a model of larval dispersal suggesting that platforms provide an important opportunity for recruitment of fish larvae and indicating that the potential contribution of platform habitat to biological resoures in this region may be significant. The study concluded that, under partial removal option, in most cases a large percentage of the fish biomass present on the platform can be preserved, whereas under complete removal option all the contribution of biological resources provided by California oil platforms would be lost.

## 1.5. AIMS OF THE STUDY

The Adriatic Sea is widely affected by many different human activities (*e.g.*, tourism, fishing, open-sea aquaculture), and the extraction of natural gas represents one of the most relevant and concerning, as oil and gas platforms are widely considered one of the main threats for marine environments and maritime navigation (Liu *et al*., 2016). In fact, this basin is characterized by a currently high drilling activity and the northern and central part of the basin host a high percentage of the offshore oil and gas platforms and related structures located in the whole Mediterranean Sea (OGP, 2005; Maggi *et al.,* 2007; Manoukian *et al*., 2010). In addition, the peculiar physiography of this long, narrow, and shallow water basin with many fresh water inputs modulates nutrient and oxygen concentrations, salinity, temperature, turbidity, currents, primary and secondary production (Marini *et al.,* 2008).

Over the next few decades, the decommissioning of several structures will be inevitable, as the existing field infrastructures at sea are approaching the end of their productive life. In fact, it has been estimated that in the period 2013-2020 an average of 38 platforms per year will be removed in Europe, with the majority of them being located along the Italian coasts of the Adriatic Sea (Scottish Enterprise, 2013). On the one hand, decommissioning of offshore oil and gas platforms could be highly desirable in order to restore the marine environment. A key issue within the decommissioning challenge of offshore platforms should be to assess the most ecologically sustainable practice in order to preserve ecosystems functions under a reasonable economical effort. On the other hand, it must be considered that, since these structures exist at sea since a long time, they could have become part of the marine ecosystem, to a certain extent. In this regard, for instance, fishing is forbidden for a radius of 500 m around each structure. These off-limit zones, if adequately expanded, could represent opportunities for larval recruitment and biomass accumulation, in a similar manner as for no-take zones of marine protected areas (Lester *et al.*, 2009; Kark *et al.*, 2015; Pondella *et al.,* 2015). This suggests that reclaiming offshore platforms while keeping them in place (or at least their submerged part) instead of their full removal could be an 'after-life' ecologically sustainable option. Nevertheless, to approach this goal, it is of primary importance to accumulate science-based knowledge and to provide insights on the potential effects of offshore platforms on hosting ecosystems and their surroundings.

In order to achieve this objective my PhD thesis has been built upon four main interrelated tasks, each of them with specific targets, outlined below.

1) The first task aims at testing the (null) hypothesis that the quantity and biochemical composition of organic matter in the sediment are not affected by the presence of offshore artificial structures. To do this, sediment samples have been collected beneath and in the proximity of the offshore structures and analyzed in terms of phytopigment, protein, carbohydrate, lipid and biopolymeric organic carbon contents.
2) The second task aims at verifying the (null) hypothesis that the abundance and biodiversity of macro-benthic communities are not affected by the presence of offshore artificial structures. To do this, the spatial distribution and the temporal variability of macrozoobenthic communities living around offshore artificial structures has been assessed through surveys conducted for two years starting after the installation of the structures (twice a year).
3) The third task aims at assessing the (null) hypothesis that the abundance, biomass and biodiversity of fish assemblages are not affected by the presence of offshore artificial structures through dedicated acoustic and fishing surveys.
4) The fourth task aims at assessing whether the offshore artificial structures under scrutiny exert a "trophic" attraction of the fish assemblages, through the gut contents analysis. Specifically, the attention is focused on two demersal fish, *Scorpaena notata* and *S. porcus*, usually occurring around the structures and defined as attracted species on the basis of their known behavior towards hard substrates (Bombace *et al.*, 1994).

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## 1.7 SUPPLEMENTARY MATERIAL TO CHAPTER 1

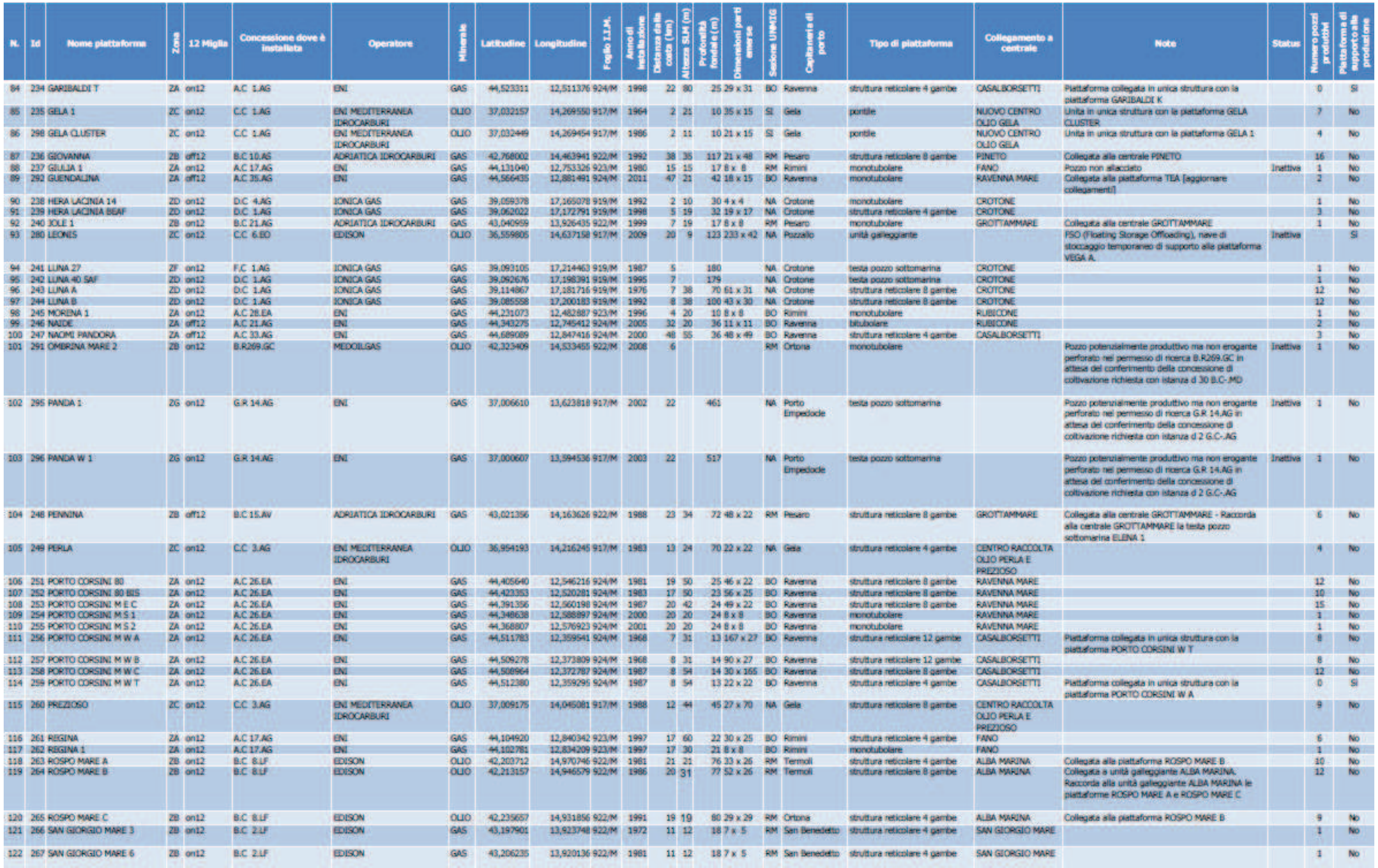
**Annex 1.1 -** Details of gas and oil offshore platforms in the Italian Seas (Ministry Economic Development, DGMRE – Italy; updated 22/12/2014).

| N. | Id | Nome piattaforma | Zona | 12 Miglia | Concessione dove è installata | Operatore | Minerale | Latitudine | Longitudine | Foglio I.I.M. | Anno di installazione | Distanza dalla costa (km) | Altezza SLM (m) | Profondità fondale (m) | Dimensioni parti emerse | Sezione UNMIG | Capitaneria di porto | Tipo di piattaforma | Collegamento a centrale | Note | Status | Numero pozzi produttivi | Piattaforma di supporto alla produzione |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 290 | ADA 2 | ZA | on12 | A.C 9.AG | ENI | GAS | 45,183634 | 12,591285 | 924/M | 1982 | 20 | 15 | 25 | 8 x 8 | BO | Ravenna | monotubolare | | Piattaforma non allacciata. Non operativa in quanto ricadente in area soggetta ad accertamento della non sussistenza di rischi apprezzabili di subsidenza sulle coste (art. 8 comma 1 della Legge 6 agosto 2008, n. 133). | Inattiva | 1 | No |
| 2 | 299 | ADA 3 | ZA | on12 | A.C 9.AG | ENI | GAS | 45,183361 | 12,591176 | 924/M | 1982 | 20 | 15 | 25 | 8 x 8 | BO | Ravenna | monotubolare | | Pozzo chiuso minerariamente. Piattaforma in attesa di decommissioning. | Inattiva | 1 | No |
| 3 | 300 | ADA 4 | ZA | on12 | A.C 9.AG | ENI | GAS | 45,183561 | 12,590910 | 924/M | 1982 | 20 | 15 | 25 | 8 x 8 | BO | Ravenna | monotubolare | | Piattaforma non allacciata. Non operativa in quanto ricadente in area soggetta ad accertamento della non sussistenza di rischi apprezzabili di subsidenza sulle coste (art. 8 comma 1 della Legge 6 agosto 2008, n. 133). | Inattiva | 1 | No |
| 4 | 164 | AGOSTINO A | ZA | on12 | A.C 3.AS | ENI | GAS | 44,540180 | 12,495518 | 924/M | 1970 | 17 | 50 | 23 | 46 x 22 | BO | Ravenna | struttura reticolare 8 gambe | CASALBORSETTI | | | 12 | No |
| 5 | 167 | AGOSTINO A CLUSTER | ZA | on12 | A.C 3.AS | ENI | GAS | 44,540685 | 12,496197 | 924/M | 1991 | 17 | 32 | 24 | 11 x 11 | BO | Ravenna | cluster | CASALBORSETTI | | | 3 | No |
| 6 | 165 | AGOSTINO B | ZA | on12 | A.C 3.AS | ENI | GAS | 44,554372 | 12,471569 | 924/M | 1971 | 15 | 50 | 22 | 46 x 22 | BO | Ravenna | struttura reticolare 8 gambe | CASALBORSETTI | | | 11 | No |
| 7 | 166 | AGOSTINO C | ZA | on12 | A.C 3.AS | ENI | GAS | 44,547174 | 12,494523 | 924/M | 1992 | 18 | 56 | 25 | 51 x 26 | BO | Ravenna | struttura reticolare 8 gambe | CASALBORSETTI | | | 12 | No |
| 8 | 168 | ALBA MARINA | ZB | on12 | B.C 8.LF | EDISON | OLIO | 42,201212 | 14,939078 | 922/M | 2012 | 19 | 22 | 74 | 262 x 42 | RM | Ortona | unità galleggiante | | FSO (Floating Storage Offloading), nave di stoccaggio temporaneo di supporto alle piattaforme ROSPO MARE A, ROSPO MARE B e ROSPO MARE C | Inattiva | | Si |
| 9 | 169 | AMELIA A | ZA | off12 | A.C 2.AS | ENI | GAS | 44,405716 | 12,660836 | 924/M | 1971 | 28 | 50 | 32 | 46 x 22 | BO | Ravenna | struttura reticolare 8 gambe | RAVENNA MARE | | | 12 | No |
| 10 | 170 | AMELIA B | ZA | off12 | A.C 2.AS | ENI | GAS | 44,407903 | 12,662218 | 924/M | 1991 | 28 | 50 | 31 | 14 x 37 | BO | Ravenna | struttura reticolare 8 gambe | RAVENNA MARE | | | 12 | No |
| 11 | 171 | AMELIA C | ZA | off12 | A.C 2.AS | ENI | GAS | 44,406935 | 12,662895 | 924/M | 1991 | 28 | 50 | 31 | 13 x 13 | BO | Ravenna | struttura reticolare 4 gambe | RAVENNA MARE | | | 12 | No |
| 12 | 172 | AMELIA D | ZA | off12 | A.C 2.AS | ENI | GAS | 44,407901 | 12,661276 | 924/M | 1992 | 27 | 57 | 30 | 30 x 28 | BO | Ravenna | struttura reticolare 4 gambe | RAVENNA MARE | | | 10 | No |
| 13 | 173 | ANEMONE B | ZA | on12 | A.C 8.ME | ENI | GAS | 44,229289 | 12,704814 | 923/M | 1999 | 20 | 20 | 23 | 16 x 13 | BO | Rimini | struttura reticolare 4 gambe | RUBICONE | | | 7 | No |
| 14 | 174 | ANEMONE CLUSTER | ZA | on12 | A.C 8.ME | ENI | GAS | 44,212786 | 12,705310 | 923/M | 1979 | 19 | 41 | 22 | 34 x 31 | BO | Rimini | cluster | RUBICONE | | | 3 | No |
| 15 | 175 | ANGELA ANGELINA | ZA | on12 | A.C 27.EA | ENI | GAS | 44,391172 | 12,343127 | 924/M | 1997 | 2 | 38 | 25 | 48 x 25 | BO | Ravenna | struttura reticolare 8 gambe | RAVENNA MARE | | | 14 | No |
| 16 | 176 | ANGELA CLUSTER | ZA | on12 | A.C 27.EA | ENI | GAS | 44,392973 | 12,344848 | 924/M | 1975 | 2 | 25 | 9 | 30 x 20 | BO | Ravenna | cluster | RAVENNA MARE | | | 4 | No |
| 17 | 177 | ANNABELLA | ZA | off12 | A.C 18.AG | ENI | GAS | 44,228781 | 13,078865 | 923/M | 1991 | 35 | 50 | 50 | 20 x 46 | RM | Rimini | struttura reticolare 8 gambe | FANO | | | 7 | No |
| 18 | 178 | ANNALISA | ZA | off12 | A.C 32.AG | ENI | GAS | 44,171042 | 13,113554 | 923/M | 1999 | 32 | 52 | 53 | 21 x 33 | RM | Rimini | struttura reticolare 4 gambe | FANO | | | 4 | No |
| 19 | 288 | ANNAMARIA B | ZA | off12 | A.C 11.AG | ENI | GAS | 44,322576 | 13,407327 | 923/M | 2009 | 59 | 41 | 60 | 21 x 30 | RM | Pesaro | struttura reticolare 4 gambe | FANO | Collegata alla piattaforma BRENDA e alla piattaforma ANNAMARIA A ubicata nella piattaforma continentale Croata | | 6 | No |
| 20 | 179 | ANTARES 1 | ZA | on12 | A.C 30.EA | ENI | GAS | 44,393988 | 12,444429 | 924/M | 1982 | 10 | 15 | 14 | 8 x 8 | BO | Ravenna | monotubolare | RAVENNA MARE | | | 1 | No |
| 21 | 180 | ANTARES A | ZA | on12 | A.C 30.EA | ENI | GAS | 44,390057 | 12,453493 | 924/M | 1985 | 11 | 38 | 15 | 43 x 25 | BO | Ravenna | struttura reticolare 6 gambe | RAVENNA MARE | | | 9 | No |
| 22 | 181 | ANTONELLA | ZA | off12 | A.C 5.AV | ENI | GAS | 44,214442 | 12,776663 | 923/M | 1976 | 23 | 50 | 29 | 46 x 22 | BO | Rimini | struttura reticolare 8 gambe | RUBICONE | | | 11 | No |
| 23 | 283 | AQUILA 2 | ZF | off12 | F.C 2.AG | ENI | OLIO | 40,930188 | 18,327114 | 921/M | 1993 | 50 | | 820 | | NA | Brindisi | testa pozzo sottomarina | FIRENZE FPSO | Collegata alla unità galleggiante FIRENZE FPSO | | 1 | No |
| 24 | 284 | AQUILA 3 | ZF | off12 | F.C 2.AG | ENI | OLIO | 40,918159 | 18,325320 | 921/M | 1995 | 50 | | 804 | | NA | Brindisi | testa pozzo sottomarina | FIRENZE FPSO | Collegata alla unità galleggiante FIRENZE FPSO | | 1 | No |
| 25 | 294 | ARGO 2 | ZG | on12 | G.C 1.AG | ENI | GAS | 36,926058 | 13,805449 | 917/M | 2008 | 20 | | 548 | | NA | Gela | testa pozzo sottomarina | | | | 1 | No |
| 26 | 182 | ARIANNA A | ZA | on12 | A.C 4.AS | ENI | GAS | 44,306251 | 12,628146 | 923/M | 1984 | 21 | 32 | 24 | 42 x 21 | BO | Rimini | struttura reticolare 6 gambe | RUBICONE | | | 6 | No |
| 27 | 183 | ARIANNA A CLUSTER | ZA | on12 | FASCIA CERVIA MARE | ENI | GAS | 44,305788 | 12,627430 | 923/M | 1992 | 20 | 35 | 23 | 11 x 11 | BO | Rimini | cluster | RUBICONE | | | 3 | No |
| 28 | 184 | ARMIDA 1 | ZA | on12 | A.C 29.EA | ENI | GAS | 44,475932 | 12,449540 | 924/M | 1973 | 14 | 17 | 18 | 8 x 8 | BO | Ravenna | monotubolare | RAVENNA MARE | | | 1 | No |
| 29 | 185 | ARMIDA A | ZA | on12 | A.C 29.EA | ENI | GAS | 44,480303 | 12,453192 | 924/M | 1985 | 13 | 38 | 18 | 48 x 25 | BO | Ravenna | struttura reticolare 6 gambe | RAVENNA MARE | | | 6 | No |
| 30 | 187 | AZALEA A | ZA | on12 | A.C 8.ME | ENI | GAS | 44,171769 | 12,714258 | 923/M | 1984 | 16 | 17 | 19 | 19 X 4 | BO | Rimini | bitubolare | RUBICONE | Prevista chiusura mineraria | | | No |
| 31 | 186 | AZALEA B | ZA | on12 | A.C 8.ME | ENI | GAS | 44,166817 | 12,720562 | 923/M | 1987 | 16 | 42 | 19 | 100 x 27 | BO | Rimini | struttura reticolare 4 gambe | RUBICONE | | | 11 | No |
| 32 | 188 | BARBARA A | ZA | off12 | A.C 7.AS | ENI | GAS | 44,047208 | 13,803467 | 923/M | 1978 | 58 | 28 | 70 | 22 x 22 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Collegata alla piattaforma BARBARA B | | 6 | No |
| 33 | 189 | BARBARA B | ZA | off12 | A.C 7.AS | ENI | GAS | 44,091609 | 13,741427 | 923/M | 1983 | 59 | 52 | 69 | 27 x 40 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Collegata alla piattaforma BARBARA T - Raccorda alla piattaforma BARBARA T anche le piattaforme BARBARA NW e BARBARA A | | 9 | No |
| 34 | 190 | BARBARA C | ZA | off12 | A.C 7.AS | ENI | GAS | 44,076859 | 13,781867 | 923/M | 1985 | 59 | 49 | 70 | 28 x 57 | RM | Pesaro | struttura reticolare 8 gambe | FALCONARA | Unita in unica struttura con le piattaforme BARBARA T e BARBARA T2 - Collegata alla piattaforme BARBARA T | | 12 | No |
| 35 | 191 | BARBARA D | ZA | off12 | A.C 7.AS | ENI | GAS | 44,030369 | 13,809339 | 923/M | 1986 | 56 | 49 | 70 | 35 x 62 | RM | Pesaro | struttura reticolare 8 gambe | FALCONARA | Collegata alla piattaforma BARBARA T | | 15 | No |
| 36 | 192 | BARBARA E | ZA | off12 | A.C 7.AS | ENI | GAS | 44,086474 | 13,757562 | 923/M | 1987 | 59 | 54 | 70 | 62 x 23 | RM | Pesaro | struttura reticolare 8 gambe | FALCONARA | Collegata alla piattaforma BARBARA T | | 15 | No |
| 37 | 193 | BARBARA F | ZA | off12 | A.C 7.AS | ENI | GAS | 44,050183 | 13,817099 | 923/M | 1988 | 59 | 54 | 70 | 40 x 50 | RM | Pesaro | struttura reticolare 8 gambe | FALCONARA | Collegata alla piattaforma BARBARA T | | 15 | No |
| 38 | 194 | BARBARA G | ZA | off12 | A.C 7.AS | ENI | GAS | 44,063905 | 13,791530 | 923/M | 1992 | 60 | 59 | 70 | 60 x 33 | RM | Pesaro | struttura reticolare 8 gambe | FALCONARA | Collegata alla piattaforma BARBARA T | | 15 | No |
| 39 | 195 | BARBARA H | ZA | off12 | A.C 7.AS | ENI | GAS | 44,069387 | 13,762702 | 923/M | 1992 | 60 | 59 | 70 | 60 x 33 | RM | Pesaro | struttura reticolare 8 gambe | FALCONARA | Collegata alla piattaforma BARBARA T | | 15 | No |
| 40 | 196 | BARBARA NW | ZA | off12 | A.C 7.AS | ENI | GAS | 44,108865 | 13,648827 | 923/M | 1999 | 55 | 30 | 68 | 10 x 12 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Collegata alla piattaforma BARBARA B | | 6 | No |
| 41 | 197 | BARBARA T | ZA | off12 | A.C 7.AS | ENI | GAS | 44,077277 | 13,781345 | 923/M | 1985 | 59 | 41 | 70 | 21 x 27 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Piattaforma di compressione - Unita in unica struttura con le piattaforme BARBARA C e BARBARA T2 – Collegata alla centrale FALCONARA - Raccorda alla centrale FALCONARA anche le piattaforme BARBARA T2-A-B-C-D-E-F-G-H-NW, CALIPSO, CALPURNIA, CLARA EST, CLAR | | 0 | Si |
| 42 | 198 | BARBARA T2 | ZA | off12 | A.C 7.AS | ENI | GAS | 44,077718 | 13,782030 | 923/M | 2000 | 60 | 68 | 71 | 28 x 32 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Piattaforma di compressione - Unita in unica struttura con le piattaforme BARBARA C e BARBARA T | | 0 | Si |
| 43 | 199 | BASIL | ZA | off12 | A.C 12.AG | ENI | GAS | 44,131649 | 13,001086 | 923/M | 1983 | 25 | 36 | 45 | 47 x 23 | RM | Rimini | struttura reticolare 4 gambe | FANO | | | 8 | No |

**Annex 1.1** - Cont.

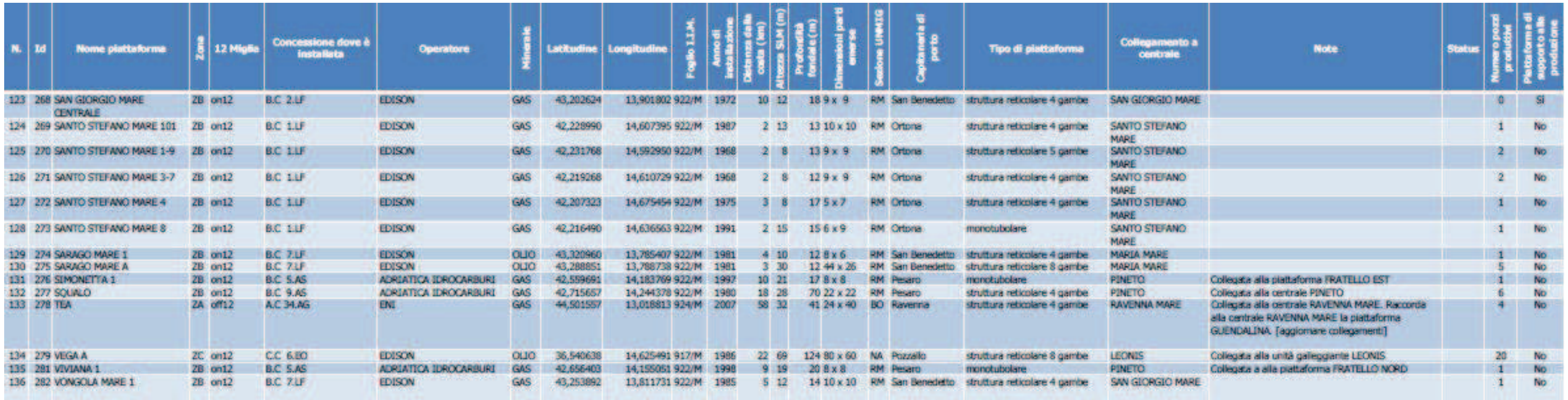
| N. | Id | Nome piattaforma | Zona | 12 Miglia | Concessione dove è installata | Operatore | Minerale | Latitudine | Longitudine | Foglio I.I.M. | Anno di installazione | Distanza dalla costa (km) | Altezza SLM (m) | Profondità fondale (m) | Dimensioni parti emerse | Sezione UNMIG | Capitaneria di porto | Tipo di piattaforma | Collegamento a centrale | Note | Status | Numero pozzi produttivi | Piattaforma di supporto alla produzione |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 44 | 200 | BENEDETTA 1 | ZA | on12 | d 39 A.C-.EA | ENI | GAS | 44,179400 | 12,581966 | 923/M | 2006 | 9 | 20 | 13 | 4 x 3 | BO | Rimini | monotubolare | RUBICONE | Pozzo non allacciato, potenzialmente produttivo ma non erogante, perforato nel permesso di ricerca A.R 95.EA in attesa del conferimento della concessione di coltivazione richiesta con istanza d 39 A.C-.EA | Inattiva | 0 | No |
| 45 | 201 | BONACCIA | ZB | off12 | B.C 17.TO | ENI | GAS | 43,592497 | 14,359527 | 923/M | 1999 | 58 | 39 | 85 | 62 X 25 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Collegata alla piattaforma BARBARA T2 |  | 10 | No |
| 46 | 301 | BONACCIA EST 2 | ZB | off12 | B.C 17.TO | ENI | GAS | 43,578672 | 14,437581 | 923/M | 2010 | 64 |  | 85 |  | RM | Pesaro | testa pozzo sottomarina | FALCONARA | Collegata alla piattaforma BONACCIA |  | 1 | No |
| 47 | 308 | BONACCIA EST 3 | ZB | off12 | B.C 17.TO | ENI | GAS | 43,578614 | 14,437583 | 923/M | 2010 | 64 |  | 85 |  | RM | Pesaro | testa pozzo sottomarina | FALCONARA | Collegata alla piattaforma BONACCIA |  | 1 | No |
| 48 | 202 | BRENDA | ZA | off12 | A.C 12.AG | ENI | GAS | 44,116443 | 13,044925 | 923/M | 1987 | 25 | 42 | 47 | 100 x 27 | RM | Rimini | struttura reticolare 4 gambe | FANO | Piattaforme BRENDA PROD e BRENDA PERF collegate in unica struttura |  | 7 | No |
| 49 | 203 | CALIPSO | ZB | off12 | B.C 14.AS | ENI | GAS | 43,827416 | 13,863461 | 923/M | 2002 | 35 | 21 | 75 | 19 x 17 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Collegata alla piattaforma BARBARA A |  | 2 | No |
| 50 | 204 | CALPURNIA | ZB | off12 | B.C 22.AG | ENI | GAS | 43,899535 | 14,153981 | 923/M | 2000 | 58 | 23 | 72 | 26 x 25 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Collegata alla piattaforma BARBARA T2 - Raccorda alla piattaforma BARBARA T2 anche le piattaforme CLARA NORD e CLARA EST |  | 5 | No |
| 51 | 205 | CAMILLA 2 | ZB | off12 | B.C 3.AS | ADRIATICA IDROCARBURI | GAS | 42,897839 | 14,246376 | 923/M | 2001 | 26 |  | 80 |  | RM | Pesaro | testa pozzo sottomarina | PINETO | Collegata alla piattaforma ELEONORA |  | 1 | No |
| 52 | 297 | CASSIOPEA 1 | ZG | off12 | G.C 1.AG | ENI | GAS | 36,936642 | 13,732618 | 917/M | 2008 | 25 |  | 586 |  | NA | Porto Empedocle | testa pozzo sottomarina |  |  |  | 1 | No |
| 53 | 206 | CERVIA A | ZA | on12 | CERVIA MARE | ENI | GAS | 44,294608 | 12,639005 | 923/M | 1986 | 21 | 50 | 23 | 46 x 22 | BO | Rimini | struttura reticolare 8 gambe | RUBICONE | Unita in unica strutture con le piattaforme CERVIA K e CERVIA CLUSTER - Collegata alla piattaforma CERVIA K |  | 10 | No |
| 54 | 209 | CERVIA A CLUSTER | ZA | on12 | CERVIA MARE | ENI | GAS | 44,295105 | 12,639697 | 923/M | 1992 | 20 | 35 | 23 | 11 x 11 | BO | Rimini | cluster | RUBICONE | Unita in unica struttura con le piattaforme CERVIA A e CERVIA K - Collegata alla piattaforma CERVIA K |  | 3 | No |
| 55 | 207 | CERVIA B | ZA | on12 | CERVIA MARE | ENI | GAS | 44,288823 | 12,645428 | 923/M | 1984 | 21 | 32 | 24 | 42 x 21 | BO | Rimini | struttura reticolare 6 gambe | RUBICONE |  |  | 5 | No |
| 56 | 208 | CERVIA C | ZA | on12 | FASCIA CERVIA MARE | ENI | GAS | 44,301650 | 12,640079 | 923/M | 1992 | 20 | 54 | 23 | 51 x 26 | BO | Rimini | struttura reticolare 8 gambe | RUBICONE |  |  | 9 | No |
| 57 | 210 | CERVIA K | ZA | on12 | CERVIA MARE | ENI | GAS | 44,295474 | 12,639076 | 923/M | 2000 | 21 | 62 | 24 | 35 x 26 | BO | Rimini | struttura reticolare 4 gambe | RUBICONE | Piattaforma di compressione - Unita in unica struttura con le piattaforme CERVIA A e CERVIA CLUSTER |  | 0 | Si |
| 58 | 211 | CLARA EST | ZB | off12 | B.C 13.AS | ENI | GAS | 43,779617 | 14,071618 | 923/M | 2000 | 45 | 23 | 77 | 26 x 25 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Collegata alla piattaforma CALPURNIA |  | 4 | No |
| 59 | 212 | CLARA NORD | ZB | off12 | B.C 13.AS | ENI | GAS | 43,939355 | 13,976674 | 923/M | 2000 | 50 | 23 | 74 | 26 x 25 | RM | Pesaro | struttura reticolare 4 gambe | FALCONARA | Collegata alla piattaforma CALPURNIA |  | 5 | No |
| 60 | 213 | CLARA OVEST | ZB | off12 | B.C 14.AS | ENI | GAS | 43,828681 | 13,711516 | 923/M | 1987 | 28 | 55 | 71 | 30 x 65 | RM | Pesaro | struttura reticolare 8 gambe | FALCONARA | Collegata alla centrale FALCONARA |  | 8 | No |
| 61 | 214 | DARIA A | ZA | off12 | A.C 13.AS | ENI | GAS | 44,067586 | 13,249138 | 923/M | 1994 | 30 | 40 | 56 | 24 x 28 | RM | Pesaro | struttura reticolare 4 gambe | FANO | Piattaforma di produzione collegata in unica struttura con la piattaforma di compressione DARIA B |  | 14 | No |
| 62 | 215 | DARIA B | ZA | off12 | A.C 13.AS | ENI | GAS | 44,066931 | 13,249706 | 923/M | 1995 | 30 | 40 | 55 | 24 x 28 | RM | Pesaro | struttura reticolare 4 gambe | FANO | Piattaforma di compressione collegata in unica struttura con la piattaforma di produzione DARIA A |  | 0 | Si |
| 63 | 216 | DAVIDE | ZB | on12 | B.C 4.AS | ADRIATICA IDROCARBURI | GAS | 43,095985 | 14,017133 | 922/M | 1980 | 17 | 18 | 30 | 18 x 14 | RM | Pesaro | monotubolare | GROTTAMMARE | Piattaforma collegata in unica struttura con la piattaforma DAVIDE 7 |  | 4 | No |
| 64 | 217 | DAVIDE 7 | ZB | on12 | B.C 4.AS | ADRIATICA IDROCARBURI | GAS | 43,095755 | 14,016886 | 922/M | 2002 | 17 | 18 | 30 | 8 x 8 | RM | Pesaro | monotubolare | GROTTAMMARE | Piattaforme collegata in unica struttura con la piattaforma DAVIDE |  | 2 | No |
| 65 | 218 | DIANA | ZA | on12 | A.C 29.EA | ENI | GAS | 44,441373 | 12,425718 | 924/M | 1971 | 10 | 16 | 15 | 32 x 26 | BO | Ravenna | cluster | RAVENNA MARE |  |  | 3 | No |
| 66 | 219 | ELENA 1 | ZB | off12 | B.C 3.AS | ADRIATICA IDROCARBURI | GAS | 43,040689 | 14,210255 | 922/M | 1989 | 27 |  | 75 |  | RM | Pesaro | testa pozzo sottomarina | GROTTAMMARE | Collegata alla piattaforma PENNINA |  | 1 | No |
| 67 | 220 | ELEONORA | ZB | off12 | B.C 3.AS | ADRIATICA IDROCARBURI | GAS | 42,840158 | 14,155689 | 922/M | 1987 | 24 | 34 | 60 | 34 x 28 | RM | Pesaro | struttura reticolare 8 gambe | PINETO | Collegata alla centrale PINETO - Raccorda alla centrale di PINETO la piattaforma EMILIO e la testa pozzo sottomarina CAMILLA 2 |  | 9 | No |
| 68 | 302 | ELETTRA | ZB | off12 | B.C 23.AG | ENI | GAS | 43,764413 | 14,215197 | 923/M | 2014 | 53 | 21 | 78 | 16 x 19 | RM | Pesaro | struttura reticolare 3 gambe | FALCONARA | Collegata alla centrale FALCONARA tramite tie-in su BONACCIA - BARBARA C |  | 1 | No |
| 69 | 221 | EMILIO | ZB | off12 | B.C 3.AS | ADRIATICA IDROCARBURI | GAS | 42,934945 | 14,243294 | 922/M | 2001 | 27 | 34 | 85 |  | RM | Pesaro | struttura reticolare 4 gambe | PINETO | Collegata alla piattaforma ELEONORA |  | 2 | No |
| 70 | 222 | EMILIO 3 | ZB | off12 | B.C 3.AS | ADRIATICA IDROCARBURI | GAS | 42,938165 | 14,233880 | 922/M | 1980 | 30 |  | 85 |  | RM | Pesaro | testa pozzo sottomarina | GROTTAMMARE | Collegata alla centrale GROTTAMMARE |  | 1 | No |
| 71 | 223 | EMMA OVEST | ZB | off12 | B.C 10.AS | ADRIATICA IDROCARBURI | GAS | 42,808505 | 14,379206 | 922/M | 1982 | 36 | 28 | 104 | 35 x 26 | RM | Pesaro | struttura reticolare 4 gambe | PINETO | Collegata alla centrale PINETO |  | 9 | No |
| 72 | 224 | FABRIZIA 1 | ZB | on12 | B.C 21.AG | ADRIATICA IDROCARBURI | GAS | 43,041377 | 14,001140 | 922/M | 1998 | 12 | 19 | 22 | 8 x 8 | RM | Pesaro | monotubolare | GROTTAMMARE | Collegata alla centrale GROTTAMMARE |  | 1 | No |
| 73 | 303 | FAUZIA | ZA | off12 | A.C 36.AG | ENI | GAS | 44,056355 | 13,554058 | 923/M | 2014 | 46 | 21 | 70 | 16 x 19 | RM | Pesaro | struttura reticolare 3 gambe | FALCONARA | Collegata alla piattaforma BARBARA B |  | 2 | No |
| 74 | 293 | FIRENZE FPSO | ZF | off12 | F.C 2.AG | ENI | OLIO | 40,924163 | 18,326210 | 921/M | 2011 | 50 | 21 | 850 | 247 X 42 | NA | Brindisi | unità galleggiante |  | FPSO (Floating Production Storage Offloading), nave di stoccaggio temporaneo di supporto alle teste pozzo sottomarine AQUILA 2 e AQUILA 3 | Inattiva | 0 | Si |
| 75 | 225 | FRATELLO CLUSTER | ZB | on12 | B.C 5.AS | ADRIATICA IDROCARBURI | GAS | 42,610534 | 14,168514 | 922/M | 1979 | 12 | 21 | 19 | 31 x 30 | RM | Pesaro | cluster | PINETO | Collegata alla centrale di PINETO - Raccorda alla centrale di PINETO le piattaforme VIVIANA 1, FRATELLO NORD, FRATELLO EST, SIMONETTA1 |  | 3 | No |
| 76 | 226 | FRATELLO EST 2 | ZB | on12 | B.C 5.AS | ADRIATICA IDROCARBURI | GAS | 42,576846 | 14,172827 | 922/M | 1980 | 13 | 17 | 17 | 8 x 8 | RM | Pesaro | monotubolare | PINETO | Collegata alla piattaforma FRATELLO CLUSTER |  | 1 | No |
| 77 | 227 | FRATELLO NORD | ZB | on12 | B.C 5.AS | ADRIATICA IDROCARBURI | GAS | 42,648861 | 14,170126 | 922/M | 1980 | 13 | 15 | 23 | 19 x 4 | RM | Pesaro | bitubolare | PINETO | Collegata alla piattaforma FRATELLO CLUSTER |  | 2 | No |
| 78 | 228 | GARIBALDI A | ZA | on12 | A.C 1.AG | ENI | GAS | 44,523023 | 12,510457 | 924/M | 1969 | 19 | 50 | 25 | 46 x 90 | BO | Ravenna | struttura reticolare 8 gambe | CASALBORSETTI |  |  | 11 | No |
| 79 | 231 | GARIBALDI A CLUSTER | ZA | on12 | A.C 1.AG | ENI | GAS | 44,523727 | 12,512050 | 924/M | 1991 | 17 | 32 | 24 | 11 x 11 | BO | Ravenna | cluster | CASALBORSETTI |  |  | 3 | No |
| 80 | 229 | GARIBALDI B | ZA | on12 | A.C 1.AG | ENI | GAS | 44,487009 | 12,531292 | 924/M | 1969 | 20 | 50 | 26 | 46 x 22 | BO | Ravenna | struttura reticolare 8 gambe | CASALBORSETTI |  |  | 13 | No |
| 81 | 230 | GARIBALDI C | ZA | on12 | A.C 1.AG | ENI | GAS | 44,531601 | 12,515280 | 924/M | 1992 | 18 | 62 | 25 | 48 x 26 | BO | Ravenna | struttura reticolare 8 gambe | CASALBORSETTI |  |  | 12 | No |
| 82 | 232 | GARIBALDI D | ZA | on12 | A.C 1.AG | ENI | GAS | 44,478183 | 12,546062 | 924/M | 1993 | 18 | 30 | 25 | 37 x 21 | BO | Ravenna | struttura reticolare 8 gambe | CASALBORSETTI |  |  | 12 | No |
| 83 | 233 | GARIBALDI K | ZA | on12 | A.C 1.AG | ENI | GAS | 44,532077 | 12,516137 | 924/M | 1998 | 22 | 80 | 25 | 29 x 31 | BO | Ravenna | struttura reticolare 4 gambe | CASALBORSETTI | Piattaforma collegata in unica struttura con la piattaforma GARIBALDI T |  | 0 | Si |

**Annex 1.1** - Cont.



| N. | Id | Nome piattaforma | Zona | 12 Miglia | Concessione dove è installata | Operatore | Minerale | Latitudine | Longitudine | Foglio I.I.M. | Anno di installazione | Distanza dalla costa (km) | Altezza SLM (m) | Profondità fondale (m) | Dimensioni parti emerse | Sezione UNMIG | Capitaneria di porto | Tipo di piattaforma | Collegamento a centrale | Note | Status | Numero pozzi produttivi | Piattaforma di supporto alla produzione |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 84 | 234 | GARIBALDI T | ZA | on12 | A.C 1.AG | ENI | GAS | 44,523311 | 12,511376 | 924/M | 1998 | 22 | 80 | 25 | 29 x 31 | BO | Ravenna | struttura reticolare 4 gambe | CASALBORSETTI | Piattaforma collegata in unica struttura con la piattaforma GARIBALDI K | | 0 | SI |
| 85 | 235 | GELA 1 | ZC | on12 | C.C 1.AG | ENI MEDITERRANEA IDROCARBURI | OLIO | 37,032157 | 14,269550 | 917/M | 1964 | 2 | 21 | 10 | 35 x 15 | SI | Gela | pontile | NUOVO CENTRO OLIO GELA | Unita in unica struttura con la piattaforma GELA CLUSTER | | 7 | No |
| 86 | 298 | GELA CLUSTER | ZC | on12 | C.C 1.AG | ENI MEDITERRANEA IDROCARBURI | OLIO | 37,032449 | 14,269454 | 917/M | 1986 | 2 | 11 | 10 | 21 x 15 | SI | Gela | pontile | NUOVO CENTRO OLIO GELA | Unita in unica struttura con la piattaforma GELA 1 | | 4 | No |
| 87 | 236 | GIOVANNA | ZB | off12 | B.C 10.AS | ADRIATICA IDROCARBURI | GAS | 42,768002 | 14,463941 | 922/M | 1992 | 38 | 35 | 117 | 21 x 48 | RM | Pesaro | struttura reticolare 8 gambe | PINETO | Collegata alla centrale PINETO | | 16 | No |
| 88 | 237 | GIULIA 1 | ZA | on12 | A.C 17.AG | ENI | GAS | 44,131040 | 12,753326 | 923/M | 1980 | 15 | 15 | 17 | 8 x 8 | RM | Rimini | monotubolare | FANO | Pozzo non allacciato | Inattiva | 1 | No |
| 89 | 292 | GUENDALINA | ZA | off12 | A.C 35.AG | ENI | GAS | 44,566435 | 12,881491 | 924/M | 2011 | 47 | 21 | 42 | 18 x 15 | BO | Ravenna | monotubolare | RAVENNA MARE | Collegata alla piattaforma TEA [aggiornare collegamenti] | | 2 | No |
| 90 | 238 | HERA LACINIA 14 | ZD | on12 | D.C 4.AG | IONICA GAS | GAS | 39,059378 | 17,165078 | 919/M | 1992 | 2 | 10 | 30 | 4 x 4 | NA | Crotone | monotubolare | CROTONE | | | 1 | No |
| 91 | 239 | HERA LACINIA BEAF | ZD | on12 | D.C 1.AG | IONICA GAS | GAS | 39,062022 | 17,172791 | 919/M | 1998 | 5 | 19 | 32 | 19 x 17 | NA | Crotone | struttura reticolare 4 gambe | CROTONE | | | 3 | No |
| 92 | 240 | IOLE 1 | ZB | on12 | B.C 21.AG | ADRIATICA IDROCARBURI | GAS | 43,040959 | 13,926435 | 922/M | 1999 | 7 | 19 | 17 | 8 x 8 | RM | Pesaro | monotubolare | GROTTAMMARE | Collegata alla centrale GROTTAMMARE | | 1 | No |
| 93 | 280 | LEONIS | ZC | on12 | C.C 6.EO | EDISON | OLIO | 36,559805 | 14,637158 | 917/M | 2009 | 20 | 9 | 123 | 233 x 42 | NA | Pozzallo | unità galleggiante | | FSO (Floating Storage Offloading), nave di stoccaggio temporaneo di supporto alla piattaforma VEGA A. | Inattiva | | SI |
| 94 | 241 | LUNA 27 | ZF | on12 | F.C 1.AG | IONICA GAS | GAS | 39,093105 | 17,214463 | 919/M | 1987 | 5 | | 180 | | NA | Crotone | testa pozzo sottomarina | CROTONE | | | 1 | No |
| 95 | 242 | LUNA 40 SAF | ZD | on12 | D.C 1.AG | IONICA GAS | GAS | 39,092676 | 17,198391 | 919/M | 1995 | 7 | | 179 | | NA | Crotone | testa pozzo sottomarina | CROTONE | | | 1 | No |
| 96 | 243 | LUNA A | ZD | on12 | D.C 1.AG | IONICA GAS | GAS | 39,114867 | 17,181716 | 919/M | 1976 | 7 | 38 | 70 | 61 x 31 | NA | Crotone | struttura reticolare 8 gambe | CROTONE | | | 12 | No |
| 97 | 244 | LUNA B | ZD | on12 | D.C 1.AG | IONICA GAS | GAS | 39,085558 | 17,200183 | 919/M | 1992 | 8 | 38 | 100 | 43 x 30 | NA | Crotone | struttura reticolare 8 gambe | CROTONE | | | 12 | No |
| 98 | 245 | MORENA 1 | ZA | on12 | A.C 28.EA | ENI | GAS | 44,231073 | 12,482887 | 923/M | 1996 | 4 | 20 | 10 | 8 x 8 | BO | Rimini | monotubolare | RUBICONE | | | 1 | No |
| 99 | 246 | NAIDE | ZA | off12 | A.C 21.AG | ENI | GAS | 44,343275 | 12,745412 | 924/M | 2005 | 32 | 20 | 36 | 11 x 11 | BO | Ravenna | bitubolare | RUBICONE | | | 2 | No |
| 100 | 247 | NAOMI PANDORA | ZA | off12 | A.C 33.AG | ENI | GAS | 44,689089 | 12,847416 | 924/M | 2000 | 48 | 55 | 36 | 48 x 49 | BO | Ravenna | struttura reticolare 4 gambe | CASALBORSETTI | | | 3 | No |
| 101 | 291 | OMBRINA MARE 2 | ZB | on12 | B.R269.GC | MEDOILGAS | OLIO | 42,323409 | 14,533455 | 922/M | 2008 | 6 | | | | RM | Ortona | monotubolare | | Pozzo potenzialmente produttivo ma non erogante perforato nel permesso di ricerca B.R269.GC in attesa del conferimento della concessione di coltivazione richiesta con istanza d 30 B.C-.MD | Inattiva | 1 | No |
| 102 | 295 | PANDA 1 | ZG | on12 | G.R 14.AG | ENI | GAS | 37,006610 | 13,623818 | 917/M | 2002 | 22 | | 461 | | NA | Porto Empedocle | testa pozzo sottomarina | | Pozzo potenzialmente produttivo ma non erogante perforato nel permesso di ricerca G.R 14.AG in attesa del conferimento della concessione di coltivazione richiesta con istanza d 2 G.C-.AG | Inattiva | 1 | No |
| 103 | 296 | PANDA W 1 | ZG | on12 | G.R 14.AG | ENI | GAS | 37,000607 | 13,594536 | 917/M | 2003 | 22 | | 517 | | NA | Porto Empedocle | testa pozzo sottomarina | | Pozzo potenzialmente produttivo ma non erogante perforato nel permesso di ricerca G.R 14.AG in attesa del conferimento della concessione di coltivazione richiesta con istanza d 2 G.C-.AG | Inattiva | 1 | No |
| 104 | 248 | PENNINA | ZB | off12 | B.C 15.AV | ADRIATICA IDROCARBURI | GAS | 43,021356 | 14,163626 | 922/M | 1988 | 23 | 34 | 72 | 48 x 22 | RM | Pesaro | struttura reticolare 8 gambe | GROTTAMMARE | Collegata alla centrale GROTTAMMARE - Raccorda alla centrale GROTTAMMARE la testa pozzo sottomarina ELENA 1 | | 6 | No |
| 105 | 249 | PERLA | ZC | on12 | C.C 3.AG | ENI MEDITERRANEA IDROCARBURI | OLIO | 36,954193 | 14,216245 | 917/M | 1983 | 13 | 24 | 70 | 22 x 22 | NA | Gela | struttura reticolare 4 gambe | CENTRO RACCOLTA OLIO PERLA E PREZIOSO | | | 4 | No |
| 106 | 251 | PORTO CORSINI 80 | ZA | on12 | A.C 26.EA | ENI | GAS | 44,405640 | 12,546216 | 924/M | 1981 | 19 | 50 | 25 | 46 x 22 | BO | Ravenna | struttura reticolare 8 gambe | RAVENNA MARE | | | 12 | No |
| 107 | 252 | PORTO CORSINI 80 BIS | ZA | on12 | A.C 26.EA | ENI | GAS | 44,423353 | 12,520281 | 924/M | 1983 | 17 | 50 | 23 | 56 x 25 | BO | Ravenna | struttura reticolare 8 gambe | RAVENNA MARE | | | 10 | No |
| 108 | 253 | PORTO CORSINI M E C | ZA | on12 | A.C 26.EA | ENI | GAS | 44,391356 | 12,560198 | 924/M | 1987 | 20 | 42 | 24 | 49 x 22 | BO | Ravenna | struttura reticolare 8 gambe | RAVENNA MARE | | | 15 | No |
| 109 | 254 | PORTO CORSINI M S 1 | ZA | on12 | A.C 26.EA | ENI | GAS | 44,348638 | 12,588897 | 924/M | 2000 | 20 | 20 | 24 | 8 x 8 | BO | Ravenna | monotubolare | RAVENNA MARE | | | 1 | No |
| 110 | 255 | PORTO CORSINI M S 2 | ZA | on12 | A.C 26.EA | ENI | GAS | 44,368807 | 12,576923 | 924/M | 2001 | 20 | 20 | 24 | 8 x 8 | BO | Ravenna | monotubolare | RAVENNA MARE | | | 1 | No |
| 111 | 256 | PORTO CORSINI M W A | ZA | on12 | A.C 26.EA | ENI | GAS | 44,511783 | 12,359541 | 924/M | 1968 | 7 | 31 | 13 | 167 x 27 | BO | Ravenna | struttura reticolare 12 gambe | CASALBORSETTI | Piattaforma collegata in unica struttura con la piattaforma PORTO CORSINI W T | | 8 | No |
| 112 | 257 | PORTO CORSINI M W B | ZA | on12 | A.C 26.EA | ENI | GAS | 44,509278 | 12,373809 | 924/M | 1968 | 8 | 31 | 14 | 90 x 27 | BO | Ravenna | struttura reticolare 12 gambe | CASALBORSETTI | | | 8 | No |
| 113 | 258 | PORTO CORSINI M W C | ZA | on12 | A.C 26.EA | ENI | GAS | 44,508964 | 12,372787 | 924/M | 1987 | 8 | 54 | 14 | 30 x 165 | BO | Ravenna | struttura reticolare 8 gambe | CASALBORSETTI | | | 12 | No |
| 114 | 259 | PORTO CORSINI M W T | ZA | on12 | A.C 26.EA | ENI | GAS | 44,512380 | 12,359295 | 924/M | 1987 | 8 | 54 | 13 | 22 x 22 | BO | Ravenna | struttura reticolare 4 gambe | CASALBORSETTI | Piattaforma collegata in unica struttura con la piattaforma PORTO CORSINI W A | | 0 | SI |
| 115 | 260 | PREZIOSO | ZC | on12 | C.C 3.AG | ENI MEDITERRANEA IDROCARBURI | OLIO | 37,009175 | 14,045081 | 917/M | 1988 | 12 | 44 | 45 | 27 x 70 | NA | Gela | struttura reticolare 8 gambe | CENTRO RACCOLTA OLIO PERLA E PREZIOSO | | | 9 | No |
| 116 | 261 | REGINA | ZA | on12 | A.C 17.AG | ENI | GAS | 44,104920 | 12,840342 | 923/M | 1997 | 17 | 60 | 22 | 30 x 25 | BO | Rimini | struttura reticolare 4 gambe | FANO | | | 6 | No |
| 117 | 262 | REGINA 1 | ZA | on12 | A.C 17.AG | ENI | GAS | 44,102781 | 12,834209 | 923/M | 1997 | 17 | 30 | 21 | 8 x 8 | BO | Rimini | monotubolare | FANO | | | 1 | No |
| 118 | 263 | ROSPO MARE A | ZB | on12 | B.C 8.LF | EDISON | OLIO | 42,203712 | 14,970746 | 922/M | 1981 | 21 | 21 | 76 | 33 x 26 | RM | Termoli | struttura reticolare 4 gambe | ALBA MARINA | Collegata alla piattaforma ROSPO MARE B | | 10 | No |
| 119 | 264 | ROSPO MARE B | ZB | on12 | B.C 8.LF | EDISON | OLIO | 42,213157 | 14,946579 | 922/M | 1986 | 20 | 31 | 77 | 52 x 26 | RM | Termoli | struttura reticolare 8 gambe | ALBA MARINA | Collegata a unità galleggiante ALBA MARINA. Raccorda alla unità galleggiante ALBA MARINA le piattaforme ROSPO MARE A e ROSPO MARE C | | 12 | No |
| 120 | 265 | ROSPO MARE C | ZB | on12 | B.C 8.LF | EDISON | OLIO | 42,235657 | 14,931856 | 922/M | 1991 | 19 | 19 | 80 | 29 x 29 | RM | Ortona | struttura reticolare 4 gambe | ALBA MARINA | Collegata alla piattaforma ROSPO MARE B | | 9 | No |
| 121 | 266 | SAN GIORGIO MARE 3 | ZB | on12 | B.C 2.LF | EDISON | GAS | 43,197901 | 13,923748 | 922/M | 1972 | 11 | 12 | 18 | 7 x 5 | RM | San Benedetto | struttura reticolare 4 gambe | SAN GIORGIO MARE | | | 1 | No |
| 122 | 267 | SAN GIORGIO MARE 6 | ZB | on12 | B.C 2.LF | EDISON | GAS | 43,206235 | 13,920136 | 922/M | 1981 | 11 | 12 | 18 | 7 x 5 | RM | San Benedetto | struttura reticolare 4 gambe | SAN GIORGIO MARE | | | 1 | No |

**Annex 1.1** - Cont.



| N. | Id | Nome piattaforma | Zona | 12 Miglia | Concessione dove è installata | Operatore | Minerale | Latitudine | Longitudine | Foglio I.I.M. | Anno di installazione | Distanza dalla costa (km) | Altezza SLM (m) | Profondità fondale (m) | Dimensioni parti emerse | Sezione UNMIG | Capitaneria di porto | Tipo di piattaforma | Collegamento a centrale | Note | Status | Numero pozzi produttivi | Piattaforma di supporto alla produzione |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 123 | 268 | SAN GIORGIO MARE CENTRALE | ZB | on12 | B.C 2.LF | EDISON | GAS | 43,202624 | 13,901802 | 922/M | 1972 | 10 | 12 | 18 | 9 x 9 | RM | San Benedetto | struttura reticolare 4 gambe | SAN GIORGIO MARE | | | 0 | Si |
| 124 | 269 | SANTO STEFANO MARE 101 | ZB | on12 | B.C 1.LF | EDISON | GAS | 42,228990 | 14,607395 | 922/M | 1987 | 2 | 13 | 13 | 10 x 10 | RM | Ortona | struttura reticolare 4 gambe | SANTO STEFANO MARE | | | 1 | No |
| 125 | 270 | SANTO STEFANO MARE 1-9 | ZB | on12 | B.C 1.LF | EDISON | GAS | 42,231768 | 14,592950 | 922/M | 1968 | 2 | 8 | 13 | 9 x 9 | RM | Ortona | struttura reticolare 5 gambe | SANTO STEFANO MARE | | | 2 | No |
| 126 | 271 | SANTO STEFANO MARE 3-7 | ZB | on12 | B.C 1.LF | EDISON | GAS | 42,219268 | 14,610729 | 922/M | 1968 | 2 | 8 | 12 | 9 x 9 | RM | Ortona | struttura reticolare 4 gambe | SANTO STEFANO MARE | | | 2 | No |
| 127 | 272 | SANTO STEFANO MARE 4 | ZB | on12 | B.C 1.LF | EDISON | GAS | 42,207323 | 14,675454 | 922/M | 1975 | 3 | 8 | 17 | 5 x 7 | RM | Ortona | struttura reticolare 4 gambe | SANTO STEFANO MARE | | | 1 | No |
| 128 | 273 | SANTO STEFANO MARE 8 | ZB | on12 | B.C 1.LF | EDISON | GAS | 42,216490 | 14,636563 | 922/M | 1991 | 2 | 15 | 15 | 6 x 9 | RM | Ortona | monotubolare | SANTO STEFANO MARE | | | 1 | No |
| 129 | 274 | SARAGO MARE 1 | ZB | on12 | B.C 7.LF | EDISON | OLIO | 43,320960 | 13,785407 | 922/M | 1981 | 4 | 10 | 12 | 8 x 6 | RM | San Benedetto | struttura reticolare 4 gambe | MARIA MARE | | | 1 | No |
| 130 | 275 | SARAGO MARE A | ZB | on12 | B.C 7.LF | EDISON | OLIO | 43,288851 | 13,788738 | 922/M | 1981 | 3 | 30 | 12 | 44 x 26 | RM | San Benedetto | struttura reticolare 8 gambe | MARIA MARE | | | 5 | No |
| 131 | 276 | SIMONETTA 1 | ZB | on12 | B.C 5.AS | ADRIATICA IDROCARBURI | GAS | 42,559691 | 14,183769 | 922/M | 1997 | 10 | 21 | 17 | 8 x 8 | RM | Pesaro | monotubolare | PINETO | Collegata alla piattaforma FRATELLO EST | | 1 | No |
| 132 | 277 | SQUALO | ZB | on12 | B.C 9.AS | ADRIATICA IDROCARBURI | GAS | 42,715657 | 14,244378 | 922/M | 1980 | 18 | 28 | 70 | 22 x 22 | RM | Pesaro | struttura reticolare 4 gambe | PINETO | Collegata alla centrale PINETO | | 6 | No |
| 133 | 278 | TEA | ZA | off12 | A.C 34.AG | ENI | GAS | 44,501557 | 13,018813 | 924/M | 2007 | 58 | 32 | 41 | 24 x 40 | BO | Ravenna | struttura reticolare 4 gambe | RAVENNA MARE | Collegata alla centrale RAVENNA MARE. Raccorda alla centrale RAVENNA MARE la piattaforma GUENDALINA. [aggiornare collegamenti] | | 4 | No |
| 134 | 279 | VEGA A | ZC | on12 | C.C 6.EO | EDISON | OLIO | 36,540638 | 14,625491 | 917/M | 1986 | 22 | 69 | 124 | 80 x 60 | NA | Pozzallo | struttura reticolare 8 gambe | LEONIS | Collegata alla unità galleggiante LEONIS | | 20 | No |
| 135 | 281 | VIVIANA 1 | ZB | on12 | B.C 5.AS | ADRIATICA IDROCARBURI | GAS | 42,656403 | 14,155051 | 922/M | 1998 | 9 | 19 | 20 | 8 x 8 | RM | Pesaro | monotubolare | PINETO | Collegata a alla piattaforma FRATELLO NORD | | 1 | No |
| 136 | 282 | VONGOLA MARE 1 | ZB | on12 | B.C 7.LF | EDISON | GAS | 43,253892 | 13,811731 | 922/M | 1985 | 5 | 12 | 14 | 10 x 10 | RM | San Benedetto | struttura reticolare 4 gambe | SAN GIORGIO MARE | | | 1 | No |

# 2. BIOCHEMICAL COMPOSITION AND SPATIAL DISTRIBUTION OF ORGANIC MATTER IN THE SEDIMENT AT OFFSHORE GAS STRUCTURES

## ABSTRACT

Beyond their primary purpose, offshore gas platforms, because of their architectural complexity and extension along the entire water column, can exert relevant ecological effects on hosting ecosystems, thus strongly influencing the surrounding environment and communities.

In this study the spatial variability of organic matter (OM) content and biochemical composition were investigated to test the null hypothesis that the benthic trophic status is not affected by the presence of offshore artificial structures. Sediment samples collected at increasing distance (0, 30 and 120 m) from two different offshore artificial structures (one subsea well-site and one four-leg platform) were analyzed for chloropigment (chlorophyll-a and phaeopigments), protein, carbohydrate and lipid contents. The results evidenced that the presence of offshore artificial structures, while having only limited effects on OM contents, can influence its biochemical composition. In addition, the magnitude of this change is affected by the dimension and architectural building of the structures. In fact, only the four-leg platform seems to have an effect on the chlorophyll-a and phaeopigments contents. The spatial extent of this effect was estimated to be evident up to 30 m distance from the structure.

## INTRODUCTION

Quantity and nutritional quality (*viz*. biochemical composition, *sensu* Pusceddu *et al.,* 2009) of organic matter in marine surface sediments affect benthic community structure and metabolism (Graf, 1992; Fabiano *et al.,* 1995; Dell'Anno *et al.,* 2003). Microphytobenthos is one of the main food sources for benthic organisms (Koop and Griffith, 1982; Plante-Cuny and Plante, 1986) and its contribution to the sedimentary OM represents a reliable descriptor of its nutritional quality (Pusceddu *et al*., 2003; 2009). For this reason, the knowledge of OM contents and, in particular, of phytopigment concentrations is of primary importance in benthic trophodynamic studies (Mayer, 1989; Fabiano *et al.,* 1995).

Recent studies have suggested the use of the carbohydrate, lipid and protein sedimentary contents as indicators of the trophic status of sediments in different marine ecosystems, from the coastal areas to the deep sea (Pusceddu *et al*., 2007a; 2007b; 2009; 2010; 2011a; 2011b). These three biochemical classes of organic compounds (usually referred to as biopolymeric organic carbon, BPC; Fabiano *et al*., 1995) all together account up to 70% of total organic carbon and represent a quite reactive fraction of sedimentary organic carbon (Dell'Anno *et al*., 2002; Pusceddu *et al*., 2007b). In fact, similar BPC contents may be characterized by different contributions of each single component, which depend upon either the origin of the organic matter or the system's efficiency in preferentially removing (mobilizing) labile rather than refractory molecules (Pusceddu *et al.*, 2003).

Until now, an increasing number of studies has been dedicated to the organic matter nutritional quality through the analysis of its biochemical composition (Fabiano *et al.,* 1995; Pusceddu *et al.,* 1999; Tselepides *et al.,* 2000, Pusceddu *et al*., 2009).

In the Mediterranean Sea, in particular, several studies have been conducted to investigate the quantity and biochemical composition of organic matter in relation to different environmental conditions, habitats and pressures, such as bottom trawling (Pusceddu *et al.,* 2005; 2014), river outflow (Dell'Anno *et al*., 2003; 2008), anthropogenically impacted areas (Dell'Anno *et al*., 2002; Bianchelli *et al*., 2016), coastal lagoons (Manini *et al*., 2003; Pusceddu *et al.,* 2003; 2007b; Pusceddu and Danovaro, 2009), fish farming activities (Pusceddu *et al*., 2007a; 2011b), sediments surrounding coral and gorgonian forests (Cerrano *et al*., 2010; Bianchelli *et al.,* 2013; Cerrano *et al*., 2015). However, to my best knowledge, no studies have been performed yet to evaluate the potential effects of oil and gas offshore platforms on the quantity and quality of sedimentary organic matter.

The distribution of organic matter on the sea floor largely depends upon primary productivity of the overlying water column which, in turn, is controlled by a complex array of factors including water column structure and circulation (Dell'Anno *et al.,* 2003). For this reason, I hypothesized that the presence of an artificial structure, while altering local circulation and currents, could modify OM contents in the sediments. In fact, it is known that these structures play an important role modifying the habitat and causing some environmental alterations, such as changes in local water currents, variations in sediment erosion or sedimentation rates, modification in bottom morphology, variation in sediment grain size and total organic contents (Manfra and Maggi, 2012). In addition, one year after rig construction, most of the submerged part of the platform structures host large fouling communities, mainly represented by mussels, but also by barnacles and bryozoans (see for instance, Stachowitsch *et al.,* 2002; Fabi *et al*., 2007; Trabucco *et al*., 2008; Spagnolo *et al.,* 2009; Manoukian *et al.,* 2010; Gomiero *et al*., 2011), whose biological activities produce large amounts of organic particles which settle on the sea bottom. For example, bivalves, falling from the platform legs could form very large mounds on the sea bottom, leading to an enrichment of the community and the development of alternative trophic chains (Bomkamp *et al*., 2004).

In this study, I tested the null hypothesis that the quantity and biochemical composition of organic matter in the sediment are not affected by the presence of offshore artificial structures.

## MATERIALS AND METHODS

### STUDY AREA AND SAMPLING DESIGN

The study was conducted in the north-central Adriatic Sea, where two artificial structures (one subsea production system and one four-leg platform) were investigated for two consecutive years after their installation (Figure 2.1).

The subsea production system (hereafter called Structure A) is located 30 nm offshore Ancona (central Adriatic Sea) at about 80 m of depth, on a sandy bottom. It consists of two well sites situated 6.5 m far from the other (center-center) inside a protection structure extending up to 5 m along the water column. The two well sites are linked together by a spool and the overall production is sent to a platform located 3.5 nm far from the well sites. The area is subjected to the Po river inflow.

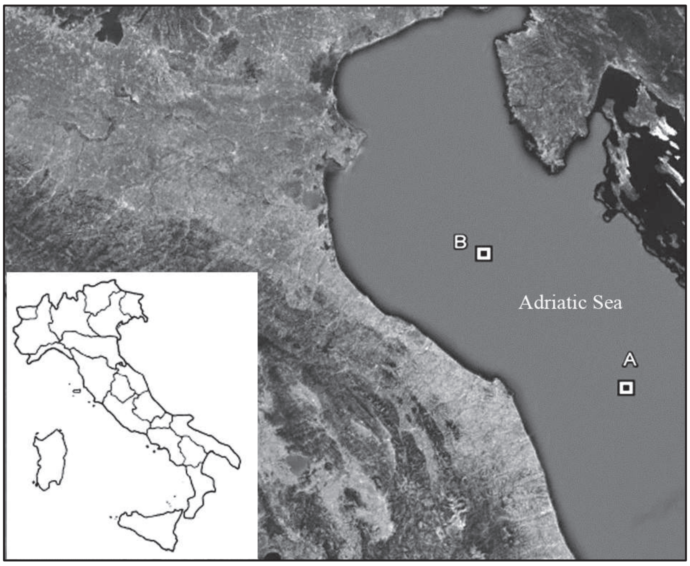


**Figure 2.1** - Study area. A and B: investigated artificial structures.

The second structure (hereafter indicated as Structure B) is a four-leg gas platform placed at 32 nm offshore Pesaro (northern Adriatic Sea) at a depth of about 60 m, in an area of offshore relict sands. The area is weakly influenced by the general circulation of the northern Adriatic Sea (usually going northwards along the Croatian coasts and southwards along the Italian side), but sometimes can be exposed to a stout hydrodinamism due to the bottom flow of dense and cold water originated in the north Adriatic during winter. These seasonal density currents are known to modify the biogeochemical properties and the spatial distribution of the sediments (Foglini *et al*., 2015). In addition, the upper layers of the water column (down to 20 m depth) can be hit by strong winds coming from North (called Bora).

At each structure, two surveys were performed and samples were collected from three sampling sites randomly selected at rising distances from the rig/well site: close to the structure (about 5 m, hereafter called 0 m) and then at 30 and 120 m from it. In each survey and at each site, three sediment samples were collected using a box corer (170 cm$^2$), totalling 9 samples per site per cruise. At each sampling site, an additional sediment sample was collected to analyse grain particle size.

The quantity and biochemical composition of sedimentary organic matter was analyzed on the top 1 cm of sediment cores obtained inserting manually Plexiglas corers in the sediment obtained from each independent box-corer deployment. I chosen to analyse only the top 1st centimeter because it ususally includes the most recent and most reactive organic matter. Sediment aliquots for biochemical analyses were stored at −20°C in Petri dishes until analyses in the laboratory.

## BIOCHEMICAL COMPOSITION OF SEDIMENT ORGANIC MATTER

Chlorophyll-a and phaeopigment analyses were carried out according to Lorenzen and Jeffrey (1980). For all of the sampling sites, pigments were extracted from superficial (0–1 cm) sediment samples (about 1 g) using 3–5 ml of 90% acetone as the extractant (24 h in the dark at 4°C). Extracts were analyzed fluorometrically to estimate chlorophyll-a, and, after acidification with 200 ml 0.1N HCl, to estimate the amounts of phaeopigments. Total phytopigment concentrations (hereafter Chloroplastic pigment equivalents, CPE) were defined as the sum of chlorophyll-a and phaeopigment concentrations, and utilized as an estimate of the organic material of algal origin, including the living (chlorophyll-a) and senescent/detrital (phaeopigment) fractions (Pusceddu *et al*., 2009; 2011a).

Protein, carbohydrate and lipid contents of the sediments were determined spectrophotometrically, according to Danovaro (2010). For the analysis of each biochemical assay, blanks were obtained using pre-combusted sediments (450°C, 2 h). Protein, carbohydrate and lipid contents were converted into carbon equivalents using the conversion factors of 0.49, 0.40 and 0.75 mg C mg$^{-1}$, respectively, and their sum defined as the biopolymeric organic carbon (BPC; Pusceddu *et al*., 2000). Sediment phytopigment concentrations were converted into carbon equivalents using a mean value of 40 μg C μg phytopigment$^{-1}$, and the percentage contribution of sediment phytopigments to BPC used as a proxy of the nutritional quality of sedimentary organic matter (Pusceddu *et al*., 2000; 2009; 2010).

## GRAIN SIZE ANALYSIS

Sediment samples were analyzed for their grain size composition according to the Udden–Wentworth Phi classification by a stack of geological test-sieves ranging from 0 Phi to +4 Phi (Wentworth, 1922), whereas the fine fraction was analyzed by sedigraph.

### DATA ANALYSIS

To explore the relationships between quantity and nutritional quality of sedimentary organic matter and sediment grain size (percent sand, silt and clay), Spearman's rank correlation tests (Siegel and Castellan, 1988) were carried out among the measured variables, pooling together data from all sampling sites and sampling periods.

To test the null hypothesis that the quantity and biochemical composition of organic matter do not differ significantly among sampling site, 1-way analysis of variance (ANOVA) was performed for each variable separately taking into account 'distance from the structure' (Distance hereafter) as a fixed factor with 3 levels (0, 30 and 120). Prior to ANOVAs, the normal distribution and heterogeneity of variances were evaluated by the Kolmogorov-Smirnov and Bartlett tests, respectively (Lindman, 1992). When significant differences were observed, Tukey's HSD tests (Lindman, 1992) were then applied to compare all pairs of group means.

The same experimental design was applied to perform PERMANOVA tests. The analysis, based on Euclidean distance matrices after normalization of the data, was carried out in the multivariate context (i.e. including all the measured variables) and separately for the two structures. To visualize differences among sampling sites in the sedimentary organic matter composition a Canonical Analysis of Principal Coordinates (CAP) was performed. This analysis also allowed to identify the variables which control the ordination (Anderson and Willis, 2003). All the multivariate analysis were carried out using PRIMER 6.1.11 and PERMANOVA+ software developed by Plymouth Marine Laboratory (Clarke and Gorley, 2006; Anderson *et al.*, 2008).

## RESULTS

Protein and lipid contents along with two of three nutritional quality indicators (namely protein to BPC and protein to carbohydrate ratios) showed significant and negative relationships with sand and positive with silt (Table 2.1).

**Table 2.1** - Spearman's rank correlation coefficient between organic matter quantity and nutritional quality in respect to the three size fractions of sediment grain. Significant correlations ($p<0.05$) are in bold. Chl-a: Chlorophyll-a; PHA: phaeopigment; PRT: Protein; CHO: Carbohydrate; LIP: Lipid; BPC: Biopolymeric carbon; CPE: Chloroplastic pigment equivalents.

| | Chl-a | PHA | PRT | CHO | LIP | BPC | CPE:BPC | PRT:BPC | PRT:CHO |
|---|---|---|---|---|---|---|---|---|---|
| sand | -0.13 | -0.16 | **-0.08** | -0.30 | **-0.36** | -0.31 | 0.02 | **-0.01** | **-0.11** |
| silt | 0.20 | 0.25 | **0.12** | 0.26 | **0.33** | 0.28 | 0.02 | **0.08** | **0.19** |
| clay | -0.01 | 0.02 | 0.02 | 0.35 | 0.38 | 0.33 | -0.08 | -0.12 | -0.03 |

## STRUCTURE A

*Univariate analyses*

Grain size did not show any significant variation at the spatial scale under scrutiny ($p>0.05$), and was characterized by a general predominance of sand (>80%) at each site (Figure 2.2).

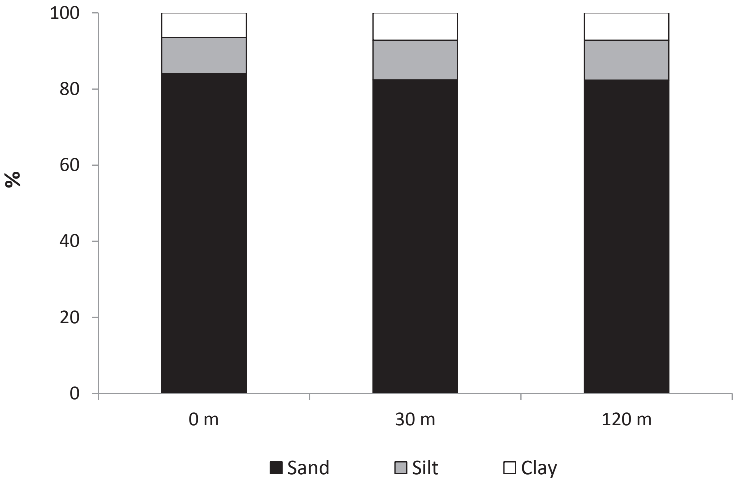


**Figure 2.2** - Grain size at the different sampling sites at Structure A.

Spatial variations in chlorophyll-a, phaeopigment, carbohydrate, protein, lipid and biopolymeric carbon at structure A are shown in Figure 2.3, whereas the indicators of nutritional quality of sedimentary organic matter are reported in Table 2.2.

Carbohydrates represented the dominant fraction of BPC, with mean values ranging from 0.35±0.03 mgC $g^{-1}$ (0 m) to 0.42±0.02 mgC $g^{-1}$ (120 m). Proteins were quantitatively the second most important compound, with the minimum and maximum values registered at 0 m (0.18±0.03 mgC $g^{-1}$) and at 30 m sites (0.32±0.07 mgC $g^{-1}$), respectively. Lipids represented the third main class of organic compounds, with values ranging from 0.04±0.01 mgC $g^{-1}$ (0 m sites) to 0.05±0.01 mgC $g^{-1}$ (30 and 120 m).

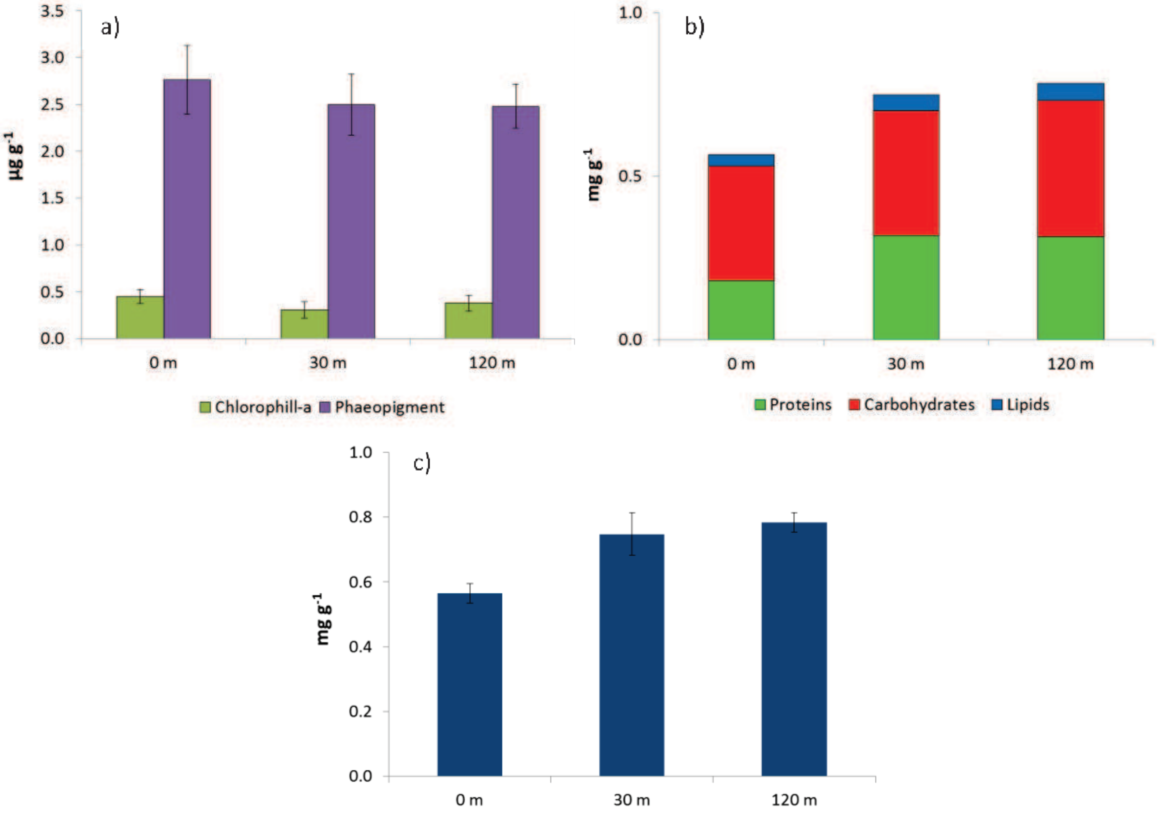


**Figure 2.3** - Mean values of a) chlorophyll-a and phaeopigments content; b) protein, carbohydrates and lipids); and c) biopolymeric carbon (BPC) at Structure A. Error bars refer to standard error.

**Table 2.2** - Nutritional quality of organic matter at Structure A.

| Site | CPE:BPC (%) | PRT:BPC (%) | PRT:CHO |
|---|---|---|---|
| 0m | 27±2 | 32±3 | 0.44±0.07 |
| 30 m | 15±2 | 41±5 | 0.73±0.20 |
| 120 m | 15±2 | 40±3 | 0.63±0.09 |

However, no significant differences among distances were evidenced by 1-way ANOVA for all the biochemical compounds concentrations, with the exception of BPC content (Table 2.3), which showed values at 0 m (0.56±0.0.3 mg $g^{-1}$) significantly lower than those at 30 m (0.75±0.06 mg $g^{-1}$) and 120 m sites (0.78±0.03 mg $g^{-1}$; Figure 2.3).

**Table 2.3** – Results of 1-way ANOVA testing for differences among sampling sites in quantity and nutritional quality of sedimentary organic matter at Structure A. Chl-a: Chlorophyll-a; PHA: phaeopigment; PRT: Protein; CHO: Carbohydrate; LIP: Lipid; BPC: Biopolymeric carbon; CPE:BPC: algal fraction of BPC; PRT:BPC: protein fraction of BPC; PRT:CHO: protein to carbohydrate ratio.

| Variable | Source | d.f. | MS | F | P | Pair-wise test |
|---|---|---|---|---|---|---|
| Chl-a | Distance | 2 | 0.031 | 0.748 | 0.49 | |
| | Residual | 15 | 0.041 | | | |
| PHA | Distance | 2 | 0.150 | 0.255 | 0.778 | |
| | Residual | 15 | 0.588 | | | |
| PRT | Distance | 2 | 0.155 | 2.966 | 0.082 | |
| | Residual | 15 | 0.052 | | | |
| CHO | Distance | 2 | 0.043 | 2.556 | 0.111 | |
| | Residual | 15 | 0.017 | | | |
| LIP | Distance | 2 | 0.001 | 1.049 | 0.375 | |
| | Residual | 15 | 0.001 | | | |
| BPC | Distance | 2 | 0.083 | 6.675 | 0.008** | 0 m < 30 m; 120 m |
| | Residual | 15 | 0.012 | | | |
| CPE:BPC | Distance | 2 | 289.6 | 13.265 | 0.000** | 0 m > 30 m; 120 m |
| | Residual | 15 | 21.8 | | | |
| PRT:BPC | Distance | 2 | 139.4 | 1.484 | 0.258 | |
| | Residual | 15 | 93.9 | | | |
| PRT:CHO | Distance | 2 | 0.127 | 1.203 | 0.328 | |
| | Residual | 15 | 0.106 | | | |

*Multivariate analyses*

The 1-way PERMANOVA analysis evidenced no significant differences among distances, as confirmed also by CAP analysis, that did not show any clear pattern in the spatial distribution of the different classes of organic compounds (Table 2.4; Figure 2.4).

**Table 2.4** - Results of 1-way PERMANOVA analyzing differences in sedimentary variables at Structure A using Distance as fixed factor.

| Source | d.f. | MS | Pseudo-F | P(perm) | Perms |
|---|---|---|---|---|---|
| Distance (Di) | 2 | 11.05 | 1.7105 | 0.112 | 999 |
| Residual | 15 | 6.46 | | | |
| Total | 17 | | | | |

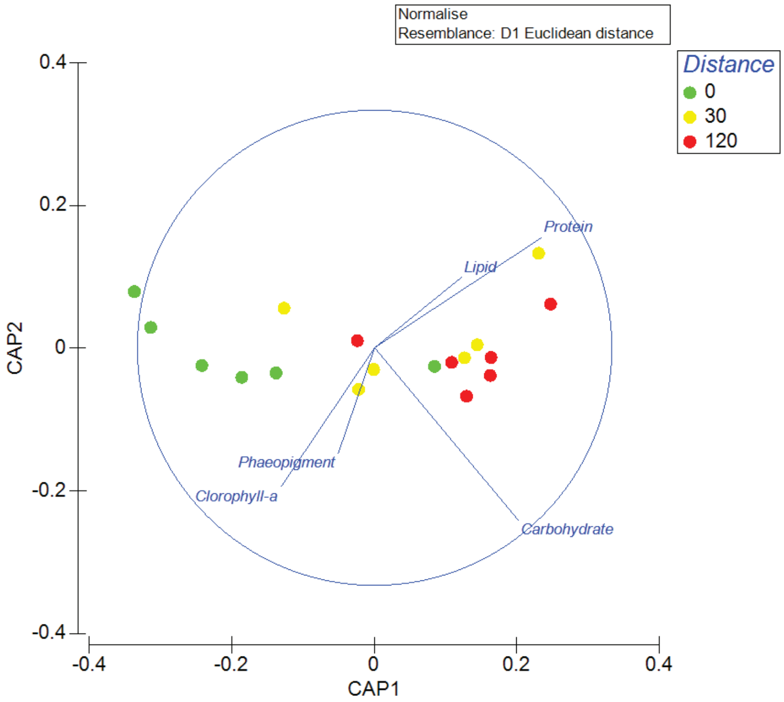


**Figure 2.4** – CAP analysis on the biochemical composition of the organic matter in the sediment collected at Structure A.

## STRUCTURE B

### *Univariate analyses*

Grain size did not vary among sampling distances, and was characterized by the predominance of sand (>70%) at each sampling sites (Figure 2.5).

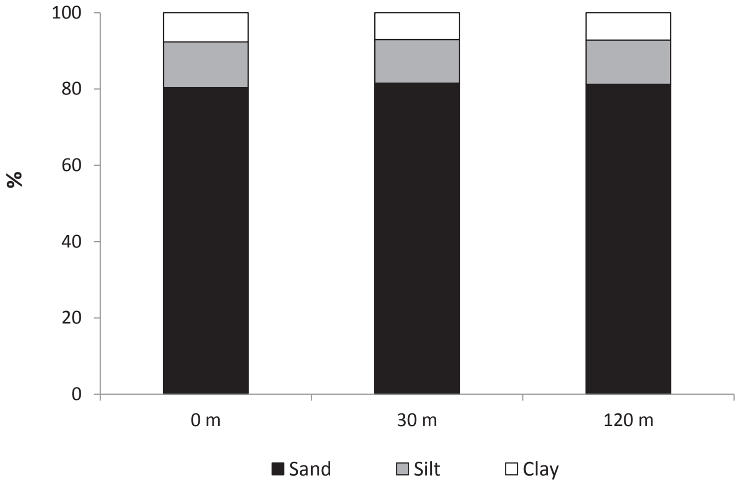


**Figure 2.5** - Grain size at the different sampling sites at Structure B.

Mean values of chlorophyll-a, phaeopigment carbohydrate, protein, lipid and biopolymeric carbon contents at Structure B are shown in Figure 2.6, whereas the mean value of nutritional quality indicators of sedimentary organic matter are reported in Table 2.5.

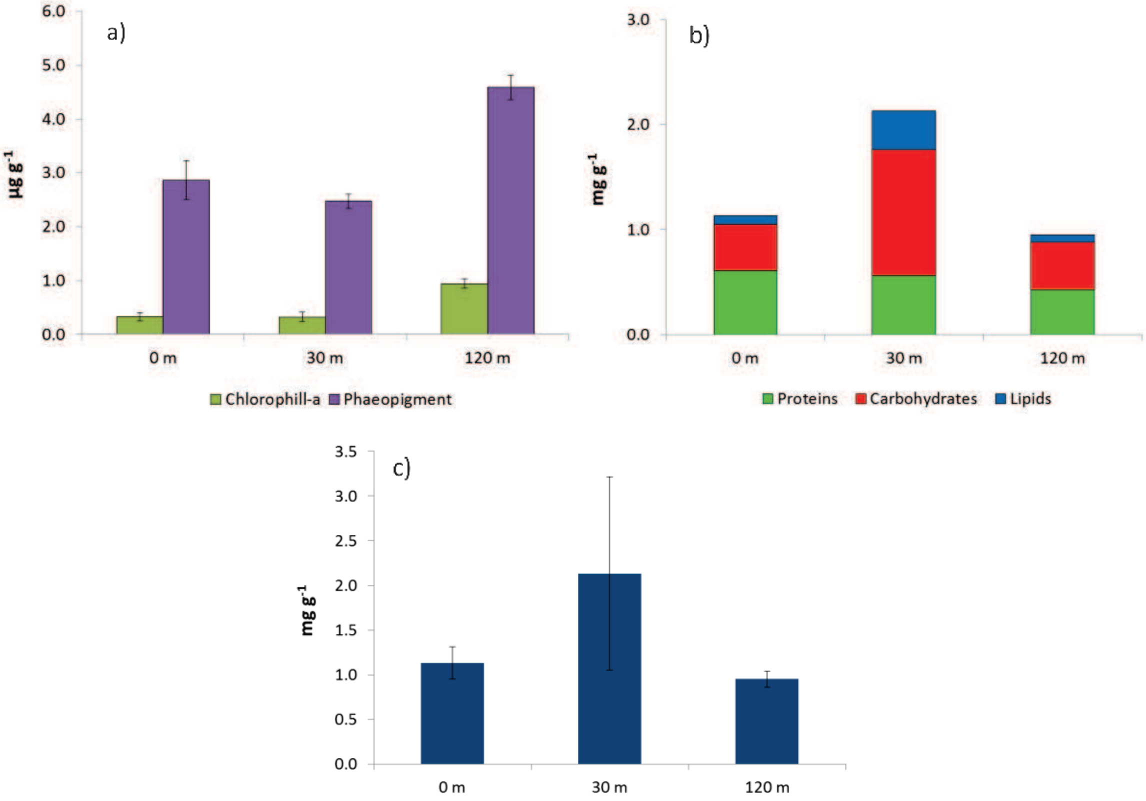


**Figure 2.6** - Mean values of a) chlorophyll-a and phaeopigments content; b) protein, carbohydrates and lipids and c) biopolymeric carbon (BPC) at Structure B. Error bars refer to standard error.

**Table 2.5** - Nutritional quality of organic matter at Structure B.

| Site | CPE:BPC (%) | PRT:BPC (%) | PRT:CHO |
|---|---|---|---|
| 0 m | 14±4 | 52±4 | 1.20±0.27 |
| 30 m | 11±2 | 41±7 | 0.84±0.20 |
| 120 m | 22±5 | 45±4 | 0.88±0.18 |

At Structure B significant differences among sampling sites emerge only for phytopigment contents (Table 2.6). Both chlorophyll-a and phaeopigment contents were significantly higher at 120 m sites (Chl-a: 0.94±0.18 μg g$^{-1}$; PHA: 4.59±0.23 μg g$^{-}$

$^{1}$) than at 0 m (Chl-a: 0.33±0.06 μg g$^{-1}$; PHA: 2.86±0.36 μg g$^{-1}$) and 30 m sites (Chl: 0.32±0.04 μg g$^{-1}$; PHA: 2.47±0.13 μg g$^{-1}$).

**Table 2.6** – Results of 1-way ANOVA testing for differences among sampling distances from the structure quantity and nutritional quality of sedimentary organic matter at Structure B. Chl-a: Chlorophyll-a; Pha: phaeopigment; PRT: Protein; CHO: Carbohydrate; LIP: Lipid; BPC: Biopolymeric carbon; CPE:BPC: algal fraction of BPC; PRT:BPC: protein fraction of BPC; PRT:CHO: protein to carbohydrate ratio.

| Variable | Source | d.f. | MS | F | P | Pair-wise test |
|---|---|---|---|---|---|---|
| Chl-a | Distance | 2 | 0.756 | 10.28 | 0.002** | 0 m; 30 m < 120 m |
| | Residual | 15 | 0.041 | | | |
| PHA | Distance | 2 | 7.598 | 25.18 | 0.000** | 0 m; 30 m < 120 m |
| | Residual | 15 | 0.302 | | | |
| PRT | Distance | 2 | 0.221 | 0.673 | 0.525 | |
| | Residual | 15 | 0.329 | | | |
| CHO | Distance | 2 | 7.023 | 0.947 | 0.41 | |
| | Residual | 15 | 7.418 | | | |
| LIP | Distance | 2 | 0.319 | 1.235 | 0.319 | |
| | Residual | 15 | 0.258 | | | |
| BPC | Distance | 2 | 2.43 | 1.003 | 0.39 | |
| | Residual | 15 | 2.423 | | | |
| CPE:BPC | Distance | 2 | 200.9 | 2.713 | 0.069 | |
| | Residual | 15 | 74.053 | | | |
| PRT:BPC | Distance | 2 | 205.89 | 1.161 | 0.34 | |
| | Residual | 15 | 177.32 | | | |
| PRT:CHO | Distance | 2 | 0.237 | 0.812 | 0.463 | |
| | Residual | 15 | 0.292 | | | |

Carbohydrates represented the main component of BPC at 0 and 30 m sites, followed by proteins and lipids. However, no significant differences were evidenced for any of the investigated compounds, as well as for BPC (Table 2.6). Mean values of carbohydrate contents ranged from 0.44±0.07 mgC g$^{-1}$ (0 m) to 1.19±0.76 mgC g$^{-1}$ (30 m), while proteins showed the lowest value at 120 m (0.43±0.06 mgC g$^{-1}$) and the highest at 0 m (0.61±0.15 mgC g$^{-1}$). Finally, lipids represented the third main class of BPC, with values ranging from 0.07±0.01 mgC g$^{-1}$ (120 m) to 0.37±0.27 mgC g$^{-1}$ (30 m).

*Multivariate analyses*

The 1-way PERMANOVA analysis evidenced significant differences in the biochemical composition of sedimentary organic matter among sampling sites at the

Structure B. Specifically, the pair-wise tests revealed significant differences between 0 m and 120 m, and between 30 m and 120 m, but no differences between 0 m and 30 m distance from the structure (Table 2.7). This was also confirmed by the bi-plot produced after the CAP analysis which showed a clear segregation of 120 m sites from the other two, mostly because of chlorophyll-a and phaeopigment contents significantly higher in the former (Figure 2.7). Sediments at 30 m distance from the Structure B were characterized by higher lipid and carbohydrate contents than those in the two other sampling sites.

**Table 2.7** - Results of 1-way PERMANOVA analyzing differences in sedimentary parameters at Structure B using Distance as fixed factor.

| Source | d.f. | MS | Pseudo-F | P(perm) | Perms |
|---|---|---|---|---|---|
| Distance (Di) | 2 | 19.153 | 3.5603 | 0.001 | 996 |
| Residual | 15 | 5.3796 | | | |
| Total | 17 | | | | |
| Pair-wise test for term Di | | | | | |
| 0 m; 30 m ≠ 120 m | | | | | |

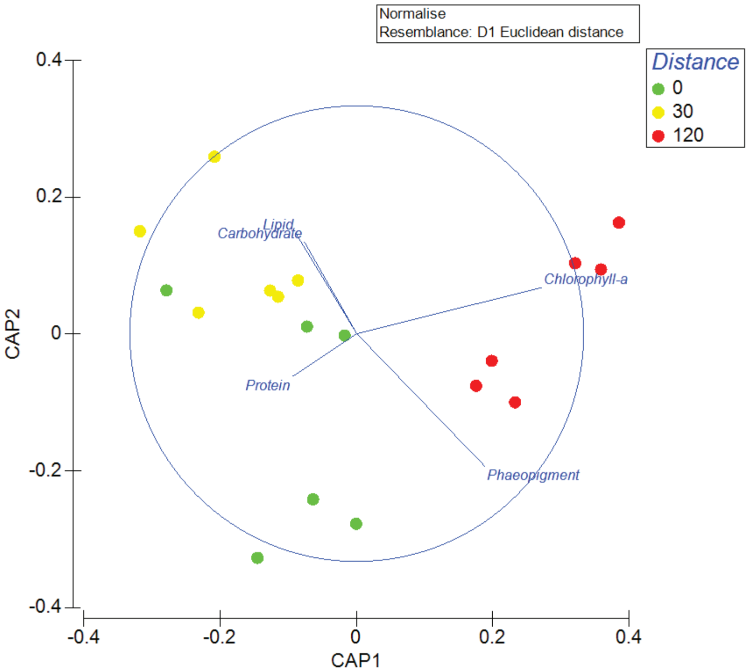


**Figure 2.7** – CAP analysis on the biochemical composition of the organic matter in the sediment collected at Structure B.

## DISCUSSION

The present study investigated the differences in quantity and quality composition of sedimentary organic matter around two offshore artificial gas structures (one subsea well-site and one four-leg platform) built in the Adriatic Sea to assess their influence.

The biopolymeric carbon has often been used as an estimate of the labile fraction of organic C, but it has been demonstrated that only a slight portion of biopolymeric C in marine sediments is actually bioavailable, thus representing only a weak descriptor of the trophic state of sediments (Pusceddu *et al.,* 2007b).

According to the threshold levels proposed by Pusceddu and Danovaro (2007), all the sediments collected at the subsea well-site should be ranked as oligotrophic, while the sediments sampled at the platform should be classified as mesotrophic (0 m and 30 m sites) and as oligotrophic (120 m site). In fact, in the surrounding of the well-site biopolymeric C showed lower values if compared with other studies conducted in the Mediterranean Sea at similar depths (Cerrano *et al.,* 2010; 2015). On the contrary, higher values were recorded at the platform, reaching values similar to those reported from highly productive areas (Dell'Anno *et al.,* 2008). In addition the results evidenced that while the biochemical composition of sedimentary organic matter at the Structure A was rather homogenous at all sampling sites, at the Structure B significantly higher contents of chlorophyll-a and phaeopigment were found at rising distance from the four-leg platform. These findings suggest that the two typologies of platform can exert different influences on the amount and biochemical composition of sedimentary organic matter. I infer that these differences could be related to the different building architecture and extension along the water column of the two structures.

As phytopigment concentrations in the sediment are a tracer of the amount of organic matter produced by photosynthesis (Dell'Anno *et al*., 2002), the higher value of chlorophyll-a and phaeopigments at 120 m sites could be explained by the fact that closer to the rig (0 and 30 m sites) there is a greater amount of filter-feeders organisms (Punzo *et al*., 2015). In fact, it is likely that these organisms, less abundant at the further distance (120 m), are responsible for the utilization of those compounds. A quite similar effect of nutritional depletion of sediments has been reported by Cerrano *et al*. (2010; 2015). Investigating the effects of the presence of gorgonian forests on the surrounding sediments, they showed that just under the colonies the amount of organic matter is significantly lower than that at few meters outside the coral forest, and concluded that this was due to the sinking particle interception activity by corals themselves.

Thus, contrarily to what expected, my study has revealed that submerged artificial structuress have no or counterintuitive effects on sedimentary organic matter contents. In fact, when present, the putative effect of the submersed structure resulted in lower OM contents, as a possible consequence of higher utilization rates of organic particles by fouling fauna associated to the structure itself. Another possible mechanism explaining this apparently counterintuitive result could be the scouring effect of the structure's pillars, around which bottom currents can remove the sediment along with their organic enrichment.

Unfortunately, I have not been able to verify the presence of this scouring mechanism, nor have I been able to investigate current speed and direction. Therefore, while this study represents a first attempt to establish the influence of offshore artificial structures on the quantity and biochemical composition of sedimentary organic matter, further studies are needed to confirm that these structures have impacts on the variability of sedimentary organic matter composition.

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# 3. SPATIAL DISTRIBUTION AND TEMPORAL VARIABILITY OF MACRO-ZOOBENTHIC COMMUNITIES AT OFFSHORE GAS STRUCTURES

## ABSTRACT

Spatial and temporal distribution of macro-zoobenthic communities around three offshore artificial structures located in the northwestern Adriatic Sea (one subsea well-site, one four-legs platform and one one-leg platform) were investigated during four surveys conducted across two years at 0, 30, 60, 120 and 1000 m distance from each structure.

Both uni- and multivariate analyses showed different spatial patterns and temporal changes of macro-zoobenthic communities in the sourrunding of the three artificial structures. These results, on the one hand, suggested that the observed variations in the stock and composition of macro-benthic communities with increasing distance from the structures could be related, to a certain extent, to the different shape and dimension of the structures themselves. Nevertheless, given also the different position at sea, these differences could be also due to the different environmental conditions surrounding the three structures. A certain fraction of temporal variability at the one-leg and four-leg platforms was likely due to the presence of bivalve mounds on the submerged part of the two structures occurring during the second year of investigation.

The results achieved in the present study highlighted also that the complexity of offshore structures can have different impacts on the pristine benthic communities, strongly affecting the amplitude and the timing required to reach a (newly) diversified and relatively stable community.

## INTRODUCTION

The Adriatic Sea is characterized by eutrophic waters and is subject to numerous, often synergistic, human-induced pressures, including coastal development (high urban density, harbors, marinas) and protection, tourism, fisheries, aquaculture, river runoff. Most importantly, it hosts the highest concentration of gas platforms of the whole Mediterranean basin, with more than 110 offshore gas platforms (Maggi *et al*., 2007) and a dense network of pipelines (unpublished data).

Offshore platforms for oil and gas extraction represent the worldwide largest man-made structures in the marine environment (Bomkamp *et al*., 2004; Friedlander *et al.,* 2014) and in the recent years their number has strongly increased, due to the raise of exploitation and research of not-renewable resources.

It is well known that oil and gas platforms, usually placed in soft sea bottoms, create an environmental discontinuity and provide hard substrates that alter the pristine habitat, enhancing biodiversity both in fish and benthic assemblages and providing the conditions for the establishment of new communities (Wolfson *et al*., 1979; Davis *et al*., 1982; Bohnsack, 1989; Herrnkind *et al.*, 1997; Fabi *et al*., 2002; 2004; 2007; Terlizzi *et al*., 2008; Trabucco *et al*., 2008; Manoukian *et al.,* 2010; Scarcella *et al*., 2011; Gomiero *et al*., 2013).

Moreover, they create a peculiar food chain support for higher-level consumers (Keenan *et al*., 2007) and may indirectly support the surrounding soft bottom benthic communities through increased production and export of organic matter (Wolfson *et al*., 1979; Page *et al*., 1999; Manoukian *et al*., 2010). These platforms may also lead to either qualitative or quantitative changes in the structure of soft-bottom benthic communities living in the area around the installations: the original communities can be affected by significant changes in competition or predation interactions, which in turn can modify trophic linkages and networks. In the Adriatic Sea, this could be a matter of concern in the long-term due to the high density of offshore platforms and related structures. Indeed, platforms could affect currents direction and intensity leading to modification of the sediment distribution and characteristics, such as particle size and sedimentation rates, altering accumulation of organic matter (Davis *et al*., 1982; Frascari *et al*., 1991; 1992; Kingston, 1992; Olsgard and Gray, 1995; Kennicutt *et al*., 1996; Wilson-Ormond *et al*., 2000; Barros *et al*., 2001; Spagnolo *et al*., 2002; Hernández Arana *et al.,* 2005; Trabucco *et al*., 2006; Terlizzi *et al*., 2008; Trabucco *et al*., 2008; Manoukian *et al*., 2010; Trabucco *et al*., 2012).

On the other hand, these structures may exert positive effects on the surrounding environment, by protecting the seabed substrates from high impacting activities, such as bottom trawling, that can be considered as the most important human impact on the seabed communities in the Adriatic Sea (Kaiser *et al.,* 2000; Lucchetti and Sala, 2012).

The ecological effect of platforms on the surrounding environment is traditionally assessed through the use of benthic organisms. They are commonly considered as good indicators of the quality of the environment as they are relatively sedentary, display long life-spans, and integrate effects of pollutants over time. They comprise diverse species that exhibit different sensitivities or tolerances to stress and also play an important role in recycling nutrients and materials between the underlying sediments and the overlying water column (Dauvin and Ruellet, 2007; Borja and Dauer, 2008). The recovery of the benthic assemblages from an unnatural perturbation is often reported as relatively fast, in the order of months to few years (Hartley and Ferbrache, 1983; Currie and Isaacs, 2005; Manoukian *et al*., 2010). However, the extent to which these perturbations affect the pristine biota and the period for full recovery depend on complex interactions between environmental features and the characteristics of the structure itself (dimension, height, material, complexity, etc.; Trabucco *et al*., 2012).

Until now the effects of offshore platforms installation in the Adriatic Sea has been studied through the assessment of macrozoobenthic communities changes (Terlizzi *et al*., 2008; Trabucco *et al*., 2008; 2012; Manoukian *et al*., 2010; Gomiero *et al*., 2013; Spagnolo *et al.,* 2014). Nevertheless, the effects of offshore gas structure dimension and complexity on the surrounding communities remain unclear.

The present study aimed at providing new insights on this issue, through the analysis of the spatial distribution and temporal variability of macro-zoobenthic communities living around three different types of offshore artificial structures, including a subsea production system, characterised by different building architectures and thus potentially different effects on benthic communities. In particular, I tested the null hypothesis that the abundance and biodiversity of macro-benthic communities are not affected by the precence of offshore artificial structures.

# MATERIALS AND METHODS

## STUDY AREA AND SAMPLING DESIGN

The study was conducted in the north-central Adriatic Sea, where three artificial structures were monitored for a period of two years (two surveys per year), starting just after their deployment (Figure 3.1).

The subsea production system (hereafter called Structure A) is located 30 nm offshore Ancona (central Adriatic Sea) at about 80 m of depth, on a sandy bottom. It consists of two well sites situated 6.5 m far from the other (center-center) inside a protection structure extending up to 5 m along the water column. The area is subjected to the Po river inflow.

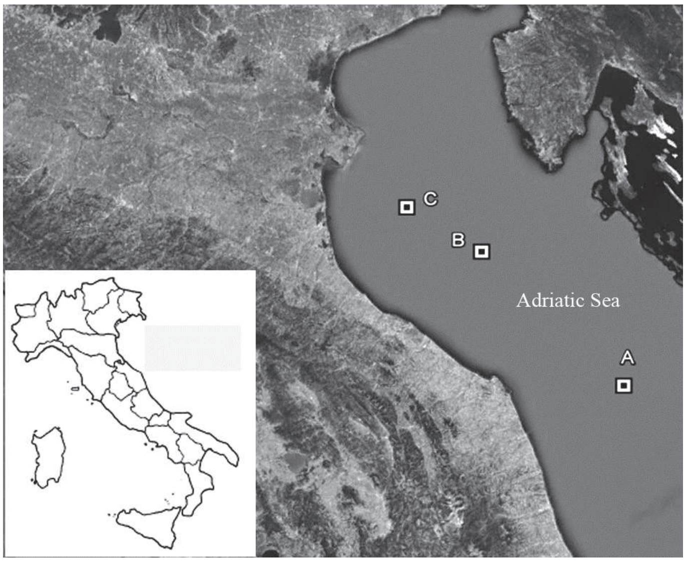

**Figure 3.1** - Study area. A, B and C: investigated artificial structures.

The second structure (hereafter indicated as Structure B) is a four-leg gas platform placed 32 nm offshore Pesaro (northern Adriatic Sea) at a depth of about 60 m. The seabed is characterized by the presence of offshore relict sands and the granulometric analysis evidenced the predominance of sands. In addition, the area is very interesting from a hydrodynamic point of view. In fact, being an area located in center of the Adriatic Sea, it is not strongly influenced by the general circulation of the basin, usually going northwards along the Croatian coasts and southwards along the Italian side. However, sometimes the area could be subjected to a stout hydrodinamism due to the bottom flow of dense water originated in the north Adriatic during winter. These currents, having different chemical and physical features, could modify the biogeochemical and spatial distribution of the sediments (Foglini *et al*., 2015). In addition, the upper layers of the water column (10-20 m) could be interested by strong wind coming from North (called Bora), that could determine changes of currents and could strongly influence sea surface temperature.

Finally, the third structure (hereafter indicated as Structure C) is a one-leg gas platform located 25 nm off Cervia (northern Adriatic Sea) at about 42 m of depth, on a sand-muddy bottom.

The sampling design was planned according to a 'gradient design' approach, used in previous studies, that is particularly useful when a stressor or disturbance attenuates with the distance from the source of impact (Ellis and Schneider, 1997; Manoukian *et al*., 2010; Punzo *et al*., 2015).

In each survey and for each structure, four sampling sites were randomly selected at rising distances from the rig/well-site: close to the structure (about 5 m; hereafter called 0), 30, 60, 120, and 1000 m from it. In each survey and at each site, 6 samples were taken using a Van Veen grab (capacity: 13 L; surface area: 0.095 $m^2$). The biological samples were sorted in situ by means of a sieve having 0.5 mm mesh size; retained organisms were fixed in 5% buffered formalin and preserved in 70% ethanol.

In the laboratory, macrofauna was sorted through a stereomicroscope and a binocular microscope, identified and classified to the species level, when possible, using standard nomenclature, numbered, and weighted.

## DATA ANALYSIS

The null hypothesis of the study was that abundance (*N*), species richness (*S*), Shannon Diversity index (*H'*), and Simpson index ($\lambda$; Simpson, 1949) and community composition of macro-zoobenthos do not differ among distances and sampling surveys.

To test this hypothesis in the univariate context (i.e. each variable separately), 2-way ANOVAs were conducted separately for each structure considering Distance and Survey as fixed factors. In the case of significant interactions among factors, a 1-way ANOVA was carried out to test for the effect of distance in each survey separately. Prior to performing ANOVAs, normal distribution and heterogeneity of variances were evaluated through the Kolmogorov-Smirnov and Bartlett tests, respectively (Lindman, 1992). When the latter was significant, the relationship between means and the respective standard deviations was analyzed to check whether the ANOVA assumptions were effective at any rate.

Spatial and temporal changes in the composition and abundance of macrofauna communities were assessed in the multivariate context using PERMANOVA under the PRIMER 6.1.11 and PERMANOVA+ packages (Clarke and Gorley, 2006; Anderson *et al.*, 2008).

The species abundance data were previously square-root transformed to reduce the contribution of prevalent taxa and therefore increase the importance of less abundance species. Afterwards, Gower exc 0-0 similarity matrix was calculated. Gower coefficient is well suited for quantitative abundance data, since it excludes double-zeros from comparison (Legendre and Legendre, 1998).

For each structure, multivariate patterns of variation among Survey (four levels fixed factor) and Distance (five levels fixed factor) factors were tested by a 2-way PERMANOVA and the significant terms were investigated using pair-wise comparisons. Successively, similarity percentage breakdown procedure (SIMPER; Clarke, 1993; Clarke and Warwick, 2001) was used to determine the contribution of individual taxa towards the dissimilarity between and similarity within distance and survey groups. Level of significance was set at $p<0.05$.

## RESULTS

### STRUCTURE A

A total of 233 macro-benthic taxa were found at the Structure A, including 88 polychaetes, 57 mollusks, 55 crustaceans, 12 echinoderms, 7 cnidarians, 5 sipunculids, 4 bryozoans, 2 ascidians and other minor taxa (3). Overall, the macro-benthic community consisted mostly of either mud- or sand-living organisms.

*Univariate analyses*

In both surveys, *N* and *S* varies significantly among surveys, whereas, in each survey, did not vary with increasing distance from the structure (Figure 3.2; Annex 3.1). Tukey's tests showed that *N* and *S* during the fourth survey were significantly higher than those in all the other sampling periods ($p<0.05$). In addition, *S* showed significant differences between the first and second surveys ($p<0.05$).

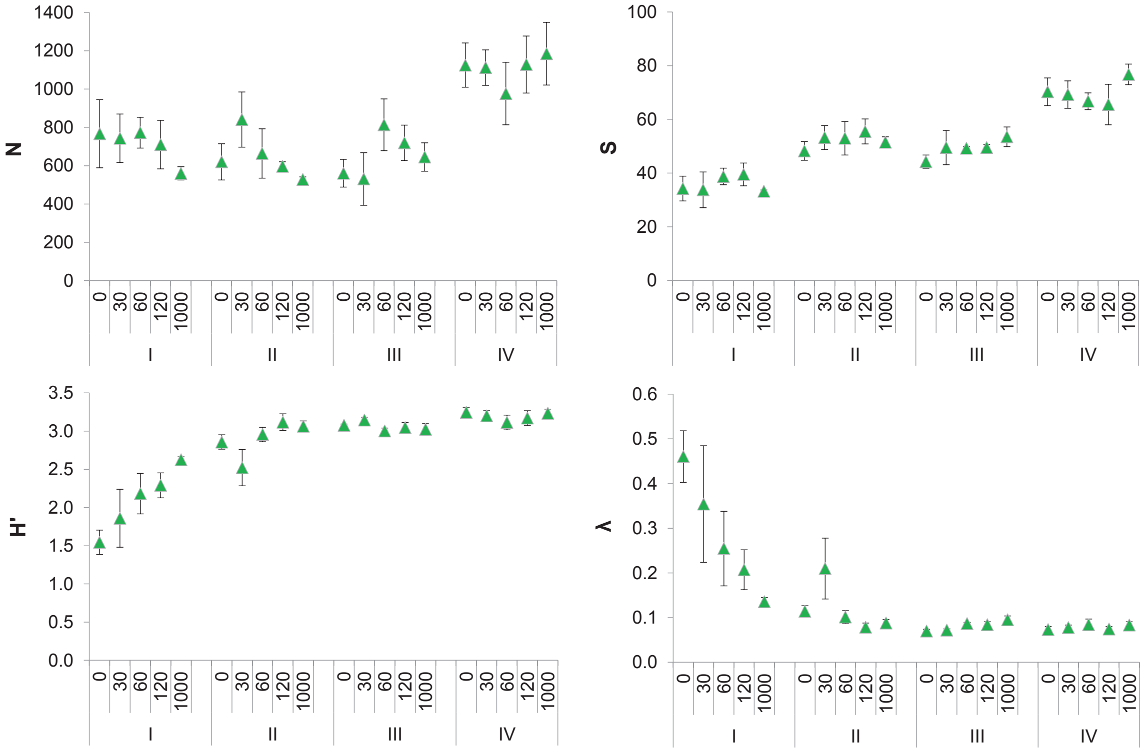

**Figure 3.2** – Mean values of univariate indices of macro-benthic communities calculated at increasing distance from Structure A during the four surveys. N: abundance (number of individuals $m^{-2}$); S: species richness; H': Shannon Diversity index; λ: Simpson index. Error bars refer to standard errors.

In both sampling periods *H'* and *λ* varied significantly among sampling sites, which is also reflected in a significant effect of the interaction Survey × Distance (Annex 3.1). The lowest *H'* value was recorded at the site at 0 m from the structure (1.54±0.16) and the highest at 1000 m (2.63±0.04; Figure 3.2), but only a few comparisons among other sampling sites resulted statistically different: 0 m vs. 120 m and 1000 m, 1000 m vs. 30 m and 120 m. The highest *λ* value occurred at 0 m distance from the structure (0.46±0.06), which however was significantly different from the value at 1000 m

(0.14±0.01; Figure 3.2). More specifically, this difference was uniquely due to the large dominance of the polychaete *Ditrupa arietina* at 0 m.

Both *H'* and $\lambda$ indices varied significantly between the first survey and all the subsequent ones ($p<0.05$). More specifically, I report here that the macro-benthic assemblages during the first survey was characterized by a less diversified community dominated by a few species, such as the polychaete *Ditrupa arietina*.

*Multivariate analyses*

Significant differences in the composition of macro-benthic communities among Distances and Surveys were found for Structure A (Table 3.1).

Pair-wise tests revealed that the compositions of macro-benthic communities at 0 m and 30 m distance from the structure were significantly different from those at 120 m and 1000 m distance, and that communities at 60 m were different from those at 1000 m. No differences were observed between communities at 120 m and 1000 m distance from the structure.

**Table 3.1** – Results of 2-way PERMANOVA and Pair-wise tests analyzing differences among macro-zoobenthos assemblages at increasing distance from Structure A during the four surveys based on Gower exc 0-0 similarity matrixes. ** = highly significant (P<0.01).

| Source | d.f. | MS | Pseudo-F | P(perm) | Perms |
|---|---|---|---|---|---|
| Survey (Su) | 3 | 5261.3 | 5.7299 | 0.001** | 999 |
| Distance (Di) | 4 | 1209.3 | 1.3171 | 0.002** | 999 |
| Di x Su | 12 | 991.26 | 1.0796 | 0.055 | 993 |
| Residual | 60 | 918.21 | | | |
| Total | 79 | | | | |
| Pair-wise tests for term Di | | | | | |
| 0m ≠ 120m; 1000m | 30m ≠ 120m; 1000m | 60m ≠ 1000m | | | |

SIMPER analysis revealed that the largest dissimilarity (49%) occurred between communities at 0 m and 1000 m distance from the structure (Annex 3.2). Such dissimilarity is mostly explained by the high abundance of the polychaete *Ditrupa arietina* and the low density of the polychaetes *Paradiopatra calliopae,* Paraonidae nd and *Nothria conchylega* at 0 m distance from the structure. The largest turnover of species on the temporal scale (57%) occurred between the first and the last survey (Annex 3.2).

## Structure B

A total of 283 taxa were found at the Structure B, including 88 polychaetes, 80 mollusks, 78 crustaceans, 14 echinoderms, 8 cnidarians, 5 bryozoans, 3 sipunculids, 2 ascidians, and other minor taxa (5). The community mostly consisted of both muddy and sandy organisms, even though since the third survey, some species typical of hard bottoms (mainly composed by *M. galloprovincialis* and polychaete serpulids) were also recorded close to the platform.

### *Univariate analyses*

As regards the index *N*, significant differences were evidenced only within the factor Survey (Figure 3.3; Annex 3.3), while no differences have been proved for factor Distance. Tukey test showed significant differences between the last survey and all the others.

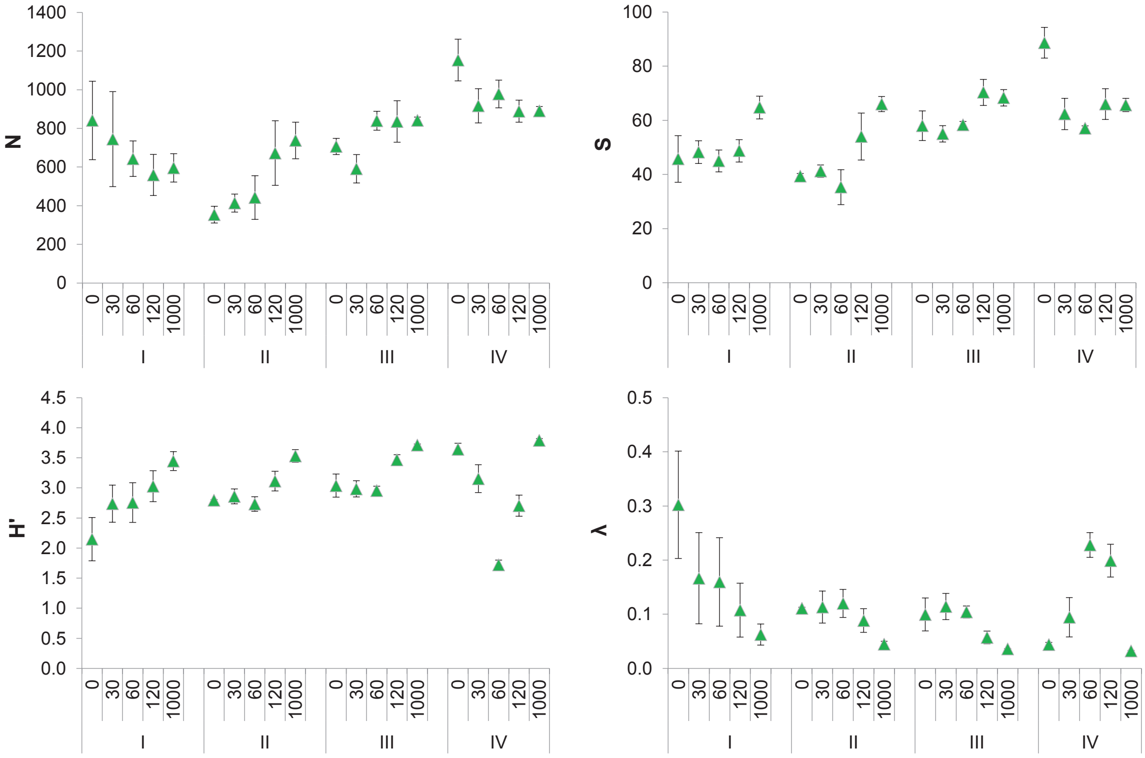

**Figure 3.3** - Mean values of univariate indices of macro-benthic communities calculated at increasing distance from Structure B during the four surveys. N: abundance (number of individuals m$^{-2}$); S: species richness; H': Shannon Diversity index; λ: Simpson index. Error bars refer to standard errors.

*S* showed a pattern similar to that recorded for *N*, with the exception of the first survey (Figure 3.3). Significant differences were evidenced for both factors but not for their interaction (Annex 3.3). In particular, in the first survey the highest value was recorded at 1000 m (64.8±4.2), even though it didn't show any significant difference in respect to the other sites. During the second survey the only difference was registered between 60 m and 1000 m, with the higher values at the latter, while no differences were evidenced in the third survey. Finally, during the last survey the highest value was registered at 0 m sites (88.7±5.7), resulting statistically different in respect to 30 m (62.3±5.8), 60 m (57.0±1.1) and 1000 m (65.7±2.5) sites.

Both *H'* and *λ* showed a different spatial trend in each sampling year causing a significant interaction between the factors Survey and Distance (Figure 3.3; Annex 3.3). As regards *H'*, in the first two surveys no differences occurred between distance, while in the third survey the highest value was recorded at 1000 m sites, resulting significant different from 0, 30 and 60 m sites. In the last survey the highest value was found at 1000 m sites (3.79±0.03), while the lowest one at 60 m sites (1.72±0.08), resulted significant differences between them and between the majority of the sites (Figure 3.3; Annex 3.3).

Looking within each survey, *λ* showed a similar pattern than that observed for *H*'. No differences have been evidenced for the first two surveys, while at the third survey 0 and 30 m sites resulted statistically different for 1000 m sites. Finally, in the fourth survey, the highest value was registered at 60 m sites and the lowest at 1000, with significant differences recorded between most of the distance (Figure 3.3; Annex 3.3).

*Multivariate analyses*

Significant differences among distances and surveys were found at Structure B (Table 3.2), indicating a potential effect of the four-leg platform on the spatial and temporal variation of macro-zoobenthic communities. Pair-wise test revealed a different spatial pattern at each sampling survey (Table 3.2).

SIMPER analysis showed the highest dissimilarity between 0 m and 1000 m sites (63%; Annex 3.4). The exclusive presence of some taxa or the higher abundance of some others at 0 m (*e.g.*, the mollusk *Falcidens gutturosus*, the polychaetes *Capitella* *capitata*, *Ampharete acutifrons* and *Owenia fusiforms*) were the major contributors to this dissimilarity.

**Table 3.2** - Results of 2-way PERMANOVA and Pair-wise tests analyzing differences among macro-zoobenthos assemblages at increasing distance from Structure B during the four surveys based on Gower exc 0-0 similarity matrixes. ** = highly significant (P<0.01).

| Source | d.f. | MS | Pseudo-F | P(perm) | Perms |
|---|---|---|---|---|---|
| Survey (Su) | 3 | 2479.7 | 3.3931 | 0.001** | 999 |
| Distance (Di) | 4 | 2749.6 | 3.7625 | 0.001** | 997 |
| Di x Su | 12 | 1077.4 | 1.4743 | 0.001** | 990 |
| Residual | 60 | 717.75 | | | |
| Total | 79 | | | | |

Pair-wise tests for term Su x Di

| I Su | II Su | III Su | IV Su |
|---|---|---|---|
| 0m ≠ 60m; 120m; 1000m<br>1000m ≠ 30m; 60m; 120m | 0m ≠120m; 1000m<br>30m≠120m; 1000m<br>60m≠120m | 0m ≠ 60m; 120m; 1000m | 0m≠120m;<br>0m≠1000m |

On temporal scale (survey groups) the highest dissimilarity (55%) has been found between the first and the last surveys while the lowest one (51%) between the first and the second survey (Annex 3.4).

### STRUCTURE C

A total of 260 taxa were recognized during the study at the Structure C. This group included 88 polychaetes, 74 mollusks, 66 crustaceans, 14 echinoderms, 6 cnidarians, 4 sipunculids, 2 ascidians, 2 bryozoans and other minor taxa (4). The community mostly consisted of both muddy and sandy organisms. Even though the majority of taxa were typical of soft-bottom communities, close to the platform hard-bottom species were also found, especially mollusks (*e.g.*, *Mytilus galloprovincialis*, *Neopycnodonte cochlear*), crustaceans (*e.g.*, *Pilumnus hirtellus*, *P. spinifer* and *Galathea* spp.) and polychaetes (*e.g.*, *Hydroides norvegicus*, *Pomatoceros triqueter*). Initially the number of these species was very low in all the sampling sites but it increased from the third survey.

### *Univariate analyses*

A similar pattern was evidenced for *N* and *S*, showing a different spatial trend in each sampling year causing a significant interaction between factors Survey and Distance (Figure 3.4; Annex 3.5).

In particular, for both indices no differences occurred among factor Distance in the two first surveys ($p>0.05$), while in the third and fourth survey higher values were recorded at 0 m sites in respect to the furthest ($p<0.05$), with the exception of the 30 m sites. In fact, at 0 m the mean value of abundance reached in the two last sampling survey was double than at the other sites.

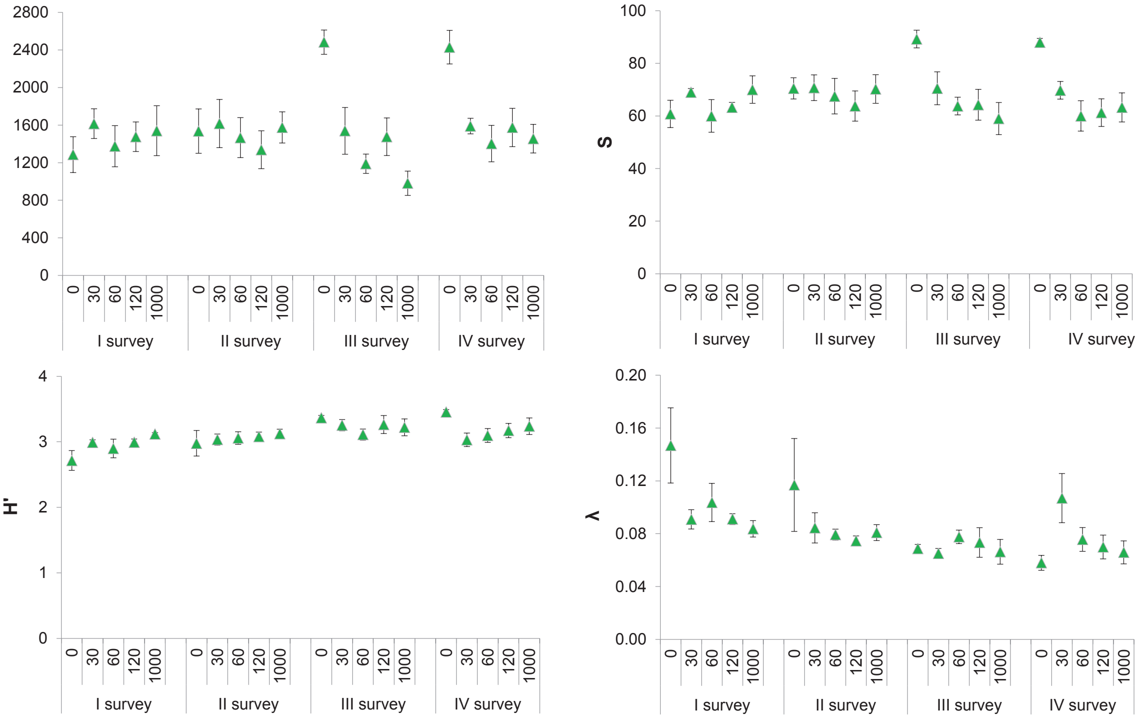

**Figure 3.4** - Mean values of univariate indices of macro-benthic communities calculated at increasing distance from Structure C during the four surveys. N: abundance (number of individuals $m^{-2}$); S: species richness; H': Shannon Diversity index; λ: Simpson index. Error bars refer to standard errors.

Shannon diversity index did not show differences within the factor Distance (Figure 3.4; Annex 3.5), while a general increased occurred starting from the third survey, evidencing statistical differences between the first and the last two surveys.

Finally, *λ* displayed a significant difference for factor Survey and also a significant interaction between Survey and Distance (Figure 3.4; Annex 3.5). Analyzing factor

Survey within each distance, only at 0 m sites were recorded significant higher value in the first survey in respect to the last two surveys.

*Multivariate analyses*

Significant differences within factor Survey and Distance and also for their interactions were found at Structure C (Table 3.3), indicating a potential effect of the platforms on the spatial and temporal variation of macro-zoobenthic communities.

Pair-wise test revealed that 0 m sites were different from 1000 m sites in the first survey, and became completely different from all the other sites in the last two surveys. On the contrary, no differences were noticed among the other distances (Table 3.3).

SIMPER analysis showed the highest dissimilarities between 0 m sites and all the other distances (Annex 3.6). The exclusive presence or the higher abundance of some taxa (such as the bivalves *Anomia ephippium* and *Kurtiella bidentata*, and the polychaetes *Sternaspis scutata* and *Minuspio cirrifera*) at 0 m were the major contributors to these dissimilarities (Annex 3.6).

**Table 3.3** - Results of 2-way PERMANOVA and Pair-wise tests analyzing differences among macro-zoobenthos assemblages at increasing distance from Structure C during the four surveys based on Gower exc 0-0 similarity matrixes. * = significant (P<0.05); ** = highly significant (P<0.01).

| Source | d.f. | MS | Pseudo-F | P(perm) | Perms |
|---|---|---|---|---|---|
| Survey (Su) | 3 | 2825.5 | 4.7081 | 0.001** | 996 |
| Distance (Di) | 4 | 2135 | 3.5575 | 0.001** | 996 |
| Su x Di | 12 | 842.64 | 1.4041 | 0.001** | 994 |
| Residual | 60 | 600.13 | | | |
| Total | 79 | | | | |

Pair-wise tests for term Su x Di

| I Su | II Su | III Su | IV Su |
|---|---|---|---|
| 0m ≠ 1000m | 0m ≠ 120m; 1000m | 0m ≠ 30m; 60m; 120m; 1000m | 0m ≠ 30m; 60m; 120m; 1000m |

On temporal scale (survey groups), the dissimilarity was slightly higher between the first and the last surveys, and slightly decreased in the comparison for the following surveys (Annex 3.6).

# DISCUSSION

Since the early 60s, a high number of offshore gas extracting platforms and related structures has been built in the Adriatic Sea. As most of them are approaching the end of their productive life, in the next few decades their decommissioning will be foreseeable (Scottish Enterprise, 2013). To approach the problem of decommissioning and the linked environmental consequences, it is therefore of primary importance to collect science-based knowledge of the effects of offshore platforms on the surrounding ecosystem.

The present study investigated the spatial and temporal variability of macro-zoobenthic communities surrounding three offshore artificial gas structures (one subsea well-site, one four-leg platform and one one-leg platform) deployed in the Adriatic Sea.

Both univariate and multivariate analyses showed different spatial patterns and temporal changes of macro-zoobenthic communities surrounding three artificial structures having different building architectures. This result, on the one hand, suggests that the observed differences in the stock and composition of macro-benthic communities among the three artificial structures could be related, to a certain extent, to the different shape and dimension of the structures themselves. Nevertheless, given also the different position at sea, these differences could be also due to the different environmental conditions.

In this regard, it is for instance worth mentioning that during the first survey a not well diversified community was recorded close to the well-site, as evidenced by the low value of *H'*, whereas at the four-leg platform the community was poor in terms of number of species and specimens. Surprisingly, in both cases the communities were dominated by the polychaete *Ditrupa arietina*. This taxa, inhabiting all types of sea bottom at depths ranging from 0 to 150 m (Gambi e Giangrande, 1985; Ten Hove and Smith, 1990), is a pioneer species and typically increases in abundance during the development of transitional communities after environmental changes, such as after dredging operations (Sardà *et al*., 2000). Even in their pioneering interpretation of the distribution of benthos in marine bottoms, Pérès and Picard (1964) related *D. arietina* with unstable soft sediments. Altogether, these information allow me suggesting that the presence of this polychaete during the first phases of my study could be related to the installation phases of the structures, confirming that the installation phase of structures at sea represents a peculiar event able to disturb manifestly the recipient benthic environment (Manfra and Maggi, 2012; Elbisy, 2015).

Starting from the second survey at the well-site, values of abundance and species richness , as well as values of Shannon Diversity and Simpson indexes were similar at all distances from the structure and overall slightly increased (or decreased for $\lambda$) till the last survey. On the contrary, in the immediate neighboring of the four-leg platform slightly higher values of abundance and species richness, as an overall sign of environmental improvement, were evident only during the fourth survey. These results suggest that the recovery times of macro-benthic communities after the installation of well-site structures (in the range of months) appeared quicker than those after installation of other platform typologies (in the order of at least two years). Such striking difference could be related to the different dimensions of the structure and to the modality of drilling activities needed to install the different structures. My findings agree with those reported previously for other structures placed in Adriatic Sea at similar depths. For instance, Manoukian *et al.* (2010) estimated two years since the installation of a platform as the time necessary for the macro-benthic to recover.

At the one-leg platform the timing of change in the macro-benthic community was rather different from that observed in the two other installations. In particular, the initial signs of impact on macro-benthos observed just after the installation of the two other installations apparently did not occur after the installation of the one-leg platform. This resulted in a persistent homogeneity in the macro-benthic community attributes among sampling sites (i.e. at increasing distance from the platform). It is worth noting here that from the third survey onwards, both abundance and species richness increased close to the platform (i.e. at the 0 m site). On the one hand, this could let hypothesizing that the improvement observed in the two other structures could have been the result of a general environmental improvement at the basin scale rather than a general recovery after structures' installation. Nevertheless, this hypothesis can be at least partially refuted since the increase in biomass observed at the one-leg platforms was almost entirely due to the development of a bivalves mound (mostly *Mytilus galloprovincialis* and *Neopycnodonte cochlear*) on the submerged part of the structure itself, rather than to a general improvement of the macro-benthic communities. The development of the large mussel mound confirms the capability of the offshore platform to host extensive fouling communities (Stachowitsch *et al*., 2002) as already found by other Authors (Fabi *et al*., 2005; 2007; Trabucco *et al*., 2006; 2008; Spagnolo *et al.,* 2002; 2006; 2009; Manoukian *et al*., 2010; Gomiero *et al*., 2011; Bergmark and Jorgensen, 2014). At the same time, I stress here that the development of such a bivalve mound allowed the establishment of a varied macro-benthic community composed by both soft- and hard-bottom species, such as the decapods *Pilumnus hirtellus*, *P. spinifer* and *Galathea* spp., the bivalves *Hiatella arctica* and *Anomia ephippium*, and the polychaetes *Hydroides* spp*.* and *Pomatoceros triqueter.* This result would allow me to conclude that the presence of platforms at sea could enhance stocks and biodiversity of macro-benthic communities, in a way similar to what observed for natural bottom "discontinuities" like seagrass meadows, kelp forests, coral reefs, and coral forests. All of these natural erected structures, abstracting the different dimension, shape and effects on bottom currents and hydrodynamics, are known to act as ecosystem engineers, favoring the colonization by many small invertebrates, enhancing habitat complexity, improving local environmental conditions, and increasing the fitness of associated species (Bruno and Bertness, 2001; Cerrano *et al.,* 2006; Borthagaray and Carranza, 2007; Cerrano *et al*., 2010; Arribas *et al.,* 2014). The apparently positive effect of offshore platform installations on macro-benthic stocks and biodiversity, however, should be considered with much caution. The presence of the platform could have caused an increased trophic status (i.e. eutrophication, *sensu lato*) thus favoring higher biomass levels. However, this appears to be not the case at all structures, as the benthic trophic status of sediments is relatively invariant with increasing distance from the subsea production structure or even lower in the proximity of the four-leg platform (see Chapter 2). On the other hand, the increased values of macro-benthic abundance and biodiversity associated with the presence of the platforms can be indeed also interpreted as sort of "concentration" mechanism, related to the typical 'FAD' (Fish Attracting Device) behavior of any submerged artificial structure.

This study confirmed that the geographical position and ecological context can play altogether important roles in the "timing" and magnitude of the above effects and resilience (after installation), as observed previously (*e.g*., Terlizzi *et al*., 2008;

Manoukian *et al.,* 2010).

The results achieved in the present study highlighted also that the complexity (as a combination of dimension and shape) of offshore structures can have different impacts on the benthic communities: I indeed showed here that different structures can affect in different ways the amplitude and the timing required to reach a (newly) diversified and stable community. Although I must acknowledge that the results of this study are spatially and temporally limited, I pinpoint that the effects of platforms can vary also because of different environmental settings.

Finally, the overall results of this study let me suggest that, in view of the incoming time for platforms' decommissioning, a case-by-case evaluation of decommissioning options should be recommended, in addition with before-after environmental impact assessments.

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# SUPPLEMENTARY MATERIAL TO CHAPTER 3

**Annex 3.1** - Results of 2-way ANOVA applied to mean values of abundance (N), species richness (S), Shannon Diversity index (H') and Simpson index (λ) at each site during the four surveys carried out at Structure A. * = significant (P<0.05); ** = highly significant (P<0.01). d.f. = degree freedom; MS = Mean sum of squares; F = Fisher value.

| Source | d.f. | **N** | | | **S** | | |
|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P |
| Survey | 3 | 0.243 | 11.026 | 0.000** | 0.275 | 37.092 | 0.000** |
| Distance | 4 | 0.021 | 0.970 | 0.430 | 0.004 | 0.563 | 0.691 |
| Survey x Distance | 12 | 0.047 | 2.136 | 0.270 | 0.005 | 0.705 | 0.740 |

| Source | d.f. | **H'** | | | **λ** | | |
|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P |
| Survey | 3 | 0.169 | 34.568 | 0.000** | 1.041 | 55.319 | 0.000** |
| Distance | 4 | 0.014 | 2.877 | 0.030* | 0.054 | 2.895 | 0.029* |
| Survey x Distance | 12 | 0.010 | 2.016 | 0.038* | 0.064 | 3.394 | 0.001** |

**Annex 3.2** - Summary of SIMPER analysis for Structure A. Average abundances (Avg. ab.) and % contribution (Contr. %) to the average similarity are given for each species within distance groups and survey groups. Only species reaching the cumulative contribution of ~50% are reported. % average dissimilarities (Avg. dis. %) between distance and survey groups are also pointed out.

| Species | Avg. ab. | Contr. % | Avg. dis. % | | Species | Avg. ab. | Contr. % | Avg. dis. % | |
|---|---|---|---|---|---|---|---|---|---|
| 0 m | | | | | I survey | | | | |
| *Ditrupa arietina* | 3.8 | 12.6 | 0m vs. 30m | 46.9 | *Ditrupa arietina* | 4.6 | 17.6 | I vs. II survey | 45.8 |
| Paraonidae nd | 3.2 | 11.1 | 0m vs. 60m | 45.4 | Paraonidae nd | 3.2 | 13.5 | I vs. III survey | 52.2 |
| Sipuncula nd | 1.6 | 5.0 | 0m vs. 120m | 45.1 | *Nothria conchylega* | 1.8 | 8.5 | I vs. IV survey | 57.5 |
| *Aphelochaeta filiformis* | 1.5 | 5.0 | 0m vs. 1000m | 48.8 | Sipuncula nd | 1.8 | 6.4 | II vs. III survey | 43.3 |
| *Glycera rouxii* | 1.2 | 4.5 | 30m vs. 60m | 45.5 | *Glycera rouxii* | 1.1 | 5.1 | II vs. IV survey | 47.0 |
| *Lumbrineris gracilis* | 1.1 | 3.9 | 30m vs. 120m | 44.9 | | | | III vs. IV survey | 41.7 |
| *Minuspio cirrifera* | 1.2 | 3.8 | 30m vs. 1000m | 48.3 | | | | | |
| *Aponuphis brementi* | 1.2 | 3.7 | 60m vs. 120m | 42.3 | II survey | | | | |
| *Ampharete acutifrons* | 1.2 | 3.5 | 60m vs. 1000m | 45.6 | Paraonidae nd | 3.2 | 10.2 | | |
| | | | 120m vs. 1000m | 42.9 | *Ditrupa arietina* | 3.1 | 7.0 | | |
| | | | | | Sipuncula nd | 2.0 | 6.4 | | |
| 30 m | | | | | *Nothria conchylega* | 2.0 | 5.9 | | |
| *Ditrupa arietina* | 4.1 | 12.3 | | | *Glycera rouxii* | 1.5 | 4.8 | | |
| Paraonidae nd | 3.2 | 10.5 | | | *Aponuphis brementi* | 1.5 | 4.5 | | |
| Sipuncula nd | 1.7 | 5.0 | | | *Timoclea ovata* | 1.3 | 4.1 | | |
| *Glycera rouxii* | 1.3 | 4.5 | | | *Aphelochaeta filiformis* | 1.4 | 4.0 | | |
| *Aphelochaeta filiformis* | 1.4 | 4.5 | | | *Ophelina cylindricaudata* | 1.4 | 4.0 | | |
| *Ampharete acutifrons* | 1.4 | 4.3 | | | | | | | |
| *Aponuphis brementi* | 1.2 | 3.9 | | | III survey | | | | |
| *Timoclea ovata* | 1.3 | 3.9 | | | Paraonidae nd | 3.5 | 10.6 | | |
| *Minuspio cirrifera* | 1.2 | 3.9 | | | *Paradiopatra calliopae* | 2.3 | 7.2 | | |
| | | | | | Sipuncula nd | 2.1 | 6.3 | | |
| 60m | | | | | *Aphelochaeta filiformis* | 1.6 | 4.9 | | |
| Paraonidae nd | 3.5 | 12.3 | | | *Ampharete acutifrons* | 1.7 | 4.7 | | |
| *Ditrupa arietina* | 3.2 | 9.0 | | | *Timoclea ovata* | 1.7 | 4.7 | | |

| | | | | | |
|---|---|---|---|---|---|
| Sipuncula nd | 1.8 | 5.3 | Sabellidae nd | 1.5 | 4.4 |
| *Glycera rouxii* | 1.3 | 4.6 | *Ditrupa arietina* | 1.7 | 4.0 |
| *Timoclea ovata* | 1.62 | 4.3 | *Minuspio cirrifera* | 1.3 | 3.8 |
| *Aphelochaeta filiformis* | 1.4 | 4.1 | | | |
| *Ampharete acutifrons* | 1.30 | 4.0 | IV survey | | |
| *Ophelina cylindricaudata* | 1.3 | 3.9 | Paraonidae nd | 4.2 | 9.0 |
| *Aponuphis brementi* | 1.2 | 3.8 | *Paradiopatra calliopae* | 3.4 | 7.5 |
| | | | *Onchnesoma steenstrupi* | 2.5 | 5.2 |
| 120 m | | | *Timoclea ovata* | 2.1 | 4.0 |
| Paraonidae nd | 3.8 | 12.3 | *Ampharete acutifrons* | 1.7 | 3.6 |
| *Ditrupa arietina* | 2.8 | 6.9 | *Aphelochaeta filiformis* | 1.9 | 3.5 |
| Sipuncula nd | 2.0 | 5.6 | *Ophelina cylindricaudata* | 1.9 | 3.5 |
| *Glycera rouxii* | 1.5 | 4.4 | *Glycera rouxii* | 1.6 | 3.5 |
| *Aphelochaeta filiformis* | 1.5 | 4.3 | *Ditrupa arietina* | 2.2 | 3.4 |
| *Lumbrineris gracilis* | 1.3 | 4.2 | Sabellidae nd | 1.6 | 3.4 |
| *Ophelina cylindricaudata* | 1.5 | 4.2 | *Aponuphis brementi* | 1.3 | 2.6 |
| *Timoclea ovata* | 1.7 | 4.2 | *Lumbrineris gracilis* | 1.3 | 2.6 |
| *Ampharete acutifrons* | 1.4 | 3.9 | | | |
| | | | | | |
| 1000 m | | | | | |
| Paraonidae nd | 3.8 | 13.2 | | | |
| Sipuncula nd | 1.8 | 6.7 | | | |
| *Aphelochaeta filiformis* | 1.7 | 5.7 | | | |
| *Ophelina cylindricaudata* | 1.8 | 5.3 | | | |
| *Glycera rouxii* | 1.4 | 4.9 | | | |
| *Lumbrineris gracilis* | 1.2 | 4.4 | | | |
| *Ampharete acutifrons* | 1.4 | 4.0 | | | |
| *Aponuphis brementi* | 1.0 | 3.7 | | | |
| *Timoclea ovata* | 1.4 | 3.5 | | | |

**Annex 3.3** - Results of 2-way ANOVA applied to mean values of abundance (N), species richness (S), Shannon Diversity index (H’) and Simpson index (λ) at each site during the four surveys carried out at Structure B. * = significant (P<0.05); ** = highly significant (P<0.01). d.f. = degree freedom; MS = Mean sum of squares; F = Fisher value.

| Source | d.f. | N | | | S | | |
|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P |
| Survey | 3 | 0.259 | 8.612 | 0.000** | 0.106 | 12.174 | 0.000** |
| Distance | 4 | 0.017 | 0.577 | 0.681 | 0.041 | 4.686 | 0.003** |
| Survey x Distance | 12 | 0.026 | 0.858 | 0.593 | 0.014 | 1.570 | 0.133 |

| Source | d.f. | H’ | | | λ | | |
|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P |
| Survey | 3 | 0.015 | 3.121 | 0.034* | 0.117 | 2.307 | 0.088 |
| Distance | 4 | 0.046 | 9.393 | 0.000** | 0.594 | 11.693 | 0.000** |
| Survey x Distance | 12 | 0.017 | 3.483 | 0.001** | 0.194 | 3.812 | 0.000** |

**Annex 3.4 -** Summary of SIMPER analysis for Structure B. Average abundances (Avg. ab.) and % contribution (Contr. %) to the average similarity are given for each species within distance groups and survey groups. Only species reaching the cumulative contribution of ~50% are reported. % average dissimilarities (Avg. dis. %) between distance and survey groups are also pointed out.

| Species | Avg. ab. | Contr. % | Avg. dis. % | | Species | Avg. ab. | Contr. % | Avg. dis. % | |
|---|---|---|---|---|---|---|---|---|---|
| Distance across Survey | | | | | Survey across Distance | | | | |
| 0 m | | | | | I survey | | | | |
| *Owenia fusiformis* | 2.5 | 9.2 | 0m vs. 30m | 55.5 | *Ditrupa arietina* | 2.8 | 6.6 | I vs. II survey | 50.6 |
| *Minuspio cirrifera* | 1.9 | 7.3 | 0m vs. 60m | 58.8 | *Owenia fusiformis* | 1.8 | 6.1 | I vs. III survey | 53.3 |
| Sabellidae nd | 1.8 | 6.5 | 0m vs. 120m | 60.0 | Paraonidae nd | 1.6 | 6.0 | I vs. IV survey | 55.2 |
| Paraonidae nd | 1.3 | 5.4 | 0m vs. 1000m | 62.8 | Sabellidae nd | 1.4 | 5.2 | II vs. III survey | 51.4 |
| *Ditrupa arietina* | 1.7 | 4.8 | 30m vs. 60m | 47.5 | *Aspidosiphon muelleri* | 1.6 | 5.1 | II vs. IV survey | 53.9 |
| *Aspidosiphon muelleri* | 1.2 | 3.8 | 30m vs. 120m | 49.9 | *Minuspio cirrifera* | 1.4 | 5.0 | III vs. IV survey | 52.0 |
| *Aponuphis brementi* | 1.1 | 3.2 | 30m vs. 1000m | 53.9 | *Aphelochaeta filiformis* | 1.3 | 4.7 | | |
| *Anomia ephippium* | 1.4 | 3.2 | 60m vs. 120m | 45.5 | *Myrtea spinifera* | 1.3 | 4.3 | | |
| *Glycera rouxii* | 0.8 | 2.7 | 60m vs. 1000m | 50.2 | *Aponuphis brementi* | 1.1 | 4.2 | | |
| *Goniada maculata* | 0.7 | 2.5 | 120m vs. 1000m | 44.1 | Sipuncula nd | 1.3 | 4.2 | | |
| *Pomatoceros triqueter* | 1.0 | 2.4 | | | | | | | |
| | | | | | II survey | | | | |
| 30 m | | | | | *Ditrupa arietina* | 2.7 | 8.4 | | |
| *Ditrupa arietina* | 3.5 | 10.4 | | | *Aspidosiphon muelleri* | 1.9 | 7.3 | | |
| *Minuspio cirrifera* | 1.8 | 6.7 | | | Paraonidae nd | 1.7 | 6.7 | | |
| Paraonidae nd | 1.6 | 6.5 | | | *Minuspio cirrifera* | 1.7 | 6.3 | | |
| *Aspidosiphon muelleri* | 1.8 | 6.5 | | | *Owenia fusiformis* | 1.4 | 5.7 | | |
| *Owenia fusiformis* | 1.7 | 6.0 | | | *Glycera rouxii* | 1.3 | 5.3 | | |
| Sabellidae nd | 1.5 | 5.1 | | | Sabellidae nd | 1.3 | 5.3 | | |
| *Aponuphis brementi* | 1.2 | 4.5 | | | *Goniada maculata* | 1.3 | 5.2 | | |
| *Aphelochaeta filiformis* | 1.0 | 3.6 | | | | | | | |
| *Myrtea spinifera* | 1.1 | 3.6 | | | III survey | | | | |
| | | | | | *Ditrupa arietina* | 3.3 | 9.0 | | |
| 60m | | | | | Sabellidae nd | 2.1 | 6.5 | | |

| | | | | | |
|---|---|---|---|---|---|
| *Ditrupa arietina* | 4.7 | 13.9 | *Aspidosiphon muelleri* | 2.2 | 6.1 |
| *Aspidosiphon muelleri* | 2.3 | 8.4 | *Owenia fusiformis* | 2.0 | 5.4 |
| *Minuspio cirrifera* | 1.5 | 5.4 | *Minuspio cirrifera* | 1.8 | 4.8 |
| Paraonidae nd | 1.4 | 5.0 | Paraonidae nd | 1.5 | 4.4 |
| *Myrtea spinifera* | 1.4 | 4.9 | *Goniada maculata* | 1.1 | 3.1 |
| *Owenia fusiformis* | 1.5 | 4.9 | *Myrtea spinifera* | 1.3 | 3.0 |
| Sabellidae nd | 1.6 | 4.6 | *Aponuphis brementi* | 1.0 | 2.8 |
| *Aponuphis brementi* | 1.2 | 4.5 | *Glycera rouxii* | 1.0 | 2.5 |
| | | | *Aphelochaeta filiformis* | 1.1 | 2.3 |
| 120 m | | | *Ampharete acutifrons* | 1.1 | 2.2 |
| *Ditrupa arietina* | 3.6 | 8.6 | | | |
| *Aspidosiphon muelleri* | 2.4 | 7.1 | IV survey | | |
| *Sipuncula nd* | 1.7 | 5.0 | *Ditrupa arietina* | 4.1 | 9.9 |
| *Myrtea spinifera* | 1.5 | 5.0 | *Minuspio cirrifera* | 2.0 | 6.1 |
| *Sabellidae nd* | 1.5 | 4.6 | *Aspidosiphon muelleri* | 1.9 | 5.7 |
| *Minuspio cirrifera* | 1.7 | 4.5 | *Aponuphis brementi* | 1.6 | 4.4 |
| Paraonidae nd | 1.6 | 4.3 | Sabellidae nd | 1.5 | 3.9 |
| *Goniada maculata* | 1.4 | 4.0 | *Myrtea spinifera* | 1.3 | 3.8 |
| *Aponuphis brementi* | 1.2 | 4.0 | Paraonidae nd | 1.4 | 3.6 |
| *Owenia fusiformis* | 1.4 | 4.0 | Sipuncula nd | 1.2 | 3.0 |
| | | | *Magelona alleni* | 1.0 | 2.8 |
| 1000 m | | | *Goniada maculata* | 1.1 | 2.8 |
| *Ditrupa arietina* | 2.4 | 5.1 | *Aphelochaeta filiformis* | 1.1 | 2.7 |
| Paraonidae nd | 1.8 | 4.3 | *Owenia fusiformis* | 1.2 | 2.6 |
| *Falcidens gutturosus* | 1.8 | 4.3 | | | |
| *Myrtea spinifera* | 1.7 | 4.2 | | | |
| *Aspidosiphon muelleri* | 1.8 | 4.0 | | | |
| *Ampharete acutifrons* | 1.8 | 4.0 | | | |
| *Aphelochaeta filiformis* | 1.7 | 4.0 | | | |
| Sipuncula nd | 1.8 | 4.0 | | | |

| | | |
|---|---|---|
| Sabellidae nd | 1.5 | 3.7 |
| *Aponuphis brementi* | 1.4 | 3.3 |
| *Goniada maculata* | 1.3 | 3.2 |
| *Minuspio cirrifera* | 1.6 | 3.1 |
| *Glycera rouxii* | 1.3 | 3.0 |

**Annex 3.5** - Results of 2-way ANOVA applied to mean values of abundance (N), species richness (S), Shannon Diversity index (H') and Simpson index (λ) at each site during the four surveys carried out at Structure C. * = significant (P<0.05); ** = highly significant (P<0.01). d.f. = degree freedom; MS = Mean sum of squares; F = Fisher value.

| Source | d.f. | **N** | | | **S** | | |
|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P |
| Survey | 3 | 0.017 | 1.256 | 0.298 | 0.005 | 1.182 | 0.324 |
| Distance | 4 | 0.054 | 4.125 | 0.005** | 0.019 | 4.214 | 0.005** |
| Survey x Distance | 12 | 0.030 | 2.299 | 0.017* | 0.009 | 2.007 | 0.039* |

| Source | d.f. | **H'** | | | **λ** | | |
|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P |
| Survey | 3 | 0.008 | 8.366 | 0.000** | 0.101 | 8.982 | 0.000** |
| Distance | 4 | 0.001 | 0.932 | 0.452 | 0.017 | 1.504 | 0.212 |
| Survey x Distance | 12 | 0.001 | 1.560 | 0.129 | 0.022 | 1.988 | 0.041* |

**Annex 3.6** - Summary of SIMPER analysis for Structure C. Average abundances (Avg. ab.) and % contribution (Contr. %) to the average similarity are given for each species within distance groups and survey groups. Only species reaching the cumulative contribution of ~50% are reported. % average dissimilarities (Avg. dis. %) between distance and survey groups are also pointed out.

| Species | Avg. ab. | Contr. % | Avg. dis. % | | Species | Avg. ab. | Contr.% | Avg. dis. % | |
|---|---|---|---|---|---|---|---|---|---|
| Distance across Survey | | | | | Survey across Distance | | | | |
| 0 m | | | | | I survey | | | | |
| *Minuspio cirrifera* | 4.2 | 7.3 | 0m vs. 30m | 44.0 | *Minuspio cirrifera* | 4.7 | 8.8 | I vs. II survey | 35.8 |
| Paraonidae nd | 3.8 | 6.0 | 0m vs. 60m | 47.5 | *Aphelochaeta marioni* | 4.5 | 7.8 | I vs. III survey | 38.4 |
| *Aphelochaeta marioni* | 3.5 | 4.7 | 0m vs. 120m | 47.0 | Paraonidae nd | 3.9 | 7.3 | I vs. IV survey | 42.0 |
| *Pectinaria koreni* | 2.7 | 4.0 | 0m vs. 1000m | 48.4 | *Ditrupa arietina* | 3.0 | 4.8 | II vs. III survey | 37.6 |
| *Sigambra tentaculata* | 2.3 | 3.2 | 30m vs. 60m | 31.1 | *Sternaspis scutata* | 2.5 | 4.2 | II vs. IV survey | 37.8 |
| *Kurtiella bidentata* | 2.4 | 2.9 | 30m vs. 120m | 29.7 | *Aspidosiphon muelleri* | 2.0 | 3.7 | III vs. IV survey | 35.0 |
| *Anomia ephippium* | 2.4 | 2.7 | 30m vs. 1000m | 31.3 | *Labioleanira yhleni* | 2.2 | 3.6 | | |
| *Aphelochaeta filiformis* | 1.8 | 2.5 | 60m vs. 120m | 29.7 | *Aphelochaeta filiformis* | 1.8 | 3.3 | | |
| *Abra prismatica* | 1.7 | 2.5 | 60m vs. 1000m | 31.4 | *Abra prismatica* | 1.7 | 3.2 | | |
| *Pomatoceros triqueter* | 1.9 | 2.4 | 120m vs. 1000m | 29.9 | *Pectinaria koreni* | 1.7 | 3.1 | | |
| *Glycera rouxii* | 1.7 | 2.4 | | | *Nephtys hystricis* | 1.52 | 2.7 | | |
| *Timoclea ovata* | 1.8 | 2.3 | | | | | | | |
| *Hyala vitrea* | 1.7 | 2.3 | | | II survey | | | | |
| *Amphiura chiajei* | 1.6 | 2.3 | | | *Ophelina cilindricaudata* | 4.4 | 7.6 | | |
| Nemertea nd | 1.5 | 2.2 | | | *Aphelochaeta marioni* | 3.9 | 7.0 | | |
| *Aspidosiphon muelleri* | 1.6 | 2.1 | | | Paraonidae nd | 3.6 | 6.4 | | |
| 30 m | | | | | *Minuspio cirrifera* | 3.4 | 6.1 | | |
| *Aphelochaeta marioni* | 4.6 | 7.6 | | | *Turritella communis* | 2.7 | 4.9 | | |
| Paraonidae nd | 4.2 | 7.1 | | | *Sternaspis scutata* | 2.5 | 4.4 | | |
| *Minuspio cirrifera* | 3.7 | 5.7 | | | *Labioleanira yhleni* | 2.2 | 3.9 | | |
| *Sternaspis scutata* | 2.6 | 4.4 | | | *Ditrupa arietina* | 2.5 | 3.8 | | |
| *Labioleanira yhleni* | 2.4 | 4.3 | | | *Aphelochaeta filiformis* | 2.1 | 3.7 | | |
| *Ophelina cilindricaudata* | 2.6 | 4.0 | | | *Aspidosiphon muelleri* | 2.0 | 3.5 | | |
| *Turritella communis* | 2.4 | 3.8 | | | | | | | |

| | | |
|---|---|---|
| *Aphelochaeta filiformis* | 2.3 | 3.7 |
| *Aspidosiphon muelleri* | 2.3 | 3.6 |
| *Abra prismatica* | 2.0 | 3.4 |
| *Notomastus aberans* | 1.9 | 3.0 |
| | | |
| 60 m | | |
| *Aphelochaeta marioni* | 4.3 | 8.4 |
| Paraonidae nd | 3.8 | 7.6 |
| *Minuspio cirrifera* | 3.1 | 6.1 |
| *Sternaspis scutata* | 2.9 | 5.7 |
| *Turritella communis* | 2.7 | 45.0 |
| *Ophelina cilindricaudata* | 2.5 | 4.3 |
| *Aphelochaeta filiformis* | 2.2 | 4.1 |
| *Ditrupa arietina* | 2.5 | 4.0 |
| *Aspidosiphon muelleri* | 2.1 | 4.0 |
| *Labioleanira yhleni* | 2.3 | 3.9 |
| 120 m | | |
| *Aphelochaeta marioni* | 4.5 | 7.7 |
| Paraonidae nd | 4.0 | 7.0 |
| *Minuspio cirrifera* | 3.0 | 5.4 |
| *Sternaspis scutata* | 3.0 | 5.2 |
| *Ditrupa arietina* | 2.7 | 4.4 |
| *Turritella communis* | 2.5 | 4.2 |
| *Aphelochaeta filiformis* | 2.3 | 4.1 |
| *Ophelina cilindricaudata* | 2.3 | 3.9 |
| *Labioleanira yhleni* | 2.2 | 3.8 |
| *Aspidosiphon muelleri* | 2.2 | 3.7 |
| *Notomastus aberans* | 1.8 | 2.8 |
| 1000 m | | |
| *Aphelochaeta marioni* | 3.9 | 7.2 |
| III survey | | |
| *Aphelochaeta marioni* | 4.2 | 7.3 |
| Paraonidae nd | 3.5 | 6.2 |
| *Minuspio cirrifera* | 2.9 | 4.9 |
| *Sternaspis scutata* | 2.2 | 4.2 |
| *Labioleanira yhleni* | 2.0 | 3.6 |
| *Aspidosiphon muelleri* | 2.0 | 3.6 |
| *Turritella communis* | 2.2 | 3.5 |
| *Aphelochaeta filiformis* | 1.8 | 3.0 |
| *Pectinaria koreni* | 2.2 | 3.0 |
| *Abra prismatica* | 1.9 | 3.0 |
| *Hyala vitrea* | 1.7 | 2.8 |
| Nemertea nd | 1.6 | 2.6 |
| *Notomastus aberans* | 1.8 | 2.5 |
| | | |
| IV survey | | |
| Paraonidae nd | 4.8 | 7.9 |
| *Aphelochaeta marioni* | 4.1 | 6.3 |
| *Aphelochaeta filiformis* | 2.7 | 4.5 |
| *Turritella communis* | 2.6 | 4.5 |
| *Sternaspis scutata* | 2.5 | 4.1 |
| *Minuspio cirrifera* | 2.8 | 3.7 |
| *Aspidosiphon muelleri* | 2.3 | 3.7 |
| *Ophelina cilindricaudata* | 2.0 | 3.2 |
| *Labioleanira yhleni* | 1.7 | 2.7 |
| *Hyala vitrea* | 1.8 | 2.4 |
| Copepoda nd | 1.7 | 2.4 |
| *Notomastus aberans* | 1.8 | 2.4 |
| Nemertea nd | 1.5 | 2.1 |
| *Magelona alleni* | 1.6 | 2.0 |

| | | |
|---|---|---|
| Paraonidae nd | 3.9 | 7.0 |
| *Minuspio cirrifera* | 3.9 | 5.1 |
| *Sternaspis scutata* | 2.5 | 4.7 |
| *Aspidosiphon muelleri* | 2.3 | 4.3 |
| *Turritella communis* | 2.4 | 4.2 |
| *Ophelina cilindricaudata* | 2.6 | 3.9 |
| *Aphelochaeta filiformis* | 2.1 | 3.7 |
| *Labioleanira yhleni* | 2.0 | 3.6 |
| *Ditrupa arietina* | 2.0 | 2.9 |
| *Nephtys hystricis* | 1.4 | 2.7 |
| *Hyala vitrea* | 1.6 | 2.6 |

# 4. FISH DETECTION AROUND THREE OFFSHORE ARTIFICIAL STRUCTURES FROM HYDROACOUSTICS AND FISHING SURVEYS

## ABSTRACT

Fixed structures at sea are known to attract fish fauna because of a combination of trophic and protection mechanisms. Most of these studies have been typically conducted by discrete sampling strategies using different nets.

In the present study, by means of either Multibeam Echosounder or experimental fishing surveys, I have investigated the composition of fish assemblages surrounding three offshore gas extraction platforms (NW Adriatic Sea) characterized by different building architectures: four-leg vs. one-leg vs. subsea well-site. Specifically, I tested the null hypothesis that abundance, biomass and biodiversity of fish assemblages close to offshore platforms do not differ from those in open waters (reference sites). In addition, for each structure, length-weight relationships were investigated for three of the most abundant species collected in order to compare population structures between close to the structures and reference sites further away.

At all the three platforms, both methods allowed observing the presence of fish abundance and biomass values close to the structures significantly higher than in outer localities. Fish abundance and biomass were generally highest in the surroundings of the four-leg platform as a possible consequence of its largest volume. Differences in the length-weight relationships between specimens collected close and at reference sites were significant only at the four- and one-leg platforms, whereas no differences were observed at the subsea well-site. The results of this study confirmed the ‘fish aggregating device’ nature of the three types of structure, and let us hypothesizing that such attractiveness is also related to the different growth patterns of attracted fish as a result of a higher food availability.

## INTRODUCTION

Gas platforms can play a relevant role on the surrounding ecosystem. As these structures extend throughout the entire water column, they may function as either artificial reefs and/or as Fish Aggregating Devices (FADs; Franks, 2000). Offshore platforms indeed can act as "aggregation centers" for a large number of either benthic and demersal fishes, but can also attract pelagic species because of the solid, reef-like nature of the structures, the pelagic fish thigmotactism (Brickhill *et al*., 2005) and by the presence of a greater amount of prey (Gallaway and Lewbel, 1982; Andaloro *et al*., 2011).

The structure of fish assemblages associated with offshore artificial structures has been widely investigated in different world regions, including, among the others, the North Sea, the Gulf of Mexico, southern California and, more recently, the west coasts of Africa (*e.g*., Stanley and Wilson, 1990; 1991; Love *et al.,* 1999; Stanley and Wilson, 2000; Jørgensen *et al.,* 2002; Løkkeborg *et al.,* 2002; Friedlander *et al*., 2014). In all these areas it has been highlighted that structures at sea promote the aggregation of fishes, which would be otherwise dispersed over wide expanses of water.

Also several studies carried out in the Adriatic Sea pointed out diverse fish species composition and densities at gas platforms placed at different depths, greater abundances at the rigs in respect to the natural sandy-mud habitat (Fabi *et al*., 2002; 2004; Scarcella *et al.,* 2011). Since it is expected that in the Adriatic Sea several offshore extraction platforms will have to be decommissioned within a few years (Scottish Enterprise, 2013), a better comprehension of the role of these structures on the surrounding marine environment becomes a priority in order to choose the best decommissioning option, among those currently available.

The assessment and study of fish assemblages associated with offshore artificial structures have been performed using numerous and different techniques, such as visual census (Carlisle *et al*., 1964; Rilov and Benayahu, 2000; Consoli *et al*., 2007; Andaloro *et al.,* 2011; 2013; Consoli *et al*., 2013), video recordings from remotely operated vehicles (Aabel *et al.,* 1977; Cripps and Aabel, 1995; Ajemian *et al*., 2015), submersible surveys (Love *et al*., 2000; 2005; 2006), acoustic surveys (Stanley and Wilson, 1998; 2000; Jørgensen *et al*., 2002; Soldal *et al*., 2002), and fishing surveys (Bombace *et al*., 1999; Fabi *et al.,* 2002; Løkkeborg *et al*., 2002; Fabi *et al*., 2004; Scarcella *et al*., 2011). Each of these techniques has advantages and disadvantages, but it has been demonstrated that the synoptic application of different methods can provide complementary results and, therefore, better insights (Consoli *et al*., 2007).

The use of acoustic techniques to map the spatial distribution of fish schools in relation to the presence of artificial structures has been largely improved in the last few decades (Stanley and Wilson, 2000; Fabi and Sala, 2002; Sala *et al*., 2007; Kang *et al*., 2011; Yuan *et al.,* 2013). In this perspective, the Multibeam Echosounder (MBES), primarily developed for seafloor mapping, has been successfully improved for digital acquisition along the water column and 3D visualization of acoustic data (Fernandes *et al*., 2002; Mayer *et al*., 2002; Howell, 2008). Hence, it represents an advanced acoustic method that has great potential as a tool in support of fisheries management used for the identification of essential fish habitats, characterization of marine protected areas, and assessment of the spatial distribution of fish both in natural environments and around artificial structures (Mayer *et al*., 1999; Howell, 2008).

The present study, carried out through dedicated acoustic and fishing surveys, was aimed to test the null hypothesis by which the abundance, biomass and diversity of fish assemblages are not affected by the presence of offshore artificial structures (one subsea well site, one four-leg platform and one one-leg platform). Even though the two methods are different and not fully comparable (*e.g*., they have been applied at different times of the day), the scope of the study was to evaluate whether their combination could provide a more comprehensive understanding of the fish assemblages associated with artificial structures.

## MATERIALS AND METHODS

### STUDY AREA

Three artificial structures (one subsea well-site, one four-leg platform, and one one-leg platform) located in the north-central Adriatic Sea were monitored for two years starting after their deployment (Figure 4.1).

The subsea production system (hereafter called Structure A) is located 30 nm from the coast, on a sandy bottom, at 80 m depth. It has a bulk volume of around 600 $m^3$ and extends up to 5 m along the water column. The four-leg platform (hereafter called Structure B) presents a bulk volume of around 38,000 $m^3$, and is sited about 32 nm offshore at ca. 60 m depth, on offshore relict sands. The one-leg platform (hereafter called Structure C) has a bulk volume of about 5,000 m and is located at 25 nm off Cervia (Northern Adriatic Sea) at about 40 m of depth, on a sand-muddy bottom.

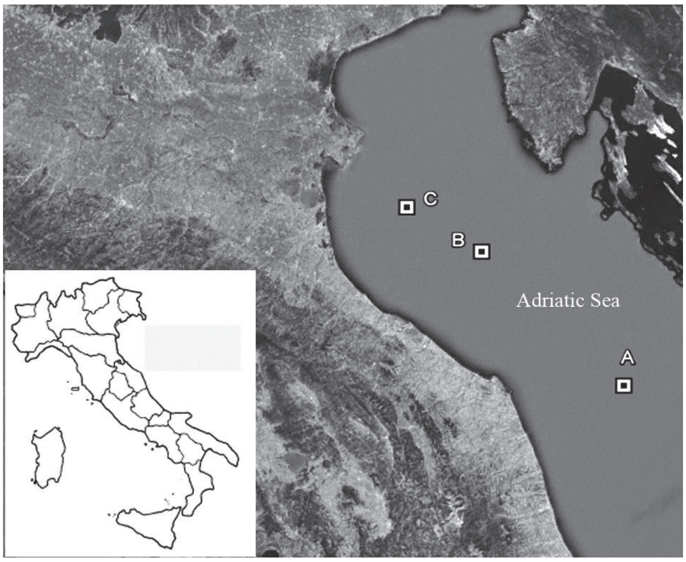


**Figure 4.1** - Study area. A, B and C: investigated artificial structures.

### SAMPLING METHODS

The fish assemblages present in the surroundings of the three artificial structures were assessed both by means of MBES and trammel net fishing surveys carried out for two years (Structure A and B: 2011 and 2012; Structure C: 2012 and 2013) starting just after their deployment.

#### *Multibeam survey*

MBES surveys were carried out on a monthly basis using a dual-head, high-resolution 300-kHz EM3002D (Kongsberg Simrad) which allows mapping of the seafloor and simultaneously acquisition of acoustic data along the water column (Fernandes *et al*., 2002; Mayer *et al*., 2002). The EM3002D has 508 beams, each with 1.5° circular beamwidth, which can collectively cover a 200° sector. A profiling sound velocimeter (Kongsberg Smart SV & Pressure 4609) was used to record sound velocity profiles and optimize the performance of detection during the surveys.

At each structure, the water column was investigated along 8 transects extending from the structure to 1200 m away in different directions and along two circular transects, one within a radius of 300 m from the structure and one 1200 m away

(Figure 4.2). A total of 18 surveys were conducted at Structure A (January, February and March surveys were not performed in each sampling year due to bad weather conditions), while 24 surveys were performed at Structure B and C. All surveys were performed at the same time of the day, from 12 am to 4 pm, at a speed of 5.5 kn.

Acoustic data were acquired using Seafloor Information System (SIS) Version 3.7.5 software, that includes additional features for water column data collection and operational parameterization features more relevant for fisheries applications.

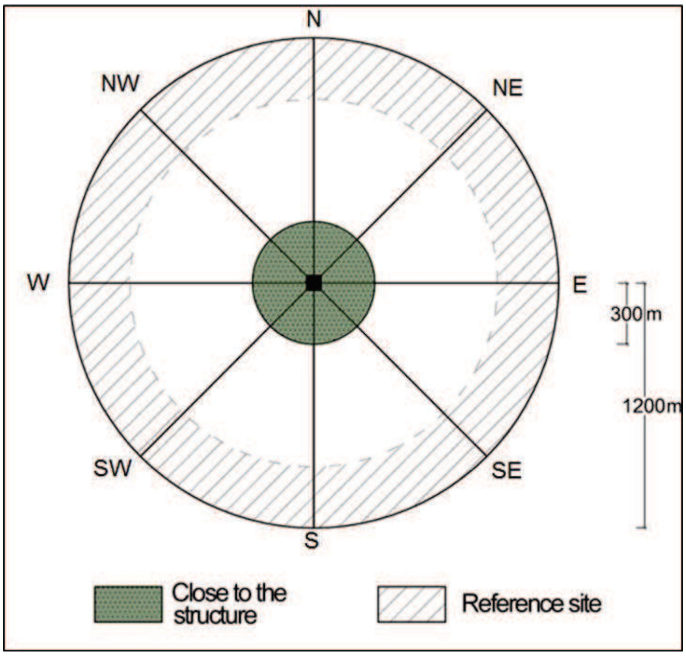


**Figure 4.2** - Sampling plan adopted for the MBES survey.

*Fishing survey*

The fishing surveys were performed on a monthly basis by means of an experimental bottom trammel net (300 m long, 3 m high, inner panel with stretched mesh size of 72 mm, outer panels with stretched mesh size of 400 mm). Differently from bottom trawling, this net can be safely set close to the rigs, thus allowing catching fish living at strict contact with the structure (*e.g.*, scorpaenids). Moreover, the trammel net is less selective than gillnets and other set gears such as hooks and traps (Scarcella *et al.*, 2011).

The net was lowered within a 50 m radius from each artificial structure (C: close to the structure), and at two sites (F1 and F2: reference sites) located 1.852 km away, used as reference sites (Figure 4.3); the position of these two sites was randomly chosen in two of the four quadrants (NW, NE, SW, and SE) at each survey. The choice of random sites allows avoiding systematic errors in the positioning of the sampling sites in two fixed points. The nets were lowered into the water at dusk and hauled in at dawn (average fishing time of 12 h). Sampling was conducted at each site (C, F1, and F2) just after the MBES survey and all sites were investigated simultaneously to operate in the same weather conditions.

A total of 22 surveys were carried out at Structure A, whereas 24 surveys were conducted at structures B and C. At Structure A, sampling was not carried out in February 2011 and March 2012, due to bad weather conditions.

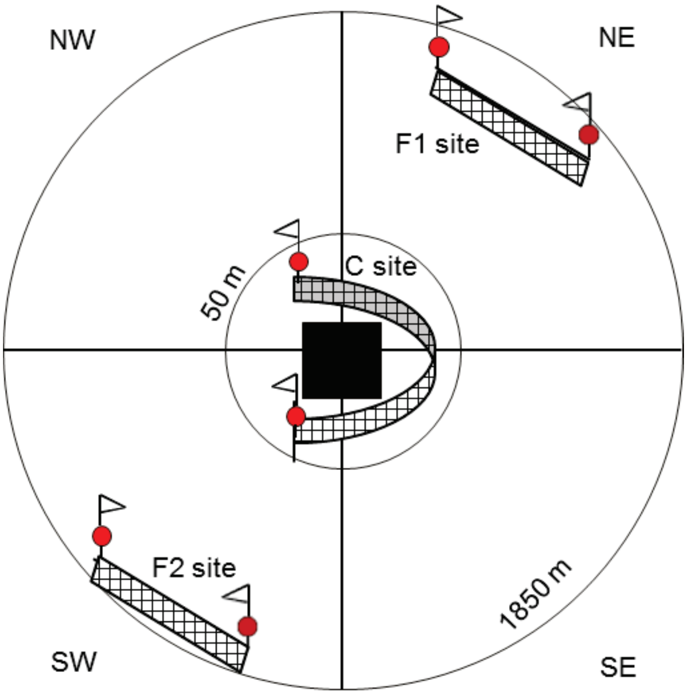


**Figure 4.3** - Sampling plan adopted for fishing survey surrounding the offshore structure (black square).

### DATA ANALYSIS

*Multibeam survey*

Acoustic data returned by MBES were analyzed using the Echoview software (Myriax, 2014). As EM3002D system cannot be calibrated to identify the species, a target strength (TS) range between -34 and -54 dB was employed for school detection. This interval was obtained from McCartney and Stubbs (1971) for mixed-specie assemblages utilizing the mean size of the different species inhabiting the area derived from a multi-year data set obtained from other investigations.

After having estimated the TS, the fish schools were detected using the cruise-scanning algorithm and setting at 80 cm the three sizes for individual school (minimum longest, minimum middle and minimum shortest dimensions; Figure 4.4). These parameters were established according to the mean size of the different species and their aggregation capability of a small but representative number of fish. Any school that was smaller than these dimensions was discarded during the 3D school detection process.

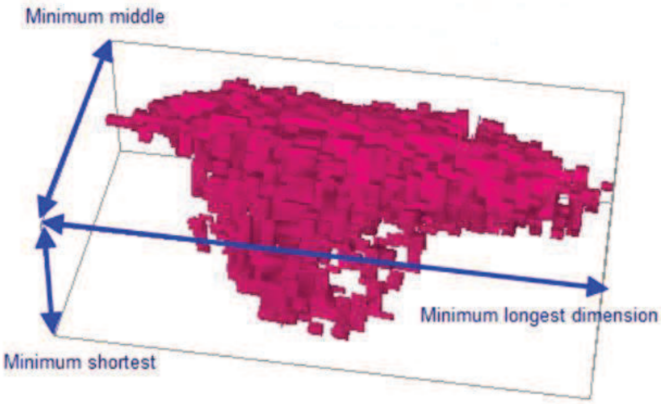


**Figure 4.4** - Scheme illustrating the size criteria for candidate 3D school region (from Myriax, 2014).

This procedure allowed to extract several acoustic variables, such as mean volume backscattering strength (mean Sv), samples number, ping number, beam number, and metric features, *e.g.*, length North-South, length East-West, height, volume, surface, minimum depth, maximum depth and geometric center depth (that is the depth at the geometric center of the 3D region; Myriax, 2014). Among all of them, in this study we considered mean Sv, volume, and geometric center depth.

Due to the presence of the so-called Fraunhofer zone (the zone farthest from the face of an ultrasound transducer, characterized by a divergence of the ultrasound beam and a more uniform ultrasound intensity; Simmonds and MacLennan, 2005), all fish echoes along the water column between 5 m from the sea surface and about 0.5 m above the seabed were recorded.

Taking into account the results evidenced by Scarcella *et al*. (2011), all the schools detected between 0 and 300 m from each structure were defined as “close” to the structure (respectively A, B and C), whereas the schools detected between 900 and 1200 m distance from the structures were defined as reference sites (hereafter termed A ref site, B ref site and C ref site, respectively). In addition, at each site all the schools were categorized in relation to their position along the water column; this allowed identifying 4 groups at Structure A (0-20 m; 20-40 m; 40-60 m; 60-80 m), 3 groups at Structure B (0-20 m; 20-40 m; 40-60 m), and 4 groups at Structure C (0-20 m; 20-40 m). Prior to the following analyses number and volume of the detected fish schools were normalized to the investigated water volume included within each depth range.

To compare number and volume of fish schools, a 3-way ANOVA was performed separately for each structure considering Year (two-levels fixed factor; i.e. 2012 vs. 2013), Site (two-levels fixed factor; i.e. close vs. reference) and Depth range (fixed factor with 4, 3 and 2 levels at Structures A, B and C, respectively; see above for depth ranges).

In addition, for each Structure and for each Site, a 1-way ANOVA was conducted considering the factor Season (fixed factor with 3 levels at Structure A and with 4 levels at Structure B and Structure C). January, February and March were included in Winter; April, May and June in Spring; July, August and September in Summer; October, November and December in Autumn.

Finally, a 1-way ANOVA was performed to evaluate differences among the three structures in term of number and volume of fish school, taking into account only the schools detected close to the structures and at the maximum depth range. This choice was made because the majority of fish schools has been found close to the sea bottom.

Prior to performing Analysis of Variance, normal distribution and homogeneity of variances were evaluated by Kolmogorov-Smirnov and Bartlett tests (Lindman, 1992), respectively. Based on the tests, data were log-transformed [log (x + 1)]. When this transformation was not sufficient to satisfy the above-mentioned assumptions, nonparametric Kruskall-Wallis tests were used (Siegel and Castellan, 1988; Zar, 1996). A multiple comparison test was also applied (Zar, 1996) if significant differences were detected by Kruskall-Wallis test.

The Tukey HSD test corrected for unbalanced samples was used to make comparisons across all pairs of group means when ANOVA tests for the factors of interest were significant ($p<0.05$).

*Fishing survey*

In the laboratory, all the organisms in the catches were identified to the lowest taxonomic level, using Whitehead *et al*. (1986) for fish and Fisher *et al*. (1987) for crustaceans and molluscs, then counted and weighted.

Species were assigned to one of the three following life traits: pelagic (P), nekto-benthic (NB) and benthic (B). Moreover, species within each group were categorized as either attracted (AT), partially-attracted (PA) or non-attracted (NA) on the basis of their behavior towards hard substrates (Bombace *et al*., 1994). AT species are habitat-limited, obligatory reef-dependent species that use hard substrates for shelter and probably forage on them or in their immediate vicinity. PA species are mobile, partially reef-dependent species that may be temporarily attracted to hard substrates, but may be also observed in open-sea areas away from rocky habitats. Finally, species that naturally occur on soft bottoms but may be present after reef deployment, even though they have no relationship with hard substrates, are considered as NA species.

The fish community was described by means of univariate measures, such as abundance (number of individuals; *N*), biomass (*W*), species richness (*Sm*) and Shannon-Wiener diversity index (*H'*; Shannon and Weaver, 1949). Due to the differences in the net set time (*e.g*., longer in winter than in summer) abundance and biomass were standardized to a 12 h set period and 500 m of net.

The differences among fish assemblages close to the structures and at reference sites during the two monitoring years were tested by means of a permutation analysis of variance using PRIMER® 6.1.11 and PERMANOVA+ software package developed by the Plymouth Marine Laboratory (Clarke and Gorley, 2006; Anderson *et al.*, 2008).

This method allowed testing of the general multivariate hypothesis of differences in the composition and/or relative abundances of organisms of different species in samples from different groups (Anderson, 2001; McArdle and Anderson, 2001). Prior to any analysis, the species abundance data were log transformed to reduce the contribution of prevalent taxa and therefore increase the importance of less abundance species. Afterwards, species contributing at least 10% of the total community abundances were selected and the Bray-Curtis similarity matrix was calculated.

For each structure, a 2-way PERMANOVA was performed using the factors Year (two levels fixed factor) and Site (three levels fixed factor). The results were also displayed using the Principal Coordinates Analysis (PCoA; Anderson and Willis, 2003; Legendre and Legendre, 1998) based on the same similarity matrix used in the PERMANOVA.

Successively, similarity percentage breakdown procedure (SIMPER; Clarke, 1993; Clarke and Warwick, 2001) was employed to determine the contribution of individual taxa towards the dissimilarity between C and F sites.

Changes in univariate measures (*N*, *W*, *Sm* and *H'*) were evaluated using the same statistical design previously described for PERMANOVA. Therefore, a 2-way Analysis Of Variance (ANOVA; Lindman, 1992) was conducted separately for each structure, after having verified that the ANOVAs assumptions were met, considering Year and Site as fixed and crossed factors.

In addition, for each structure, a 2-way ANOVA was utilized to compare abundance and biomass of the total catches and abundance of the catches of the main species categories separately (NB, B, and P) from the fishing surveys, using Year and Site as fixed and orthogonal factors.

One-way ANOVAs were also carried out separately within each site to investigate the effect of Season (fixed factor with 4 levels).

Finally, to evaluate changes in univariate measures (*N*, *W*, *Sm* and *H'*) among the three structures, a 2-way ANOVA was performed considering the factor Structure (fixed factor with 3 levels) and Year (fixed factor with 2 levels). Since the factor Year was significant for *N*, *W* and *H'*, a 1-way ANOVA testing for differences among structures was performed separately for each year.

The Tukey HSD test corrected for unbalanced samples was used to make comparisons across all pairs of group means when ANOVA tests for the factors of interest were significant ($p<0.05$).

In addition, for each structure, length-weight (L-W) relationships were investigated for three of the most abundant species in order to compare population structures between sites close to the structure and reference sites. In particular, the relationships were assessed for *Chelidonichthys lucerna*, *Trisopterus minutus capelanus* and *Pagellus bogaraveo* at Structure A, for *C. lucerna*, *T. minutus capelanus* and *Pagellus erythrinus* at Structure B, and for *C. lucerna*, *T. minutus capelanus and Scomber scombrus*, at Structure C. To test for possible significant differences between the specimens caught close to the structure and reference sites, the Student's t-test was used for comparison of the L-W relationship slopes (Zar, 1996). Finally, for each species the percentage of specimens sexually mature was calculated considering the values of size at maturity reported in Tsikliras and Stergiou (2014).

## RESULTS

### STRUCTURE A

*Multibeam survey*

The mean number and mean volume of the schools detected at each depth range at Structure A and at its reference site are reported in Annex 4.1. During the study period, the schools at Structure A were characterized by a mean Sv of -49.9±2.0 dB (median: -50.0 dB) and the average Sv values of the center of 50% of schools ranged from -50.8 dB to -49.0 dB (Figure 4.5).

The mean of the geometric center depth of the fish schools was 73.5±6.7 m (median: 74.3 m; i.e. 6 m above the sea bottom) indicating that most fish schools were very close to the seabed.

At the reference site for Structure A the mean Sv of fish schools was -50.3±1.8 dB (median: -50.6 dB), with the average Sv values of the center of 50% of schools ranging from -51.2 dB to -49.5 dB (Figure 4.5). The mean of the geometric center depth was 75.4±6.0 m (median: 77.3 m; i.e. 3 m above the sea bottom).

The significantly highest number of schools was recorded close to the seabed and within 300 m from the Structure A, whereas no statistical differences in the schools volume were observed between sites (Annex 4.2). The ANOVA analysis revealed no significant seasonal (temporal) changes at all sites, both in terms of number and volume of schools.

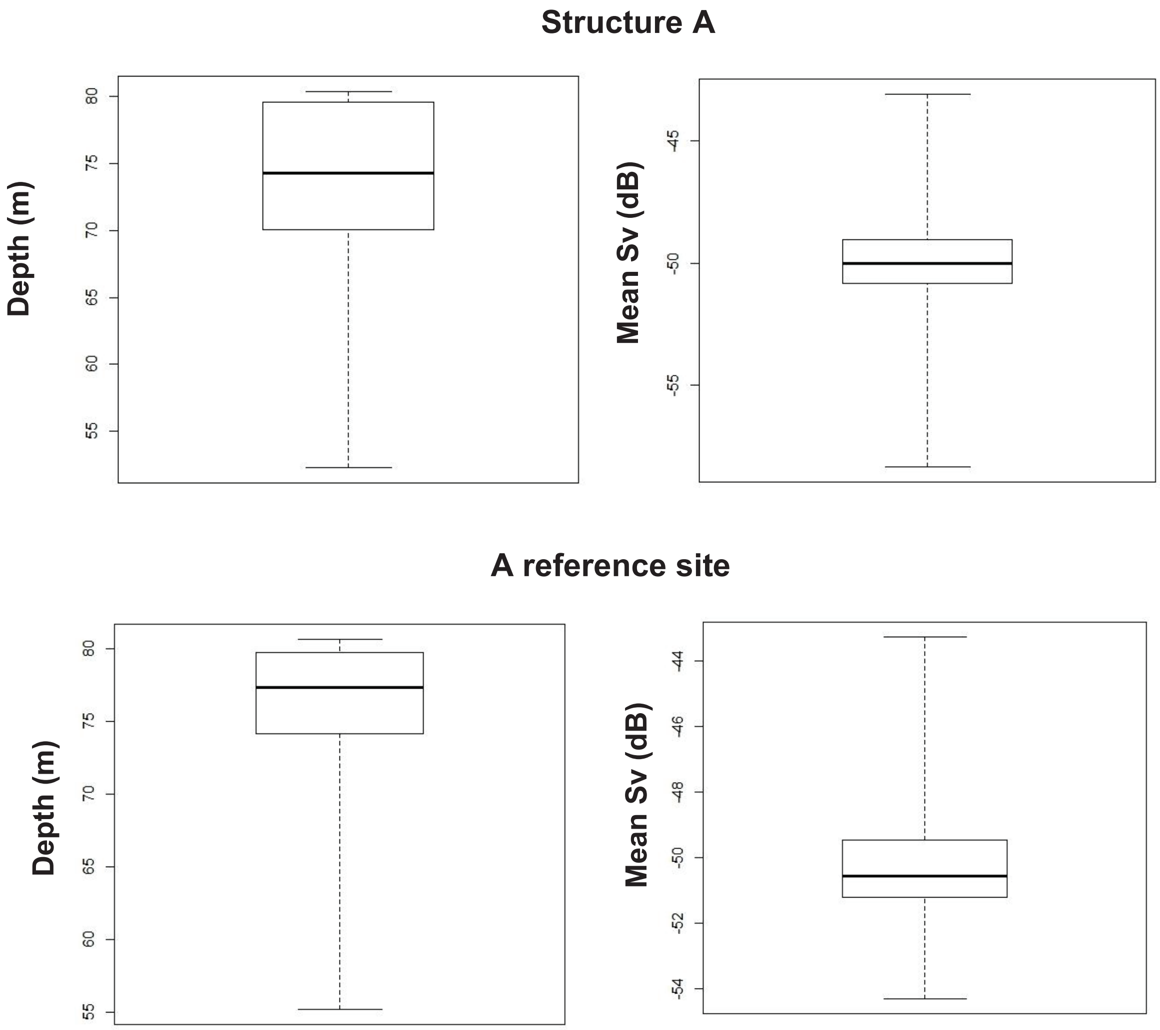


**Figure 4.5** - Boxplot of mean Sv and depth of the fish schools detected at Structure A and at A reference site.

*Fishing survey*

During the whole study period a total of 41 species were encountered, 35 of which were fish, 3 crustaceans and 2 mollusks (Annex 4.3). In particular, in the first year 27 species were recorded at C site, 24 of which were fish, 2 crustaceans and 1 mollusks, whereas a total of 19 and 18 species were registered respectively at F1 and F2 sites, comprising only fish at F1 and 14 fish, 3 crustaceans and 1 mollusk at F2. In the second year, a total of 19 species were observed at C site, whereas a total of 16 and 20 species were recognized respectively at F1 and F2 sites, including only 15 fish and 1 mollusk in F1, and 19 fish and 1 crustacean in F2.

Significantly higher abundance and biomass values were observed at C site when compared to F sites (Figure 4.6; Annex 4.4), whereas no differences were observed either between the two F sites or between the two sampling years. Also species richness followed a same pattern, with values close to the structures significantly higher than those at the reference sites. Finally, only during the second sampling year, *H'* showed higher value at C site in respect to F sites.

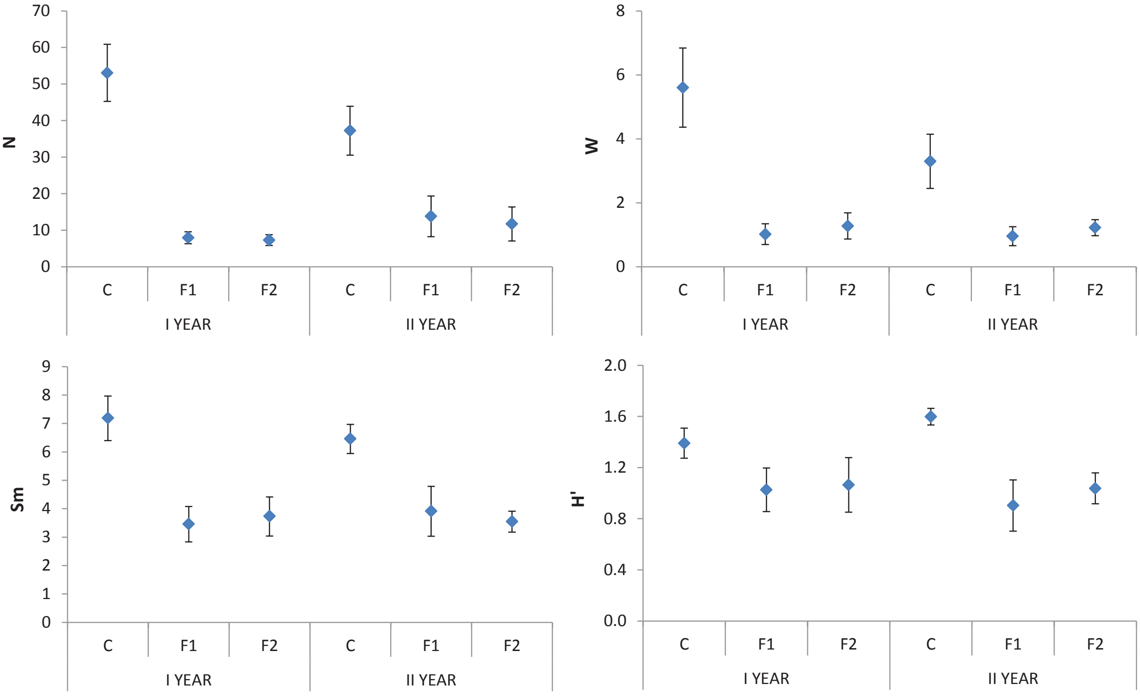


**Figure 4.6** - Mean values of univariate indices obtained for fish assemblages at each site (C: close to the rig; F1 and F2: reference sites) during the two sampling years. N: abundance (N. ind $500m^{-1}$ $12h^{-1}$); W: biomass (kg $500m^{-1}$ $12h^{-1}$); Sm: species richness; H': Shannon-Wiener diversity index. Error bars refer to standard errors.

The PCoA ordination, explaining about 40% of total variation, evidenced a segregation of the site close to the structure (C site) from both F sites (Figure 4.7).

Such segregation was statistically significant as confirmed by the PERMANOVA test, carried out pooling together all samples from each sampling time. The analysis showed significant differences for both factors separately (i.e. sampling year and site), whereas no significant differences were observed for the interaction among factors (Table 4.1). Also in this case, pair-wise tests revealed highly significant differences among C and F1 and F2 sites.

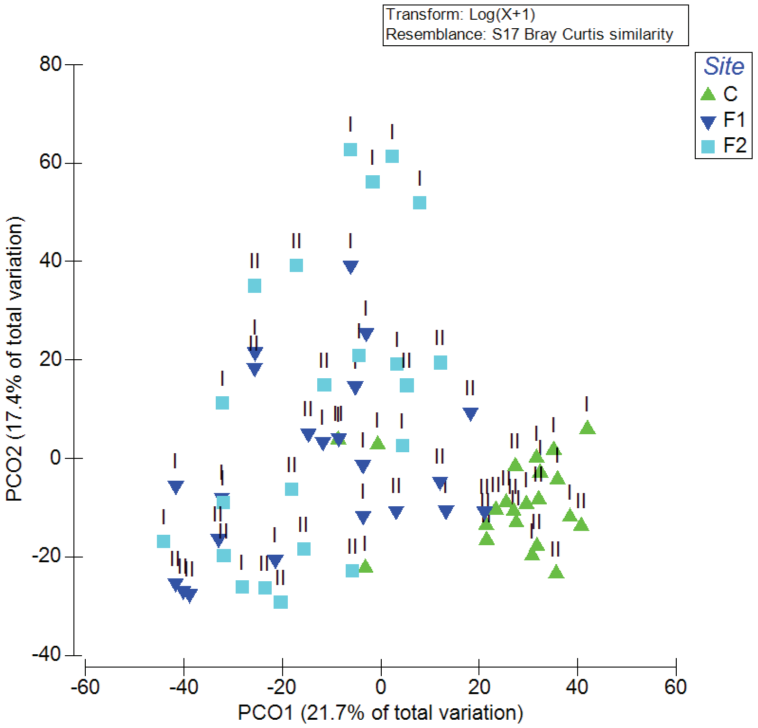


**Figure 4.7** – Results of Principal Coordinates Analysis (PCoA) on the abundance of fish assemblages sampled at Structure A during the two sampling years.

**Table 4.1** – Results of 2-way PERMANOVA and Pair-wise tests comparing the fish assemblages sampled close to the structure and at reference sites at Structure A during the two sampling years. * = significant (P<0.05); ** = highly significant (P<0.01).

| Source | d.f. | MS | Pseudo-F | P(perm) | Perms | Pair-wise tests |
|---|---|---|---|---|---|---|
| Year | 1 | 4752.9 | 1.9561 | 0.038* | 998 | Year I ≠ Year II |
| Site | 2 | 14692 | 6.0468 | 0.001** | 998 | C≠ F1; F2 |
| Year x Site | 2 | 1906.3 | 0.78454 | 0.734 | 999 | |
| Residuals | 60 | 2429.8 | | | | |
| Total | 65 | | | | | |

The dissimilarities between C and F sites were mainly due to *Pagellus bogaraveo*, *Boops boops* and *Trisopterus minutus capelanus*, whose abundance was significantly higher close to the structure than at the respective reference sites (Annex 4.5).

In both years, no seasonal variations were observed for both fish abundance and biomass at each sampling site (p>0.05; Figure 4.8).

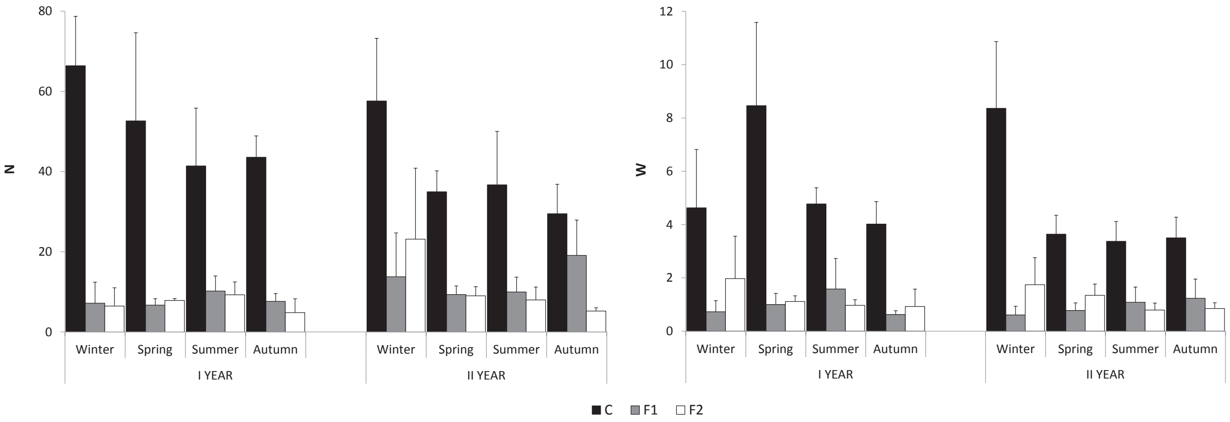


**Figure 4.8** - Mean values of abundance (N; N. ind $500m^{-1}12h^{-1}$) and biomass (W; kg $500m^{-1}$ $12h^{-1}$) obtained for each season close to the Structure A (C) and at the reference sites (F1 and F2). Error bars refer to standard errors.

During both sampling years the catch rates of nekto-benthic and pelagic groups were significantly more abundant at C site when compared to those at the F sites ($p<0.01$; Figure 4.9), whereas no significant differences were observed between F sites ($p>0.05$). On the contrary, no significant differences between sites were observed for the benthic group ($p>0.05$).

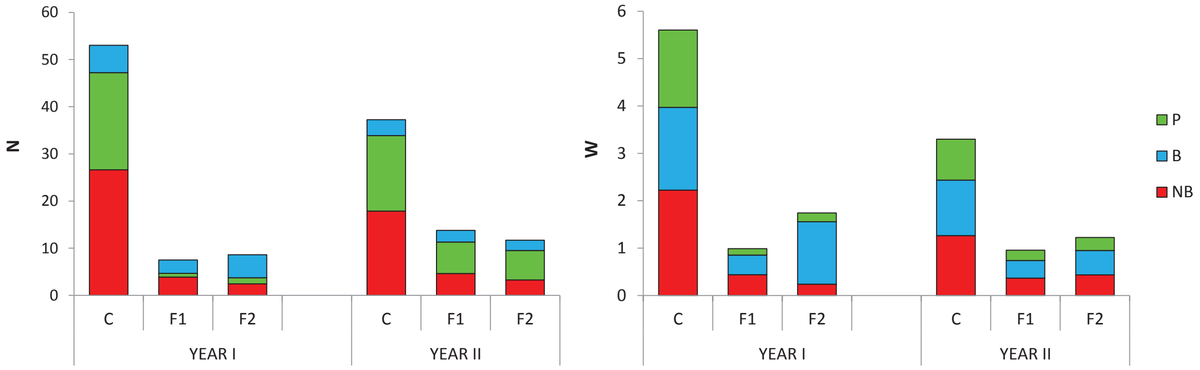


**Figure 4.9** - Mean abundance (N; N. ind $500m^{-1}12h^{-1}$) and mean biomass (W; kg $500m^{-1}$ $12h^{-1}$) obtained for each category (NB: nekto-benthic; B: benthic; P: pelagic) at each site (C: close to the structure; F1 and F2: reference sites).

At all sites the nekto-benthic group was almost exclusively composed by *Pagellus bogaraveo*, *Trisopterur minutus capelanus* and *Merluccius merluccius*, whereas pelagic species mainly consisted of *Boops boops* and *Engraulis encrasicolus* (Annex 4.3). Benthic species were mainly represented by *Chelidonichthys lucerna*, *Nephrops* *norvegicus* and *Eutrigla gurnardus* at C site, and by *C. lucerna*, *Trachinus draco*, and *Lophius budegassa* at F sites.

No significant differences (p>0.05) in the slope of the L-W relationships were observed between C and F sites for all the considered species (Figure 4.10). For both *C. lucerna* and *T. minutus capelanus* the percentage of the sexually mature individuals was significantly higher at the reference site (*C. lucerna*: 63.3%; *T. minutus capelanus*: 75.0%) than at the close site (*C. lucerna*: 58.3%; *T. minutus capelanus*: 58.2%). For *P. bogaraveo*, all the specimens collected presented a TL lesser than the maturity size.

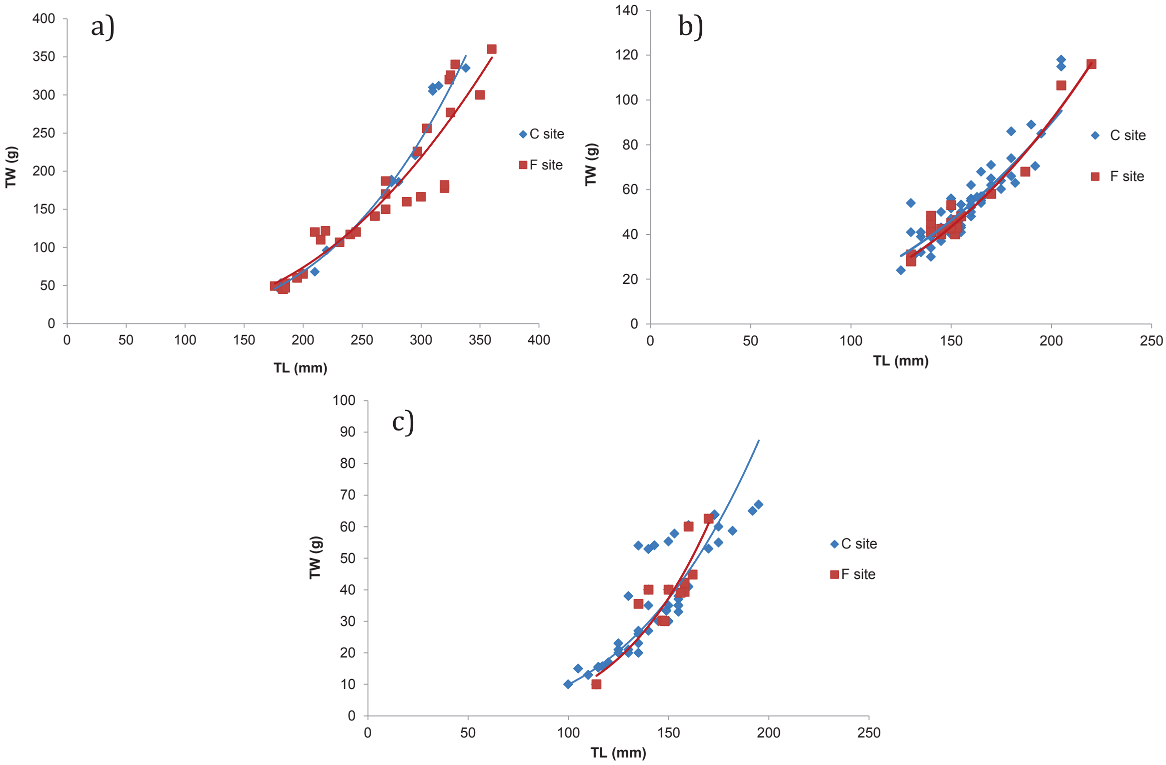


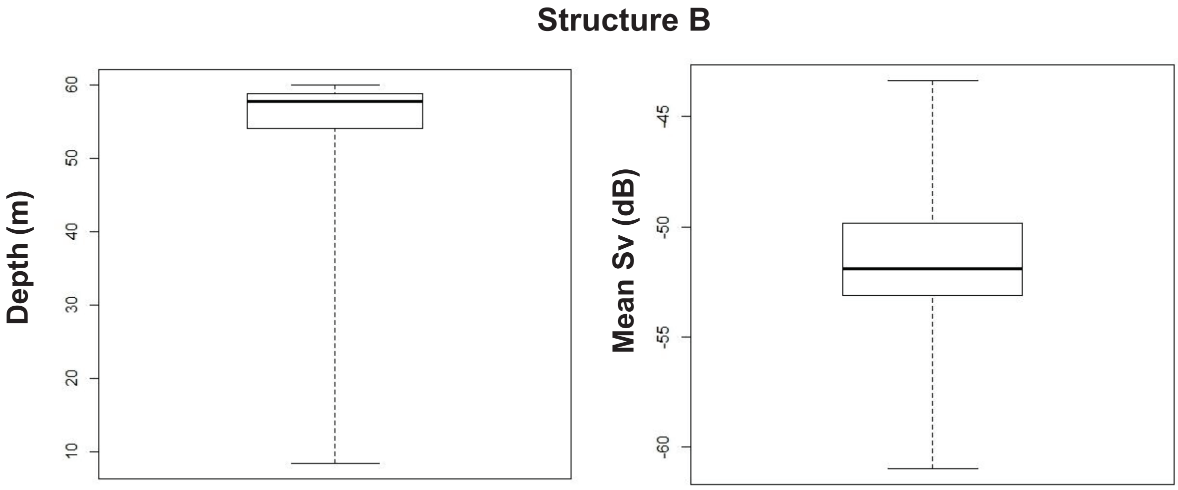
**Figure 4.10** - Length-weight relationships of *Chelidonichthys lucerna* (a), *Trisopterus minutus capelanus* (b) and *Pagellus bogaraveo* (c) collected at C and F sites.

## STRUCTURE B

### *Multibeam survey*

The mean number and mean volume of the schools detected at each depth range close to Structure B and at the B ref site are reported in Annex 4.6.

In the overall period at Structure B the mean Sv of fish schools was -51.6±2.7 dB (median: -51.9 dB); the center of 50% of them having a range of mean Sv values between -53.1 dB and -49.8 dB (Figure 4.11).



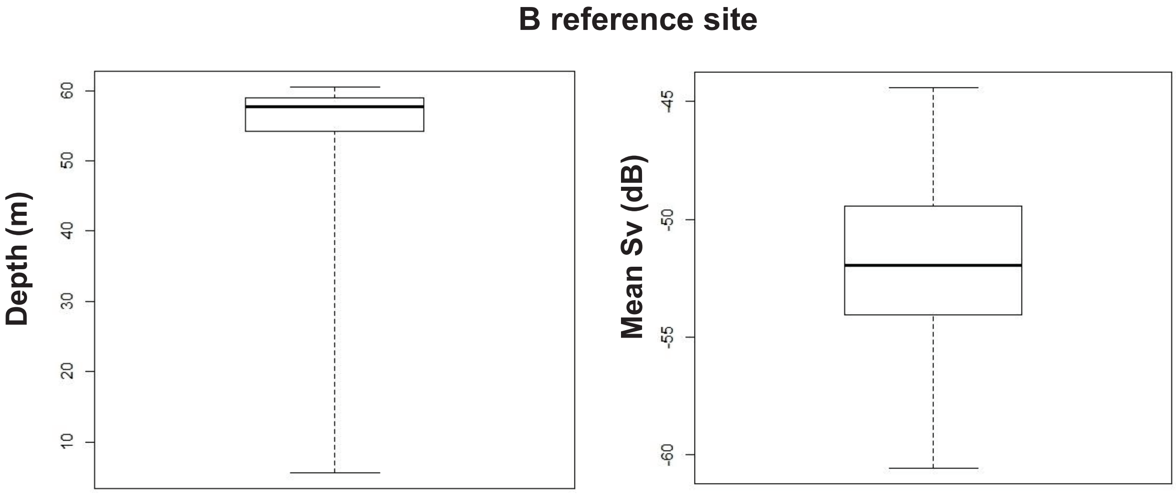


**Figure 4.11** - Boxplot of mean Sv and depth of the fish schools detected at Structure B and at B reference site.

The mean of geometric center depth (positional feature) was 53.5±10.5 m (median: 57.8 m; i.e. 2 m above the sea bottom) indicating that most of fish schools stood close to the seabed. At B reference site the mean Sv of all fish schools was -51.8±3.2 dB (median: -52.0 dB); in this case the center of 50% of them having mean Sv values ranging between -54.0 dB and -49.4 dB (Figure 4.11). The mean of geometric center depth was 54.0±9.7 m (median: 57.7; i.e. 2 m above the sea bottom) indicating that also in this case most of fish schools stood close to the seabed.

The highest number and the highest volumes of schools were recorded close to the seabed and within 300 m from structure, as evidenced by statistical analysis, while no differences were evidenced between the two sampling years (Annex 4.7).

Regarding the seasonal pattern, most of schools was recorded in winter and spring, although ANOVA tests highlighted significant differences only between spring and summer in terms of number of schools at both sites ($p<0.05$). No seasonal differences were evidenced in terms of volume of schools.

*Fishing survey*

In the overall period a total of 74 species were registered, 62 of which were fish, 6 mollusks and 6 crustaceans (Annex 4.8). In particular in the first year 61 species were recorded close to the Structure B (C), 53 of which were fish, 4 mollusks and 4 crustaceans, whereas a total of 38 species were recognized at both reference sites (F1 and F2), including 35 fish and 3 crustaceans in F1, and 34 fish, 1 mollusk and 3 crustaceans in F2. In the second year, 57 species were observed at C site (48 fish, 6 crustaceans and 3 mollusks), 29 at F1 site (25 fish, 3 crustaceans and 1 mollusks) and 38 at F2 site (35 fish, 2 mollusks and 1 crustacean).

For all the univariate indices higher significant values were recorded at C site in respect to F sites (Figure 4.12; Annex 4.9), while no differences were observed both between F sites and between the two sampling years.

The PCoA ordination, explaining more than 40% of total variation, showed a clear segregation of the site hosting the structure from both F sites (Figure 4.13). Such segregation was statistically significant as confirmed by the PERMANOVA test. The analysis showed significant differences only for factor Site, while no statistically differences were evidenced for Year and for the interaction among factors (Table 4.2). Pair-wise tests revealed highly significant differences among C and F1 and F2 sites.

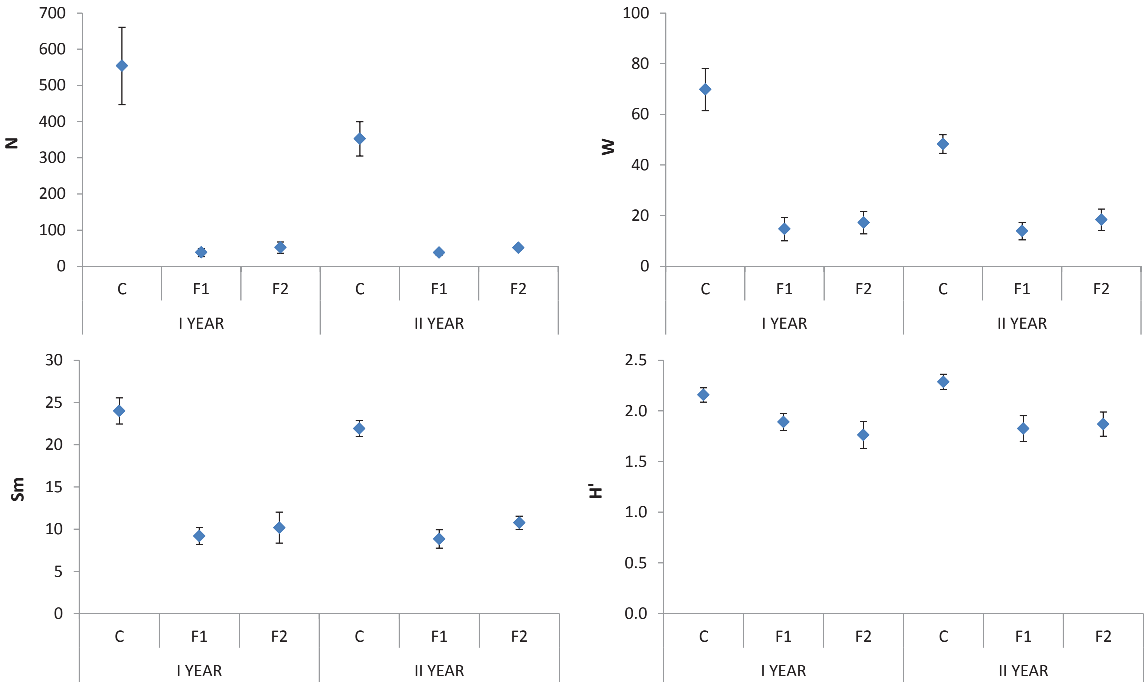


**Figure 4.12** - Mean values of univariate indices obtained for fish assemblages at each site (C: close to the rig; F1 and F2: reference sites) during the two sampling years. N: abundance (N. ind 500m$^{-1}$ 12h$^{-1}$); W: biomass (kg 500m$^{-1}$ 12h$^{-1}$); Sm: species richness; H': Shannon-Wiener diversity index. Error bars refer to standard errors.

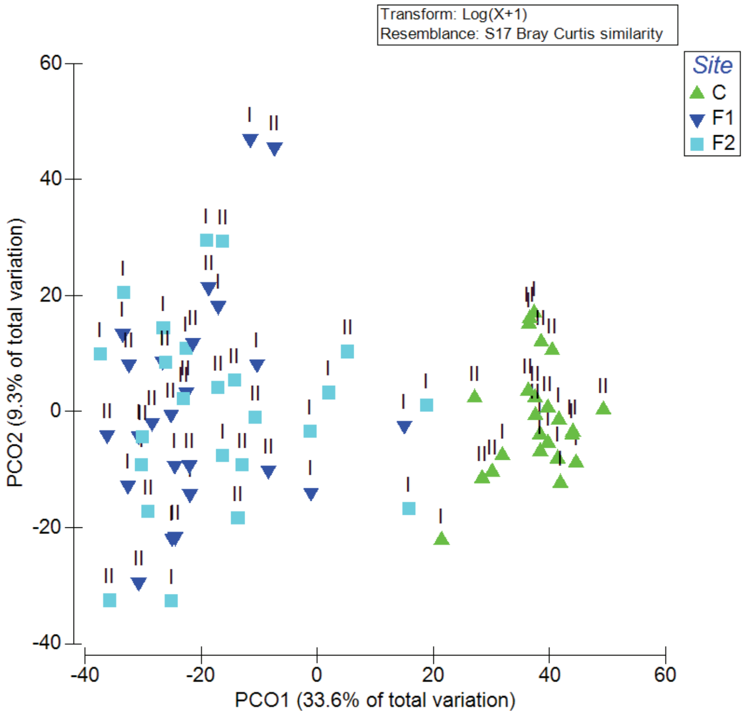


**Figure 4.13** - Results of Principal Coordinates Analysis (PCoA) on the abundance of fish assemblages sampled at Structure B during the two sampling years.

Species that mainly contribute to the dissimilarities between C and F sites were *P. bogaraveo*, *T. minutus capelanus*, *Trachurus mediterraneus* and *Boops boops,* more abundant at C site in respect to F sites (Annex 4.10).

**Table 4.2** – Results of 2-way PERMANOVA and Pair-wise tests comparing the fish assemblages sampled at Structure B during the two sampling years. * = significant (P<0.05); ** = highly significant (P<0.01).

| Source | d.f. | MS | Pseudo-F | P(perm) | Perms | Pair-wise tests |
|---|---|---|---|---|---|---|
| Year | 1 | 2815.9 | 1.5256 | 0.095 | 998 | |
| Site | 2 | 26589 | 14.406 | 0.001** | 998 | C ≠ F1; F2 |
| Year x Site | 2 | 874.69 | 0.4739 | 0.994 | 997 | |
| Residuals | 66 | 1845.7 | | | | |
| Total | 71 | | | | | |

No seasonal differences (p>0.05) were evidenced at C site and at F1 site both for abundance and biomass (Figure 4.14). Differently, at F2 a statistical difference was highlighted only between winter and autumn in terms of number (p<0.05), while no difference was showed in terms of weight (p>0.05).

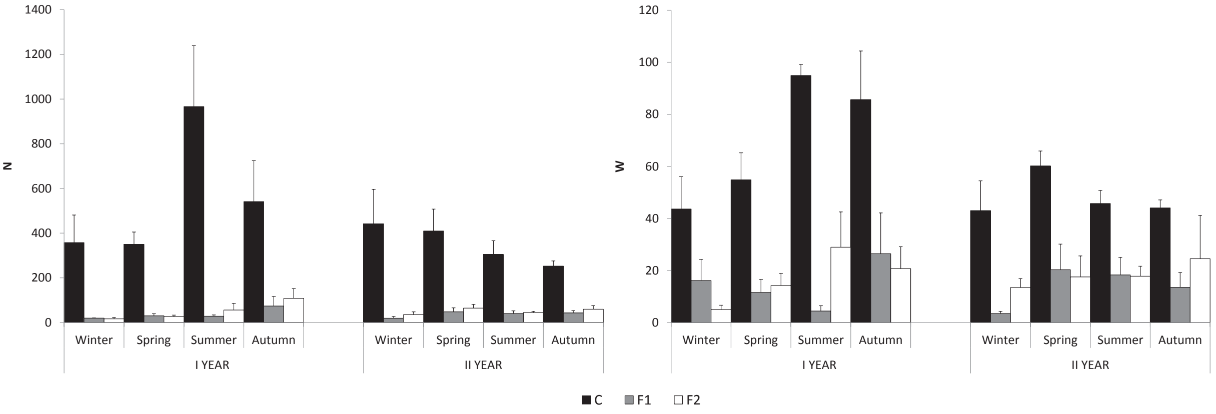


**Figure 4.14** - Mean values of abundance (N; N. ind 500m$^{-1}$12h$^{-1}$) and biomass (W; kg 500m$^{-1}$ 12h$^{-1}$) obtained for each season close to the Structure B (C) and at the reference sites (F1 and F2). Error bars refer to standard errors.

In the overall period the catch rates of all groups (NB, B and P) were significantly more abundant at C than at F sites (p<0.01), while no differences were obtained between F1 and F2 (p>0.05; Figure 4.15). The same pattern was also observed for the biomass, with higher value recorded at the site close to the structure in respect to the farther ones.

Nekto-benthic species were almost exclusively represented by *P. bogaraveo*, *T. minutus capelanus*, and *P. erythrinus* at all sites (Annex 4.8).

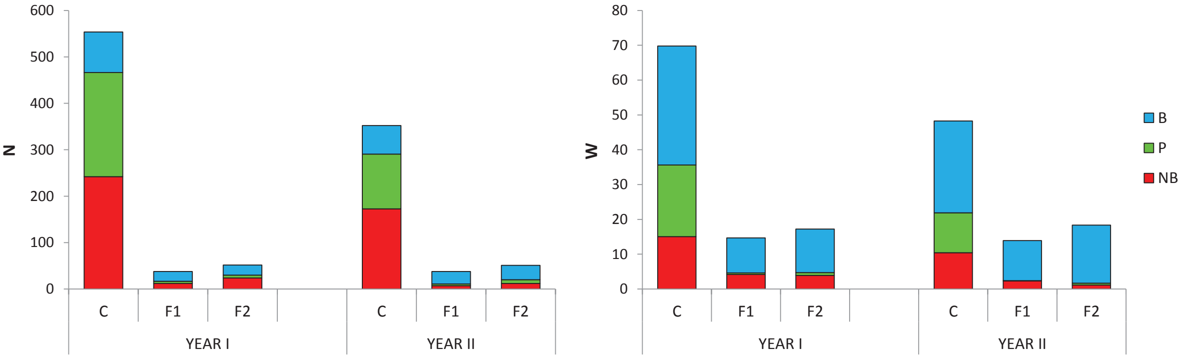


**Figure 4.15** - Mean abundance (N; N. ind 500m$^{-1}$12h$^{-1}$) and mean biomass (W; kg 500m$^{-1}$ 12h$^{-1}$) obtained for each category (NB: nekto-benthic; B: benthic; P: pelagic) at each site (C: close to the structure; F1 and F2: reference sites).

Pelagic group mainly consisted of *B. boops*, *T. mediterraneus*, and *E. encrasicolus* at C, while was dominated by *E. encrasicolus* and *S. pilchardus* at F sites. Finally, benthic species mainly consisted of *Maja squinado*, *C. lucerna* and *Torpedo marmorata* at C site, and of *M. squinado, Solea solea* and *Squalus acanthias* at F1 and F2.

Concerning length-weight relationships, for *Trisopterus minutus capelanus* and *P. erythrinus* significant differences ($p<0.05$) were highlighted between C and F sites (Figure 4.16), while no differences were evidenced for *C. lucerna*.

In addition, for all the species considered, the higher percentage of the individuals having a TL greater than the maturity size was caught close to the structure.

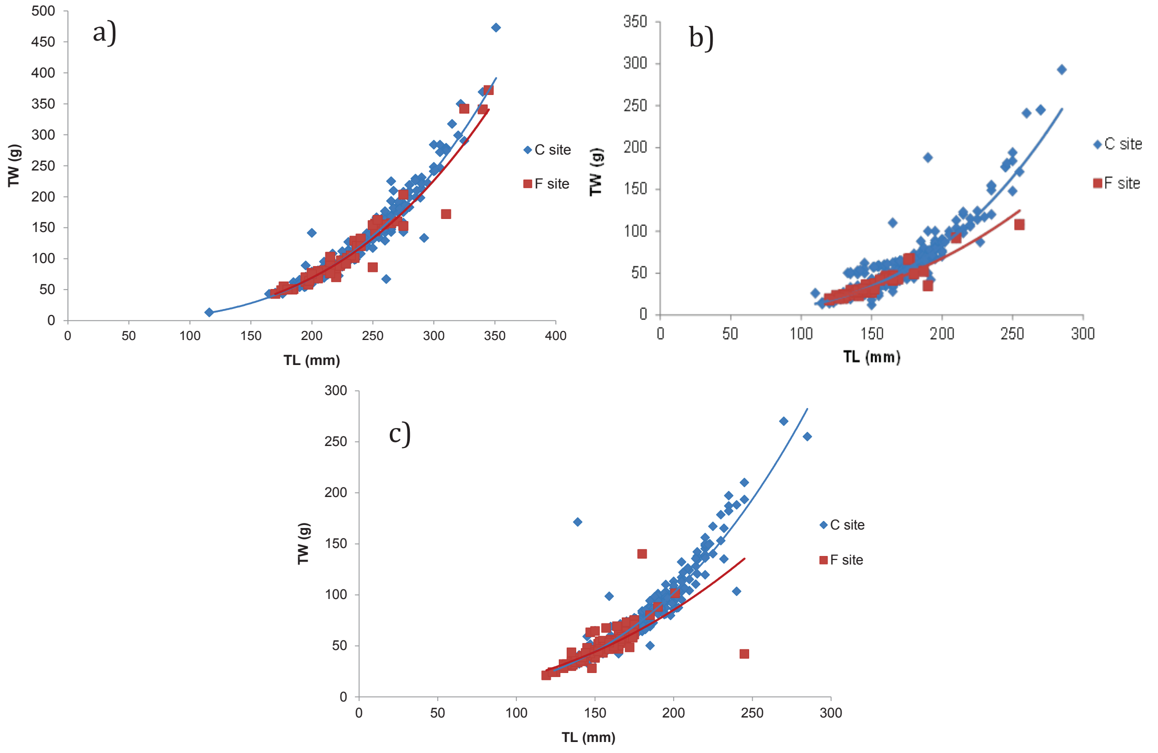


**Figure 4.16** - Length-weight relationships of *Chelidonichthys lucerna* (a), *Trisopterus minutus capelanus* (b) and *Pagellus bogaraveo* (c) collected at C and F sites.

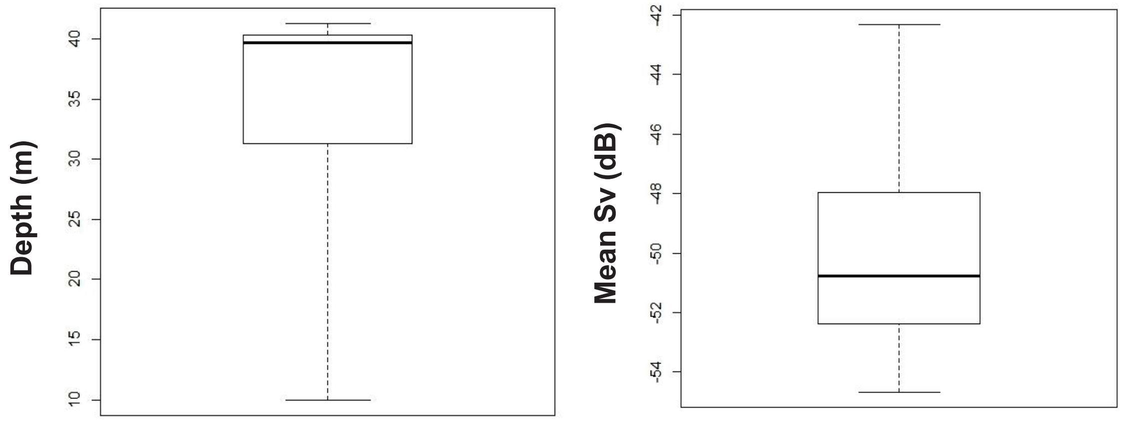
## STRUCTURE C

### *Multibeam survey*

The mean number and volume of the schools detected at each depth range in the C surroundings and at C ref site are reported in Annex 4.11. Considering the overall sampling period at Structure C the mean Sv of all fish schools was -50.0±2.9 dB (median: -50.8 dB); the center of 50% of them having a range of mean Sv values between -52.4 dB and -48.0 dB (Figure 4.17).

The average of geometric center depth (positional feature) was 36.9±7.3 m (median: 39.7 m; i.e. 1 m above the sea bottom) indicating that most of fish schools stood close to the seabed. At C reference site the mean Sv of all fish schools was -50.7±2.0 dB (median: -51.0 dB); in this case the center of 50% of them having mean Sv values ranging between -52.2 dB and -49.3 dB (Figure 4.17). The mean of geometric center depth was 38.1±4.7 m (median: 39.9; i.e. 1 m above the sea bottom) indicating that also in this case most of fish schools stood close to the seabed.

Structure C



C reference site

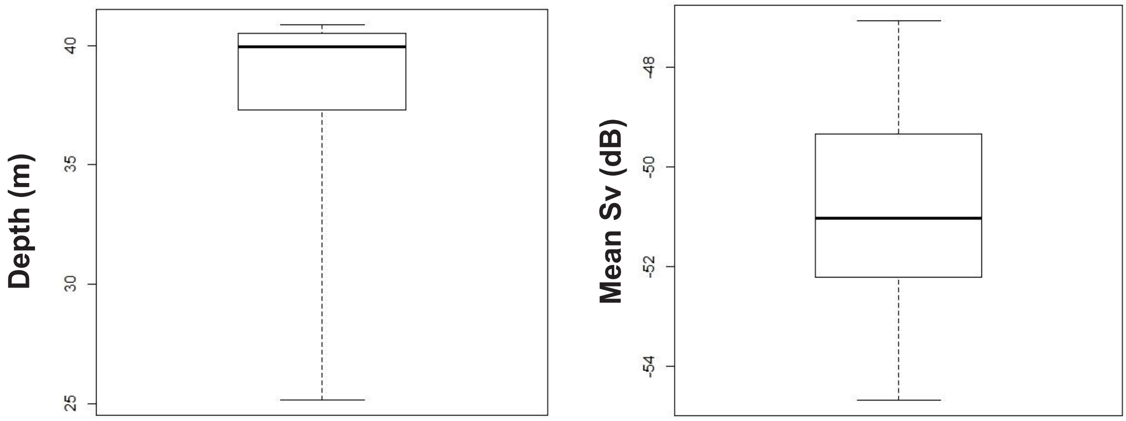


**Figure 4.17 -** Boxplot of mean Sv and depth of the fish schools detected at Structure C and at C reference site.

Statistical analysis confirmed the highest occurrence of fish schools strictly close to Structure C, both in terms of number and volume, in respect to C reference site. In addition, even though the higher number and the higher volumes of schools were recorded close to the seabed, no statistical differences were evidenced (Annex 4.12).

Regarding the seasonal pattern, no significant differences were highlighted through ANOVA test at both sites ($p>0.05$).

*Fishing survey*

In the overall period, a total of 52 species were registered, 45 of which were fish, 4 crustaceans and 3 mollusks (Annex 4.13). In particular in the first year after construction 36 species were recorded close to the Structure (C site), 30 of which were fish, 4 crustaceans and 2 mollusks. At the reference sites were recognized a total of 22 and 25 species, respectively at F1 and F2 site, including 18 fish, 3 crustaceans and 1 mollusk in F1, and 22 fish and 3 crustaceans species in F2. In the second sampling year a slightly reduction occurred everywhere: a total of 30 species were recorded at C site, comprising 24 fish, 4 crustaceans and 2 mollusks, whereas a total of 20 species were observed at F1 (16 fish, 2 crustaceans and 2 mollusks), and 24 species at F2 (21 fish and 3 crustaceans).

Mean abundance (*N*) evidenced higher significant values at C site in respect to F sites, as confirmed by the statistical analysis, while no differences occurred between the two reference sites (Figure 4.18).

Moreover, a higher abundance was observed at C site in the first year in respect to the second one, while no significant variations were evidenced at F sites during the overall period (Annex 4.14). For both *W* and S*m* the higher values were recorded at C site in respect to F sites in each sampling year. Contrarily, *H’* didn’t display any significant difference both between year and among site (Annex 4.14).

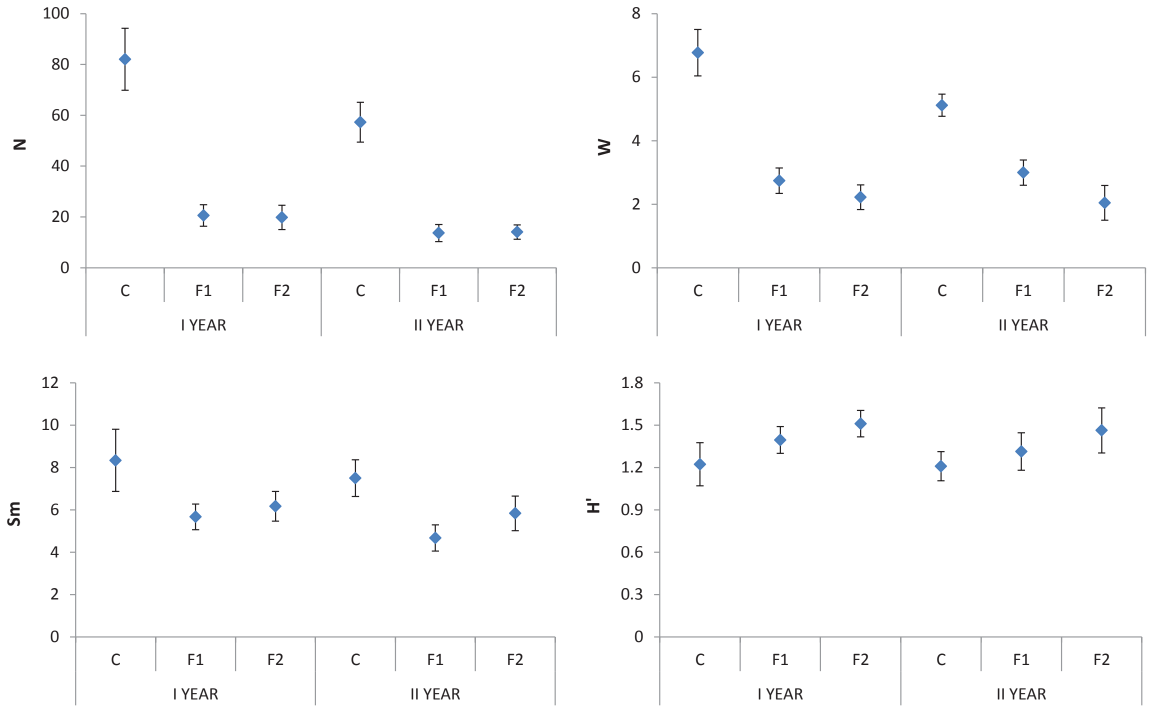


**Figure 4.18** - Mean values of univariate indices obtained for fish assemblages at each site (C: close to the rig; F1 and F2: reference sites) during the two sampling years. N: abundance (N. ind $500m^{-1}$ $12h^{-1}$); W: biomass (kg $500m^{-1}$ $12h^{-1}$); Sm: species richness; H’: Shannon-Wiener diversity index. Error bars refer to standard errors.

The PCoA ordination explained more than 35% of total variation and showed a separation of the site hosting the structure from both F sites (Figure 4.19).

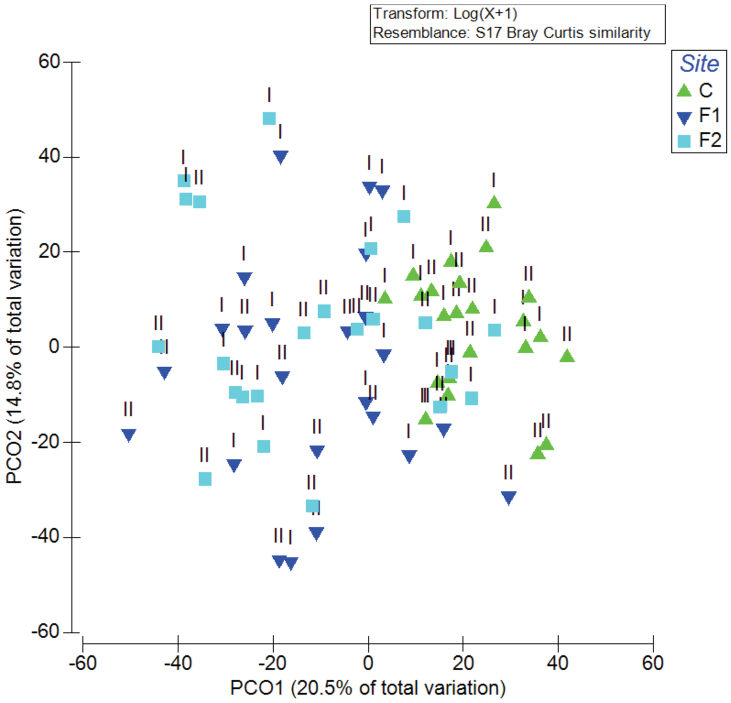


**Figure 4.19** – Results of Principal Coordinates Analysis (PCoA) on the abundance of fish assemblages sampled at Structure C during the two sampling years.

This was confirmed by the PERMANOVA test which revealed significant differences for each factor (Year and Site) separately, while the interaction was not significant (Table 4.3). Pair-wise tests revealed highly significant differences among C and F1 and F2 sites.

**Table 4.3** – Results of 2-way PERMANOVA and Pair-wise tests comparing the fish assemblages sampled at Structure C during the two sampling years. * = significant (P<0.05); ** = highly significant (P<0.01).

| Source | d.f. | MS | Pseudo-F | P(perm) | Perms | Pair-wise tests |
|---|---|---|---|---|---|---|
| Year | 1 | 4598.8 | 1.9808 | 0.042* | 999 | Year I ≠ Year II |
| Site | 2 | 13683 | 5.8932 | 0.001** | 999 | C≠ F1; F2 |
| Year x Site | 2 | 1139.6 | 0.49086 | 0.965 | 997 | |
| Residuals | 66 | 2321.7 | | | | |
| Total | 71 | | | | | |

Species that mainly contribute to the dissimilarities between C and F sites were *Trisopterus minutus capelanus*, *Squilla mantis* and *Merlangius merlanguss*, resulted more abundant at C site in respect to F sites (Annex 4.15).

ANOVA tests highlighted no seasonal differences (p>0.05) for both abundance and biomass during the overall period at each sampling site (Figure 4.20).

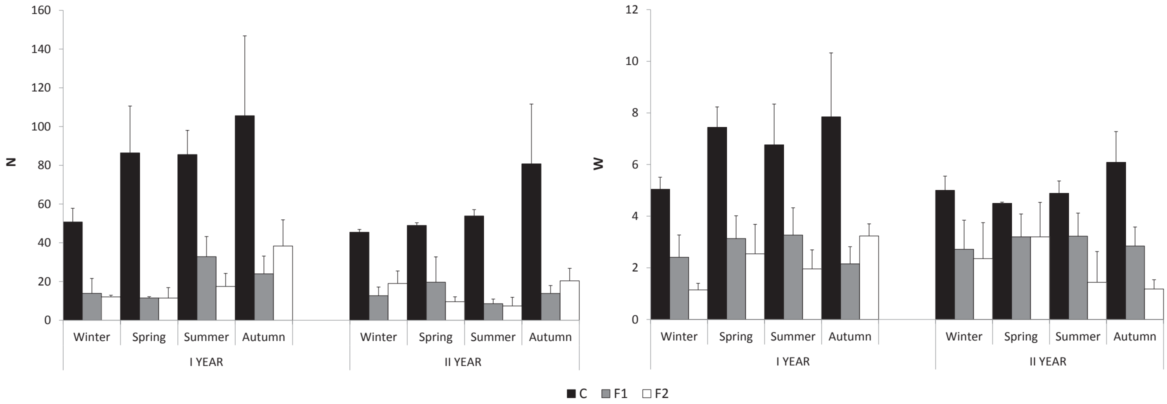


**Figure 4.20** - Mean values of abundance (N; N. ind $500m^{-1}$ $12h^{-1}$) and biomass (W; kg $500m^{-1}$ $12h^{-1}$) obtained for each season close to the Structure C (C) and at the reference sites (F1 and F2). Error bars refer to standard errors.

Taking into account the abundance and biomass of main groups (B, NB and P), statistical analysis showed a different pattern for each category (Figure 4.21).

The catches rates of nekto-benthic group resulted significantly higher at C in respect to F sites (p<0.05), both in terms of number of individuals and of weight (Figure 4.21), while no differences were observed between F1 and F2 sites (p>0.05). Benthic group evidenced significant differences between C and F2 sites (p<0.05), both in terms of abundance and of biomass, with higher value close to the structure. On the contrary, no statistical differences were registered among sites for pelagic groups (p>0.05).

Nekto-benthic species were almost exclusively represented by *T. minutus capelanus*, *P. bogaraveo* and *M. merlangus* at all sites (Annex 4.13). Pelagic species mainly consisted of *Engraulis encrasicolus and Scomber japonicus* at C site, while they were dominated by *E. encrasicolus* and *S. scombrus* at F sites. Finally, benthic species mainly consisted of *Chelidonichthys lucerna* and *Aequipecten opercularis* at C, and of *Solea solea* and *C. lucerna* at F1 and F2.

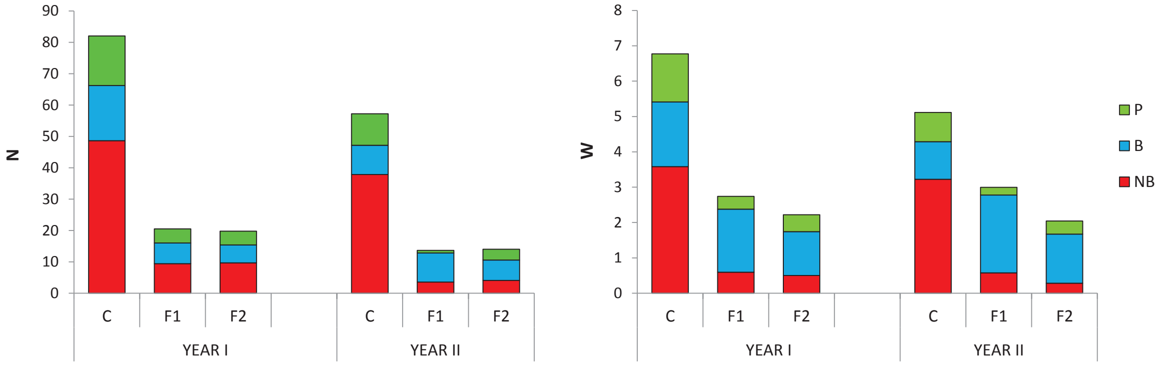


**Figure 4.21** - Mean abundance (N; N. ind $500m^{-1}12h^{-1}$) and mean biomass (W; kg $500m^{-1}$ $12h^{-1}$) obtained for each category (NB: nekto-benthic; B: benthic; P: pelagic) at each site (C: close to the structure; F1 and F2: reference sites).

L-W relationships evidenced significant difference between C and F site only for *T. minutus capelanus* (Figure 4.22). In addition, for both *C. lucerna* and *T. minutus capelanus* the higher percentage of the individuals having reached the maturity size was collected at the reference site, while an opposite situation was evidenced for *S. scombrus*.

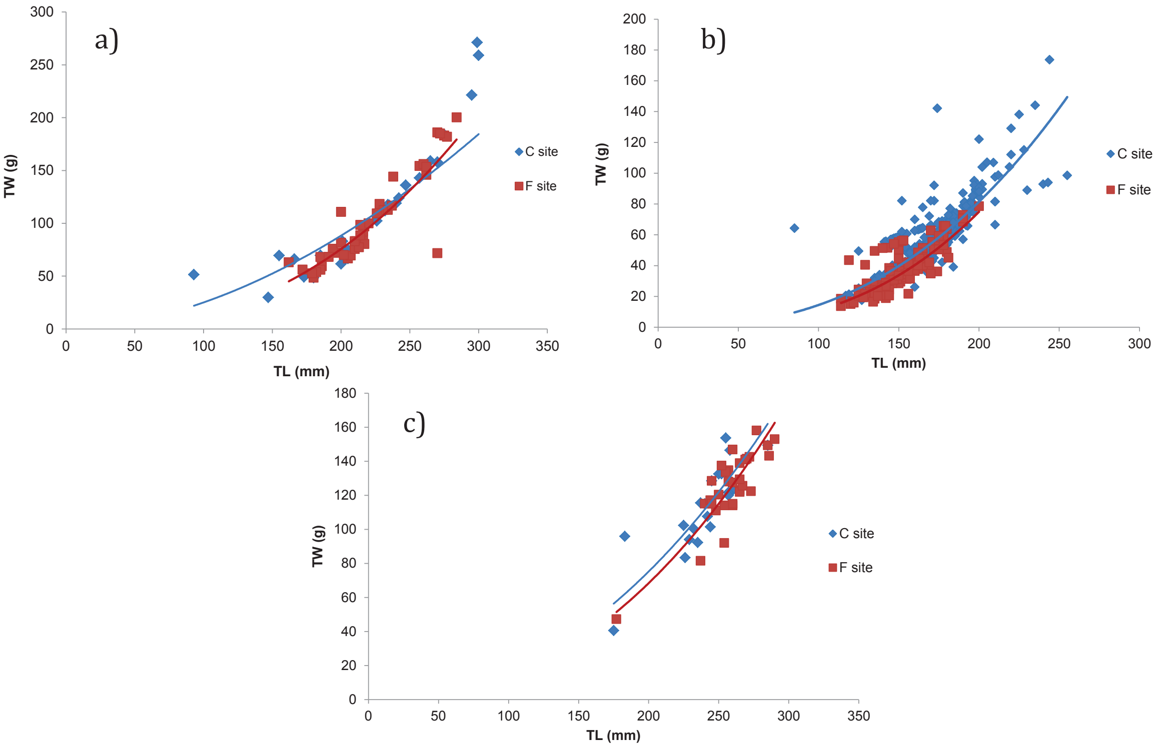


**Figure 4.22** - Length-weight relationships of *Chelidonichthys lucerna* (a), *Trisopterus minutus capelanus* (b) and *Scomber scombrus* (c) collected at C and F site.

*Multibeam survey*

Both number and volume of fish schools varied significantly among the three structures (Table 4.4) with values at Structure B significantly higher than those in the other two structures.

**Table 4.4** - Results of 1-way ANOVA and post-hoc comparisons (HSD test) carried out to ascertain differences in the number (N) and volume (V) of fish schools among the three structures. St A: Structure A; St B: Structure B; St C: Structure C. * = significant (P<0.05); ** = highly significant (P<0.01).

| Source | d.f. | **N** | | | **V** | | |
|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P |
| Between groups | 2 | 0.000 | 4.602 | 0.012* | 0.000 | 7.160 | 0.001** |
| Within groups | 39 | 0.000 | | | 0.000 | | |
| Total | 41 | | | | | | |
| | | St B > St C > St A | | | St B > St A; St C | | |

In addition, a significant difference was also evidenced for N between Structure A and Structure C, with the highest values registered at the latter. No significant differences were observed for volume between the two structures.

*Fishing survey*

In the first sampling year *N*, *W* and *H’* showed higher significant values at Structure B in respect to Structure A and Structure C, whereas no significant differences were observed between the Structure A and C (Table 4.5).

In the second year, *N*, *W* and *H’* evidenced higher significant values at Structure B in respect to Structure A and Structure C. In addition, *N* and *W* showed higher values at Structure C in respect to Structure A, while an opposite trend was followed by *H’*.

**Table 4.5** – Results of 2-way ANOVA carried out to ascertain differences in fish abundance (N), biomass (W), species richness (Sm), and Shannon Wiener index (H') among the three structures during the two sampling years. St A: Structure A; St B: Structure B; St C: Structure C. * = significant (P<0.05); ** = highly significant (P<0.01).

| Source | d.f. | **N** | | | **W** | | |
|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P |
| Structure (St) | 2 | 6.469 | 133.461 | 0.000** | 9.650 | 216.750 | 0.000** |
| Year (Ye) | 1 | 0.351 | 7.236 | 0.009** | 0.525 | 11.782 | 0.001** |
| St x Ye | 2 | 0.000 | 0.007 | 0.993 | 0.049 | 1.100 | 0.339 |
| | | Year 1 | | | Year 1 | | |
| | | St B > St A; St C | | | St B > St A; St C | | |
| | | Year 2 | | | Year 2 | | |
| | | St B > St C > St A | | | St B > St C > St A | | |

| Source | d.f. | **Sm** | | | **H'** | | |
|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P |
| Structure (St) | 2 | 2.119 | 102.299 | 0.000** | 0.508 | 33.104 | 0.000** |
| Year (Ye) | 1 | 0.013 | 0.637 | 0.428 | 0.031 | 2.006 | 0.162 |
| St x Ye | 2 | 0.001 | 0.038 | 0.962 | 0.006 | 0.391 | 0.678 |
| | | Year 1 and Year 2 | | | Year 1 | | |
| | | St B > St A; St C | | | St B > St A; St C | | |
| | | | | | Year 2 | | |
| | | | | | St B > St C > St A | | |

## DISCUSSION

More than 110 gas platforms are placed in the northern and central Adriatic Sea (Maggi *et al.*, 2007; Manoukian *et al.*, 2010) where these structures constitute one of the largest artificial habitat in the whole basin.

Taking into account that the central and northern Adriatic Sea is heavily exploited by trawlers and that all kinds of fisheries are forbidden within a radius of 500 m from each platform, these structures can putatively act as "protected zones" and might contribute to sustain overexploited stocks (GFCM, 2009). On the other hand, the presence of oil and gas platforms in the marine environment can create a number of environmental and social problems.

Hence, in the light of the upcoming decommissioning issue, it is essential to deeply understand both the spatial distribution of fish around these structures and the ecological processes which drive the different fish species close to them.

In the last twenty years there has been an increasing use of Multibeam Echosounder (MBES) for acoustic applications in fisheries research with advancements in hardware technology, digital acquisition of acoustic backscatter in the water column and 3D visualization of acoustic data (Hafsteinsson and Misund, 1995; Gerlotto *et al*., 1999; 2000; Misund and Coetzee, 2000; Gerlotto and Paramo, 2003; Soria *et al*., 2003; Paramo *et al*., 2007; Howell, 2008; Gurshin *et al.,* 2009; Weber *et al*., 2009; Yuan *et al*., 2013). This technique has been often associated with other acoustic methodologies (Gerlotto *et al.,* 2000; Misund and Coetzee, 2000; Brehmer *et al*., 2003; Gerlotto and Paramo, 2003; Gurshin *et al*., 2009) as well as with fishing surveys (Howell, 2008; Weber *et al*., 2009; Yuan *et al*., 2013), and results an extremely efficient tool to provide additional information on fish spatial distribution, school morphology and classification, migrations and abundance.

The present study was aimed to test the null hypothesis by which the abundance, biomass and diversity of fish assemblages are not affected by the presence of offshore artificial structures (1 subsea well site, 1 four-leg platform and 1 one-leg platform) through dedicated acoustic and fishing surveys. In addition, the study allowed to investigate the suitability of MBES as a reliable tool for assessing consistence and spatial distribution of fish schools around the structures. This methodology, in fact, provides additional information that, associated to the data obtained through traditional fishing surveys, allows a better understanding of the effects exerted by the presence of offshore structures on the fish communities inhabiting their surroundings.

The most relevant problem encountered during MBES surveys was the impossibility to map the fish schools swimming within a radius of 10 m from the platform: this was due to the great amount of beams reflected by the iron frame which constitutes the submerged portion of the structure extending from the seabed to the surface. Hence, the abundance of fish schools at the site closest to the platforms was most likely underestimated. As highlighted also by Yuan *et al*. (2013), the noise could be minimized increasing the TS threshold. However, also in this case some fish traces would be excluded (Watkins and Brierley, 1996; Romare, 2001), leading to a persistent underestimation of the fish assemblages.

On the other hand, the trammel net tends to underestimate small pelagic fish, such as *E. encrasicolus* and *S. pilchardus*, and large pelagic fish (*e.g*., *Thunnus thynnus* and *Seriola dumerili*) due to its selectivity and its limited height when compared with that of the water column (Fabi *et al.*, 2004; Scarcella *et al.,* 2011).

However, in spite of these issues linked to the two different methodological approaches, both acoustic and fishing surveys evidenced a higher abundance of fish close to the structures when compared to the respective open-sea reference sites and a higher occurrence of fish in the surroundings of the four-leg platform in respect to the other two structures. These results confirm that: (i) these artificial structures exert an aggregation effect on the fish assemblages, and (ii) the magnitude of this attraction is possibly related to the bulk volume of the structures, which are characterized by very different size, building architecture and, consequently, different extension along the water column. Indeed, a similar evidence was also observed comparing the effects of a few artificial reefs of different dimensions deployed in the coastal area of the northern and central Adriatic Sea (Bombace *at al*., 1994).

MBES surveys evidenced that most of fish schools tend to stay close to the seabed in day-time, as already observed during studies carried out around gas and oil platforms located in the Gulf of Mexico (Reynolds, 2015). This can explain the reason why both MBES and fishing surveys gave a similar seasonal pattern of the fish assemblage at the one-leg platform and at the well site, but not at the four-leg platform. The highest abundance of fish recorded in spring at this structure through the MBES surveys might be related to large aggregations of small pelagic fish, mainly sardine and anchovy characterized by a schooling behavior especially during their reproductive periods (winter and spring respectively; Morello and Arneri, 2009). These species tend to stay near the bottom or in deep water during the day and to move towards the surface in night-time (Giannoulaki *et al.,* 1999). Therefore, it is likely that the fishing surveys were not able to highlight the occurrence of these schools because of the limited height of the net along the water column, confirming that trammel net underestimates small pelagic fish. On the other hand, trammel net is very efficient to catch nekto-benthic and benthic fish, while MBES appears not suitable to assess groundfish because their acoustic backscatter is masked by the bottom backscatter.

In addition, the length weight relationships calculated for some of the most abundant species evidenced a higher biomass of fish close to the two platforms, while no difference was observed at the well site. This confirm the different effects of these structures on the fish assemblages in relation to their dimension, evidencing that their attractiveness is also related to the different growth patterns as a result of varied food availability.

Although the data reported in the present study are only referred to a limited time period, they confirm the need of adopting different monitoring methods to get a better understanding of the effects of artificial structures on the associated fish assemblage (Consoli *et al*., 2007). In this context, MBES may represent a very useful tool to obtain complementary information on the spatial distribution and abundance of fish in respect either to the water depth or to the different typology of structures.

Finally, without entering into the ongoing discussion “attraction vs. production” to explain the increased fish abundance at artificial structures (Brickhill *et al*., 2005), the effects of the investigated structures resulted particularly evident in the north-western Adriatic Sea, and its magnitude could be related to the volume occupied by the structure itself. The aggregation effect exerted by the gas platforms in addition with the magnitude of this attraction, mainly related with the volume and complexity of the structures, should be taken into account when a decommissioning programme have to be set. The findings achieved suggest that the complete removal option will likely result in the loss or dispersal of fish living in the surrounding of platform structures, exposing them to increased fishing pressure, as previously evidenced by other Authors (Bernstein *et al.,* 2010; Pondella *et al*., 2015). Therefore, from an ecological point of view, leaving the platform in situ (or at least its submerged part) at the end of its productive live, could be considered as a viable alternative option to the complete removal in Adriatic Sea.

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# SUPPLEMENTARY MATERIAL TO CHAPTER 4

**Annex 4.1** - Mean number (N) and volume (V) of fish schools (±standard error) detected at each depth range close to the Structure A (A) and at the reference sites (A ref site).

| | | **A** | | **A ref site** | |
|---|---|---|---|---|---|
| | Depth (m) | N (N $km^{-3}$) | V ($m^3$ $km^{-3}$) | N (N $km^{-3}$) | V ($m^3$ $km^{-3}$) |
| I YEAR | 0-20 | 0.0±0.0 | 0.0±0.0 | 0.00±0.00 | 0.00±0.00 |
| | 20-40 | 0.0±0.0 | 0.0±0.0 | 0.00±0.00 | 0.00±0.00 |
| | 40-60 | 32.5±27.2 | 5,411.0±4,527.2 | 0.00±0.00 | 0.00±0.00 |
| | 60-80 | 406.2±170.8 | 176,728.0±124,872.7 | 170.19±26.85 | 28,898.23±10,352.30 |
| II YEAR | 0-20 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 |
| | 20-40 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 |
| | 40-60 | 75.7±75.7 | 8,444.1±8,444.1 | 5.3±5.3 | 2,343.3±2,343.3 |
| | 60-80 | 575.9±141.0 | 198,673.0±106,510.6 | 191.21±84.8 | 39,712.4±17,040.4 |

**Annex 4.2** - Results of 3-way ANOVA carried out on factors Year, Site and Depth (fixed factors), comparing the number (N) and volume (V) of school detected at A and A ref site. * = significant ($P<0.05$); ** = highly significant ($P<0.01$).

| Source | d.f. | **N** | | | | **V** | | |
|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | | MS | F | P |
| Year (Ye) | 1 | 0.453 | 8.558 | 0.287 | | 0.417 | 0.462 | 0.502 |
| Site (Si) | 1 | 2.144 | 40.487 | 0.000** | A >>A ref site | 1.197 | 1.327 | 0.259 |
| Depth (De) | 1 | 0.944 | 17.823 | 0.000* | 60-80>>40-60<br>60-80>>20-40<br>60-80>>0-20 | 0.076 | 0.084 | 0.774 |
| Ye x Si | 1 | 0.059 | 1.118 | 0.300 | | 0.149 | 0.165 | 0.687 |
| Ye x De | 1 | 2.37E-5 | 0.000 | 0.983 | | 0.051 | 0.057 | 0.814 |
| Si x De | 1 | 0.044 | 0.831 | 0.370 | | 0.061 | 0.068 | 0.796 |
| Ye x Si x De | 0 | - | - | - | | - | - | - |
| Error | 27 | 0.053 | | | | 0.902 | | |
| Total | 33 | | | | | | | |

**Annex 4.3** - Total abundance (N. ind $500m^{-1}$ $12h^{-1}$) of species caught at Structure A (C: close to the structure; F1 and F2: reference sites). B: benthic; P: pelagic; NB: necto-benthic; AT: attracted; PA: partially-attracted; NA: not attracted.

| | | | | I YEAR | | | II YEAR | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **C** | **F1** | **F2** | **C** | **F1** | **F2** |
| **Crustaceans** | *Calappa granulata* | B | NA | | | 4.62 | | | 1.44 |
| | *Maja squinado* | B | NA | 1.66 | | 3.10 | | | |
| | *Nephrops norvegicus* | B | NA | 5.61 | | 1.58 | | | |
| **Mollusks** | *Eledone cirrhosa* | B | PA | | | 1.73 | | | |
| | *Sepia officinalis* | B | NA | 1.32 | | | 0.82 | | |
| **Fish** | *Conger conger* | B | AT | | | | | | 1.50 |
| | *Mullus surmuletus* | B | AT | 3.61 | | | 4.04 | | 1.69 |
| | *Scorpaena notata* | B | AT | 5.32 | | | 1.44 | | |
| | *Scorpaena porcus* | B | AT | 2.78 | | | 2.97 | | |
| | *Scorpaena scrofa* | B | AT | 1.80 | | 1.37 | | | |
| | *Chelidonichthys lucerna* | B | NA | 14.36 | 7.41 | 12.04 | 16.01 | 12.31 | 3.62 |
| | *Eutrigla gurnardus* | B | NA | 5.45 | 1.76 | 3.45 | 2.95 | 1.50 | 1.46 |
| | *Lepidotrigla cavillone* | B | NA | 1.80 | 1.76 | | 1.44 | | |
| | *Lophius budegassa* | B | NA | 3.56 | 4.45 | 4.68 | 2.37 | | 1.32 |
| | *Lophius piscatorius* | B | NA | 2.78 | | | | | |
| | *Microchirus variegatus* | B | NA | | 3.08 | 1.57 | | 3.14 | |
| | *Mullus barbatus* | B | NA | 2.79 | 1.56 | | | 3.00 | |
| | *Psetta maxima* | B | NA | | | | 1.48 | | 1.44 |
| | *Raja asterias* | B | NA | | | | | 1.50 | |
| | *Scophthalmus rhombus* | B | NA | | 1.56 | | | 1.34 | |
| | *Scyliorhinus canicula* | B | NA | 1.45 | 1.76 | 4.45 | 1.97 | | 1.30 |
| | *Solea solea* | B | NA | | | | | | 1.50 |
| | *Squalus acanthias* | B | NA | 1.45 | | 1.73 | | | |
| | *Torpedo marmorata* | B | NA | 3.46 | | | 1.35 | | |
| | *Trachinus draco* | B | NA | 4.88 | 7.66 | 7.71 | | 4.41 | 4.93 |
| | *Uranoscopus scaber* | B | NA | | 1.76 | 3.15 | | | 3.24 |
| | *Merlangius merlangus* | NB | NA | 7.74 | 3.33 | | | | |
| | *Merluccius merluccius* | NB | NA | 53.34 | 28.25 | 15.98 | 57.08 | 32.85 | 25.60 |
| | *Pagellus bogaraveo* | NB | PA | 176.50 | 8.96 | 6.28 | 85.92 | 9.35 | 8.35 |
| | *Pagellus erythrinus* | NB | PA | | | | 2.94 | 1.37 | 1.97 |
| | *Serranus cabrilla* | NB | PA | | | | | | 1.69 |
| | *Trisopterus minutus capelanus* | NB | PA | 55.08 | 4.76 | | 50.70 | 7.18 | |
| | *Alosa fallax fallax* | P | NA | | 2.85 | | | | 1.50 |
| | *Engraulis encrasicolus* | P | NA | 68.84 | 1.76 | 1.73 | 70.63 | 60.85 | 61.64 |
| | *Sardina pilchardus* | P | NA | | | | | 2.71 | 1.69 |
| | *Boops boops* | P | PA | 134.94 | 1.76 | | 96.23 | 6.15 | 1.46 |
| | *Scomber japonicus* | P | PA | 10.15 | | 3.34 | 3.09 | 1.34 | |
| | *Scomber scombrus* | P | PA | | 1.28 | | | 2.68 | 1.44 |
| | *Spicara maena* | P | PA | 8.23 | 1.56 | 1.73 | 4.49 | | |
| | *Trachurus mediterraneus* | P | PA | 3.05 | | | 1.60 | | |
| | *Trachurus trachurus* | P | PA | 1.58 | | | | | |
| **Total Density** | | | | **583.52** | **87.31** | **80.24** | **409.52** | **151.68** | **128.78** |
| **Total Species Richness** | | | | **27** | **19** | **18** | **20** | **16** | **20** |

**Annex 4.4** - Results of 2-way ANOVA applied to mean values of abundance (N), biomass (W), species richness (Sm), and Shannon Wiener index (H') per each site during the two monitoring years carried out at Structure A. * = significant (P<0.05); ** = highly significant (P<0.01).

| Source | d.f. | **N** | | | | **W** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | Tukey test | MS | F | P | Tukey test |
| Year | 1 | 0.037 | 0.309 | 0.581 | | 0.091 | 0.673 | 0.415 | |
| Site | 2 | 4.226 | 35.433 | 0.000** | C>> F1; F2 | 3.181 | 23.516 | 0.000* | C>>F1; F2 |
| Year x Site | 2 | 0.145 | 1.215 | 0.304 | | 0.193 | 1.430 | 0.247 | |

| Source | d.f. | **Sm** | | | | **H'** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | Tukey test | MS | F | P | Tukey test |
| Year | 1 | 0.379 | 0.078 | 0.781 | | 0.006 | 0.023 | 0.880 | |
| Site | 2 | 73.197 | 15.097 | 0.000** | C>>F1; F2 | 1.778 | 6.574 | 0.003* | C>>F1; F2 |
| Year x Site | 2 | 1.924 | 0.397 | 0.674 | | 0.159 | 0.587 | 0.559 | |

**Annex 4.5** - Summary of SIMPER analysis showing contribution to the total dissimilarity (Contr. %) by the prey species causing the dissimilarity among Site at Structure A. Only species reaching a cumulative contribution of ~70% are reported.

| **C vs. F1** | | | | **C vs. F2** | | | |
|---|---|---|---|---|---|---|---|
| Species | | Contr. % | Av. dis % | Species | | Contr. % | Av. dis % |
| *Pagellus bogaraveo* | C>F1 | 16.3 | 72.8 | *Pagellus bogaraveo* | C>F2 | 15.8 | 80.0 |
| *Boops boops* | C>F1 | 15.9 | | *Boops boops* | C>F2 | 15.5 | |
| *Trisopterus minutus capelanus* | C>F1 | 10.6 | | *Trisopterus minutus capelanus* | C>F2 | 10.0 | |
| *Engraulis encrasicolus* | C>F1 | 8.8 | | *Merluccius merluccius* | C>F2 | 9.2 | |
| *Merluccius merluccius* | C>F1 | 7.7 | | *Engraulis encrasicolus* | C>F2 | 8.1 | |
| *Chelidonichthys lucerna* | C>F1 | 6.6 | | *Chelidonichthys lucerna* | C>F2 | 5.7 | |
| *Trachinus draco* | F1>C | 3.0 | | *Trachinus draco* | F2>C | 2.9 | |
| *Spicara maena* | C>F1 | 3.0 | | *Spicara maena* | C>F2 | 2.8 | |

**Annex 4.6** – Mean number (N) and volume (V) of fish schools (±standard error) detected at each depth range close to the Structure B and at the reference sites (B ref site).

| | | **B** | | **B ref site** | |
|---|---|---|---|---|---|
| | Depth (m) | N (N km$^{-3}$) | V (m$^3$ km$^{-3}$) | N (N km$^{-3}$) | V (m$^3$ km$^{-3}$) |
| I YEAR | 0-20 | 300.4±300.4 | 387.8±387.8 | 40.3±40.3 | 19.3±19.3 |
| | 20-40 | 138.8±138.8 | 1,367.0±1,367.0 | 62.9±62.9 | 55.5±55.5 |
| | 40-60 | 2,596.8±426.6 | 293,972.8±95,530.0 | 896.8±213.5 | 56,284.7±26,883.7 |
| II YEAR | 0-20 | 255.7±130.8 | 1,516.5±806.8 | 0.0±0.0 | 0.0±0.0 |
| | 20-40 | 299.4±116.9 | 1,530.0±624.5 | 5.8±5.8 | 23.3±23.3 |
| | 40-60 | 4,301.6±615.0 | 302,582.9±82,365.6 | 747.3±165.1 | 30,237.0±8,047.2 |

**Annex 4.7**- Results of 3-way ANOVA carried out on factors Year, Site and Depth (fixed factors), comparing the number (N) and volume (V) of school detected at B and B ref site. * = significant (P<0.05); ** = highly significant (P<0.01).

| Source | d.f. | **N** | | | | **V** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | | MS | F | P | |
| Year (Ye) | 1 | 0.726 | 7.623 | 0.492 | | 0.117 | 0.328 | 0.569 | |
| Site (Si) | 1 | 2.126 | 22.318 | 0.000** | B >>B ref site | 4.799 | 13.427 | 0.001* | B >>B ref site |
| Depth (De) | 2 | 0.715 | 7.510 | 0.001* | 40-60>>0-20<br>40-60>>20-40 | 9.755 | 27.292 | 0.000** | 40-60>>0-20<br>40-60>>20-40 |
| Ye x Si | 1 | 0.206 | 2.167 | 0.147 | | 0.000 | 0.001 | 0.977 | |
| Ye x De | 2 | 0.409 | 4.292 | 0.419 | | 0.187 | 0.522 | 0.596 | |
| Si x De | 2 | 0.042 | 0.446 | 0.643 | | 0.077 | 0.216 | 0.807 | |
| Ye x Si x De | 1 | 0.007 | 0.077 | 0.783 | | 0.262 | 0.734 | 0.396 | |
| Error | 51 | 0.095 | | | | 0.357 | | | |
| Total | 61 | | | | | | | | |

**Annex 4.8** - Total abundance (N. ind $500m^{-1}$ $12h^{-1}$) of species caught at Structure B (C: close to the structure; F1 and F2: reference sites). B: benthic; P: pelagic; NB: necto-benthic; AT: attracted; PA: partially-attracted; NA: not attracted.

| | | | | I YEAR | | | II YEAR | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | C | F1 | F2 | C | F1 | F2 |
| Crustaceans | *Dromia personata* | B | AT | | | | | 1.33 | |
| | *Homarus gammarus* | B | AT | 22.09 | 3.01 | 3.12 | 13.40 | | |
| | *Palinurus elephas* | B | AT | 3.74 | | | 2.57 | | |
| | *Calappa granulata* | B | NA | 3.79 | 1.46 | 1.25 | 6.66 | 12.19 | |
| | *Maja squinado* | B | NA | 266.13 | 68.39 | 89.40 | 141.55 | 72.75 | 75.15 |
| | *Nephrops norvegicus* | B | NA | | | | 1.97 | | |
| | *Squilla mantis* | B | NA | | | | 1.70 | | |
| Mollusks | *Octopus vulgaris* | B | AT | 5.52 | | 2.87 | 2.94 | | 1.64 |
| | *Pecten jacobaeus* | B | NA | 1.55 | | | | | |
| | *Sepia officinalis* | B | NA | 18.23 | | | 76.38 | 6.77 | 7.85 |
| | *Loligo vulgaris* | P | PA | | | | 2.72 | | |
| | *Illex coindetii* | P | NA | 29.42 | | | | | |
| Fish | *Conger conger* | B | AT | 1.47 | | | 1.62 | | |
| | *Mullus surmuletus* | B | AT | 63.91 | | 1.25 | 26.59 | | 2.39 |
| | *Scorpaena notata* | B | AT | 32.51 | 8.17 | 16.94 | 36.35 | 21.15 | 18.07 |
| | *Scorpaena porcus* | B | AT | 25.92 | | | 30.67 | | |
| | *Scorpaena scrofa* | B | AT | 6.37 | 4.46 | | 2.75 | | |
| | *Chelidonichthys lucerna* | B | NA | 327.43 | 38.47 | 10.26 | 135.40 | 12.61 | 11.00 |
| | *Citharus linguatula* | B | NA | 3.84 | 4.50 | 8.01 | 3.00 | 1.33 | 7.49 |
| | *Eutrigla gurnardus* | B | NA | 13.09 | 1.33 | | 1.48 | | 4.28 |
| | *Lepidotrigla cavillone* | B | NA | 4.12 | 1.40 | 1.38 | 1.32 | | 1.64 |
| | *Lophius budegassa* | B | NA | 4.65 | | 1.51 | 1.24 | 6.90 | 2.96 |
| | *Lophius piscatorius* | B | NA | 3.36 | | 1.25 | | | |
| | *Microchirus ocellatus* | B | NA | 1.26 | 2.81 | 1.56 | 1.37 | 5.50 | 1.27 |
| | *Microchirus variegatus* | B | NA | 8.44 | 14.07 | 15.28 | 5.64 | 29.53 | 33.78 |
| | *Mullus barbatus* | B | NA | 55.11 | 1.49 | 11.18 | 60.16 | 3.98 | 6.05 |
| | *Phycis blennoides* | B | NA | 10.63 | | | | | |
| | *Psetta maxima* | B | NA | 1.37 | | 1.51 | 2.90 | 1.36 | 1.64 |
| | *Raja clavata* | B | NA | | 6.81 | 9.91 | | 7.29 | 9.71 |
| | *Raja miraletus* | B | NA | | 1.56 | | | | |
| | *Scophthalmus rhombus* | B | NA | | | | 2.69 | | 2.58 |
| | *Scyliorhinus canicula* | B | NA | 3.23 | 4.42 | 4.04 | | 23.37 | 20.06 |
| | *Solea solea* | B | NA | 10.53 | 42.00 | 38.14 | 23.07 | 27.03 | 34.86 |
| | *Squalus acanthias* | B | NA | 8.19 | 29.70 | 26.53 | 13.01 | 79.46 | 111.69 |
| | *Torpedo marmorata* | B | NA | 98.62 | 7.58 | 4.12 | 99.72 | 2.77 | |
| | *Torpedo torpedo* | B | NA | 3.74 | | | 9.74 | | |
| | *Trachinus draco* | B | NA | 22.08 | 11.59 | 11.41 | 4.67 | 2.80 | 13.62 |
| | *Trigloporus lastoviza* | B | NA | | | | | | 1.19 |
| | *Uranoscopus scaber* | B | NA | 2.93 | | | 7.98 | 1.30 | 1.31 |
| | *Phycis phycis* | B | PA | 14.30 | | 1.25 | 19.56 | | |
| | *Dentex dentex* | NB | AT | | | | 1.24 | | |
| | *Dicentrarchus labrax* | NB | AT | | | | 1.82 | | |
| | *Diplodus sargus sargus* | NB | AT | 2.71 | | | 5.49 | | |
| | *Diplodus vulgaris* | NB | AT | 9.71 | 1.26 | | 8.69 | | |
| | *Sparus aurata* | NB | AT | 50.33 | 1.56 | | 14.50 | | |
| | *Spondilyosoma cantharus* | NB | AT | 44.17 | | | 8.50 | | |
| | *Merlangius merlangus* | NB | NA | 8.62 | 1.40 | 2.97 | | 1.33 | 1.19 |
| | *Merluccius merluccius* | NB | NA | 9.21 | 7.21 | 10.27 | 17.79 | 14.72 | 15.50 |
| | *Mustelus mustelus* | NB | NA | | 2.67 | | | | |
| | *Myliobatis aquila* | NB | NA | 4.99 | 7.86 | 5.14 | 1.37 | 4.23 | 1.18 |
| | *Pagellus acarne* | NB | NA | 74.81 | 1.26 | 1.25 | 78.15 | | 1.19 |
| | *Diplodus annularis* | NB | PA | 1.48 | | | 1.48 | | |
| | *Pagellus bogaraveo* | NB | PA | 1,816.11 | 67.81 | 110.43 | 1,045.95 | 2.82 | 7.89 |
| | *Pagellus erythrinus* | NB | PA | 241.22 | 32.67 | 70.55 | 504.55 | 35.51 | 83.44 |
| | *Serranus hepatus* | NB | PA | 1.26 | 2.81 | | 1.62 | 2.80 | 1.48 |
| | *Trisopterus minutus capelanus* | NB | PA | 639.08 | 18.25 | 85.93 | 381.11 | 25.96 | 32.63 |
| | *Zeus faber* | NB | PA | 1.55 | | | | | |
| | *Sphyraena sphyraena* | P | AT | 1.37 | | | | | |
| | *Alosa fallax fallax* | P | NA | 7.96 | 1.68 | | 1.24 | 1.45 | |
| | *Engraulis encrasicolus* | P | NA | 605.73 | 14.27 | 18.45 | 103.99 | 27.86 | 45.42 |
| | *Euthynnus alletteratus* | P | NA | 17.32 | 1.26 | 7.93 | 14.59 | | 10.61 |
| | *Sardina pilchardus* | P | NA | 59.08 | 16.12 | 16.82 | 37.23 | 14.98 | 31.36 |
| | *Sardinella aurita* | P | NA | 1.37 | | | | | |
| | *Sprattus sprattus sprattus* | P | NA | | | | | | 1.33 |
| | *Boops boops* | P | PA | 618.34 | 2.60 | 12.45 | 302.86 | | 1.33 |
| | *Sarda sarda* | P | PA | 13.28 | | | | | |
| | *Scomber japonicus* | P | PA | 235.22 | 1.40 | 3.12 | 258.36 | | 1.94 |
| | *Scomber scombrus* | P | PA | 69.15 | | 3.08 | 57.36 | | 1.27 |
| | *Spicara maena* | P | PA | 109.34 | | 2.59 | 229.63 | | 4.59 |
| | *Spicara smaris* | P | PA | 1.55 | | | 7.07 | | |
| | *Trachurus mediterraneus* | P | PA | 575.02 | 14.08 | 1.56 | 235.95 | | |
| | *Trachurus picturatus* | P | PA | 7.89 | | | | | |
| | *Trachurus* spp | P | PA | | | | 1.37 | | |
| | *Trachurus trachurus* | P | PA | 339.45 | 5.25 | 7.02 | 162.83 | | |
| **Total Density** | | | | **6,644.90** | **454.65** | **621.76** | **4,225.57** | **451.06** | **612.61** |
| **Total Species Richness** | | | | **61** | **38** | **38** | **57** | **29** | **38** |

**Annex 4.9** - Results of 2-way ANOVA applied to mean values of abundance (N), biomass (W), species richness (Sm), and Shannon Wiener index (H') per each site during the two monitoring years carried out at Structure B. * = significant ($P<0.05$); ** = highly significant ($P<0.01$).

| Source | d.f. | **N** | | | | **W** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | Tukey | MS | F | P | Tukey |
| Year (Ye) | 1 | 0.002 | 0.022 | 0.833 | | 0.002 | 0.012 | 0.911 | |
| Site (Si) | 2 | 8.836 | 111.043 | 0.000** | C > F1; | 4.208 | 31.367 | 0.000** | C > F1; F2 |
| Ye x Si | 2 | 0.131 | 1.644 | 0.201 | | 0.099 | 0.736 | 0.483 | |

| Source | d.f. | **Sm** | | | | **H'** | | |
|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | Tukey test | MS | F | P |
| Year (Ye) | 1 | 0.003 | 0.107 | 0.744 | | 0.058 | 0.436 | 0.512 |
| Site (Si) | 2 | 1.332 | 45.885 | 0.000** | C > F1; F2 | 1.196 | 9.024 | 0.098 |
| Ye x Si | 2 | 0.032 | 1.085 | 0.334 | | 0.069 | 0.517 | 0.599 |

**Annex 4.10** - Summary of SIMPER analysis showing contribution to the total dissimilarity (Contr. %) by the prey species causing the dissimilarity among Site at Structure B. Only species reaching a cumulative contribution of ~50% are reported.

| **C vs. F1** | | | | **C vs. F2** | | | |
|---|---|---|---|---|---|---|---|
| Species | | Contr. % | Av. dis % | Species | | Contr. % | Av. dis % |
| *Pagellus bogaraveo* | C>F1 | 8.6 | 81.2 | *Pagellus bogaraveo* | C>F2 | 8.6 | 77.0 |
| *Trisopterus minutus capelanus* | C>F1 | 5.8 | | *Trachurus mediterraneus* | C>F2 | 5.7 | |
| *Trachurus mediterraneus* | C>F1 | 5.5 | | *Trisopterus minutus capelanus* | C>F2 | 5.4 | |
| *Boops boops* | C>F1 | 5.3 | | *Boops boops* | C>F2 | 5.3 | |
| *Pagellus erythrinus* | C>F1 | 4.5 | | *Scomber japonicus* | C>F2 | 4.3 | |
| *Spicara maena* | C>F1 | 4.3 | | *Spicara maena* | C>F2 | 4.1 | |
| *Scomber japonicus* | C>F1 | 4.2 | | *Chelidonichthys lucerna* | C>F2 | 3.7 | |
| *Chelidonichthys lucerna* | C>F1 | 3.5 | | *Pagellus erythrinus* | C>F2 | 3.5 | |
| *Pagellus acarne* | C>F1 | 3.5 | | *Pagellus acarne* | C>F2 | 3.5 | |
| *Torpedo marmorata* | C>F1 | 3.3 | | *Torpedo marmorata* | C>F2 | 3.4 | |
| *Maja squinado* | C>F1 | 3.1 | | *Maja squinado* | C>F2 | 3.1 | |

**Annex 4.11** - Mean number (N) and volume (V) of fish schools (±standard error) detected at each depth range close to the Structure C and at the reference sites (C ref site).

| | | **C** | | **C ref site** | |
|---|---|---|---|---|---|
| | Depth (m) | N (N km$^{-3}$) | V (m$^3$ km$^{-3}$) | N (N km$^{-3}$) | V (m$^3$ km$^{-3}$) |
| I YEAR | 0-20 | 56.5±56.5 | 50.6±50.6 | 0.0±0.0 | 0.0±0.0 |
| | 20-40 | 1,655.9±258.7 | 158,147.3±70,913.6 | 588.0±108.6 | 19,514.2±8,555.3 |
| | | | | | |
| II YEAR | 0-20 | 0.0±0.0 | 0.00±0.00 | 0.0±0.0 | 0.0±0.0 |
| | 20-40 | 2,314.0±398.3 | 161,318.7±65,714.1 | 693.0±196.2 | 19,195.8±9,825.1 |

**Annex 4.12** - Results of 3-way ANOVA carried out on factors Year, Site and Depth (fixed factors), comparing the number (N) and volume (V) of school detected at C and C ref site. * = significant (P<0.05); ** = highly significant (P<0.01).

| Source | d.f. | **N** | | | | **V** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | | MS | F | P | |
| Year (Ye) | 1 | 0.05 | 0.632 | 0.431 | | 0.048 | 0.167 | 0.685 | |
| Site (Si) | 1 | 2.84 | 30.572 | 0.000** | C > C ref site | 4.693 | 16.282 | 0.000** | C > C ref site |
| Depth (De) | 1 | 0.08 | 0.960 | 0.333 | | 2.272 | 7.882 | 0.007** | 20-40>0-20 |
| Ye x Si | 1 | 0.02 | 0.216 | 0.644 | | 0.069 | 0.239 | 0.627 | |
| Ye x De | 0 | - | - | - | | - | - | - | |
| Si x De | 0 | - | - | - | | - | - | - | |
| Error | 44 | 0.09 | | | | 0.288 | | | |
| Total | 48 | | | | | | | | |

**Annex 4.13** - Total abundance (N. ind $500m^{-1}$ $12h^{-1}$) of species caught at Structure C (C: close to the structure; F1 and F2: reference sites). B: benthic; P: pelagic; NB: necto-benthic; AT: attracted; PA: partially-attracted; NA: not attracted.

| | | | | I YEAR | | | II YEAR | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | C | F1 | F2 | C | F1 | F2 |
| **Crustaceans** | *Homarus gammarus* | B | AT | 1.15 | | | 2.50 | | |
| | *Maja squinado* | B | NA | 9.49 | 13.91 | 2.45 | 3.01 | | 0.90 |
| | *Nephrops norvegicus* | B | NA | 2.84 | 6.56 | 1.58 | 1.24 | 11.13 | 5.80 |
| | *Squilla mantis* | B | NA | 27.63 | 7.49 | 13.69 | 44.72 | 30.28 | 18.83 |
| **Mollusks** | *Eledone moschata* | B | PA | 1.49 | 1.22 | | 1.45 | 4.16 | |
| | *Aequipecten opercularis* | B | NA | 114.44 | | | 16.18 | | |
| | *Sepia officinalis* | B | NA | | | | | 0.94 | |
| **Fish** | *Gaidropsarus mediterraneus* | B | AT | | 4.38 | | | | |
| | *Scorpaena notata* | B | AT | 12.02 | | 0.94 | 12.82 | | |
| | *Scorpaena porcus* | B | AT | 4.44 | | | | | |
| | *Arnoglossus laterna* | B | NA | | | | | | 1.32 |
| | *Buglossidium luteum* | B | NA | 1.15 | | | 1.45 | | 1.10 |
| | *Cepola macrophthalma* | B | NA | 0.97 | | | | | |
| | *Chelidonichthys lucerna* | B | NA | 14.23 | 11.56 | 12.67 | 12.27 | 10.86 | 10.89 |
| | *Eutrigla gurnardus* | B | NA | 1.49 | 0.94 | 1.88 | 2.13 | 4.50 | 1.88 |
| | *Gaidropsarus biscayensis* | B | NA | | | 4.86 | | | 2.12 |
| | *Lepidotrigla cavillone* | B | NA | | | | 1.41 | | |
| | *Microchirus variegatus* | B | NA | | | | | 1.88 | |
| | *Mullus barbatus* | B | NA | 4.64 | 0.94 | 1.88 | 4.72 | 4.16 | 3.27 |
| | *Ophidion barbatum* | B | NA | | 0.93 | | | | |
| | *Psetta maxima* | B | NA | | 1.14 | 1.13 | | 2.33 | 4.19 |
| | *Raja asterias* | B | NA | | | 1.53 | | 2.16 | |
| | *Raja clavata* | B | NA | 0.97 | | 1.58 | | 3.32 | |
| | *Scyliorhinus canicula* | B | NA | | | 0.94 | | | 0.94 |
| | *Scyliorhinus stellaris* | B | NA | | | | | 1.36 | |
| | *Solea solea* | B | NA | 9.39 | 25.00 | 17.49 | 6.19 | 31.18 | 22.64 |
| | *Squalus acanthias* | B | NA | 1.93 | 4.35 | 4.23 | | 3.24 | 2.70 |
| | *Trachinus draco* | B | NA | | | | 2.13 | | |
| | *Gobius niger* | B | PA | 2.46 | 1.14 | 1.89 | | | 0.94 |
| | *Diplodus sargus sargus* | NB | AT | 0.95 | | | | | |
| | *Spondilyosoma cantharus* | NB | AT | | | | 1.41 | | |
| | *Merlangius merlangus* | NB | NA | 33.62 | 54.76 | 67.76 | 29.04 | 8.83 | 17.84 |
| | *Merluccius merluccius* | NB | NA | 4.70 | 6.00 | 5.30 | 2.41 | 11.56 | 4.59 |
| | *Diplodus annularis* | NB | PA | 4.34 | | | 2.47 | | |
| | *Pagellus bogaraveo* | NB | PA | 55.31 | | 3.78 | 28.75 | | |
| | *Serranus hepatus* | NB | PA | 0.97 | | | 2.12 | | |
| | *Trisopterus minutus capelanus* | NB | PA | 484.23 | 52.33 | 39.26 | 387.89 | 22.23 | 27.01 |
| | *Alosa fallax fallax* | P | NA | 3.87 | 1.13 | 4.81 | | 5.31 | 2.03 |
| | *Engraulis encrasicolus* | P | NA | 79.73 | 23.55 | 22.98 | 17.86 | | 21.83 |
| | *Naucrates ductor* | P | NA | | 0.93 | | | | |
| | *Prionace glauca* | P | NA | | | | 1.10 | | |
| | *Pteroplatytrygon violacea* | P | NA | 0.97 | | | | | 1.02 |
| | *Sardina pilchardus* | P | NA | 20.27 | 1.22 | 5.65 | 20.27 | 1.22 | 5.65 |
| | *Sardinella aurita* | P | NA | | | | 1.26 | | |
| | *Sprattus sprattus sprattus* | P | NA | 4.47 | | 1.45 | | | |
| | *Boops boops* | P | PA | 14.27 | | 1.22 | 26.41 | | 1.22 |
| | *Scomber japonicus* | P | PA | 40.18 | | | 22.11 | | |
| | *Scomber scombrus* | P | PA | 12.03 | 25.50 | 16.73 | 12.76 | 3.29 | 8.02 |
| | *Spicara maena* | P | PA | 11.25 | 1.57 | | 13.11 | | 2.00 |
| | *Spicara smaris* | P | PA | 0.97 | | | | | |
| | *Trachurus mediterraneus* | P | PA | 0.97 | | | 3.45 | | |
| | *Trachurus trachurus* | P | PA | 0.97 | | | | | |
| **Total Density** | | | | **984.80** | **246.55** | **237.70** | **684.65** | **163.92** | **168.71** |
| **Total Species Richness** | | | | **36** | **22** | **25** | **30** | **20** | **24** |

**Annex 4.14** - Results of 2-way ANOVA applied to mean values of abundance (N), biomass (W), species richness (Sm), and Shannon Wiener index (H') per each site during the two monitoring years carried out at Structure C. * = significant ($P<0.05$); ** = highly significant ($P<0.01$).

| Source | d.f. | **N** | | | | **W** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | Tukey test | MS | F | P | Tukey test |
| Year | 1 | 0.395 | | 0.035* | I > II | 4.977 | 1.748 | 0.191 | |
| Site | 2 | 3.797 | | 0.000** | C > F1; F2 | 98.18 | 34.48 | 0.000** | C >F1; F2 |
| Year x Site | 2 | 0.001 | 0.3852 | 0.990 | | 6.034 | 2.119 | 0.128 | |

| Source | d.f. | **Sm** | | | | **H'** | | |
|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | Tukey test | MS | F | P |
| Year | 1 | 0.052 | 1.272 | 0.263 | | 0.041 | 0.217 | 0.643 |
| Site | 2 | 0.210 | 5.091 | 0.009* | C >F1; F2 | 0.439 | 2.311 | 0.107 |
| Year x Site | 2 | 0.009 | 0.209 | 0.812 | | 0.007 | 0.037 | 0.964 |

**Annex 4.15** - Summary of SIMPER analysis showing contribution to the total dissimilarity (Contrib. %) by the prey species causing the dissimilarity among Site at Structure C. Only species reaching a cumulative contribution of ~60% are reported.

| **C vs. F1** | | | | **C vs. F2** | | | |
|---|---|---|---|---|---|---|---|
| Species | | Contr. % | Av. dis % | Species | | Contr. % | Av. dis % |
| *Trisopterus minutus capelanus* | C>F1 | 20.2 | 75.5 | *Trisopterus minutus capelanus* | C>F2 | 19.8 | 72.3 |
| *Squilla mantis* | C>F1 | 7.4 | | *Squilla mantis* | C>F2 | 7.2 | |
| *Merlangius merlangus* | C>F1 | 6.6 | | *Merlangius merlangus* | C>F2 | 6.6 | |
| *Solea solea* | F1>C | 5.9 | | *Solea solea* | F2>C | 6.3 | |
| *Engraulis encrasicolus* | C>F1 | 5.1 | | *Engraulis encrasicolus* | C>F2 | 5.4 | |
| *Aequipecten opercularis* | C>F1 | 4.9 | | *Aequipecten opercularis* | C>F2 | 5.1 | |
| *Chelidonichthys lucerna* | F1>C | 4.4 | | *Chelidonichthys lucerna* | F2>C | 3.9 | |
| *Scomber scombrus* | C>F1 | 3.8 | | *Scomber scombrus* | F2>C | 3.9 | |
| *Spicara maena* | C>F1 | 3.3 | | *Boops boops* | C>F2 | 3.7 | |

# 5. TROPHIC ATTRACTION OF FISH ASSEMBLAGES BY OFFSHORE ARTIFICIAL STRUCTURES

## ABSTRACT

Stomach contents of small red and black scorpionfish (*Scorpaena notata* and *Scorpaena porcus*) caught at offshore gas structures and surrounding areas were investigated to assess the potential role of the structures on the feeding habits of these ecologically and commercially important species. Stomach contents were examined from 309 *S. notata* and 96 *S. porcus* specimens obtained either by trammel net fishing trials close to the structures as well as by rapido trawling in the surrounding area.

The diet composition of *S. notata* specimens caught at offshore artificial structures was significantly different from that of conspecific individuals living in the natural habitat. Similar, though weaker, differences were observed also for *S. porcus*. These results indicated the presence of a trophic effect of the offshore artificial structures on both investigate species. Ultimately, although the analysis of stomach contents evidenced that both species mainly prefer crustaceans prey, the overall differences in the targeted species suggested that there is no interspecific competition.

## INTRODUCTION

The high concentration and diversity of fish around gas and oil platforms has been repeatedly documented by several studies, but the degree to which they contribute to increased production is still a topic for debate (Jørgensen *et al*., 2002; Scarcella *et al*., 2012). Feeding habits of fish living in man-made marine habitats have been the subject of several investigations, but aggregation criteria for prey vary considerably and comparisons are difficult (Relini *et a*l., 2002). For example, in most of the studies, prey are aggregated by major taxa (orders, classes, etc.) and only in few cases diets are studied at the species level allowing the comparison with macrofauna communities inhabiting the artificial and natural environments (Relini *et al*., 2002).

The small red scorpionfish *Scorpaena notata* Rafinesque, 1810 is a small-sized benthic species (generally less than 20 cm) that inhabits preferably rocky bottoms, even though it is also caught by trawlers operating on sandy-muddy bottoms in the proximity of hard substrates. The black scorpionfish *Scorpaena porcus* Linnaeus, 1758 is a littoral species of medium size (up to 25 cm), commonly found in inshore waters in rocky habitats and seagrass meadows (Hureau and Litvinenko, 1986; La Mesa *et al*., 2010).

Both scorpionfish are reef dwelling species regularly found close to the steel jackets of platforms and artificial reefs of the Adriatic Sea (Bombace *et al*., 1994; Fabi *et al*., 2004; Casellato and Stefanon, 2008). These species indeed seem to find an ideal habitat both within platform structures and in the mussel (*Mytilus galloprovincialis*) mounds which fall from the upper parts of the platforms on the seabed, increasing the complexity of the flat sea-bottom and creating a specific habitat (Consoli *et al*., 2013). Similarly, other Authors (Love *et al*., 2000; Stanley and Wilson, 1990; 1997) evidenced that some others *Scorpaeniformes* (i.e Sebastidae) predominated close to offshore structures in California and Gulf of Mexico.

*S. notata* and *S. porcus* are distributed in the eastern Atlantic Ocean from the British Isles to Morocco and throughout the Mediterranean Sea to the Black Sea, where *S. notata* is represented by the subspecies *Scorpaena notata afimbria* (Hureau and Litvinenko, 1986; Fischer *et al.*, 1987; La Mesa *et al*., 2010; Figure 5.1). Although in the past *S. notata* was ranked as rare in the northern Adriatic Sea (Hureau and Litvinenko, 1986), nowadays it has been frequently collected close to both natural and artificial hard substrates (Fabi *et al*., 2004; Casellato and Stefanon, 2008).

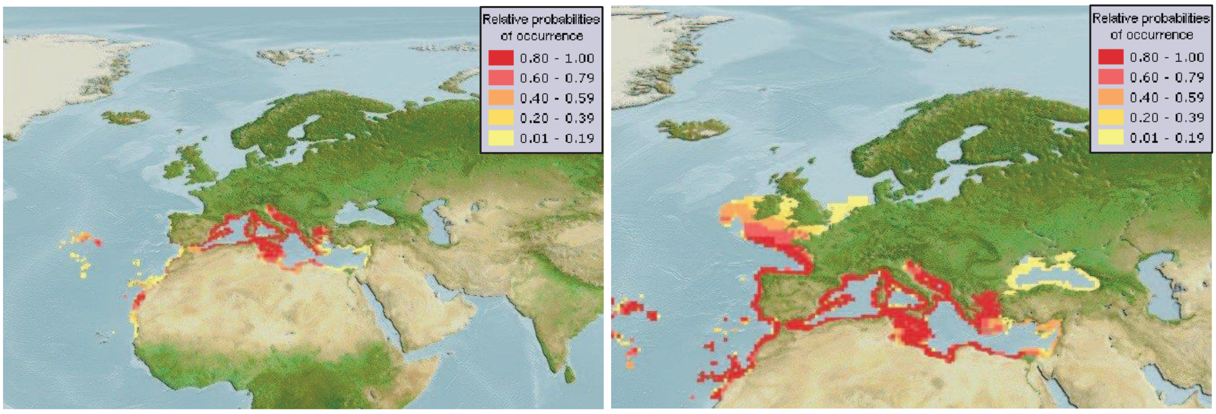

**Figure 5.1** - Native distribution of *Scorpaena notata* (left map) and *Scorpaena porcus* (right map). From www.aquamaps.org (August 2013).

Both species represent two of the most important predators in the trophic net of seagrass and rocky habitats in Mediterranean Sea (Bell and Harmelin-Vivien, 1982; 1983; Hureau and Litvinenko, 1986; Harmelin-Vivien et al., 1989; Morte *et al*., 2001; Relini *et al.,* 2002; 2007; Scarcella, 2010). *S. notata* also represents a by-catch species along its whole bathymetric distribution range from shallow to deeper waters, where it is caught by trammel nets and trawling, respectively (Ordines *et al.*, 2009; Scarcella, 2010).

Both species are sedentary during daytime, even though they are not completely inactive, whereas during the night they are engaged in finding food, increasing their activity (Harmelin-Vivien *et al*., 1989; Pashkov *et al*., 1999).

They feeds mainly on decapod crustaceans and fish (Relini *et al*., 2002; Ordines *et al*., 2009). Due to its sedentary behavior, *S. porcus* it is typically a sit-and-wait ambusher and feeds almost exclusively on motile prey (Harmelin-Vivien *et al*., 1989), such as small fishes (gobies and blennies), crustaceans and other invertebrates (Bradai and Bouain, 1990; Pallaoro and Jardas, 1991; Carpentieri *et al*., 2001; Morte *et al*., 2001; Relini *et al.,* 2002; Silvestri *et al*., 2002; Follesa *et al.,* 2004).

Even if several biological aspects of both species have been widely studied in the Mediterranean Sea, such as habitat preferences (Relini *et al*., 2002; Ordines *et al*., 2009), diet (Harmelin-Vivien *et al*., 1989; Morte *et al*., 2001; Castriota *et al*., 2012), gonad morphology (Muñoz *et al*., 1996; 2002a; 2002b), fecundity and reproductive cycle (Muñoz *et al*., 2005), age and growth (La Mesa *et al*., 2010; Scarcella, 2010; 2011a; 2011b), only a studies took into account the feeding behavior of specimens living in association with artificial structures (Relini *et al*., 2002; Ordines *et al*., 2009), but none of them was carried out close to offshore gas structures.

To provide insights on the potential role of this typology of artificial structures on *S. notata* and *S. porcus* feeding habits I: (1) investigated the diet of *S. notata* and *S. porcus* living close (GS) and far (NH) from offshore gas platforms through the analysis of their stomach contents; (2) compared the diet composition of the two species, in order to evidence any possible interspecific competition for prey.

# MATERIALS AND METHODS

## STUDY AREA, FISH SAMPLING AND STOMACH CONTENT ANALYSIS

Specimens of *S. notata* and *S. porcus* were collected in the northwestern Adriatic Sea (Figure 5.2) between January 2011 and December 2014 in an area surrounding three offshore artificial structures (GS) and at reference sites (NH) having the same geo-morphological features of the studied area (*e.g.*, depth and grain size) but with no artificial structures.

The investigated artificial structures were located at about 45 to 60 km from the coast, at a depth ranging from 40 to 80 m on muddy-sandy bottom.

In order to assess the possible trophic attraction effect of the artificial structures, for both species the same number of full stomachs found in the GS sites was randomly chosen for NH sites. In particular, given that at GS sites 112 and 35 full stomachs have been found for *S. notata* and *S. porcus*, respectively, the same number has been taken into account for NH sites.

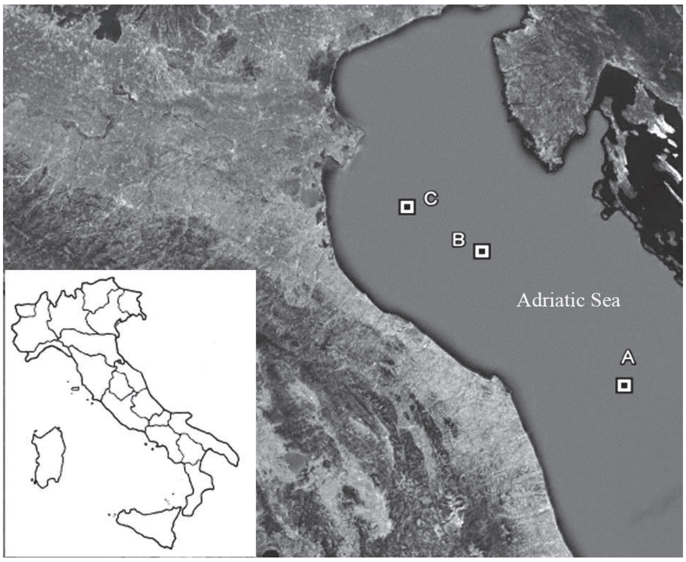

**Figure 5.2** – Study area. A, B and C: investigated artificial structures.

*S. notata* and *S. porcus* specimens close to the artificial structures were collected through fishing samples using trammel nets (inner panel: 70 mm; outer panel: 400 mm stretched mesh size), which enabled to operate at a short distance from the structures.

Conversely, at the reference sites specimens were gathered both with trammel nets and modified rapido trawl (width: 3.69 m; weight: 200 kg; codend stretched mesh size: 40 mm; Grati *et al.*, 2013). Concerning rapido trawl, hauls were randomly located over the whole sampling area and the gear was generally towed on the bottom at about five knots for 15-30 minutes during daylight hours, depending on the seabed sediments and associated benthic biocenosis. Rapido trawls were provided with DST Logic Temperature and Depth Recorders. The use of these devices and the fixed size of the gear mouth allowed us to estimate the swept area in each sampling station (Grati *et al.*, 2013). On the contrary, trammel nets were set at dusk and pulled in at dawn, for a mean deployment time of 12 h.

It is known that the size distribution of a sample could be affected by the selectivity of the gears employed (Scarcella *et al.*, 2011b). However, the fishing gears used for samplings are non-selective for the species investigated. In fact, the small meshes of the rapido trawl make unfeasible for both *S. notata* and *S. porcus* to escape the codend, mainly due to the peculiar shape of these species, in particular the large dimension of the head, even in the smallest specimens. On the other hand, the trammel net is non-selective for *Scorpaenidae* species, due to the presence of spines in their head, which strongly improve the catch for entangling. For these reasons, I assumed the samples collected using different nets as being reliably comparable.

In the laboratory, each fish was measured to the nearest mm (TL, total length) and weighed to the nearest 0.1 g (TW, total weight), while stomachs were removed and preserved in 70% ethanol. Stomach content analysis was carried out under a stereomicroscope (Zeiss Stemi 2000-C; magnifications of 6.5x to 50x) together with an optical microscope (Zeiss) and prey items were identified to the lowest possible taxonomic level, counted and weighed to the nearest 0.1 mg, after removing excess water with blotting paper. Preys were identified following taxonomic features reported by Fisher *et al.* (1987) for fishes, and by Fauvel (1923; 1927), Alvarez (1968), Riedl (1991), Falciai and Minervini (1992) and Ruffo (1982; 1989; 1993) for crustaceans and other invertebrates.

Not integer preys that could not be identified were catalogued as digested matter.

## LENGTH-WEIGHT RELATIONSHIP AND GROWTH

For each species, individual length frequency was obtained separately for GS and NH populations. Afterwards, comparison between the length frequency distribution of the two populations was performed using Kolmogorov-Smirnov test (Sokal and Rohlf, 1995). To allow a better comparison, for both population only the specimens with stomach contents were taken into account (i.e., individuals with empty stomachs were not measured).

The length-weight (L-W) relationship was modeled separately for GS and NH populations by fitting the following exponential equation: $TW = a \times TL^b$, where $a$ is the coefficient of shape and $b$ is the power fulfilling the dimensional balance.

A $t$ test was used to verify the relationship of isometry/allometry ($b$ = 3; Sokal and Rohlf, 1995). In cases where $b$ = 3 the growth of fish was considered as isometric, whereas for $b$<3 or b>3, the growth was considered as allometric negative or positive, respectively.

## DIET ANALYSIS

The trophic spectrum, feeding pattern and prey selectivity of *S. notata* and *S. porcus* were analyzed in relation to GS (pooling together specimens from the three structures) and NH sites. For each species, the vacuity coefficient (VC = number of empty stomachs*100/number of stomachs examined) was also calculated. To evaluate the rate of feeding activity, the feeding incidence (%FI = individuals with identifiable prey remains/total number of fishes × 100) was calculated. Prey diversity was measured by the Shannon-Wiener diversity index (*H'*; Shannon and Weaver, 1949) as follows: $\mathrm{H}' = \sum \mathrm{P_i} \times \ln \mathrm{P_i}$, where $\mathrm{P_i}$ is the proportion of each different prey item contributing to the whole diet. This index was used to assess the breadth of the prey spectrum.

In addition, for each prey the following indexes were calculated (Pinkas *et al*., 1971; Hacunda, 1981):

- abundance percentage (N% = number of individuals of prey i/total number of prey*100)

- weight percentage (W% = weight of prey i/total weight of all prey*100)
- frequency of occurrence (F% = number of stomachs containing prey i/total number of stomachs containing prey*100)
- relative importance index (IRI = [N% + W%]*F%)
- percentage relative importance index (IRI% = [IRI / ΣIRI]*100).

Preys with N% less than 5% were considered as occasional.

A 2-way PERMANOVA (Anderson, 2001; McArdle and Anderson, 2001) was performed in order to investigate variations in diet composition between Species (fixed factor with 2 levels) and Sites (fixed factor with 2 levels) as main sources of variability, using the set of prey abundances as the multivariate response variable. Data were previously log-transformed to reduce data skewness and improve homogeneity of variances (Clarke and Warwick, 2001), and analyzed on the basis of Gower distance coefficient excluding double-zeros. Gower coefficient was selected because it is suitable to describe distance for quantitative abundance data in the case of a large concurrency of double zeros (Legendre and Legendre, 1998). Successively, similarity percentage breakdown procedure (SIMPER; Clarke, 1993; Clarke and Warwick, 2001) was used to determine the contribution of individual taxa towards the dissimilarity between and similarity within Species and Site groups.

The above analyses were performed using the PERMANOVA and SIMPER routines included in the statistical software PRIMER 6+ and PERMANOVA+ software developed by Plymouth Marine Laboratory (Clarke and Gorley, 2006; Anderson *et al.*, 2008). For all tests, confidence limits were set as significant with $p<0.05$.

## RESULTS

### LENGTH-WEIGHT RELATIONSHIP AND GROWTH

***Scorpaena notata*** - A total of 197 *S. notata* specimens was caught at GS sites, with a total length ranging from 92 to 199 mm (mean TL: 148 mm±20 mm), and a mode at 165 mm TL (Figure 5.3). The slope $b$ of the length-weight relationship (3.14±0.05) was significantly > 3.00 ($t$ test for allometry, $p<0.05$) indicating a positive allometric growth for this species (Figure 5.4).

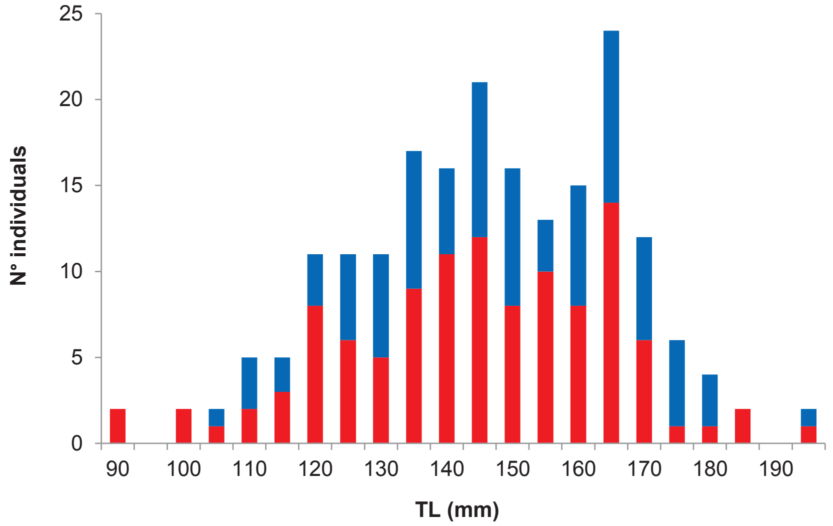

**Figure 5.3** – Length frequency distributions of *Scorpaena notata* specimens caught at GS sites. In red specimens with full stomach; in blue specimens with empty stomach.

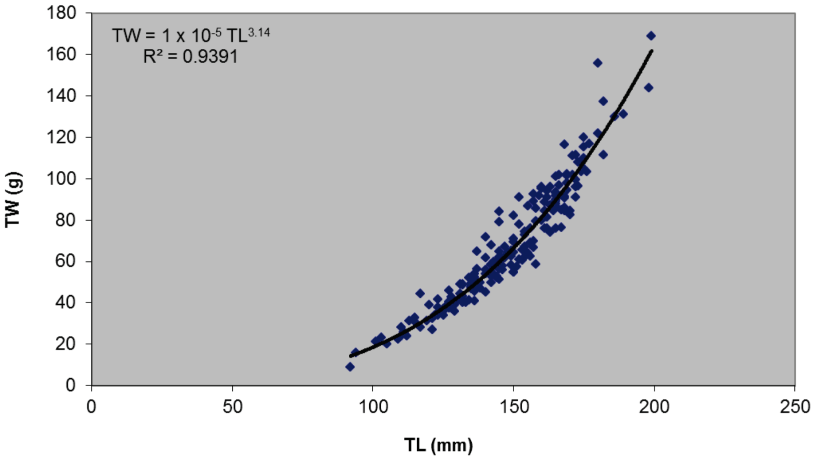

**Figure 5.4** – Length-weight relationship of *Scorpaena notata* specimens caught at GS sites.

Specimens collected at NH sites (n = 237) showed a total length ranging from 54 to 174 mm, with a mean of 128±23 mm and a mode at 135 mm TL. The slope *b* of the length-weight relationship (2.99±0.05) was not significantly different from 3.00 (*t* test for allometry, p>0.05) indicating an isometric growth (Figure 5.5).

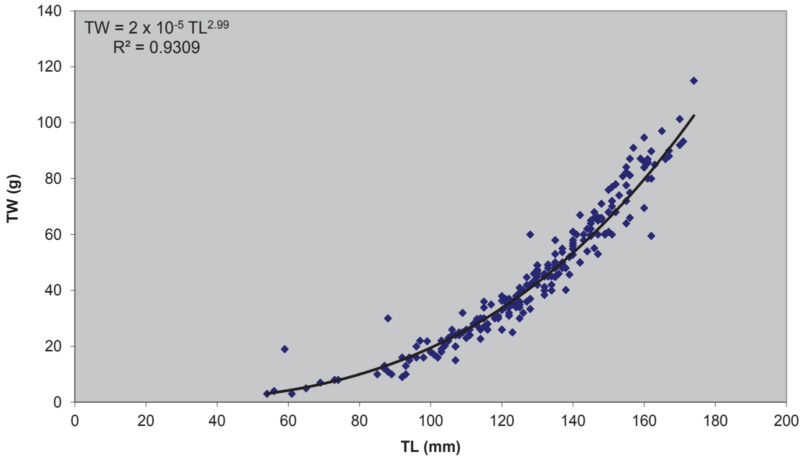

**Figure 5.5** – Length-weight relationship of *Scorpaena notata* specimens caught at NH sites.

Considering only the specimens with stomach contents (Figure 5.6), the comparison between NH and GS population evidenced a significant difference ($p<0.01$) in the length frequency distributions.

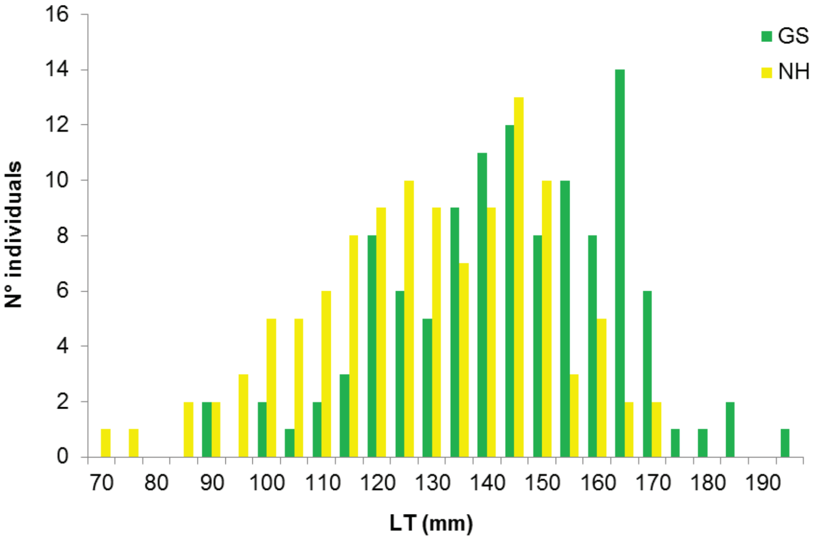

**Figure 5.6** – Length frequency distributions of *Scorpaena notata* specimens sampled at GS and NH sites. Only the specimens with stomach contents were considered.

***Scorpaena porcus*** - A total of 61 *S. porcus* was sampled at the GS. Specimens ranged from 140 to 259 mm TL, having a mean TL of 206±30 mm and two modes at 205 and 220 mm TL (Figure 5.7). The length-weight relationship analysis (Figure 5.8) allowed to verify an isometric growth, as the slope *b* (3.06±0.06) resulted not significantly different from 3.00 (*t* test for allometry, p>0.05).

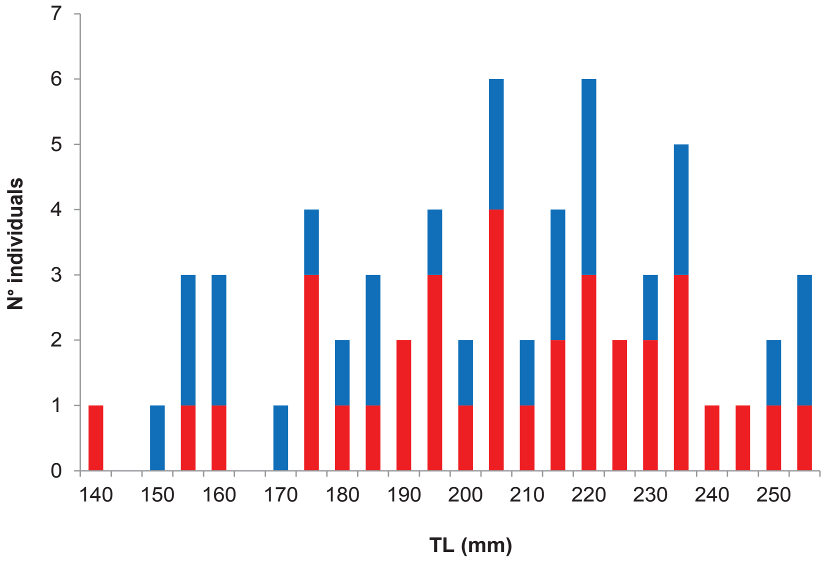

**Figure 5.7** - Length frequency distributions of *Scorpaena porcus* specimens caught at GS sites. In red specimens with full stomach; in blue specimens with empty stomach.

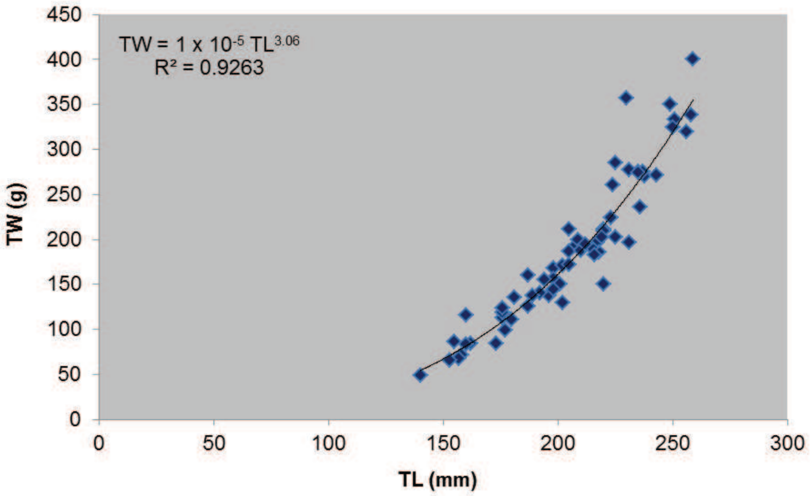

**Figure 5.8** - Length-weight relationship of *Scorpaena porcus* specimens caught at GS sites.

Specimens collected at NH sites (n = 58) showed a total length ranging from 83 to 235 mm, with mean TL of 146±37 mm and a mode at 138 mm. Also in this case, the length-weight relationship analysis evidenced an isometric growth (Figure 5.9) with a slope *b* equal to 2.99±0.06 and not significantly different from 3.00 (*t* test for allometry, $p>0.05$).

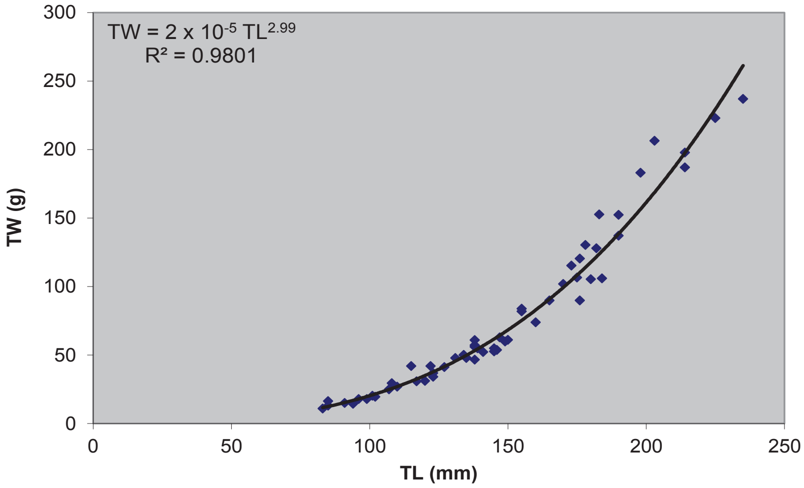

**Figure 5.9** - Length-weight relationship of *Scorpaena porcus* specimen caught at NH sites.

Taking into account the specimens with stomach contents, the comparison between NH and GS population evidenced significant difference ($p<0.001$) in the length frequency distributions (Figure 5.10).

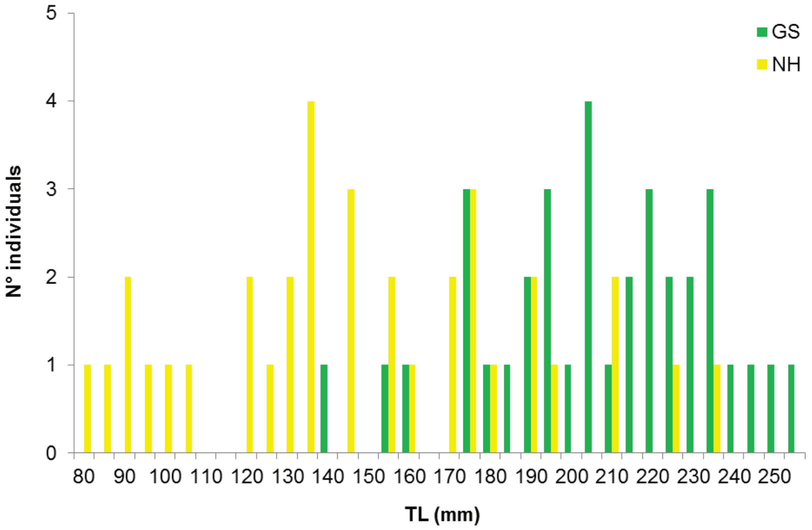

**Figure 5.10** – Length frequency distributions of *Scorpaena porcus* specimens sampled at GS and NH sites. Only the specimens with stomach contents were considered.

The same number of full stomachs found in the GS site (n = 112 for *S. notata*; n = 35 for *S. porcus*) has been taken into account for NH.

The results of the 2-way PERMANOVA revealed significant differences in the diet composition either between Species or between Sites, whereas no differences were observed for the interaction of factors (Table 5.1).

**Table 5.1** - Results of 2-way PERMANOVA and Pair-wise tests using Species and Site as main factors. SN = *Scorpaena notata*; SP = *Scorpaena porcus*. * = significant ($P<0.05$); ** = highly significant ($P<0.01$).

| Source | df | MS | Pseudo-F | P(perm) | Perms |
|---|---|---|---|---|---|
| Species (Sp) | 1 | 5690.9 | 2.2842 | 0.017* | 999 |
| Site (Si) | 1 | 7930.2 | 3.183 | 0.001** | 997 |
| SpxSi | 1 | 2470.7 | 0.99167 | 0.413 | 9998 |
| Res | 290 | 2491.4 | | | |
| Total | 293 | | | | |
| Pair-wise test for pairs of levels of the factor 'Site' | | | | | |
| GS ≠ NH for SN (P = 0.004**) | | GS = NH for SP (P = 0.065) | | | |
| Pair-wise test for pairs of levels of the factor 'Species' | | | | | |
| SN ≠ SP at GS site (P = 0.038*) | | SN = SP at NH site (P = 0.197) | | | |

The pair-wise tests carried out separately for the two species revealed significant differences in the diet composition between GS and NH sites only for *S. notata* (Table 5.1). Pairwise tests revealed also significant differences in the diet composition between *S. notata* and *S. porcus* only at GS sites.

The diets of *S. notata* and *S. porcus* caught at GS sites were significantly different (Table 5.1). SIMPER analysis confirmed this result highlighting a dissimilarity of 93%, with *P. spinifer*, *Cirolana* sp, *G. rhomboides*, and *L. depurator* as the main contributors to this difference (Table 5.2).

**Table 5.2** - Results of SIMPER analysis showing the contribution to the total dissimilarity (Contr. %) by the prey taxa causing most to the overall dissimilarity in the diet composition between *Scorpaena notata* (SN) and *Scorpaena porcus* (SP) caught at GS sites. Only species reaching a cumulative contribution of ~70% are reported.

| Species | SN vs. SP | Contr.% |
|---|---|---|
| *Pilumnus spinifer* | SN < SP | 19.4 |
| *Cirolana* sp | SN > SP | 11.3 |
| *Goneplax rhomboides* | SN < SP | 10.4 |
| *Liocarcinus depurator* | SN < SP | 9.6 |
| Decapoda nd | SN < SP | 6.3 |
| *Liocarcinus maculatus* | SN > SP | 5.1 |
| Teleostea nd | SN < SP | 3.5 |
| *Ebalia deshayesi* | SN > SP | 3.5 |
| *Processa* sp | SN > SP | 2.8 |
| Total | | 71.9 |
| Average dissimilarity = 93.42% | | |

***Scorpaena notata*** - Of the 197 stomachs of *S. notata* caught at GS, 112 (57%) contained food items, and vacuity coefficient was 43%. Excluding the digested material, the stomach content contained 34 different prey taxa, with an average number of 1.34 prey per stomach. The *H'* prey diversity index was equal to 2.88.

The food composition of these specimens together with the values of dietary indices for each prey item are shown in Annex 5.1 and illustrated in Figure 5.11. Crustacean decapods represented the most abundant prey (N%: 52.6%; W%: 63.6%). The decapod *Pilumnus spinifer* was the most important species in terms of W% (28.6%), whereas the isopod *Cirolana* sp. was the most important taxon in terms of N% (20.5%) and F% (19.6%).

According to the IRI%, the most important prey was *Cirolana* sp (35.6%), followed by *P. spinifer* (28.6%) and *Liocarcinus maculatus* (5.6%).

Predation on bivalves, polychaetes and fish was not important (N%<5%).

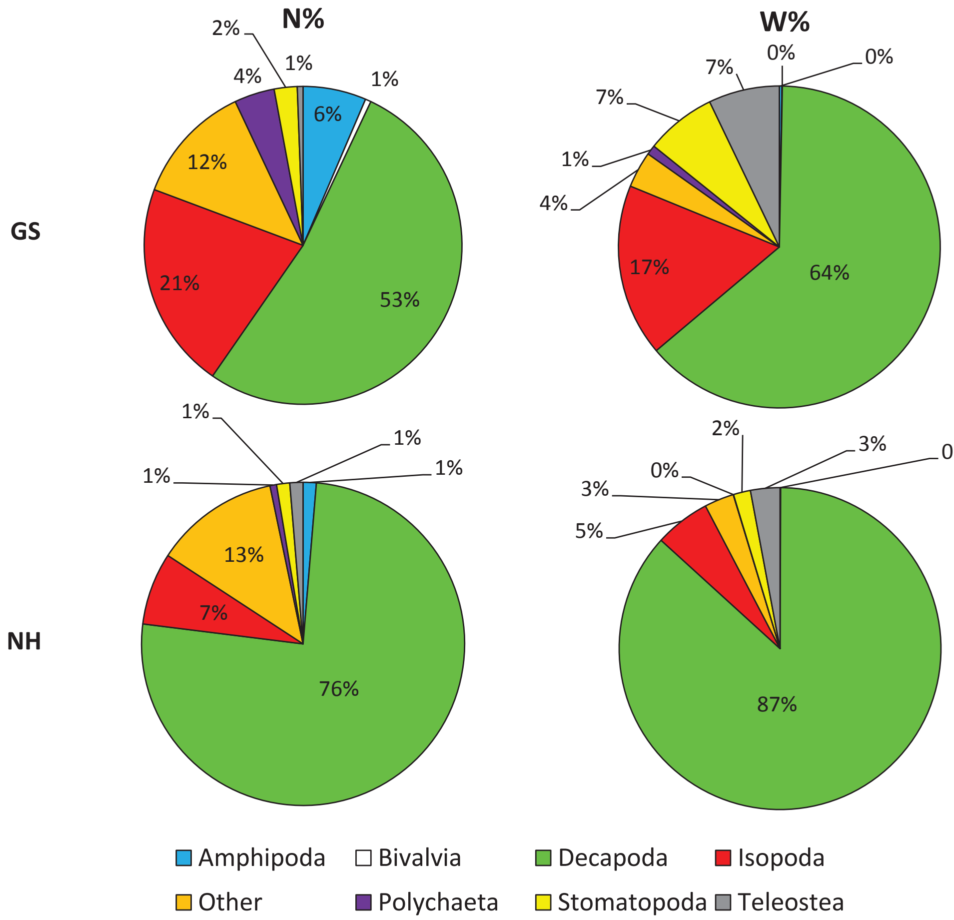

**Figure 5.11** – Diet composition of *Scorpaena notata* collected at GS and NH sites: abundance percentage (N%) and weight percentage (W%) calculated for the main taxonomic groups of prey.

The diet composition of *S. notata* specimens collected at the NH is reported in Annex 5.2 and illustrated in Figure 5.11. Excluding the digested material, the stomach contained 24 different prey taxa, with an average number of 1.19 preys per stomach. The *H'* prey diversity index was equal to 2.74.

The diet of *S. notata* at the NH site included mostly crustacean decapods (N%: 75.7; W%: 86.7). The decapod *G. rhomboides* was the most important prey, showing the highest value in terms of N% (11.8%), W% (14.9%) and F% (15.2%), which resulted in highest IRI% values (23.6%). Less important species were decapods belonging to the genera *Galathea* (IRI%: 14.6%) and *Munida* (8.4%). Other invertebrates and fish were only occasional preys (N%<5%).

Differences in the diet composition between *S. notata* individuals collected at GS and NH sites were mostly explained by poorly represented taxa like Amphipoda, Bivalvia, Isopoda and Polychaeta, which were all virtually more abundant in the stomach of specimens caught at GS than at NH. Such difference appears more evident when the lowest taxonomic level of prey is considered. In fact, the SIMPER analysis, which took into account all the preys showed a ca. 97% dissimilarity in the diet composition of specimens caught at GS and NH sites, evidenced that the preys that mainly contributed to this difference were the isopod *Cirolana* sp, and the decapods *G. rhomboides*, *P. spinifer* and *Galathea* sp (Table 5.3).

**Table 5.3** - Results of SIMPER analysis showing the contribution to the total dissimilarity (Contr. %) by the prey taxa causing most to the overall dissimilarity in the diet composition of *Scorpaena notata* for the factor Site. Only species reaching a cumulative contribution of ~60% are reported. GS: gas structures; NH: natural habitat.

| **Species** | **GS vs. NH** | **Contr. %** |
|---|---|---|
| *Cirolana* sp | GS > NH | 12.1 |
| *Goneplax rhomboides* | GS < NH | 10.1 |
| *Pilumnus spinifer* | GS > NH | 8.4 |
| *Galathea* sp | GS < NH | 7.5 |
| Decapoda nd | GS < NH | 7.5 |
| *Liocarcinus maculatus* | GS > NH | 7.5 |
| *Melicertus keraturus* | GS < NH | 5.1 |
| *Liocarcinus depurator* | GS < NH | 5.1 |
| Total | | 63.3 |
| Average dissimilarity = 96.7% | | |

***Scorpaena porcus*** **-** Overall, 35 stomachs (57%) contained prey and 26 (43%) were empty; 16 taxa have been recorded in the stomach contents, most of them belonging to crustaceans. A low average number of prey per stomach was found (mean: 1.31), whereas the Shannon-Wiener prey diversity index was equal to 2.28.

The diet composition of *S. porcus* is reported in Annex 5.3 and illustrated in Figure 5.12, together with the values of dietary indices for each prey item. Crustacean decapods represented the most abundant prey (N%: 68.6; W%: 92.1). *Liocarcinus depurator* was the most important prey in terms of W% (33.8%), whereas *P. spinifer* was the most abundant prey, reaching the highest values of abundance, frequency of occurrence and relative abundance (N%: 21.6; F%: 31.4; IRI%: 34.3). Fish and other invertebrate groups (*e.g.*, bivalves and gastropods) can be considered as occasional preys (N%<5%).

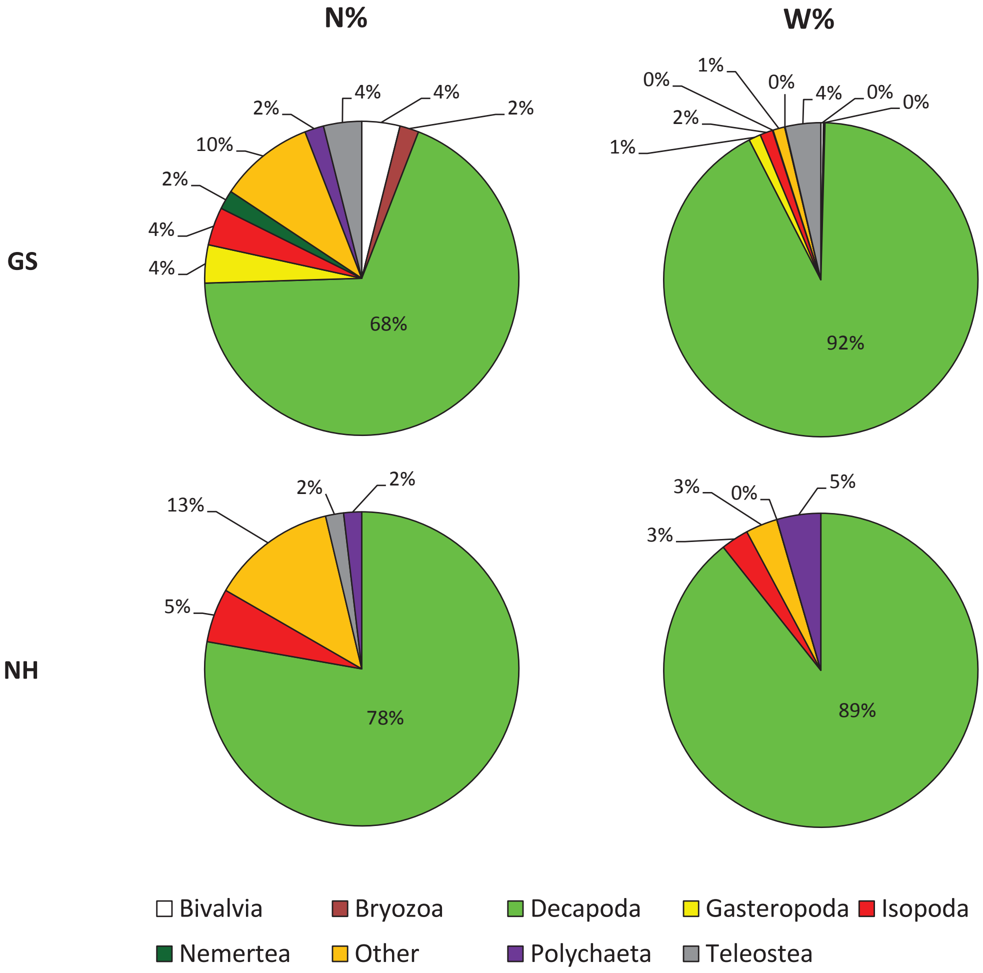

**Figure 5.12** - Diet composition of *Scorpaena porcus* collected at GS and NH sites: abundance percentage (N%) and weight percentage (W%) calculated for the main taxonomic group of prey.

The diet composition of *S. porcus* specimens collected at NH sites is reported in Annex 5.4 and illustrated in Figure 5.12. Excluding the digested material, the stomachs of individuals caught at NH sites contained 13 different prey taxa, with an average number of 1.34 preys per stomach. The *H'* prey diversity index was equal to 2.06.

The most important taxa were crustaceans decapods (N%: 77.8; W%: 89.3), with the decapod *L. depurator* being the most abundant prey in terms of abundance (N%: 22.2), weight (W%: 60.8), and relative abundance (IRI%: 47.3), whereas the decapod *G. rhomboides* was the most important prey in terms of frequency of occurrence (F%: 25.7%).

Differences in the diet composition between *S. porcus* specimens collected at GS and NH sites were mostly explained by poorly represented taxa such as Bryozoa, Bivalvia and Gasteropoda, which were all virtually more abundant in the stomach of specimens caught at GS than at NH. The SIMPER analysis, which took into account all the preys showed a ca. 92% dissimilarity in the diet composition of specimens caught at GS and NH sites, pointed out the decapods *L. depurator, P. hirtellus* and *G. rhomboides* as the preys that mainly contributed to this difference (Table 5.4). The former resulted more abundant at NH sites while the others at GS sites.

**Table 5.4 -** Results of SIMPER analysis showing contribution to the total dissimilarity (Contr. %) by the prey taxa contributing most to the overall dissimilarity in the diet composition of *Scorpaena porcus* according to the factor Site. Only species reaching a cumulative contribution of ~80% are reported.

| **Species** | **GS vs. NH** | **Contr. %** |
|---|---|---|
| *Liocarcinus depurator* | GS < NH | 18.6 |
| *Pilumnus spinifer* | GS > NH | 17.2 |
| *Goneplax rhomboides* | GS > NH | 17.1 |
| Decapoda nd | GS < NH | 13.2 |
| *Cirolana* sp | GS < NH | 4.9 |
| Teleostea nd | GS > NH | 4.8 |
| *Processa* sp | GS < NH | 4.7 |
| Total | | 80.5 |
| Average dissimilarity = 92.1% | | |

## DISCUSSION

### *Population parameters of S. notata and S. porcus: a comparison at the Mediterranean Sea scale*

I report here that, for both *S. notata* and *S. porcus*, length frequency distribution calculated for specimens collected at offshore gas structures (GS) was significantly different from that of specimens caught at natural habitats (NH). This result confirms previous findings (Scarcella *et al*. 2011a), evidencing larger specimens of *S. porcus* and S. *notata* caught at GS than those observed at NH.

Again, the length-weight (L-W) relationship of the specimens collected during this study allowed to identify a positive allometric growth for *S. notata* specimens caught at GS sites and an isometric growth for *S. notata* collected at NH sites and for both *S. porcus* populations. This means that *S. notata* specimens grows faster in weight than in length, while *S. porcus* specimens grows in length and weight at the same rate, confirming previous studies carried out in the Adriatic Sea (La Mesa *et al*., 2010;

Scarcella, 2010) and, for *S. notata*, in the NW Mediterranean Sea (Balearic Islands; Ordines *et al.,* 2009).

The value of the *b* parameter in the L-W relationship obtained in the present study for *S. notata* caught at gas structures was similar to that found by Ordines *et al.* (2009) in the NW Mediterranean Sea (Balearic Islands), but was slightly higher than those recorded during other studies carried out in other areas of Mediterranean, such as Adriatic Sea (Dulcic and Kraljevic, 1996; La Mesa *et al*., 2010; Scarcella, 2010; Scarcella *et al.*, 2011b), the Aegean Sea (Stergiou and Moutopoulos, 2001; Karakulak *et al.,* 2006) and the Western Mediterranean Sea (Merella *et al.,* 1997; Morey *et al*., 2003; Table 5.5). In addition, it was possible to observe a difference in the growth between GS and NH specimens, evidencing a faster growth in GS specimens.

**Table 5.5** – Values of *b* parameter obtained from length-weight relationships of *S. notata* and *S. porcus* (M: Male; F: Female; N.I.: not indicated).

| **Species** | **Area** | **Reference** | ***b* value** | **sex** |
|---|---|---|---|---|
| *Scorpaena notata* | Adriatic Sea | Scarcella *et al*., 2011b | 3.08 | M&F |
| | | Scarcella, 2010 | 3.08 | M&F |
| | | La Mesa *et al*., 2010 | 3.12 | M&F |
| | | Dulcic and Kraljevic, 1996 | 2.64 | M&F |
| | Aegean Sea | Karakulak *et al.,* 2006 | 3.02 | N.I. |
| | | Stergiou and Moutopoulos, 2001 | 2.73 | M&F |
| | Western Mediterranean Sea | Ordines *et al*., 2009 | 309 | M |
| | | | 3.14 | F |
| | | Morey *et al.,* 2003 | 3.04 | M&F |
| | | Merella *et al.,* 1997 | 2.98 | N.I. |
| *Scorpaena porcus* | Adriatic Sea | Scarcella, 2010 | 2.98 | M&F |
| | | La Mesa *et al*., 2010 | 3.12 | M&F |
| | | Jardas and Pallaoro, 1992 | 3.03 | M&F |
| | Ligurian Sea | Silvestri *et al*., 2002 | 2.91 | M&F |
| | Aegean Sea | Karakulak *et al.,* 2006 | 2.92 | N.I. |
| | | Moutopoulos and Stergiou, 2002 | 2.89 | M&F |
| | Western Mediterranean Sea | Campillo, 1992 | 3.08 | M&F |
| | | Kaim-Malka and Jacob, 1985 | 3.08 | M&F |
| | Black Sea | Bilgin and Çelik, 2009 | 3.06 | M |
| | | | 3.07 | F |

Regarding *S. porcus*, the values of *b* parameter obtained in the present study were similar to those evidenced by Bilgin and Celik (2009) in Black Sea specimens, and by different Authors in Adriatic Sea (Jardas and Pallaoro, 1992; Scarcella, 2010), and in Western Mediterranean Sea (Kaim-Malka and Jacob, 1985; Campillo, 1992), while lower values were found in Aegean Sea (Moutopoulos and Stergiou, 2002; Karakulak *et al*., 2006; Table 5.5). On the other hand, taking into account only the specimens caught at gas structures, the value resulted similar to that obtained by La Mesa *et al.* (2010) for the specimens sampled at platform sites in Adriatic Sea.

### *Diet composition of scorpenids in the Adriatic Sea*

Considering the food preferences, for both species the diet was mainly based on crustacean decapods, which constituted more than 70% of food intake, while the other prey groups detected (*e.g*., fish, mollusks, etc.) only play a marginal role.

In particular, for *S. notata* the main preys were *Pilumnus spinifer* and *Liocarcinus maculatus* at GS site, and *Goneplax rhomboides* and *Galathea* sp at NH site, while *S. porcus* predominantly feed on *Liocarcinus depurator* and *P. spinifer* at GS site, and on *P. hirtellus* and *G. rhomboides* at NH site. The important role played by decapods was already stated in other studies (Harmelin-Vivien *et al*., 1989; Arculeo *et al*., 1989; Morte *et al*., 2001; Relini *et al*., 2002), although these Authors found some other species due to the different investigated geographic area or to the different habitat.

The diet of *S. notata* was also characterized by isopods belonging to the genus *Cirolana*, while predation on fish seems to be negligible, as well as on mollusks and polychaetes. This was probably due to the small dimensions of this species.

Another issue worth of attention deals with the vacuity coefficient of the stomachs: the percentage of empty stomachs in specimens sampled at GS sites was lower than that reported by Castriota *et al.* (2012) in a similar environmental asset in the Adriatic Sea. In addition this percentage was similar to that reported by Harmelin-Vivien *et al*. (1989) and also to that obtained in autumn by Pallaoro and Jardas (1991), while it was high when compared with studies carried out in the Gulf of Valencia (Morte *et al*., 2001) and Balearic Islands (Ordines *et al*., 2009). These differences could be related to the different fishing gear used in the two studies, and to the catch obtained in different hour of the day. In fact, fish were collected through trawling survey carried out during daytime by Morte *et al*., (2001) and Ordines *et al.* (2009). On the contrary, in the present study most of the specimens were caught during nighttime using trammel net. Due to the fact that Scorpaenids are nocturnal species, their feeding activity starts in the evening until the dawn while during daytime they spend time to complete digestion and to rest (Pallaoro and Jardas, 1991). In this way, specimens sampled at sunset, when trammel nets are set into the sea, had not yet fed, while during daytime these species presents a sedentary behavior and can be captured more easily by an active fishing gear. A similar result has been previously found by Castriota *et al.* (2012) using gillnets.

However, it is useful to evidence that both fishing gears used during this study are defined as non-selective for *Scorpaenidae* species and, in addition, it would not be possible to use other net (such as trawling), since that trammel net is the only one capable to operate at a short distance from the platforms.

Although the diets of the two target species consisted of similar high taxonomic groups, they differ in their diets, according to what previously observed by other studies (Harmelin-Vivien *et al.*, 1989; Morte *et al.*, 2001; Castriota *et al*., 2012). This result indicates that no competition for prey exists between the two investigated species. This holds true in particular for the specimens caught at offshore gas structures, suggesting that the higher availability of prey in this habitat favors a better segregation of diets.

For *S. notata* a statistical difference has been detected in diet composition between specimens caught surrounding offshore gas structures in respect to those living in the natural habitat. One of the difference concerns the highest presence of the taxa Isopoda, Amphipoda and Polychaeta in the diets of GS specimens, even though looking at the species level, only crustacean species were responsible to the dissimilarity. A similar pattern was also observed by Ordines *et al*. (2009), which demonstrated a different diet of *S. notata* specimens in correspondence to seagrass and maërl beds, revealing a faster growth in specimens inhabiting bottoms with the highest algal biomass. This result suggests that offshore artificial structures can reflect the ecosystem engineering behaviour of seagrass meadows and maërl beds, creating a high quality habitat for *S. notata*, not only because of the creation of new shelters due to the increased structural complexity, but also due to the higher abundance of its main preys.

On the contrary, my results didn't evidence a significant trophic relationship for *S. porcus* specimens, as previously found by Relini *et al.* (2002).

The bases of artificial structures offer protection and prey availability for both these cryptobenthic species, exerting a trophic role in the *S. notata* specimens more than in the *S. porcus* ones. The different pattern evidenced by the two species could be explained by two hypotheses. The first concerns the small size of the sample and the lower number of full stomach collected for *S. porcus* during the study in respect to *S. notata*, reducing the probability to found an evident difference. The other hypothesis regards the more opportunistic behavior of *S. notata*, that completely exploits the prey available at offshore structures (La Mesa *et al*., 2010; Scarcella *et al*., 2011a). Moreover, others Authors pointed out that artificial structures, and in particular gas platforms, positively affect *S. notata* and, to a lesser degree, *S. porcus* populations in terms of maximum size, growth performance and longevity (La Mesa *et al*., 2010; Scarcella *et al*., 2011a).

On the other hand, the exclusive presence of some species belonging to hard substrates biocenosis (such as *P. spinifer*, *Typton spongicola* and *Amathia semiconvoluta*) in the diet of both species caught at GS site support the hypothesis that the offshore gas structures exert a trophic role in the diet of *S. notata* and, in a certain extent of *S. porcus*.

In conclusion, offshore artificial structures could be considered essential habitats for the success and development of *S. notata* and *S. porcus* population. In fact, these species are frequently found in close proximity to hard substrates (Fabi *et al*., 2004; Casellato and Stefanon, 2008), playing likely a more important role in the benthic fish community of rocky habitat than previously thought. Moreover, these species are strictly related to the offshore artificial structures, in terms of maximum size and from a trophic point of view mainly for *S. notata*, confirming that fish spend more time in habitats where they have better conditions for developing their life cycle (Minello, 1999; Ordines *et al*., 2009).

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**Annex 5.1** - Diet composition of *Scorpaena notata* collected at GS sites and dietary indexes calculated for each prey item: abundance percentage (N%), weight percentage (W%), frequency of occurrence (F%), index of relative abundance (IRI), and IRI percentage (IRI%).

| **Phylum/Class** | **Species/Taxa** | **N%** | **W%** | **F%** | **IRI** | **IRI %** |
|---|---|---|---|---|---|---|
| CRUSTACEA | | | | | | |
| Amphipoda | Amphipoda nd | 0.58 | 0.02 | 0.89 | 0.54 | 0.03 |
| | *Hippomedon bidentatus* | 0.58 | 0.00 | 0.89 | 0.53 | 0.03 |
| | *Hippomedon massiliensis* | 1.75 | 0.10 | 1.79 | 3.31 | 0.16 |
| | *Lysianassa* sp | 1.75 | 0.09 | 0.89 | 1.64 | 0.08 |
| | *Orchomene grimaldii* | 1.75 | 0.06 | 2.68 | 4.85 | 0.23 |
| Decapoda | *Alpheus glaber* | 4.09 | 0.96 | 4.46 | 22.55 | 1.08 |
| | *Callianassa subterranea* | 2.34 | 0.16 | 2.68 | 6.68 | 0.32 |
| | Decapoda nd | 4.68 | 0.23 | 5.36 | 26.28 | 1.26 |
| | *Ebalia deshayesi* | 3.51 | 0.48 | 5.36 | 21.38 | 1.03 |
| | *Galathea* sp | 2.34 | 0.91 | 3.57 | 11.61 | 0.56 |
| | *Goneplax rhomboides* | 4.09 | 12.58 | 6.25 | 104.23 | 5.01 |
| | *Ilia nucleus* | 0.58 | 2.01 | 0.89 | 2.32 | 0.11 |
| | *Inachus* sp | 0.58 | 0.02 | 0.89 | 0.54 | 0.03 |
| | *Liocarcinus depurator* | 1.17 | 4.14 | 1.79 | 9.49 | 0.46 |
| | *Liocarcinus maculatus* | 8.19 | 2.61 | 10.71 | 115.64 | 5.56 |
| | *Melicertus kerathurus* | 0.58 | 0.05 | 0.89 | 0.57 | 0.03 |
| | *Monodaeus couchi* | 0.58 | 0.77 | 0.89 | 1.21 | 0.06 |
| | Paguridae nd | 0.58 | 0.14 | 0.89 | 0.65 | 0.03 |
| | *Parthenope angulifrons* | 0.58 | 3.44 | 0.89 | 3.60 | 0.17 |
| | *Pilumnus hirtellus* | 1.17 | 3.42 | 1.79 | 8.19 | 0.39 |
| | *Pilumnus spinifer* | 10.53 | 28.63 | 15.18 | 594.31 | 28.59 |
| | *Processa* sp | 4.09 | 2.24 | 6.25 | 39.56 | 1.90 |
| | *Solenocera membranacea* | 2.34 | 0.68 | 3.57 | 10.79 | 0.52 |
| | *Typton spongicola* | 0.58 | 0.09 | 0.89 | 0.60 | 0.03 |
| Isopoda | *Cirolana* sp | 20.47 | 17.20 | 19.64 | 739.86 | 35.59 |
| | *Eurydice* sp | 0.58 | 0.11 | 0.89 | 0.62 | 0.03 |
| Stomatopoda | *Squilla mantis* | 2.34 | 7.10 | 3.57 | 33.73 | 1.62 |
| MOLLUSCA | | | | | | |
| Bivalvia | *Corbula gibba* | 0.58 | 0.04 | 0.89 | 0.56 | 0.03 |
| POLYCHAETA | | | | | | |
| | Aphroditidae nd | 0.58 | 0.70 | 0.89 | 1.15 | 0.06 |
| | *Hyalinoecia tubicola* | 0.58 | 0.20 | 0.89 | 0.70 | 0.03 |
| | Paraonidae nd | 0.58 | 0.00 | 0.89 | 0.52 | 0.03 |
| | Pilargidae nd | 0.58 | 0.02 | 0.89 | 0.54 | 0.03 |
| | Polychaeta nd | 1.75 | 0.03 | 2.68 | 4.78 | 0.23 |
| TELEOSTEA | | | | | | |
| | Gobiidae nd | 0.58 | 7.13 | 0.89 | 6.88 | 0.33 |
| OTHER | | | | | | |
| | Digested matter | 12.28 | 3.64 | 18.75 | 298.57 | 14.36 |

**Annex 5.2** - Diet composition of *Scorpaena notata* collected at NH sites and dietary indexes calculated for each prey item: abundance percentage (N%), weight percentage (W%), frequency of occurrence (F%), index of relative abundance (IRI), and IRI percentage (IRI%).

| **Phylum/Class** | **Species/taxa** | **N%** | **W%** | **F%** | **IRI** | **IRI%** |
|---|---|---|---|---|---|---|
| CRUSTACEA | | | | | | |
| Amphipoda | Amphipoda nd | 0.66 | 0.02 | 0.89 | 0.60 | 0.04 |
| | *Hippomedon massiliensis* | 0.66 | 0.04 | 0.89 | 0.63 | 0.04 |
| Decapoda | *Alpheus glaber* | 0.66 | 5.22 | 0.89 | 5.25 | 0.31 |
| | Decapoda nd | 8.55 | 3.06 | 10.71 | 124.39 | 7.25 |
| | *Ebalia deshayesi* | 3.29 | 2.86 | 3.57 | 21.95 | 1.28 |
| | *Eurynome aspera* | 0.66 | 1.22 | 0.89 | 1.68 | 0.10 |
| | *Galathea* sp | 9.87 | 10.12 | 12.50 | 249.88 | 14.56 |
| | *Goneplax rhomboides* | 11.84 | 14.86 | 15.18 | 405.36 | 23.62 |
| | Larvae of decapoda | 0.66 | 0.00 | 0.89 | 0.59 | 0.03 |
| | *Liocarcinus depurator* | 7.89 | 6.53 | 8.93 | 128.79 | 7.51 |
| | *Liocarcinus maculatus* | 4.61 | 3.44 | 5.36 | 43.10 | 2.51 |
| | *Macropodia longipes* | 0.66 | 0.13 | 0.89 | 0.70 | 0.04 |
| | *Melicertus keraturus* | 6.58 | 7.18 | 8.93 | 122.85 | 7.16 |
| | *Monodaeus couchi* | 0.66 | 0.78 | 0.89 | 1.28 | 0.07 |
| | *Munida* sp | 5.92 | 14.34 | 7.14 | 144.72 | 8.43 |
| | Paguridae nd | 0.66 | 0.05 | 0.89 | 0.63 | 0.04 |
| | *Pilumnus hirtellus* | 2.63 | 11.70 | 3.57 | 51.19 | 2.98 |
| | *Pisidia* sp | 0.66 | 0.29 | 0.89 | 0.84 | 0.05 |
| | *Processa* sp | 6.58 | 2.94 | 3.57 | 33.99 | 1.98 |
| | *Solenocera membranacea* | 3.29 | 1.98 | 3.57 | 18.81 | 1.10 |
| Isopoda | *Cirolana* sp | 7.24 | 5.58 | 5.36 | 68.65 | 4.00 |
| Stomatopoda | *Squilla mantis* | 1.32 | 1.72 | 1.79 | 5.42 | 0.32 |
| TELEOSTEA | | | | | | |
| | Teleostea nd | 1.32 | 2.96 | 1.79 | 7.63 | 0.44 |
| POLYCHAETA | | | | | | |
| | Aphroditidae nd | 0.66 | 0.03 | 0.89 | 0.61 | 0.04 |
| OTHER | | | | | | |
| | Digested matter | 12.50 | 2.97 | 17.86 | 276.27 | 16.10 |

**Annex 5.3** - Diet composition of *Scorpaena porcus* collected at GS sites and dietary indexes calculated for each prey item: abundance percentage (N%), weight percentage (W%), frequency of occurrence (F%), index of relative abundance (IRI), and IRI percentage (IRI%).

| **Phylum/Class** | **Species/Taxa** | **N%** | **W%** | **F%** | **IRI** | **IRI %** |
|---|---|---|---|---|---|---|
| BRYOZOA | | | | | | |
| | *Amathia semiconvoluta* | 1.96 | 0.14 | 2.86 | 6.01 | 0.16 |
| CRUSTACEA | | | | | | |
| Decapoda | Decapoda nd | 7.84 | 0.29 | 8.57 | 69.67 | 1.82 |
| | *Ebalia deshayesi* | 1.96 | 0.73 | 2.86 | 7.70 | 0.20 |
| | *Ethusa mascarone* | 1.96 | 0.71 | 2.86 | 7.63 | 0.20 |
| | *Goneplax rhomboides* | 17.65 | 32.39 | 22.86 | 1143.68 | 29.93 |
| | *Liocarcinus depurator* | 15.69 | 33.79 | 20.00 | 989.57 | 25.90 |
| | *Monodaeus couchi* | 1.96 | 4.00 | 2.86 | 17.04 | 0.45 |
| | *Pilumnus spinifer* | 21.57 | 20.13 | 31.43 | 1310.66 | 34.30 |
| Isopoda | *Cirolana* sp | 3.92 | 1.32 | 5.71 | 29.94 | 0.78 |
| MOLLUSCA | | | | | | |
| Bivalvia | *Corbula gibba* | 1.96 | 0.24 | 2.86 | 6.29 | 0.16 |
| | *Scapharca demiri* | 1.96 | 0.04 | 2.86 | 5.71 | 0.15 |
| Gasteropoda | *Calyptraea chinensis* | 1.96 | 0.02 | 2.86 | 5.65 | 0.15 |
| | *Turritella communis* | 1.96 | 1.22 | 2.86 | 9.09 | 0.24 |
| NEMERTEA | | | | | | |
| | Nemertea nd | 1.96 | 0.06 | 2.86 | 5.77 | 0.15 |
| POLYCHAETA | | | | | | |
| | *Pomatoceros triqueter* | 1.96 | 0.05 | 2.86 | 5.74 | 0.15 |
| TELEOSTEA | | | | | | |
| | Teleostea nd | 3.92 | 3.66 | 5.71 | 43.30 | 1.13 |
| OTHER | | | | | | |
| | Digested matter | 9.80 | 1.22 | 14.29 | 157.42 | 4.12 |

**Annex 5.4** - Diet composition of *Scorpaena porcus* collected at NH sites and dietary indexes calculated for each prey item: abundance percentage (N%), weight percentage (W%), frequency of occurrence (F%), index of relative abundance (IRI), and IRI percentage (IRI%).

| **Phylum/Class** | **Species/taxa** | **N%** | **W%** | **F%** | **IRI** | **IRI %** |
|---|---|---|---|---|---|---|
| CRUSTACEA | | | | | | |
| Decapoda | Decapoda nd | 16.67 | 4.84 | 20.00 | 430.05 | 12.24 |
| | *Ebalia deshayesi* | 1.85 | 0.37 | 2.86 | 6.35 | 0.18 |
| | *Galathea* sp | 1.85 | 0.42 | 2.86 | 6.48 | 0.18 |
| | *Goneplax rhomboides* | 18.52 | 15.61 | 25.71 | 877.61 | 24.97 |
| | *Jaxea nocturna* | 1.85 | 0.62 | 2.86 | 7.07 | 0.20 |
| | *Liocarcinus depurator* | 22.22 | 60.83 | 20.00 | 1661.0 | 47.26 |
| | *Monodaeus couchi* | 1.85 | 2.39 | 2.86 | 12.13 | 0.35 |
| | Paguridae nd | 1.85 | 0.33 | 2.86 | 6.23 | 0.18 |
| | *Pilumnus hirtellus* | 1.85 | 1.28 | 2.86 | 8.95 | 0.25 |
| | *Processa* sp | 9.26 | 2.65 | 8.57 | 102.12 | 2.91 |
| Isopoda | *Cirolana* sp | 5.56 | 2.85 | 5.71 | 48.05 | 1.37 |
| TELEOSTEA | | | | | | |
| | Teleostea nd | 1.85 | 4.52 | 2.86 | 18.20 | 0.52 |
| POLYCHAETA | | | | | | |
| | Ampharetidae nd | 1.85 | 0.01 | 2.86 | 5.31 | 0.15 |
| OTHER | | | | | | |
| | Digested matter | 12.96 | 3.29 | 20.00 | 324.99 | 9.25 |

# 6. SYNTHESIS OF MAIN RESULTS AND CONCLUSIONS

The Adriatic Sea is characterized by a high drilling activity, hosting most of the offshore oil and gas platforms and related structures situated in the Mediterranean Sea (OGP, 2005; Maggi *et al.,* 2007; Manoukian *et al*., 2010).

Due to the relative short life of these structures, most of them will be decommissioned within the next few decades. Until now, the decommissioning matter was not a main concern in Italy but this will change in the next few years due to the presence of old infrastructures. In fact, forecasts suggested that in the period 2013-2020 an average of 38 platforms a year will be removed in Europe, the majority of which is located in the Adriatic Sea (Scottish Enterprise, 2013).

Nowadays, a number of different potential decommissioning options exist and each will result in an array of both environmental and socioeconomic impacts, some positive and some negative (Bernstein *et al.*, 2010). It was observed that these impacts are perceived and valued differently by stakeholders with differing perspectives (Bernstein *et al*., 2010; Kruse *et al.,* 2015). For example, for someone the decommission platforms could be an opportunity to remove these structures from the marine environment, thereby restoring the seabed to its original and natural state. On the other hand, the decommissioning may also be perceived as a new investment opportunity represented by converting the platforms to other potentially valuable uses with economic and/or scientific benefits. In fact, a number of alternatives have been proposed, including their use as artificial reefs (either left in place or transferred to a designated reefing location, rigs-to-reefs), in offshore wind energy projects, as platforms for solar panel arrays, in offshore aquaculture projects, or as sites for ocean instrumentation or tourism (Bernstein, 2015). Another viewpoint is that decommissioning provides the opportunity to maintain a large part of the biological communities inhabiting offshore platforms, thus preserving an ecological resource that contributes to increase the biological production. Finally, decommissioning may be also an opportunity for the State to obtain financial benefit through the sharing of avoided decommissioning costs, hence increasing resources available to support efforts that produce environmental and socioeconomic benefits (Bernstein *et al*., 2010).

Among all the possible decommissioning options, the partial removal or complete removal are the most feasible and discussed (Bernstein *et al*., 2010). These choices will have different types and levels of impact to the extent that valued resource functions are maintained, increased, decreased, or removed. For instance, in terms of effects on marine resources, a complete removal of the structures may re-allow access to relatively small areas of the sea, but the impacts on certain valuable species may outweigh this potential gain in area if increased fishing pressure reduces the size of the population (Kruse *et al.,* 2015). On the other hand, in the case of partial removal, increased access may predominantly benefit only commercial fixed nets, as well as recreational fishers, but this may reduce a platform's ability to contribute to the preservation or recovery of fish populations also targeted by other types of gears (Kruse *et al.,* 2015).

To approach the decommissioning challenge and to assess the most ecologically sustainable practice of decommissioning in order to preserve ecosystem functions under a reasonable economical effort it becomes of primary importance understanding the role and the potential effects of offshore platforms on hosting ecosystems and their surroundings.

For this reason, in order to provide insights on the effects of artificial structures on hosting ecosystems, my PhD thesis has been built upon the achievement of four main interrelated tasks. Specifically, taking into account three different gas extracting artificial structures (a subsea well-site, a four-leg platform, a one-leg platform), I tested the following four (null) hypotheses:

i) the quantity and biochemical composition of organic matter in the sediment (in terms of phytopigment, protein, carbohydrate, lipid and biopolymeric organic carbon contents) do not vary at increasing distance from two (a subsea well-site and a four-leg platform) of the three investigated structures (Chapter 2);

ii) the abundance and biodiversity of macro-benthic communities do not vary at increasing distance from each of the three offshore artificial structures (Chapter 3);

iii) the abundance, biomass and biodiversity of fish assemblages close to each offshore structures do not differ from those in open waters (Chapter 4);

iv) the diet of two demersal fish (namely *Scorpaena notata* and *Scorpaena porcus*) do not vary among specimens collected close to the offshore structures or in open waters (Chapter 5).

Considering the first task, I report that chlorophyll-a and phaeopigment sedimentary contents (representing the most labile fractions of OM) significantly increase with increasing distance from the platform, while no differences occurred at the well-site. The lowest contents of phytopigments at the platform sites in respect to the further distances could be related to the higher abundance of filter-feeder organisms living on the platform legs (Punzo *et al.,* 2015). This result suggests that offshore platforms with a complex and multifaceted architecture can mirror, at a much larger spatial scale, the ecosystem engineering behaviour of branched corals living in incoherent sediments (Cerrano *et al*., 2010; Bianchelli *et al.,* 2013).

Within the second task, macro-zoobenthic communities living in the surroundings of the three artificial structures showed different spatial patterns and temporal changes. In the first survey a not well diversified community was recorded close to the well-site whereas at the four-leg platform the community was poor in terms of number of both species and specimens. Starting from the second survey at the well-site, values of biotic indexes (abundance, species richness, Shannon Diversity and Simpson) were similar at all distances from the structure and overall slightly increased (or decreased for $\lambda$) till the last survey. On the contrary, strictly close to the four-leg platform slightly higher values of abundance and species richness were recorded only during the last survey, as an overall signal of environmental improvement. Finally, at the one-leg platform the initial signs of impact on macro-benthos observed just after the installation of the two other installations apparently did not occur. These results suggest that the observed differences in the stock and composition of macro-benthic communities among the three artificial structures could be related, to a certain extent, to the different shape and dimension of the structures themselves. Nevertheless, given also the different position at sea, these differences could be also due to the different environmental conditions.

The presence of platforms at sea could enhance stocks and biodiversity of macro-benthic communities in a way similar to what observed for seagrass meadows, kelp forests, coral reefs, and coral forests, favoring the colonization by many small invertebrates, enhancing habitat complexity, improving local environmental conditions, and increasing the fitness of associated species (Bruno and Bertness, 2001; Cerrano *et al.,* 2006; Borthagaray and Carranza, 2007; Cerrano *et al*., 2010; Arribas *et al.,* 2014).

In the third task both acoustic and fishing surveys evidenced a higher abundance of fish close to the structures in respect to the respective open-sea reference sites and a higher occurrence of fish in the surroundings of the four-leg platform in respect to the other two structures according to the different building architecture and dimensions of the three structures and their different extension along the water column. These findings confirm the 'fish aggregating device (FAD)' nature of the artificial structures, letting me hypothesizing that such attractiveness is related to the different growth patterns of attracted fish, as a consequence of the varied food availability close the structures.

This hypothesis has been also confirmed by the results achieved within the fourth task. In fact, it has been evidenced that offshore artificial structures can form a high quality habitat for *S. notata*, not only because of the creation of new shelters due to the increased structural complexity of the seabed, but also due to the higher abundance of preys, mirroring the ecosystem engineering behavior of seagrass meadows and maërl beds. In fact, for *S. notata* a different diet was observed between specimens caught in correspondence of offshore gas structures and those living in their natural habitat, while no significant trophic relationships were evidenced for *S. porcus* specimens, as previously found by Relini *et al.* (2002). On the other hand, it is worth noting the exclusive presence of some species belonging to hard substrate biocenoses (such as *P. spinifer*, *Typton spongicola* and *Amathia semiconvoluta*) in the diet of both species caught at offshore artificial structures. All these findings suggest that the bases of artificial structures offer protection and prey availability for both these cryptobenthic species, exerting a certain influence on the feeding habits of *S. notata* and, though more weakly, on *S. porcus*. The most likely hypothesis to explain this difference regards the behavior and home range of the two species. In fact, *S. notata* is an opportunistic species that completely exploits the prey available at offshore structures (La Mesa *et al*., 2010; Scarcella *et al*., 2011); it has a wide distribution, being found on concrete or in sandy-muddy bottoms (Scarcella, 2010). Conversely*, S. porcus* is a coastal species usually living in close proximity of artificial structures, like artificial reef.

Finally, as a corollary result, it was evidenced that, although both species mainly prefer crustaceans prey, the differences in their diets suggest no interspecific competition relationships between the two congeneric species, as already observed by other Authors (Harmelin-Vivien *et al.*, 1989; Morte *et al.*, 2001; Castriota *et al*., 2012).

In summary, what emerged was that offshore artificial structures in Adriatic Sea act as ecosystem engineers reflecting the behavior of coral reefs, seagrass meadows and maërl beds. These findings result in the aggregation effect exerted by these structures on fish and macrobenthic assemblages. In fact, the platform jacket, horizontal crossbeams, conductors and pilings create an intricate structure that provides a large surface area of hard substrate for sessile invertebrates, as well as important habitat for fishes (Pondella *et al*., 2015).

The higher abundance and biomass of fish close to the structures could be explained by several factors, which include, among the others, the thigmotropic effect exerted by the submerged parts of the structures, the increased availability of food, and the decreased risk of predation close to the platforms compared to the open sea (Bohnsack *et al*., 1991). The exclusive presence or the higher abundance of several species with high affinity to hard substrates, such as the crustaceans *Palinurus elephas* and *Homarus gammarus*, the benthic fish *Mullus surmuletus*, *S. porcus*, and the necto-benthic *Diplodus vulgaris*, *Sparus aurata*, *Spondilyosoma cantharus*, *Dentex dentex* and *Dicentrarchus labrax* close to the structures confirm the 'FAD' nature of these structures (Hastings *et al*., 1976; Love *et al.,* 2005).

The results of this study evidenced also that the magnitude of the attraction is related to the dimension, volume and building architecture of the structures (Bombace *et al.,* 1994).

Similar results emerged for the macro-benthic communities, highlighting that the dimension and the complexity of offshore structures have different impacts on the benthic communities and that these features of the structures can also affect the amplitude and the timing required to reach a new diversified and stable community.

In view of the upcoming platform's decommissioning programme, because each offshore structure is unique, a specific evaluation, taking into account accurate cost analysis, risk assessment and environmental assessment, is necessary for each offshore facility. In the light of the findings reported here, I conclude that a case-by-case evaluation of decommissioning options should be recommended in Adriatic Sea, in addition with before-after environmental impact assessments, in order to avoid any secondary effect on the actually established fish and benthic communities.

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