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Monitoring of Impacts of Offshore Platforms in the Adriatic Sea (Italy)

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1. Introduction

The oil and gas industry is truly global, with operations conducted in every corner of the world, since the worldwide increasing of energy demand has strongly raised the exploitation of non-renewable resources. The date of birth of the offshore industry is commonly regarded as 1947, when it was successfully completed by Kerr-McGee the first well in the Gulf of Mexico (Chakrabarti et al., 2005). Since 1950 about 7,000 platforms have been constructed and installed around the world, and today most of these structures, which represent more than 65% of the total, are located along the American coast of the Gulf of Mexico, the remainder is concentrated in the North Sea, Middle East, Africa, Australia, Asia and South America (Wilson III and Heath, 2008). Approximately 0.4% of world reserves of oil and gas are located in the Mediterranean basin (Pinder, 2001) and therefore this area represents one of the areas that will have greater expansion in offshore activities in the coming years (Maksound, 2004). In sixty years, Italy has produced 75% of the gas discovered. The natural gas production in 2010 was 8 billion cubic meters. The oil and gas production wells in the entire Italian territory are on the whole 1200 and the platforms at sea are 127, which extract especially gas (Paini, 2001; Assomineraria, 2004; 2011). These offshore structures are mainly distributed along the Northern and Central Adriatic coasts (about 90 platforms (De Biasi et al., 2006; Maggi et al., 2007), on depths between 10 and 120 meters, but also in the Ionian Sea and in the Strait of Sicily (www.eni.it).

The offshore activities comprise different phases linked to exploitation of gas and oil reservoirs: a) the exploration phase to probe the position and the geological characteristics of well and then to install a steel platform; b) the production phase to extract oil and gas; c) the decommissioning phase, when the commercial life of well is finished (Oil Industry International Exploration & Production Forum/United Nations Environment Programme [E&P Forum/UNEP], 1997).

Oil and gas exploration and production operations have the potential for a variety of impact on the environment, depending upon the stage of the process, the nature and sensitivity of the surrounding environment, pollution prevention, mitigation and control techniques. With regards to the aquatic environment, the principal problems are linked to

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the presence of the offshore structures and then to waste streams of drilling fluids, cuttings, well treatment chemicals and produced waters (Neff, 1987; Neff et al., 1992; Osenberg et al., 1992; Olsgard & Gray, 1995; Commission protecting and conserving the North-East Atlantic [OSPAR], 1999, 2009; Peso-Aguiar et al., 2000; Barros et al., 2001; Pinder, 2001; Cicero et al., 2003, 2004, Trabucco et al., 2006a, 2006b; Terlizzi et al., 2008; Manoukian et al., 2010). In particular, produced water is water produced along with oil and gas and so it may include a) naturally-occurring water layer present in oil and gas reservoirs, b) water that has been injected into the reservoirs to help force the oil to the surface and c) any chemicals added during the production and treatment process. The positioning of a permanent structure and the discharge of produced water, may generally modify environmental quality, causing effective changes of the physical-chemical characteristics of water column and sediment and also perturbations on the marine living communities and on the sea-bottom geomorphology. These impacts have been described in details in Manfra & Maggi (n.d.).

Monitoring programs have been developed worldwide in all the areas characterized by an intense extraction and production activity (e.g. North Sea, Gulf of Mexico and Adriatic Sea), also taking into consideration national and international sea protection policies and legislations. Among major international conventions, it's worth mentioning the Barcelona Convention (Barcellona Convention, 1979), with its Offshore Protocol, which represents a regional regulatory framework for the Mediterranean basin, but it doesn't supply technical tools to manage with environmental control activities. Good framework for the environmental monitoring of effluents resulting from offshore activities is provided by the OSPAR Convention (OSPAR, 1992; Stagg, 1998). This was born in 1992 for the protection of the marine environment, issued and signed by the countries of the North-East Atlantic area and by the European Economic Community. It worked out the guidelines for monitoring the environmental impact of offshore oil and gas activities, which represent a strategy adoptable to assess the impact resulting from the different phases of offshore activities (exploration, production and decommissioning) (OSPAR, 1999). Besides, some environmental protection measures are reported in the guidelines on environmental management in oil and gas exploration and production based on the collected experience gained by UNEP and the oil industry (E&P Forum/UNEP, 1997). At national level, the environmental compatibility of offshore platform construction and their eventual impacts are evaluated by an Environmental Impact Assessment (EIA) and a monitoring plan, respectively. Concerning waste streams, the Ministry Decree 28th July 1994 requires a) the produced water chemical composition, b) the produced water discharge control, imposing a threshold value (40 mg/l) for total mineral oil content, c) a toxicity assessment for drilling fluids, cuttings and chemicals. Then, the Legislative Decree 152/2006 permits produced water discharge exclusively if an environmental monitoring plan verifies the absence of risks for waters and marine ecosystems (MD, 1994; LD, 1999; LD, 2006).

Given the current (international and national) environmental regulatory, the application of environmental monitoring tools is required to avoid, minimize and mitigate the potential impacts arising from exploration and production of oil and gas (Maggi et al., 2007). In this paper we describe a multidisciplinary monitoring approach, applied from the Italian Institute for Environmental Protection and Research (ISPRA) which since 2000 assesses potential impacts due to offshore platform presence and produced water discharge in the Adriatic Sea.

2. An integrated approach to project monitoring plans

Monitoring of chemical-physical characteristics of water and sediment, together with ecotoxicological assays, bioaccumulation analyses and macrozoobenthic soft-bottom community structure investigations, let to provide the necessary information for assessing the actual spatial and temporal perturbations occurring in the marine ecosystem. The Adriatic Platform Monitoring (called next "APM ") matches information on physical, chemical and biotic variables in order to give the best description of the environmental quality status (Directive 2000/60/EC; Chapman, 1990, 1996), so as:

1. to monitor selected chemical and physical variables of water column and sediment;
2. to evaluate effects on biota;
3. to identify spatial-temporal trend of the eventual alteration that could occurred;
4. assessing mitigation measures;
5. defining guidelines supporting regulations and decisions.

The investigations on water column, sediment and biota, with geophysical analysis on the sea bottom allow to study, thus highlighting, the natural features of the marine environment and then the changes due to presence of the offshore structures. This in order to realize an ecological vision towards an ecosystem approach in the protection of the Mediterranean, one of the innovative features proposed to reduce land-based pollution in the Mediterranean Sea (Barcelona Convention, 1979). In particular, the APM provide to measure several different parameters (Cianelli et al., 2011):

- physical-chemical (temperature, salinity, density, oxygen, nutrient, current speed and direction, etc.)
- chemical (contaminant concentrations)
- geological (sediment grain size)
- geomorphological (bottom batimetry and morphology)
- bioassays (e.g. biomarkers and toxicity tests)
- ecological (benthic community structure)

The comparison of these parameters with the background level (or reference conditions) can provide an indication on the potential levels of concern. The APM was born with the characteristic of "flexibility"; in fact, results and data obtained during the occurring of the monitoring activities could be useful to arrange and modify the whole sampling strategy.

All aspects (sampling, storage, laboratory analysis and data analysis) related to the above parameters are described below, distinguishing between platform and produced water discharge monitoring.

3. Sampling strategy

In order to investigate the impact of the platform structure, a *radial* sampling design can be performed for all matrices, allocating stations around the platform according to fixed distance from it rather than using a randomized placement (Fig1). This choice seemed to be more appropriate to highlight environmental changes when the point source of disturbance is known (Ellis & Schneider, 1997; Cicero et al., 2004).

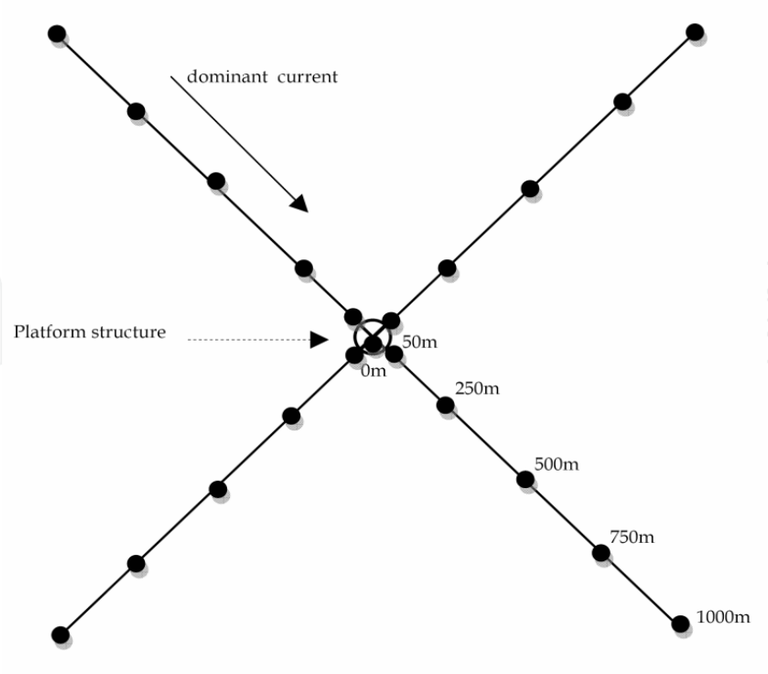


Fig. 1. Sampling strategy for platform monitoring.

To highlight the natural and anthropic features of the sea bed and provide detailed sea floor maps, geophysical investigations can be performed on a square shape area surrounding the platform (wide about 4 km2) by means of Multibeam Echosounder and Side Scan Sonar. The survey area can be completely covered by parallel navigation lines; transects have to ensure overlapping coverage.

With regards to the produced water impact, the water samples can be collected on a transect along the actual current from the point of discharge, instead sediment can be sampled on a transect oriented in the direction of the dominant current (Fig. 2 and 3).

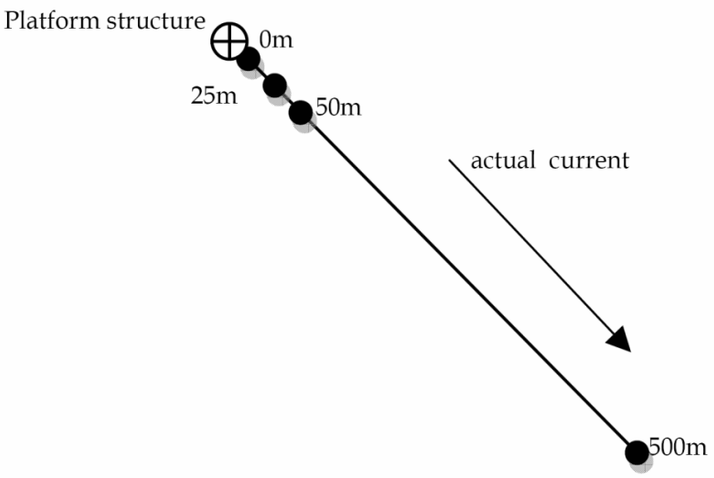


Fig. 2. Water sampling strategy for produced water monitoring.

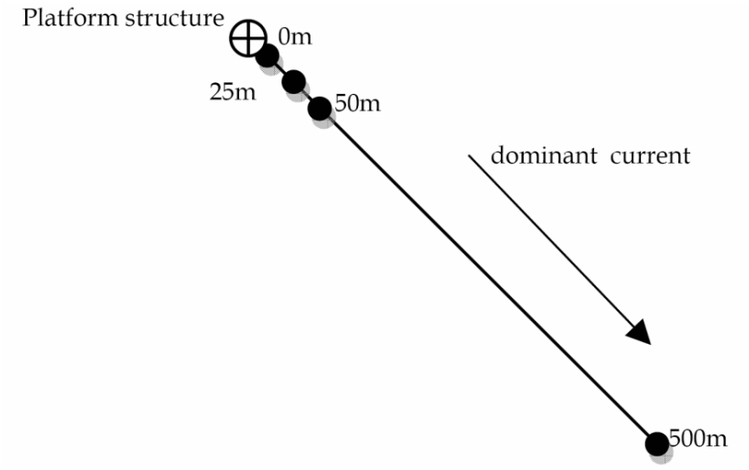


Fig. 3. Sediment sampling strategy for produced water monitoring.

Furthermore, in order to obtain an exhaustive rigorous environmental framework, all matrices should be sampled also in a control area, presenting the same geo-morphological characteristics of the investigated area, but not directly influenced by the off-shore activities.

Biological elements (e.g. mussels used for the bioaccumulation and biomarker analyses) can be taken on different depths, considering the level of the discharge, on the nearest leg to the discharged pipe along the main current (OSPAR, 1999) (Fig. 4).

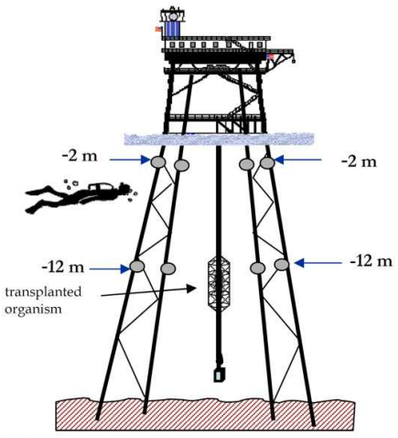


Fig. 4. Mussel sampling strategy for produced water monitoring.

Monitoring frequency can comprise one or two sampling campaigns before the installation of the platform or the beginning of the produced water discharge; two sampling cruises, during the first year of the platform life, or after the beginning of the produced water discharge, aimed at representing condition of maximum and minimum mixing of the water column. Then one survey, scheduled for each following year of activity, to monitor both types of impacts.

In particular, geophysical investigation have to be performed both before the installation of the platform and during the first year of the platform life. Then, these investigations can be carried out every two or three years.

The acquisition of meaningful data demands correct sampling and storage procedures. These may be quite diverse for different parameters in the same matrices or for the equal parameters in different matrices. In general separate samples must be collected for physical-chemical and biological analyses because the sampling and preservation techniques are quite different. Usually the shorter the time interval between sampling and analysis, the more accurate the analysis will be.

4. Matrix sampling

4.1 Water

Some physic-chemical properties can be measured in the water without sampling. Conductance, Temperature, and Density, generally, are monitored by means of a hydrological CTD profiles acquired using the multiparametric probe; the probe can also be equipped with additional sensors for fluorescence, transmittance, dissolved oxygen and pH.

In order to determine chemical compound concentrations, total suspended matter and toxicity, water samples can be collected by Niskin bottles. Consequently, some analyses can require the filtration treatment (e.g. nutrients or metal analysis), while others can be carried out on whole sample (e.g. PAH or TBT analysis).

The measure of water velocity during sampling cruises is fundamental to identify the directions of transect along the actual current from the point of discharge. The Acoustic Doppler Current Profile (ADCP) is, today, the instrument commonly used to collect the profiles of water velocity. It is based on a principle of sound waves called the Doppler effect and is useful to measure how fast water is moving across an entire water column.

4.2 Sediment

Bottom sediment deposits can be sampled by grab samplers or box corer, which are designed to recover sediment material from the top few centimeters of the seabed (IAEA, 2003). One of the most commonly grab samplers used for surface sediments is the Van Veen, which is capable of collecting sediment material up to about 20 cm in depth. The sampler has large access doors for convenient removal of the upper sample layers (USEPA, 1997). The box corer uses an open-ended rectangular box, found in various sizes. It is designed for a minimum of disturbance of the sediment surface by bow wave effects, which is important for quantitative investigations (IAEA, 2003; USEPA, 1997). Through box corer sediments may be sampled at different level (e.g. 0-3 and 8-10).

The samples for chemical, physical and ecotoxicological analyses can be carried out by Van Veen grab or box corer, depending on the number of sediment levels to collect. In any case, sampling device has to permit to collect a representative, undisturbed samples. The material, after homogenization, has to be stored in suitable vessels and at adequate temperature depending on different analyses.

The quantitative samples of benthic soft-bottom macrofauna can be performed on all stations identified for sediment analysis, using a grab or a box corer. At each platform and at each station, the number of replicas to be made is established to be sure to take representative volume (Picard, 1965). The material collected can be sieved on board with a mesh of 0.5 mm or 1 mm, then fixed in appropriate preservative.

4.3 Biota

Bioaccumulation and biomarker analyses may be carried out on organisms living in the surround of the offshore structure. Mussels (e.g. *Mytilus galloprovincialis*) can be collected on platform legs; otherwise native mussels, collected from a reference site and transplanted for 4-6 weeks in the investigated platform area, can be used. These organisms may be sampled at two different depths (e.g. superficial and 12 m, respectively) and, for each depth, different samples, constituted by the whole tissues, prepared and stored at -20°C, until processed for accumulation analysis. Specifically for biomarker analysis, after recovery, mussel tissues have to be frozen in liquid nitrogen and maintained at -80°C until biochemical and histological parameter analyses; haemolymph have to be withdrawn from adductor muscle and immediately analysed for lysosomal membrane stability and DNA damages (Gorbi et al., 2008).

4.4 Produced water

Produced water must be sampled directly onboard platform, after oil separation system and stored in glass or teflon vessels for different analysis (chemical analysis, toxicity tests and physical characterization).

5. Analysis

5.1 Physical-chemical analysis

The principal parameters to be monitored are those providing general physical-chemical characteristics of the water column (Fig. 5). Temperature, transparency and turbulence are, certainly, among main physical parameters affecting aquatic life: for example, temperature is able to regulate the rate of biological processes, transparency to determine the growth of algae and turbulence is an important factor in mixing and transport of nutrients. Nevertheless the salinity of water and the dissolved oxygen play a key role in determining the kinds of life forms present, while conductance reflects the total concentration of dissolved ionic material.

In addition, if platform discharges produced water it may be important to investigate others parameters in environmental matrices. These components must be chosen in light of the produced water composition (e.g. metals, total mineral oils, phenols, aromatic and aliphatic hydrocarbons) (Fig. 5). In fact, produced water is characterized by organic (aliphatic hydrocarbons, aromatic hydrocarbons, etc.) and inorganic components (metals, nutrients, etc.) and then, in some cases, by chemicals (anticorrosive agents, biocides, etc.) added to the water after its removal from the reservoir. The specific chemical composition of the produced water depends on the geological reservoir, the field operations and the exploitation level (Cianelli et al., 2011). Besides, the knowledge of the speed and direction of current (Fig. 5) near the produced water discharge point allows to collect water samples along the true direction of the produced water plume. For this reason, the profile collection of water velocity during sampling cruises is important to determine the directions of transect along the actual current from the point of discharge.

5.2 Chemical analysis

Chemical analysis is known to allow to identify and quantify different single compounds, potentially responsible for the environmental contamination; in this case it is possible to

obtain a measure of pollution. The presence of offshore platforms may cause chemical alteration of aquatic ecosystem, especially if the platform discharges produced water. The corrosion protection systems of the installations (sacrificial anodes) release amounts of heavy metals in the form of ions; through absorption on particulate matter, these ions can reach the sediment or bioaccumulate in organisms living on and/or nearby the submerged structures. Moreover the produced water discharge can have effects on marine environment as a consequence of its chemical composition. In addition, it should be considered that around the platform, environmental effects are also determined by the release of organotin compounds (present in the paint used to protect the underwater components from biofouling), although today these paints are prohibited. Due to their physical and biological characteristics, sediment and biota are be able to accumulate various classes of chemicals, such as trace metals, polycyclic aromatic hydrocarbons (PAHs), aliphatic hydrocarbons, halogenated organic compounds, phosphate organic pesticides, etc.

So, the chemical parameters investigated in water, sediment and biota should be selected taking into account all kind of release by offshore structure or activities linked to the presence of platform. Therefore, the analytical determinations cover inorganic compounds (e.g. metals, sulfurs and oxides) and organic compounds (hydrocarbons with low and high molecular weight, organometallic compounds and organochlorinated compounds) (Fig. 5).

5.3 Sedimentological analysis

Grain size is the most fundamental physical property of sediment. Sediments consisting of grains of different size and mainly categorized as sand, silt or clay; they are classified according to the size and size distribution of their grains in the categories described in the Wentworth classification. The information on sediment grain size allows to study trends in surface processes related to the dynamic conditions of transportation and deposition. Moreover, sediments are the ultimate sink for contaminants in the marine environment. The relationships between physical properties and chemical characterization of sediment are a basic point of environmental impact assessment in order to determine whether or not contamination related to offshore activities has occurred. Grain size distributions (Fig. 5) in sediments depend on the distance from the platform, current speeds and water depths. In some platforms the sand content of sediments at the near-field stations was increased above background sediment by 35–60%. Also fragmented carbonate skeletal material was visible, derived from organisms encrusting the underwater parts of the platform.

5.4 Geomorphological analysis

Geomorphological investigation (Fig.5) performed by geophysical devices (e.g. Side Scan Sonar Multibeam echosounder) allow to study the morphological characteristics of the sea bottom, thus highlighting the natural features and the presence of anthropic offshore structures. This kind of investigation represents an essential tool for the effective management of the marine environment and to study accurately the impact of man activities on the seabed (Kenny et al., 2003, Collier & Brown, 2005). The acoustic investigations (Fig. 5) permit to monitor sea-bottom geomorphological modification, can also allow to map the alterations and supply the background information necessary for a correct planning of sampling activities and represent the basis for a long-term monitoring study. These data, together with the results of the multidisciplinary approach, provide more

information on the potential environmental impact due to the presence of offshore platforms (Virno et al., 2004). In fact, the interference of the structure with the seabed is confined to a limited area on which you could detect changes in the morphology of the seabed due to changes in current fields generated by stakes driven into the seabed.

5.5 Biological analysis

A series of biological analysis tools may be employed to monitor environmental effects when a platform is installed and/or a produced water is discharged into the sea (Manfra & Maggi, n.d). Ecotoxicological analyses (biomarkers and toxicity tests) may be carried out to study produced water and environmental matrices (Fig. 5). Some aspects related to these investigations are briefly described.

5.5.1 Biomarkers

Alterations at the molecular and cellular levels (biomarkers) can provide a sensitive indication of early changes, which often represent the first warning signals of environmental disturbance, even in the absence of acutely toxic responses. There are some studies on biomarkers related to the monitoring protocol of Adriatic gas platforms (e.g. Gorbi et al. 2007, 2008; Fattorini et al., 2008). In these papers some analyses are reported as main biomarkers for monitoring impacts of offshore platforms in the Adriatic Sea. Induction of metallothioneins, peroxisomal proliferation and activity of acetylcholinesterase may be measured as markers for specific classes of chemicals. Oxyradical metabolism and appearance of oxidative-mediated toxicity reveal a more general onset of cellular disturbance. In addition to individual antioxidants (superoxide dismutase, catalase, glutathione S-transferases, glutathione reductase, Se-dependent and Se-independent glutathione peroxidases, and levels of total glutathione), the total oxyradical scavenging capacity (TOSC) allow a quantification of the overall capability to neutralize specific forms of intracellular reactive oxygen species (ROS; i.e. peroxyl and hydroxyl radicals). Cellular damages are evaluated as lysosomal destabilization (membrane stability, accumulation of lipofuscin and neutral lipids), lipid peroxidation products (malondialdehyde) and DNA integrity (strand breaks and micronuclei); the air survival test is finally applied to evaluate the overall physiological condition of mussels. Biomarker analyses have to carried out according to standardized procedures. Multivariate statistical analyses (principal component analysis, PCA) of biomarkers and accumulation data may be applied to discriminate between different sites and/or different sampling period.

5.5.2 Toxicity tests

Toxicity tests may be carried out on species directly exposed to produced water or to environmental matrices, collected in offshore platform area. APM proposes toxicity tests both for monitoring of effects connected to platform presence and to produced water discharge. In the first case, it may be better exposure to sediments (whole or aqueous phases as pore water or elutriate) while in the second case seawaters and produced waters, not only sediments, may give useful information on toxic effects. The toxicity assessment requires that almost three species, belonging to different trophic levels, are employed for toxicity testing. In APM, some species have to be planned in time: *Vibrio fischeri* (Bacteria), *Dunaliella tetiolecta* (Algae), *Brachionus plicatilis* (Rotifera), *Artemia franciscana* and *Tigriopus fulvus*

(Crustacea), *Paracentrotus lividus* (Echinodermata) and *Dicentrarchus labrax* (Osteichthyes). It is very important that the test battery permits to observe both sub-lethal and lethal "endpoints" (type of effect that can be measured in a toxicological test). In APM the following endpoints are studied: bacterial bioluminescence, algal growth, fertilization and development with echinodermata, and finally mortality with rotifera, crustacea and osteichthyes. Each bioassay has to be carried out according to standardized protocols. Statistical programs (e.g. Trimmed Spearman-Karber method and Probit analysis) allow us to analyze the relationship between a stimulus (dose) and a response (such as death or sub-lethal effects), calculating e.g. the concentration that induces the 50% effect (EC_{50}) or no observed effect concentration (NOEC). These values are interpreted according to toxicity scales to give a toxicity judgment (e.g. no toxic, low toxic, high toxic etc.).

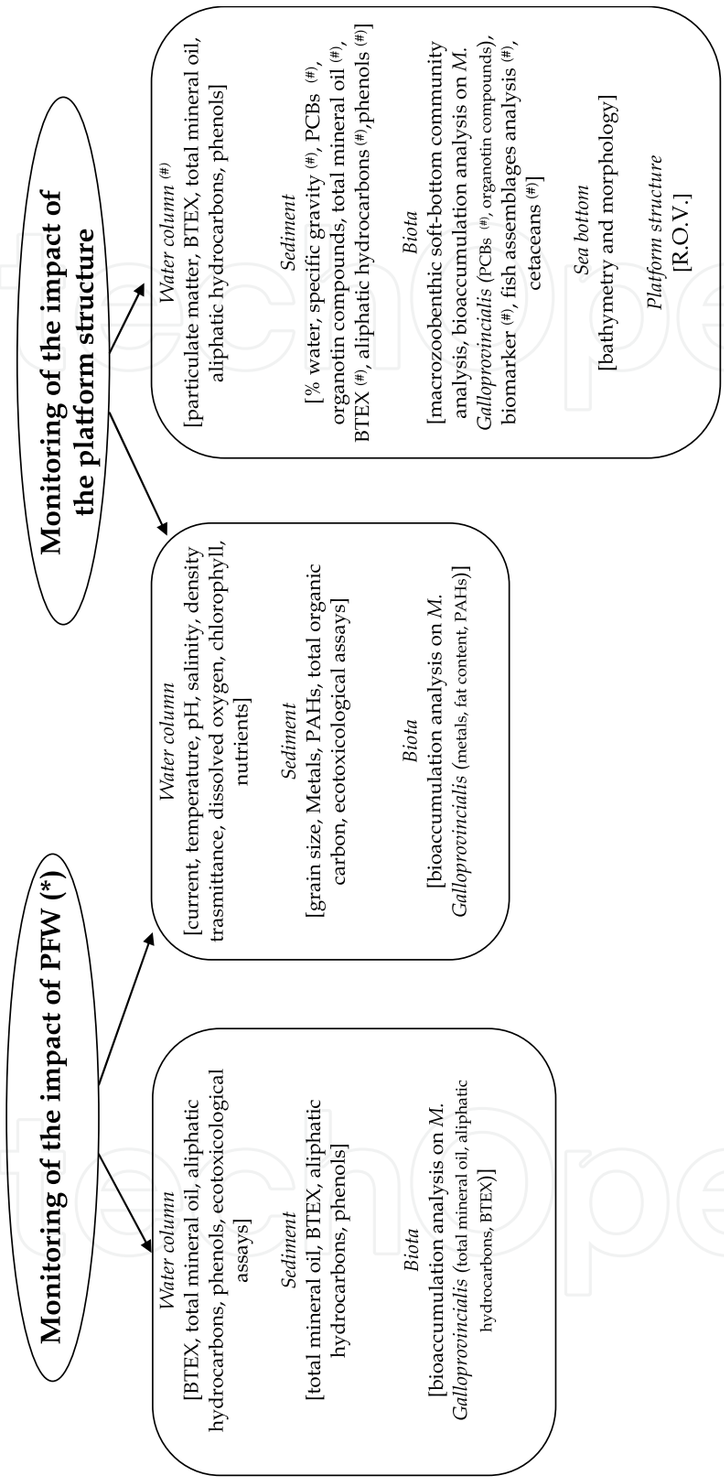
5.6 Ecological analysis: Macrozoobenthic community structure

Offshore activities can induce changes in the characteristics of sediment near the offshore structures. The extent to which the biota is affected by these types of perturbations depends on complex interactions between environmental characteristics of the site and the characteristics of the platform. Several studies have proved that the presence and the activity of off-shore platforms might have some sort of impact on biological communities inhabiting the surrounding seabed.

In general, the artificial structures placed in the sea create a discontinuity, and provide a hard substrate that alters the initial state, providing the conditions for the establishment of new ecosystems (e.g. Trabucco et al., 2008; Terlizzi et al., 2008). In general, the presence of the structures can cause perturbations on the macrofauna assemblage structure more understandable and clear than those raised by the produced water discharge. In particular the variations in sediment physical features (sediment grain-size, sedimentation rates) might determine qualitative and quantitative changes in the structure of soft-bottom benthic communities living in the area around the installations (Davis et al., 1982; Frascari et al., 1991, 1992; Kingston, 1992; Olsgard & Gray, 1995; Barros et al., 2001; Spagnolo et al., 2002; Hernández Arana, 2005; Fontana et al., 2008; Terlizzi et al., 2008; Trabucco et al., 2006a, 2008; Manoukian et al., 2010). In order to evaluate possible change in the soft-bottom community structure due to the presence of the offshore platform, qualitative and quantitative analysis should be performed and ecological studies carried out (Fig. 5). The systematic recognition of organisms should be made at the species level at least for the most representative groups (Polychaeta, Mollusca, Crustacea, Echinodermata). The number of individuals can be count for each species. The data thus obtained may be used for the calculation of the following biological indices:

- Total Abundance (N);
- Total species richness (S);
- Index of Shannon-Weaver species diversity (H ', Shannon & Weaver, 1949).
- Index of evenness (J', Pielou, 1974).

The temporal and spatial evolution of the benthic community may also be evaluated through the application of multivariate analysis (nMDS, PCO, CA, CCA, etc..) and appropriate indices to assess the stress level of the communities found (eg index M-AMBI – Multivariate AZTI Biotic Index, Muxika et al., 2007).



#optional investigation

(*) PFW characterization: BTEX, total mineral oil, aliphatic hydrocarbons, PAHs, phenols, metals, total nitrogen, sulphurs, sulphorate compounds, suspended matter, total organic carbon, ecotoxicological assays.

Fig. 5. Parameters to analyze for platform and produced water monitoring.

6. Conclusions

The APM is the result of more than ten years of experience, gained by ISPRA in the drawing up of monitoring projects to assess potential environmental impacts linked to offshore platforms, then the performance of the analytical methodologies and the carrying on the monitoring activities.

This approach has proved to be the best, based on a long-term multidisciplinary studies, allowing us to collect integrated data. In the framework of an ecosystem approach as recommended by the latest most innovative legislation in the field of environmental protection, APM provides environmental guidelines particularly useful for the public administration and decision makers in the safeguard of the marine ecosystem.

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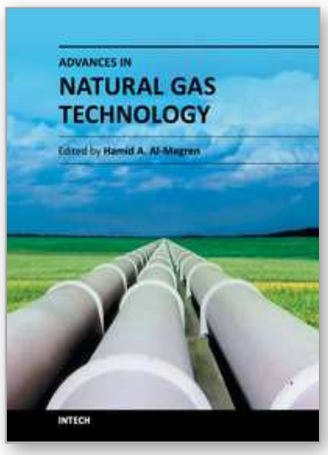
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Natural gas is a vital component of the world's supply of energy and an important source of many bulk chemicals and speciality chemicals. It is one of the cleanest, safest, and most useful of all energy sources, and helps to meet the world's rising demand for cleaner energy into the future. However, exploring, producing and bringing gas to the user or converting gas into desired chemicals is a systematical engineering project, and every step requires thorough understanding of gas and the surrounding environment. Any advances in the process link could make a step change in gas industry. There have been increasing efforts in gas industry in recent years. With state-of-the-art contributions by leading experts in the field, this book addressed the technology advances in natural gas industry.

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