DPSIR Model

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Contributor: Claudia Labianca , Sabino De Gisi , Francesco Todaro , Michele Notarnicola

The Driving force – Pressure – Status – Impact - Response (DPSIR) framework has been widely used in literature to analyse environmental problems. The DPSIR facilitates the investigation of all the possible cause-effect relationships and to plan appropriate technological responses. This contribution shows an application of the DPSIR to the remediation of contaminated sites, exploiting the case study of the Mar Piccolo di Taranto (Southern Italy). Methodologically, several references were considered, whose information was classified according to the logical scheme of the DPSIR. Among the results it is interesting to observe how, due to its natural hydrogeological network conformation, the Mar Piccolo represents the final receptor of pollutants from industrial, anthropic and agricultural activities. The mobility of contaminants from sediments to the water column and the subsequent bioaccumulation into marine organisms pose a serious threat of unacceptable magnitude to human safety. Responses may concern restriction of area use, control of pollution fonts as well as the implementation of suitable contaminated marine sediment remediation measures. It is noted that the preliminary organization of the existing data can lead to the development of a DPSIR-based Environmental Decision Support System (EDSS).

Environmental pollution DPSIR Remediation technologies

1. Introduction

Industrialization and economic development have led to population growth and rapid urbanization in Europe over the years. On the other hand, this also produced environmental and health problems, due to the deterioration of the environment mainly because of industrial and anthropic activities. Environmental matrices can be contaminated by pathogenic microorganisms (E. coli, coliform and Salmonella), heavy metals, and organic compounds (hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), aromatic solvents, polychlorinated biphenyls (PCBs)), and other [1]. Several coastal-marine sites in Europe coexist with large industrial and port settlements that have compromised, over time, the entire marine ecosystem. Some of these areas have been included by the National Programme for Environmental Remediation and Recovery in the contaminated Site of National Interest (SNI) list (Italian Ministerial Decree 468/2001) and recovery and remediation activities are required [2].

The main anthropic impacts, such as urban wastewater discharge, industrial operations, oil leakages, fertilizer and pesticide residues, have compromised the whole ecosystems worldwide generating health problems to human beings. Scientific research and decisions are generally limited to a particular scientific field or economic concern. El Hattab *et al.* [3] adopted a Sustainable Urban Drainage Systems (SuDS) for urban drainage to cope with population growth and urban sprawl. Bovenberg and Smulders [4] created a model on pollution-augmenting technological change. Neris *et al.* [5] improved a computational code for human health risk assessment HHRISK. Ash and Fetter

[6] investigated the correlations between demographic trend and pollution in cities through the EPA's Risk-Screening Environmental Indicators Model. Several models have tried to describe and analyze the environmental compartments, but cause effect relations have been rarely discussed. DPSIR (Driving force–Pressure–State–Impact–Response) model [7][8] is a causal framework for the description of the interactions between society and the environment. In the case of an extremely compromised site, all the various cause-effect relationships for the development of the DPSIR framework have to be carefully analyzed. However, sometimes environmental changes can hardly be attributed to a single cause [9]. In literature, many researches showed the application of the DPSIR model to understand and plan responses for complex polluted sites. Lofrano *et al.* [10] evaluated the environmental situation of the Sarno river, one of the most polluted rivers in Europe, in the last 60 years, considering main socio-economic and environmental issues. Caeiro *et al.* [11] adopted the DPSIR model to assess social and economic pressures of the Sado estuary. Huang *et al.* [12] incorporated GHG-related indicators into a DPSIR model and evaluated their relationships. Lin *et al.* [13] analyzed temporal changes in regional coastal wetland ecosystem in Xiamen (China) by using a DPSIR model, collecting data from 1950 to 2005. By applying the DPSIR framework, this research aims at assessing the factors that contribute to the degradation of one of the most polluted marine basin in Europe. This review of information from scientific papers, public datasets, and technical reports aims at highlighting all industrial, socio-economic and environmental issues that made the Mar Piccolo of Taranto a site of extreme environmental crisis.

2. DPSIR Framework

DPSIR model is based on a chain of causal links starting from “driving forces” (economic, environmental and human activities) through “pressures” (emissions, waste, discharges etc.) leading to “states” (physical, chemical and biological situation of biota and environment) and “impacts” on targets such as ecosystems and human health, eventually giving political or technical “responses”.

All various cause-effect relationships have to be carefully analyzed when developing a DPSIR framework for an extremely complex case study.

As a first step, all the possible data and information about the five elements of the DPSIR chain need to be identified and collected, describing the relationships between the origins and consequences of environmental problems. In order to understand their dynamics, it is useful to focus on the links between the DPSIR elements. Responses can modify any element of the chain: driving forces through structural interventions, pressures through technological and prescriptive actions, states through remedial actions and impacts through the economic compensation for the damage. Figure 1 shows a schematic representation of the DPSIR framework applied to the case study described in section 3.

Figure 1. DPSIR framework.

3. Case study description

Mar Piccolo of Taranto is an inner marine basin, part of the Ionian Se in the South of Italy, and it is part of the Gulf of Taranto together with the Mar Grande (Figure 2).

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Figure 2. Localization of industrial activities near the Mar Piccolo of Taranto.

Its total surface area reaches about 21 km^2. It is structured in two inlets, called “First Seno” and “Second Seno”, 15 m deep and 10 m deep, respectively.

The Mar Piccolo is connected to the Mar Grande through the Navigable channel and the Porta di Napoli channel [14]. In addition, the Mar Piccolo is characterized by the presence of local channels, rivers and submarine water springs called “citri”.

In the last half century, severe industrial impacts affected this basin, making the Mar Piccolo one of the most polluted environmental areas in Europe.

4. Results and discussion

Figure 3 shows the DPSIR framework applied to the case study of the Mar Piccolo of Taranto.

Figure 3. DPSIR framework of the study.

The main **driving force** identified and affecting the site is the population growth over the years. Taranto is the most populous city in the Mar Piccolo area with 195,279 inhabitants in 2019. From 1861 to 1921 the inhabitants' number in Taranto grew from 24,528 to 97,853 units [15]. This was due especially to the development of the Military Arsenal and shipyards. In addition, in 1965 the steel factory “Italsider” (today called Ex-Ilva or ArcelorMittal) was inaugurated. It became one of the most productive steel centers in Europe, bringing the city to a growth of 17%

with a concurrent per capita income increasing of 274% from 1961 to 1971 [15]. Furthermore, through the map of land use (2011), it was possible to identify all cultivated areas falling into the Mar Piccolo catchment area. ISTAT data provided information about fertilizers and pesticides employed in agriculture in this area [16]. Connecting these two information and assuming run-off as one of the main impacts to Mar Piccolo, an amount of pollutants and nutrients coming from agricultural activities fall into the Mar Piccolo. In addition, among the various industrial activities located in the Taranto area, the major one is the Ex-Ilva steel plant in terms of emissions quantity and extension of working areas [17].

The industrial impact can be also associated to the presence of the Italian Navy shipyard with its dry docks on the south bay of the first inlet, to a petroleum refinery station and to a concrete factory on the west side (Figure 2) [18]. Additional relevant anthropic activities can be identified: intensive mussel farm production (with 30,000 tons/y), fishing-boat activity in both bays, nine sewage discharge pipes, and small rivers draining nutrients into the basin [19]. Legal and illegal dump sites falling into the Mar Piccolo catchment area can represent a possible source of contamination due to leachate moving into the subsoil and reaching groundwater.

The main **pressures** are represented by the nutrients and contaminants produced by the above-mentioned driving forces, and reaching the Mar Piccolo basin, through surficial/deep groundwater, run-off, rivers and citri. The basin is subjected to both private (Military Arsenal) and public sewage discharges. The Aiedda channel releases the wastewater discharges of eight municipalities into the second bay [14]. An estimated total amount of 100,000 equivalent inhabitants is expected to discharge into the Mar Piccolo with about 18,272 m^3/d, of which about the 85% into the second bay, with an amount of organic matter equal to 6.7 t/d of BOD_5 [20]. The nitrogen and phosphorus daily release into the basin has been estimated in 17.2 t/d and 0.3 t/d, respectively [21]. Consequently, the marine water quality may be affected by the infiltration of contaminants due to non-controlled sewage discharges, industrial waste abandoned, use of chemical products in agriculture, but also the karstic nature of soil and subsoil. However, a sampling campaign of the groundwater carried out by ARPA Puglia [22] showed acceptable values for both metals and PCBs concentrations.

Another aspect related to the industrial activities is the air quality. A study on air pollution conducted by Gariazzo *et al.* [17] revealed the extension of the impact of emitted pollutants (SO_2, NO_x, CO and primary PM10) to a large area of the local territory, including the First Inlet of Mar Piccolo. However, a direct correlation between air pollutants and fall out into Mar Piccolo water is still not demonstrated.

For what concerns the "**states**", several characterizations of marine sediments have been carried out in the last decades. From 2005 to 2009, the Italian institute for the environmental protection and research (ISPRA) characterized through a sampling campaign both inlets of the Mar Piccolo for a total number of 1517 of samples [22]. The sediment environmental quality state resulted complex and characterized by organic and inorganic pollutants in high concentrations in all the First Bay and some part of the Second one. A spread contamination by heavy metals was found on all the surficial layer (0-50 cm) with some hot spots (i.e. Military Arsenal and Citro Citrello). Mercury (Hg) is the heavy metal which showed the highest concentrations in most samples. Organic compounds are present less in terms of area and amount. Total hydrocarbons were found especially in the mussel farming area in the first layer of the first inlet.

For what concern eco-toxicological tests, Costa *et al.* [23] and Todaro *et al*. [24] exposed organisms from different trophic levels to elutriate and whole contaminated sediment. Despite the high levels of sediment contamination, unexpectedly low toxic effects were observed in the biological compartment for both studies.

Narracci *et al*. [25] evaluated the toxicity level in the Mar Piccolo by Microtox® system, vibrios, total, and fecal coliform densities. Results showed an elevated level of toxicity in sediments, while the interstitial water showed biostimulatory phenomenon. It is noteworthy that vibrios and coliforms were more abundant in water than in sediment samples. However, a 2-year monitoring plan of the seabed allowed to produce a biocenotic map by the Italian CONISMA [22], which identified many species among which several were protected species according to the SPA/BIO protocol (Barcelona convection), such as *Tethya citrina, Geodia cydonium, Pinna nobilis, Maja squinado, Paracentrotus lividus, Epinephelus marginatus, Aphanius fasciatus, Signatus sp., Hippocampus hippocampus H. guttulatus* and the marine turtle *Caretta Caretta*.

In July 2013, a Digital Terrain Model (DTM) of Mar Piccolo seabed showed three anomalies in the first inlet, mainly related to anthropic excavations and/or a previous shipwreck [22].

Moreover, from 2015 to 2016 all quantities and typologies of waste in the First Bay were identified, analyzed and collected with the technical support of the Coast Guard and Sogesid [26], as part of the convention with the Special Commissioner of the Italian government for urgent measures of reclamation, environmental improvements and redevelopment of Taranto area. Results showed that the most common and abundant litters were abandoned cars, tires, waste related to mussel and fishing farming, and urban waste.

A compromised state of environmental matrices may lead to serious **impacts** to biota and the environment. It is extremely important to understand the mobility of pollutants in environmental media. Di Leo *et al.* [27] investigated the effects of sediment resuspension on PCB fate and transport. After the resuspension event, results showed that PCBs in sediments increased of the 15%, instead, in the dissolved phase it increased from 0.82 to 4.82 ng/l and in the particulate phase from 0.22 to 202.21 ng/l. Additionally, after resuspension, the particulate phase was found enriched in heavy congeners.

The Italian research center of Taranto investigated the role of granulometry on the bioavailability and mobility of pollutants [22]. They considered two sediment-sampling stations in the Arsenal area. The 43% and 52% of PCBs was detected in the fraction <63 µm, respectively in Station 1 and 2. It is evident that the high percentage of fine and extremely fine fractions in sediments can lead to a higher possibility to connect with pollutants [28].

Furthermore, for what concerns human health, Cavallo and Stabili [29] identified the degree of pathogenic microbial pollution, vibrios, fecal coliforms and Escherichia coli densities in *Mytilus galloprovincialis* species collected in 30 sampling sites in the Mar Piccolo. Many Vibrio species such as *Vibrio alginolyticus, V. mediterranei,* *V. parahaemolyticus, V. diazotrophicus, V. nereis, and V. splendidus* were present both in water and in mussel samples; *V. vulnificus, V. cincinnatiensis, V. orientalis, V. anguillarum, V. marinus, V. hollisae* were found in mussels. This shows the risks related to pathogenic vibrio species potential transmission of infection to man and other marine organisms.

Bioaccumulation data showed that PCDD/Fs and DL-PCBs contamination in mussels was higher in the First Bay, with DL-PCBs as dominant chemicals in all samples, followed by PCDFs and PCDDs [30][31]. Consequently, the exceeding limits of the EC Regulation in the first inlet, involved the prohibition of mussel commercialization from this basin [30]. For what concerns bioaccumulation of metals, Cardellicchio et al. [32] analyzed samples of Mytilus galloprovincialis, determining by atomic absorption spectrophotometry (AAS) the concentrations of metals Cd, Cu, Pb, Zn, Fe and As in the whole soft tissue of mussels. Results showed that the metal content was within the permissible range for safe consumption by humans.

All the above remarks raise several questions about the importance of food safety and the relation between diet and human health. Giandomenico *et al.* [33] investigated public health risks associated with consuming seafood harvested from Mar Piccolo. In reference to the permissible limits set by EC Regulations, results showed that Cd and Pb levels were over the limit in the *H. trunculus* and in the fish *T. trachurus,* respectively. Also PCBs were found over the legal limit in all sampled species with the exception of *M. galloprovincialis* in one station. In particular, in the fish *T. trachurus* the concentration of six target PCBs was five times higher than the EC limit.

Another worldwide main issue caused by anthropogenic inputs is eutrophication. This happens especially to areas with limited water exchange [34], salt marshes and lagoons [35], such as the Mar Piccolo of Taranto. A comparison with a 20-year dataset revealed a drastic change in nutrient concentrations after the year 2000. Nutrient inputs were reduced (up to −90% in the first inlet), validating the functionality of the treatment plants discharging into Mar Piccolo and varying the biogeochemical characteristics of Mar Piccolo from relatively eutrophic to moderately oligotrophic [36].

Furthermore, phytoplankton dynamics were investigated by Caroppo *et al.* [37] with particular reference to harmful algal blooms (HABs). They distinguished about 25 harmful species over the years, such as the potentially domoic acid producers *Pseudo-nitzschia cf. galaxiae* and *Pseudo-nitzschia cf. multistriata*.

Lastly, the dewatering pump belonging to the steel factory represents another anthropic impact for the first inlet. It was used for cooling down blast furnace circuits and it withdrew about 35 m^3/s of Mar Piccolo water in the last thirty years [38]. Such water usage has modified the local circulation in the First Bay [14], causing a higher salinity level, due to the input of water from Mar Grande, and consequently a different environment for the biological species [1].

The sections D-P-S-I are essential to completely understand the critical framework of the Mar Piccolo area, laying the groundwork for proper measures to take.

The main first actions to take for a site with an environmental and sanitary crisis consist in structural and normative-based **responses**. Several are the structural responses given about Mar Piccolo over the years but many more are still under study and testing, such as the on-site and technological actions.

With the national Law n. 349 of 08/07/1986, all Taranto territorial and marine parts were declared “area of high risk of environmental crisis”. The Decree of 10/01/2000 defined the perimeter of the Contaminated Site of National Interest (SNI) of Taranto where Mar Piccolo is included. Subsequently, with the Decree n. 468 of 18/09/2001, the Italian Ministry of the Environment approved the “National Program of remediation and environmental restoration of contaminated sites of national interest” describing priority interventions in terms of economic resources and definition of a public tender for the implementation of the measures.

As above said, after a monitoring plan started in 2011, the ordinance n. 1989 of 22/07/2011 declared the prohibition of harvesting, handling and commercialize mussels in the First Inlet. Another important action was the protocol of understanding signed among the Italian Ministry of the Environment and the Protection of Territory and Sea, the Italian Ministry of Infrastructures and Transports, the Italian Ministry of Economic Development, the Italian Ministry for the Territorial cohesion, the Apulia Region, the Taranto province, Taranto Municipality and the Special Commissioner of the Port of Taranto on the 26/07/2012.

As a second step, a technological action can be planned in order to prevent, remove, abate, or contain the presence or effects of any hazardous matter in the environment. Extensive research has been conducted on remediation technologies over the years. Contaminated sediment management strategies may consider *in situ* and *ex situ* techniques. *In situ* remediation alternatives normally involve Monitored Natural Recovery (MNR) [39] and *in situ* containment and treatment, such as passive/active capping with sand or reactive amendments such as activated carbon, organoclay, zero-valent iron [40][41]. *Ex situ* remediation options can include dredging and subsequent Stabilization/Solidification (S/S) [42], sediment washing [43], thermal desorption [44], vitrification [45], and/or their combination. However, the definition of a remediation project requires deep knowledge of the study area. In this respect, the study of the contaminated matrices is of great importance, especially for critically complex sites.

Within Life4MarPiccolo project [46], the institute for Coastal Marine Environment of Taranto studied and proposed an implementation of a pilot wastewater treatment plant using the technology of microfiltration. The project aims at recovering a marine area of 3000 sqm, using a pilot system based on the use of membrane technology, internationally defined as Best Available Technologies (BAT).

The key to develop robust new cause-effect relationships is in the accurate initial data setup. However, the heterogeneity of the data with the acquisition in different temporal scales are an intrinsic weakness of the DPSIR approach, as stressed by Lewison *et al*. [47]. More details are available at Labianca *et al*. [48].

5. Conclusions

The contribution underlined the complex situation of the Mar Piccolo of Taranto in South of Italy due to long-lasting anthropic impacts. Existing data and knowledge on the Mar Piccolo were synthesized in order to connect the major causes and effects affecting the site in the last half century.Conclusions of this research are as follows: (i) The Mar Piccolo is a strongly anthropized environment as, due to its natural hydrogeological conformation, it is the final receptor of pollutants coming from all industrial and agricultural activities, wastewater treatment plants and other anthropic activities; (ii) Mussel farming activity represents a productive economic activity for Taranto but involving, unfortunately, strong impacts to the ecosystem; (iii) The mobility of contaminants in the water column showed the potential serious risk related to the bioaccumulation of organisms from different trophic levels, and subsequently to human safety.

Following the DPSIR framework, used as model of the analysis, it was possible to gauge the responses to put into place. Some of the responses in terms of plans, programs and actions already taken by the Apulia Region and the Special Commissioner of the Italian Government were reported. Other technological responses were suggested. The identification, control and regulation of the driving forces assumes a fundamental role to ensure the remediation lasting over time.

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