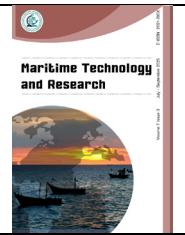




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Research Article

First Algerian artificial reef O.R.1 in Oran coastline: Construction, immersion and scientific monitoring

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Article information	Abstract
Received: September 15, 2024 Revision: January 7, 2025 Accepted: January 11, 2025	The first Algerian implantation of artificial reefs in Oran coastline was carried out on an experimental basis with the main objective to diversify and increase fishing potentialities along the Algerian coasts. University Oran1 Ahmed BENBELLA, the marine ecology association Barbarous, the Directorate of Fisheries and Fishery Resources of Oran (DPRH), and the Ministry of Fisheries and Fish Resources (MPRH) sought to direct fishing to a more sustainable fishing with more appropriate resource management. To this end, an artificial reef was implanted in order to increase biodiversity and fish biomass. O.R.1 (Oran Reef one) consisted of 68 modules, with two structures of 34 modules; each structure had a superposed form to create a chaotic structure (one to the East, and one to the West), with a total surface of 15 m ² . Immersion was at 30m depth on a sandy substrate, with the immersion campaign lasting for 4 months, from April to July 2015. The scientific monitoring of the artificial reef allowed the authors to follow the evolution of structures (e.g., siltation) and biomass estimation of fauna and flora inhabiting the structure. After six months of immersion, monitoring in and around both structures reported the presence of more than 37 species, distributed among algae, mollusks gastropods, sponges and fish. Also, it was noticed that the number of species inventoried near the reef had been increasing since the beginning of monitoring, especially the biomass of fish such as red porgy, common two-banded seabream, black head seabream, amberjacks, scorpionfish, rainbow wrasse, and comber.
Keywords Artificial reef; Biodiversity; Scientific monitoring; Specific richness; Biomass; Oran coastline	

1. Introduction

According to FAO (2021), several fishing regions all over the world have illustrated a diminishing tendency in capture since coming to maxima over these last decades. These sensitive production areas have produced 19.9 percent of global catch on average in recent years, and include the Northeast Atlantic (Region 27), the Northwest Atlantic (Region 21), the West Mid-Atlantic (Region 31), the Mediterranean Sea and Black Sea (Region 37), the Southwest Pacific (Region 81), and the Southeast Atlantic Ocean (Region 47). These results have been confirmed by studies conducted on a large scale in the Mediterranean (Damalas et al., 2015; Piroddi et al., 2020). Therefore, maintaining durability and sustainability of these resources is not only of socio-political importance, but also of economic and environmental importance. The United Nations Fish Stocks Agreement (United Nations, 1995) and FAO Code of Conduct for Responsible Fisheries (FAO, 1995) require that fish stocks be maintained or restored at levels sufficient to produce a

maximum sustainable yield (MSY). To fulfill the targets of these worldwide settlements, fishery administration specialists ought to embrace an evaluation of the state of fish stocks and create successful management plans (FAO, 2021). It is worth noting that marine pollution (Bellas et al., 2016; Boucetta et al., 2016; Pedrotti et al., 2016; Rouabhi, et al., 2016; Benaissa et al., 2022) and the introduction of marine alien species (Streftaris & Zenetos, 2006; Corrales et al., 2018; Grimes et al., 2018; Hussein & Bensahla-Talet, 2019a; Hussein et al., 2020a) can contribute greatly to decrease in exploitable marine resources. Several works on Algerian fisheries stock assessment highlight the fact that the majority of exploitable stocks are at their optimum yield, or overfished, in the case of crustaceans (Massutí et al., 2008; Bensahla Talet et al., 2016), cartilaginous fish (Ordines et al., 2011; Zelmat el al., 2017), pelagic fish (Dalouche et al., 2019; Rahmani et al., 2020) benthopelagic fish (Bensahla Talet et al., 2017a; 2017b; Mahdi et al., 2018; Dalouche et al., 2019), and benthic fish (Benghali et al., 2014; Kherraz et al., 2014; Bensahla Talet et al., 2016).

University Oran1 Ahmed BENBELLA, the marine ecological association Barbarous, the Directorate of Fisheries and Fishery Resources of Oran (DPRH) and the Ministry of Fisheries and Fish Resources (MPRH) worked together for the realization of an artificial reef in order to increase fish production and create new marine habitats around the Oran shoreline. In this context, the Project Manager, Mr. Kais Boumediene HUSSEIN, PhD in Ecology and Marine Biology, researcher at University Oran1 and also a member of the association Barbarous (scientific advisor), was solicited to appraise the scientific background part in order to lead the feasibility study, initial diagnosis of the environmental situation, and scientific monitoring after immersion. Can these coasts be more productive? Can fishermen hope to improve their lives? The answer to both questions is affirmative given that, initially, this project was an ecological and environmental response to a rapidly growing and disturbing human pressure practiced on the marine environment, leaving the living resources increasingly vulnerable. Favorable currents, extensive soft bottoms near the seagrass *Posidonia oceanica*, and commitment of different environment actors were sufficient to allow the launch, in 2015, the pilot project of an artificial reef, called Oran Reef 1-O.R.1. This first experience on the national scale level fitted perfectly into the built-in optical management of coastal areas, initiated by the government through its axis 1 of Aquapêche 2020 plan, designed to increase natural resources and sustain human activities, and promoting the settlement of some marine spaces that were initially unproductive. The success of the artificial reef project was based on forged strong links between University Oran1, the Barbarous association, the DPRH of Oran, and all sea users in the immersion zone. O.R.1 is a useful tool, used to convince governments to install artificial reefs for production and sustainable exploitation of the marine environment. In this context, the artificial reef O.R.1 aims to:

- Implant a living laboratory for monitoring and understanding of the mechanisms of production in a reef;
- Evaluate the different constraints during reef implementation and propose practical solutions;
- Demonstrate the effectiveness of reefs as a tool to increase yields and biodiversity conservation, and
- Highlight the role of reefs in transforming unproductive areas into sanctuaries of biodiversity, with all the socio-economic benefits that come with this.

2. Material and methods

The present study was initiated by delineating the overarching ecological context of the region, informed by the findings of an initial diagnostic evaluation (baseline condition). This assessment was based on an inventory of the existing populations and, where relevant, certain stages in the construction of the reef (resources allocated land-based and underwater operations).

Consequently, a simulation was conducted to evaluate the impact of marine currents on the artificial reef. This analysis was complemented by the provision of recommendations aimed at optimizing the design and placement of the structure.

2.1 Implantation zone of O.R.1

The area chosen for the deployment of Oran artificial reef 1 (O.R.1) was “les Andalouses Bay” (Figure 3) at N 35° 44.499’ W 000°51.967’ at Bousfer beach situated, on the Oran coastline (Figure 1) between Bousfer beach and Plane Island.

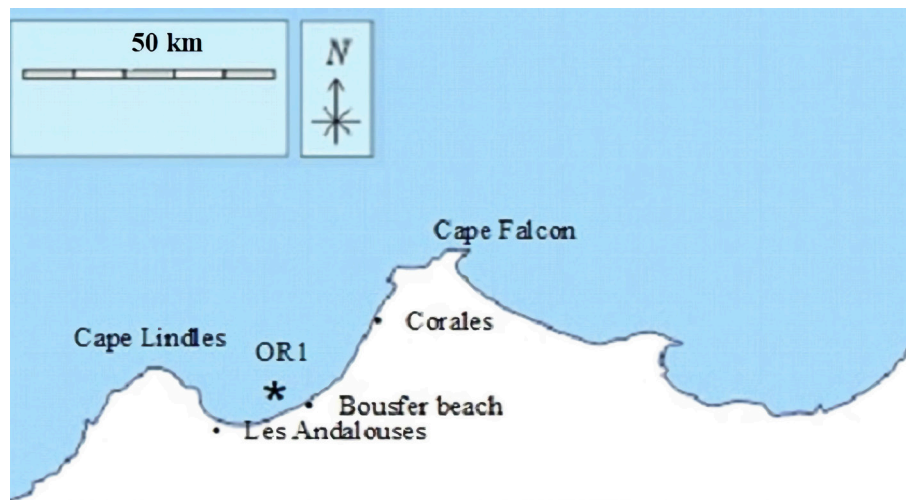


Figure 1 Map of the implantation area for O.R.1 in the Les Andalouses Bay.

This zone corresponds to a wide sandy bottom with a vast seagrass, *Posidonia*, which extends from 5 to 25 m isobaths (Hussein & Bensahla Talet, 2019b). The choice was guided by conditions offered by the site at a depth of 30m isobath, a soft slope with sandy bottom surrounded by *Posidonia oceanica* herbarium, and a very important hydro dynamism. Indeed, the first pilot reef is a real rocky habitat that will, initially, allow the settling of species dependent on this type of substrate as a nursery; it will allow the renewal of fish stocks and increase yields of artisanal fishing present along the Oran coasts.

2.2 Climatic and physicochemical factors

The area is under the influence of four air masses: an anticyclone from the Azores, Iceland low pressures, winter high pressure from Northern Europe and, rarely, Saharan low pressure (Bouras et al., 2007). Also, the area is subject to a warm and dry climate, together with low rainfall, even in winter. The displacement of air masses is channeled through the mountainous range bordering the sea. The annual temperature of shallow water is between 14.5 and 24 °C, with an annual average of 18 °C. In summer, thermal stratification is observed at depths between 20 and 30 m. The dissolved oxygen content of the water is inversely proportional to the temperature in the deep waters, where the minimum registered oxygenation is about 4.23 ml/l (in summer) and a maximum of 4.43 ml/l (in winter). The pH values are around 8.2 to 8.3. Salinity is constant at depths below 250 m, rising to 38.4 psu, which is the characteristic of Mediterranean waters. At the lower shore, this parameter fluctuates between 36.7 and 37.1 psu, under the influence of Atlantic waters (Boutiba, 1992).

2.3. Hydrodynamism

The Atlantic Ocean waters entering the Mediterranean basin through the Strait of Gibraltar generate a great anticyclonic movement in the Alboran basin, closely along the Spanish coasts. This current takes the south direction at Cabo de Gata, where it meets the Mediterranean

levant flow taking the south west direction (Romero-Cózar et al., 2020). The combined flow (known as the Oran front current) then moves to Oran (**Figures 2 and 3**), then divides into two branches: the current located furthest to the East is the current which sweeps the Algerian coastline and is named the Algerian current (Tintore et al., 1988; Swee et al., 1990).

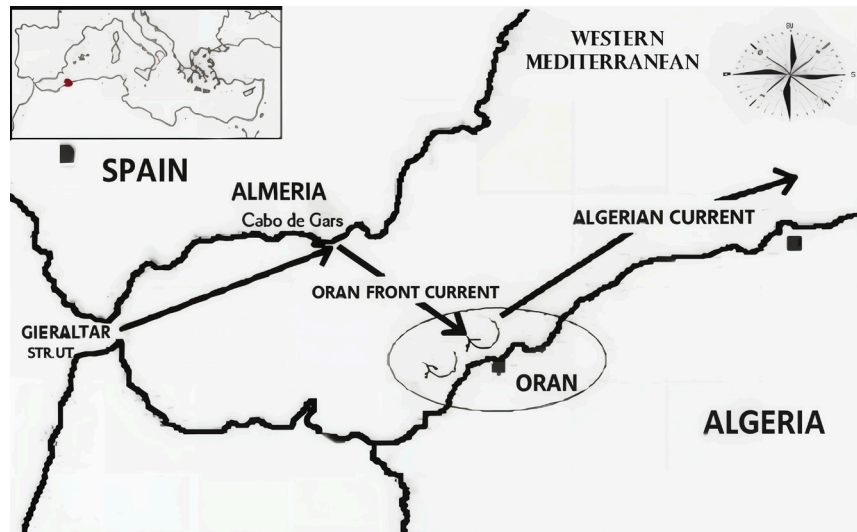


Figure 2 State of current flow (horizontal hydrodynamism) at Oran coastline.

This movement is horizontal to the coastline, and the vertical movement of water is mainly due to the topography and underwater reliefs of the Algerian-Provencal basin of the Oran coast that exhibit a fall of the continental shelf (**Figure 3**).

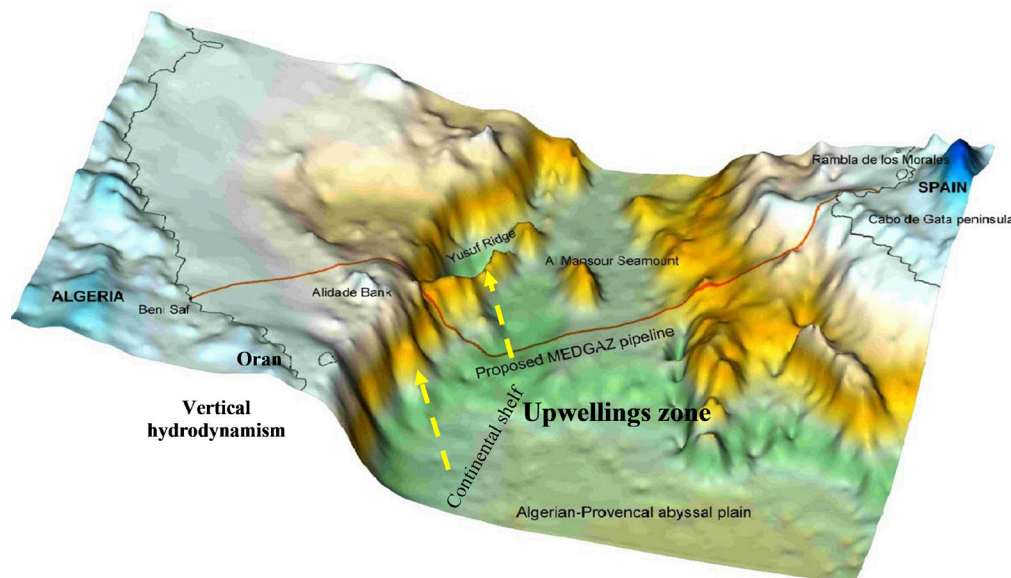


Figure 3 Location of the continental shelf and influence of vertical currents on the Oran coast (ERM Iberia, 2004, Adapted).

Algeria has a coastline of around 1,680 km from the Algerian-Moroccan border in the West to the Algerian-Tunisian border in the East, characterized by a reduced continental shelf with the exception of the extreme western region (Ghazaouet) and the El Kala region in the extreme eastern region (MATE, 2009). Leclaire (1972) noticed a variability in the width of the submarine coastal border of western Algeria, as it is only 10 km off Cap-Falcon, and nearly 90 km in the Gulf

of Ghazaouet, and that the west-Algerian continental shelf is considered to be the narrowest in the Mediterranean (average width of 7 km, with a mean depth of 150 m). 100 m bottoms are encountered after only a few miles, which has an important upwelling action that enriches the area in terms of nutrients (Hussein, 2015).

2.4. Initial diagnosis (zero state)

To emphasize the importance of conducting an initial diagnosis of the situation to be improved, eight dives were carried out over one year, with two dives conducted per season. During these dives, key observations were made regarding the nature of the seabed, bathymetry, existing species inventory, seasonal variations, and weather conditions. Additionally, the GPS coordinates of the immersion zone were recorded. The scientific assessment of the initial state identified a depth of 30 meters, characterized by a sandy seabed with dunes shaped by currents (**Figure 4**). This biocenosis consisted of patches of gravel and organogenous sand, partially clogged with sandy-muddy sediments of heterogeneous size and mixed origins (terrigenous and organogenic). The initial inventory identified the presence of four species (Hussein, 2015) that persisted throughout the year, serving as key indicators of this biota (**Figure 4**). Within this desert-like habitat, certain species contributed to the formation of a seasonal epifloral and epifaunal facies, reflecting more specific environmental conditions. These were primarily represented by gravellicolous, mixticolous, and sabulicolous species, which were photographed prior to intervention as part of establishing the baseline (zero state).

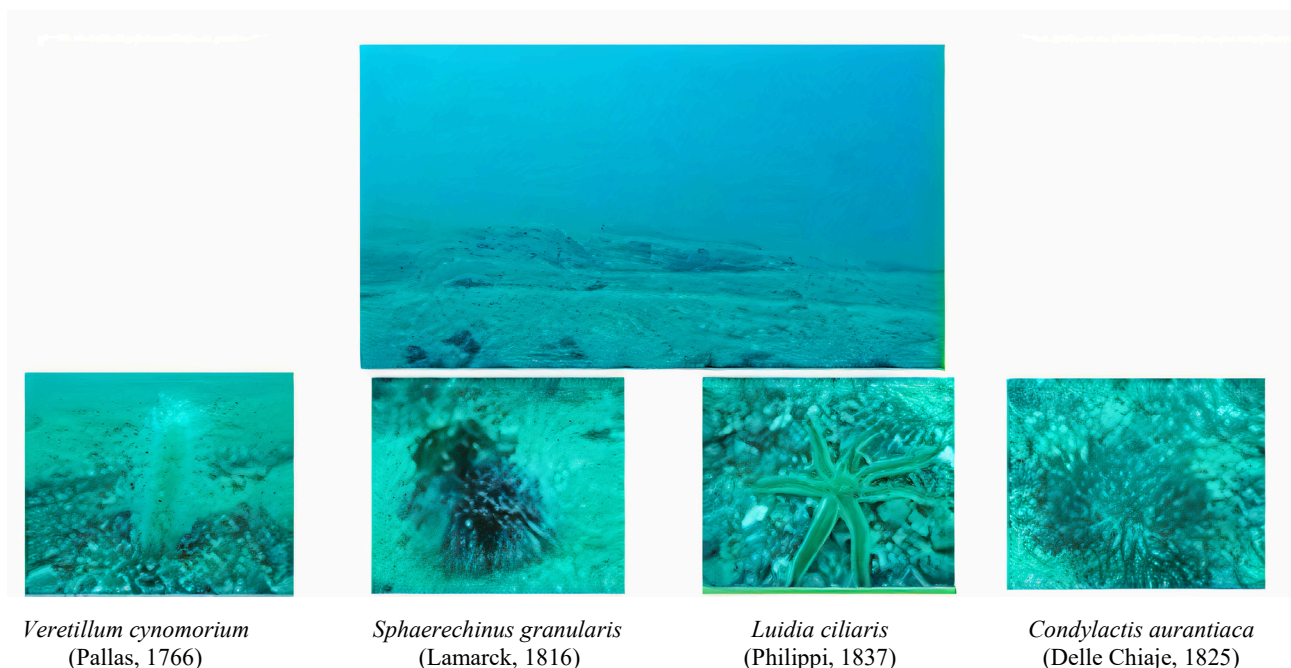


Figure 4 Top: sandy bottoms and dunes of the station before immersion; bottom: species identified during the initial diagnosis.

2.5 Realization, proposals and model design

The architecture of artificial reefs plays a crucial role in influencing their productivity. Therefore, the structure was meticulously designed and optimized to better accommodate the fauna and flora intended for development. The innovative reef design featured a three-dimensional (3D) structure (**Figure 5**), crafted by naval engineers from the association Barbarous using ANSYS-CFX 13.0 software.

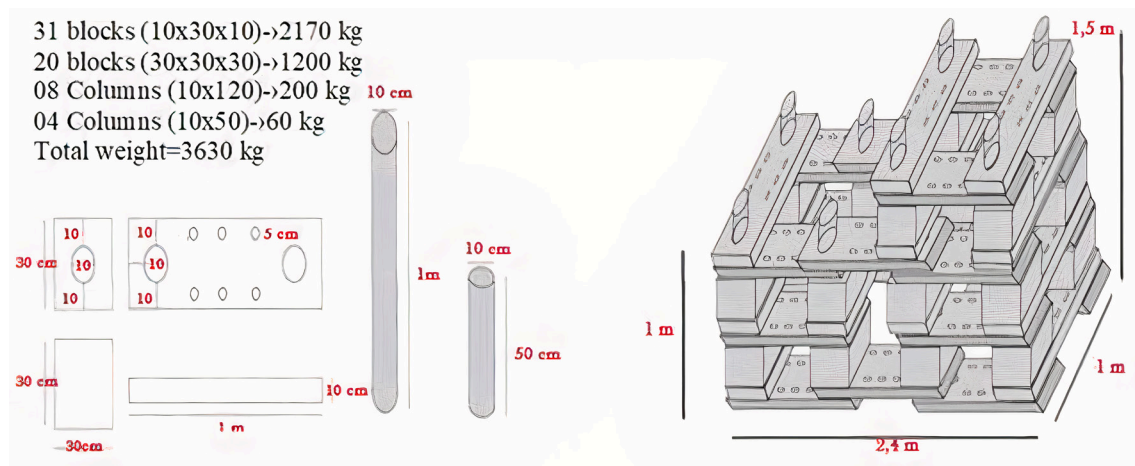


Figure 5 Presentation of the 3D model architecture of the artificial reef O.R.1.

The reef structure underwent a validity simulation review by a technical study of resistance to marine currents (**Figure 6**), carried out by University of Sciences and Technology of Oran, USTO-MB and the technological institute of fishing and aquaculture of Oran using the ANSYS CFX-13.0 software, which was composed of four independent and complementary modules:

- 1) The mesher (ICEM CFD 13.0), allowing defining, configuration, and managing of the mesh.

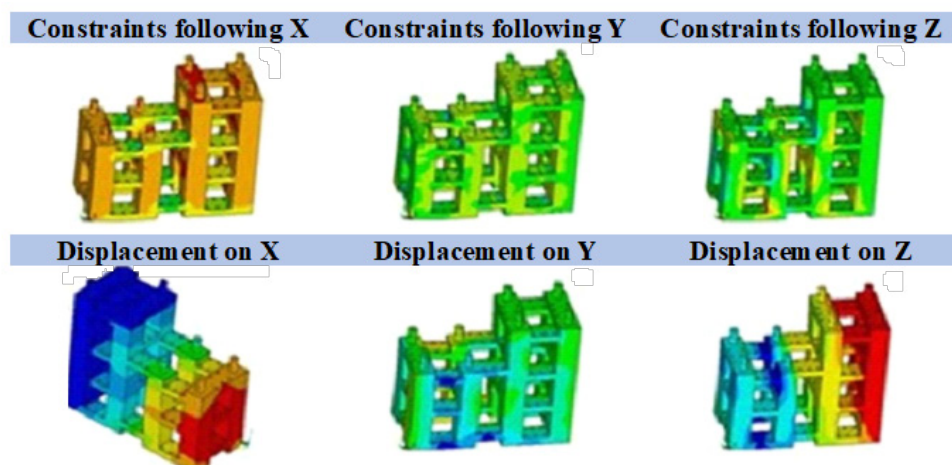


Figure 6 Simulation and constraints exercised by marine currents on the seabed in the implantation area of the O.R.1 structure, (ANSYS CFX-13.0 software-USTO-M.B).

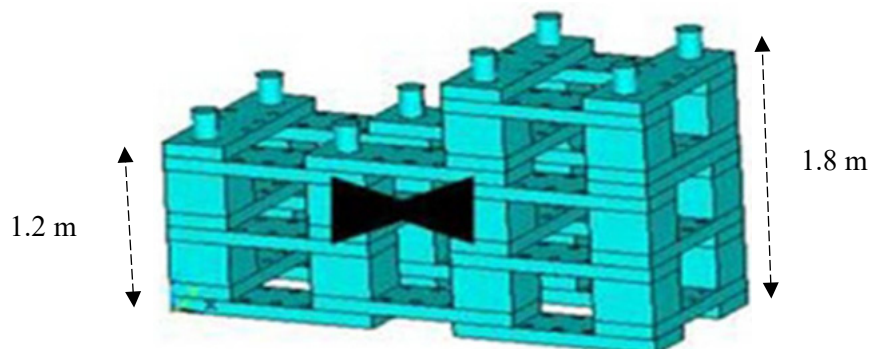


Figure 7 Corrections and recommendation suggested for the shape of the O.R.1 Structure.

2) The pre-processor, allowing data preparation, fluid properties setting, and specification of boundary and limits.

3) The solution solver (Solver Manager), allowing the solving of model equations, modeling of the problem, and displaying of information about the convergence progress of the sought parameters.

4) The post-processor, allowing representation of the results on the screen as contours, curves, and current lines. It appeared, from the simulation presented in **Figure 6**, that the situation involved a change in the heights and extensions of stiffeners. These adjustments are highlighted in **Figure 7**, which illustrates the proposed corrections and recommendations for optimizing the shape of the O.R.1 structures. The modifications, such as changes to the heights and extensions of stiffeners (indicated by black triangles), aimed to enhance resistance to marine currents and ensure stability in the implantation area. Once the structure shape was corrected, the module construction started in February 2014 (**Figure 8**) and lasted two months, with rudimentary equipment to turn a simple idea into a tangible reality.



Figure 8 Stages of different modules construction of Oran reef 1 (O.R.1).

O.R.1 consists of 68 modules of reinforced concrete, two structures of 34 modules (about 3m length, 1m wide, and 1.8m height); each structure has a superimposed independent form to create a chaotic structure full of refuges for fish, (one facing the East, and the other facing the West). During the implantation phase, 20 modules were transported by boats and immersed at the site, which was previously tagged for easy locating (**Figure 9**).

Following the immersion of the construction materials, the underwater phase commenced, involving the mobilization of over 20 divers for the in-situ assembly of the O.R.1 structures at a depth of 30 m (**Figure 10**). The state of the sea and prevailing meteorological conditions (López Ornat, 2006) played a critical role in determining the timing and progress of the operation, which spanned from April to July 2015.



Figure 9 Maritime transport, marking, and module immersion.

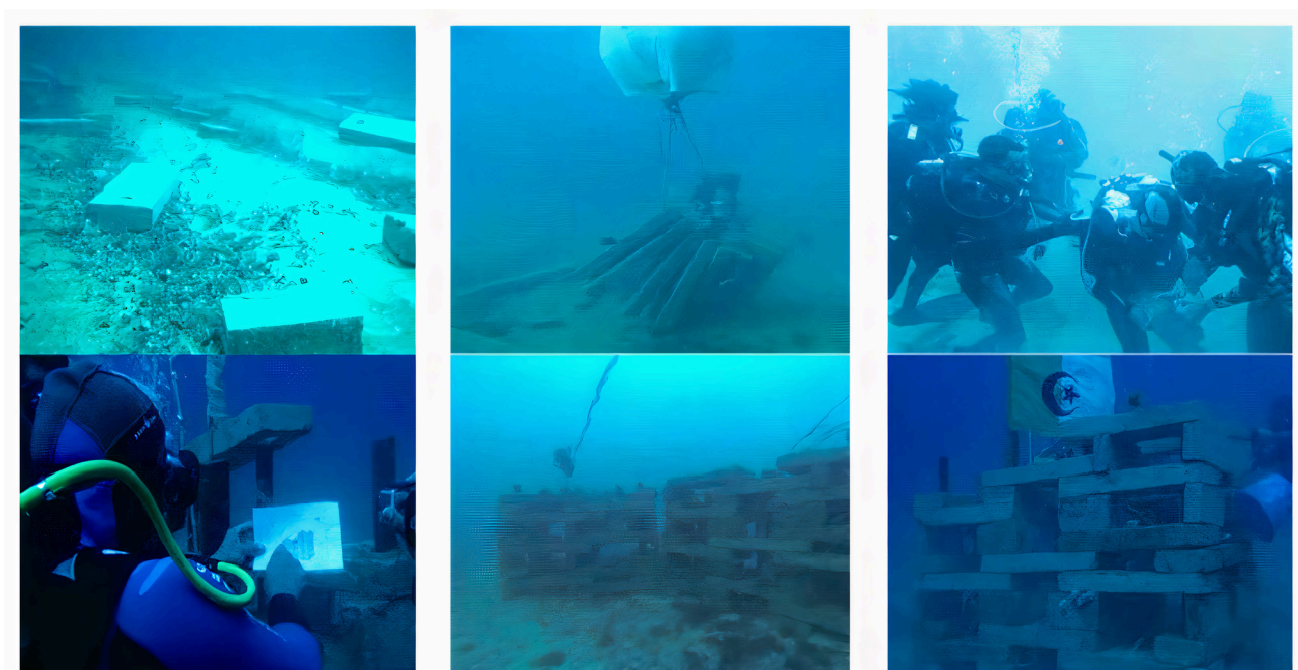


Figure 10 Submarine construction and montage of the two structures of O. R.1.

O.R.1 was deployed at N 35 ° 44. 454 'W 000 °52. 016 ', about 2.340 m from the line of Bousfer coast, in les Andalouses Bay at a depth of 30 m on a background of a gently sloping sandy soft bottom of a total volume of 10 m³ and a total surface area of 15 m². The site was marked by a float for easy localization and future work for biologist divers.

2.6 Scientific monitoring

Scientific monitoring of the reef was done (**Figure 11**) to follow the evolution over time of the reef structure, flora and fauna colonization of both structures, and the estimation of the evolution of various fish populations that colonize the reef (qualitative, quantitative, abundance, biomass, ecological indices, and specific diversity).



Figure 11 Scientific monitoring (observations, sampling, counting, underwater photography) of O.R.1.

The objective was to assess both the qualitative and quantitative impact of artificial reef immersion on certain faunal populations, primarily fish, along the Oran coast. Various studies monitoring artificial reefs in the western Mediterranean (Bayle-Sempere & Ramos-Esplá, 1993; Bortone & Mille, 1999; Dalias et al., 2006; Lenfant et al., 2007) provided a framework for this research. Species observed in and around the artificial reef structures were identified using standardized marine biological classification protocols. For visually detectable species, such as fish and larger invertebrates, direct observation and sampling techniques were applied. Species identification was carried out through underwater visual censuses conducted by trained marine biologists and divers, adhering to established reef fish survey methodologies (Bohnsack and Bannerot, 1986). Whenever possible, species were identified in situ using standard field guides for Mediterranean marine fauna (Bouderesque, 2004)

For the identification of smaller organisms, such as algae, sponges, and certain invertebrates, samples were carefully collected and preserved for laboratory analysis. In the laboratory, species were identified using a combination of morphological and taxonomic techniques. Samples were first examined under a stereomicroscope or compound microscope to observe diagnostic features. Where necessary, sections were prepared to analyze internal structures. Identification was performed using specialized taxonomic keys and reference guides relevant to the Mediterranean marine ecosystem, including Mediterranean Marine Benthic Fauna (Pérès & Picard, 1964), Keys for the Identification of Marine Invertebrates (Riedl, 1983), and Field Guide to Mediterranean Seaweeds (Cormaci et al., 1992). When required, online taxonomic databases, such as WoRMS (World Register of Marine Species), were consulted to validate nomenclature and ensure updated classification. The process adhered to standard protocols for laboratory-based species identification, ensuring accuracy and consistency in the results.

2.6.1 Scientific monitoring methodology

Some parameters have proven to be good indicators for measuring the influence of reefs on surrounding wildlife, and were therefore used in this study:

- The specific composition of populations;
- The biomass of a number of species with economic interest.

2.6.2 Fixed fauna and flora monitoring

The monitoring of flora and fixed fauna began on July 24th, 2015, coinciding with the completion of the assembly of O.R.1. Three scientific monitoring operations were performed; the first follow-up was performed the same day at the end of assembly of both structures, with the second 3 months and the third 6 months after implantation. However, the implementation of quadrats was only possible after five months of immersion. During each dive, the structure surface was photographed by divers to illustrate the chronological development of the overall settlement of the flora and fixed fauna. To complete these data, the specific diversity in the both structures was measured in situ to determine the minimal colonization of fixed fauna and flora on the concrete modules, and so could provide information about the average low biodiversity of all structures.

To assess biodiversity among the fixed fauna, quadrant sampling techniques were employed directly on the artificial reef structures. Quadrants of known dimensions were placed at representative points on each reef module to standardize the area surveyed. Within each quadrant, visual counts and photographic sampling were conducted. Photographs were analyzed in the lab, where species were identified using field guides and taxonomic keys specific to Mediterranean marine fauna (Boudouresque et al., 2004). This method allowed for a standardized and repeatable assessment of fixed fauna diversity across modules.

2.6.3 Mobile species monitoring (Fish and invertebrates)

Visual counting of benthic species has been used (Harmelin-Vivien et al., 1985; Ramos Espla & Baylesempere, 1989; Wantiez & Kulbicki, 1995) given that it is a non-destructive technique that has developed considerably since its first use in 1954 by Brock on Hawaiian fish population (Wantiez & Kulbicki, 1995). It is particularly applicable to fragile habitats sensitive to destruction, such as coral reefs (Galzin, 1979) or marine reserves. Today this technique is used in most studies on fish populations of coastal environments, especially in scientific monitoring of artificial reefs (Bortone et al., 1986; Bortone, 1991; Francour et al., 1999)]. Some of the methods of obtaining data are as per the bellow:

- Watching videos from diving research locations (Helfman, 1983; Cole, 1990; Harmelin et al., 1995).

- By visual counts made in situ by a diver who notes the data directly on a submergible plate (Charbonnel et al., 2000).

- The use of a submersible plate remains a relatively reliable and easy to use technique, which is used in the majority of studies (Helfman, 1983; Cole, 1990; Harmelin et al., 1995; Francour, 1997; Francour et al., 1999; Charbonnel et al., 2000). Visual count technique has been, and continues to be, widely employed to assess the impact of artificial reefs (Charbonnel et al., 1996). During sampling, each diver noted the species encountered and the number and size of individuals. The limitations of this technique, including observer bias, the difficulty in detecting cryptic or fast-moving species, the influence of environmental conditions on visibility, and the potential impact of diver presence on fish behavior, have been well-documented (Brock, 1954; Lenfant et al., 2007). Also, to limit the sources of errors, each approach and count was identically made by a single person (Bortone, 2000). Due to the difficulty of approaching them, mobile species like annular black head and common seabreams were recorded first. Vicinity species and/or inside the reef: Labridae, Combers, Scorpionfish, Damselfish; Gobies, Apogons (Cardinal fish) were recognized by browsing, in a very conscientious manner the sides of and within each structure.

2.6.4 Individuals counting and size consideration

Less than 10 specimens were recorded individually; six classes of abundance were used (11- 30, 31 - 50, 51 - 100, 101 - 200, 201 - 500, >500) (Harmelin-Vivien, 1982; 1984; Charbonnel et al., 1995). Three size classes were commonly used: small (S), medium (M) and large (L) (Harmelin-Vivien, M. L., 1982; Harmelin-Vivien, 1984; Charbonnel et al., 1995; Charbonnel et al., 1996; Francour et al., 1999; Bortone, 2000; Charbonnel et al., 2000). The class limits could vary from one species to another according to the maximum size (L_{max}) given by the literature (Fisher et al., 1987; Fabi et al., 2011; Froese and Pauly, 2020): Small (0 to 1/3 of L_{max}) medium (1/3 to 2/3 of L_{max}) and large (2/3 of L_{max}).

2.6.5 Biomass

During each visit, random counts were made and, for each of them, the divers performed during a first pass, counting difficult to approach mobile species and taking into account a total surface area count corresponding to the width of the structure plus 5m each side thereof (around the reef). Then, during a second pass, the divers recorded all species located on the reef, with special attention paid to the various cavities created by the concrete blocks positioned within the structure.

3. Results and discussion

3.1 Monitoring of flora and fixed fauna

This first artificial reef in Algeria was immersed in an ecologically depleted area in order to increase fish production and enhance marine biodiversity. To ease the study, two categories were selected; fixed species (macro phytobenthos and macro zoobenthos) and mobile species represented by fish and invertebrates. As stated previously, before implantation of the reef, the initial (zero state) diagnosis revealed the existence of four species that originally inhabited this desertic habitat. Initial observations during the first dives revealed the absence of flora within the structures. Wildlife was limited to the presence of squid eggs attached to the walls and ropes, as well as filamentous algae on the outer walls of the two structures.

By August 24th, 2015, a month after immersion, noticeable changes were observed across all monitored modules. Filamentous algae had spread over all the structures. The colonization pattern appeared nearly identical across the modules, characterized by the presence of white sponges on a few blocks outside the eastern structure, a single sea cucumber (*Holothuria tubulosa*), an increased number of squid eggs, and one individual of *Octopus vulgaris* within a vertical column.

Three months after the immersion, on October 24th, 2015, the in situ and visual analyses of the reef and its surroundings revealed a significant increase in biodiversity. Over 25 species were identified, a sixfold increase in species richness compared to initial observations. This biodiversity encompassed algae, gastropods, mollusks, sponges, and fish. Filamentous algae continued to dominate all structures. However, additional colonization was noted, including the presence of the white sponge (*Grantia compressa*) on some blocks of the eastern structure, the appearance of *Lithophyllum* sp. on the western structure, the near-total disappearance of squid eggs, the presence of two small *Octopus vulgaris* individuals in the vertical columns, and the emergence of nudibranchs, bryozoans, and hydroids. The disappearance of squid eggs likely corresponds to the natural lifecycle of squids, where eggs laid in July and August typically hatch by October. During these three months, new species continued to colonize the reef, with some using it as a temporary refuge. For instance, scorpion fish individuals colonize the reef during juvenile stages and vacate it as they mature, allowing smaller congeners to take their place.

By January 24th, 2016, six months after immersion, species richness had increased further, with over 37 species recorded. These included algae, invertebrates, and fish. During the winter season, filamentous algae declined, giving way to red algae (*Lithophyllum incrustans*), which covered over

30 % of the reef's surface area. In some areas, the concrete structures were completely overgrown with this Rhodophyte. The west O.R.1 structure, aligned parallel to the orientation of the dunes shaped by marine currents, experienced accelerated colonization. This orientation facilitated the settlement of juveniles, fertilized eggs, and plankton on the walls of both the western and eastern structures. The interior of the structures witnessed significant colonization by sponges, worms, and tunicates, while the external faces hosted diverse species, including *Dictyota dichotoma*, *Lithothamnion valens*, *Lithophyllum incrustans*, the sponge *Grantia compressa*, ascidians such as *Diplosoma listerianum* and *Botryllus* sp., the nudibranch *Cratena peregrina*, flat oysters (*Ostrea edulis*), and the urchin *Sphaerechinus granularis*.

Overall, species richness within the reef showed a consistent increase, rising from an average of four species in July 2015 to 25 in October 2015 and reaching 37 by January 2016. This progression highlights the reef's role in supporting and enhancing marine biodiversity over time. After six months of immersion, monitoring in and around the both structures reported the presence of more than 37 species, distributed among algae, mollusks gastropods, sponges, and fish.

3.2 Mobile species monitoring (fish and invertebrates)

During the six months following the immersion of the structures, several mobile species, including fish and invertebrates, were identified. Observations indicated a continuous increase in the number of species recorded and individuals counted near the artificial reef. Additionally, new species were noted either within or around the structures, marking a notable shift in habitat preferences. These species, which were previously confined to rocky areas and herbariums, now appeared to frequent the reef (**Table 1**). 22 individuals of red scorpion fish (*Scorpaena scorpa*), both small and medium in size, were observed. Two individuals of common octopus (*Octopus vulgaris*) were also documented, one residing on the vertical column of the reef and the other found between the two modules. The area was populated by approximately 20 medium-sized individuals of comber (*Serranus cabrilla*) and 8 to 10 large individuals of red porgy (*Pagrus pagrus*). Around 50 individuals of ornate wrasse (*Coris julis*) were seen in the vicinity of the surrounding structures. Furthermore, 41 specimens of blackhead seabream (*Diplodus vulgaris*), ranging from medium to large sizes, were identified, alongside 15 large individuals of annular seabream (*Diplodus annularis*). Red mullet (*Mullus barbatus*) was also occasionally observed near the reef. A notably large cuttlefish was documented within the eastern structure, while four brown wrasses (*Labrus merula*) were identified inside the western structure. This diversity and abundance highlight the ecological significance and success of the artificial reef in attracting and supporting a variety of marine species.

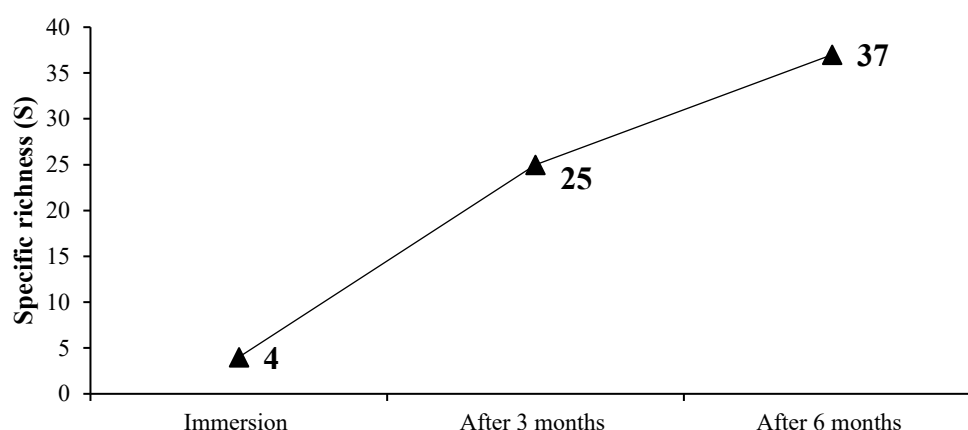


Figure 12 Temporal evolution of species richness (S) observed in O.R.1 from July 2015 to January 2016.

3.3 Specific richness

The first 5 months after installation of the reef were characterized by an important increase in the number of species (**Figure 12**), a result of the attractive effect (Beldade et al., 2006) played by the artificial reef implemented in the area.

3.4 List of species recorded before and after immersion

Species encountered before and after immersion of O.R.1 are listed in **Table 1**.

Table 1 Recapitulative list of species encountered before and after immersion.

Existing species before immersion	Species dependent on (O.R.1)
	Fixed Species (Flora and Fauna)
	<i>Dictyota dichotoma</i> , <i>Cratena peregrina</i>
	<i>Grantia compressa</i> , <i>Dardanus calidus</i>
	<i>Lithophyllum incrustans</i> , <i>Diplosoma listerianum</i>
	<i>Lithothamnion valens</i> , <i>Holothuria tubulosa</i> ,
	<i>Botryllus sp.</i> , Hydrozoa (2 species)
	Bryozoans. Mollusks
	Gastropods
	<i>Spirographe Sp.</i>
	Squid Eggs
<i>Veretillum cynomorium</i>	
<i>Sphaerechinus granularis</i>	Mobile species (Fish and Invertebrates)
<i>Condylactis aurantiaca</i>	<i>Apogon imberbis</i> , <i>Chromis</i>
<i>Luidia ciliaris</i>	<i>chromis</i> , <i>Parablennius rouxi</i> ,
	<i>Coris julis</i> , <i>Scorpaena scorfa</i> ,
	<i>Diplodus annularis</i> , <i>Seriola dumerili</i>
	<i>Diplodus sargus</i> , <i>Serranus cabrilla</i> ,
	<i>Diplodus vulgaris</i> , <i>Serranus scriba</i> ,
	<i>Mulus barbatus</i> , <i>Symphodus roissali</i> ,
	<i>Muraena helena</i> , <i>Symphodus tinca</i> ,
	<i>Oblada melanura</i> , <i>Octopus vulgaris</i> ,
	<i>Pagrus pagrus</i> , <i>Sepia officinalis</i> ,

Species diversity increased more or less steadily since the start of monitoring. From November 2015, the 4th month of immersion, it seemed that the species richness stabilized. However, the presence of fish in the vicinity of the reef was significant and can be explained by the presence of some species considered as the first links of the marine trophic chain already installed by occupying a large part of the space phenomenon known as the reef effect (Leitão, 2013; Jones et al., 2020). Regardless, significant changes in parameters related to the mobile fauna were to be expected. Indeed, on reefs as natural environments, these parameters show large variations depending on the season and other specific parameters such as reproduction period.

3.5 Species biomass evaluation

From *in situ* counting data, it is possible to estimate the biomass (in grams per wet weight) using the length-weight relationship of the different species (Harmelin-Vivien et al., 1985) and, for each size class (Small, Medium, and Large), average weight was calculated. This weight corresponds to the average of the weight calculated for size limits of each length class (Harmelin-Vivien et al., 1985; Jones et al., 2020). The biomasses of these species were often the parameter that assisted in judging the effectiveness of the artificial reef (**Figure 13**). Also, this economic

parameter is important. Nevertheless, biomass values should be interpreted with caution, and it should be considered that they rather represent an order of magnitude.

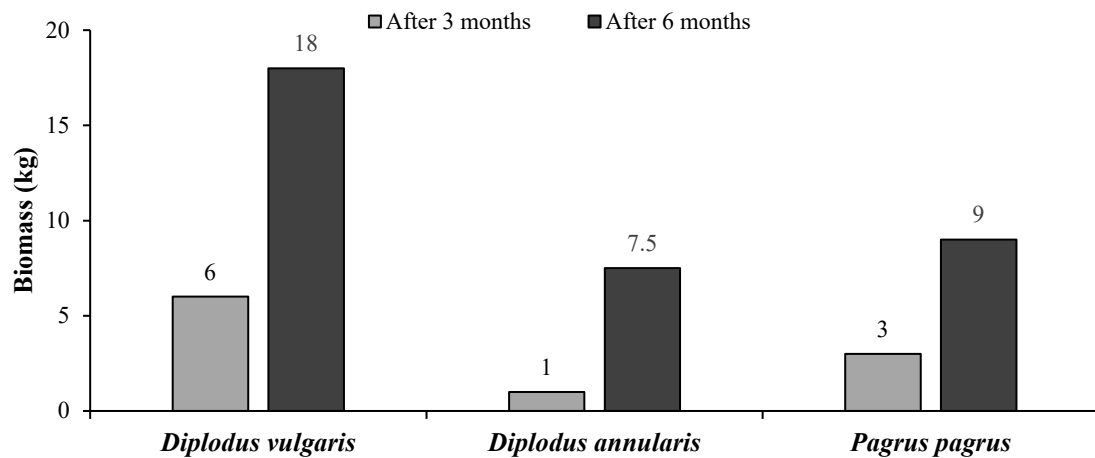


Figure 13 Temporal evolution and estimation of annular, black head, and common seabream biomasses in Oran Reef 1 after six months of scientific monitoring.

For each expedition (3rd and 6th months), biomass of red porgy (*Pagrus pagrus*), blackhead seabream (*Diplodus vulgaris*), and annular seabream (*Diplodus annularis*) were studied exclusively, given their commercial importance, rather than other species found in O.R.1 (Figures 13 and 14).

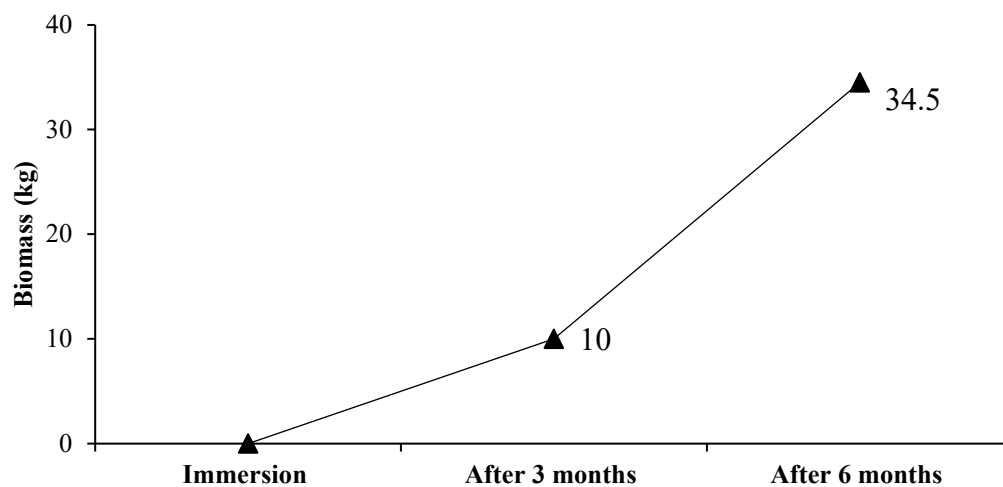


Figure 14 Temporal evolution of the mean biomass of three species after six months of scientific monitoring.

The biomass evolution showed an overall increase, since it evolved from an average biomass of 10 kg in October 2015 to 34.5 kg in late January 2016. This increase was mostly due to implementation of O.R.1, which offered a favorable environmental situation with its complex structure. The nutrient intake created around the reef could also favor the presence of juveniles and may thus have had consequences on increasing the richness and biomass (Hussein, 2015). Also, biomass estimates for species with high mobility is extremely variable. Indeed, the presence of a bench of fifty amberjacks (*Seriola dumerilii*) or thousands of bogue juveniles on the reef can strongly influence biomass when it coincides with the sampling period. But these species are naturally

present in certain seasons. It will be interesting to follow the long term development of other species biomass that come to settle on the two reef structures.

3.6 Estimating the economic profitability of O.R.1

The biomass estimates of *Diplodus vulgaris*, *D. annularis*, and *Pagrus pagrus* allowed the synthesis of possible economic profitability of artificial reef O.R.1, using the relationship weight/sale price, with a suggested sale price for red porgy (1400 Da/kg or 7.77 €/kg), for the blackhead seabream (500 Da/kg or 2.77 €/kg), and an appreciable price for the annular seabream (600 Da / kg or 3.33 €/kg). Prices have been set following an investigation made at Oran fishery and fishermen.

Table 2 Estimated economic profitability of the reef in Euro/kg, depending on the relation weight/sale price, of three high economic value species during two periods after immersion.

Species	<i>Diplodus vulgaris</i>	<i>Diplodus annularis</i>	<i>Pagrus pagrus</i>	Total Per period
3 Months	3,000 Da/kg (16.62 €/kg)	600 Da/kg (3.33 €/kg)	4,200 Da/kg (23.31 €/kg)	43.26 €/kg
6 Months	9,000 Da/kg (49.86 €/kg)	4,500 Da/kg (24.97 €/kg)	12,600 Da/kg (69.9 €/kg)	144.73 €/kg

Knowing that the area occupied by O.R.1 is 15 m², economic profitability of the reef after 6 months of immersion was evaluated at 144.73 €/kg (**Table 2**). In the case of extension of the reef to an area of 1 km², the extrapolation of economic benefit of the reef will be estimated at 9.64 million €/kg. From these results, it can be deduced that the installation of artificial reefs on the Oran shoreline can lead to reasonable management of the national fishery resources, and transform initially unproductive environments to more productive habitats.

A review of the literature on artificial reefs in the Mediterranean region and worldwide reveals that reef structures can effectively enhance biodiversity and fish biomass. As with the findings of the Oran Reef 1 (O.R.1) study, other Mediterranean studies, such as those conducted in Tabarca Marine Reserve (Spain), reported significant increases in species richness following the installation of artificial reefs (Bayle-Sempere & Ramos-Esplá, 1993). This finding corroborates our observation of increased biodiversity within six months of reef immersion, with more than 37 species recorded, encompassing algae, mollusks, and various fish species. The observed increase in fish biomass in O.R.1, from initial values to approximately 34.5 kg within six months, is consistent with the findings of previous artificial reef projects in Leucate and Le Barcarès (France) (Koeck, 2012).

Similarly, the reefs exhibited comparable augmentations in fish biomass over brief monitoring intervals, linked to the “reef effect” and the multidimensional structures that offer refuge and breeding sites (Dalias et al., 2006; Lenfant et al., 2007). The economic benefits of artificial reefs, as demonstrated in O.R.1 with commercially important species like the red porgy and blackhead seabream, are also highlighted in other studies. For example, reefs in the Parc Marin de la Côte Bleue (France) (Lavissee et al., 2010) have demonstrated that artificial structures not only enhance local fisheries by supporting higher fish populations, but also contribute to sustainable fishery practices by acting as no-fishing zones that help replenish nearby exploited areas (Charbonnel et al., 2000). The role of environmental factors, such as substrate type and water currents, observed in O.R.1 is in accordance with research conducted in the Alboran Sea and Cabo de Gata (Spain)

(Gervasio et al., 2002), where currents and substrate were found to significantly influence species settlement and distribution around artificial reefs (Romero-Cózar et al., 2020).

The proximity of *Posidonia oceanica* meadows to O.R.1 may have similarly permitted the rapid colonization of algae and benthic species. It is important to emphasize the potential of artificial reefs like O.R.1 to contribute to the restoration of marine habitats and to promote long-term ecological stability. It should be noted that the creation of artificial reefs can positively impact marine ecosystem health, which can in turn have a beneficial effect on adjacent natural habitats. This is due to the fact that such reefs support an increase in biodiversity and biomass. Furthermore, it is important to acknowledge the potential of these reefs to assist in the restoration of species populations that have been adversely affected by overfishing and habitat degradation. This could contribute to the advancement of broader conservation initiatives within the Mediterranean region.

The potential of artificial reefs to serve as fish aggregation sites and safe zones for breeding, thereby supporting sustainable fisheries in the long term, is a topic worthy of discussion. The increased biomass and presence of commercially valuable species, such as the red porgy and blackhead seabream, indicate a promising economic benefit for local fisheries, which may result in a reduction in fishing pressure on natural reefs. It should be noted that, over time, local communities may experience economic growth as a result of eco-tourism, diving, and recreational fishing, which are often generated in the vicinity of artificial reefs. In the absence of sufficient financial and human resources, it is important to acknowledge that the monitoring period (six months) provides a limited perspective on long-term trends in species diversity, biomass, and ecological interactions.

It is further proposed that an extended monitoring period, spanning several years, will facilitate a more comprehensive understanding of seasonal variations, succession patterns, and the stability of established communities. It should be recognized that the results obtained from a single artificial reef installation (O.R.1) on the Oran coastline may not be directly applicable to other locations with different environmental conditions. It is proposed that similar installations be replicated in diverse habitats along the Algerian coastline in order to validate the findings and assess the effects of environmental variability. Although visual surveys were selected for their efficiency, it is acknowledged that they are not optimal for detecting smaller or cryptic species. Subsequent studies will integrate molecular techniques, such as environmental DNA (eDNA), to provide a more comprehensive assessment of biodiversity. It is imperative to exercise caution and consider the potential for unintended ecological consequences, such as shifts in predator-prey dynamics or the attraction of invasive species, in biodiversity enhancement projects. Such disruptions have the potential to alter the stability of local ecosystems and the balance of biodiversity. It is imperative that environmental monitoring be conducted on a regular basis, in conjunction with the implementation of adaptive management practices, in order to promptly detect and address any potential impacts. This approach ensures that the interventions achieve their intended conservation goals while minimizing any associated ecological risks.

4. Conclusions

The study successfully located and marked the submerged reef by installing measuring devices to facilitate future management efforts. After six months of scientific monitoring, the findings revealed significant ecological and economic improvements. The overall richness of the reef increased by a factor of 9.25, indicating substantial ecological recovery. Additionally, the number of fish species observed on the reef has grown, accompanied by a notable recruitment of new individuals. Furthermore, the biomass of three economically valuable fish species increased by approximately 35 kilograms, yielding an economic benefit of 26,100 Algerian dinars per kilogram,

equivalent to 144.73 euros per kilogram. These results underscore the reef's ecological recovery and its potential economic contribution to local fisheries.

Data are rather encouraging for the future, but still remain at very low levels. Depending on the results of the pilot experience, a statement already found (Devaux & Millerioux, 1976) it would be interesting to pursue scientific monitoring of Oran artificial reef beyond three years. Indeed, the monitoring results are promising, and clearly demonstrate that implantation of artificial reefs will keep a significant number of spawners alive for longer, maximizing the production of eggs with a positive effect on the recruitment of juveniles and renewal of fish stocks. The major objective of this experience is to induce and test environmental factors, and possibly to ascertain if the Oran coastal bottom can accommodate productive artificial reefs.

According to the results, the answer is yes, and productive reefs can be installed successfully, and this is due to the favorable conditions of the coast, which enhances colonization by flora and fauna in a rich and varied manner. In Algeria, the future of artificialization of soft substrate should be a priority of the Ministry of the Environment and Fisheries and their respective partners. This priority aims primarily for the protection of coastal biodiversity, which is in close relation with artisanal fisheries. It also constitutes an effective means for managing fisheries resources and developing ecotourism related to the practice of recreational diving. Finally, the ecological and reasoned artificialization of the coastal environment should lead to the implementation of a realistic coastal fisheries management strategy, in accordance with integrated coastal zone management (ICZM). These habitats, once artificialized, become more productive than the original natural space, and lead to a better exploitation of renewable resources in the context of conservation and sustainable development.

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Annex: Illustration of some species photographed during study



O.R.1



Grantia compressa



Diplodus vulgaris



Diplodus vulgaris & *Pagrus pagrus*



Scorpaena scorfa



Scorpaena scorfa



Pagrus pagrus



Sepia officinalis



Diplodus annularis



Parablennius rouxi



Holothuria tubulosa



Cratena peregrina



Squid eggs



Labrus merula



Gastropod & Mollusks



Octopus vulgaris