Artificial reef along the French Mediterranean coastline: toward innovative integrated biodiversity management

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ARTIFICIAL REEF ALONG THE FRENCH MEDITERRANEAN COASTLINE: TOWARD INNOVATIVE INTEGRATED BIODIVERSITY MANAGEMENT

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Abstract – Coastal zones are subjected to cumulative human pressure and it is necessary to protect and manage these productive and sensitive marine ecosystems. Artificial Reefs (AR) are relevant tools to overcome these challenges. AR were originally used for fisheries purposes, however for nearly a decade they have also been used in ecological engineering in order to restore specific habitat functionalities. In the meantime, they are also employed to manage human activities e.g.: eco-mooring, as a substitute for natural reefs for diving activities. The review of the latest projects on the French Mediterranean coast shows that apart from the ecological and management objectives, AR are also social tools that could help to enlarge an integrated approach of an ecosystem-based management. Their assessments will have to take into account the entire social-ecological system by using a systemic approach.

Introduction

Nowadays coastal ecosystems are strategically important in the Mediterranean Sea. As the numbers of marine activities increase, so does the pressure on biodiversity. Therefore, it is vital to protect and manage the coastal environment.

Ecological protections as well as the economic development of coastal areas are complex to balance. The recent French report on marine habitat [9], has shown that more than 80% of French coastal habitat is in bad or very bad ecological states. The huge decrease in biodiversity due to the high level of artificialization and pollution threaten main ecological functionalities, future ecosystem health and human activities.

For fifty years, Artificial Reefs (AR) have been deployed (Figure 1) to respond to the decrease in fish stocks [12]. The main objective of these structures was to sustain artisanal fisheries and to enhance fish stocks [5]. The materials used were mostly decommissioned products like old, concrete pipes [12]. The main stakeholders were angler organizations and local or regional authorities. Since the first submersion in 1968 in Palavas-Les-Flots, 26 areas of AR have been established along the French Mediterranean coast with a common objective to increase fish productions (Figure 1). The biggest AR's project named "operation Prado" was conducted in Marseille's Bay in 2007. It was designed to enhance fisheries production, but it was also the first project which incorporated the used of AR as a tool of ecological restoration of marine habitats. Since 2010, the main goal of AR projects was to experiment

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with restoration or the creation of key ecological functions: spawning or nurseries. They are also designed to target commercial fish like sea bass or sea bream.

In this study, we present the latest AR projects for fisheries production, development of coastal activities (recreational, eco-mooring) and ecological restoration to offset the negative human impact along the French Mediterranean coast. They are not only innovative because of their ecological objectives and design, but also as a tool for human coastal activities [10]. This diversification in the use of AR is interesting because it makes it possible to manage human activities in coastal areas with one tool. At the end, the understanding of social-ecological systems could help to manage the coastline and also find solutions to protect the marine environment.

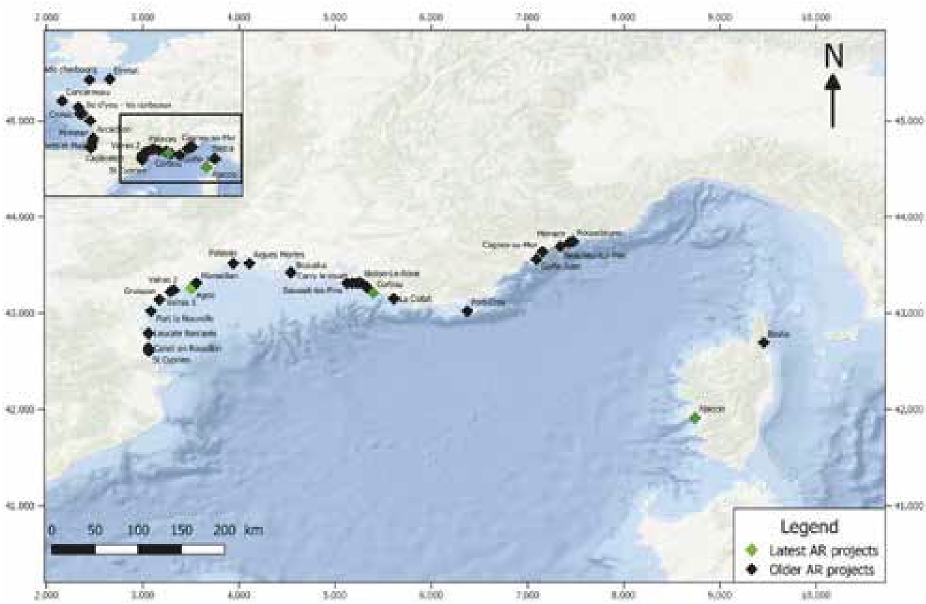

Figure 1 - Maps of the locations of Artificial Reefs along the Mediterranean French coast (Jessica Salaün).

Materials and Methods

Four AR projects have been reviewed according to these new objectives:

- Bio-mimetic AR in the Ajaccio bay in Corsica. Three types of AR were submerged by Corsica's Environmental Office (CEO) in 2017. They use bio-mimetic technology to recreate the roughness of a natural reef and a chemical reaction to consolidate natural sedimentary particles. They had chosen material such as concrete, metal or broken shells to construct AR. Each AR had different fish targets. Multiple partners had been involved in this project: a scientific community with the Engineering school of Alès and the

University of Montpellier, Geocorail company with their innovative process and also angler organizations with their knowledge of the fisheries. At the end of the experiment and depending on the results, others AR could be submerged to increase the artificial area.

- Rexcor project. On the Cortiou's bay near Marseille in 2018 36 AR were submerged. This project has been conducted in the Marine Protected Area (MPA) of the "Parc National des Calanques" (PNC) and more specifically located at the end of an old sewerage pipe. This project was initiated in 2013, following a call for sustainable ideas and a tender process lead by the PNC, the water agency and the "Pôle mer Méditerranée". The bid was awarded to "Seaboost/Egis" in partnership with "CDC biodiversity" and "Architeuthis" [4]. A total of 36 AR with different designs were submerged. They used bio-mimetic technology to recreate the shape of the natural habitat. Each type of AR was deployed in four sites located at different distances from the end of the pipe. Monitoring is scheduled to evaluate the efficiency of the colonisation on the AR and the effect of this new habitat on the local biodiversity [11].
- Xreef project. In the MPA of the Agathoise coast, 32 artificial reefs were submerged in 2019, in order to delimit 300 m of the coastline (Figure 2). Seaboost Co. and XtreeE Co designed AR with 3D printing technology to provide cavities of different shapes and sizes adapted to the Mediterranean coastal fauna and flora.

Figure 2 - 3D printing AR in Agde (Renaud Dupuy de la Grandrive).

- RECIF LAB project in Agde's harbour submerged micro-reefs for mooring floating piers at the entrance of the port in 2020. This project has been conducted by the city of Agde with the cooperation of Seaboost Company. They had obtained a Future Investment Program (PIA) subvention from the Environment and Energy Management Agency (ADEME) that encourages the development of new tools and services with marine ecological engineering [1]. Recif lab project in Agde also plans to submerge an artificial landscape structure around natural Brescou reef. It will be built by means of 3D concrete printing. The monitoring will be led by a professional team of marine biologist divers of the MPA.

Results

In the future Mediterranean coasts will have to face increased marine activities and more coastal facilities which will have an impact on marine ecosystems [10]. The environment and biodiversity suffer from the effect of human activities, such as outfall sewerage pipe, anchoring, scuba diving and fishing.

France has developed a framework to avoid, reduce and then compensate for the impact of facilities projects on the ecosystem. Regarding this policy, ARs appear to be effective tools to compensate for the degradation of natural functionalities. An innovative feature of the last French reef projects is the association of ecological objectives with social ones. They respond to the necessity of both protecting and managing coastal areas.

Create new habitat and promote ecological value:

In the bay of Ajaccio, AR was used to provide hard substrate on a sandy sea bottom. They aim to attract crustaceans and commercial fish like lobsters and red sea bream (*Dentex dentex* L., 1758). AR are designed with roughness to facilitate the colonization by benthic fauna, which is the first echelon of the trophic chain. This deployment of AR provides new habitat to specific species in a naturally deprived area.

This program was built in cooperation with local actors like fishermen and free divers. The publicity around the ecological purpose of AR, highlights the environmental actions of the CEO and upgrades the biodiversity of Bay of Ajaccio. The social benefits are twofold: firstly, enhancing scientific knowledge with the results of a three-years-survey and secondly, generating economic profits resulting from the ecological valorisation of the bay.

Helping restoration of natural functionalities and restricted access:

REXCOR was an ecological restoration project that consisted of facilitating the resilience of fish in the area of an old sewerage pipe. The AR had been designed to enhance surface orientations for colonization and create caves as well as natural substrate.

To ensure ecological results, the PNC have forbidden all activities in the area and only researchers have access to the AR for monitoring purposes. Protection of marine ecosystem in providing new substrate also entails limited access of natural substrate. A team of marine patrol officers informs visitors of the policy to ensure that everyone respect the rules. The PNC also raises awareness among divers of good ecological gestures by means of implementing a charter.

Protection through the creation of artificial support for human activities:

RECIF LAB in Agde had developed several AR projects coupling social and ecological objectives. The first one was the Xreef project with the replacement of the old delimiting system of the swimming area with 3D printed AR. This new buoyage system optimised the cost of maintenance by reducing the number of interventions to only once a year [8]. This system also provides new habitat for the marine fauna.

The second project, submerged AR as a support for floating piers. The micro-reefs are eco-designed [10] to offer safe ballasting to the new mooring system in a dedicated area at the entrance of the harbour [2]. The floating piers system is also designed with cystoseira transplantation to create new habitat for small fish .

The last project had involved the creation of landscape AR to provide a new area for scuba diving and shift underwater diving activity from coralligenous marine habitat.

Discussion

With the on-going development of MPA, solutions for restoration or regulation of human activities are expected to increase. A financial program to restore ecological functionalities has been set up by European community and France with programs like “water quality” and Natura 2000 regulation [10]. ARs in France and Europe have recently been used more specifically to restore ecosystems and less to develop fisheries. As ARs seem to respond to this new objective of restoration, they are mostly deployed in already protected areas like MPA or Natura 2000 sites.

In light of the projects presented, ARs could be used in different ways; it can provide supplementary substrate and habitat for benthic and more generally marine fauna and it can sustain ecosystem’s functionalities to substitute natural substrates. This tool has been chosen to respond to both environmental and social economic issues. Environmental issues focus not only on ecological restoration, but also on overcoming the challenging effect of climate change. AR are developed for experimental research and used as a field for observing marine life. Social and economic issues consist of implementing effective coastal management. AR coupled with public investments permit to unify actors of a territory around an environmental project. When the main purpose is ecological, ARs are not used without social restrictions. For example, as they are employed for restoration, policy is implemented to regulate access to these areas. On the other hand, when the social ARs are deployed, they also respond to the ecological concerns by protecting the natural surrounding area.

As ARs are deployed in response to ecological and social objectives, social-ecological studies should be established as a relevant research axis. The most recent approach is to couple the modelling of trophic network with social-network modelling. For example, Ecological Network Analysis (ENA) is a well-known method to quantify how species interact and influence their environment [6]. Social-network modelling also reveals key actors of the network and highlights their connection within the ARs network (Figure 3). Multi-factor analysis takes into account both social and ecological results which helps to design effective management strategies and facilitates the comprehension of their functioning [7]. They could also evaluate ARs efficiency with a systemic approach which helps managers to choose the best tools to balance ecological and social expectations.

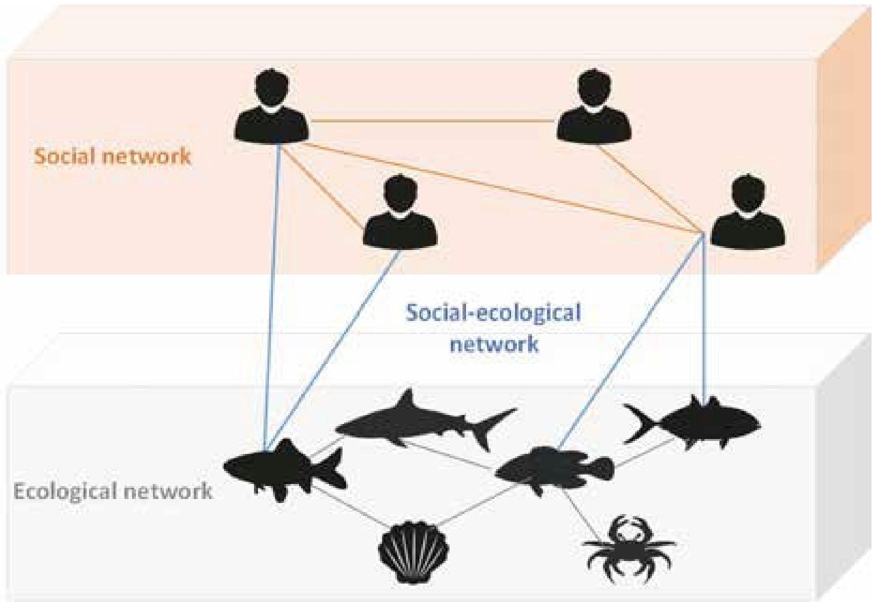

Figure 3 - Example of social-ecological network [3].

Conclusion

ARs do not work as an isolated system. To be useful, they need to be considered as multi-use tools. Primarily used as fishery management tools, their objectives have evolved to include ecological purposes like habitat restoration and social aims such as recreational or eco-mooring tools. The evaluation of the efficiency of new AR objectives also needs to evolve and some adjustments are required. Previously, if assessments had been done, they focused only on some ecological components like commercial fish [13]. Now they will have to take into account the entire social-ecological system, which has been created around AR tools by using a social ecological approach.

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