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DESCRIPTION OF A THEORETICAL SOCIAL-ECOLOGICAL APPROACH TO MANAGE ARTIFICIAL REEFS

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ARTIFICIAL REEF
ACTOR NETWORK THEORY
TROPHIC NETWORK
SOCIAL-ECOLOGICAL NETWORK

ABSTRACT. – Network analysis is used to address diverse ecological, social, economic and management questions, but few studies combine social and ecological issues in a single analysis. Understanding the links between social and ecological networks helps in establishing coastal management strategy for the sustainable use of marine resources. The aim of this research study is to apply this approach to artificial reefs (AR) along the French metropolitan coasts. For fifty years, AR has been deployed in France with a single main goal: to sustain artisanal fisheries by enhancing resources. Assessing the effectiveness of this tool requires considering each stakeholder's initial intentions and comparing them to the actual results (social and ecological). Network analysis provides a holistic view of the relations between all the actors of the system that offers a basis for suggesting a suitable management strategy for each objective identified.

INTRODUCTION

Nowadays coastal ecosystems are strategically important in French marine areas. As the number of marine activities and their pressure on biodiversity and resources increase, there is increasing necessity to protect and manage the coastal environment. Achieving a balance between the ecological protection and the economic development of coastal areas is a complex matter. The drastic decline of biodiversity and marine resources and the increasing level of pollution are a threat to the major ecological functions, the health of ecosystems and human activities.

For more than fifty years, Artificial Reefs (AR) have been deployed in France (Fig. 1) to respond to the decline in fish stocks (Tessier *et al.* 2015). The main aim of these structures is to sustain artisanal fisheries and enhance fish stocks (Fabi *et al.* 2011). Assessments of their effectiveness, when they have been carried out, have been focused only on certain ecological components such as commercial fishes, for example (Véron *et al.* 2008). In 2012, despite a regional strategy for the Languedoc-Roussillon Region regarding the management of AR, there are still almost 10 areas of AR with no monitoring (Cépralmar, Région Languedoc-Roussillon, 2015). The lack of feedback raises questions regarding the real ecological and social efficacy of these structures.

A social-ecological study seems to be an appropriate research axis to understand the functioning of AR on the basis of a holistic approach. The study begins with an understanding of expectations of each of the territorial actors and stakeholders regarding the deployment of AR. Then ecological results are assessed with modeling of the food web before and after immersion of AR. In the third part, the social network will be analyzed on the basis of all the available data (such as report files, legal authorization) and the patterns of change in the social-ecological system will be highlighted. Finally, the comparison of the objectives identified with the social and ecological results will provide a basis for the assessment of the overall functioning of AR. The aims of this work are to understand how the social-ecological system could help to extend the integrated approach, and find solutions for better management of the coastline.

MATERIALS AND METHODS

Study areas: For each of the three French metropolitan coasts, two types of AR areas have been selected where possible: areas of active management and areas of soft management. To define the soft management of AR, we refer to the Mediterranean strategy for Languedoc-Roussillon (Cépralmar, Région Languedoc-Roussillon 2015), which recommends monitoring every three to five years and other criteria such as type of funding, communication and management (Table I).

In the English Channel, only two places have immersed AR: in Cherbourg harbor in the North Cotentin and off the coast of Etretat in the eastern basin (Fig. 2). On the Atlantic coast, more numerous sites with AR means that three of them could be selected: the island of Yeu in the north of the Bay of Biscay for the soft management group, Capbreton and Oléron Island representing active management for the southern and northern part of the Bay of Biscay (Fig. 2). On the Mediterranean coast, 26 AR have been established since the first deployment in 1968.

"An artifical reef is a submerged (or partly exposed to tides) structure deliberately placed on the seabed to mimic some functions of a natural reef, such as protecting, regenerating, concentrating and/or enhancing populations of living marine resources (Fabi *et al.* 2015)

Example of AR in English Channel at Cherbourg site
(© Nicolas Job and Michel Mansais *in* Chevalier & Leroy 2019)

Example of AR in Mediterranean Sea at Agde site
(© Sylvain Blouet in Blouet *et al.* 2012)

Example of AR in Atlantic at the Landes site (© ALR/Jean Célestrino)

Fig. 1. – Pictures of Artificial Reefs' structures (J. Salaün).

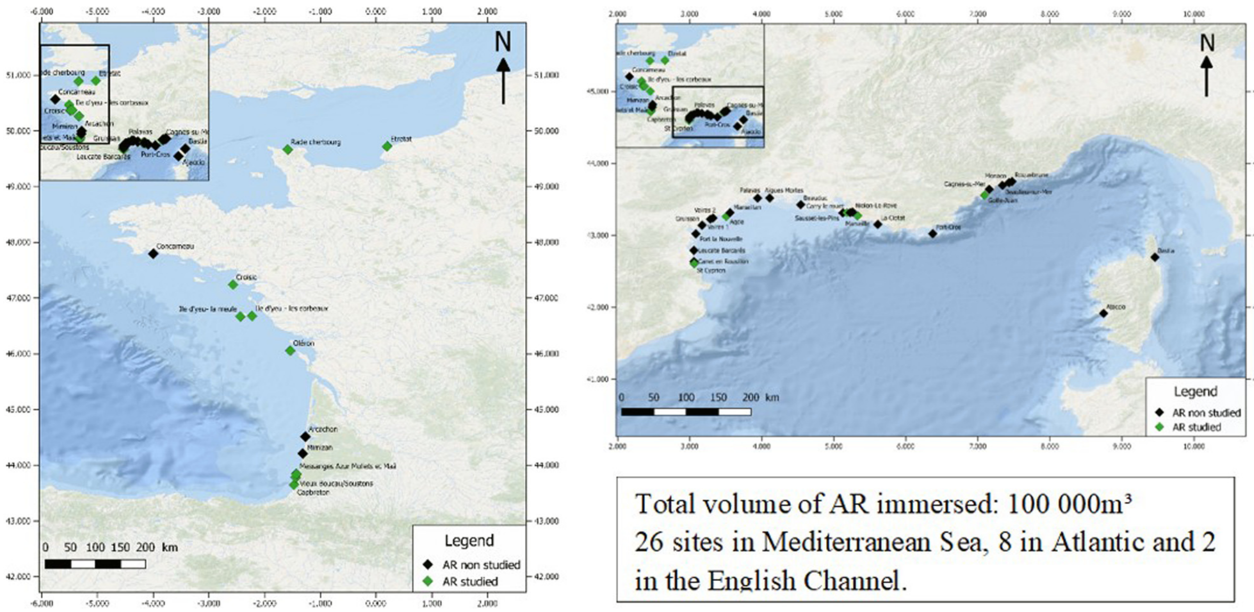

Fig. 2. – Maps of Atlantic, English Channel and Mediterranean locations of Artificial Reefs along the metropolitan coast of France (J. Salaün).

The latest AR project is the Prado reef in the bay of Marseille (the largest AR in the Mediterranean and in Europe, with a gross volume of 27,300 m^3; Charbonnel *et al.* 2011) and will be studied as the active management group with the Agde AR. For the soft management group, AR sites such as Gruissan or Niolon in the Côte Bleue Marine Park have been identified (Fig. 2). Other sites with mixed management could also be studied such as Vallauris/Golfe-Juan or Leucate.

Translation process method: The four-stage method of analysis within the Actor Network Theory (ANT) framework was used (Crozier & Frieberg, 1977). This frame was developed by Callon (1986) and Latour (1987) to understand the process of innovation and how scientific facts become constructed (Latour 1987). The translation process method consists in describing each step of the network construction and finding the Required Crossing Point that gathers all actors in order to achieve a mutually desired out-come (Jeacle 2017). In the ANT framework, actors can be human or non-human. The translation process method is described on the basis of four stages (Callon 1986, Reverdy 2013, Lombard-Latune 2018): (i) 'problematization', is the initial step that defines the individual issues and proposes common solutions; (ii) 'interest', is the step when the common project begins and each actor defines their motivation; (iii) 'enrolment' corresponds to the role played by each actor; (iv) 'mobilization' is a stage that makes it possible to extend and consolidate the actor network around the common project.

The data sources for this study derive from qualitative open-ended interviews of each actor for each study area (Alami *et al*. 2013). Actors are identified by project documentation and by the interviewed actors themselves. At the beginning of the interviewing survey, a social network is built, which is then completed by the other interviewees and so on, until that the last interview does not provide any new information to the constructed network (Kaufmann 2016).

Trophic modeling approach: The trophic network has been constructed by using the Ecopath with Ecosim software (Polovina 1984, Christensen & Pauly 1992, Christensen *et al*. 2008).

The Ecopath model was parameterized with two main equations. The first one describes the production for a group *i* and its predator *j* (Eq. 1) whereas the second describes the energy balance within a group i (Eq. 2):

$$B_iP / B_i = j = 1nB_jQ / B_jDC_{ij} + Y_i + E_i + BA_i + PB_i \text{ x } B_i(1 - EE_i) \quad \text{(Eq. 1)}$$

$$Q_i = P_i + R_i + U_i \quad \text{(Eq. 2)}$$

where the parameters are biomass (B, gCm^{-2}), production rate (P/B, $year^{-1}$), consumption rate (Q/B, $year^{-1}$), proportion of *i* in the diet of *j* (DC_{ij}, diet composition), total fishery catch rate (Y_i, gCm^{-2}), net migration rate (E_i, $year^{-1}$), biomass accumulation (BA_i, $year^{-1}$), ecotrophic efficiency (EE_i), respiration (R_i, gCm^{-2}) and unassimilated food (U_i).

Functional groups were defined by using biological and ecological characteristics of species. Functional groups have been chosen to be the same on both models for the Atlantic and the English Channel. For Mediterranean AR, a model already exists (Cresson *et al*. 2014). Twenty-three groups have been made: plunge and pursuit diver seabirds, surface feeder seabirds, marine mammals, representing top predators, benthopelagic cephalopods, benthic cephalopods, Gadidae, piscivorous fish, benthos feeder fish, Labridae, Sparidae, flatfish, planktivorous fish, commercial decapods, benthic invertebrates as Predators, Scavenger/Omnivorous, Filter, surface deposit feeder, subsurface deposit feeder, meiofauna, Zooplankton, Bacteria, Phytoplankton and Detritus. For all those groups, data was collected from the literature and/or from field measurements.

Table I. – Criteria to define managerial type.

Criteria	Differences	Managerial type
Objectives	Production	–
	Protection	–
Survey	Scientific survey	1
	Dissemination of results (report, publication, oral communication)	2
Management	Limited access	1
	Supervised activities	2
	Supervised sites	2
Authorization	Upload legal concession	1
	New immersion	2
Communication	Press articles	1
	Press articles and public awareness campaign	2
Funding	Occasional	1
	Annual	2

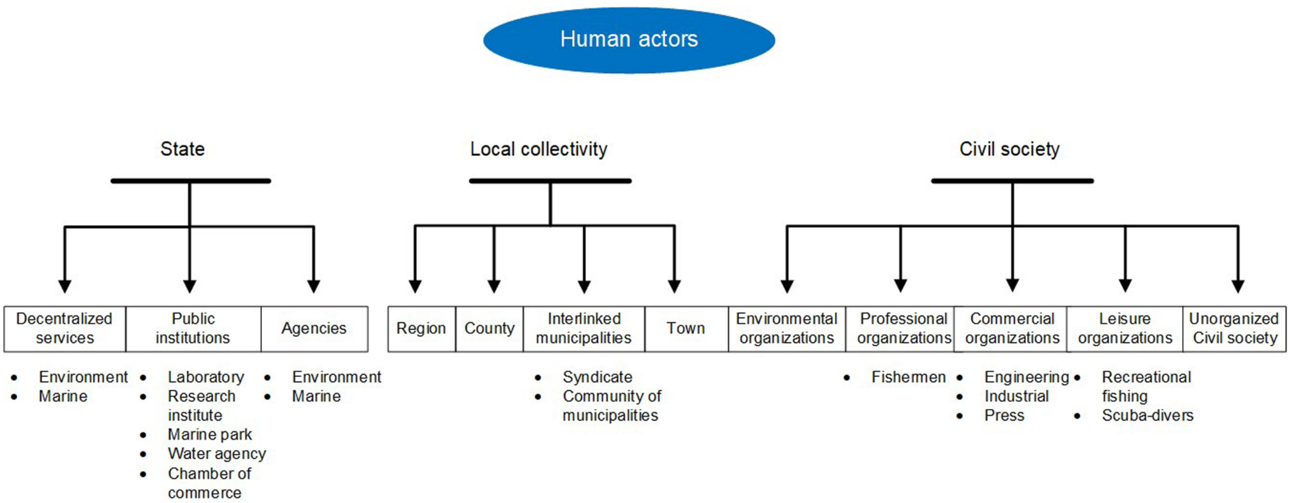

Fig. 3. – Type of social structures of artificial reef actors (J. Salaün).

Graph theory and network analysis: In the social-ecological network, nodes represent social actors of AR and links between interactions. Human actors have been grouped within three types of social structure (Fig. 3): state, local collectivity or civil society (Meur-Ferec 2006). They are also characterized by the type of actions that they carry out with regard to AR (financial support, technical support, governance, management, monitoring, users, etc.). All relations between actors can be divided into four general groups: information flow, technical material flow, monetary flow or human and skills flow. Links are directed from donor to receiver and are unweighed. Quantifying their strength or intensity will require a high degree of data that are not always available, such as the frequency of information flow. The network is analyzed using the iGraph package in R v3.5.2 (R Core Team 2019).

RESULTS

The revealed goals of AR

Each territorial actor has its own goal to achieve. The sociology of translation makes it possible to reveal them. Generally, the territorial actors of AR are:

– French State with DREAL, DIRM, DDTM, AFB and scientists from IFREMER or CNRS or universities;

– Local authority of Regional, *Département* or municipal territories;

– Civil society including environmental associations, professional associations, professional organizations, leisure associations and commercial activities.

They have different goals: developing marine activities, protecting their professional activity, improving knowledge of marine systems, enforcing regulation, promoting their business, their political group or territory, developing tourism, etc. The translation of their own goals in relation with the AR immersion project will reveal their real objectives.

Analysis of ecosystem organization

Ecological Network Analysis (ENA) is one well-known method to quantify how species interact with and influence their environment (Haak *et al.* 2017). For example, some of these indicators are:

– The Total System Throughput: it is the overall flows of the network;

– The effective Trophic Level (TL) indicates the effective position of species in the trophic network of AR;

– The Omnivory Index (OI) is a measure representing the diversity of the trophic level prey of a predator (Christensen & Walters 2004). This indicator indicates the selective predators that are fully dependent on their prey.

The Mixed Trophic Impact (MTI) routine is used to assessing the effect that biomass modification of one group could have on the biomass of other groups in the network (Ulanowicz & Puccia 1990).

The keystones index completes the analysis by assessing the effect that a minimal biomass variation will have on the biomass of another group (Libralato *et al.* 2006). From this assessment it is possible to understand the relative importance of the top-down or bottom-up trophic control in this AR ecosystem.

Analysis of social system

As the social systems are built before, after 5 years of immersion and nowadays, comparison of the architecture of those systems should indicate the key steps of their evolution. Some indicators such as density, degree centrality and betweenness centrality will be calculated to analyze models.

The density indicator measures the connectivity of a global web, by dividing the total number of connections present by the total number of possible connections (Kong *et al.* 2019). In AR networks, the increase or decrease in density indicates the involvement of territorial actors. The degree centrality represents the interconnection of network nodes, corresponding to the nodes' relation activities (number of neighbors of a node). Articulation points or betweenness centrality is a node that when it is gone, separates the network into pieces. This node plays a key role like a bridge between two distinct groups of actors. All these indicators make it possible to reveal key actors of the network and enable us to understand their connection within the AR network. This analysis helps in the design of effective management strategy and facilitates the comprehension of their functioning (Kluger *et al.* 2019).

DISCUSSION

AR ecosystem model

Trophic network modeling has been developed over decades and has been applied to various marine ecosystems around the world. This approach has been particularly used to understand the effect of fisheries on the entire ecosystem (Trites *et al.* 1999, Coll *et al.* 2006, Lassalle *et al.* 2011, Banaru *et al.* 2013, Moullec 2015, Bentorcha *et al.* 2017, Bentley *et al.* 2018). Recently, this approach has been extended to other research domains such as management of Marine Protected Area (Valls *et al.* 2012, Hermosillo-Núñez *et al.* 2018), rehabilitation measures (Espinosa-Romero *et al.* 2011, Guan *et al.* 2016) or to simulate the effect of wind farming on the ecosystem (Pezy *et al.* 2017, Raoux *et al.* 2018). Like wind farms, AR are mostly deployed on soft bottom habitats. They create hard substrate that will be colonized by different populations. Using ENA on this AR ecosystem makes it

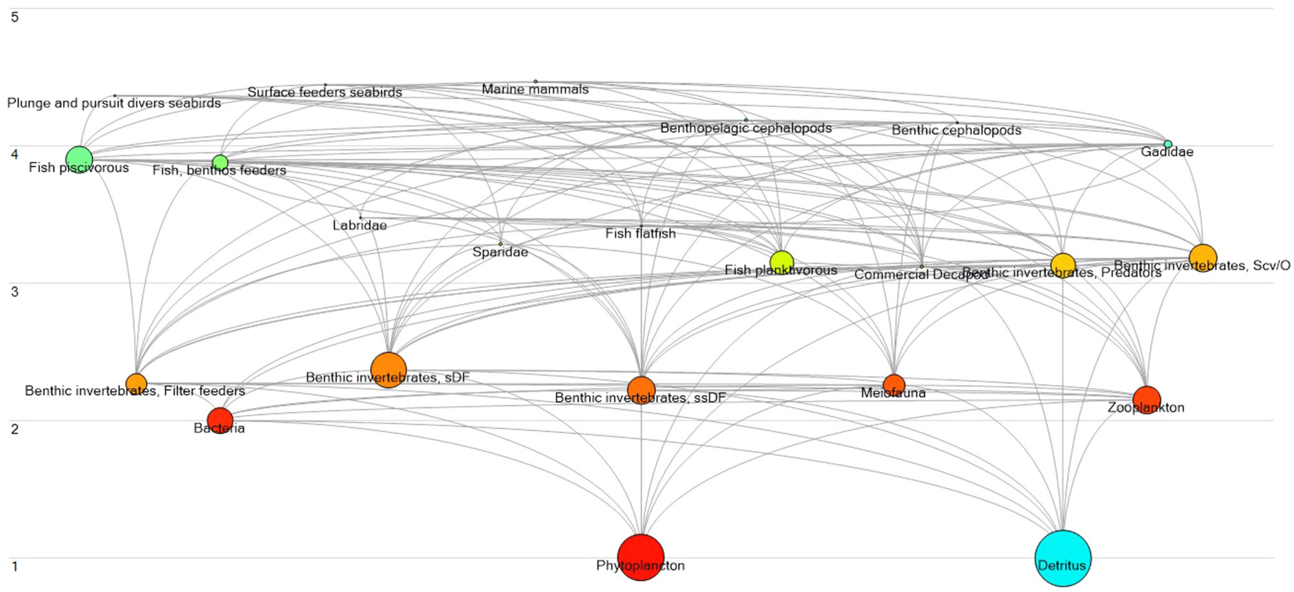

Fig. 4. – Trophic modeling of Cherbourg before installation of Artificial Reefs (adapted from A. Raoux).

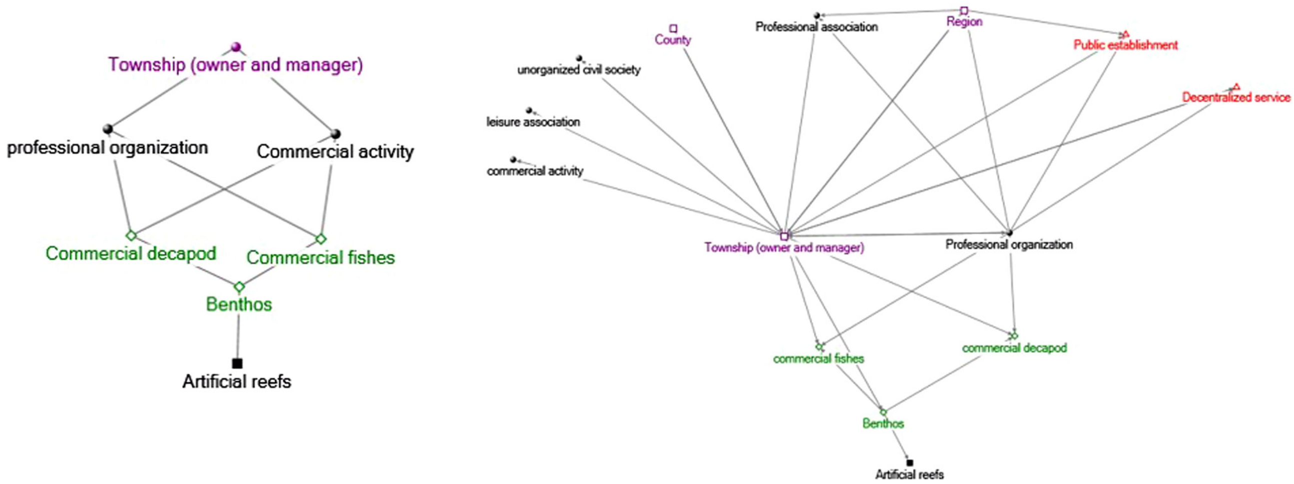

Fig. 5. – Example of social-ecological system of two Artificial Reefs areas: soft management on the left and active management on the right (J. Salaün).

possible to highlight the trophic modification linked to the introduction of hard substrate on soft habitats (Fig. 4).

Social-ecological model

Modeling before AR, after five years of immersion, and nowadays, offers the means to assess the social-ecological efficacy of AR. The assessment compares the identified goals to the actual results from a holistic point of view. These assessments show that, depending of the structure of the social-ecological network (Fig. 5) but also in function of the social type of the manager, results (social and ecological) are different. Furthermore, some actors such as fishers' organizations are essential and crucial at the beginning of the project but less interested during the "exploitation" step. In contrast, some actors could appear in the network only in this phase, such as leisure or environmental associations. Analyses of these assessments reveal the best social-ecological organization for each AR goal. This result can be used for future projects as an example of a social-ecological project adapted to the objectives of AR.

CONCLUSION: MANAGEMENT OF COASTAL AREAS

The uses of AR in function of new goals, such as ecological restoration (functionalities: nursery, spawning or protection) are a valuable help for the management of coastal activities (tourism, diving, artisanal and recreational fisheries). Recent AR deployments have targeted fisheries production, development of coastal activities (recreational, eco-mooring) and ecological restoration to offset human negative impacts (water filtering, nursery). They are innovative with regard to their ecological objectives but also materials and their proposal of new territorial dynamic governance goals to manage coastal areas (Pioch & Léocadie 2017). They try to address issues linked to diving for recreational activities, innovative biomimetic AR dedicated to targeted species production such as the spiny lobster *Palinurus elephas* (Fabricius, 1787) or the common dentex *Dentex dentex* (Linnaeus, 1758), the association between ecological restoration and mooring systems, or to enhance water filtration at the Marseille urban sewage treatment plant (Pioch *et al*. 2019). As the purposes and actors around AR are very diverse, the social-ecological approach is of interest to develop an overall management strategy for coastal areas under multi-use pressures.

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