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An Ecosystem Approach for understanding status and changes of Nador lagoon (Morocco): application of food web models and ecosystem indices

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ABSTRACT

The work applies food web models to the Lagoon of Nador (Morocco) and subsequently estimates ecosystem indices. This effort supports the evaluation of the ecosystem status and the implementation of the Ecosystem Approach (EcAp), endorsed by the contracting parties of the Barcelona Convention for the Mediterranean Sea. The Lagoon of Nador, on the Mediterranean coast of Morocco, suffered from eutrophication during recent decades. We used indices derived from Ecological Network Analysis for investigating the most relevant features of ecosystem functioning in the decade 2000–2010 (*present scenario*), and comparing them with those of the 1980s (*past scenario*). As the Lagoon includes different habitats, the methodology was applied to each of them, in order to assess their contribution to the functioning of the whole ecosystem. Results highlighted an increase in Total System Throughput (TST) in the *present scenario* when compared with the *past one*, also associated to an increase of Total Respiration (TR) and of the ratio between Total Primary Production and Total Respiration (TPP/TR). Under the *present scenario* Nador lagoon shows a decreased cycling efficiency. The sensitivity analysis highlighted the capability of TST and Comprehensive Cycling Index (CCI) in detecting changes, in agreement with other recent studies on responses of food web functioning to eutrophication. The results are discussed in respect to three specific aspects, related with the application of food Web Models and Ecological Network Analysis in the EcAp context: i) data availability; ii) spatialization of indicators; iii) selected set of indicators. The results also highlight the important role of sensitivity/uncertainty analysis when implementing food web models in data-scarce systems.

1. Introduction

Food web models (FWMs) have been widely used for studying trophic networks in coastal and marine ecosystems and are recognized by scientists as consolidated, operative tools for analysis and assessment of ecosystem functioning (Belgrano et al., 2005). These models were first applied at steady-state and made available through specific packages such as Ecopath (Polovina, 1984; Christensen and Walters, 2004), NETWRK (Ulanowicz and Kay, 1991), and inverse methods (Vézina and Platt, 1988). Such models can be used to assess changes in the external or internal ecosystem fluxes (e.g. fishery, migration, resuspension/sedimentation) and to evaluate spatial or temporal changes in ecosystem structure. Starting from FWMs results, the study of food web functioning can be deepened and detailed through Ecological Network Analysis (ENA) (e.g. Ulanowicz, 2004, 2011; Fath et al., 2013). ENA has been applied to a wide variety of estuarine and coastal environments, again for studying variations of food web functioning in time (e.g Baird and Ulanowicz, 1989) and in space (e.g. Christensen, 1995).

To preserve and improve the health of Mediterranean coastal and marine ecosystems, two policy processes are presently running in parallel: the Ecosystem Approach (EcAp), involving the contracting parties of the Barcelona Convention (Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean, (UNEP(OCHA)/MED IG.6/7) and the Marine Strategy Framework Directive (Directive, 2008/56/EC, MSFD), concerning EU member States. These legislative frameworks target the common aim of reaching Good Environmental Status (GEnS). Both

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policies define the environmental quality at the ecosystem level in an integrative way, by means of Ecological Objectives (EO) and Qualitative Descriptors (D), respectively summarizing the whole ecosystem functioning (Borja et al., 2011). Progress towards EcAp entails important challenges for all Mediterranean countries: many indicators, identified for the set of EO/D, as well as the entire framework, are new, and it will take a considerable effort to make them operational and validate them. This is especially true in the case of North African coast, where countries are legally bounded to the adoption of Barcelona Convention and thus directly involved in the implementation of EcAp. In this area, data on marine waters are scarcer than in the rest of the Mediterranean, and the need to improve monitoring efforts is challenging (Garmendia et al., 2015).

Four indicators were selected within EcAp EO number 4 'Marine Food Webs' (UNEP/MAP, 2012). These were Indicator 4.1.1: Production per unit biomass estimates for selected trophic groups and key species, for use in models predicting energy flows in food webs; Indicator 4.2.1: Proportion of top predators by weight in the food webs; Indicator 4.2.2: Trends in proportion or abundance of habitat-defining groups, and Indicator 4.2.3: Trends in proportion or abundance of taxa with fast turnover rates. At present, however, the process of implementation of food web indicators within UNEP/MAP monitoring programs is still far from complete and, therefore, they were not included in the list of common indicators to be used in the 'First phase integrated monitoring and assessment program' (UNEP/MAP, 2014). Also on the EU policy side, the use of food web models as tools for assessing indicators pertaining to MSFD D number 4 'elements of marine food webs' is still under evaluation and definition (ICES, 2014).

In this context, this work contributes to EcAp implementation at the Mediterranean level, strengthening and expanding the application of FWMs and derived ecosystem indices, to support the evaluation of the EO/D number 4. As a case study, the paper shows the results of food web models and ENA derived ecosystem indices developed for the Nador lagoon, located in the Mediterranean coast of Morocco. It is worthwhile noting that, based on a recent review on FWMs implemented for the Mediterranean (Coll and Libralato, 2012), out of 40 FWMs published in the last 30 years, only one dealt with a North Africa ecosystem, namely with the Gulf of Tunisi (Errais, 2010). Assessing the status of Nador lagoon ecosystem and investigating its evolution in recent decades represents an additional objective of the present study: recent investigations on submerged habitats and macrobenthic communities (Pranovi et al., unpublished data; Rezzoum and Najih, unpublished data) revealed major modifications in bottom habitats distribution and sharp decrease in abundances/biomass of benthic macrofauna in the lagoon, when compared with years 1980 and 1990 (Guelorget et al., 1987; Lefebvre et al., 1996). Consistently, the present study has the following specific objectives:

- comparing the present condition of the lagoon food web with those reported for the 1980s, with a particular focus on the role potentially played by eutrophication in determining the observed changes;
- documenting the value of FWMs-ENA application in the framework of EcAp, as tools providing support to understanding, monitoring and managing coastal ecosystems.

2. Materials and methods

2.1. Study site

The Nador lagoon, also called Sebkha Bou Areg or Mar Chica, is located in the North-Eastern part of Morocco, on the Mediterranean coast (Fig. 1). It is the second largest lagoon complex of Northern Africa (115 km^2, 25 km long and 7.5 km wide), the largest of Morocco and the only one located along its Mediterranean coast. A 25 km long sandbar separates the lagoon from the sea: the water exchange is guaranteed by a 6 m deep inlet which was dredged in 2011, while the older one is now naturally silting up. The lagoon is divided into two basins: the southern one communicates directly with the sea and is larger and deeper than the northern one, which is not connected to the sea. The hydrodynamic circulation within the lagoon is mainly wind driven (Guelorget et al., 1987; Hilmi, 2005) and the water renewal time before the construction of the new inlet was estimated in about 80 days (Hilmi, 2005). The lagoon is characterized by an extraordinary diversity of habitats (swampy zones, dunes, shallow waters) and very high fauna and flora biodiversity. It is also important as wintering and stopover site for more than 150 species of birds (Dakki, 2003): hence it was recognized as a Ramsar site in 2005. The lagoon is a nursery area for several fish species and it hosts rare and endangered plants, birds and invertebrate species, as well as several endemic and rare species. Artisanal fishing has always been one of the main activities in the Lagoon: the target species are generally migratory, high market value (sea bream, sea bass, eel, octopus).

Due to the evolution of natural and anthropogenic drivers, the lagoon ecosystem was subjected to increasing relevant pressures starting from the 1980s: eutrophication, chemical pollution, decreased water renewal, silting and modification of bottom structure, habitat destruction. One major driver has been represented by the excessive urbanization and urban sprawl (the population in the lagoon area has rapidly grown in the last 40 years, being at present about 245,000 inhabitants (Dakki, 2003). This caused disturbances to natural zones and determined the replacement of wetlands with built up areas. Pollution from various sources represents another relevant environmental issue: fertilizers are used in the drainage basin, iron mines and other industrial residues have been discharged in the lagoon, urban solid wastes have been dumped along the lagoon margins and urban waste waters are discharged, as treatment systems were under-sized (Ruiz et al., 2006). Consequently, different types of environmental impacts have been observed: e.g. contamination of lagoon sediments from heavy metals and organic compounds have been extensively documented (Lefebvre et al., 1996; Sabhi et al., 2000; El Moumni et al., 2004; Bloundi et al., 2008, 2009; Inani, 1995; Bellucci et al., 2003; Er-Raioui et al., 2012), even if Gonzales et al. (2007) reported that trace element concentrations in the sediments demonstrated scarce bioavailability. Eutrophication of lagoon waters and toxic algae blooms have been also reported (El-Madani et al., 2001, 2011; Daoudi, 2011; Daoudi et al., 2012). The Moroccan government has started to implement a depollution program for the lagoon, in parallel with the realization of important infrastructure to boost tourism in the area.

2.2. Food web models (FWMs)

The trophic structure of Nador lagoon was described by means of a steady-state food web model, in which the ecosystem is represented as a set of compartments, including species, or groups of species, having similar ecological and trophic features. At steady-state, the biomass production and import of each compartment are balanced by consumption and export. The overall budget of the ecosystem is determined by solving a system of linear equations, describing the budget for each compartment. In accordance with the notation used by Savenkoff et al. (2007a,b) and Brigolin et al. (2011), the mass-balance equation for the each i compartment can be written as: