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Ecosystem health of a Mediterranean semi-enclosed embayment (Amvrakikos Gulf, Greece): Assessing changes using a modeling approach

Chiara Piroddi [a,*], Dimitrios K. Moutopoulos [b], Joan Gonzalvo [c], Simone Libralato [d]

[a] Institute of Marine Science, Spanish Research Council, Passeig Marítim de la Barceloneta, 37-49, E-08003 Barcelona, Spain
[b] Department of Fisheries-Aquaculture Technology, Technological Education Institute of Western Greece, Mesolonghi, Greece
[c] Tethys Research Institute, Viale G. B. Gadio 2, 20121 Milan, Italy
[d] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Oceanography Division, Via Beirut 2/4 (Ex-Sissa Bulding), 34151 Trieste, Italy

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ABSTRACT

Marine and coastal ecosystems are important for human wellbeing in multiple ways and yet they are subject to increasing anthropogenic stressors which pose serious threats to their health status. In this context, we used an ecosystem modeling approach to assess and quantify the health status of a semi-enclosed embayment of the Mediterranean Sea, the Amvrakikos Gulf (surface: 405 km^2; maximum depth: 60 m) (Ionian Sea). In particular, we built a food web model of the Gulf ecosystem for the 1980 and we fit it to time series from 1980 to 2013. The aim of the study was to: (1) investigate dynamics of marine resources in the last three decades considering the effect of changes in rivers run off, development of fish farming and dynamics of fisheries as the major anthropogenic drivers affecting the system; (2) assess structural and functional changes of the Gulf, using model derived indicators obtained from temporal simulations. Results indicated that the strongest drivers in the Amvrakikos food web were changes in nutrients and organic matter mostly from the loads of two local rivers. Trends in ecological indicators, which explained changes in the structure of the Gulf, highlighted a degradation of the demersal compartments of the food web and a relative stability of the pelagic ones mainly due to high eutrophication levels. By including several ecosystem drivers into the model, the present study is intended as a tool for assessing Amvrakikos ecosystem health and for developing future management policies in the Gulf.

1. Introduction

Marine ecosystems are increasingly impacted worldwide by a series of threats that include overfishing (e.g., Pauly et al., 2005), aquaculture (e.g., Naylor et al., 2000), eutrophication (e.g., Diaz and Rosenberg, 2008), habitat loss and degradation (e.g., Dobson et al., 2006), climate change (e.g., Overland et al., 2010), pollution (e.g., Islam and Tanaka, 2004) and species invasion (e.g., Libralato et al., 2015). Possible irreversible impacts and synergies among these threats are posing doubts on the long term sustainability of goods and services currently provided by marine ecosystems (Halpern et al., 2012), with the result that many national and international regulations (e.g., European Marine Strategy Framework Directive, [MSFD; 2008/56/EC]; Convention of Biological Diversity, [CBD]) are intervening to assess, control and reduce stress induced by the aforementioned threats.

Yet, while a large body of studies focus on the impact of a single factor on specific compartments of marine and coastal environments, the assessment of cumulative and cascading effects of different threats remains poorly studied as well as the trade-offs that might rise when managing them in an integrated framework (Link et al., 2010). For this reason, there has been a growing interest to develop more comprehensive tools capable of assessing the effects of anthropogenic impacts within a single common framework (Halpern et al., 2008; Libralato and Solidoro, 2009; Travers et al., 2009) in order to facilitate the setting of targets and implementation of management measures (Cury et al., 2008; Kaplan et al., 2012; Piroddi et al., 2015). The development of ecosystem models, despite requiring a large amount of multidisciplinary data to be accurate, has increased in the last decades (Heymans et al., 2014; Piroddi et al., 2015) mainly driven by a worldwide movement toward ecosystem-based management approach (Levin et al., 2009; Pikitch et al., 2004). Ecosystem modeling approaches are particularly valuable in the context of

* Corresponding author.
E-mail address: cpiroddi@hotmail.com (C. Piroddi).

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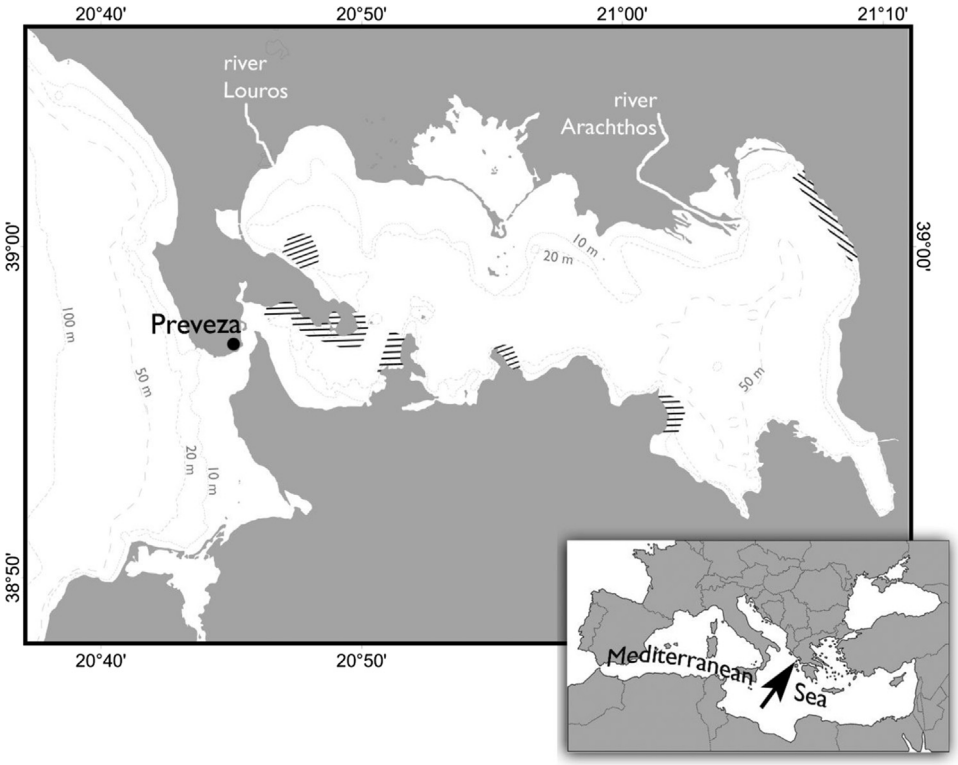

Fig. 1. The Amvrakikos Gulf map with depth profile and the location of fish farms represented by black lines.

European policies like the MSFD which requires an integrative assessment of the health status of marine and coastal ecosystems in relation to the cumulative effect of different pressures (Cardoso et al., 2010). In the following Directive, the assessment of ecosystem status and the setting of reference values and targets to achieve "Good Environmental Status" (GEnS) should be done through the use of indicators (Borja et al., 2014) which are already, at least partly, important ecosystem model outputs (Piroddi et al., 2015). Model derived indicators can in fact serve to evaluate whether an ecosystem and its services are well maintained and sustainably used so that the suitable management measures can be proposed (Piroddi et al., 2015; Shin et al., 2010).

Here we assessed the health status of the Amvrakikos Gulf (Greece, Fig. 1) which has been defined an ideal "natural laboratory" for ecosystem assessments (Bearzi et al., 2008) due to its small size, its semi-enclosed morphology (Katselis et al., 2013), its richness of charismatic megafauna (Bearzi et al., 2008) and because it provides several goods and services (EC, 2009). The Gulf is the final receptor of freshwater and nutrient loads from surrounding areas and from two important rivers, hosts several aquaculture sites (mostly fish farms active since the end of the 80s), and its resources are exploited by local small-scale fisheries. Nevertheless, despite being protected by national, European and international regulations for its diverse wildlife and wetlands (EC, 2009; Gonzalvo et al., 2014), the Gulf has undergone in the past decades through severe changes that have degraded rapidly the entire ecosystem (Katselis et al., 2013; Spyratos, 2008). It has indeed become seasonally hypoxic/anoxic (Kountoura and Zacharias, 2013) resulting in more than 50% of habitat loss on the seafloor (Ferentinos et al., 2010). Under such complex scenario, the Gulf represents a perfect case-study for applying ecosystem modeling approach and its model can be possibly of interest for other world's ecosystems facing similar pressures. The aims of our work were twofold: (1) investigate the dynamics of marine resources in the Amvrakikos Gulf from 1980 to 2013 considering the effect of rivers run off, fish farms and fisheries as major anthropogenic drivers affecting the system and (2) look at structural and functional changes of the ecosystem using model derived indicators obtained from temporal simulations.

2. Materials and methods

2.1. Study area

The Gulf of Amvrakikos (Fig. 1) is a semi-enclosed embayment of approximately 405 km^2 (excluding marshes and lagoons), situated in north-western Greece that communicates with the Ionian Sea through the Preveza Channel: a narrow (minimum width of 370 m) and shallow (<5 m at the shallowest point and $\sim$20 m at the deepest) 3 km-long corridor. Its fjord-like hydrographic regime, because of a shallow sill, reduces deep-water exchange with the open sea; the mean depth of the Gulf is approximately 30 m (its maximum is 60 m), with a seabed mostly covered by mud or sand (Ferentinos et al., 2010). Surface salinity fluctuates widely but remains low throughout the year (17–35‰: Friligos et al., 1997) while sea-surface temperatures range between 9.0 °C and 30.6 °C (Friligos et al., 1997; Panayotidis et al., 1994). Water quality of the Gulf is influenced by the runoff of two rivers (Louros and Arachthos), located in the northern shore (Friligos et al., 1997; Kountoura and Zacharias, 2013), which is controlled by dams operating since 1953 and 1980 for Louros and Arachthos respectively (Ferentinos et al., 2010). Moreover, the Gulf is affected by fish farms, agriculture, livestock and discharges from domestic sewage from coastal towns and villages (Ferentinos et al., 2010; Gonzalvo et al., 2014). In the last 20–30 years, the deeper layers of the water column have become seasonally hypoxic/anoxic, with the western side seasonally hypoxic and the eastern seasonally anoxic (Kountoura and Zacharias, 2013), while the epipelagic layers are still characterized by abundant marine life (Bearzi et al., 2008; Gonzalvo et al., 2014; Panayotidis et al., 1994).

Commercial fisheries operating in the study area include only