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Artificial neural network approach to population dynamics of harmful algal blooms in Alfacs Bay (NW Mediterranean): Case studies of *Karlodinium* and *Pseudo-nitzschia*

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ABSTRACT

The dinoflagellate *Karlodinium* and the diatom *Pseudo-nitzschia* are bloom-forming genera frequently present in Alfacs Bay. Both microalgae are associated with toxic events. Therefore, understanding their population dynamics and predict their occurrence in short-term is crucial for an optimal management of toxic events for the local shellfish production and ecosystem managers.

Artificial neural networks have been successfully used to model the complex nonlinear dynamics of phytoplankton. In this study, this approach was applied to predict absence-presence and abundance of *Karlodinium* and *Pseudo-nitzschia* microalgae in Alfacs Bay (NW Mediterranean) using biological and/or environmental variables. Neural Interpretation Diagram (NID) and Connection Weight Approach (CWA) methodologies were applied to obtain ecological information from the models.

The dataset used was long-term (1990–2015) time series of environmental and phytoplankton variables from different monitoring stations established in Alfacs Bay (Ebre Delta), meteorological data and Ebre River flow rates.

Several models were presented. The best ones were achieved for one-week ahead procedures performed with environmental and biological variables using all the available data. A sensitivity analysis showed the larger the data set used, the better the models obtained. However, *Karlodinium* absence-presence models developed with five years of data present high accuracy.

The size of the neural networks denotes complex relationships between environmental and phytoplankton variables. The environmental variables had stronger influence on the abundance models while biological variables had more importance in the absence-presence models. These results highlight a complex ecosystem in Alfacs Bay involving anthropogenic, climatic and hydrologic factors forcing phytoplankton dynamics. In addition, a change in the ecosystem dynamics regarding *Karlodinium* is detected. The configuration and the accuracy achieved with the models allow their use in different real-world applications as automated systems and/or monitoring programs.

1. Introduction

Alfacs Bay, situated in the Ebre Delta (NW Mediterranean), sustains the major shellfish production area of the Spanish Mediterranean. The temperate climate, calm and enclosed waters and a high nutrient content from different sources (natural and anthropogenic) of this ecosystem give the necessary conditions to favour the proliferation of abundant microalgae, which is necessary for the shellfish growth.

However, Harmful Algae (HA) are periodically responsible of these phytoplankton outbursts. Depending on the HA, different types of negative consequences accompany these phenomena, such as illness and death in human consumers of contaminated fish and shellfish, as well as mortalities of wild and farmed fish and other animals, or a deterioration of the water quality. These negative impacts have enormous consequences on the local aquaculture industry causing serious economic losses. Therefore, early warning could alert shellfish harvesters and environmental managers and allow precautionary measures to be taken to minimise the negative impacts of HAs.

To prevent food intoxication, to improve the management of shellfish harvesting areas and to comply with European and

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national legislation, a weekly sampling strategy is being carried out in Alfacs Bay since 1987, as part of a monitoring program of the shellfish harvesting areas in the Catalan coast. The embayment is monitored comprehensively for the presence and concentrations of harmful microalgae and marine toxins among other variables.

More than twenty years of data were acquired on potential harmful phytoplankton species as well as on environmental conditions in Alfacs Bay. During these years, many projects were carried out in this ecosystem to study different processes such as the hydrodynamic, the nutrients and the phytoplankton community (Andree et al., 2011; Artigas et al., 2014; Camp 1994; Camp and Delgado, 1987; Fernández-Tejedor et al., 2010; Llebot et al., 2011; among others). This significant amount of information acquired allows the development of models to explicitly predict Harmful Algal (HA) occurrences.

In this paper, we present the development of several short-term forecast models of HAs in Alfacs Bay. Environmental and/or biological data were used as input variables. Two types of models were performed: absence-presence and abundance. Two objective species were chosen to model due to their importance at global and/or local scale: the diatom *Pseudo-nitzschia* and the dinoflagellate *Karlodinium*. The genus *Pseudo-nitzchia* is one of the potential harmful phytoplankton taxa that are monitored in Alfacs Bay. Some species of this genus can produce domoic acid (DA), which causes Amnesic Shellfish Poisoning (ASP). *Pseudo-nitzschia* is regularly present in Alfacs Bay with abundances that easily exceed 10^6 cells L^{-1}. However, there haven't been ASP closures in the area since the monitoring program has been established (Cembella et al., 2010). *Karlodinium* is an icthyotoxic dinoflagellate. Its' first detection during a bloom in Alfacs Bay was in 1994, associated to farm fish (*Sparus aurata*) and shellfish mortalities (*Mytilus galloprovincialis*). During this episode, *Karlodinium* abundances reached 20×10^6 cells L^{-1}. In this area blooms of *Karlodinium* are recurrent.

For both microalgae, data were gathered from the Monitoring Programme for the Quality of Waters in Shellfish Harvesting Areas of the regional government of Catalonia. Due to the feasibility of the monitoring program that requires evaluating phytoplankton communities in numerous stations in a short time, the methodology used to detect and quantify these taxa is the inverted light microscopy (Utermhöl method). However, it does not allow distinguishing between all *Pseudo-nitzschia* species neither between *Karlodinium* species, and therefore they are gathered in the groups *Pseudo-nitzschia* and *Karlodinium*. For modelling purposes it is important to mention that according to the study of Andree et al. (2011), *Pseudo-nitzschia* in Alfacs Bay is composed of a minimum of eight species (*Pseudo-nitzschia arenysensis*, *P. brasiliana*, *P. calliantha*, *P. delicatissima*, *P. fraudulenta*, *P. galiaxiae*, *P. multistriata*, *P. pungens*); and *Karlodinium* is composed of a minimum of two species: *Karlodinium veneficum* and *K. armiger* (Bergholtz et al., 2006).

The type of model chosen was the Artificial Neural Network (ANN). It is an Artificial intelligence tool that has been proven useful to predict phytoplankton population dynamics (Barciela et al., 1999; Lee et al., 2003; Maier et al., 1998; Velo-Suárez and Gutiérrez-Estrada, 2007). The advantages of neural networks are: (i) they are relative easy to set up; (ii) they can provide quick response and hence are well-suited for real time operation; (iii) their capability to deal with incomplete or inconsistent data and (iv) to model dynamic, non-linear and noisy data, especially when the underlying physical/biological relationships are not fully understood (Lee et al., 2003).

A requirement to obtain a good generalisation with neural network models is to have a big data set. This allows the model to learn more complex relationships, as it is the case of the phytoplankton dynamics. Therefore, the strategy addressed in this paper is to gather the maximum available data in a unique dataset. In addition, models trained with different amount of data are developed to test the necessary length of the time-series to obtain significant models.

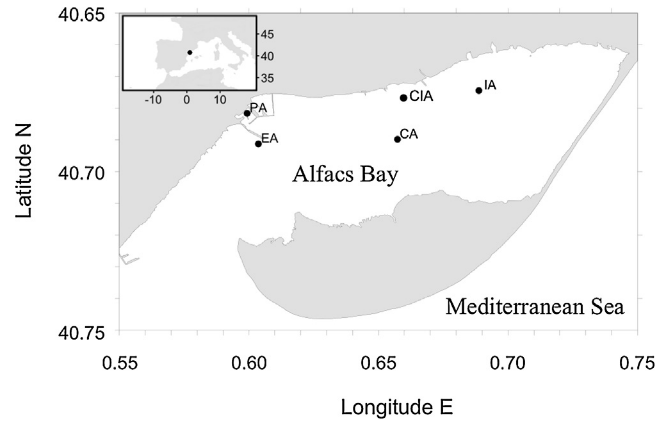

Fig. 1. Study area showing the location of the monitoring program stations of Alfacs Bay.

ANNs were usually labelled as a black box approach because they provide little explanatory insight into the relative influence of the independent variables in the prediction process (Olden and Jackson, 2002). However, a number of methods have been developed to obtain interesting information from these models. In this study, Neural Interpretation Diagram (NID, Özesmi and Özesmi, 1999) and Connection Weight Approach (CWA, Olden and Jackson, 2002) have been applied.

The main objective of this study is to perform absence-presence and abundance models for HAs in Alfacs Bay (NW Mediterranean), concretely to forecast *Pseudo-nitzschia* and *Karlodinium* abundances and also to gain more information about HAs in this ecosystem. To do that, time series of more than 20 years of biological and environmental variables were used. First, the similarities of the available data cases were analysed to build them in a unique data set. Second, drivers of phytoplankton dynamics were identified. Third, ANNs were developed and were finally analysed to obtain ecological information on the contribution of the independent variables to the HA forecasting. Finally, a sensitivity analysis was carried out to test the necessary length of the time series to obtain significant models.

2. Material and methods

2.1. Study area

The study was carried out in Alfacs Bay (Ebre River Delta, Northwestern Mediterranean Sea; Fig. 1). It has an area of 49 km^2 and an average depth of 3.13 m with a maximum of 6m. It is a positive estuary, where freshwater inputs exceed evaporation. Freshwater inflows mainly from irrigation channels situated in the north of the bay that collect water from rice fields. They were only active from April to October before 2000 and from April to December after 2000. Freshwater input is also present from groundwater and from treatment plants inputs. Mediterranean seawater enters the bay through a 2 km wide mouth situated in the Southwest. The residence time of water in the bay varies between one week and 3–4 weeks (Berdalet et al., 2013).

The local topography, with the coastal mountain chain breached by the Ebre River valley, exerts a significant control on wind climate. In general, four wind directions dominate in this area: NE, E, SW and NW (Bolaños et al., 2009).