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Artificial neural networks for modeling time series of beach litter in the southern North Sea

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ABSTRACT

In European marine waters, existing monitoring programs of beach litter need to be improved concerning litter items used as indicators of pollution levels, efficiency, and effectiveness. In order to ease and focus future monitoring of beach litter on few important litter items, feed-forward neural networks consisting of three layers were developed to relate single litter items to general categories of marine litter. The neural networks developed were applied to seven beaches in the southern North Sea and modeled time series of five general categories of marine litter, such as litter from fishing, shipping, and tourism. Results of regression analyses show that general categories were predicted significantly moderately to well. Measured and modeled data were in the same order of magnitude, and minima and maxima overlapped well. Neural networks were found to be eligible tools to deliver reliable predictions of marine litter with low computational effort and little input of information.

1. Introduction

During the last decades, anthropogenic marine litter has become a major environmental problem (Barnes et al., 2009). Marine debris is ubiquitous in all marine compartments ranging from the pelagic and benthic zones (Galgani et al., 2000; Thiel et al., 2011) to intertidal regions and beaches (Santos et al., 2009; Velander and Mocogni, 1998). Beach pollution with marine litter not only evokes esthetic and economic concern (Smith et al., 1997), but also has adverse effects on biota and the ecosystem via ingestions of micro- and mesoplastic by animals (Browne et al., 2008; van Franeker et al., 2011) and via entanglements of animals in derelict fishing gear, such as residuals of nets, fishing lines, and all kinds of cords, ropes, and ribbons (Fowler, 1987; Gregory, 2009; Votier et al., 2011).

The Marine Strategy Framework Directive (MSFD) of the European Union (EU, 2008, 2010) promotes the attainment of the Good Environmental Status (GES) of European marine waters by 2020. Among other environmental stressors, marine litter has become a descriptor of the environmental status of European marine waters. Indicators of GES have to be defined, and monitoring programs need to be developed and tested for their effectiveness, efficiency, and reliability for monitoring the success of measures implemented to combat the pollution of European seas with marine litter.

In the past worldwide, monitoring of beach litter has been carried out in diverse manners, which were mainly based on availability of human and economic resources, rather than on scientific criteria, such as representativeness, statistical reliability, and effectiveness. Few studies provided recommendations of beach litter monitoring based on these criteria (Ribic and Ganio, 1996; Ribic et al., 2010; Velander and Mocogni, 1999). However, with the exception of the OSPAR Marine Beach Litter program for the North-East Atlantic (OSPAR, 1992), in Europe standardized beach litter monitoring, with the purpose of the evaluation of litter pollution on beaches, is lacking. The OSPAR surveys have been carried out consistently since 2001 (OSPAR, 2010). Within the OSPAR program standardized monitoring of beach litter has been performed on 78 beaches bordering on the North-East Atlantic and the North Sea. 1000 m- and 100 m-long sections of beach were selected based on criteria, such as sediment composition, accessibility, beach cleaning programs, and other characteristics. Standard surveys of the abundances of 112 litter items have been carried out four times each year in spring, summer, autumn, and winter.

Statistical evaluations of monitoring data can help to improve beach litter monitoring programs. For example, Tudor et al. (2002) attempted to assign sources of marine litter to single items by applying principal component analyses. However, factor loadings

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indicated non-consistent linkage between single variables and sources, owing to the fact that transport processes altered compositions of marine litter. Therefore, there is still considerable need for identifying indicators of sources of beach litter.

Among statistical models, artificial neural networks (ANN) have seldom been applied to forecast beach pollution with marine litter (Balas et al., 2004; Balas and Tur, 2006). In ANN, few representative litter items can be used as predictors of general categories, such as all objects originating from fishing, made of plastic, or used as packaging material. In addition, ANN may serve to assign single litter items to litter sources, such as fishing, shipping, and tourism, with some degree of certainty. Until present, assignment to a given source has relied on expert knowledge and consensus rather than on statistical criteria.

Therefore in this study the following hypotheses were postulated:

- By means of ANN, the assignment of single litter items to source categories and other general categories can be validated.
- ANN with little input information are reliable tools to model abundances and compositions of general beach litter categories.

In this study, in order to verify these hypotheses, a simple prototype of ANN was developed and used to simulate time series of general litter categories on seven beaches in the southern North Sea. Data from the OSPAR beach litter monitoring program (OSPAR, 2010) were provided by the OSPAR Intersessional Correspondence Group Marine Litter (ICG ML). In the study at hand, these data fed into the newly developed ANN and were used to calibrate and validate their simulations.

2. Materials and methods

2.1. Monitoring of beach litter

Since 2001, regular surveys of beach litter pollution have been carried out on standardized lengths (100 m) of beach on the North-East Atlantic coast within the framework of the OSPAR convention (OSPAR, 1992). Beaches included in the monitoring program were selected according to the following criteria:

- composed of sand or gravel and exposed to the open sea,
- accessible to surveyors all year round,
- accessible for ease of marine litter removal,
- a minimum length of 100 m and if possible over 1 km in length,
- free of 'buildings' all year round,
- not subject to any other litter collection activities.

Ideally, surveys were carried out at intervals of about three months in winter (mid-December–mid-January), spring (April), summer (mid-June–mid-July), and autumn (mid-September–mid-October). A total of 78 100 m-long beach sections located on the European coasts of the North-East Atlantic and the North Sea were surveyed according to the Guidelines for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area (OSPAR, 2010).

During surveys, the abundance of macroscopic beach litter was recorded on standard 100 m sections of beach along the coastline. Data on the amount of litter on a given section of coastline were recorded at the item level. Items are identifiable pieces of litter such as plastic bottles, Tetrapak containers, metal drinks cans, rubber gloves, etc. Each piece of litter was assigned to one of 112 different items. Only intact objects and fragments >2.5 cm in the longest dimension were used for this analysis, although fragments smaller than 2.5 cm were recorded during surveys. Items were assigned to different categories according to the material they are made of (e.g. plastic/polystyrene, rubber, cloth/textile, paper/cardboard, wood, metal, glass, and ceramic/pottery) or their use (sanitary and medical waste). All litter was collected and removed from the monitored section during the survey. In addition, each item was assigned to a given purpose, such as packaging, user item, consumer, and professional, by experts of the ICG ML. Numerous temporal and spatial gaps in coverage are present in the dataset, because the survey programs of the OSPAR member states did not start at the same time, were forced to stop for a time due to lack of funding and/or were terminated before 2012. The monitoring data were provided by the OSPAR ICG ML. Justification of the survey method applied concerning beach cleaning activities, buffer areas, and recording litter abundances instead of weights is given in Schulz et al. (2013). In addition, these authors provide results of descriptive and analytical statistics of all OSPAR beach litter time series from 2001 to 2011.

2.2. Study site

The study site is part of the coast of the North Sea, a semi-enclosed shelf sea adjacent to the Northern Atlantic Ocean (Fig. 1). The North Sea is connected to the Atlantic via a) the English Channel between England and France/Belgium and b) the Norwegian Sea located between Scotland and Norway. Westerly winds and predominant counterclockwise currents mainly transport floating and submerged objects from the Channel along the southern coast eastward to the German Bight (Vauk and Schrey, 1987).

Seven beaches of 100 m length each, located at the southern coast of the North Sea (Fig. 1, large subfigure), were selected from the OSPAR beach litter monitoring database, namely Sylt (OSPAR beach ID DE1), Minsener Oog (OSPAR beach ID DE3), Juist (OSPAR beach ID DE5), Bergen (OSPAR beach ID NL1), Noordwijk (OSPAR beach ID NL2), Veere (OSPAR beach ID NL3), and Terschelling (OSPAR beach ID NL4).

In this sub-region of the North Sea, marine litter originates from several sources, such as fishing, shipping, and tourism. Plastic debris comprises the major part of total marine litter with portions between 50% and 70%, while the major fraction of marine litter recorded on these beaches is packaging (OSPAR, 2009).

2.3. Selection of beach litter variables

Prior to creating a prototype of ANN, three single litter variables were selected as input variables, namely tangled nets, strapping bands, and crisp and sweet packaging, which are attributable to the source variables 'sum of fishing items', 'sum of shipping items', and 'sum of tourism items', respectively. These three single categories served as predictors, because they are among the most abundant single beach litter categories and show considerable variation over time. Season coded by numerical integers (winter = 1, spring = 2, summer = 3, autumn = 4) was chosen as additional predictor, because in the North Sea, irrespective of the kind of beach litter, almost all significant seasonal patterns of litter abundances peak in spring, while they are usually low during the other seasons (Schulz et al., 2013). These authors discuss hydrological and climatic forces as major reasons for the described seasonal patterns, dominating over other factors, such as direct littering on beaches, which should lead to a peak of tourism-related items in summer and autumn surveys.

Within the ANN, the sum of litter variables originating from fishing, shipping, and tourism, as well as total plastic, and total packaging material were chosen as dependent variables, because these variables include the vast majority of beach litter items recorded. In addition, the selected items are also representative of plastic and in part of packaging material.