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Relative contribution of multiple stressors on copepod density and diversity dynamics in the Belgian part of the North Sea

Yana Deschutter[a,b,*], Gert Everaert[a,c], Karel De Schamphelaere[a], Marleen De Troch[b]

[a] Ghent University, Laboratory of Environmental Toxicology and Aquatic Ecology, Coupure Links 653, B-9000 Ghent, Belgium
[b] Ghent University, Marine Biology, Krijgslaan 281 – S8, 9000 Ghent, Belgium
[c] Flanders Marine Institute (VLIZ), Wandelaarkaai 7, B-8400 Ostend, Belgium

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ABSTRACT

The effect of multiple stressors on marine ecosystems is poorly understood. To partially bridge this knowledge gap we investigated the relative contribution of environmental variables to density and diversity dynamics of the zooplankton community in the Belgian part of the North Sea. We applied multimodel inference on generalized additive models to quantify the relative contribution of chlorophyll *a*, temperature, nutrients, salinity and anthropogenic chemicals (i.e. polychlorinated biphenyls and polycyclic aromatic hydrocarbons) to the dynamics of calanoid copepod species in the Belgian part of the North Sea. Temperature was the only predictor consistently showing a high importance in all models predicting the abundances of the selected copepod species. The relative contribution of other predictors was species-dependent. Anthropogenic chemicals were important predictors for three out of six species indicating that chemical mixtures at low concentrations should not be left unattended when performing risk assessments in a natural environment.

1. Introduction

As human population is expanding, coastal and shallow marine ecosystems are increasingly experiencing multiple disturbances (Airoldi and Beck, 2007; Crain et al., 2008). Ongoing climatic changes are leading to changes in sea water temperature, salinity and pH (IPCC, 2014; Wiltshire and Manly, 2004). Several effects of climate change on marine ecosystems and species distributions have already been reported: latitudinal shifts in plankton and fish species, local species extinctions, invasion of non-native species, changes in community structures and mismatches between successive trophic levels (Pitois et al., 2012; Wernberg et al., 2012). In addition to these physical stressors, marine ecosystems have to deal with a wide range of chemical pollutants that end up in the marine environment due to human activities (Weis, 2014). In the Belgian part of the North Sea (BPNS), multiple micropollutants are present and some of them exceed their corresponding Environmental Quality Standard (EQS) indicating their potential harmful effects (Janssen et al., 2010). These chemical mixtures can cause adverse effects to organisms, even when the individual components of the mixture are present at concentrations below their individual no effect concentrations (Janssen et al., 2010). Current risk characterization has shown to be insufficient to integrate the effects of these chemical mixtures (Janssen et al., 2010) and does not take into account the fact that stressors resulting from climate change are likely to affect contaminant exposure and toxic effects and vice versa (Moe et al., 2013; Schiedek et al., 2007). To guarantee a sustained biodiversity and thus ecosystem functioning, the understanding of the relative importance of the main factors in marine ecosystems is crucial (European Marine Board, 2013; Crain et al., 2008). Laboratory studies have shown that synergistic effects are common when multiple stressors are acting together on an ecosystem (Crain et al., 2008). However, laboratory tests do not necessarily reflect the conditions prevailing in nature, making field observations crucial to validate the results of laboratory tests to more natural conditions (Galic et al., 2010; Holmstrup et al., 2010).

Zooplankton populations are good indicators of environmental stress (Hays et al., 2005; Taylor et al., 2002). Zooplankton consists of drifting organisms with limited swimming capacities who largely depend on currents in the water column. This makes their responses to environmental stressors relatively straightforward to interpret (Richardson, 2008). Most zooplankton species are short-lived (< 1 year), allowing for a tight coupling between environmental changes and population dynamics (Hays et al., 2005, Taylor et al., 2002). Subtle environmental perturbations are even known to be amplified within this community (Taylor et al., 2002). At the base of the marine pelagic food web, they form the plant-animal interface and any

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[*] Corresponding author at: Ghent University, Laboratory of Environmental Toxicology and Aquatic Ecology, Coupure Links 653, B-9000 Ghent, Belgium.
E-mail address: Yana.Deschutter@UGent.be (Y. Deschutter).

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change in the structure of this community is therefore propagated to higher trophic levels. Impacts of stressors on zooplankton communities are expressed through changes in species distributions and abundances, changes in timing of life cycle events and modified community structures (Richardson, 2008). An increased understanding of the relative importance of different stressors for this functional group is a good step forward to identify the main drivers of changes in the marine ecosystem. One specific taxonomic group, Copepoda (Crustacea), comprises 66% of total zooplankton abundances in the BPNS and is part of the holoplankton (organisms spending their entire life as plankton in the water column), making them suitable indicators for changes in the zooplankton community (Van Ginderdeuren et al., 2014).

The BPNS is among the most intensively exploited marine areas in the world, with a large variety of activities concentrated in a small region (Douvere et al., 2007). Even though regulations about the release of toxicants in the environment are becoming more stringent, several persistent organic pollutants (POPs) are still present in this region at concentrations exceeding international quality standards (Everaert et al., 2014; Ghekiere et al., 2013; Janssen et al., 2010). Polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) are intensively studied POPs as they are part of the OSPAR List of Chemicals for Priority Action (OSPAR, 2007) and are often used as POPs model substances (Desaules et al., 2008; Everaert et al., 2014, 2015a; Schuster et al., 2010; Wania and Mackay, 1999). Our study aims to quantify the relative contribution of chlorophyll *a*, temperature, nutrients, salinity and POPs (more specifically PCBs and PAHs) to density and diversity dynamics of the zooplankton community in the BPNS. To do so, we applied multimodel inference to generalized additive models on calanoid copepod abundance and diversity data collected monthly from February 2015 to February 2016 at three stations in the BPNS.

2. Materials and methods

2.1. Data collection

Simultaneous zooplankton and water samples have been collected on a monthly basis from February 2015 to February 2016 at three stations in the BPNS. These stations were selected as we expect differences in their zooplankton dynamics (Van Ginderdeuren et al., 2014). Two nearshore stations were selected: station 700 located close to the harbour of Zeebrugge, situated near the mouth of the Scheldt River, and station 120 close to the harbour of Nieuwpoort, together with the offshore station ZG02 which is situated within the Flemish banks in the western part of the BPNS (Fig. 1).

In total 100 zooplankton and 32 water samples were collected. Triplicate zooplankton samples were collected as in Van Ginderdeuren et al. (2014) with a WP2 zooplankton net (70 cm diameter, 200 μm mesh size) fitted with a flow meter that was towed in an oblique haul from bottom to surface at each station. Zooplankton was fixed and stored in a 4% formaldehyde solution. Calanoid copepods (Crustacea, Copepoda, Calanoida) were identified in the lab to the lowest taxonomic level possible using a stereomicroscope (Leica MZ 10) to identify the abundances of the different taxonomic groups. At each sampling station, CTD (conductivity – temperature – depth profile, using a Seabird 19plusV2 CTD) data were collected, together with measurements of dissolved oxygen and oceanographic, meteorological and navigational data using measurement devices on board the RV Simon Stevin (Flanders Marine Institute, 2017a). Water samples were taken with Teflon-coated Niskin bottles at a depth of 3 m. Nutrient and pigment concentrations were measured in these samples next to the concentration of a selection of polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (Table 1). The concentration of these toxicants was determined with gas chromatography–mass spectrometry (Trace GC and Trace DSQ, Thermo Electron Cooperation) after liquid-liquid extraction of the filtered (0.45 μm) water samples. To do so, internal standards were added to 4 L of water, which was extracted three times with dichloromethane. The extract was dried on Na$_2$SO$_4$, and subsequently concentrated to 0.2 mL using a rotavapor and a concentration apparatus with N$_2$. Before the final concentration anthracene-d10 was added as recovery standard. All solvents used were of purity suitable for organic residue analysis. Nutrient and pigment concentration data collected during our sampling campaigns were provided by the LifeWatch observatory as part of the Flemish contribution to the LifeWatch ESFRI by Flanders Marine Institute (2017b).

2.2. Model construction

Generalized additive modelling (GAM) (Zuur et al., 2009; Wood, 2006) was used to determine the main drivers of the abundance and distribution of calanoid copepod species in the BPNS. As opposed to generalized linear models, who are limited to the assumption that the

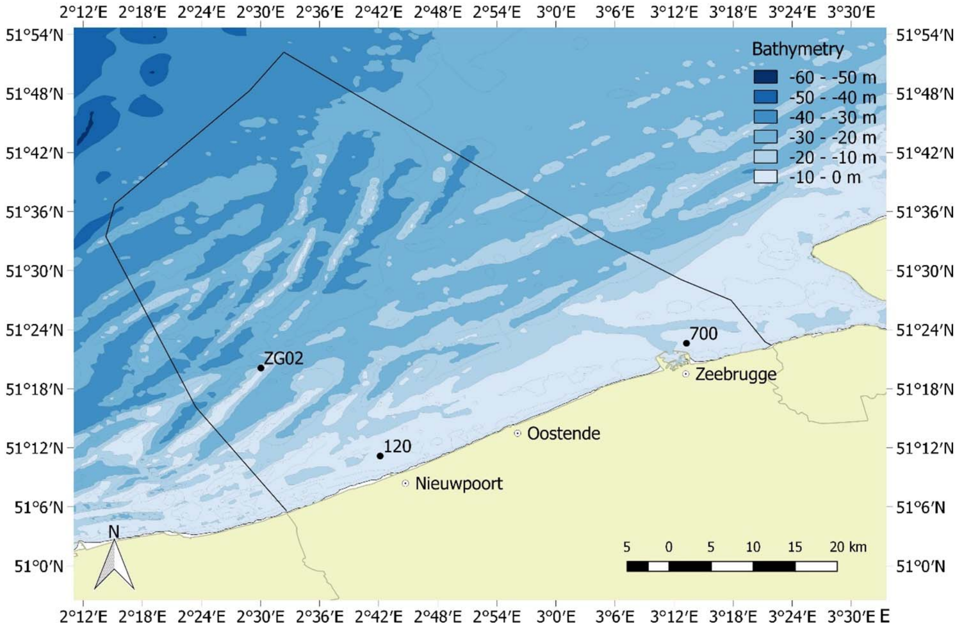

Fig. 1. Sampling locations in the Belgian part of the North Sea. Station 120: 51° 11′ 1″ N, 2° 42′ 07″ E, station 700: 51° 22′ 6″ N, 3° 12 ‘2″ E, station ZG02: 51° 20′ 0″ N, 2° 30′ 0″ E.

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