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Identification of potential surrogates to determine functional parameters of periphytic ciliate colonization for bioassessment in coastal waters

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A B S T R A C T

Protozoa, and specifically ciliates, can be used as bioindicators to assess environmental impacts. We developed a feasible, time-efficient protocol to determinate the functional parameters of periphytic ciliate colonization for bioassessment. Ciliate colonization dynamics at five different taxonomic levels (species, genus, family, order, class) were studied in coastal waters of the Yellow Sea, northern China from May to June 2010. Samples were collected, using glass slides as an artificial substratum, at depths of 1 and 3 m. The results showed that: (1) ciliates colonization curves had similar patterns, increasing in taxa over time (at all taxonomic levels), and the MacArthur–Wilson model provided a good fit to these data, at both depths: as taxonomic level increased (from species to class) the colonization rates (G) remained reasonably consistent, below class, and the time to reach the 90% equilibrium species number ($T_{90\%}$) decreased; (2) colonization dynamics showed similar temporal variations in community pattern at all five taxonomic levels; and (3) predictors of biodiversity (total number of taxa, richness, diversity, evenness) at the species level were tightly coupled (linearly) with biodiversity estimates at all higher levels, except class. These findings suggest that the high taxonomic levels, up to order, may be used as robust, time-efficient surrogates to determine the functional parameters of periphytic ciliate fauna. These observations provide guidance on improving sampling strategy for marine monitoring programs on large spatial and temporal scales.

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1. Introduction

Functional parameters of protozoan colonization have been widely used to evaluate the loading capacity or assimilative capacity of aquatic ecosystems for contaminant inputs (Cairns and Henebry, 1982; Railkin, 1995; Azovsky, 1988; Franco et al., 1998; Burkovskii and Mazei, 2001; Norf et al., 2007). Among these measures, the estimated equilibrium species number (S_{eq}) is generally negatively correlated with concentrations of organic pollutants and toxic levels of contaminants, while the colonization rate (G) is generally high in waters with lower environmental stress (Cairns and Henebry, 1982; Xu et al., 2002). So far, such colonization-based monitoring programs and associated ecological research have traditionally been conducted at the species level (Xu et al., 2005; Coppellotti and Matarazzo, 2000). However, this is laborious and limits their use for monitoring programs, especially by the environmental agencies that often deal with time restrictions and large scale studies (Xu et al., 2009; Zhang et al., 2012, 2013).

An alternative to examining the entire species assemblage is to identify suitable surrogates (e.g., higher taxonomic groups such as family or order) that reflect the sensitivity of the species assemblage to the environmental changes (Heino and Soininen, 2007; Xu et al., 2011a). Although the effectiveness of taxonomic surrogates has been clearly demonstrated for community-based research on both metazoan and protozoan assemblages (Stark et al., 2003; Khan, 2006; Xu et al., 2011a), to date there have been no studies that evaluate the use of surrogates to assess colonization rates for monitoring programs.

Protozoa, and specifically periphytic ciliates, are recognized bioindicators, because of their rapid growth rates, ubiquitous distribution in aquatic ecosystems, and ease of sampling. Furthermore, there has recently been an increase of user-friendly taxonomic references to identify them and development of standardized methodologies for their temporal and spatial assessment. (Lynn, 2008; Song et al., 2009; Strüder-Kypke, 1999; Mieczan, 2010; Xu

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et al., 2009, 2011a,b, 2012, 2014; Zhang et al., 2012, 2013) These attributes also make periphytic ciliates ideal for studying colonization rates, as many species will colonize a substrate in a few days. Finally, as they are relative immobile, this also allows extended monitoring of defined areas, especially for tidally influenced coastal waters.

Thus, here we focus specifically on temporal change in the taxonomic structure of periphytic ciliate fauna, in a typical coastal system (Yellow Sea, Qingdao, northern China). Our primary aim was to determine the extent to which taxonomic levels above that of species (i.e., genus, family, order, class) can be used, for bioassessment. To do this, we examined three aspects of colonization: (1) functional parameters associated with standard, model colonization curves, by applying the model of MacArthur and Wilson (1967); (2) temporal dynamics during colonization, dividing colonization into initial, transitional, and equilibrium states; and (3) change in biodiversity, by examining four standard indices.

2. Materials and methods

2.1. Data collection

The study site was located in the harbor of the Olympic Sailing Center at Qingdao, northern China (Fig. 1). This is a typical coastal area of Yellow Sea with an average depth of ~8 m, transparency of ~3 m and an average tidal range of 3 m. This region also reflects the type of environment that might require assessment, due to potential anthropogenic divers.

A total of 280 glass slides (each 17.5 cm^2) were used as artificial substrates for collecting periphytic ciliates; slides were deployed at 1 m and 3 m below the surface, to assess if sampling at 1 m is preferable (as proposed by Zhang et al., 2013). For each depth, seven PVC frames were deployed, each holding 20 slides. At each sampling time (days 1, 3, 7, 10, 14, 21, 28) 20 slides were randomly collected across the seven frames. Samples were collected simultaneously from each depth.

We assessed the number of periphytic taxa at five levels: species, genus, family, order and class. Identification and enumeration of taxa were conducted following methods of Xu et al. (2009, 2011b). Taxonomic classification of ciliates was based on keys and guides (e.g., Song et al., 2009; Berger, 1999; Lynn, 2008).

2.2. Data analysis

2.2.1. Functional parameters of colonization

Colonization by periphytic ciliates was assessed by sampling replicate glass slides over time to determine the rate at which colonization occurred and the maximum number, for each taxonomic level. Then the colonization equilibrium model of MacArthur and Wilson (1967, Eq. (1)) was fitted to the data:

$$S_t = S_{eq}(1 - e^{-Gt}), \quad (1)$$

where S_t = the total number of taxa at time t; S_{eq} = the estimated equilibrium number of taxa (i.e. the asymptote of the response); and G = the colonization rate constant. The statistic $T_{90\%}$ (the time taken to reach 90% S_{eq}) was determined as an intuitive index of the rate of colonization, to reveal the speed at which communities colonize a substrate. Eq. (1) was fitted to the data using a nonlinear curve fitting function (Sigmaplot v11, Systat Company Inc.), and estimates of S_{eq} and G were obtained; from these, $T_{90\%}$ was then determined. Fitness tests were conducted to determine whether the taxon numbers observed at each time interval fit with the MacArthur–Wilson model at the 0.05 significance level.

2.2.2. Temporal variations in community pattern

Community structure was analyzed using PRIMER 6 (Clarke and Gorley, 2006). The distance-based redundancy analysis (dbRDA) of PERMANOVA+ was used to summarize temporal variations in community pattern, using Bray–Curtis similarities from the fourth root-transformed species-abundance data, respectively (Anderson

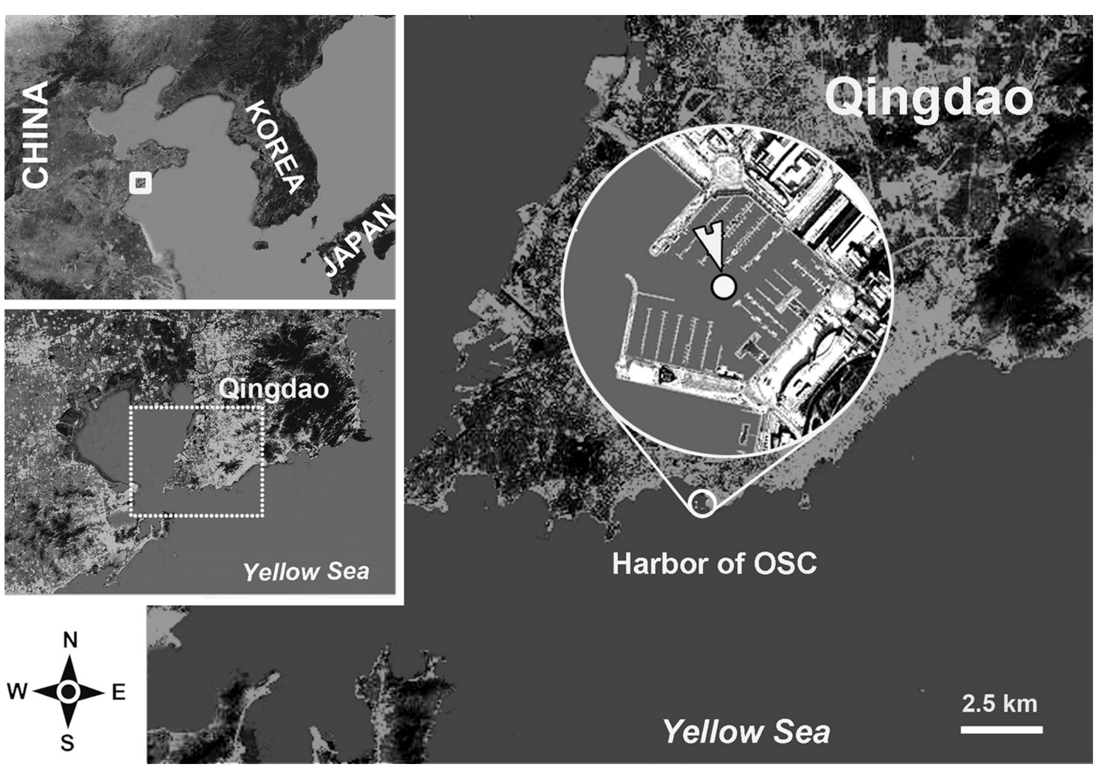

Fig. 1. Sampling station, which was located in the harbor of the Olympic Sailing Center (OSC) at Qingdao, on the Yellow Sea coast of northern China.

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