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Correspondence between zooplankton assemblages and the Estuary Environment Classification system

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ABSTRACT

We tested whether variability in zooplankton assemblages was consistent with the categories of estuarine environments proposed by the 'Estuary Environment Classification' system (EEC) (Hume et al., 2007) across a variety of North Island, New Zealand, estuaries. The EEC classifies estuaries in to eight categories (A to F) based primarily on a combination of three abiotic controlling factors: ocean forcing, river forcing and basin morphometry. Additionally, we tested whether Remane's curve, which predicts higher diversities of benthic macrofauna and high and low salinities, can be applied to zooplankton assemblages. We focused on three of the eight EEC categories (B, D and F), which covered the range of estuaries with river inputs dominating (B) to ocean influence dominating (F). Additionally, we included samples from river (FW) and sea (MW) to encompass the entire salinity range. Zooplankton assemblages varied across the categories examined in accordance with a salinity gradient predicted by the EEC. Three groups of zooplankton were distinguishable: the first formed by the most freshwater categories, FW and B, and dominated by rotifers (primarily Bdelloidea) and estuarine copepods (*Gladioferans pectinatus*), a second group formed by categories D and F, of intermediate salinity, dominated by copepods (*Euterpina acutifrons*), and a final group including the purely marine category MW and dominated also by *E. acutifrons* along with other marine taxa. Zooplankton diversity responded to the salinity gradient in a manner expected from Remane's curve. The results of this study support others which have shown salinity to be the main factor driving zooplankton community composition and diversity.

1. Introduction

'Transitional waters' is a miscellaneous term that covers a wide range of aquatic ecosystems including estuaries, fjords, lentic lagoons, river mouths, tidal creeks, deltas and similar coastal environments (e.g., McLusky and Elliott, 2007; Tagliapetra et al., 2009; Basset et al., 2012). The boundary between one type of transitional water and another is not always clear, with each of these ecosystems differing from the others in their hydrology, morphology, geology and biology. In the present study, we focus on estuaries, which can in general be defined as "*semi-enclosed coastal bodies of water which have a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage*" (Pritchard, 1967). A number of attempts to classify estuaries has been carried out, taking into account abiotic factors (e.g., geomorphology; Hume and Herdendorf, 1988; Reddering, 1998), the origin and evolution of estuaries (Roy, 1984), hydrology and salinity (Hansen and Rattray, 1966; Scott, 1993), or combinations of the above (Engle et al., 2007). However, such classifications are human impositions, and do not always correspond well with the biotic nature of the systems. Nevertheless, such classifications are not trivial, as they can influence political, management and conservational resources actions (Bowker and Star, 2000).

Hume et al. (2007) developed a classification system for estuarine environments in New Zealand, referred to as the 'Estuary Environment Classification' (EEC). This classification system, in short, is based on a hierarchical view of the abiotic components that comprise estuarine environments. The EEC postulates that climatic, oceanic, riverine and catchment factors 'control' a hierarchy of processes, which broadly determine the physical and biological

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characteristics of estuaries. Since its development, the classification system has been applied in New Zealand and other areas of the world, although with modifications (e.g., South Korea) (Jang and Hwang, 2013). Based on the EEC, it is expected that the hydrodynamic processes, including riverine and oceanic inputs, should determine the characteristics of the estuaries, such as water clarity, stratification, proportion of intertidal area, and salinity. Simultaneously, it is expected that these features will shape the biological characteristics of the estuaries. However, the correspondence between the EEC (based exclusively on abiotic factors) and biological characteristics has not yet been tested.

Within estuarine environments, salinity values typically acquire the shape of a gradient, which is directly linked to the hydrogeomorphology (i.e., the content of freshwater is greater in upper than in lower estuary areas), which is in line with the provisions of EEC system. This salinity gradient has been demonstrated by numerous studies to be one of the most important factors driving the heterogeneity of habitats and biodiversity in both terrestrial and aquatic ecosystems (e.g., Dobson and Frid, 1998; Wagner, 1999; Briggs and Taws, 2003; Silvestri et al., 2005). With this salinity gradient can be expected changes in community composition and species richness. Richness is expected to be higher in systems with salinity values close to purely fresh- or fully marine-waters than in brackish (transitional) waters. This is an expression of the biodiversity pattern 'Remane's curve' (Remane, 1934), which although sometimes questioned (e.g., Barnes, 1989; Attrill and Rundle, 2002; Telesh et al., 2011a), is still typically considered as the model that best describes the general pattern of diversity in aquatic systems.

Given the differences in physical conditions among types of estuaries defined by the EEC, and the salinity gradient expected because of them, a correspondence between hydrogeomorphological types of estuarine environments based on the EEC, and biological assemblages determined by the salinity gradient, could be expected. In the present study, we tested whether three categories of estuaries assessed by the EEC show a correspondence with the distribution of the zooplankton assemblages. We hypothesize that: 1) the taxonomic composition of zooplankton will vary concomitant with the EEC categories, and composition will change across a gradient from greater freshwater influence to greater marine influence; and that 2) a pattern of zooplankton diversity will be observed consistent with Remane's curve. The expected patterns in taxonomic composition and diversity were analysed for zooplankton assemblages, which are commonly disregarded in studies of transitional environments in favour to macro-communities (e.g., benthic macroinvertebrates or fish). However, zooplankton play a prominent role in the functioning of aquatic ecosystems as, for example, key links in foodchains between primary producers and fish (Capriulo et al., 2002; Turner, 2004).

2. Material and methods

2.1. Estuary Environment Classification (EEC)

The purpose of EEC is to categorize estuaries according to their externally influenced physical characteristics (Hume et al., 2007). EEC is composed of four levels according to the spatial scales and processes, with Level 1 being the broadest scale (regional level ranging 10^6-10^4 km^2) and Level 4 the finest (sub-estuary level ranging 1–0.1 km^2) (see Fig. 1 in Hume et al., 2007). Within the large-scale variation described at Level 1, the variation in characteristics among individual whole estuaries are dominated first by estuary-scale 'hydrodynamic' processes (Level 2) and then by 'catchment' processes (catchment geology and catchment land cover) (Level 3). For this study, we examined estuaries within a single region, and thus considered the estuary types recognised at Level 2 (i.e., estuary-scale). Level 2 discriminates estuaries based on basin morphometry, and the degree of river and oceanic forcing. We also chose Level 2 because this level will have the greatest influence on biological characteristics among estuaries in a given area, as the biota ultimately will be directly affected by the hydrodynamic processes occurring within estuaries, due to their circulation, mixing, stratification, flushing and sedimentation.

2.2. Selection of the sites

Fifteen sites around the North Island, New Zealand (Fig. 1), were surveyed in October and November 2011 (austral spring). The sites were selected based on the EEC system developed by Hume et al. (2007). However, not all categories within Level 2 could be sampled for a variety of reasons; for example, logistic limitations prevented us from reaching some sites, while some categories were represented by a limited number of estuaries. Therefore, in our selection of the EEC categories used, we considered the following criteria: estuaries in each category were well represented in the North Island, they were logistically feasible to reach, categories were not very similar to each other and they were geographically well distributed (i.e., whenever possible, for the same category, say B, we chose three estuaries from this category, one in the north, one in the east, and one in the west of the island). Eventually, we chose three (B, D and F) of the eight categories (A to H), as these were well represented in the North Island, provided a contrast in types of estuary across the full gradient of categories, and also enabled for sampling to be undertaken of estuaries of the same category at geographically separated sites (Fig. 2). Additionally, we also collected samples from three rivers (freshwater, FW) and three ocean sites (marine water, MW). Thus, the final design consisted of five categories (FW, B, D, F and MW), with three sites per category, and three sampling stations per site (replicates) separated by 500 m each, which yielded a total of 45 samples (Table 1). For further description of the selected estuaries including land use and land cover, refer to Appendix 1.

2.3. Sampling procedure

At each sampling station, 40 L of water was filtered through a plankton net (40 μm mesh). Sampling was undertaken by wading, with samples collected at a depth of 0.5 m–1.5 m. Zooplankton were preserved in ca. 75% ethanol (final concentration). In the laboratory the contents of each vial were washed through a 40 μm mesh to remove ethanol, and samples made up to a known volume ranging from 10 mL to 200 mL (depending on the amount of sediment or zooplankton within the samples). Samples were enumerated in 5-ml aliquots in a Perspex counting tray until at least 300 individuals were encountered (13 of 45 samples), or until the entire sample was examined if less than 300 individuals were found (the remaining 32 samples). All zooplankton samples were collected approximately 3 h before or after low and high tide providing an influence of both fresh- and marine water. Additionally, at each sampling station standard water-chemistry variables were measured *in situ* using field electrodes (Yellow Springs Instruments, Ohio, USA, and Orion, England), including surface water temperature (°C), salinity, dissolved oxygen concentration (mg/L), and pH.

2.4. Data analysis

Changes in salinity and the other water-chemistry variables among categories were analysed using one-way ANOVA for parametric data (pH and water temperature) and Kruskal-Wallis test for