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The utility of body size indices derived from optical plankton counter data for the characterization of marine zooplankton assemblages

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ABSTRACT

To evaluate the utility of size-based indices derived from an Optical Plankton Counter (OPC) through detection of spatial and temporal trends in zooplankton biomass, zooplankton size data were collected with an OPC across the Scotian Shelf region of the northwest Atlantic Ocean in April and October of 1997, 1998, and 1999. Eight size-based indices were computed – three simple size metrics (arithmetic mean, geometric mean, coefficient of variation) and metrics derived from the Normalized Biomass Size Spectrum (NBSS; *X*- and *Y*-coordinates and curvature of a fitted quadratic function) and the Pareto distribution (*Y*-intercept and slope). Results indicate that the simple size indices and those derived from the Pareto distribution consistently accounted for the greatest portion of annual variation in zooplankton biomass whereas indices derived from the NBSS accounted only for some secondary patterns. Simple indices also accounted for the greatest portion of spatial variance in zooplankton biomass whereas the NBSS and Pareto accounted for secondary patterns. Patterns in zooplankton communities based on these indices reflected broad taxonomic trends and were related to independent observations on atmospheric and hydrographic conditions in the study area. Size-based zooplankton data from continuous survey instruments can provide powerful adjuncts to both freshwater and marine aquatic monitoring.

1. Introduction

Since its initial design and development (Herman, 1992), the Optical Plankton Counter (OPC) has been used extensively for the study of both marine and freshwater zooplankton assemblages. This instrument records both the sizes (approximately 0.25–20 mm) and counts of particles every 0.5 s as it is towed or vertically dropped through the water column in a variety of patterns suited to a user's specific purposes. Data can be analyzed over spatial scales ranging from meters to kilometers depending on the speed and duration of OPC deployment. Perhaps the principal innovation the OPC brought to zooplankton ecology was the collection of automated and easily processed information on body size, a metric known to be a strong correlate of a wide variety of ecological processes in nature (Peters, 1983).

The OPC has been used in a wide variety of applications including spatial relations between zooplankton abundance and physical factors such as hypoxia (Kimmel et al., 2010) and water circulation and water masses (Skardhamar et al., 2007; Zhang et al., 2006), the vertical distribution and migration of zooplankton (Labat et al., 2009), spatial analyses of small-scale zooplankton gaps and patches (Currie et al., 1998), larval hake growth in relation to the concentration of their zooplankton prey (Mullin and Cass-Clay, 1997) and spatial overlap of right whales and their zooplankton prey (Baumgartner et al., 2003), zooplankton population growth and mortality rates (Heath, 1995; Zhou et al., 2004), design of zooplankton surveys (Yurista et al., 2009), and the use of neural networks to predict surface zooplankton biomass (Woodd-Walker et al., 2001). These investigators employed a variety of metrics to describe zooplankton assemblages including simple abundance, biomass, or size (Fossheim and Primicerio, 2008; Campbell and Dower, 2008), and various body size distributions (Sourisseau and Carlotti, 2006; Herman and Harvey, 2006; Nogueira et al., 2004).

Despite the widespread use of the OPC, there has been very little effort to critically determine the most ecologically informative size metric(s) that could be derived from OPC body size data. One exception is a study by Yurista et al. (2006) who evaluated the usefulness of size distributions as well as mean body size and biomass concentration to discriminate zooplankton assemblages among the St. Lawrence Great Lakes that differ in physical and biological properties, and among spatial zones within the lakes.

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They found that all metrics differed among the epilimnia of all five Great Lakes, and all but one differed among the hypolimnia, with Lake Erie having the greatest mean size and abundance of zooplankton while Lake Ontario had the smallest and least abundant. Some metrics differed statistically among spatial zones within lakes, but there was much less consistency in which ones were involved from one lake to another and in zones compared (near shore to offshore, eplimnion to hypolimnion). Yurista et al. (2006) concluded that size spectra parameters can discriminate zooplankton communities among and within the Great Lakes although they did not give information on the relative statistical power of their various metrics. While these results are useful, we feel the question of appropriate OPC-based zooplankton descriptors is of sufficient importance to not only explore a broader range of size metrics but also to make the assessment on a marine ecosystem in which large-scale circulation patterns, salinity gradients, and more continuous size distributions of zooplankton make it quite distinct from freshwater lakes. The size structure of a zooplankton community is likely to be a good biological index because numerous ecological processes are functions of body size (e.g., growth rate, metabolic rate, prey size range; Peters, 1983) and body size is responsive to various stressors (e.g., non-indigenous introductions; Shurin, 2001) and can provide the basis describing functional and structural food-web models (Woodward et al., 2005). Mean zooplankton body size is frequently used to classify different functional groups (e.g., herbivores; Cyr and Pace, 1992) and can provide explanations for the relationship between community structure and environmental parameters (e.g., climate change: Arnott et al., 2003).

The striking regularities in the body size distribution of aquatic organisms across trophic levels have lead to the use of sized-based approaches for analyzing aquatic ecosystems (Sheldon et al., 1972). The function and organization of aquatic ecosystems can be described by theoretical and empirical models that explore the flow of biomass from the smallest to largest organisms through a food web in steady state (Platt and Denman, 1978; Thiebaux and Dickie, 1992; Sprules and Goyke, 1994; Kerr and Dickie, 2001). Size-based indices have a solid theoretical and empirical foundation and can reveal patterns and explain variation in aquatic communities that are neither apparent nor conceivable from conventional taxonomic approaches. The expansion of size-based indices, particularly the use of the body size spectrum, has paralleled advances in aquatic sampling technology (e.g., Huntley et al., 2006). The optical plankton counter (OPC), used by the Atlantic Zone Monitoring Program (AZMP) to continuously collect high-resolution zooplankton size data, is ideal for the application of size-based metrics and has been used by others to describe spatial and temporal trends in zooplankton assemblages (Yurista et al., 2006).

The objective of our study was to assess the relative abilities of eight size-based zooplankton indices (arithmetic and geometric mean body size, coefficient of variation, *X*- and *Y*-coordinates of the vertex and curvature of a quadratic function of the Normalized Biomass Size Spectrum (NBSS), and the *Y*-intercept and slope of a Type I Pareto Distribution), derived from OPC data, to characterize and distinguish marine zooplankton assemblages along broad-scale temporal (annual and seasonal) and spatial (cross- and along-shelf) gradients on the Scotian Shelf region of the northwest Atlantic Ocean. The simple measures of mean and variation are typical statistical descriptors whereas the NBSS and Pareto are models of body-size distribution based on ecological principles and simple statistical probability, respectively. Within the limits of our data, we provide a general biological framework relating these size patterns in zooplankton assemblages to independent information on patterns in taxonomic structure of the zooplankton communities, and to trends in temperature, vertical stratification, and general circulation.

2. Methods

2.1. Study area

The Scotian Shelf is a 96 000 km^2 area of the North American continental shelf extending 125–230 km off the Atlantic shore of Nova Scotia. Numerous offshore shallow (<100 m) banks and deep (>100 m) mid-shelf basins characterize the area's complex bottom topography. Regional hydrography (e.g., advection and mixing) is influenced by bottom characteristics and comprises five main water masses with marked seasonal variations in temperature and salinity affecting cross- and along-shelf distributions and vertical divisions through the water column (Houghton et al., 1978; Loder et al., 1997). The water column has two layers in winter when cool, fresh water overlies warmer, more saline water and three layers in summer consisting of a warm surface layer and a cooler deep layer separated by an intermediate gradient zone (Loder et al., 1997). Temperature and density gradients in the water column cause biological matter to aggregate in the very productive upper layers. The effects of temperature and salinity on water movements and water column stratification can affect zooplankton spatial distribution (Mullin et al., 1985).

Long-term atmospheric and oceanographic records of the Canadian Maritime region of the northwest Atlantic reveal that the years 1997, 1998, and 1999 exhibited exceptional variation in atmospheric condition, sea surface temperature, and general water mass distribution (DFO, 1998, 1999; Ouellet et al., 2003). In particular, anomalously cold incursions of Labrador Slope water were recorded near the end of 1997 (2 °C below normal at depths 100–300 m), penetrating the deep Shelf basins by the latter part of 1998 (>3 °C below normal at depths >300 m)). However, air temperatures in 1999 were higher (monthly air temperature anomalies ~ 2 °C above normal) than the preceding years leading to unusually warm waters (monthly sea surface temperature anomalies of 2–6 °C) and an intense (time integrated chlorophyll a concentration ~ 350 mg m^{-2}) and early spring phytoplankton bloom (~ 3 weeks earlier in the anomalies timing of spring blooms; Ouellet et al., 2003; Platt et al., 2003).

2.2. Field data collection.

Physical and biological data were collected with electronic sensors during 3-week cruises in April and October from 1997 to 1999 as part of the AZMP. Four cross-shelf transects and one across the Cabot Strait were sampled (Fig. 1). For each cruise the five transects were sampled except in October of 1997 and 1999 when the number of transects was reduced to four (Roseway line was omitted, Fig. 1). At specific stations (6–9 per transect, maximum of 38 per cruise, Fig. 1) a vertical optical plankton counter (VOPC) was lowered from surface to ~ 5 m above maximum depth or to 475 m at deep stations and raised to the surface with a profiling rate at 1 m s^{-1} on the ascent and descent. The VOPC consists of a frame containing an OPC (2×22 cm sampling tunnel, $2 \times 0.4 \times 22$ cm light beam, Model OPC-1T, Focal Technologies, Inc., Dartmouth, NS) and a conductivity–temperature–depth (CTD) sensor (Model SBE-25, Sea-Bird Electronics, Inc., Bellevue, WA) equipped with an in situ fluorometer (Sea-Tech, Inc., Albuquerque, NM) with two standard plankton ring nets (0.2 m diameter, 140 μm and 80 μm mesh for spring and fall cruises, respectively) mounted on either side of the electronic sensors. The plankton nets sampled on the profile ascent while all other sensors recorded measurements in