Marine Pollution Bulletin 126 (2018) 43–50

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

A relative contribution of carbon from green tide algae *Cladophora glomerata* and *Ulva intestinalis* in the coastal food webs in the Neva Estuary (Baltic Sea)

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ARTICLE INFO

Keywords:
Coastal eutrophication
Gulf of Finland
Macroalgae
Macroinvertebrates
Fish
Stable isotopes (Bayesian mixing model)

ABSTRACT

We analyzed stable isotope composition of carbon and nitrogen of suspended organic matter (seston) and tissues of macroalgae, macroinvertebrates and fish from the coastal area of the highly eutrophic Neva Estuary to test a hypothesis that organic carbon of macroalgae *Cladophora glomerata* and *Ulva intestinalis* produced during green tides may be among primary sources supporting coastal food webs. The Stable Isotope Bayesian mixing model (SIAR) showed that consumers poorly use organic carbon produced by macroalgae. According to the results of SIAR modeling, benthic macroinvertebrates and fish mostly rely on pelagic derived carbon as a basal resource for their production. Only some species of macroinvertebrates consumed macroalgae. Fish used this resource directly consuming zooplankton or indirectly via benthic macroinvertebrates. This was consistent with the results of the gut content analysis, which revealed a high proportion of zooplankton in the guts of non-predatory fish.

1. Introduction

Modern definition considers eutrophication as “an increase in the rate of supply of organic matter to an ecosystem” (Nixon, 1995). This definition is based on the fact that organic matter is a major control for the marine food web (Omstedt et al., 2014). In shallow coastal zone eutrophication leads to proliferation of fast-growing ephemeral macroalgae, so-called green tides. This phenomenon is increasingly observed worldwide and is generally considered as a symptom of coastal eutrophication (Smetacek and Zingone, 2013). Green macroalgae *Cladophora glomerata* (L.) Kutz. and *Ulva intestinalis* L. are among the most common bloom-forming macroalgae in the Baltic Sea (Vahteri et al., 2000; Blomster et al., 2002; Nikulina and Gubelit, 2011).

The Neva Estuary, situated at the top of the Gulf of Finland (Fig. 1), is one of the most eutrophic areas of the Baltic Sea (Telesh et al., 2008; Golubkov and Alimov, 2010). The primary productivity and biomasses of autotrophic and heterotrophic organisms in the estuary are among the highest in the Baltic (Golubkov, 2009; Golubkov et al., 2017), mainly due to eutrophic effects of the high nutrient inflow from the Neva River, the most affluent river of the Baltic Region. The estuary is generally characterized by a number of features common to other major Baltic estuaries. As most of them, the Neva Estuary is 1) brackish-water, non-tidal, shallow, 2) strongly affected by wind-mixing, 3) with stochastic water exchange with deep part of the Gulf of Finland, 4) with fluctuations of ecosystem parameters caused mainly by physical factors, 5) with horizontal and vertical gradients of salinity, nutrients and plankton abundance, 6) with intensive benthic-pelagic coupling, 7) sensitive to nutrient loads (eutrophication), 8) characterized by intensive accumulation of humic substances, 9) with dominance of eurytopic species, and 10) with high biological diversity and productivity (Telesh et al., 2008).

The coastal zone of the Neva Estuary supports diverse and productive communities. Macrofauna list includes > 170 species, inhabiting a shallow coastal zone of the estuary (Berezina et al., 2009). Coastal zone provides also spawning and feeding habitats for many fish. Macroalgal beds in stony littoral areas of the Neva Estuary are dominated by the fast-growing green opportunistic algae *C. glomerata*, *U. intestinalis* and *Ulva* sp. In some sites of the coastal zone *C. glomerata* and *Ulva* spp. may form joint blooms (Gubelit et al., 2016). During recent decades these algae were recorded in the majority of coastal areas of the estuary (Gubelit and Kovalchuk, 2010; Nikulina and Gubelit, 2011; Gubelit et al., 2016). The algae grow rapidly in late spring and early summer, and then start degrade and detach from substrate forming drifting mats of decaying algae, which accumulate on the shore as storm casts and deteriorate coastal habitats (Gubelit and Berezina, 2010). The storm casts of decayed macroalgae may reach two tons of wet weight per 100 m of the shoreline (Golubkov et al., 2003b). Algal decomposition causes low oxygen content, thus exerting a strong

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http://dx.doi.org/10.1016/j.marpolbul.2017.10.032
Received 8 August 2017; Received in revised form 18 September 2017; Accepted 15 October 2017

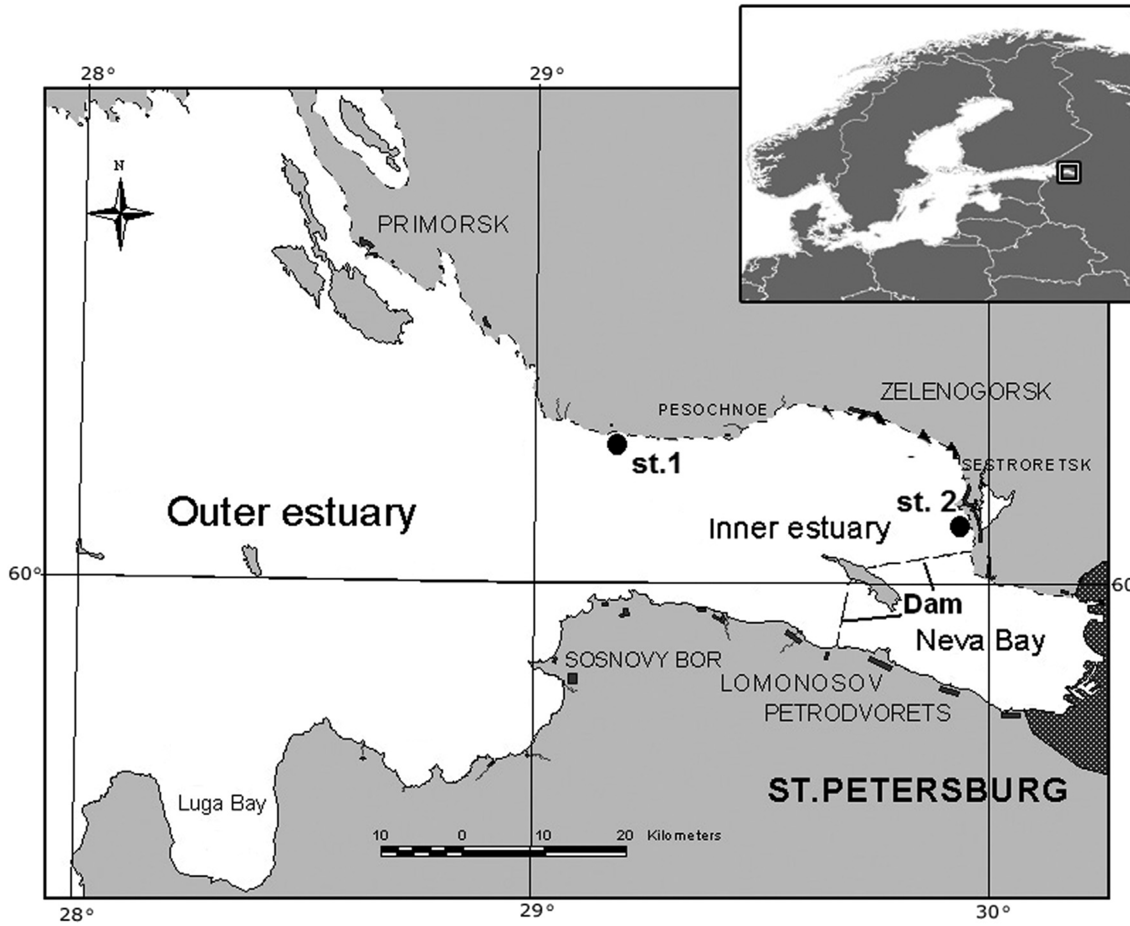

Fig. 1. Study area scheme indicating two sampling sites in the Middle Neva estuary.

negative influence on benthic animals as the latter die in de-oxygenated habitats (Berezina and Golubkov, 2008).

There are also some positive aspects of macroalgae influence on environmental conditions in the nearshore habitats of the Neva Estuary. Midsummer algal biomass reached 567 g $DW{\cdot}m^{-2}$ and primary production 5–8 g C m^{-2} d^{-1} (Golubkov et al., 2003b; Gubelit and Berezina, 2010; Nikulina and Gubelit, 2011), which is several times high than primary production of phytoplankton (Golubkov et al., 2003a, 2017). It creates an extensive pool of organic matter, which potentially might be utilized by invertebrates. Moreover, *C. glomerata* has high concentration of essential polyunsaturated fatty acids (Gubelit et al., 2015) and potentially may be an important source of them for consumers of different trophic levels. However, the data on the use of *Cladophora* and *Ulva* algae as food items by herbivores are inconsistent and seem to be species-specific. Certain invertebrates like amphipods and gastropods may graze these macroalgae (Duffy and Hay, 2000; Berezina, 2007; Guidone et al., 2015), but other species are not able to consume alive algae due to a relative robust cell walls of *Cladophora* or due to allelochemical toxic exudates produced by *Ulva* species (Berezina et al., 2005; Peckol and Putnam, 2017).

The study aims to evaluate the importance of organic matter produced by two different macroalgae species during their blooms for coastal food webs. Alternative food sources for primary consumers in shallow coastal zone are phytoplankton-derived organic matter that sinks to the bottom or is consumed directly from the water column by filtering macroinvertebrates. We tested a hypothesis that organic carbon derived from macroalgae is the main basal resource of carbon for the coastal food webs in midsummer during green tides. This goal was attained by performing stable isotope analysis of macroalgae, tissues of zoobenthos and fish, and suspended organic matter (seston) consisting of phytoplankton and detritus in a shallow coastal area of the Neva Estuary. We applied Bayesian mixing model (SIAR; Parnell et al., 2010) to quantify basal resource used by various consumers. This approach enables depicting a proportional contribution of different sources in the diet of a consumer relying on inherent isotopic variation between different resources (Layman et al., 2012). As a result of the informative predictions generated by the Bayesian mixing model approach, this method is rapidly becoming a standard quantitative application for estimating diet resources (Colborne et al., 2016).

Published data on the food preference of fish in the coastal zone of the eastern Gulf of Finland are rather scarce. For this reason we studied feeding patterns of fish to improve interpretation of SIAR's results.

2. Material and methods

2.1. Study sites

The Neva Estuary receives water from the Neva River. Its water discharge averages 2490 m^3 s^{-1} (78.6 km^3 yr^{-1}). The Neva Estuary consists of three parts: the upper part (Neva Bay), the middle part (Middle or Inner estuary), and the lower part (Lower or Outer estuary) (Fig. 1). The Inner estuary is the slightly brackish-water basin in the eastern Gulf of Finland and is located between the Kotlin Island and the longitude of ca. 29° E. The salinity of offshore surface waters in this part of the estuary ranges from < 1 to 3 PSU and depth from 12 to 14 m in the eastern part and up to 30 m in its western part. Concentration of chlorophyll *a* in the Inner estuary reaches 24 mg/m^3 and plankton primary production – 2.5 g C m^{-2} d^{-1} in midsummer (Golubkov et al., 2017), when short time cyanobacteria blooms occurred. A more detailed description of the Neva Estuary is given elsewhere (Telesh et al.,