

Review ESD-2021-73_V2_RX

" Global climate change and the Baltic Sea ecosystem: direct and indirect effects on species, communities and ecosystem functioning

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General comments

In general, the compilation of results are more distinct and text easy to read.

All the "To sum up,.. " paragraphs are much appreciated. Significant improvement.

The fact that many more mesocosm studies relevant for climate-change effect has been reported need to be clarified and preferably some references added. Also, clarify that just a selected number of studies using defined test variables are presented in table 1.

Some correction of terminology and language is required as suggested below.

I recommend publication after these minor revisions.

Specific comments

r. 150 Variation between year is weather variations as climate variations are defined as differences between 30-year periods.

r. 293 The reported period is wrong.

r. 467 I would avoid "loop" as having an unclear and even misleading meaning (instead "microbial (part of the) food web". How is "loop" justified? Microorganisms constitute the original food web in the biosphere and is an integral part of the modern food web. It both contribute to biomass flow and remove biomass by respiration. As most organisms.

r. 481 Correct to "betaproteobacteria". Indeed, all "proteo" phrases need correction.

r. 506 Please correct to "In the northern Quark, ..."

r 907-909 This is likely relevant for the Baltic proper and Kattegat but less for the Gulf of Bothnia. The potential effects of simultaneously increasing DOC discharge is neglected in the scenario proposed.

r.970-973. If flagellate pressure is released bacterioplankton would increase. Please match with the scenario proposed in the last sentence. Also, "loop" preferably changed to "food web".

r. 979. More correctly expressed "... maintained bacterial biomass production despite reduced phytoplankton production...".

r. 1182-1185 There are more valuable mesocosm studies so a "(e.g, Lindh et al. 2015....)" would be appropriate or better adding some more examples covering larger parts of the food web (some suggested below).

r. 1216 Please add " , microbial food web....". Typically overlooked in current models.

r. 1308 I suggest to add: "Continuation and expansion of long term ecological studies in collaboration with environmental monitoring programs is also crucial for validating experimental results and advance our knowledge of environmental and meteorological drivers on large spatial and temporal scales."

r. 1340 Please change to "...the Gulf of Bothnia (...)" as demonstrated also in the Bothnian Sea.

r.1388-1390 Should ecological safe fish catches be added here as a reliable and required measure?

r. 1427 I suggest to specify "...in the Baltic Sea for selected test variables". Several studies referred to in the text, and some covering other test variables, are omitted

End of comments.

Suggested selected mesocosm references

Amin, R. M., et al. (2012). "Partition of planktonic respiratory carbon requirements during a phytoplankton spring bloom." Marine Ecology-Progress Series **451**: 15-29.

We studied the effect of variable phytoplankton biomass and dominance of the diatom *Skeletonema marinoi* on the planktonic community respiratory carbon requirement over a period of 14 d (14 to 28 April 2008) in 3 different mesocosms filled with natural water at Espegrend marine biological field station in Raunefjord, Norway. The carbon requirement was measured on mesozooplankton (the calanoid copepod *Calanus finmarchicus*) and 3 other size fractions of plankton- <200 μ m (dominated by microzooplankton), <15 μ m (dominated by nanoplankton including most of the phytoplankton) and particles passing GF/C filters (dominated by bacterioplankton)-by measuring oxygen consumption using an optode system with 2 Sensor Dish Readers. The respiratory carbon requirement showed no clear trend over time for any of the 4 groups. The mesozooplankton contributed the least to the total community carbon requirement, corresponding to <6% of primary production. In contrast, microzooplankton and nanoplankton consistently dominated the community carbon requirement, corresponding to >50% of the primary production, while bacterioplankton showed an intermediate and variable contribution (ca. <20% with a maximum of 50%). Feeding experiments on mesozooplankton (*C. finmarchicus*) 2 d before the peak in phytoplankton biomass showed that the copepods ingested from 2.4 to 4.3 times their respiratory carbon requirements, thus providing a high potential for growth. Respiratory carbon requirements of mesozooplankton were not significantly related to dominance or quantity of food available, whereas the respiratory carbon requirements of other groups were all related to the production of 22:6(n-3) fatty acid. The present study confirms the important role of microorganisms in the biological carbon transformation through the food web during a phytoplankton spring bloom.

Andersson, A., et al. (2013). "Can Humic Water Discharge Counteract Eutrophication in Coastal Waters?" Plos One **8**(4): 13.

A common and established view is that increased inputs of nutrients to the sea, for example via river flooding, will cause eutrophication and phytoplankton blooms in coastal areas. We here show that this concept may be questioned in certain scenarios. Climate change has been predicted to cause increased inflow of freshwater to coastal areas in northern Europe. River waters in these areas are often brown from the presence of high concentrations of allochthonous dissolved organic carbon (humic carbon), in addition to nitrogen and phosphorus. In this study we investigated whether increased inputs of humic carbon can change the structure and production of the pelagic food web in the recipient seawater. In a mesocosm experiment unfiltered seawater from the northern Baltic Sea was fertilized with inorganic nutrients and humic carbon (CNP), and only with inorganic nutrients (NP). The system responded differently to the humic carbon addition. In NP treatments bacterial, phytoplankton and zooplankton production increased and the systems turned net autotrophic, whereas the CNP-treatment only bacterial and zooplankton production increased driving the system to net heterotrophy. The size-structure of the food web showed large variations in the different treatments. In the enriched NP treatments the phytoplankton community was dominated by filamentous >20 μ m algae, while in the CNP treatments the phytoplankton was dominated by picocyanobacteria <5 μ m. Our results suggest that climate change scenarios, resulting in increased humic-rich river inflow, may counteract eutrophication in coastal waters, leading to a promotion of the microbial food web and other heterotrophic organisms, driving the recipient coastal waters to net-heterotrophy.

Bamstedt, U. and J. Wikner (2016). "Mixing depth and allochthonous dissolved organic carbon: controlling factors of coastal trophic balance." Marine Ecology Progress Series **561**: 17-29.

The interacting effects of different mixing depths and increased allochthonous dissolved organic carbon (DOC) on the ratio of heterotrophic to autotrophic production (i.e. trophic balance) was evaluated in a mesocosm study with a stratified water column. An autumn plankton community from the northern

Bothnian Sea showed significantly decreased phytoplankton production and somewhat increased bacterial production with added DOC. In addition, increased mixing depth further reduced phytoplankton production. With a deep pycnocline and added DOC, the system became net-heterotrophic, with an average bacteria-to-phytoplankton production ratio of 1.24. With a deep pycnocline without added DOC, the trophic balance was changed to 0.44 (i.e. autotrophic). With a shallow pycnocline, the system remained net-autotrophic irrespective of DOC addition. We propose that increased precipitation in northern Europe due to climate change may result in changed density stratification and increased allochthonous DOC transport to the sea, leading to more heterotrophic coastal aquatic ecosystems. Such a scenario may entail reduced biological production at higher trophic levels and enhanced CO₂ emission to the atmosphere.

Dahlgren, K., et al. (2011). "The influence of autotrophy, heterotrophy and temperature on pelagic food web efficiency in a brackish water system." *Aquatic Ecology* **45**(3): 307-323.

Climate change has been suggested to lead to higher temperature and increased heterotrophy in aquatic systems. The aim of this study was to test how these two factors affect metazooplankton and food web efficiency (FWE was defined as metazooplankton production divided by basal production). We tested the following hypotheses: (1) that lower metazooplankton production and lower FWE would be found in a food web based on heterotrophic production (bacteria) relative to one based on autotrophic production (phytoplankton), since the former induces a larger number of trophic levels; (2) the metazooplankton in the heterotrophic food web would contain less essential fatty acids than those from the autotrophic food web; and (3) that higher temperature would lead to increased FWE. To test these hypotheses, a mesocosm experiment was established at two different temperatures (5 and 10°C) with a dominance of either autotrophic (NP) or heterotrophic basal production (CNP). Metazooplankton production increased with temperature, but was not significantly affected by differences in basal production. However, increased heterotrophy did lead to decreased fatty acid content and lower individual weight in the zooplankton. FWE increased with autotrophy and temperature in the following order: 5CNP < 10CNP < 5NP < 10NP. Our results indicate that in the climate change scenario we considered, the temperature will have a positive effect on FWE, whereas the increase in heterotrophy will have a negative effect on FWE. Furthermore, the quality and individual weight of the metazooplankton will be reduced, with possible negative effects on higher trophic levels.

Lefebvre, R., et al. (2013). "Impacts of elevated terrestrial nutrient loads and temperature on pelagic food-web efficiency and fish production." *Global Change Biology* **19**(5): 1358-1372.

Both temperature and terrestrial organic matter have strong impacts on aquatic food-web dynamics and production. Temperature affects vital rates of all organisms, and terrestrial organic matter can act both as an energy source for lower trophic levels, while simultaneously reducing light availability for autotrophic production. As climate change predictions for the Baltic Sea and elsewhere suggest increases in both terrestrial matter runoff and increases in temperature, we studied the effects on pelagic food-web dynamics and food-web efficiency in a plausible future scenario with respect to these abiotic variables in a large-scale mesocosm experiment. Total basal (phytoplankton plus bacterial) production was slightly reduced when only increasing temperatures, but was otherwise similar across all other treatments. Separate increases in nutrient loads and temperature decreased the ratio of autotrophic:heterotrophic production, but the combined treatment of elevated temperature and terrestrial nutrient loads increased both fish production and food-web efficiency. CDOM: Chl a ratios strongly indicated that terrestrial and not autotrophic carbon was the main energy source in these food webs and our results also showed that zooplankton biomass was positively correlated with increased bacterial production. Concomitantly, biomass of the dominant calanoid copepod *Acartia* sp. increased as an effect of increased temperature. As the combined effects of increased temperature and terrestrial organic nutrient loads were required to increase zooplankton abundance and fish production, conclusions about effects of climate change on food-web dynamics and fish production must be based on realistic combinations of several abiotic factors. Moreover, our results question established notions on the net inefficiency of heterotrophic carbon transfer to the top of the food web.