Marts 2023

Complexity of coastal ecosystems – two examples

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Please cite: Gertz F. 2023. Complexity of coastal ecosystems – two examples. Technical note from SEGES Innovation.

Danish estuaries are diverse with different depth, stratification, water exchange and catchments all introducing a variety of complexity to the ecosystems. Included in this notes are two of many examples that the relatively simple relation between N-load and summer chlorophyll used in all three RBMP do not explain the complexity in the eco-systems.

1. Ringkøbing Fjord, a 300 km^2 lagoon with a sluice to the North Sea located at the west coast of Jutland and with a catchment of 3.470 km^2 of mainly sandy soils.
The ecosystem of the lagoon collapsed in the late 1970's introducing high algae biomasses and low secchi depth values (0.5 m). In the middle of the 1990's it was decided to obtain a higher salinity and with this decision the clam *Mya arenaria* invaded the lagoon in large numbers with high filtrating rates and effectively controlling the algae biomass and therefore also increased the secchi depth to around 2 m (ref1). Due to the effective filtration, the concentration of inorganic nitrogen (DIN) was relatively high in the summer months the first years after the regime shift in 1996 (figure 1 and Appendix). Indicating that DIN is not controlling the chlorophyll-a concentration. The first years after the regime shift Ulva was not found in any significant amount but that changed gradually, and Ulva became widely distributed in the lagoon due to good light conditions and sufficient summer DIN and DIP concentrations. Since the regime shift Ulva has been main indicator for eutrophication since chlorophyll-a most of the time is controlled by filtration. In a period in 2019 and 2020 the salinity in the lagoon was too low to support the existence of Mya arenaria which affected the filtration capacity and as seen in figure 1 (and Appendix) the chlorophyll-a increased in that period.

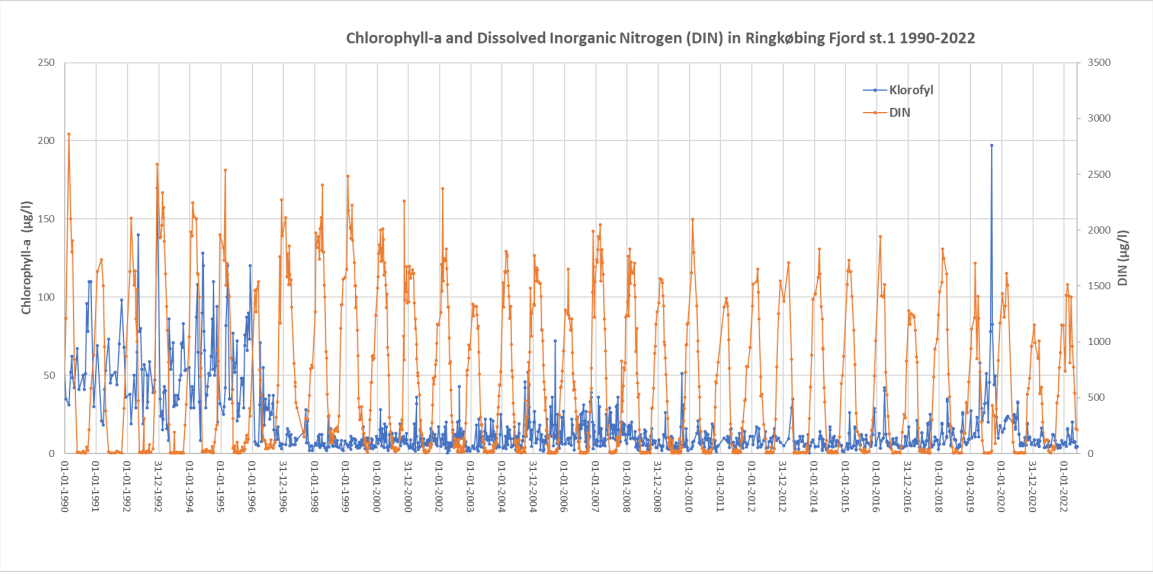

Figure 1. Chlorophyll-a concentrations and DIN concentrations in Ringkøbing Fjord 1990-2022. (Appendix larger figure)

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In the RBMPIII the years 2014-2019 are used to set the status value of average summer chlorophyll-a figure 2. Summer average (May-September) is 15,8 µg/l but without 2019 the average is 7,5 µg/l. Enough to obtain Good Ecological Potential if 2019 is not included (The lagoon has status as modified).
However, the general problem in RBMPIII for Ringkøbing Fjord (lagoon) is that the reduction target for nitrogen in the catchment is calculated based upon N-loads being related to the chlorophyll-a concentration and not to the Ulva biomass.

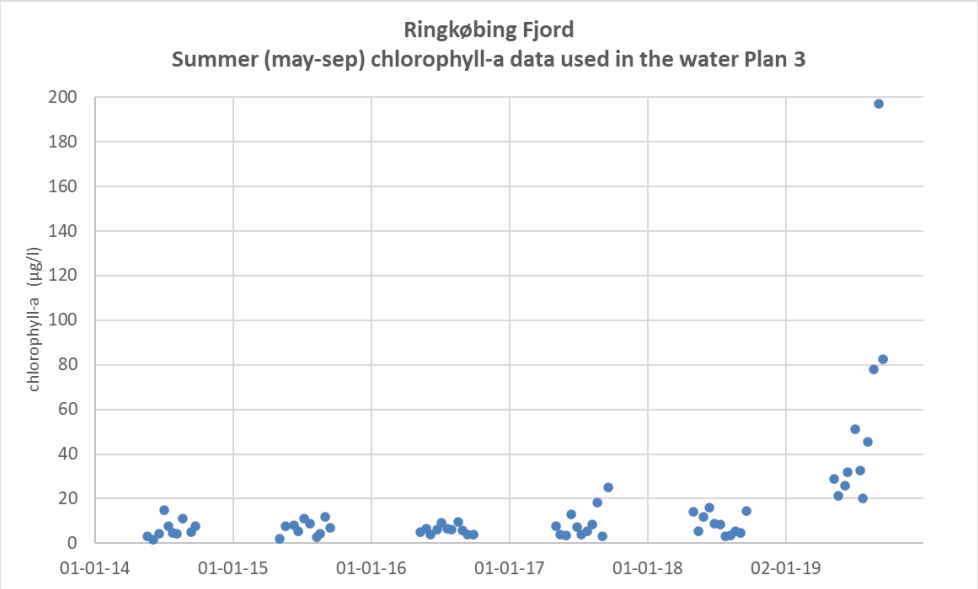

Figure 2. Summer chlorophyll-a concentrations in Ringkøbing Fjord 2014-2019.

2. Roskilde Fjord is an estuary located on Zealand as part of a larger estuary including Isefjord with connection to Kattegat. The Roskilde Fjord is relatively narrow and long with an area of 123 km^2 and a catchment of 730 km^2. The average resident time for Roskilde Fjord has been reported to be 90 days in Staehr et al 2016 (Ref 2) but they refer to Josefson and Rasmussen 2000 (Ref3) and this reference is a *personal comment.* In a new study by Nielsen M.H 2022 (Ref4) it is reported that the residence time is 3-4 weeks and much lower than earlier reported.

In RBMPIII monitoring data for 2017-2019 summer average (may-sep) have been used to select status for the northern part of the fjord (figure 3). The chlorophyll average is 4.5 µg/l for the 3 years and above the target of 2.9 µg/l for the boundary between good and moderate status. A characteristic pattern is emerging in each of the three years. Low chlorophyll concentrations in the spring (May) at typically 2 µg/l or below, increasing during the summer to typically 6-8 µg/l and up to 11 µg/l.
In the spring and summer period the N-load from land decreases to the fjord (north part) from an average of 64 ton TN in marts to 6,5 ton TN in June and July and then increases again in August to 10 ton TN and in September to 15 ton TN. Same pattern in monthly N-loads from land is seen to the inner part of the Roskilde Fjord.
This indicates a more complex ecosystem where phosphorus, oxygen depletion and residence time could also play a role, while the more direct link between N-load from land and summer chlorophyll seems too simple to explain the complexity in the ecosystem.

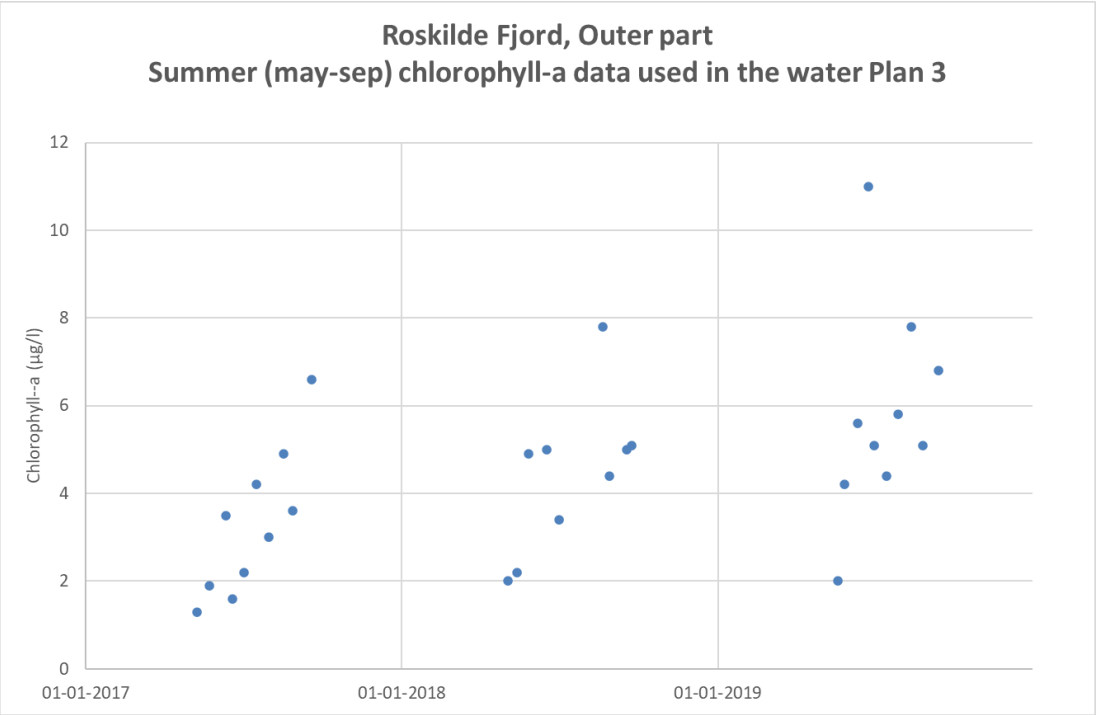

Figure 3. Summer chlorophyll-a concentrations in Roskilde Fjord, Outer Part 2017-2019.

References

Ref1: Petersen J. K, HANSEN J. W, LAURSEN M. B, Clausen P., Carstensen J., Conley D. J, *REGIME SHIFT IN A COASTAL MARINE ECOSYSTEM.* Ecological Applications, 18(2), 2008, pp. 497–510, 2008. The Ecological Society of America.

Ref2: Peter A. Staehr, Jeremy Testa, Jacob Carstensen, 2016. *Decadal Changes in Water Quality and Net Productivity of a Shallow Danish Estuary Following Significant Nutrient Reductions*. Estuaries and Coasts DOI 10.1007/s12237-016-0117-x

Ref3: A. B. Josefson and B. Rasmussen, 2000. *Nutrient Retention by Benthic Macrofaunal Biomass of Danish Estuaries: Importance of Nutrient Load and Residence Time*. Estuarine, Coastal and Shelf Science (2000) 50, 205–216. doi:10.1006/ecss.1999.0562.

Ref4: Nielsen M H, 2022. *The physical oceanographic conditions in a range of fjords and coastal areas in Denmark.* Report from Marine Science & Consulting ApS.
Link:

Ref5: Gertz F, Thostrup L K, Møller K D, 2022. *Nutrient limitations in Danish Coastal Waters* Report from SEGES Innovation P/S.
Link:

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Appendix