BIOMONDO Pilot 1

Impact of eutrophication and habitat changes on the water quality of shallow lakes

Introduction

Nutrient concentrations have increased substantially in lakes and rivers throughout the world (Heathwaite et al. 1996; Revenga et al. 1998), resulting in eutrophication, changes in water column trophic status, harmful algal blooms, loss of submerged macrophytes affecting sedimentation and turbidity, and biodiversity loss. In addition, habitat changes may alter flow regimes and sediment load. Monitoring such changes in water quality should be a fundamental part of any freshwater biodiversity monitoring program.

In this BIOMONDO pilot we, therefore, explore the possibilities of integrating EO data into Delft3D. Delft3D is a world leading 3D modelling suite to investigate hydrodynamics, sediment transport and morphology, and water quality for fluvial, estuarine and coastal environments, and is used in many places around the world, such as the Netherlands, USA, Hong Kong, Singapore, Australia, Venice.

Within Delft3D, the Delwaq engine simulates the far- and mid-field water and sediment quality due to a variety of transport and water quality processes. The BLOOM module describes the biogeochemical processes. State variables are phytoplankton biomass and chlorophyll-a, associated nutrient concentrations as well as oxygen. The phytoplankton is subject to gross primary production, respiration, excretion, mortality, grazing, resuspension and settling resulting in net growth (biomass increase or decrease). The phytoplankton module BLOOM includes specific formulations for these processes with the exception of excretion, grazing, resuspension and settling. The combination of Delwaq and BLOOM is often referred to as Delft3D-ECO. The model is coupled to the Delft3D-FLOW (for simulation of hydrodynamics) and Delft3D-WAVE (for simulation of waves) results and describes the fate (processes) and transport of the state variables.

Objectives

Within this pilot we can tackle a variety of objectives of which the most important are:

1. To monitor and assess impact of changes in water column trophic status, especially eutrophication and sediment load
2. To monitor and assess impact on algae blooms/cyanobacteria
3. To monitor and assess impact of habitat improvement measures for turbidity reduction, e.g. creation of islands, removal of barriers for fish, creation of low-wind areas for development of macrophytes improve connectivity with other wetlands in land-water interface.
4. To monitor and assess changes in seasonal dynamics (e.g. phenology of phytoplankton growth, EBV phenology)

These objectives mainly contribute to the science question “How will the diversity of life and ecosystem services in freshwater systems change with increasing pollution and eutrophication?” and will be tackled in the following way:

- **Objective 1:**
    - EO based products of chl-a, total suspended matter (TSM) and light extinction will be produced for all the years that Sentinel-2 has been operational. Operational services including satellite missions (e.g. ENVISAT-MERIS, Sentinel-3 OLCI) will be included for coarser spatial resolution, e.g. to provide a larger historical dataset. Furthermore, the potential of primary production (PP) derived from EO data will be investigated. No operational services or PP algorithms are yet available for freshwater systems. Nevertheless, algorithm approaches will be tested and evaluated concerning their applicability.
    - In situ data on phytoplankton, chl-a, light extinction, transparency and TSM data will be collected (though Rijkswaterstaat) to relate EO chl-a and TSM products. In 2022: in situ primary production measurements will be done by Rijkswaterstaat for Biomondo. These data will be compared to the EO PP products.
    - Model: the Delft3D model will provide support for the observed chl-a (a.o. through modelled nutrient dynamics) and TSM (through the effects of wind on hydrodynamics and hence TSM transport) patterns.

- **Objective 2:**
    - EO based products with cyanobacteria indicator (in addition to the chl-a maps mentioned under Objective 1) will be produced to be able to see if cyanobacteria occurrences intensify temporally and spatially. We will investigate near future hyperspectral sensors, e.g. EnMap, to identify approaches for determining phycocyanin concentrations.
    - In situ data on phytoplankton (see Objective 1) will be used to support the EO phycocyanin indicator products.
    - Model: the Delft3D model will provide information on nutrient dynamics and hydrodynamics to help explain the observed changes in cyanobacteria concentrations.

- **Objective 3:**
    - EO based products on especially TSM will show the effects of the Marker Wadden on (possible) turbidity reduction. These data will support the bird foraging behavior research in this area.
    - In situ data (in addition to what has been mentioned under the other objectives) on bird numbers and foraging will be provided by the bird foraging behavior program of national park Nieuw-Land.
    - The Delft3D model will fill gaps between measurements (both EO and in situ)

- **Objective 4:**
    - The same data produced under the other objectives will serve to contribute to this objective as well. In addition, EO SWT products will be used for this objective since this is an important parameter to study changes in phenology.

If time permits, we will explore possibilities of linking Delft3D with models of change in biodiversity as well, e.g. with the GLOBIO model, and we will explore the possibility of developing a new EO product describing primary productivity in freshwater systems.

Pilot sites

We have chosen the IJsselmeer area as the primary site for this pilot. The IJsselmeer area (Figure 1) is an important site to study (reverse) eutrophication and habitat changes on biodiversity because 1) parts in this area have high concentrations of suspended sediments (Markermeer), 2) a shift took place from a lake, dominated by harmful algal blooms, to less harmful algae and 3) many restoration measures have been undertaken or are still in construction such as the Marker Wadden (part of the to be constructed national park Nieuw-Land). The IJsselmeer area is a freshwater lake area divided into three sections: 1) the IJsselmeer itself, 2) Markermeer/IJmeer and 3) Border lakes. All three are Ramsar and Natura 2000 sites. With the closure of the Afsluitdijk in 1932, the former Southern Sea estuary was transformed into the freshwater Lake IJsselmeer. Subsequently, a string of so-called border lakes and Lake Markermeer were created by land reclamation projects and the construction of dams. These alterations serve safety, provide drinking water supplies, and created agricultural land. Owing to the change in category, the lakes are “heavily modified” according to the definition of the Water Framework Directive (WFD).

Figure 1 Location of the IJsselmeer area, showing the IJsselmeer itself in the northern part of the system and the Markermeer in the southern part.

The lakes serve as a major stop for many migratory waterfowl species such as the Common Pochard or Tufted Duck. In the past, these species mainly fed on the zebra mussels which contributed almost 100% to their diet. Since the second half of the 1980's, this lake area has observed a reduction in nutrients (N, P). This ongoing oligotrophication resulted in a change of the phytoplankton composition (from large colony-forming species (mainly cyanobacteria) to smaller species (small green algae) with a high turnover rate of nutrients). The zebra mussels somehow could not survive well enough on these new species of algae and were replaced by its relatives, the quagga mussels. This species feeds on the smaller phytoplankton species but the consequence of this is that the food quality of these mussels is much lower than the zebra mussels. Because of this (though there are other hypotheses that could explain the decrease such as improved habitats elsewhere and less frozen periods in the Baltic Sea which may lead to less migration), the bird numbers are still decreasing in the area.

Also, other modifications in the food web took place. For example, the European smelt has decreased in numbers, probably due to warming of the water temperature and over-fishing, and many exotic species (benthic invertebrates as well as fish species such as gobies) are now dominating the food web. Especially the Markermeer suffers from these changes because this lake is very turbid because suspended solids cannot leave the system. In this lake, several measures are constructed to provide sheltered habitats for the development of macrophytes, (spawning) fish, and other species at higher trophic levels. One of these measures is the creation of islands (Marker Wadden), that also aim to improve the water quality of Lake Markermeer for higher trophic levels such as red listed and other aquatic herbivorous, fish-eating, and mussel-eating waterfowl. With EO we can detect these changes in habitat type (as shown in Figure 2) to complement our analysis when needed/of interest to stakeholders.

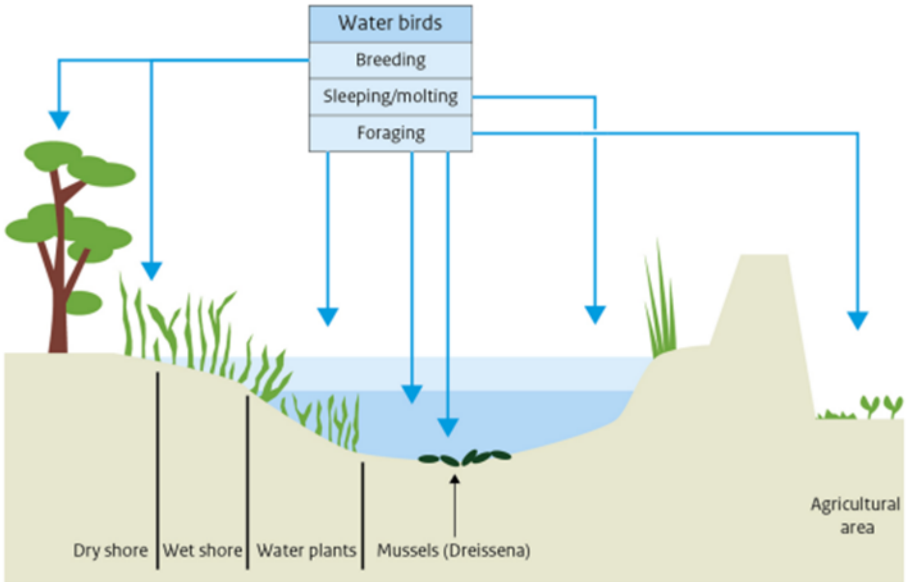

Figure 2 Different ecotopes in a lake with the ecological relation of birds in the ecosystem (Van Puijenbroek et al., 2015).

As can be seen from the described activities, we will combine EO data for several parameters with available in situ data coming from Rijkswaterstaat (Early Adopter) and from other sources as well (e.g. University of Amsterdam who is doing monthly cruises on the lake). The EO requirements for this pilot site are therefore products on:

- Chlorophyll-a
- Phycocyanin indicator
- Total suspended matter (TSM)

- Surface water temperature (SWT)
- Light extinction

For this pilot we will focus on the Sentinel 2 time period but will extend the EO data with previous missions and operational services which cover the time period >10 years from today. For this area, a Delft3D hydrodynamic-water quality model is available which will use the EO products either directly as input or as validation. There are separate Delft3D models available for both Markermeer and IJsselmeer. The models combine hydrodynamics (Delft3D-FLOW) with water quality processes (Delft3D-Delwaq and if necessary, expanded with the BLOOM module for primary production). For these lakes we would like to do simulations with the models in which concentrations of suspended matter/solids (TSM), chlorophyll-a and primary production are the output. We can then compare the outcome of the models for these parameters with the EO products for these same parameters. Model and EO output can then be compared to each other using the Target Value (Jolliff et al., 2009), an overall model performance metric that takes the bias, root mean square error and correlation into account. A Matlab code is available for this exercise. A specific year for this activity will be selected. As a next step, instead of using EO data only as verification of model performance, we will split EO data: a selection will be used as direct input in the model and the rest as validation of model performance (again using the Target Value metric). The improved models will be better able to assess the impact of the nature restoration measures that are taking place as well as the ones to be implemented on phytoplankton, turbidity and production.

Simultaneously, a research program around the creation of a new national park (Nieuw-Land), of which the Marker Wadden is a part, is taking place. In this project, several bird species are tracked to follow their foraging behaviour in the area, especially piscivorous bird species as common tern. One of the objectives is to see if these birds make use of (gradients of) water transparency to hunt for fish. The gradients in water transparency are influenced by wind and activities such as habitat construction and dredging. The EO products from BIOMONDO (turbidity, chl-a) will be linked to the foraging patterns of the birds. This will directly tackle the objective "Monitor and assess impact of changes in water column trophic status, especially eutrophication and sediment load (EBV productivity)" and "Monitor and assess impact of habitat improvement measures for turbidity reduction".

References

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