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EO supported assessment of fish ecology in Lake Vänern

Internationally coordinated environmental protection programs require assessment of ecological status of habitats and mapping of the distribution of species and habitats in European as well as Swedish freshwaters. These mandatory assessments are hampered today by the size of the largest lakes and the enormous number of lakes in total. Besides assessing the distribution of essential habitats (spatial), there is also a need to assess the environmental status of water bodies (temporal), as requested by EU's Water Framework Directive (WFD). Given the large number of lakes in Sweden (circa 96 000 lakes exceeding 10 hectares) and comparatively large size of many systems, these directives constitute a heavy financial burden when using traditional monitoring tools. However, prime ecological indicators (primary production, transparency, etc.) can be measured by remote sensing. This information can then be used in spatial modeling to optimize fish monitoring programs and to extend their coverage and interpretation potential.

Remote sensing has the advantage of covering large areas and enabling a fast and resource-efficient method to map prime characteristics of aquatic habitats.

Lake Vänern

Several of the largest lakes in the European Union are situated in Sweden. Our four largest lakes; Vänern, Vättern, Mälaren and Hjälmaren, have a historical, cultural, ecological as well as economic importance. A major part of the Swedish population is living within 100 km distance from these four lakes. These large systems offer many important ecosystem services such as drinking water, navigation, recreation and fisherie. Lake Vänern is Sweden's most important lake for commercial fishing and one of the most popular lakes for recreational fishing. It is Swedens largest lake with a surface area of 5650 km^2. The catchment area corresponds to 10% of Swedens surface and is dominated by forests (2/3). Lake Vänern consists of two major basins with more than 22 000 islands and islets.

In general, the ecological status with respect to total phosphorus, Secchi depth and chlorophyll of great Lake Vänern is high at all three available control stations, and has been stable over the last years (Sonesten, 2014). Nitrogen and phospourus concentrations have consistently decreased since early/mid 80's and have remained stable during the 2000s. The phospourus concentrations are almost at estimated backgound levels, but high concentration prevails locally in smaller bays. Highly eutrophicated areas existis. Nitrogen is still elevated and manly caused by high nitrogen losses from surrounding farmland. The amount of Total Organic carbon (TOC) is today halved compared to 40 years ago (Sonesten et. al., 2004).

Water quality status maps for modelling of fish species distribution and density

The possibility to use MERIS based water quality products in combination with monitoring data (hydroacoustic data as well as multi-mesh bentic gillnets) for fisheries management, assessment of ecosystem status and identification of essential habitats in Sweden's large lakes, has recently been investigated in a Swedish Space Board and end user funded project (Philipson et al., 2014) and included Diversity II products.

Figure 1 shows the location of available monitoring data in Lake Vänern. The mean position of each gillnet and/or acoustic transect segment was analysed with predictor layers derived from MERIS. Besides MERIS based predictors, depth at the sampling site and distance to the shoreline, was used in the analysis.

Using these datasets, fish assemblage composition using multivariate regression trees were explored and analysed. Multivariate regression trees form groups of data by repeatedly splitting data into clusters minimizing variation within groups and maximizing variation between groups. In order to test specifically for the importance of remote sensing data one tree using all predictor variables, one without the remote sensing predictors, one tree using only the remote sensing predictors and one tree using the remote sensing variables combined with nearest distance to shoreline.

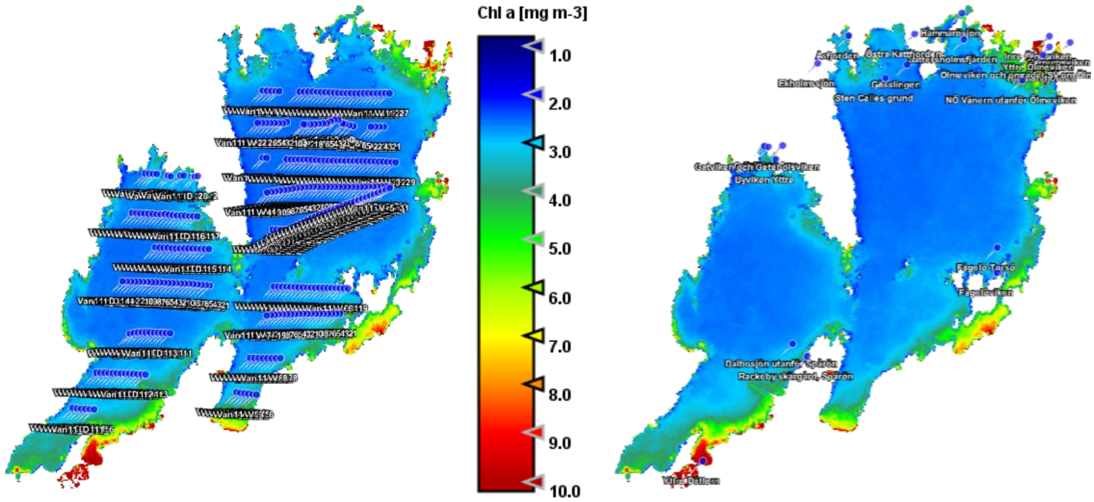

Figure 1a and b. High density hydroacoustic data (a) and multi-mesh gillnet stations (b) plotted on 9 year monthly Chl a mean (August) Diversity II data.

For <u>inshore</u> areas, depth at the sampling site, together with chlorophyll a as well as CDOM (Colored Dissolved Organic Matter), explained a significant part of the variation in fish assemblage composition. There was an apparent shift in species composition at the median position of the thermocline (inshore = 12.2 m) indicated by the first split in all multivariate trees (Fig. 2a). In a situation where bathymetric maps not are available and depth thus is omitted from the analyses, remote sensing layers can still contribute to valid multivariate trees with similar errors as with depth, particularly if a GIS-derived parameter such as distance to shoreline can act as a proxy substitute for depth in the analysis. The habitat categorizations obtained by the tree analysis were used to create GIS-layers in order to visualize the distribution of different assemblages in the studied lakes and water bodies (Fig. 2b).

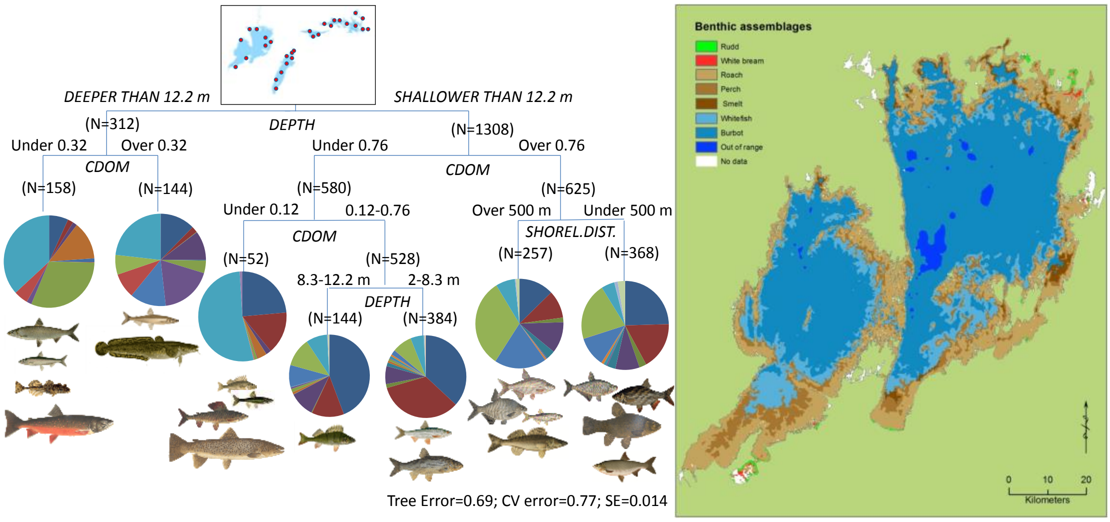

Figure 2a and b. (2a) The results of a multivariate tree analysis on inshore fish assemblage composition in L. Vänern, L. Vättern, L. Mälaren and L. Hjälmaren based on catches in multi-mesh gillnets. The figure illustrates the splits of the communities into distinct assemblage groups. The pictures of fish species represent the characteristic species (not necessarily the most common) in each group. A summary of the overall errors of the tree is given in the lower right corner. (2b) Map predictions illustrating the results from multivariate trees applied on L. Vänern using CDOM, depth and nearest distance to shoreline as predictors inshore and offshore benthic assemblages combined.

For <u>pelagic</u> areas, remote sensing predictors were particularly important for construction of multivariate trees. Trees based only on remote sensing predictors were almost as good as trees based on a combination of all predictors. Trees obtained with a combination of nearest distance to shoreline and remote sensing parameters were even slightly better than trees obtained with all predictors combined. Trees built only using depth and nearest distance to shoreline had significantly larger relative error than trees built using some kind of remote sensing information indicating that remote sensing variables are particularly important predictors for pelagic fish assemblages.

In addition, several candidate metrics to specificatlly describe the influence of eutrophication on fish assemblages in large lakes using MERIS data as pressure variables were tested. The hypothesis was that eutrophication primarily enhances the production of phytoplankton and thus leads to increased levels of Chl a and CDOM but also secondarily by negatively affecting the depth penetration of macrophytes and leading to a more pronounced re-suspension of sediments by wave action, thus also leading to increased levels of TSM. The analysis included all stations and both hudroacoutic and gillnet data, but not for all metrics. Two of the thirteen tested metrics appeared to be very promising: the density of pelagic fishes (number per hectare) and the percentage of cyprinids (when roach is excluded). The percentage of cyprinids is representing the species-shifts that take place as a consequence of eutrophication (Westerbom et al., 2006, Olin et al., 2013). Figure 3b shows a prediction of the total density of pelagic fishes in Lake Vänern, based on a linear regression model using MERIS based CDOM estimates and monitoring data.

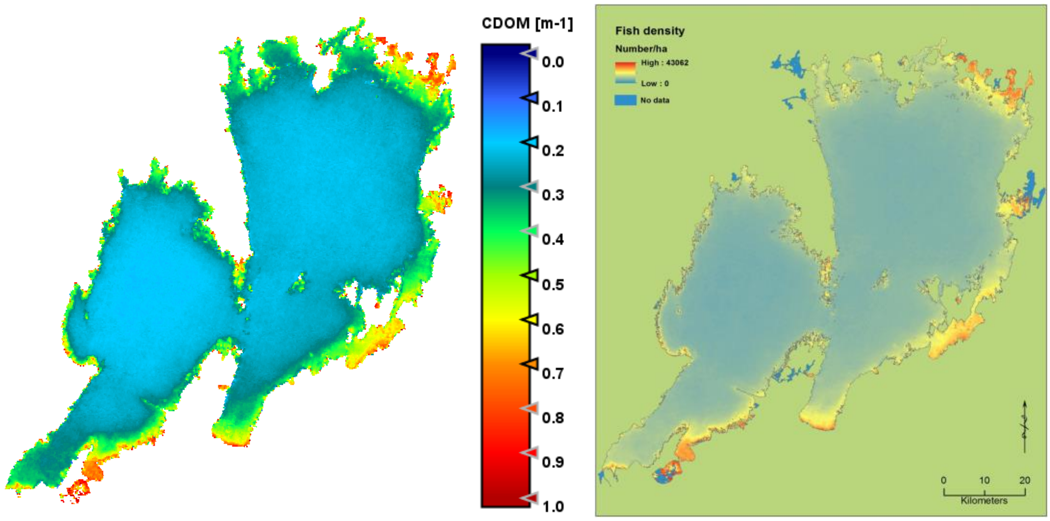

Figure 3a and b. (3a) 9 year monthly CDOM mean (August) Diversity II data (3b) Map prediction of the total density of pelagic fishes applied to L. Vänern. The prediction was based on a linear regression model with CDOM in August (as shown in 3a) as the main predictor variable. Note that this prediction is an illustration of how remote sensing layers can be used but that it has not been properly validated against field data.

Conclusions

The applicability of remote sensing methods for fisheries management, assessment of ecosystem status and identification of essential habitats in Sweden's large lakes has been evaluated and demonstrated (Philipson et al., 2014) and it was concludes that MERIS based products could support the assessment of the WFD quality factors phytoplankton, transparency and fish in the investigated lakes. Two potential candidate metrics were identified that could serve as tools to assess the impact on fish ecology from eutrophication in large lakes. These should be futher evaluated. The results could also support the design of fish monitoring programs. Since CDOM/Chl a in many cases could be used as the main predictors for fish distribution and assemblage composition it is possible to use these parameters to assure that all the existing habitats/assemblages are covered in the programs. In addition, the phytoplankton production in a water body is known to limit the yield of most fisheries. If the production prerequisites can be described using remote sensing it can be used as a rough measure of potential long-term yield of a fishery and deviations from predicted catches can be used to interpret the exploitation level in a water body.

It was shown that MERIS based data layers could be a useful contribution to model the distribution of individual species and assemblages as well as the characteristics of their habitats. However, since depth in many cases is the single most important environmental factor, bathymetry maps must be markedly improved to enable modelling of the distribution of essential habitats in these systems. An important factor that could improve the potential to model distributions would be to collect data on fish abundance and presence more evenly along the environmental gradients described by MERIS data. One example is monitoring data from hydro-acoustics that has been focused on the very largest open basins and thus do not cover the entire productivity gradient.

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