The Limfjord, Denmark (SSA 5)

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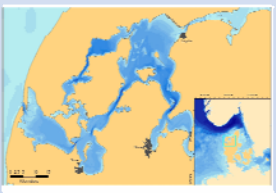
SYSTEM BOUNDARIES



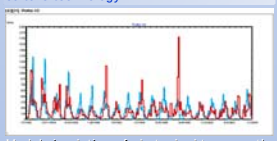
Geographically and virtually, the SSA 5 area includes the Limfjord (social & economic components) and the Skive Fjord (ecological component).

SSA 5 – the Limfjord

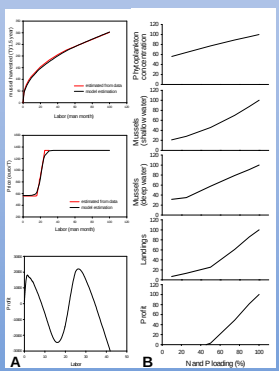
The Limfjord is situated in Northern Jutland, Denmark. With a coastline of 1000 km and a surface area of 1500 km², the Limfjord is the largest former fjord in Denmark. Today, it has a western inlet from the North Sea and eastern channel connecting with the Kattegat. The catchment area of the fjord is 7528 km², of which 62% is occupied by agriculture.

CATWOE

Customers, beneficiaries/victims: Mussel fishery & farming staff, farmers sustainable production, agriculture/farm workers. **Actors:** Fish boat owners, fish farmers, mussel industry, boat & fish gear suppliers, agriculture/farm owners. **Transformation:** Demand for water clarity, demand for mussels. **Worldview:** Mussel production is an important income source in the area. **Owners:** The EU, Ministry of Environment, Ministry of Food, Agriculture & Fisheries (incl. regional), municipals. **Environment:** Agriculture technology, regulating laws, upland assimilation, marshland/wetlands, mussel dredging impacts, mussel harvest and culture technology.



Model simulation of phytoplankton growth (---) is calibrated close to the values measured in the real system (---).



A. Optimisation of labour is a model innovation used in the economic component. B. Model simulation of reduction in percentage of nitrogen (N) and phosphorus (P) loadings.

SAF: SYSTEM DESIGN

POLICY ISSUE

'Interaction between eutrophication and mussel production'

The policy issue was decided on by the SSA team, based upon the stakeholder foci of "**no fish**" and "**hypoxia**" as well as on data availability. Today, mussel fishery is the most important harvest yield in the fjord.

SAF: FORMULATION STEP

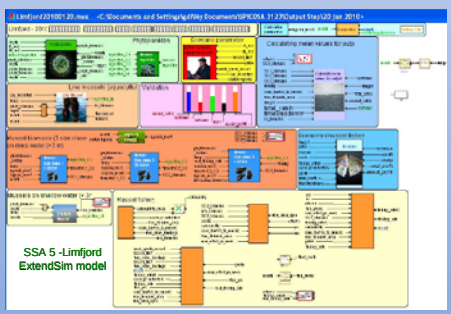
From conceptual to ExtendSim model

The conceptual model of the virtual system, developed during the Design Step, was converted mathematically using the software ExtendSim using empirical relationships auxiliary models and standard equations of relevance. The Ecological model component includes nutrient loadings (N, P), phytoplankton growth, mussel growth (five functional groups) and hypoxia events in Skive Fjord. The socio-economic model component comprises mussel fishery and mussel farming in the Limfjord that were later down-scaled to 1/7 (equal to the Skive Fjord area). Model simulations were calibrated using data.

SAF: APPRAISAL STEP

Model sensitivity & simulation

The model components were linked together into a single model. Model sensitivity was tested (e.g. phytoplankton mortality) and several scenarios were simulated, e.g. system response to changes in nutrient loadings (N, P), mussel fishery and mussel farming.



SAF: OUTPUT STEP

The SPICOSA stakeholders were impressed by the model results and found that the capacity to run scenarios could prove to be useful in integrated management of nutrient loadings and mussel production. There were requests to continue the development of the model to include other issues as well (e.g. fish, toxic chemicals). This will require model updates and mining of supporting data.

This is the first Limfjord model that includes both an ecological and a socio-economic component and allows scenarios to be run and compared. Scenarios include two types of mussel production for food, and a potential measure of nutrient removal from the estuary. KerCoast was received positively (in a paper version, as the supporting server was out of order). There were several unforeseen outcomes. For instance, the model shows that the mussels appear to be food limited even at high nutrient loadings. The SAF facilitated valuable discussions between the science team and the stakeholders, to which also the model scenarios were an eye-opener to the complexity of the system.

ECOSYSTEM GOODS AND SERVICES

Provisioning: Food provision. **Regulation:** Disturbance prevention; Bioremediation of waste. **Cultural:** Cultural heritage & identity; Cognitive benefits; Feel-good. **Option-use value:** Future unknown & speculative benefits. **Supporting:** Primary production; Habitat provision; Nutrient cycling; Soil formation & retention; Resilience & resistance (Wiethüchter 2007, Assessment of ecosystem goods and services provided by the coastal zone system Limfjord, 65 pp).

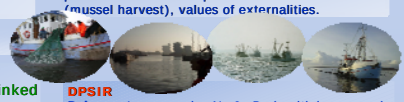
1st SPICOSA stakeholder meeting on 4th October 2007.

Limfjord stakeholders (SPICOSA)

Central Society of the Limfjord Fishermen, Danish Society of Nature Conservation, Danish Society of Recreational Fisheries, Limfjord Museum, Virksund & Omegn Fishery Society, Danish Shellfish Center, Danish Directorate of Fisheries Nykøbing Mors, Danish Society of Shellfish Aqua-culture, Society of Mussel Fisheries, Vesthimmer-land & Han Herred Recreational Fisher-men, Holstebro Municipal, Holstebro-Struer Harbour, Thyborøn Harbour, Tourist Office VisitNordjylland, University of Aarhus, and the regional sections of the Ministry of Environment, MC AAL, and MC RIN.

KEY INDICATORS

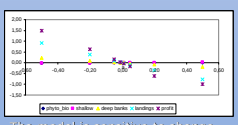
Ecological: e.g. water clarity, chlorophyll concentration, frequency and distribution of hypoxia, mussel biomass, filtration capacity. **Economic:** N and P loading, mussel harvest, production from aquaculture. **Social:** Profits (mussel harvest), values of externalities.



DPSIR

Driver: Increase in N & P (multiple causes). **Pressure:** Nutrient load. **State:** Change from fish to mussels, change of macro vegetation to phytoplankton (regime shifts). **Impact:** Hypoxia, water quality/clarity. **Response**: Water Framework Directive targets of reducing nutrient loads to the fjord system.

Mussel ingestion is an important internal feedback-loop of the Limfjord ExtendSim model.



The model is sensitive to change in grazing of phytoplankton by other species than mussels.

- 2nd SPICOSA stakeholder meeting, 26th February 2008.
- Dissemination at the 15th Danish Marine Science Meeting, 27th January 2009.
- Dissemination at the annual ICES WGIC2M meeting, 23 March 2009.
- 3rd SPICOSA stakeholder meeting , 2nd June 2009.
- Public workshop on the Limfjord, 3rd June 2009.
- Scientific workshop on the Limfjord, 4th June 2009.
- 4th SPICOSA stakeholder meetings, 20th & 21st January 2010.