Lake management: a Danish perspective

Denmark: 5.9 million people
43,000 km²

13 mio pigs, export: 19 million/year
1.5 mio catle, export: 0.5 million/year
Xxx poultry, export 102 million/year
Grain production: 9 million tons/year
= 1,500 kg per person/year (but most goes into pigs)

Maybe we should eat more grain than pigs

Agricultural area: 63% (highest in EU)

Many similarities between Denmark and The Netherlands also regarding our environment
(We dont have large lakes, but at least they are above above sea level)

Martin Søndergaard,
+ many colleauges
Section of Lake Ecology

AARHUS UNIVERSITET
INSTITUT FOR ECOSCIENCE
Denmark

Amsterdam,
12 October 2022

MARTIN SØNDERGAARD
SENIORFORSKER

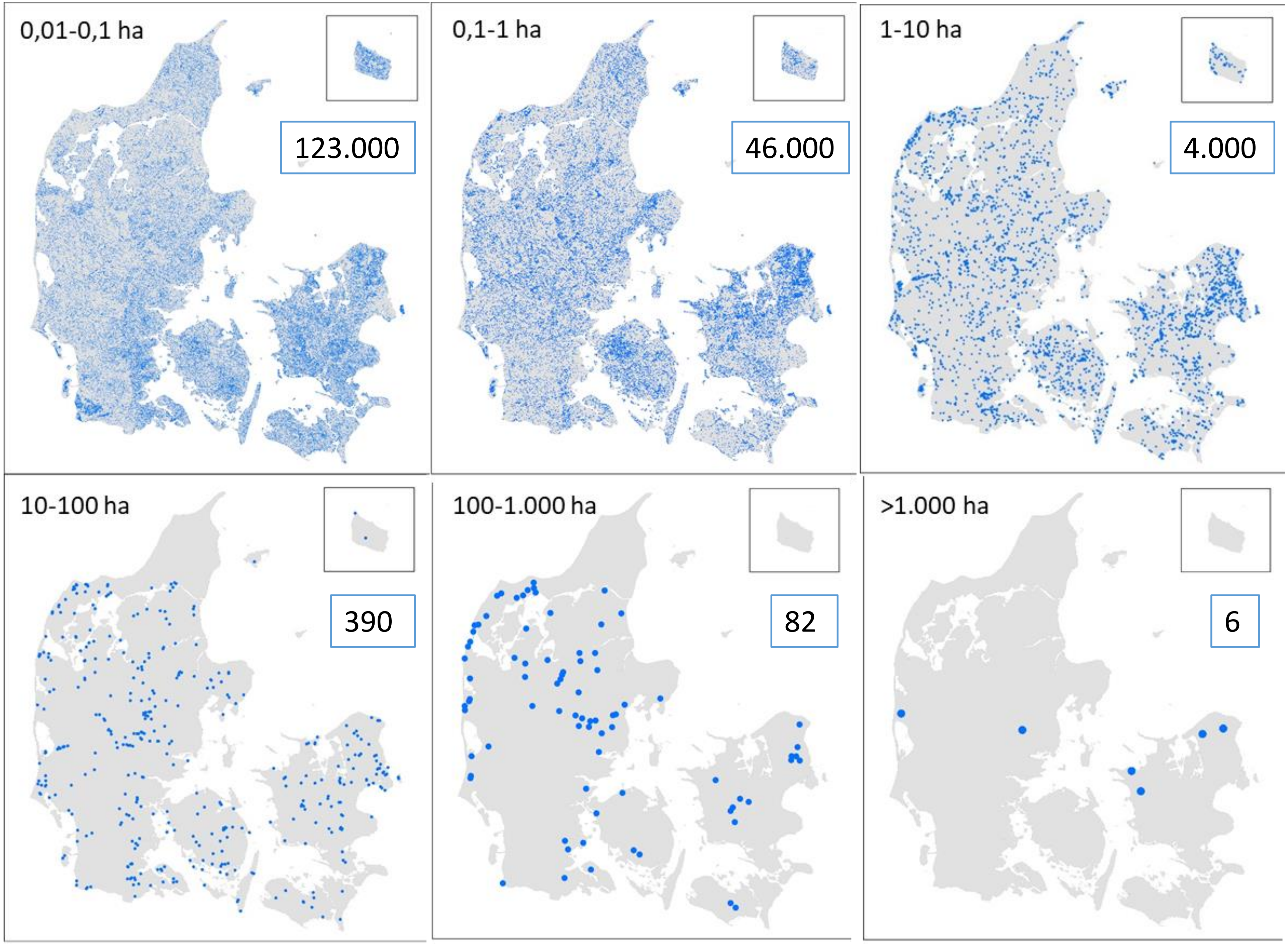
Lakes and ponds in Denmark

173.000 > 100 m²

Ponds > 100 m² are protected by law.

Only 986 lakes included in the Water Framework Directive, but all > 5 ha and some between 1 and 5 ha

Most are more or less impacted by human activities



From: Ejrnæs et al., 2021

Laws to improve the aquatic environment in Danmark: a 50 years long story

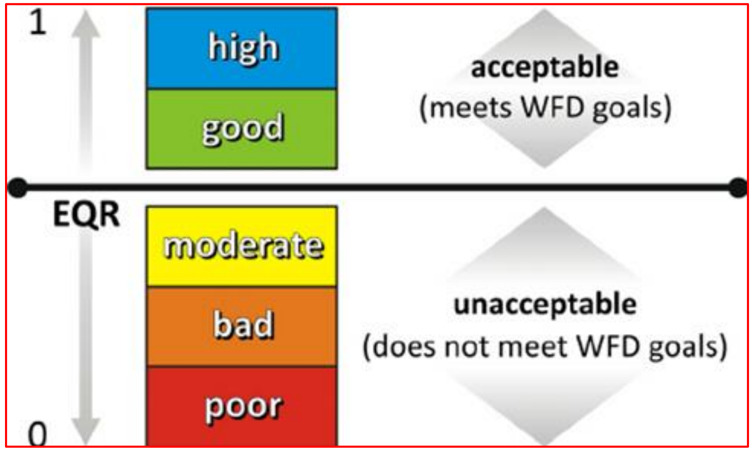
Regional/national based

- Improved and more wastewater treatment (ca. 1970 – 1990)
- Aquatic plan I (1987):
  - Reduce N emission by 50% and P emission by 80%
  - P-stripping in wastewater plants > 500-5,000 PE
  - Increased use of P-free washing powder
  - 9 months storage capacitity of manure
  - 65% winter green fields
- Aquatic plan II (1998):
  - Changed farming practice to reduce nutrient loss
  - Establish more wetlands and lakes to increase N-removal
- Aquatic plan III (2005):
  - 50% reduction of P surplus in agriculture
  - 50.000 ha buffer zones along lakes and rivers
- Green growth (2009/2010), bufferzones, restorations
- 1st Water Management plans (2009-2015)
- 2sd Water Management plans (2016-2021)
- 3rd Water Management plans (2021-2027)
- 4th Water Management plans ?

Defines a new and more systematic monitoring, (still running today)

EU's Habitatdirective (1992)

EU's Water Framework Directive (2000).



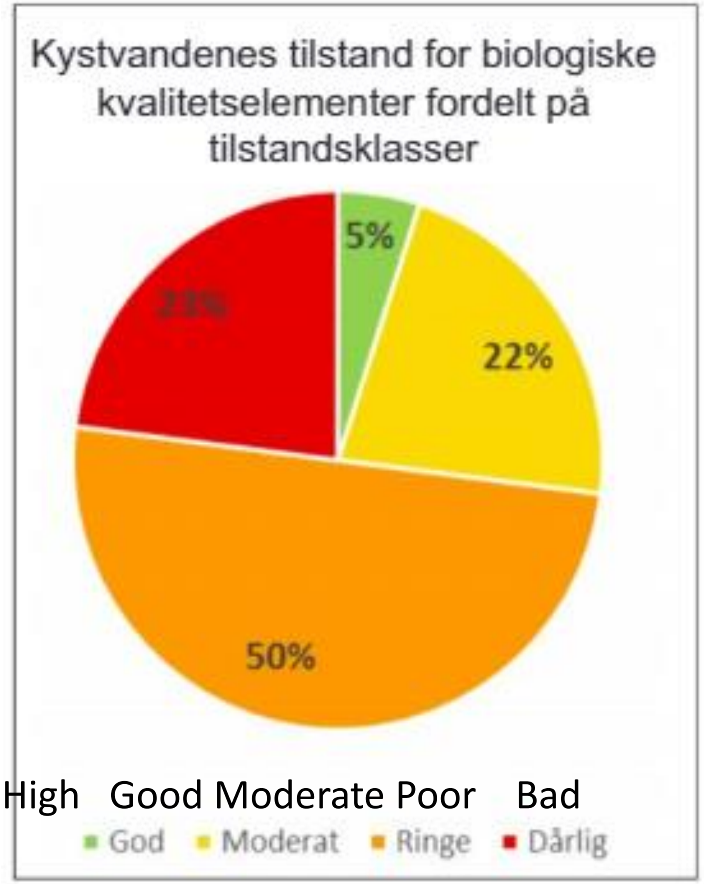
EU based

Environmental status of the aquatic environment in Denmark criteria from the Water Framework Directive

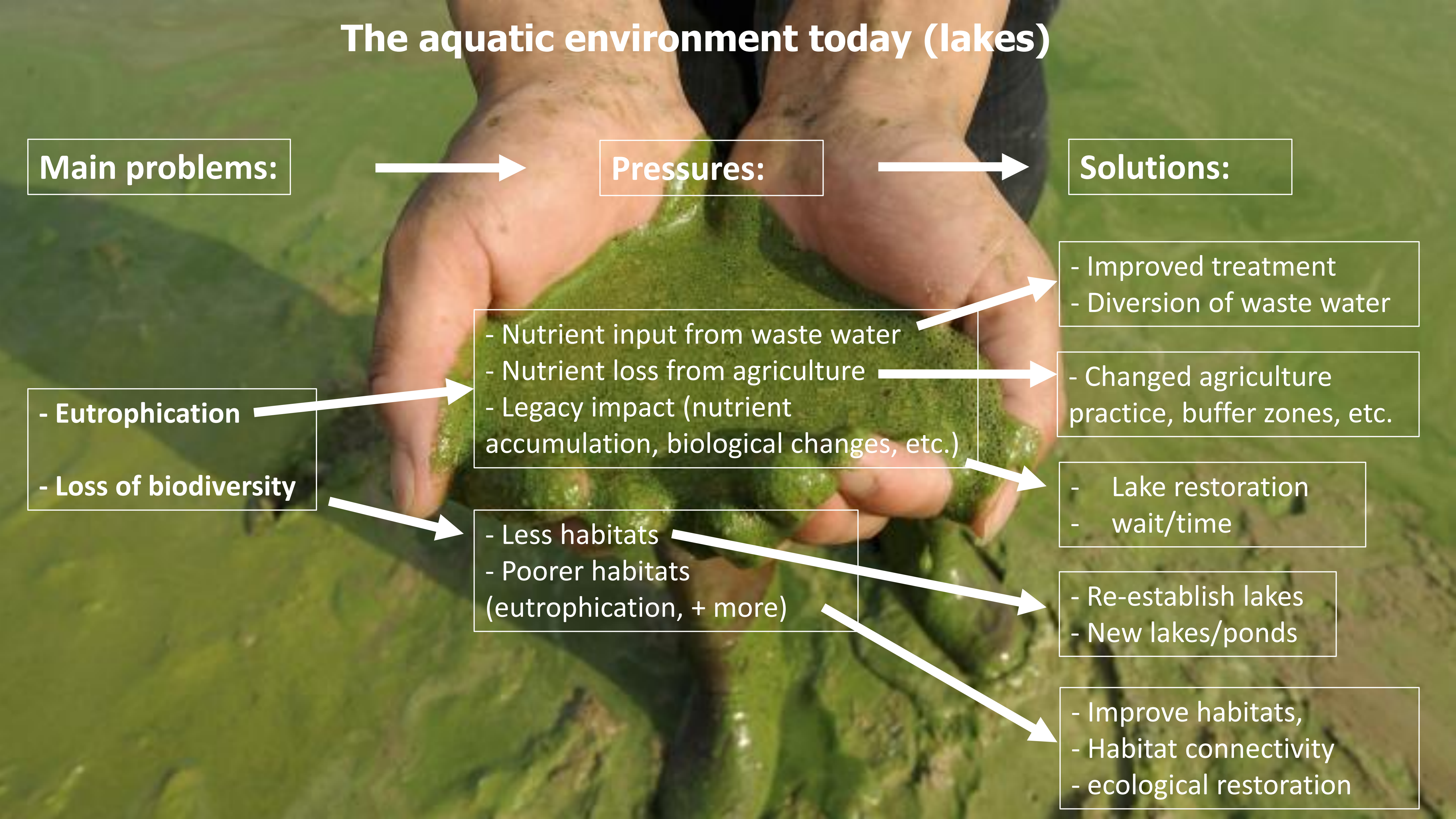
Rivers

Lakes

Coastal areas



From Danish EPA: https://mst.dk/natur-vand/vandmiljoe/vandomraadeplaner/


The aquatic environment today (lakes)
Main problems:
Pressures:
Solutions:
- Eutrophication
- Loss of biodiversity
- Nutrient input from waste water
- Nutrient loss from agriculture
- Legacy impact (nutrient accumulation, biological changes, etc.)
- Less habitats
- Poorer habitats (eutrophication, + more)
- Improved treatment
- Diversion of waste water
- Changed agriculture practice, buffer zones, etc.
- Lake restoration
- wait/time
- Re-establish lakes
- New lakes/ponds
- Improve habitats,
- Habitat connectivity
- ecological restoration

Example 2

Reestablisment (2002) of Lake Aarslev (100 ha) – a nature based solution

Main purpose:

- To increase retention of nitrogen and phosphorus, so less input to downstream lakes and coastal areas.
- Recreation an important side effect (near city of Aarhus)

Positive impacts:

- Retain 15-20% of nitrogen and phosphorus loading (up to 380 kg N/ha/year).
- High recreational value for local people.

Negative impacts:

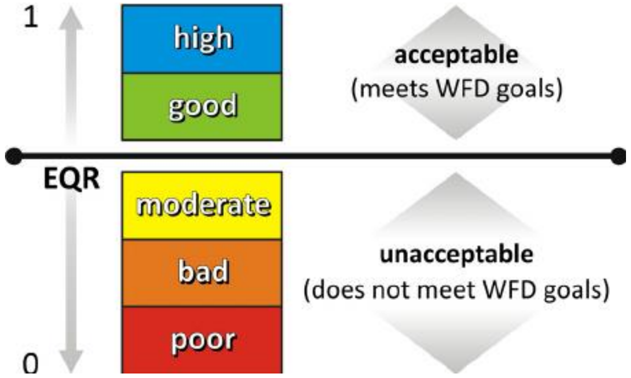
- Turbid lake (receives a lot of nutrients)
- Decreased migration possibilites for fish (80% of trouts are eaten during the passage of the lakes)

Example 2

From law to action (Lake Aarslev)

EU:
Water Framework Directive:
Good ecological quality in surface waters

DK, goverment:
Implementation of EU directive in Danish laws



Aarhus University:
Guide/advisor

DK, Environmental Agency (EPA):
Define what is needed and suggest methods

DK, Environmental Agency:
Suggest actions plans

Financial options

Actions plans

Consultation process

Application from Aarhus Municipality to EPA suggesting to establish Aarslev Engsø in order to reduce the nitrogen loading the Aarhus Bay

Approval by EPA

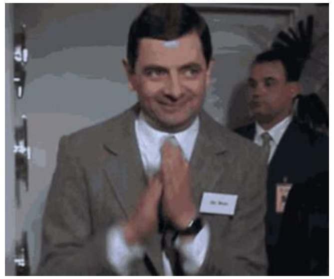
Aarhus Municipality makes detailed plans

Acceptance by land owners, adjustments

Practical planing, contractors etc.

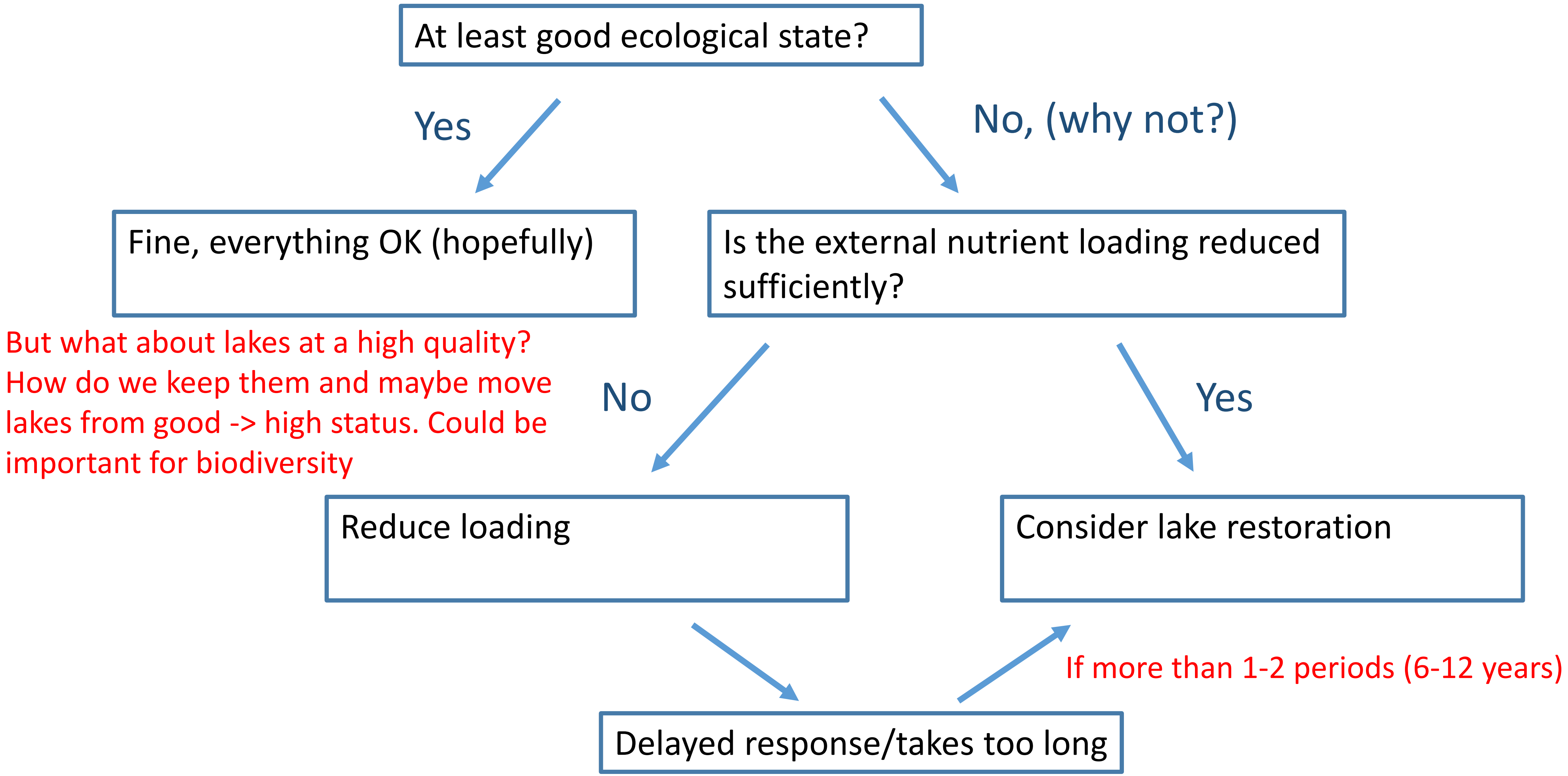
Information to citizens

Action, make the lake



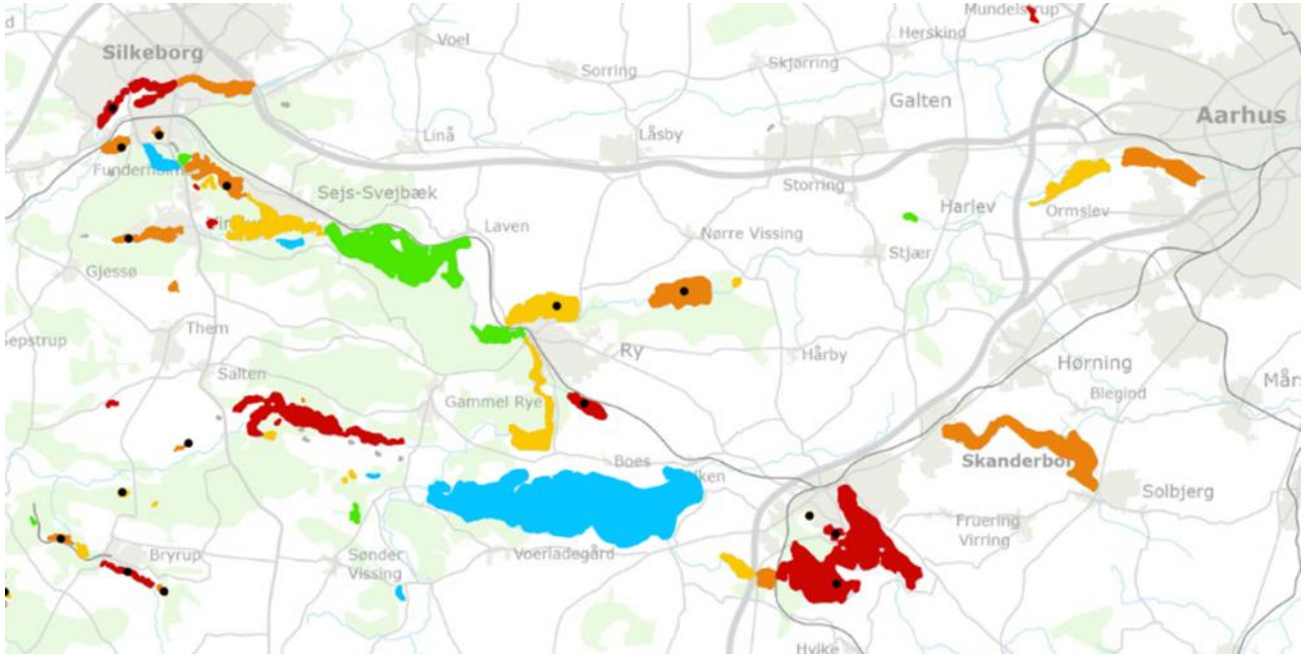
Effects and happy people (hopefully)

Overall decision tree implementing the Water Framework Directive



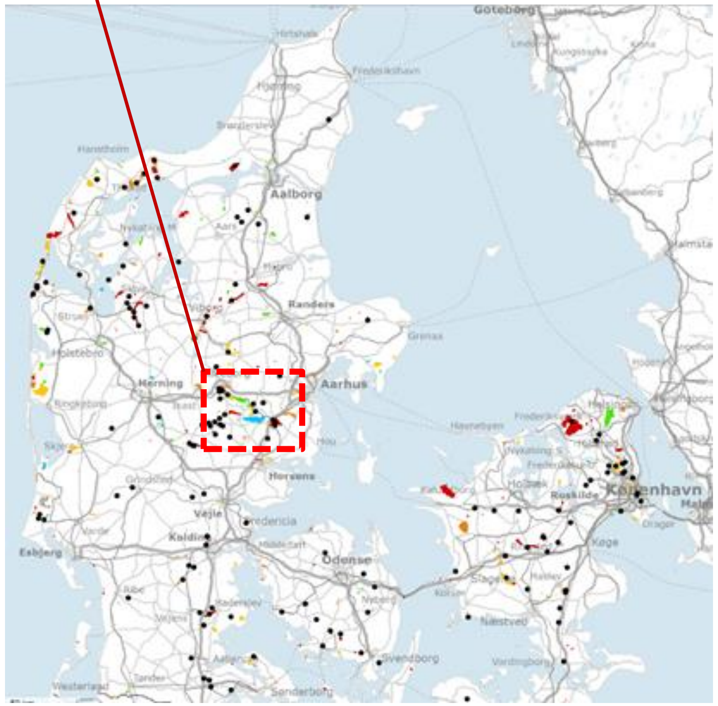
Example 3: presentation of lake status (GIS platform), -> public involvement

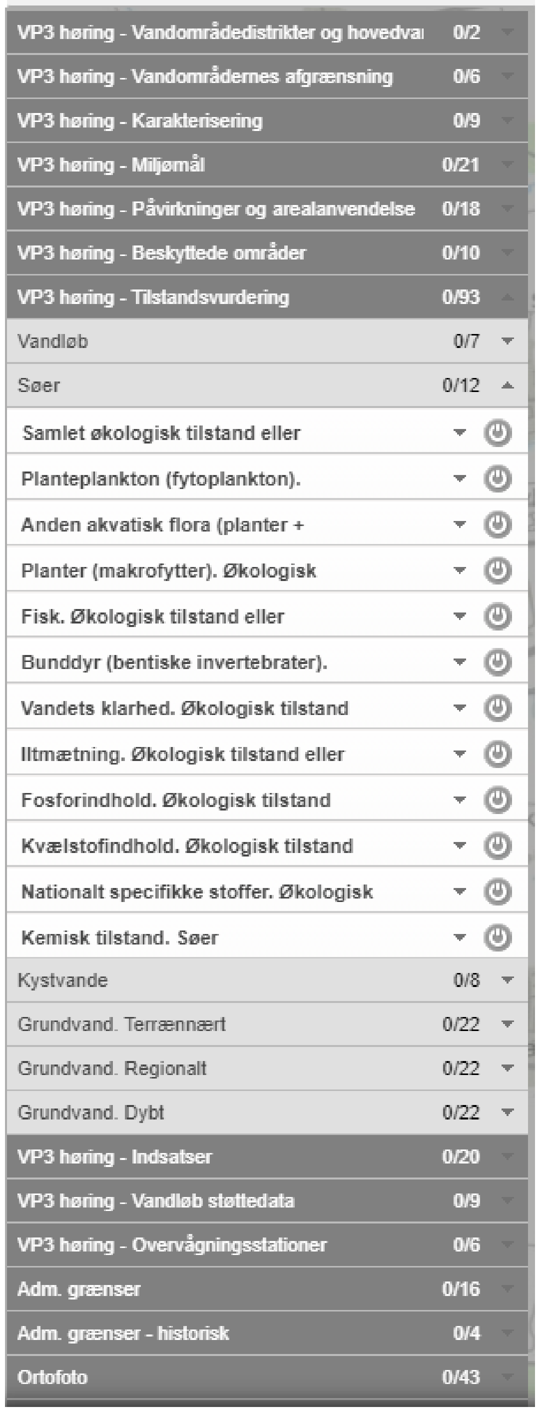
https://www2.mst.dk/Udgiv/publikationer/2019/12/978-87-7038-143-7.pdf



Ecological quality

From Danish EPA: https://mst.dk/natur-vand/vandmiljoe/vandomraadeplaner/





Example 3: Actions plans

Detailed descriptions on:

- Description of water districts
- Pressures
- Actions plans

So far the only measure (except lake restoration) is to reduce the external phosphorus loading. In the future also nitrogen?

https://mim.dk/media/226716/vandomraadeplanerne-2021-2027.pdf

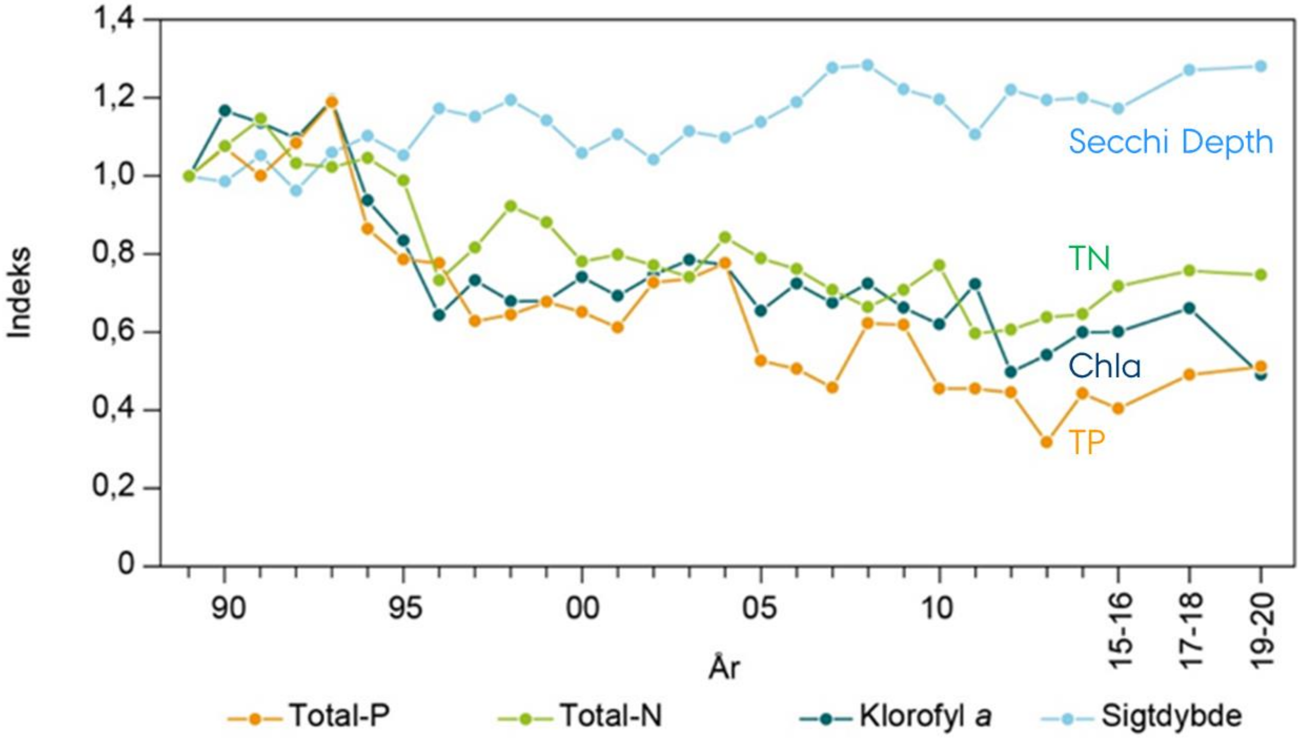
Still in consultation process

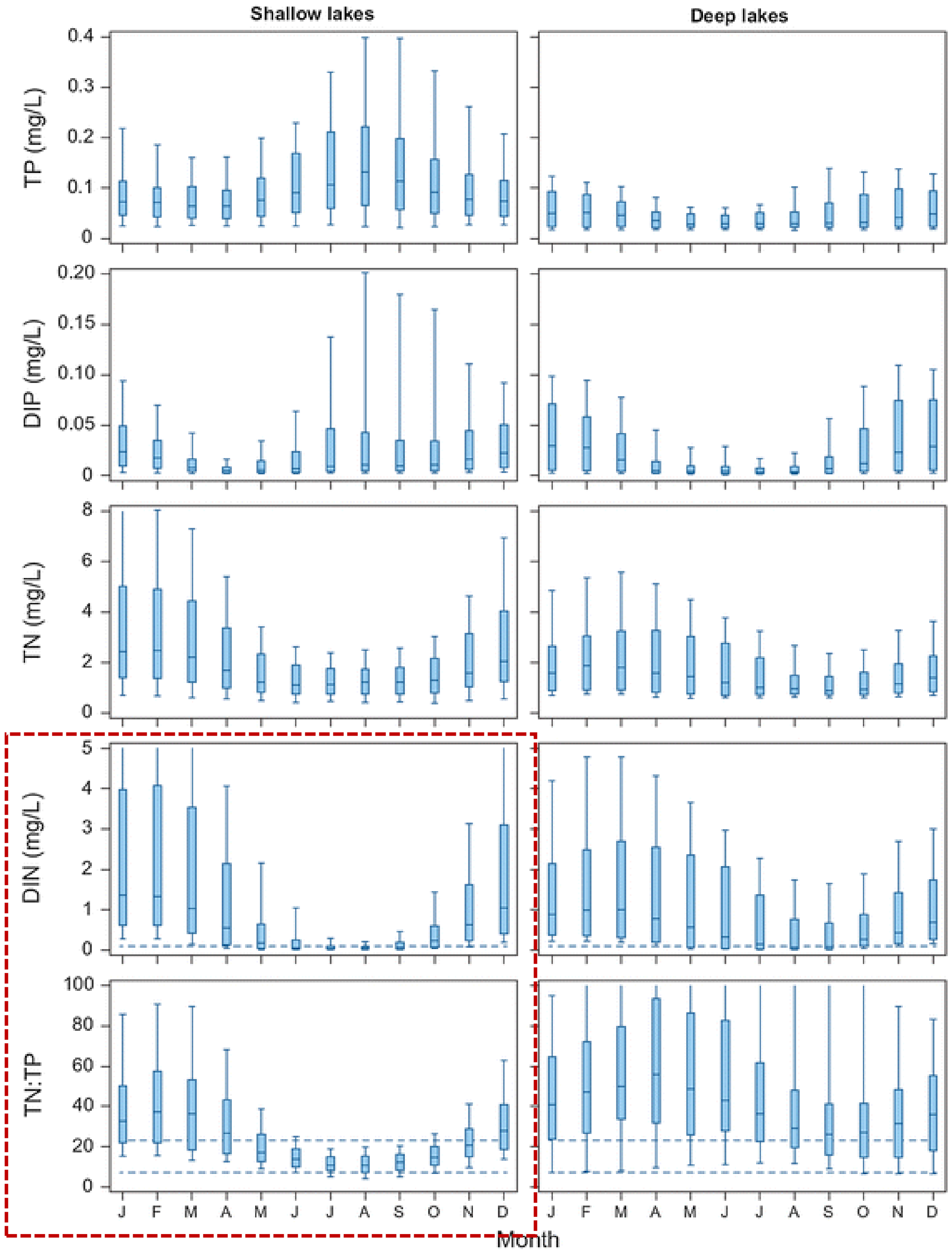
Example on action plans for lakes (made for each of 987 lakes included

Lake name area Phosphorus loading P- Reduction needed

Hovedvandopland	id	Sønavn	Note	Søareal	Oplandsareal	Belastning_2016_2018	Baselinebelastning_2027	Målbelastning	Indsatsbehov
				ha	ha	kg P/år	kg P/år	kg P/år	kg P/år
1.2	248	Arup Vejle		388	1207	305	297	314	-
1.2	252	Bjørnkær		8	147	41	37	50	-
1.2	255	Borbjerg Møllesø	4	13	285	164	161	99	62
1.2	256	Bredmose Fjends	4	4	117	52	51	19	32
1.2	258	Brokholm Sø		82	2958	1493	1457	678	779
1.2	260	Bølling Sø	4	311	2958	379	368	805	-
1.2	265	Ferring Sø		314	2051	1430	1412	530	882
1.2	268	Flade Sø		486	1186	570	568	339	229
1.2	269	Flyndersø nordlige del	6	271	8023	-	-	-	-
1.2	270	Flyndersø sydlige del	6	149	6941	-	-	-	-
1.2	273	Gjeller Sø		55	168	49	48	43	5
1.2	274	Glenstrup Sø		349	6064	2031	1958	1215	743
1.2	285	Gravlev Sø		20	449	240	237	172	65
1.2	294	Hauge Sø	4	15	613	188	183	159	24
1.2	295	Helle Sø	6	25	660	-	-	-	-
1.2	296	Hjerk Nor		63	5981	2318	2253	1163	1090
1.2	297	Holmgård Sø	4	14	1191	862	845	392	453
1.2	299	Horn Sø		27	955	632	619	203	416
1.2	301	Hygum Nor		28	3742	1245	1227	780	446
1.2	307	Jølby Nor		5	6273	4383	4281	1154	3126

Example 3: Actions plans
(has it worked and is using phosphorus only a good strategy?)





Nitrogen also important, parcitularly during summer →

Seasonal TN:TP ratios and DIN concentrations in shallow (n = 12, lake months = 2590) and deep (n = 6, lake months = 1723) lakes. The box plots show 10, 25, 75 and 90% fractiles. The line DIN = 0.1 mg/l indicates a boundary of potential DIN limitation (Camarero & Catalan, 2012). The two lines in the TN:TP figures display the TN:TP ratio (by mass), which can be used to identify potentially N-limited (TN:TP < 7) (Abell et al., 2010) or P-limited (TN:TP > 22.6) lakes (Guildford & Hecky, 2000)

https://doi.org/10.1007/s10750-017-3110-x

Example 4: Lake restorations (from eutrophication)

- Reduce external nutrient loading sufficiently (mainly phosphorus, but nitrogen also relevant)

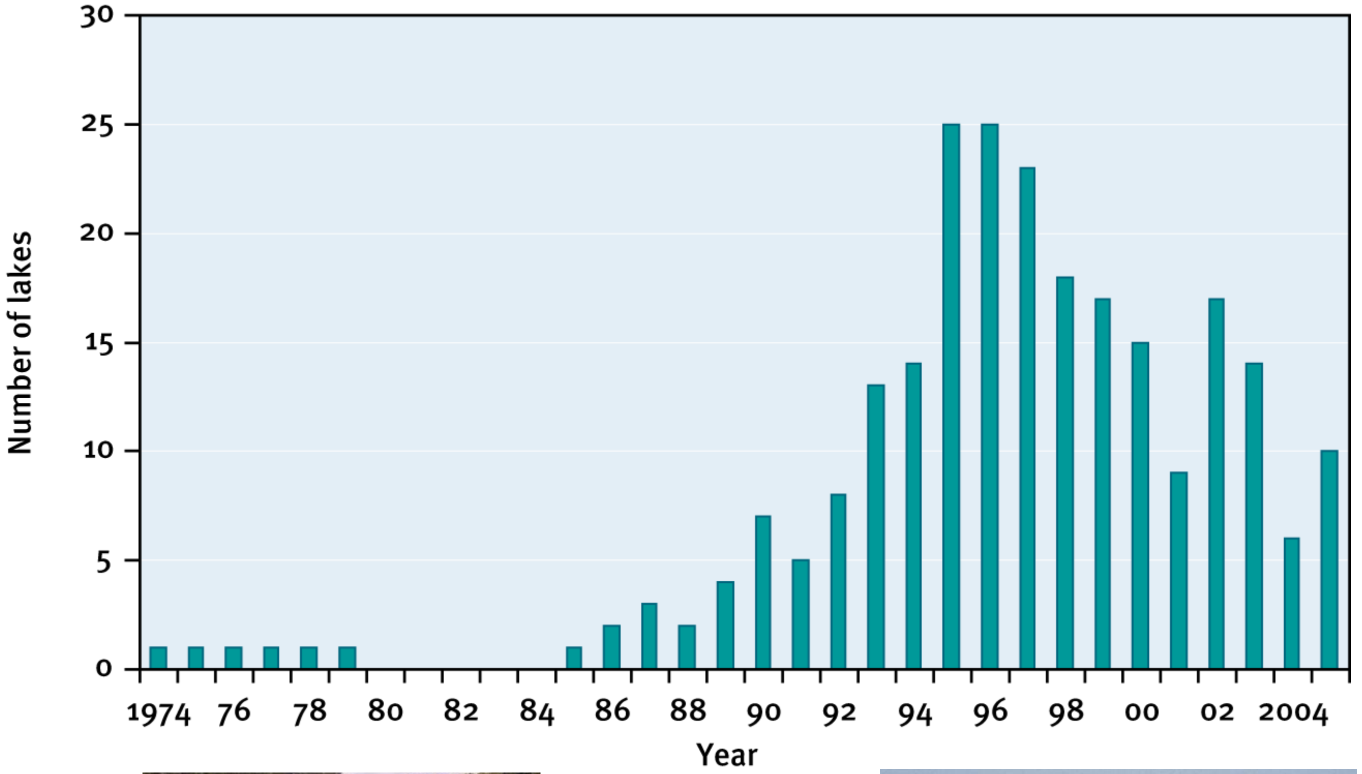
- Lake restoration (in-lake measures)
  - Reduce phosphorus availability (bottom-up control of phytoplankton)
  - Increase filtration (from zooplankton etc.) of phytoplankton (top-down control) and decrease sediment resuspension from fish. Biomanipulation.

Used in Denmark

- Add extra phosphorus sorption capacity (alum, iron, phoslock, lime, etc.)
- Increase natural P sorption capacity (oxygenation)
- Remove phosphorus (sediment removal, hypolimnetic withdrawal, fish removal)

- Fish removal (zoo-benthivorous species)
- Add piscivorous species
- Introduce filtrators (zebra mussel)
- Introduction/protection of submerged macrophytes

Example 4: Lake restorations (from eutrophication)




Alum treatment


Sediment removal

Lake restoration types and number of lakes restored in Denmark since 1990:

Sediment removal (large lakes):	1
P-fixation (aluminium (Phoslock)):	7 (1)
Oygenation hypolimnion:	6
Pike stocking:	65
Fish removal (roach, bream):	>50
Combined fish removal/Phoslock:	1

Plans (2021-2027): 40 lakes

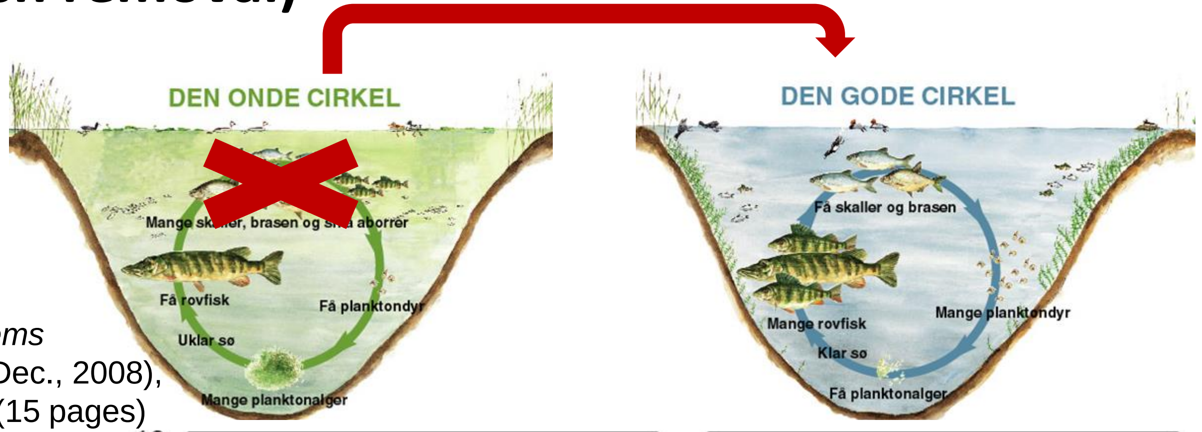

Fish removal

Biomanipulation (fish removal)

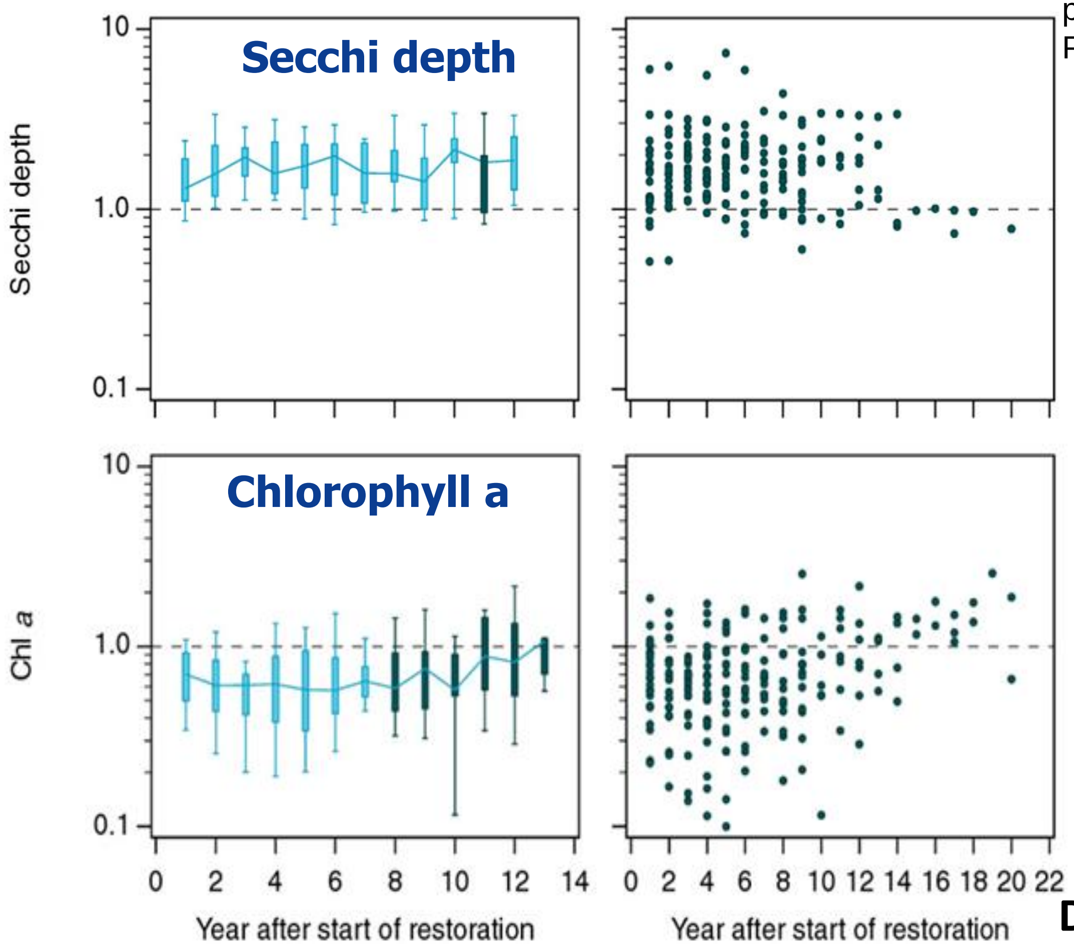
Aim: Increase grazing control by zooplankton on phytoplankton, less resuspension by fish

Experience: often good effects for 5-10 years, then lakes tend to return to turbid conditions.

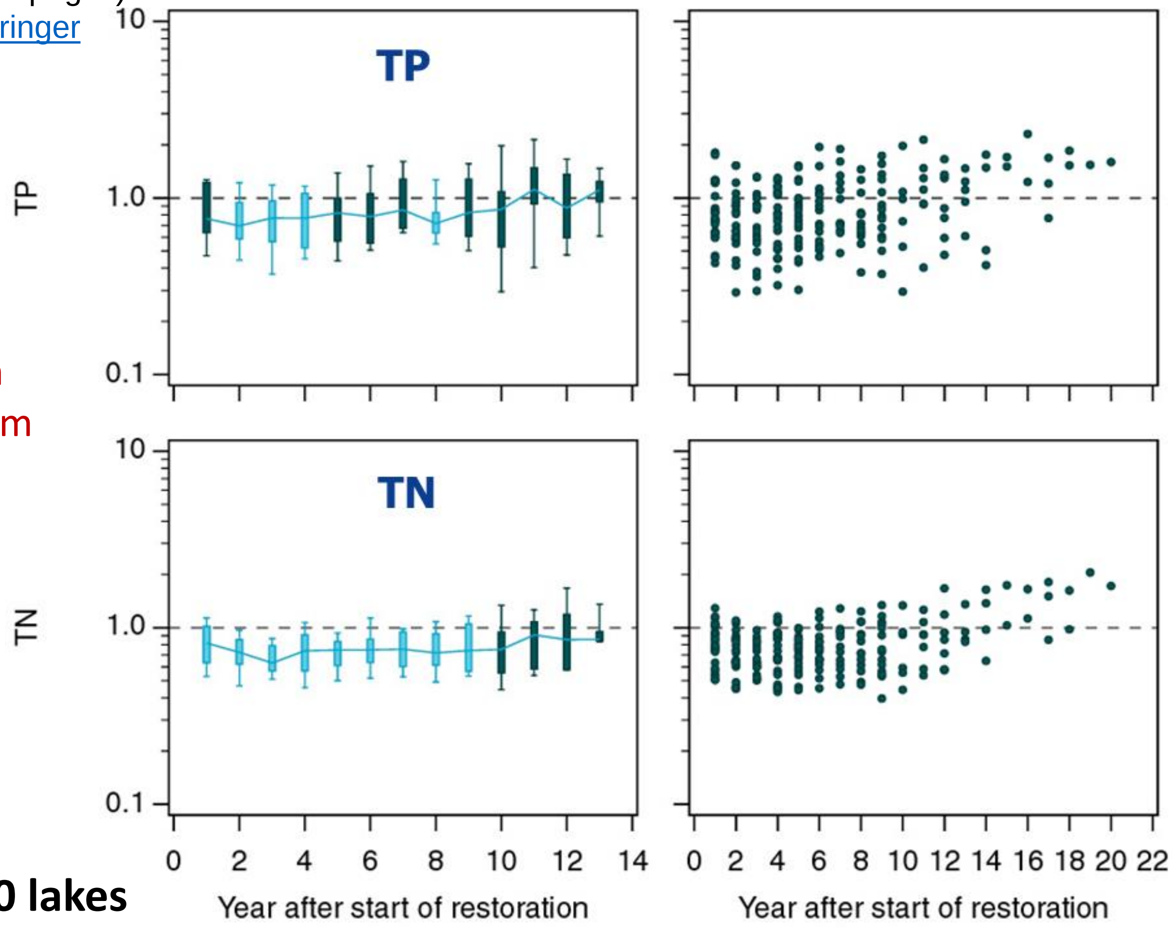
Negative: No permanent effects?



From: Ecosystems
Vol. 11, No. 8 (Dec., 2008), pp. 1291-1305 (15 pages)
Published by: [Springer]

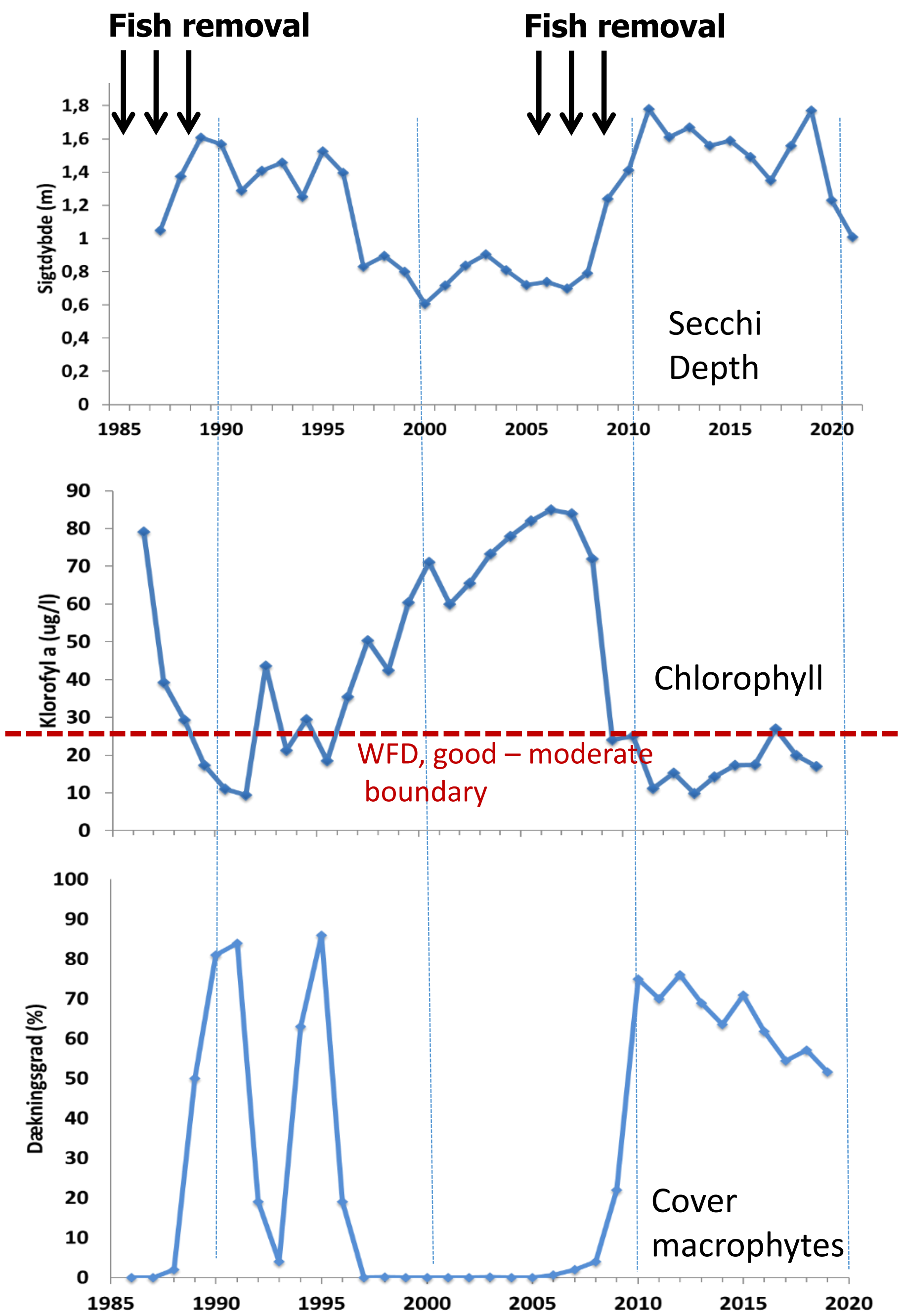


Higher N and P retention when from turbid -> clear



Data from 40 lakes

Case study Lake Væng: 2* fish removals

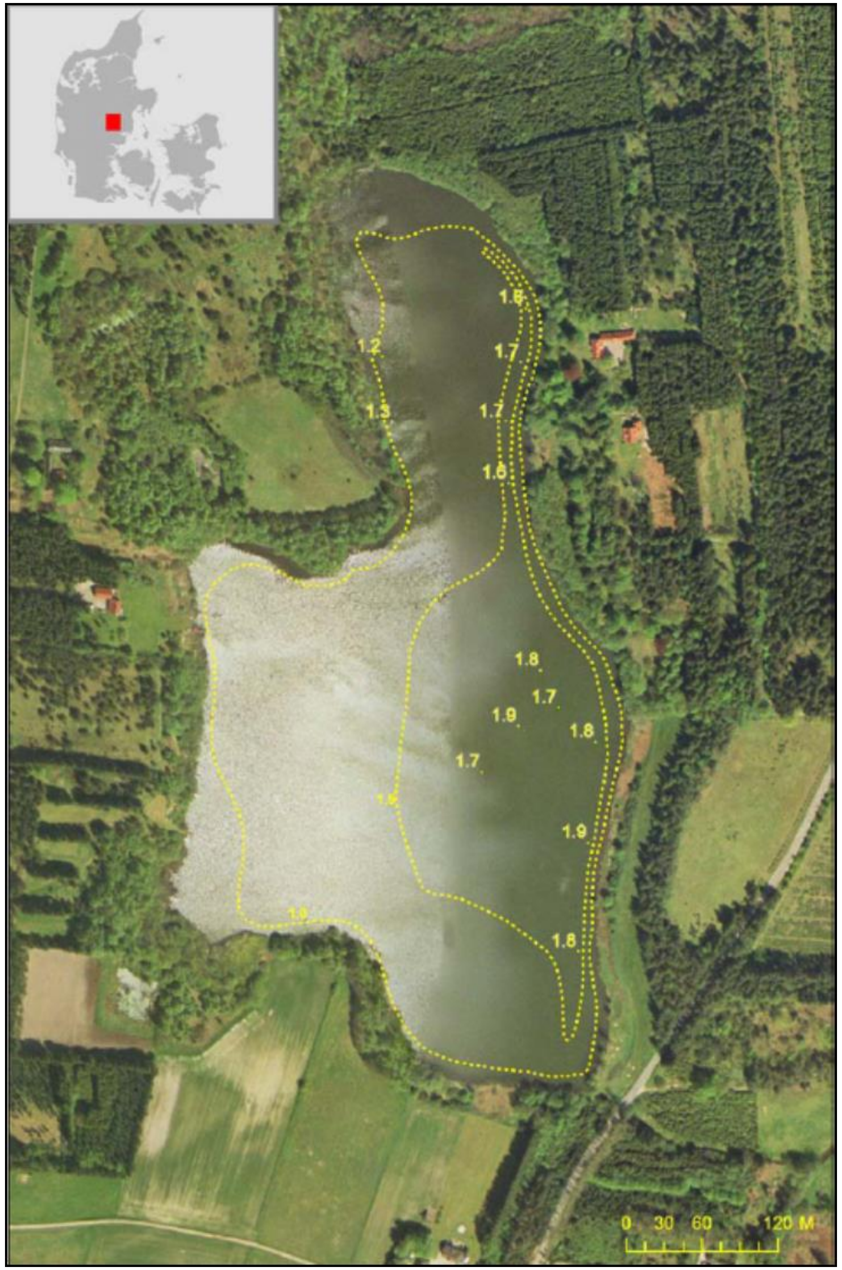


- Area: 16 ha
- Mean depth: 1.2 m
- Max depth: 1.9 m
- Hydraulic retention time: 15-25 days (70% is groundwater)

- Received sewage from a town from 1964-1981. From 1981 sewage was diverted reducing P loading from 4 to 1.5 g P/m2/year.
- 1. fish removal: 1986-1988 (ca. 4 tons roach and bream)
- 2. fish removal: 2007-09 (ca. 2.7 tons roach and bream removed)

Roach

Bream



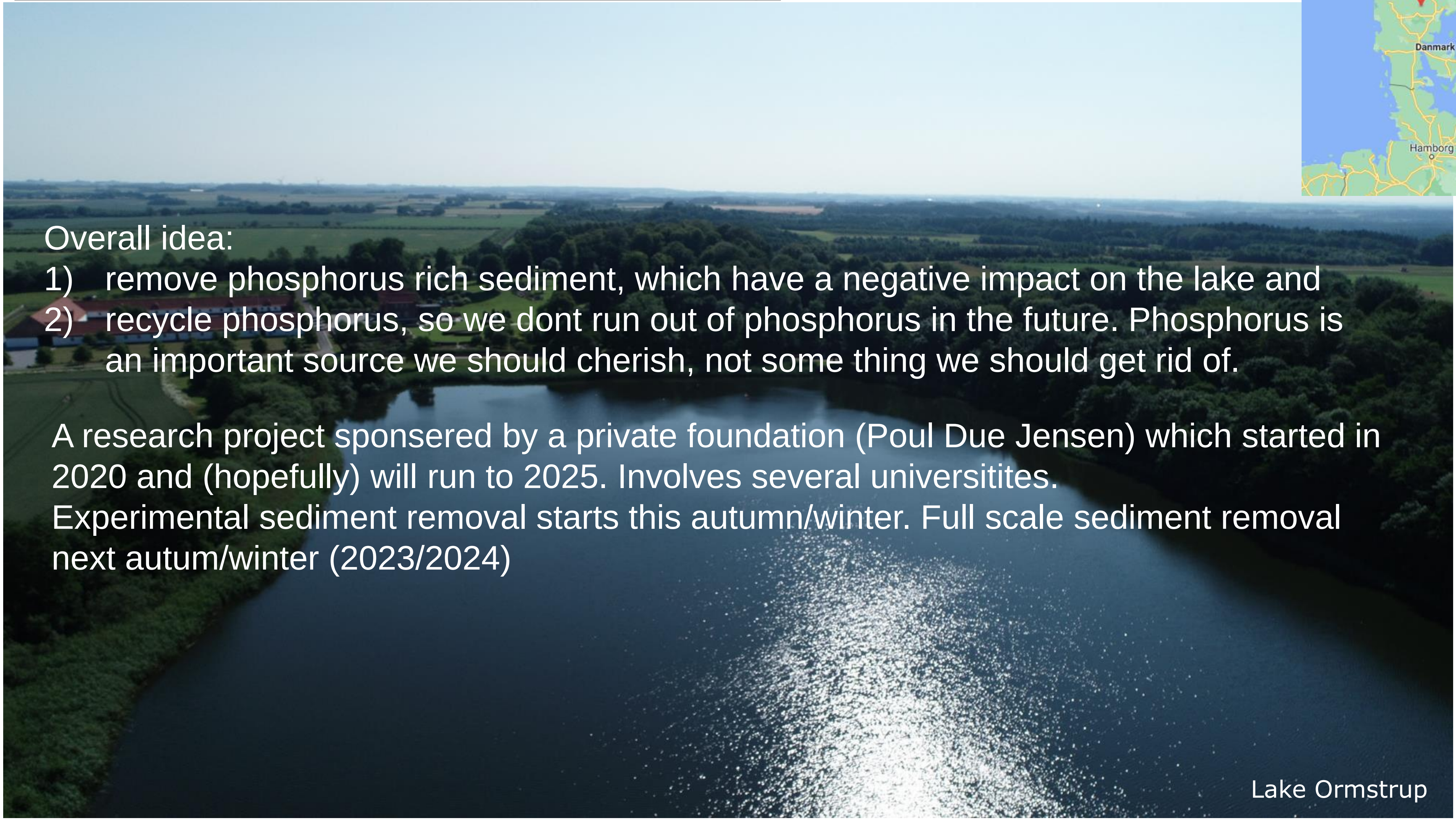
Water **2017**, *9*(1), 43; https://doi.org/10.3390/w9010043

Example 5: Lake restorations (from eutrophication) version 2.0:
Restoration and phosphorus recycling (Lake Ormstrup)

Overall idea:

1) remove phosphorus rich sediment, which have a negative impact on the lake and
2) recycle phosphorus, so we dont run out of phosphorus in the future. Phosphorus is an important source we should cherish, not some thing we should get rid of.

A research project sponsered by a private foundation (Poul Due Jensen) which started in 2020 and (hopefully) will run to 2025. Involves several universitites.
Experimental sediment removal starts this autumn/winter. Full scale sediment removal next autum/winter (2023/2024)


Lake Ormstrup

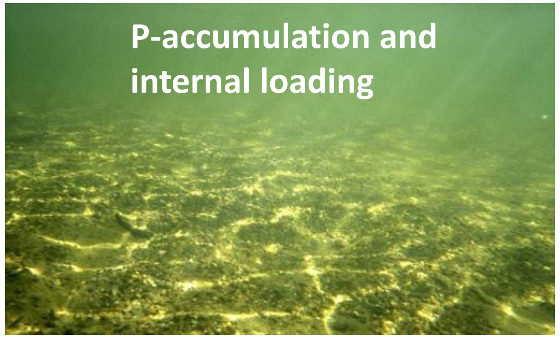
The future: P-recycling and green transition

Problem

global reserves will only last for 100-200 years?

Additional problems

Sustainable Phosphorus Alliance



Solution

+ sediment Ormstrup | No addition | + fertilizer

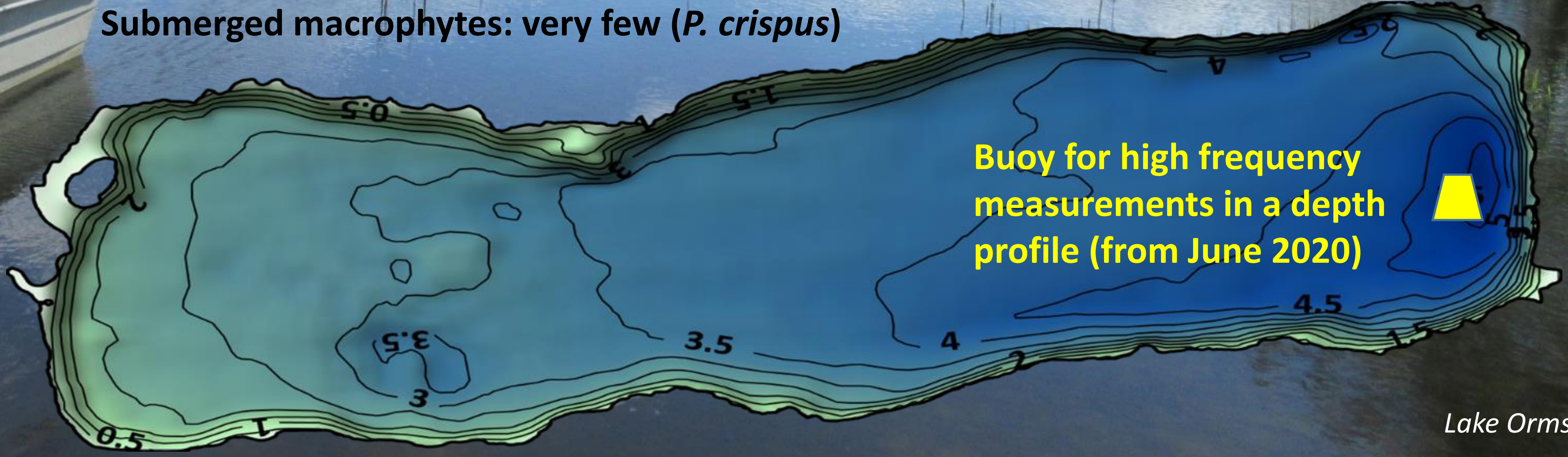
A project running in Lake Ormstrup with support from :

POUL DUE JENSEN / GRUNDFOS FOUNDATION

See Hydrobiologia
https://doi.org/10.1007/s10750-022-05039-9

Area: 11 ha
Mean depth: 3.2 m
Max. Depth: 5.5 m
Hydraulic ret. Time: ca. 1 year (maybe longer)
Mean summer TP: 400-600 ug/l
Mean summer chlorophyll a: 60 ug/l
Submerged macrophytes: very few (*P. crispus*)

→ Low external loading -> very high internal P-loading



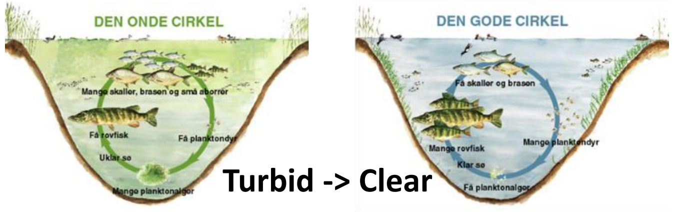
Lake Ormstrup

The future of lake restoration and elements in the green transition:

GHG:
The emission of green house gasses (fx. methane) can be reduced by establishing more clear water lakes.

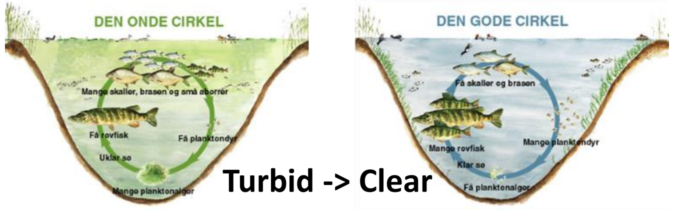
Methane emission reduced

Biodiversity:
The overall biodiversity will increase if lakes are restored from a turbid to a clear water state, because of a higher habitat diversity.



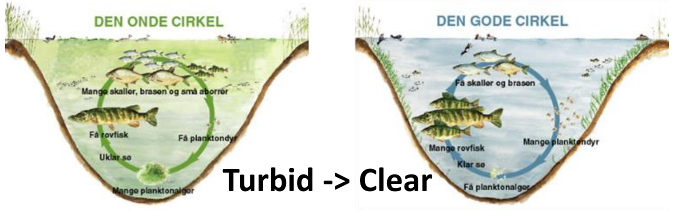
Increased biodiversity

Nutrient retention:
Clear water lakes, for example established by lake restoration retain both more phosphorus and nitrogen than turbid lakes. -> less nutrient load to down stream aquatic systems (example Lake Væng).



Increased N and P retention

Climate change effects:
The ongoing and predicted climate change effects will demand an increased effort in reducing the external nutrient loading (and maybe lake restorations) in order to for example avoid increased blooms of cyanabacteria and fullfil the requirements of the Water Framework Directive.



More load reduction needed