Lake brownification

Effects and relationship to ecological state classification

Brownification of lakes is a widely spread phenomenon, which is caused mainly by increasing loading of dissolved organic carbon (DOC) but also iron (Fe) has an important role

(Roulet & Moore 2006, Monteith et al. 2007, Weyhenmeyer et al. 2016)

Brownification is driven by several factors, the importance of which varies areally; climate change, decreased sulphur deposition, catchment land use (e.g. ditching)

(de Wit et al. 2016, Weyhenmeyer et al. 2016, Asmala et al. 2019, Meyer-Jacobs et al. 2019, Estlander et al. 2021)

Compared with eutrophication, brownification has not been given the same attention in water protection

For instance the environmental permits of peat mining do not usually include regulations to reduce DOC-loading

PÄÄTÖS Nro 44/2020 Dnro ESAVI/26713/2018, 11.2.2020 Vähärahka

Pintavalutuskentän puhdistustehon on oltava kentän kolmannen toiminta-vuoden alusta lähtien vähintään seuraava:

Kiintoaine	50 %
Kokonaisfosfori	35 %
Kokonaistyppi	20 %

PÄÄTÖS Ympäristöluvat Nro 52/2021 Dnro ISAVI/1848/2020, 10.5.2021, Jylhäsuo

Pintavalutuskentällä on saavutettava vuosikeskiarvona ilmaistuna vähin-tään seuraavat puhdistustehot tai enintään seuraavat lähtevän veden pitoi-suudet:

	Puhdistusteho	Lähtevän veden pitoi-suus
Kiintoaine	50 %	4 mg/l
Kokonaisfosfori	50 %	40 µg/l
Kokonaistyppi	20 %	1 500 µg/l

Overland flow areas, that are commonly used as BAT-technique in forestry and peat mining, are mostly ineffective in controlling DOC-loading and can even increase the loading (Klöve et al. 2012, Karppinen & Postila 2015)

Fe is ignored in the regulations (Fe-loading is reduced by overland flow areas)

Why has brownification not received the same amount of attention compared with eutrophication?

Brownification has severe consequences for the functioning of aquatic ecosystems (oxygen conditions, light availability, production, predator-prey interactions)

Many stakeholders see brownification as a problem (recreation, fishing, domestic water use)

Brownification is difficult to control, because it is largely caused by dissolved substances

Effects of brownification are often not considered significant, when the recipient waters have a high background water colour

Ecological state classification and brownification

The effects of brownification are not well known

What does it matter, if the water colour increases in a high-coloured lake ?

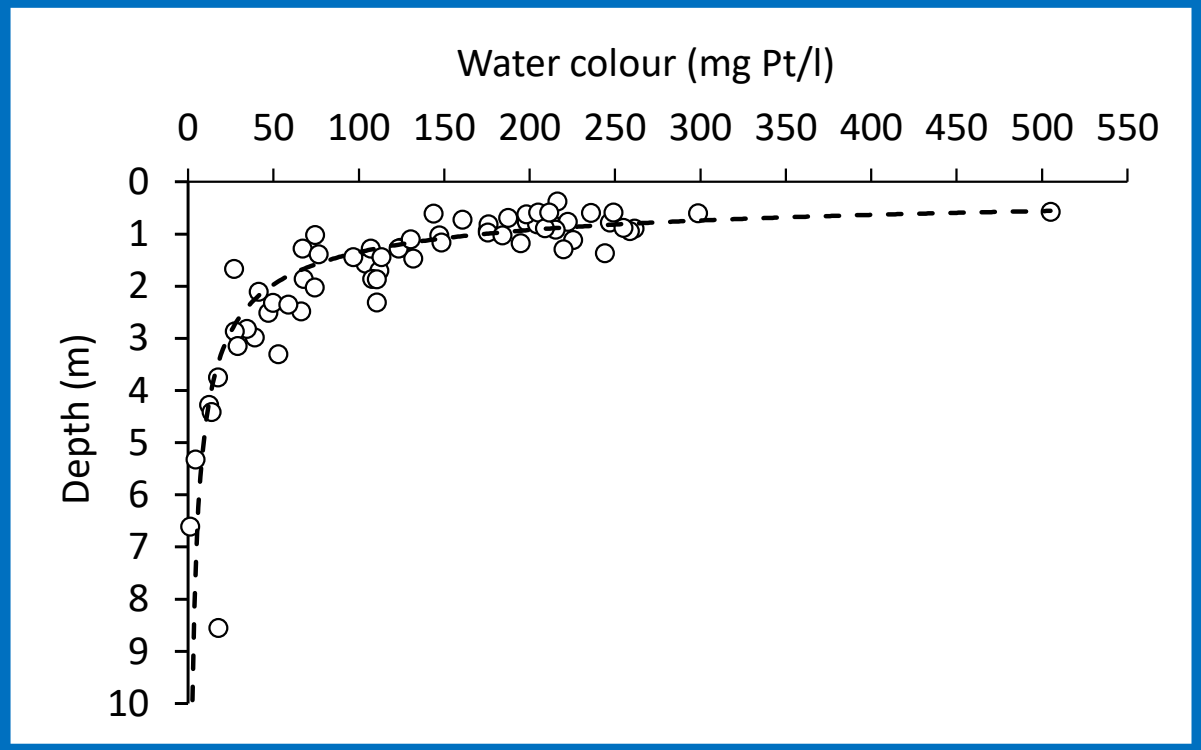
Kokemäenjoen-Saaristomeren-Selkämeren vesienhoitoalueen vesienhoitosuunnitelma vuosille 2022-2027:

”Uusien turvetuotantoalueiden sijoittamisen suunnittelussa otetaan huomioon valuma-alueen kuormitus sekä alapuolisen vesistön tila ja herkkyys aiheutuvalle lisäkuormitukselle”

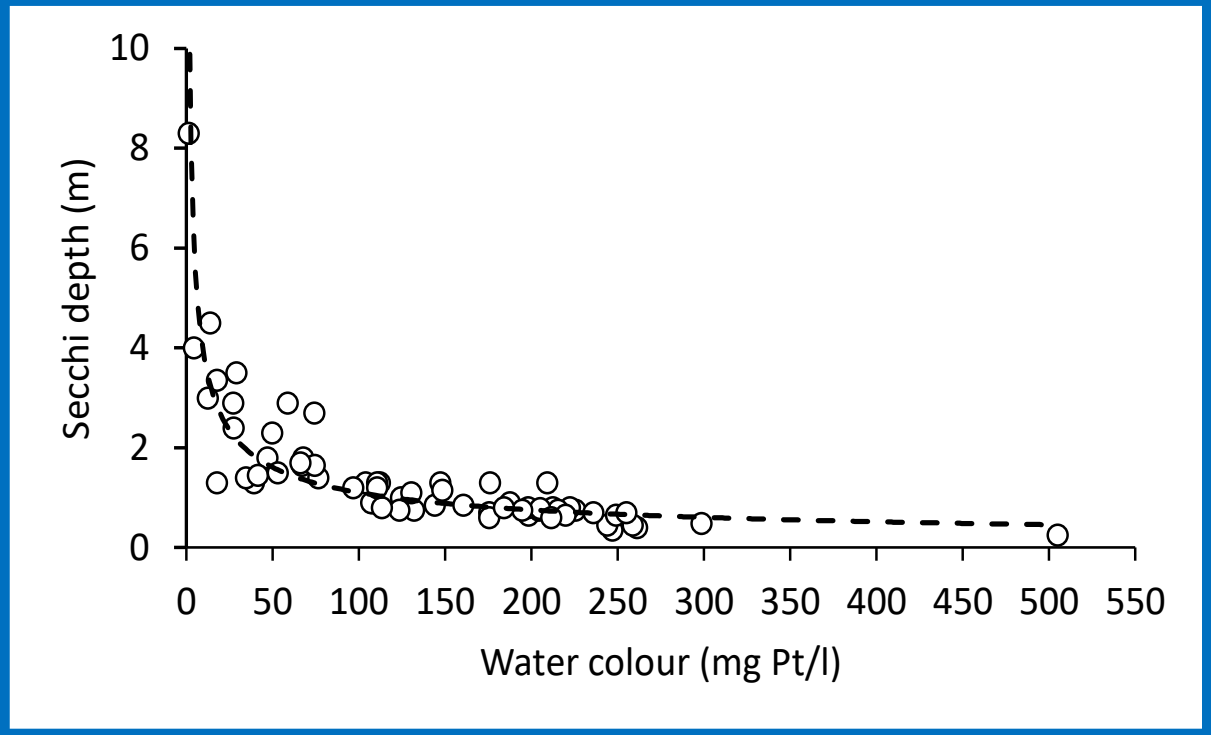
The sensitivity of recipient waters must be taken into account when planning the location of new peat mining areas

How do we define the sensitivity of lakes to brownification?

The thickness of photosynthetic layer along a water colour gradient (67 lakes in southern and Central Finland) (Horppila et al. 2022)



Secchi depth along a water colour gradient

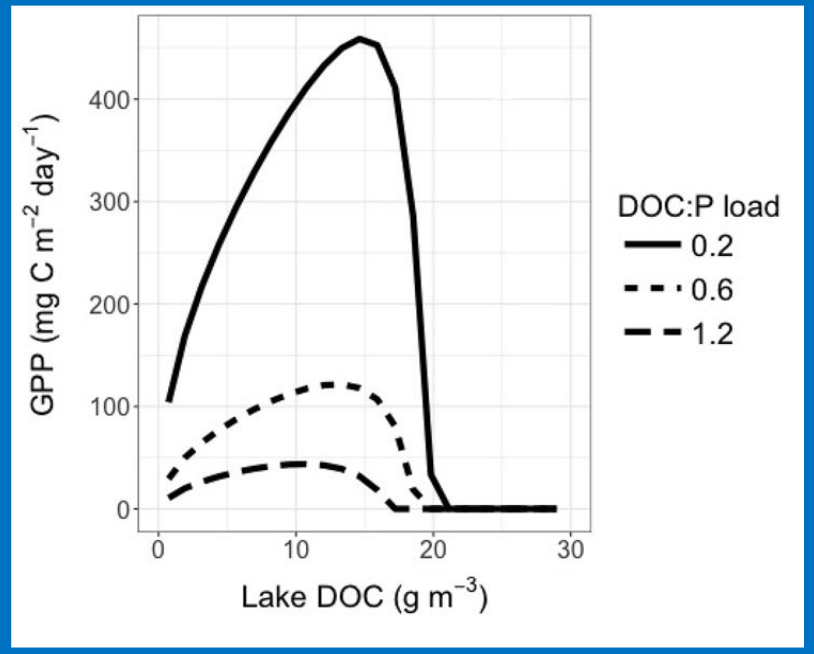


With a given increase in water colour, the absolute change in light environment and Secchi depth is higher at low than at high water colour

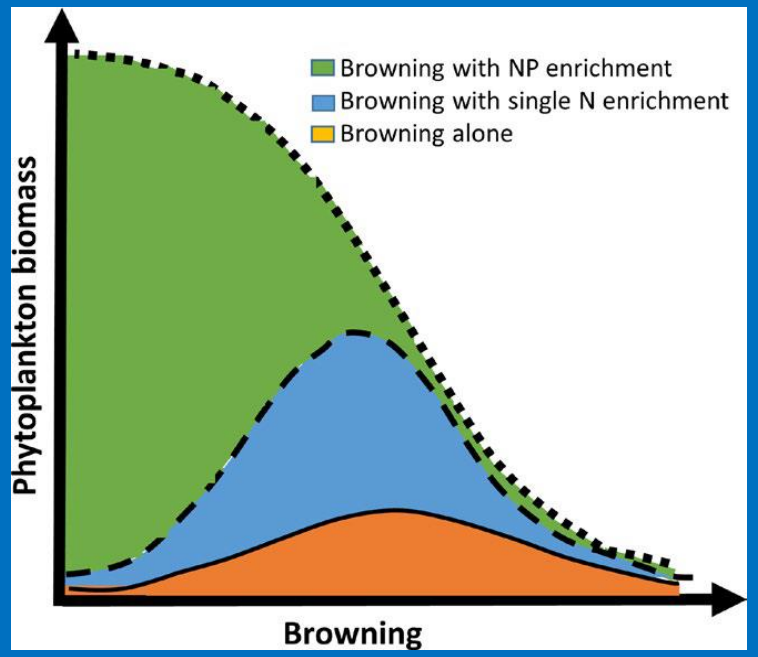
Increasing water colour causes only minor changes in the ecosystem if the background colour is high?

Numerous studies have suggested that after a certain threshold, increasing DOC starts to have a negative effect on lake productivity (nutrient limitation turns to light limitation)

Kelly et al. (2018)



Bergström & Karlsson (2019)

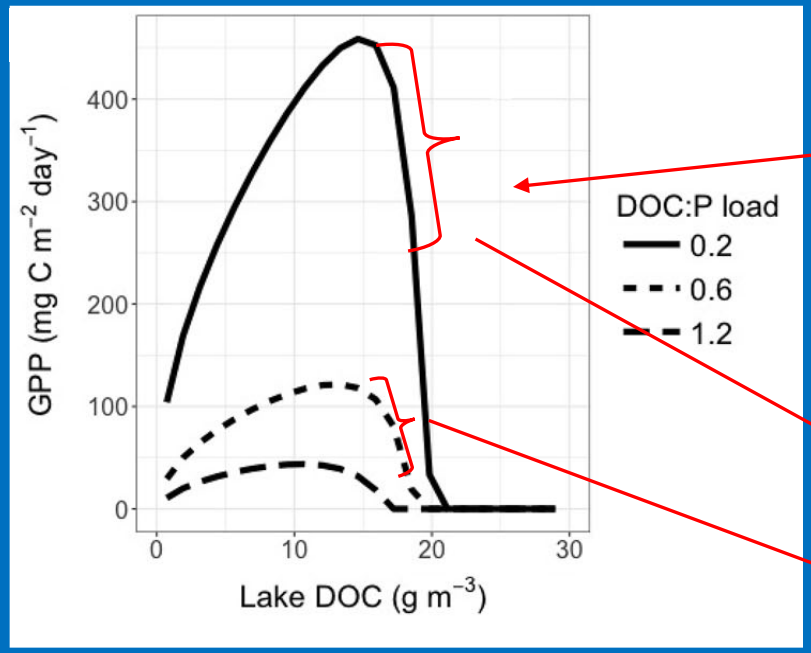


Above the threshold, a given change in DOC and water colour can have as strong effects on productivity as below the threshold, but to an opposite direction

Also the structure and dominance relationships of biotic communities change along the water colour gradient

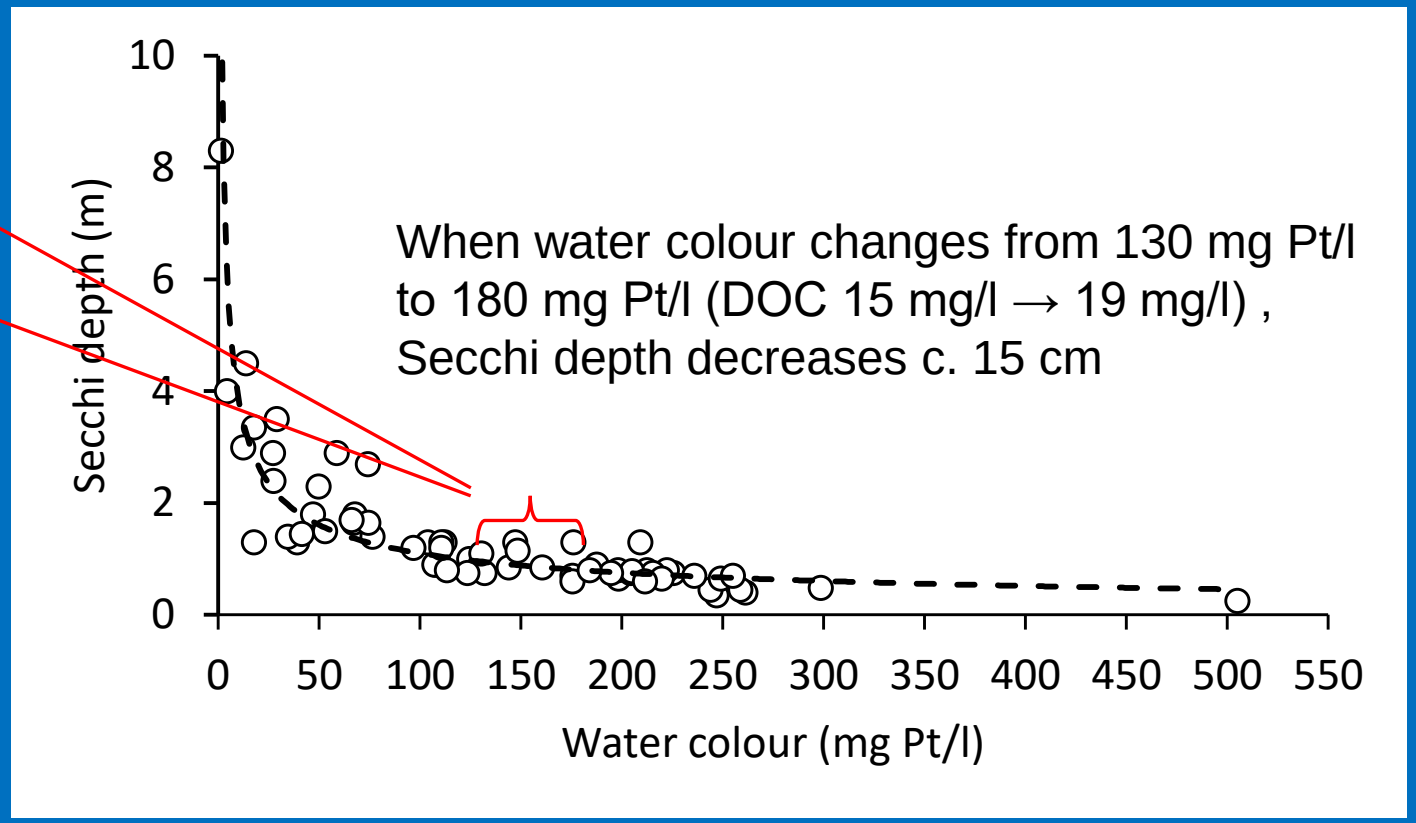
Suggested nutrient limitation-light limitation thresholds for DOC; 10-15 mg/l (Hanson et al. 2003), 6-14 mg/l (Solomon et al. 2015), 11 mg/l (Bergström & Karlsson 2019, northern lakes)

Kelly et al. (2018)



For instance DOC-concentration 15 mg/l corresponds to water colour of c. 130 mg Pt/l (Estlander ym. 2021)

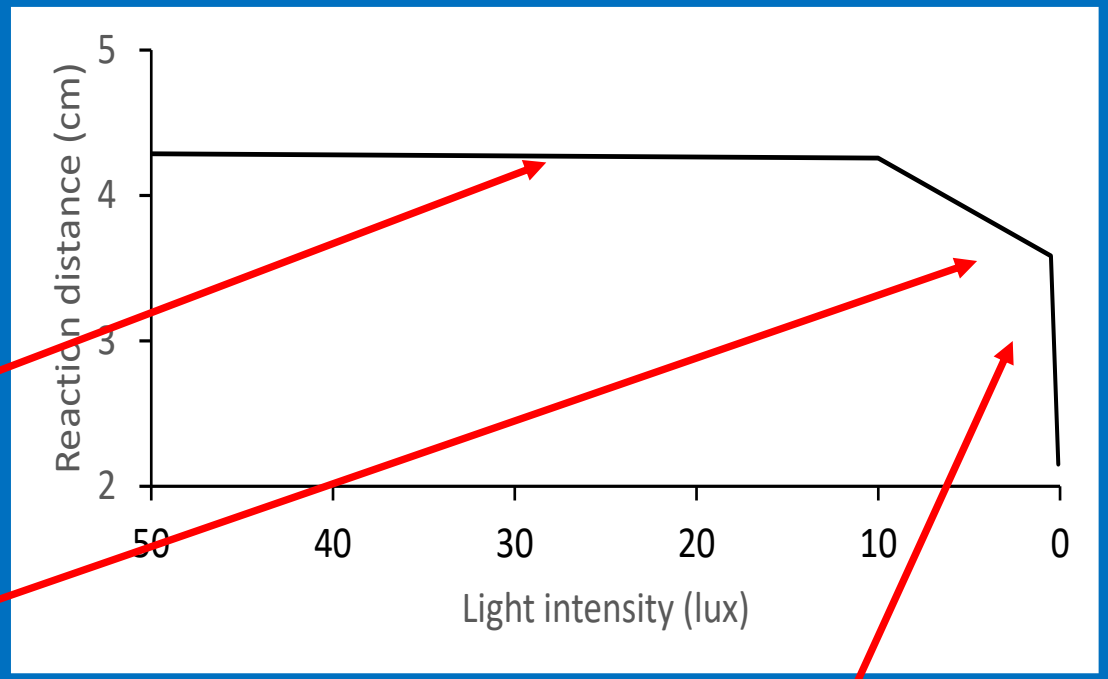
Even at higher water colour levels, a change in colour can cause strong effects on productivity



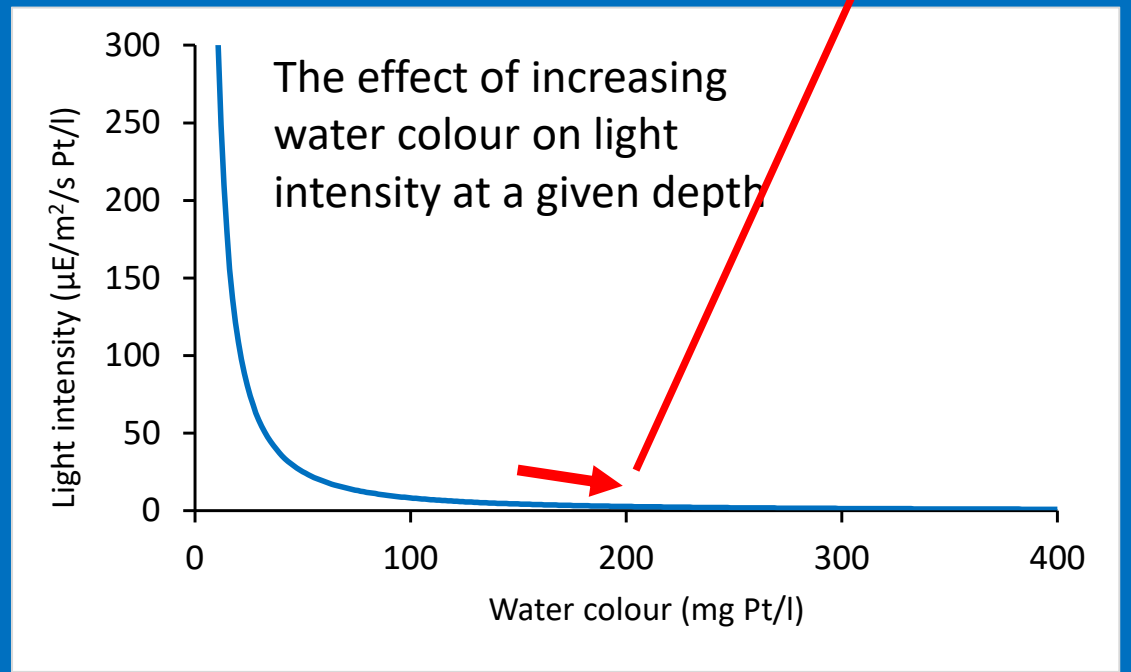
The ecosystem can face substantial changes although water quality does not seem to change considerably

The effect of light intensity on the distance where perch detects its prey (Richmond et al. 2004)

At high light levels, a reduction in light intensity has only small effects on prey detection



At low light levels, even a small change causes a substantial change in prey detection



When water colour is high (light level is low), even a small change in water colour can have strong effects on predation by fish → effects on growth rate

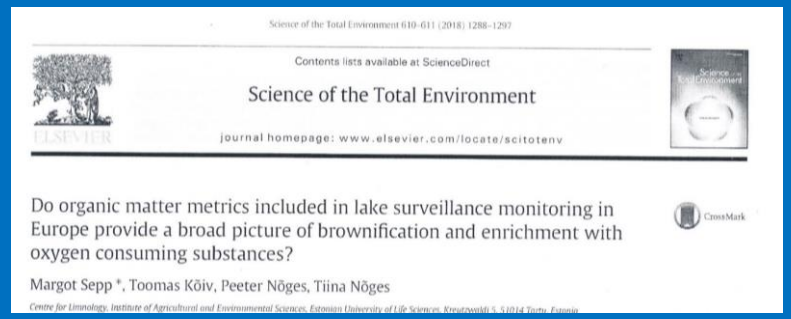
A change in water colour can cause severe changes in ecosystem functions also in lakes that have a high natural water colour

Many catchment land use activities that induce brownification (ditching, peat mining) are concentrated in catchments that have a high peatland coverage i.e. where lakes often have a high natural water colour

Brownification and ecological status of lakes

If more strict regulations preventing brownification are wanted, the effects of brownification should be seen when the ecological state of lakes is monitored

Does the present ecological state classification take brownification into account?


Science of the Total Environment 610–611 (2018) 1288–1297

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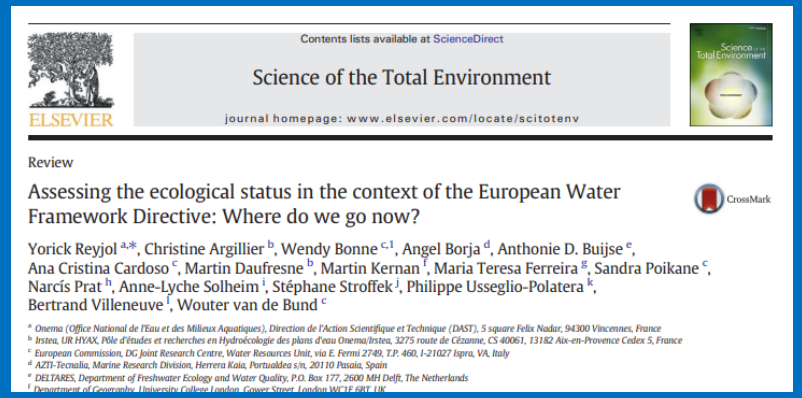
Do organic matter metrics included in lake surveillance monitoring in Europe provide a broad picture of brownification and enrichment with oxygen consuming substances?

Margot Sepp *, Toomas Kõiv, Peeter Nõges, Tiina Nõges

Centre for Limnology, Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Kreutzwaldi 5, 51014 Tartu, Estonia

Effects of brownification are partly similar to the effects of eutrophication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Review

Assessing the ecological status in the context of the European Water Framework Directive: Where do we go now?

Yorick Reyjol [a,*], Christine Argillier [b], Wendy Bonne [c,1], Angel Borja [d], Anthonie D. Buijse [e], Ana Cristina Cardoso [c], Martin Daufresne [b], Martin Kernan [f], Maria Teresa Ferreira [g], Sandra Poikane [c], Narcís Prat [h], Anne-Lyche Solheim [i], Stéphane Stroffek [j], Philippe Usseglio-Polatera [k], Bertrand Villeneuve [l], Wouter van de Bund [c]

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P- and N-loading often increase concomitantly with DOC-loading

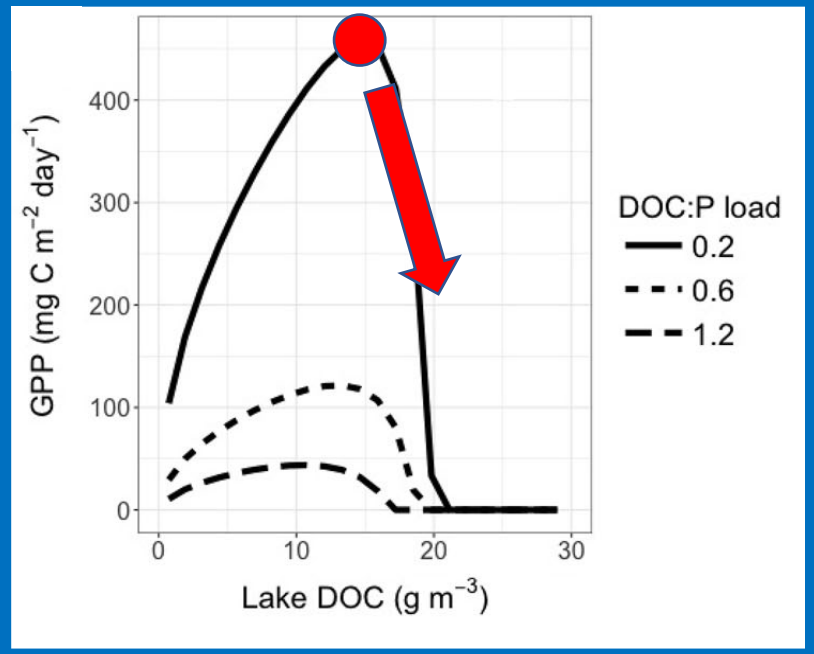
Brownification has also effects different to those of eutrophication

Phytoplankton biomass and ecological status of lakes

		Kokonaisbiomassa (mg/l)					
Tyyppi	N	VA	E/ Hy	Hy/ T	T/ V	V/ Hu	HuAlar
Vh	17	0,35	0,45	**0,9**	**1,9**	**3,8**	6,6
Ph	21	0,6	**0,75**	**1,5**	**3,0**	**6,0**	10,2
Kh	13	**0,6**	**0,75**	**1,5**	**3,0**	**6,0**	10,2
SVh	28	0,4	0,5	0,9	1,7	3,4	5,1
Sh	16	0,5	0,6	0,9	1,8	3,7	5,6
Rh	15	0,6	1,3	2,4	4,8	9,6	14,4
MVh	6	0,9	1,1	1,6	3,2	6,4	9,6
Mh	9	1,0	1,3	2,5	5,0	10	15
MRh	4	1,2	2,0	4,0	8,0	16	24
Lv	5	0,6	0,8	1,2	2,4	4,8	7,2
PoLa	16	0,25	0,35	0,75	1,5	3,0	4,5
Rr							
Rk	8	0,6	1,1	2,3	4,6	9,2	13,8
ELS-las-kenta		ELS = VA / MuuttujanArvo					

In all lake types, between all ecological states, a decrease in phytoplankton biomass indicates a change to a better state i.e. towards the pristine state

Brownification can have an opposite effect



Is the percentage of harmful cyanobacteria a good indicator to describe the effects of brownification on phytoplankton?

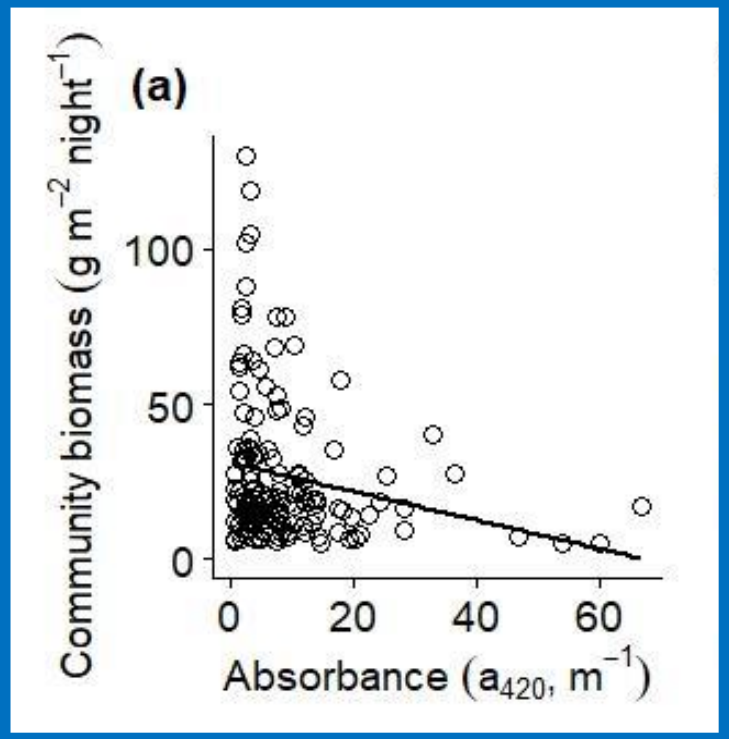
Several studies have suggested that flagellated species may increase with increasing water colour (Arvola et al. 1999, Deininger et al. 2017, Lenard et al. 2018, Huovinen 2021)

In fish communities, a two-way classification is in use (both increasing and decreasing biomass can reflect human impact)

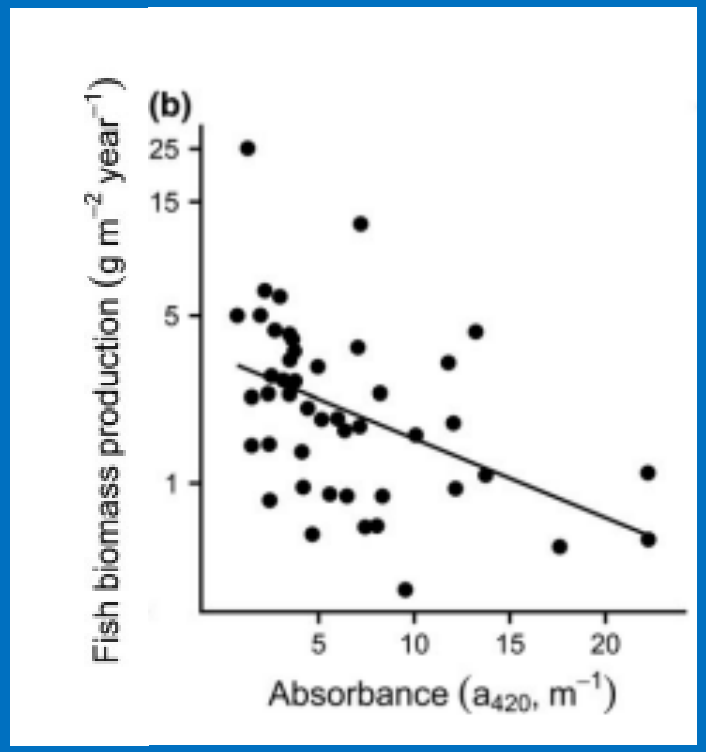
Usually the interpretation is that increasing fish biomass indicates a change to a worse ecological state

Brownification often causes a decrease in fish production and biomass

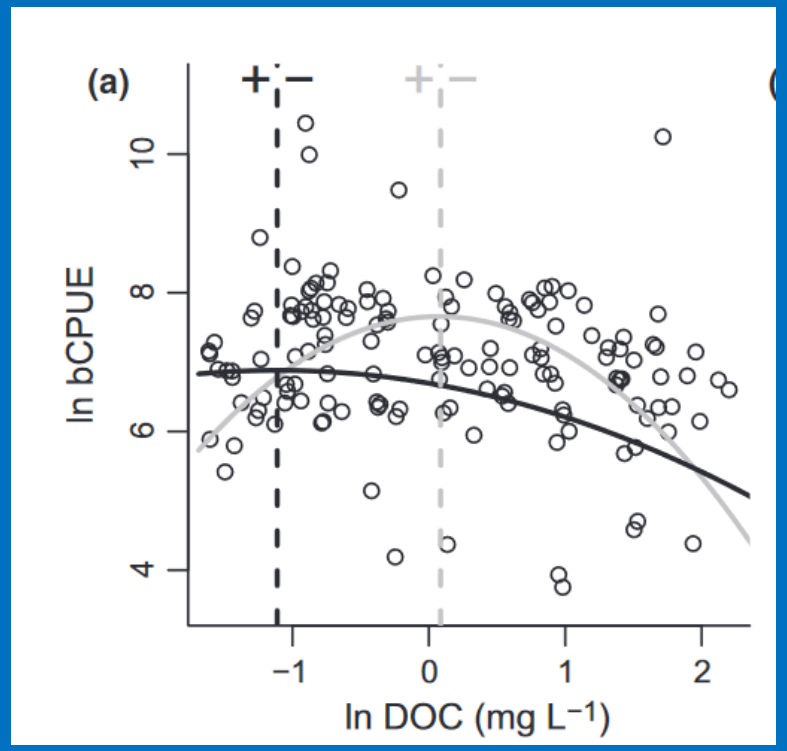
Koch (2019)



Van Dorst et al. (2019)



Finstad et al. (2014)



The presently used indicators may suggest that the ecological state of a lake is changing towards the natural state, although it is changing to another direction


Vesienhoidon toimenpiteiden suunnittelu vuosille 2022–2027

Turvetuotanto

30.1.2020

Metsätalous- ja turvetuotantotiimi

Kasvillisuuskenttä/kosteikko, ei pumppausta:

”Humusta huuhtoutuu kasvillisuuskentiltä etenkin talvella ja kesällä ja kosteikoilta lisäksi syksyllä. Poistaa melko tehokkaasti fosforia, typpeä hieman”

”Kasvillisuuskentillä/kosteikoilla arvioitiin olevan myönteinen vaikutus pintavesien ekologiseen tilaan”

Vegetation fields and wetlands retain P effectively, but increase the leaching of humic substances to recipient waters

The effect of vegetation fields and wetlands on the ecological state of surface waters is positive

Based on the classification criteria presently used

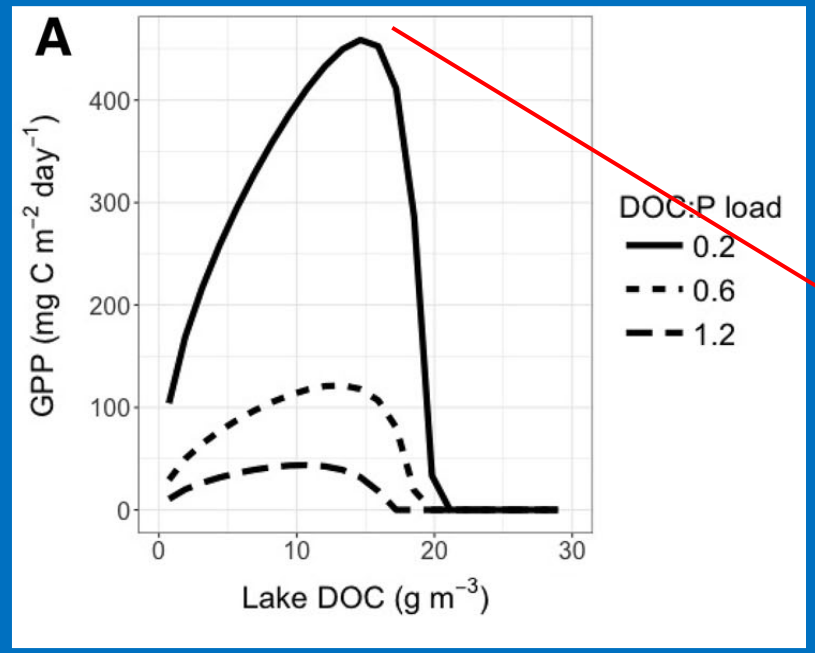
Ecological state classification should be developed to reveal the effects of brownification

The use of water colour as a factor that determines the lake type

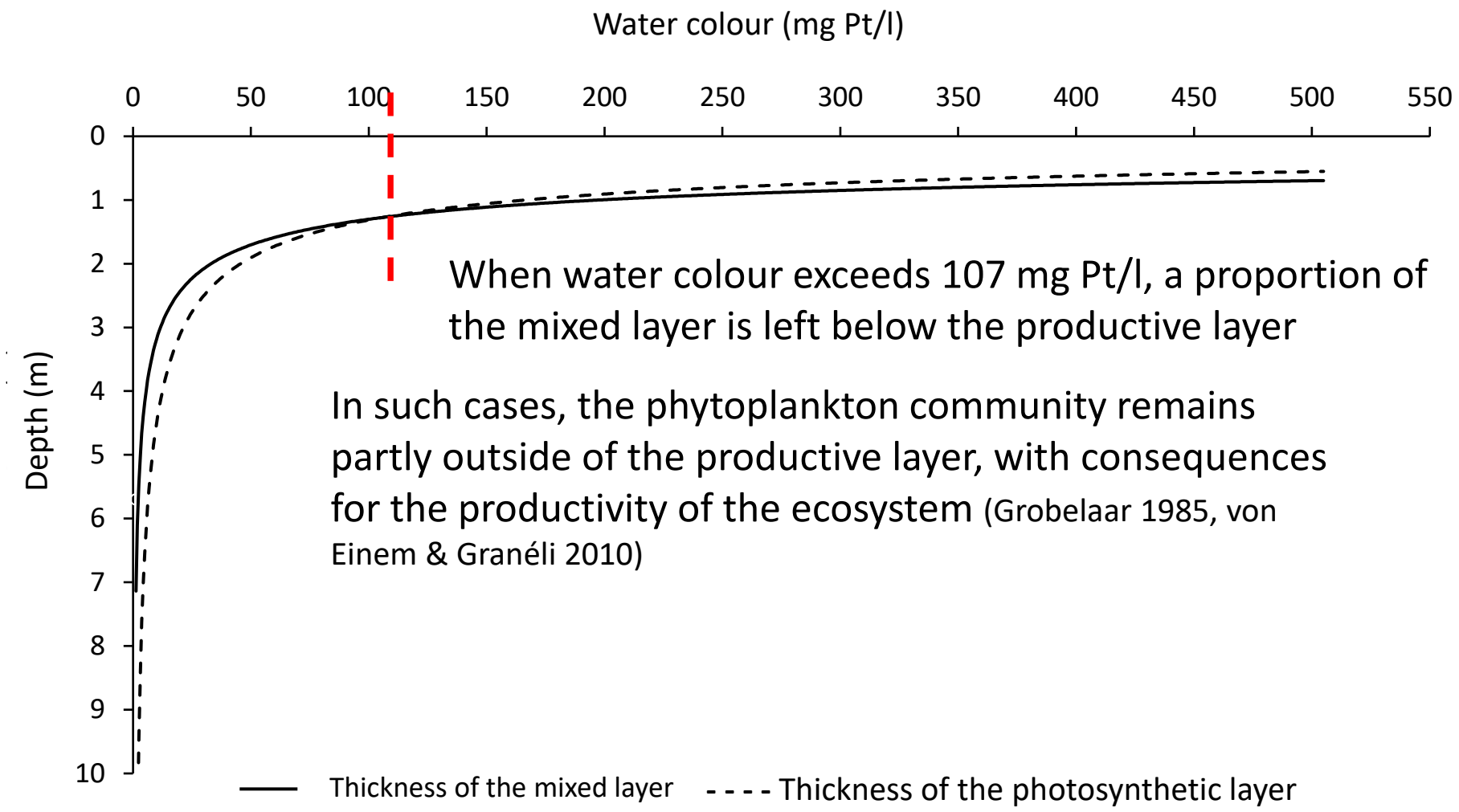
Information needs

For phytoplankton, a two-way classification system is probably needed – increasing water colour can lead to a better or to a worse ecological state

(Kelly et al. 2018)



What is the threshold colour in different lakes?

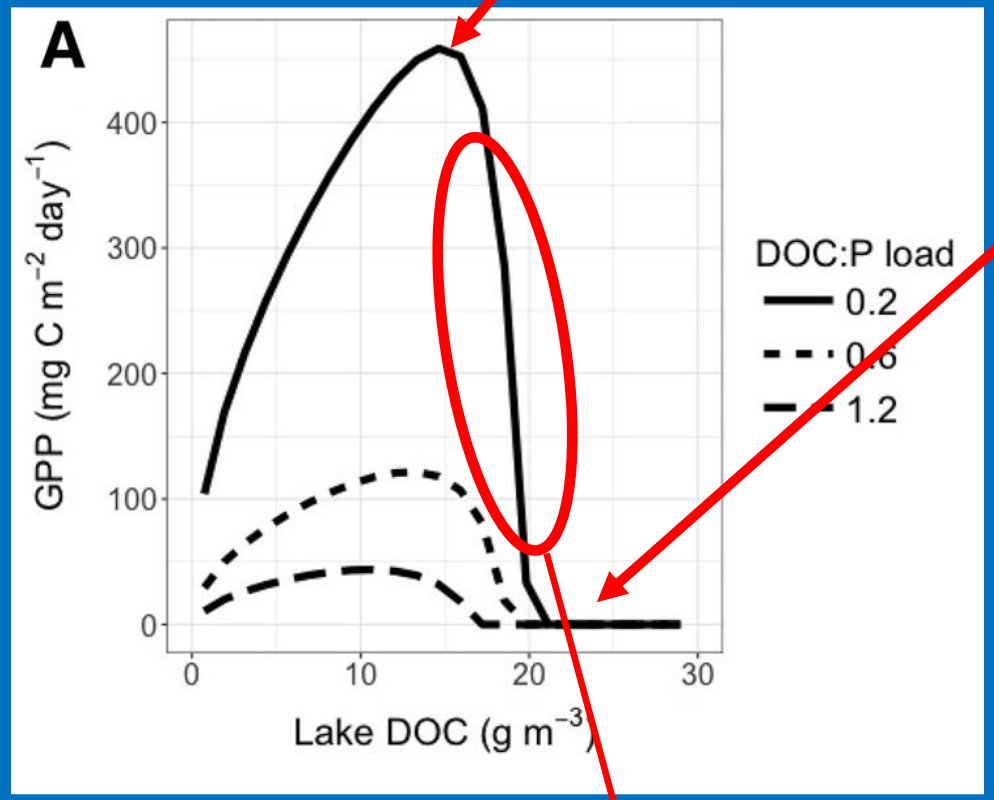


When water colour exceeds 107 mg Pt/l, a proportion of the mixed layer is left below the productive layer

In such cases, the phytoplankton community remains partly outside of the productive layer, with consequences for the productivity of the ecosystem (Grobelaar 1985, von Einem & Granéli 2010)

Water colour 107 mg Pt/l corresponds to DOC-concentration 13.4 mg/l, which is within the limits of suggested nutrient limitation-light limitation thresholds

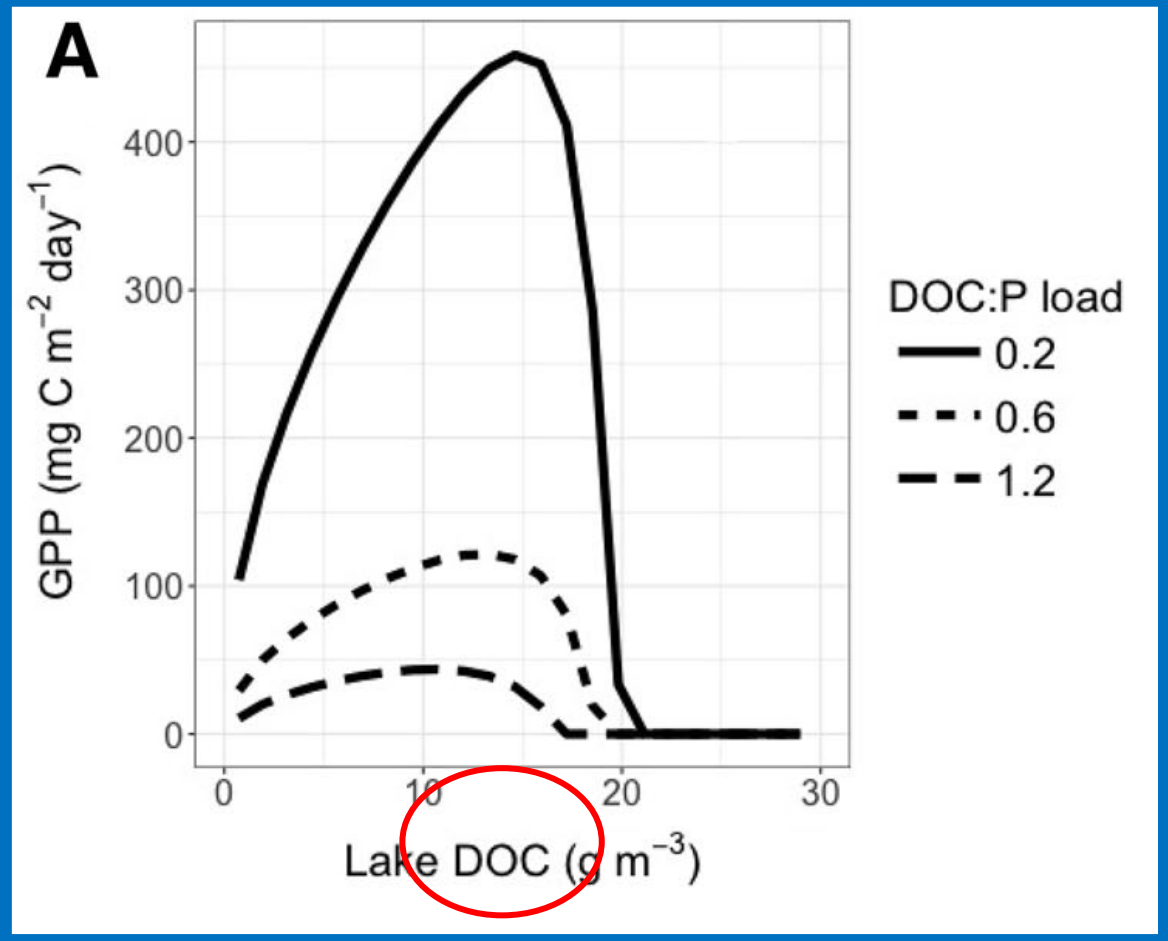
Kelly et al. (2018)



Production estimates too low at high DOC levels – more data on high-colour lakes needed

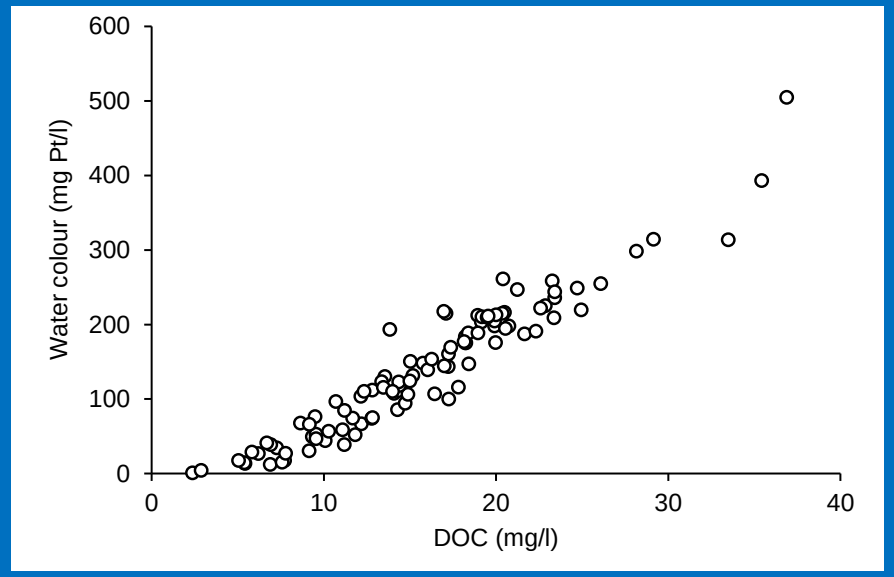
Compensatory mechanisms? Changes in species composition; flagellated species? Changes in the chlorophyll content of phytoplankton?

Kelly et al. (2018)



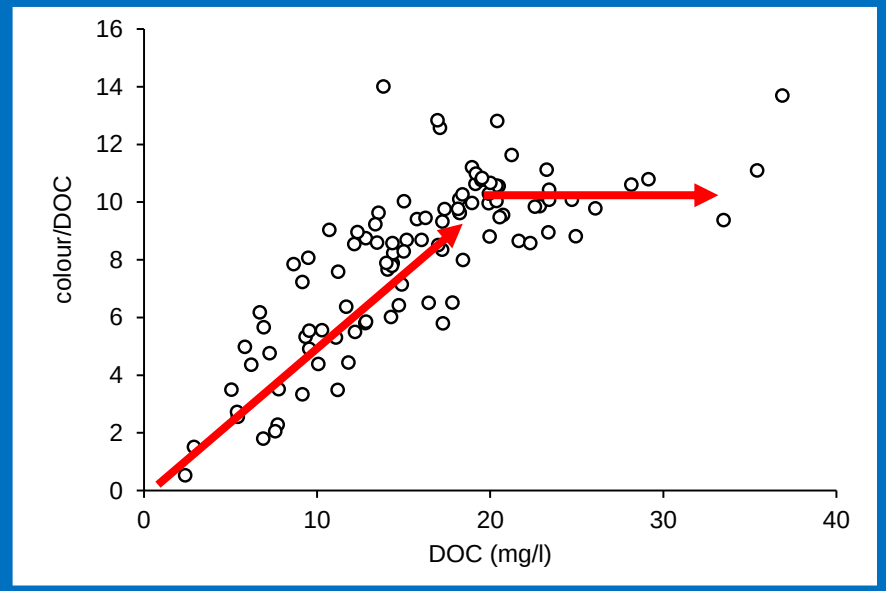
The role of Fe?

Estlander et al. (2021) modified



DOC is the main regulator of water colour

But this is not the whole story

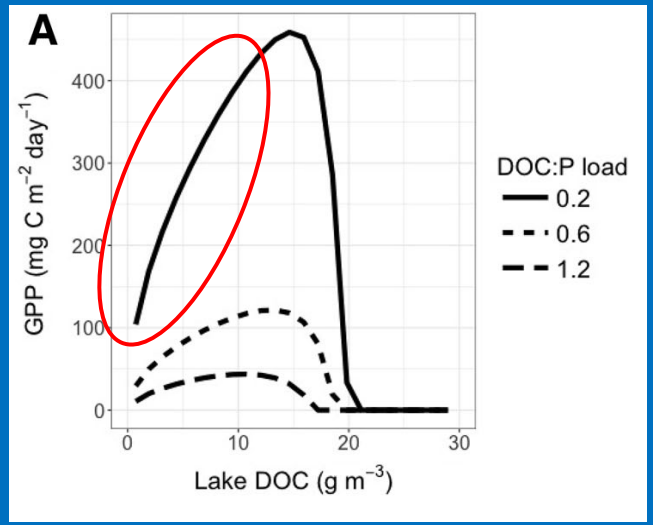


Water colour per unit of DOC increases up to DOC concentration 15-20 mg/l

The effect of Fe

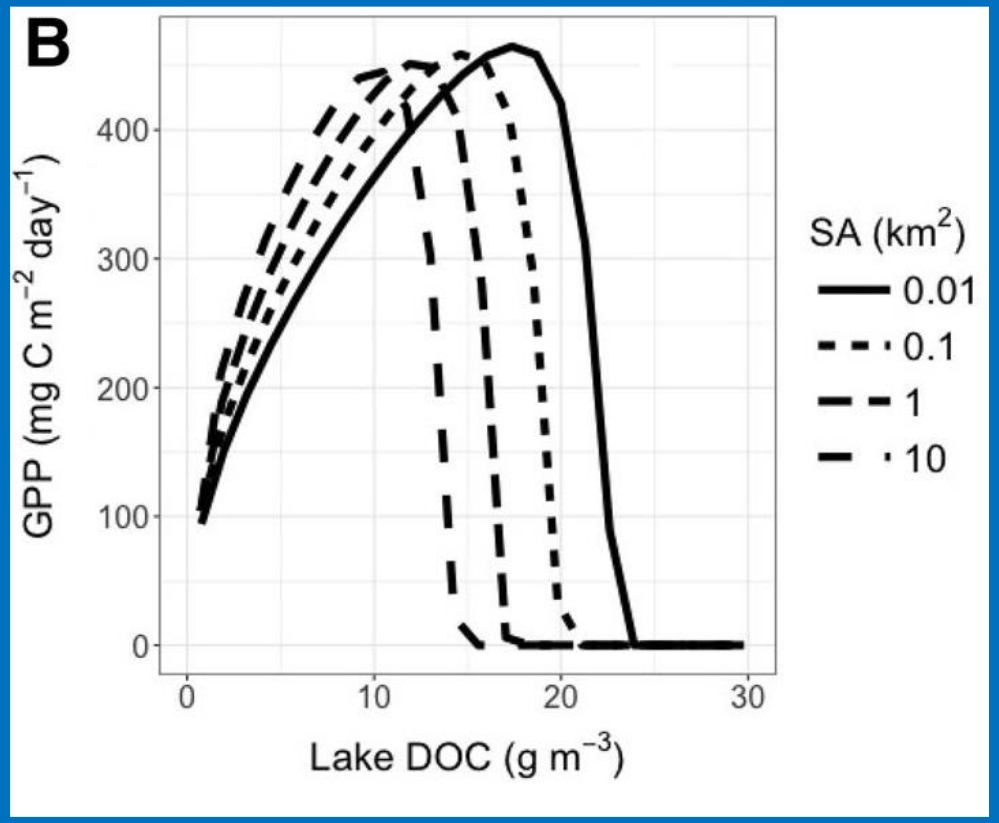
Fe increases light attenuation up to 15-20 mg/l DOC concentration (colour 130-195 mg Pt/l)
(Horppila et al. 2022)

Effects of Fe on lake productivity at low DOC concentrations?



Lake size is also of importance; water colour at the nutrient limitation-light limitation threshold probably decreases as lake size increases

(Kelly et al. 2018)



With a given water colour (and light attenuation), large lakes have deeper mixed layers than small lakes

Other biotic communities?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Charophytes collapse beyond a critical warming and brownification threshold in shallow lake systems

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Fundamental research needed to clarify how different biotic communities respond to brownification (Albrecht et al. 2022, Blanchet et al. 2022)

The use of available data in searching indicators specific for brownification (indicator species, community structure, physiology)

New data are also needed

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Thank you for your attention!