A discussion on the paper "Submerged macrophytes as indicators of the ecological quality of lakes"

Martin Søndergaard *et al*., 2009

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Outline

- Background
- Objective
- Methods
- Results and discussion
- Conclusion

Background

- Submerged macrophytes play an important role in the biological structure and functioning of lakes (Schriver *et al.*, 1995).

- Macrophytes have long been used in the classification of lakes (Palmer, Bell & Butterfield, 1992).

- Methods to characterise lake macrophyte communities have traditionally focused on the presence of 'indicator' species often based on expert judgement (Schneider, 2007). Quantitative metrics, such as per cent coverage of whole lake area, have been given less attention.

Objective

- Evaluate the efficacy of different macrophyte metrics as indicators of eutrophication.

Macrophyte metrics
- qualitative metrics: presence／absence of species
- quantitative metrics: species richness,
  maximum colonization depth (C_{max}),
  total coverage (COV),
  plant volume inhabited (PVI).

- Develop a simple macrophyte index based on a combination of the best qualitative and quantitative metrics to describe the ecological quality of lakes.

Methods

Samples collection of lakes

From: 300 Danish lakes

Time: Once or twice monthly during 1 May–1 October from 2004 until 2006

Objective: To get mean summer concentrations of water chemistry (TP, TN, Chla, SS, TA)

	Number of lake-years	Mean	Minimum	Median	Maximum
Mean depth (m)	296	2.6	0.1	1.6	15.0
Max depth (m)	232	5.7	0.2	3.2	37.7
Area (ha)	341	110	1	12	3954
Alkalinity (meq L^{-1})	313	2.1	−0.06	2.1	8.0
Total phosphorus (mg P L^{-1})	314	0.167	0.010	0.089	4.74
Total nitrogen (mg N L^{-1})	317	1.65	0.29	1.37	9.07
Suspended solids (mg dw L^{-1})	163	18	0	8	591
Chlorophyll *a* (μg L^{-1})	309	55	0	34	666

Table 1 Selected morphometric and chemical data of the study lakes (summer means)

Methods

Investigation of submerged macrophytes

Time: During maximum abundance between 1 July and 15 August

Observation sites: 30–375 sampling points distributed along transects covering the whole lake area and all depth zones. The number of sampling points increased with lake size.

Objective: To get macrophyte metrics

(species presence, COV, C_{max}, PVI……)

Ps: For COV and PVI, only lakes with mean depth <3 m were used.

For C_{max} , only lakes with C_{max} < maximum depth were used.

Results and discussion

A. Species (charophytes)

TP: <0.05 to >0.2 mg P L^{-1}
Chla: <15 to >100 µg L^{-1}

TP: <0.06 mg P L^{-1}
Chla: <20 µg L^{-1}

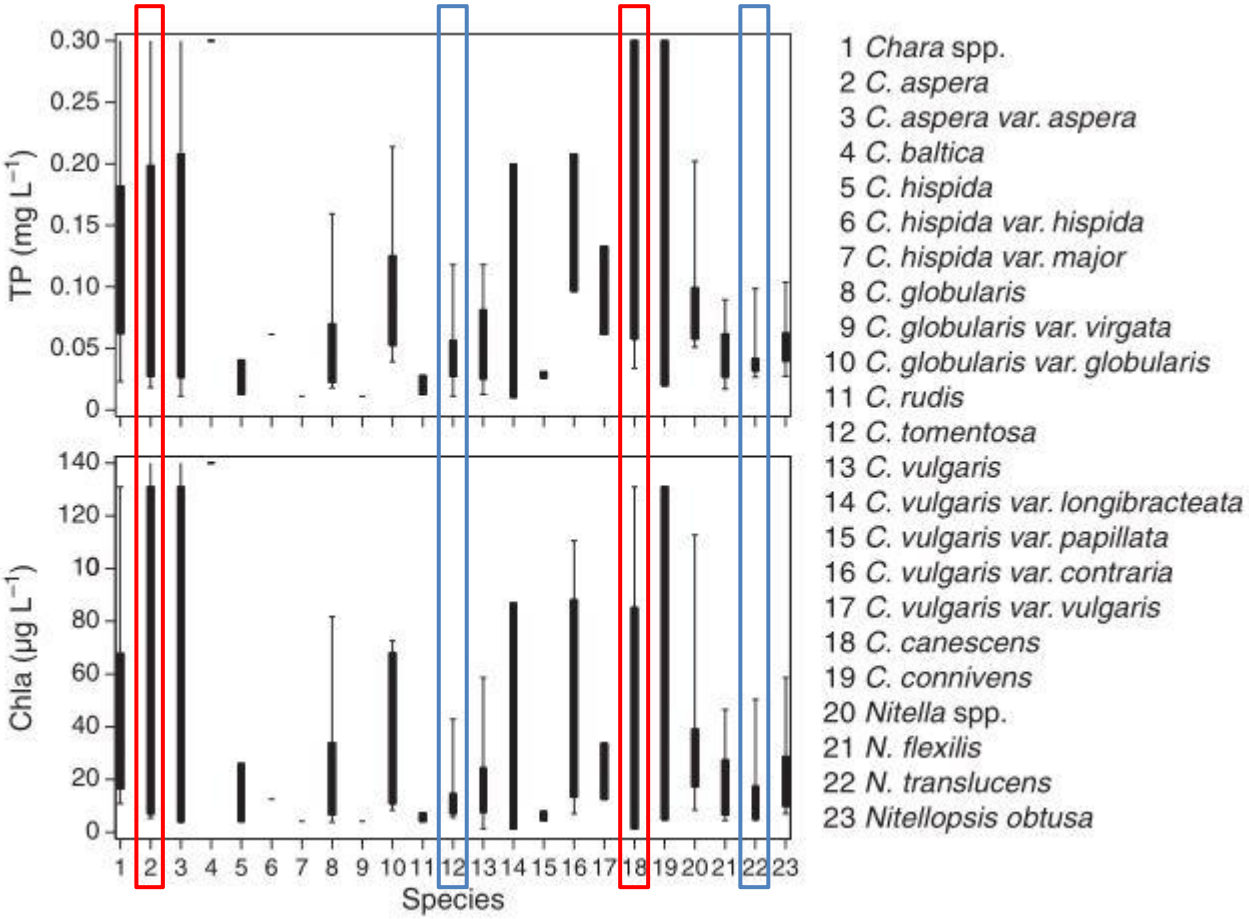
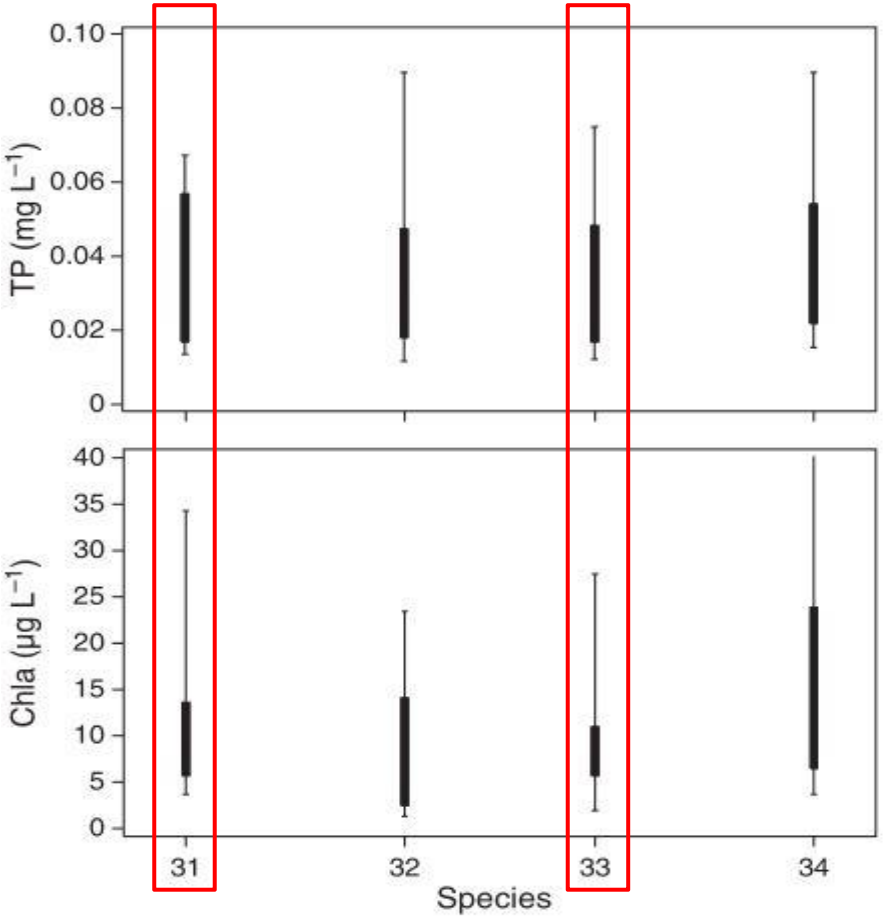


Fig 1 Distribution of charophytes relative to total phosphorus and chlorophyll *a* concentrations in lakes with area >1 ha (*N* = 266). Boxes show 25 and 75% percentiles and lower and upper lines represent 10 and 90% percentiles, respectively.

Results and discussion

A. Species (isoetids)

TP: ＜0.04 mg P L^{-1}
Chla: ＜10 μg L^{-1}



31 *Isoetes lacustris*
32 *Isoetes echinospora*
33 *Lobelia dortmanna*
34 *Littorella uniflora*

Fig 2 Distribution of isoetids relative to total phosphorus and chlorophyll *a* concentrations in lakes with area >1 ha (*N* = 266). Boxes show 25 and 75% percentiles and lower and upper lines represent 10 and 90% percentiles, respectively.

Results and discussion

A. Species (potamogeton)

TP: ＜0.05 mg P L^{-1}
Chla: ＜20 μg L^{-1}

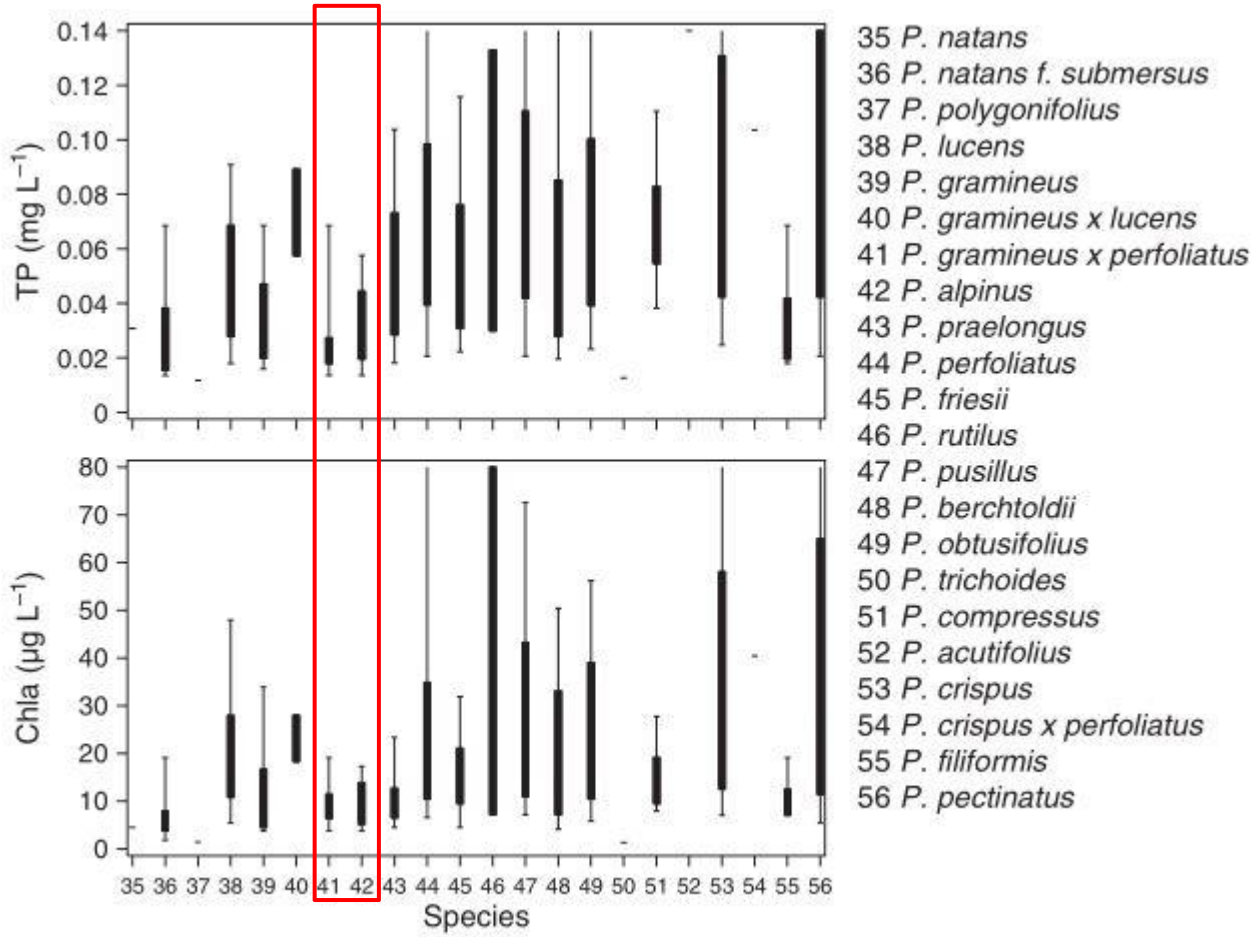


Fig 3 Distribution of *Potamogeton* species relative to total phosphorus and chlorophyll *a* concentrations in lakes with area>1 ha (*N* = 266). Boxes show 25 and 75% percentiles, and lower and upper lines represent 10 and 90% percentiles, respectively.

Results and discussion

A. Species

Table 2 List of submerged macrophyte species found in at least six lakes (N = number of lakes). TP_med is the median TP concentration and Chl_med the median chlorophyll a concentration (summer means) of the lake where they were recorded. An X shows lake Chl and TP classes having 75% of the taxon observations

Species	*N*	TP_med (mg P L^{-1})	Chl_med (µg L^{-1})	Chl_Q3 < 25 µg L^{-1}	TP_Q3 < 0.050 mg P L^{-1}
41 *Potamogeton gramineus* × *perf.* (Weber)	9	0.020	9	X	X
33 *Lobelia dortmanna* (L.)	25	0.025	9	X	X
39 *P. gramineus* (L.)	15	0.027	7	X	X
31 *Isoetes lacustris* (L.)	15	0.027	9	X	
55 *Potamogeton filiformis* (Pers.)	7	0.027	11	X	X
93 *Elatine hexandra* ((Lapierre), DC.)	7	0.027	11		
42 *Potamogeton alpinus* (Balbis)	8	0.030	7	X	X
34 *Littorella uniflora* (L.)	53	0.032	11	X	
32 Isoetes echinospora (L.)	12	0.033	9	X	X
43 *Potamogeton praelongus* (Wulfen)	14	0.039	8	X	
75 *Callitriche hamulata* (Kütz. ex W.D.J. Koch)	14	0.039	10	X	

Results and discussion

B. Species richness

Table 3 Results of regression analyses of COV, PVI, C_{max}, species richness+1(sp. number+1) with TP (mg P L^{-1}), Chla (μg L^{-1}),TN (mg N L^{-1}) and lake area (in ha). Only significant relationships are shown here. For species richness, lake area was also included in the multiple regression

Metric	Variables	*N*	*P*	R^2
Log (COV)	0.07 – 0.77*log (TP)	201	<0.001	0.11
Log (COV)	2.11 – 0.87*log (Chla)	198	<0.001	0.24
Log (PVI)	−0.62 – 0.79*log (TP)	199	<0.001	0.07
Log (PVI)	1.70 – 1.05*log (Chla)	196	<0.001	0.21
Log (C_{max})	−0.06 – 0.37*log (TP)	191	<0.001	0.24
Log (C_{max})	0.79 – 0.30*log (Chla)	190	<0.001	0.21
Log (C_{max})	0.32 – 0.23*log (TP) – 0.15*log (Chla)	189	<0.001	0.24
Log (sp. number+1)	0.38 – 0.41*log (TP)	256	<0.001	0.22
Log (sp. number+1)	1.22 – 0.29*log (Chla)	253	<0.001	0.17
Log (sp. number+1)	0.87 – 0.52*log (TN)	258	<0.001	0.12
Log (sp. number+1)	0.53 + 0.20*log (area)	279	<0.001	0.14
Log (sp. number+1)	0.11 + 0.21*log (area) – 0.43*log (TP)	256	<0.001	0.36

Chla, chlorophyll *a*; C_{max}, maximum colonisation depth; COV, mean macrophyte coverage; PVI, plant volume inhabited; TP, total phosphorus; TN, total nitrogen.

Results and discussion

C. Maximum colonisation depth (C_{max})

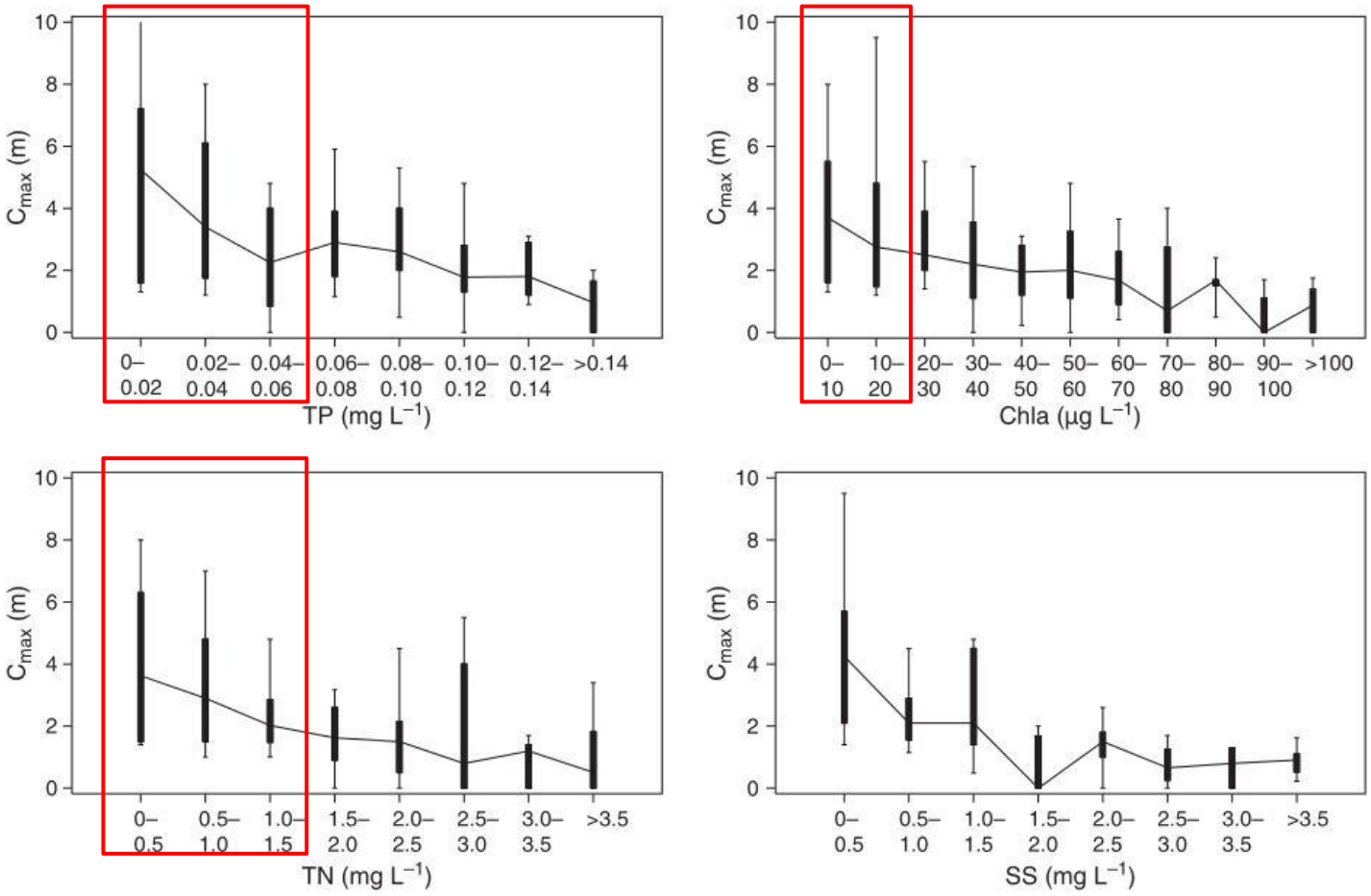


Fig 4 Maximum colonisation depth (C_{max}) relative to total phosphorus (N = 191), total nitrogen (N = 190), suspended solids (N = 110) and chlorophyll *a* (N = 190) for lakes with surface area >1 ha and maximum lake depth greater than C_{max}. Median values are connected by lines.

Results and discussion

C. Maximum colonisation depth (C_{max})

Table 3 Results of regression analyses of COV, PVI, C_{max}, species richness+1(sp. number+1) with TP (mg P L^{-1}), Chla (μg L^{-1}),TN (mg N L^{-1}) and lake area (in ha). Only significant relationships are shown here. For species richness, lake area was also included in the multiple regression

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Results and discussion

C. Maximum colonisation depth (C_{max})

TP/Chla category	C_{max} Significance	C_{max} N	COV Significance	COV N	PVI Significance	PVI N
TP (mg P L^{-1})						
0–0.02	++	14		12	+	12
0.02–0.04		25		29	+	29
0.04–0.06	−−	27		33		33
0.06–0.08		21		24		24
0.08–0.10		19		18		18
0.10–0.12	−−	14		20		20
0.12–0.14		11		16		16
>0.14	−−	58	−−−	86	−−−	86
Chla (μg L^{-1})						
0–10		30		40		40
10–20	++	31		35	++	35
20–30		18		23		23
30–40		20		27		27
40–50		14		14		14
50–60		15		18		18
60–70		10	+	15		15
70–80	−−	6	−	5		5
80–90		5		8		8
90–100		7		10		10
>100		32		39		39

Chla, chlorophyll *a*; C_{max}, maximum colonisation depth; COV, mean macrophyte coverage; PVI, plant volume inhabited; TP, total phosphorus.

Table 4 Results of tests (t-test) of C_{max}, COV and PVI against total nitrogen concentrations within specific TP and Chla categories. +/-, $P < 0.1$; ++/--, $P < 0.05$; +++/---, $P < 0.01$; empty cell: not significant, $P > 0.1$

Results and discussion

D. Coverage (COV)

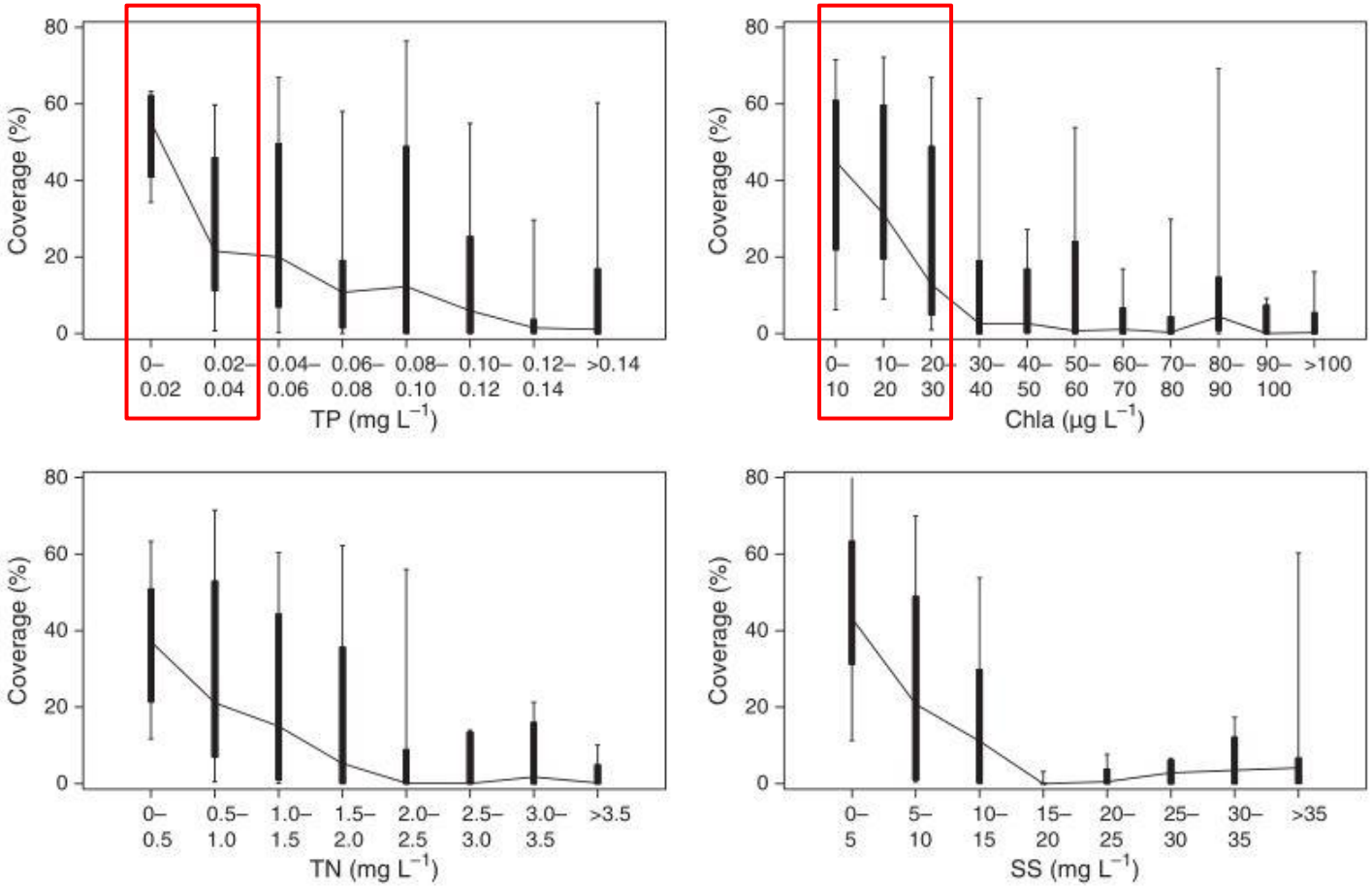

Fig 5 Mean macrophyte coverage relative to total phosphorus (N = 201), total nitrogen (N = 242), suspended solids (N = 111) and chlorophyll *a* (N = 198) for lakes with surface area >1 ha and mean lake depth <3 m. Median values are connected by lines.

Results and discussion

D. Coverage (COV)

Table 3 Results of regression analyses of COV, PVI, C_{max}, species richness+1(sp. number+1) with TP (mg P L^{-1}), Chla (μg L^{-1}),TN (mg N L^{-1}) and lake area (in ha). Only significant relationships are shown here. For species richness, lake area was also included in the multiple regression

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Chla, chlorophyll *a*; C_{max}, maximum colonisation depth; COV, mean macrophyte coverage; PVI, plant volume inhabited; TP, total phosphorus; TN, total nitrogen.

Results and discussion

E. Plant volume inhabited (PVI)

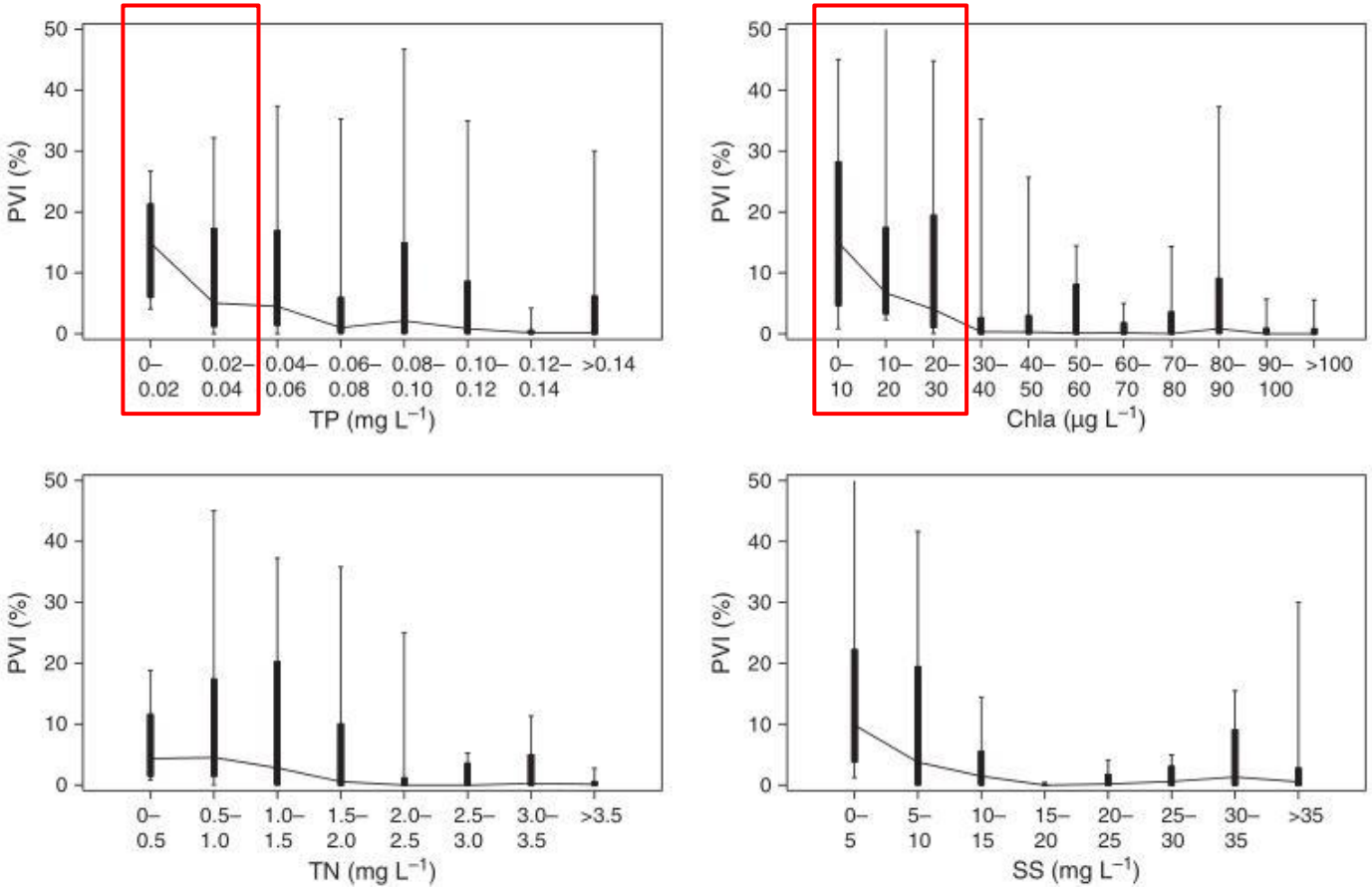

Fig 6 Proportion of mean plant volume inhabited of submerged macrophytes relative to total phosphorus (N = 199), total nitrogen (N = 242), suspended solids (N = 125) and chlorophyll *a* (N = 196) for lakes with surface area is >1 ha and mean lake depth <3 m. Median values are connected by lines.

Results and discussion

E. Plant volume inhabited (PVI)

Table 3 Results of regression analyses of COV, PVI, C_{max}, species richness+1(sp. number+1) with TP (mg P L^{-1}), Chla (μg L^{-1}),TN (mg N L^{-1}) and lake area (in ha). Only significant relationships are shown here. For species richness, lake area was also included in the multiple regression

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Chla, chlorophyll *a*; C_{max}, maximum colonisation depth; COV, mean macrophyte coverage; PVI, plant volume inhabited; TP, total phosphorus; TN, total nitrogen.

Results and discussion

F. COV and PVI at low alkalinity

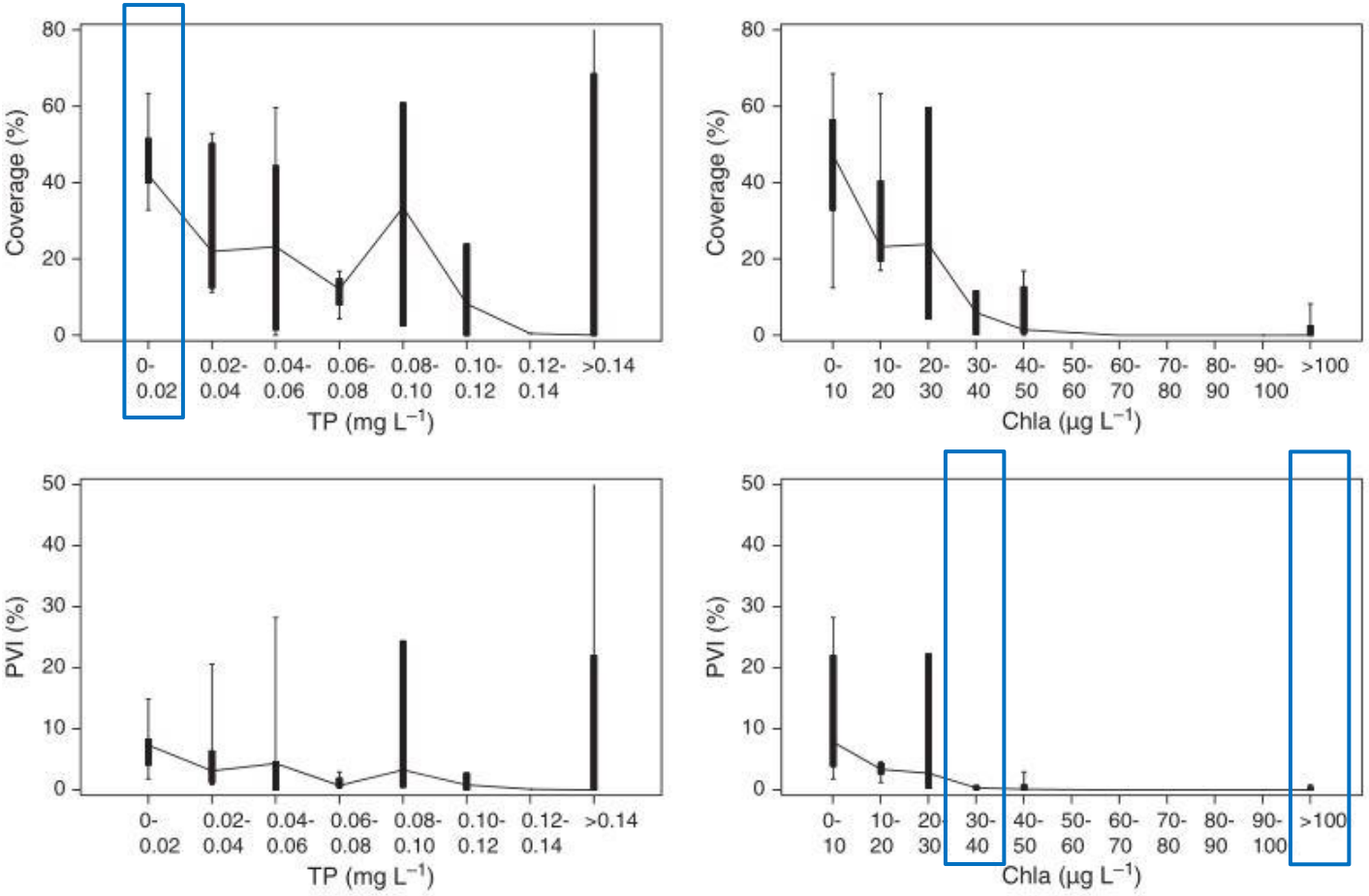

Fig 7 Mean macrophyte coverage and proportion of mean plant volume inhabited of submerged macrophytes in lakes with low alkalinity (total alkalinity < 0.2 meq L^{-1}) relative to total phosphorus (N = 42) and chlorophyll *a* (N = 42) for lakes with surface area >1 ha and mean lake depth <3 m. Median values are connected by lines.

Results and discussion

G. Variability among years

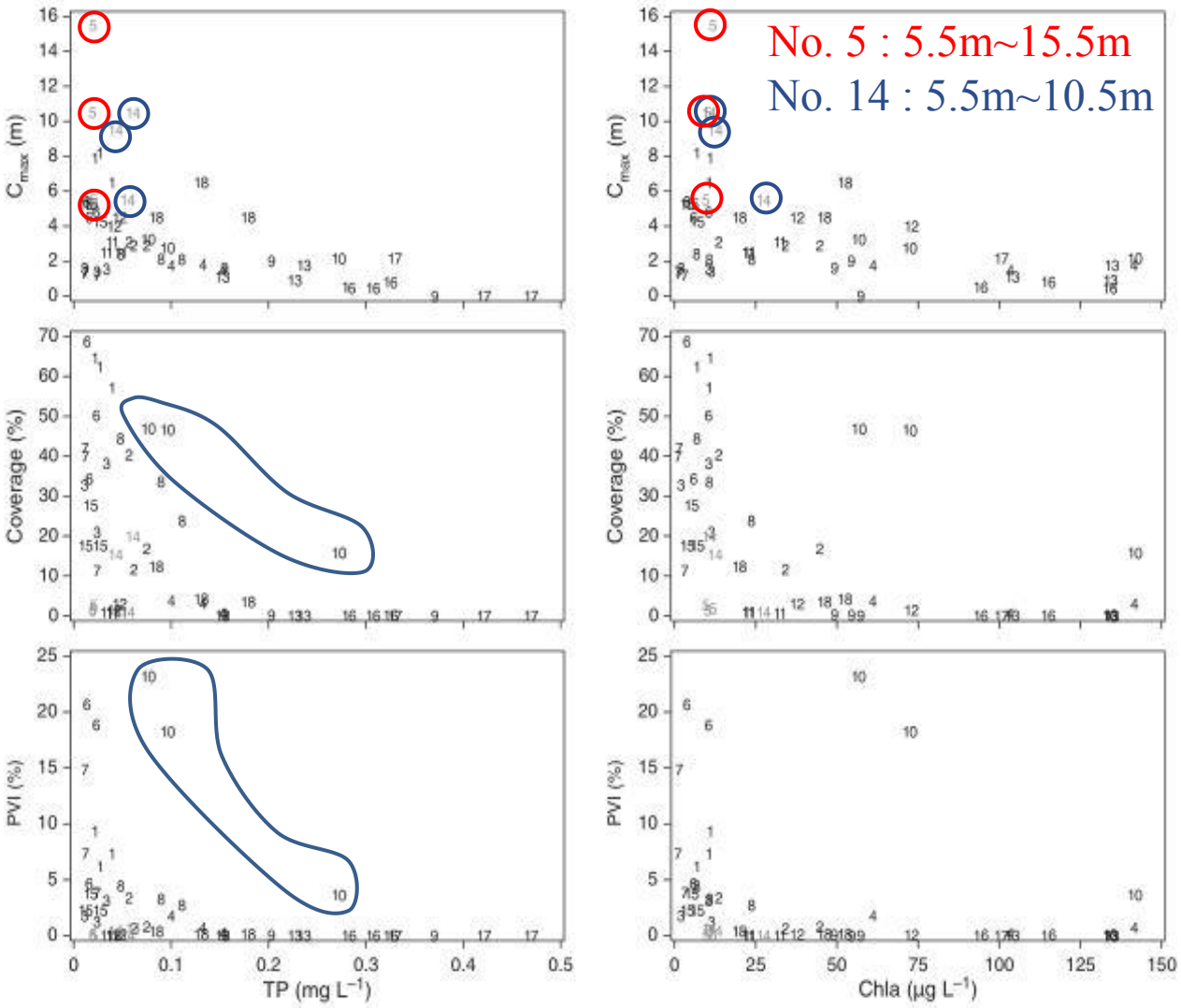

Fig 8 Maximum colonisation depth, mean macrophyte coverage and proportion of mean plant volume inhabited in 18 lakes (no.1–18) sampled from 2004 until 2006. Two lake-years with chlorophyll *a* >200 μg L^{-1} are not included.

Results and Discussion

H. Calculation of macrophyte index

Table 5 Example of calculating scores and a submerged macrophyte index for lakes of different size (>100, 10–100 and <10 ha) and depth (shallow lakes, mean depth ≤3 m; deep lakes, mean depth >3 m)

	Deep lakes			Shallow lakes		
	3 points	2 points	1 point	3 points	2 points	1 point
Number of indicator species*	>100 ha: ≥3 10–100 ha:≥2 <10 ha: ≥1	>100 ha: =2 <100 ha: =1	>100 ha: =1 <100 ha: =0	>100 ha: ≥3 10–100 ha: ≥2 <10 ha: ≥1	>100 ha: =2 <100 ha: =1	>100 ha: =1 <100 ha: =0
Species richness†	$>5.8*area^{0.26}$	$>5.7*area^{0.24}$	$>4.7*area^{0.19}$	$>5.8*area^{0.26}$	$>5.7*area^{0.24}$	$>4.7*area^{0.19}$
C_{max}	>5 m	4–5 m	3–4 m	–	–	–
COV	–	–	–	≥40%	20–40%	10–20%
Total score‡						

C_{max}, maximum colonisation depth; COV, mean macrophyte coverage; *N*, number of lakes; TP, total phosphorus.

*The six species with TP_Q3 < 0.05 mg P L^{-1} in Table 2.

†Calculations are based on regression (species no = $a*area^b$, area in ha) of lakes with TP <0.025 mg P L^{-1} (3 points, $N = 20$), lakes with TP between 0.025 and 0.05 mg P L^{-1} (2 points, $N = 45$) and lakes with TP between 0.05 and 0.1 mg P L^{-1} (1 point, $N = 75$), according to the TP boundaries given by Søndergaard *et al.* (2005).

‡Total score can subsequently be translated to a biological quality index or ecological class, for example: score 8–9: high, score 6–7: good, score 4–5: moderate, score 2–3: poor, score 0–1: bad.

Results and Discussion

I. Application of the index

Table 6 Scores and ecological class calculations (based on Table 5) for three lakes with mean depth (z) >5 m and three lakes with mean depth <3 m. High, good, moderate, poor and bad are indicated by H, G, M, P and B, respectively, and defined as shown in Table 5

				Metric value/score				
Lake /no	Year	Total phosphorus (mg P L^{-1})	Chlorophyll *a* (μg L^{-1})	Indicators	Richness	Maximum colonisation depth	Mean macrophyte coverage	Total score/Class
Hornum/2	2004	0.057	13.6	1/2	12/3	–	40/3	8/H
Z = 1.6 m	2005	0.075	44.7	1/2	17/3	–	17/1	6/G
Area = 12 ha	2006	0.062	34.1	1/2	9/1	–	12/1	4/M
Holm/7	2004	0.024	3.1	2/3	8/1	–	11/1	5/M
Z = 0.8 m	2005	0.012	1.1	2/3	5/0	–	40/3	6/G
Area = 12 ha	2006	0.012	1.4	2/3	8/1	–	42/3	7/G
Kvie/8	2004	0.111	23.7	2/3	12/1	–	24/2	6/G
Z = 1.2 m	2005	0.090	10.7	2/3	11/1	–	33/2	6/G
Area = 30 ha	2006	0.048	6.8	2/3	13/2	–	44/3	8/H
Ravn/5	2004	0.021	9.7	0/0	16/1	5.6/3	–	4/M
Z = 15.0 m	2005	0.020	10.3	2/2	14/1	10.5/3	–	6/G
Area = 177 ha	2006	0.020	11.8	1/1	14/1	15.5/3	–	5/M
Arreskov/10	2004	0.273	142.0	0/0	4/0	2.1/0	–	0/B
Z = 6.5 m	2005	0.097	72.6	0/0	7/0	2.7/0	–	0/B
Area = 317 ha	2006	0.077	56.9	0/0	10/1	3.2/1	–	2/P
Fure/14	2004	0.061	10.8	0/0	22/1	10.5/3	–	4/M
Z = 13.5 m	2005	0.044	12.7	0/0	24/1	9.5/3	–	4/M
Area = 941 ha	2006	0.056	27.6	0/0	11/0	5.5/3	–	3/P

Conclusion

- Most species occurred at a wide range of phosphorus and chlorophyll *a* (Chla) concentrations. Species indicative of eutrophication were rare, since most species found mainly at high TP and Chla levels were also observed at relatively low TP and Chla levels.

- Submerged macrophyte coverage, PVI and the C_{max} were negatively correlated with TP and Chla. However, variability among lakes was high.

- Submerged macrophytes responded clearly to eutrophication. The simple index based on species richness, presence of indicator species, coverage and C_{max} might be used to track major changes in macrophyte communities and for lake classification.

Thanks for your listening!