Eutrophication and lake restoration influence on nutritional quality of food webs

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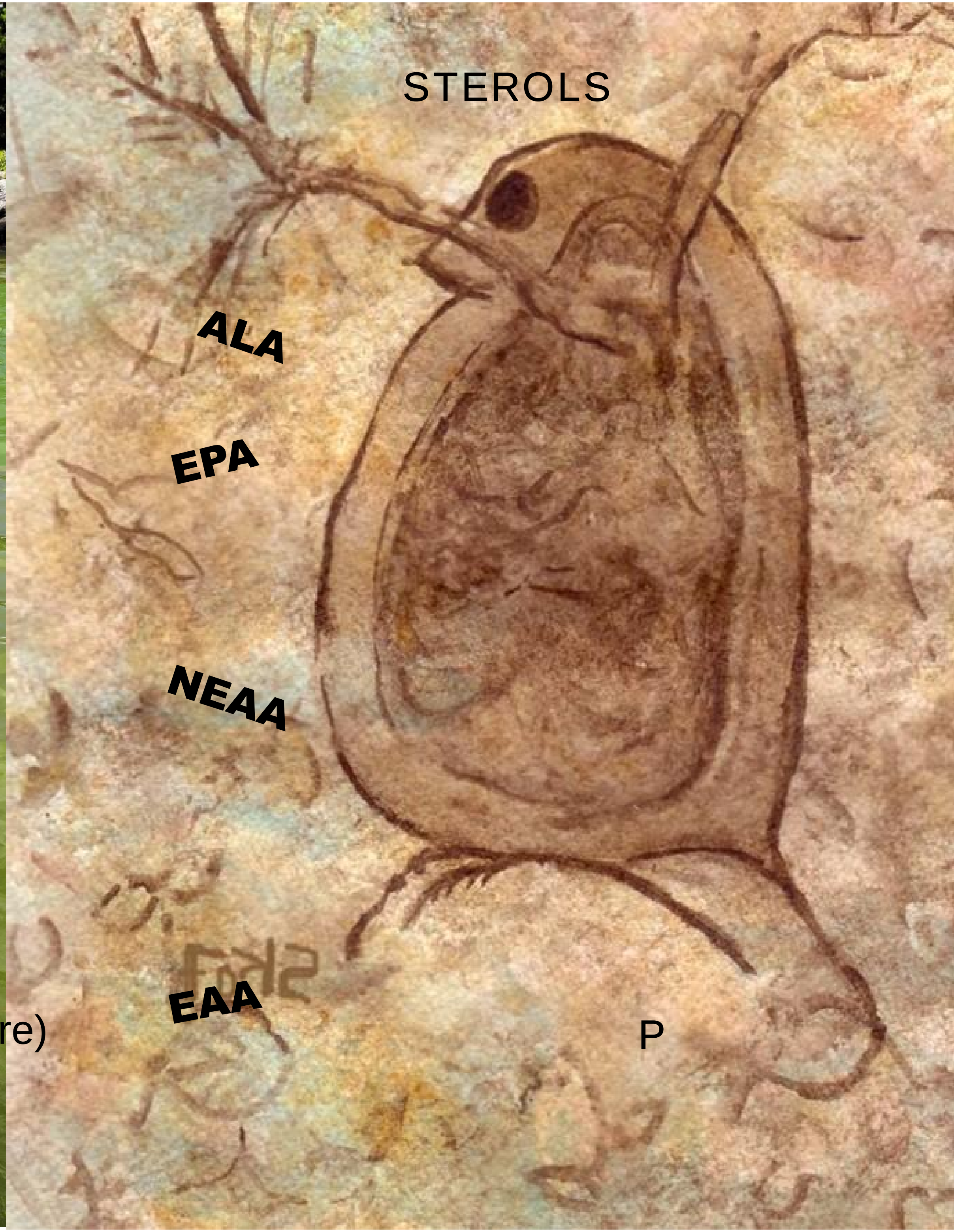
Photo by Kirsi Kuoppamäki



ESSENTIAL BIOMOLECULES

- Nutritionally <u>essential biomolecules</u> are defined as compounds that cannot be synthetized *de novo* in animals or as that are insufficiently synthetized *de novo* for optimal growth and reproduction.

ESSENTIAL BIOMOLECULES FOR ZOOPLANKTON

CAROTENOIDS

- ASTAXANTHIN

β-CAROTENE

ECHINENONE

CANTHAXANTHIN

STEROLS

- CHOLESTEROL

PHYTOSTEROLS

HIGH EFFICIENCY

(Fucosterol, brassica-sterol, stigma-terol)

LOW EFFICIENCY

(b-sitosterol, desmo-sterol, chondrilla-sterol)

FATTY ACIDS

ω-3 PUFA	**ω**-6 PUFA
DHA (22:6w3)	ARA (20:4w6)
EPA (20:5w3)	
SDA (18:4w3)	DPA (22:5w6)
ALA (18:3w3)	GLA (18:3w6)
	LIN (18:2w6)

AMINO ACIDS

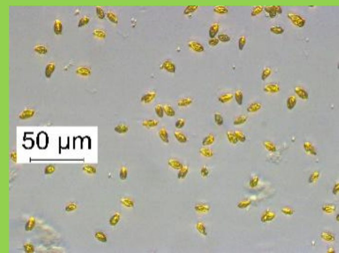
Arginine*
Histidine*
Isoleucine
Leucine
Lysine
Methionine
Phenylalanine
Threonine
Tryptophan
Valine

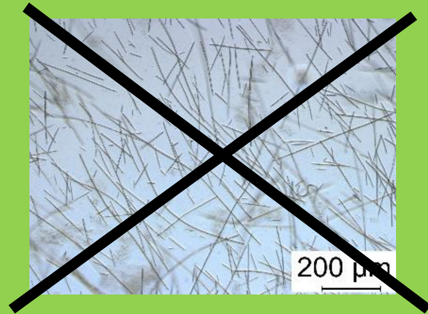
ESSENTIAL BIOMOLECULES

- In freshwater systems essential biomolecules are synthesized by phytoplankton.

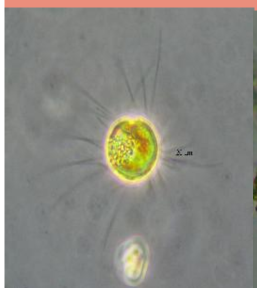
- ASTAXANTHIN IS SYNTESIZED ONLY BY GREEN ALGAE BUT Β-CAROTENE IS SYNTHESIZED BY ALL PHYTOPLANKTON TAXA.

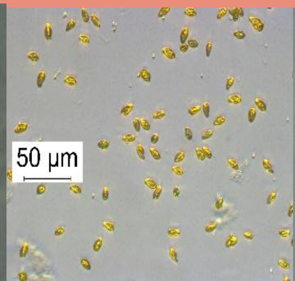
- STEROLS ARE SYNTHESIZED ALL PHYTO TAXA BUT NOT BY CYANOBACTERIA. CRYPTOPHYTES ARE BEST SOURCE FOR STEROLS.

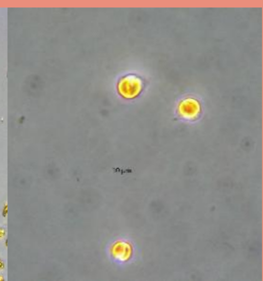




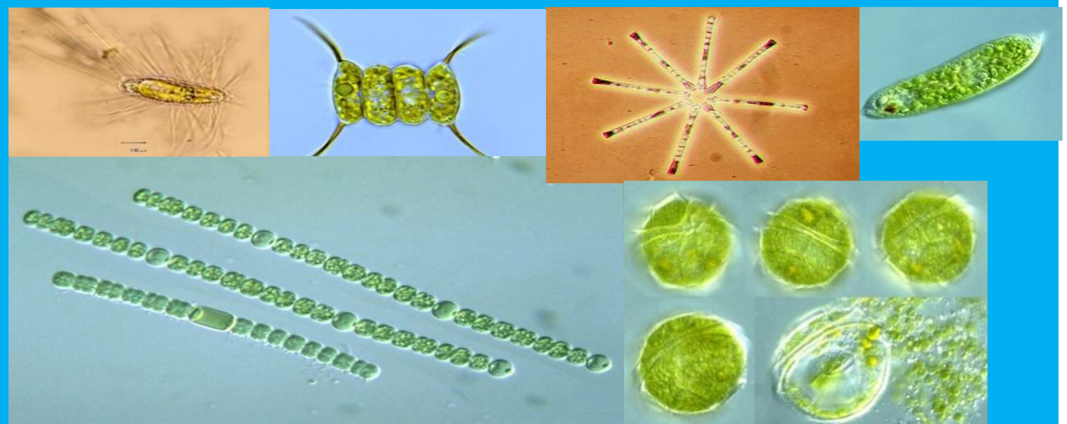
- ALA (18:3W3) AND LIN (18:2W6) ARE SYNTHESIZED BY ALL PHYTOPLANKTON TAXA, BUT EPA (20:5W3) AND DHA (22:6W3) ARE SYNTHESIZED BY ONLY FEW TAXA.

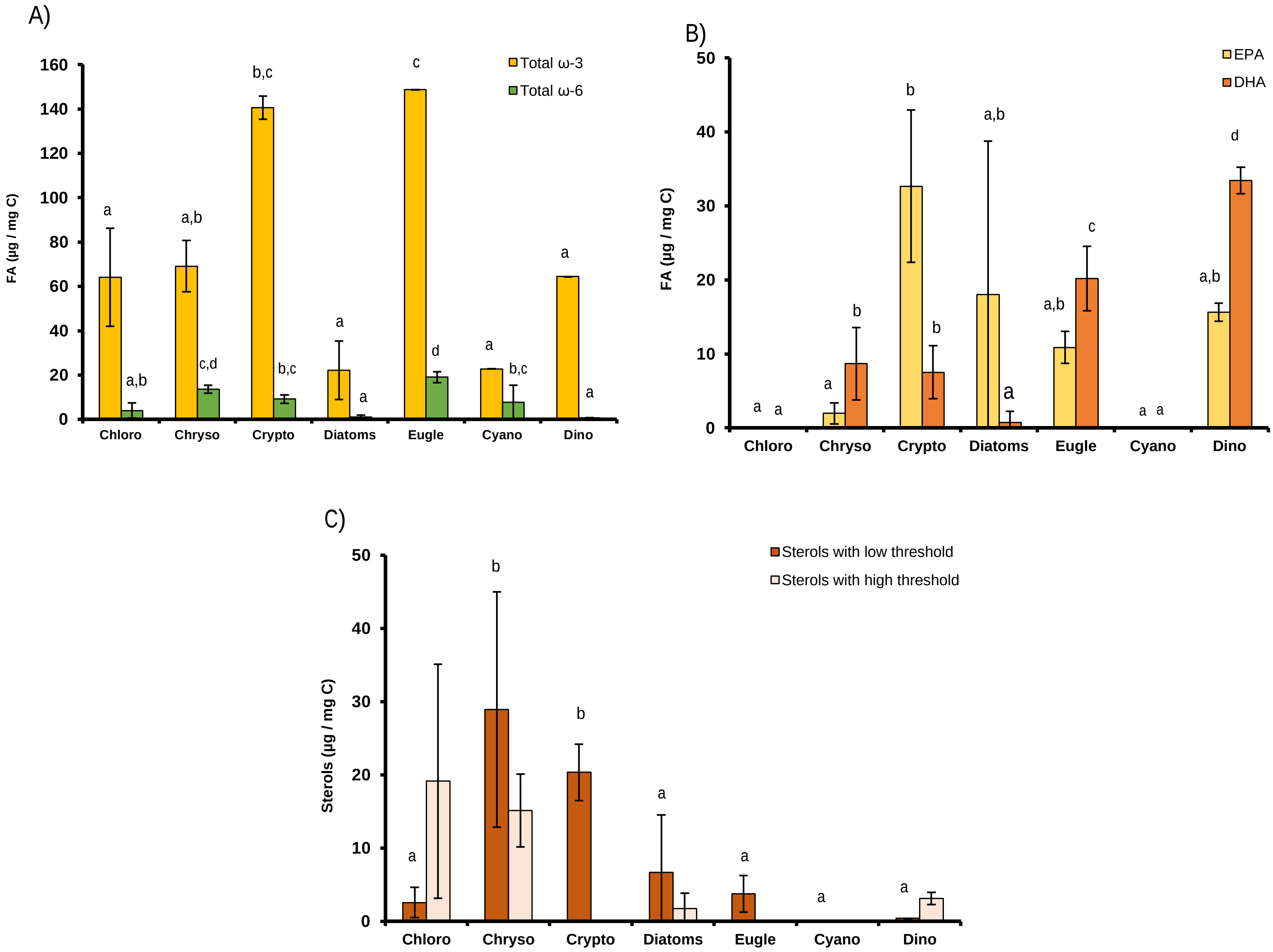






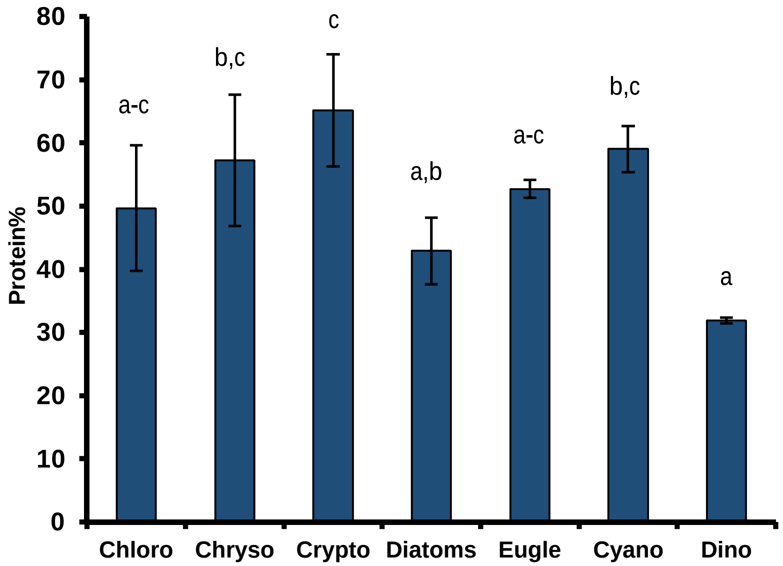
- AMINO ACIDS ARE SYNTHESIZED BY ALL PHYTOPLANKTON TAXA AS WELL BY BACTERIA, BUT CONCENTRATIONS VARY.





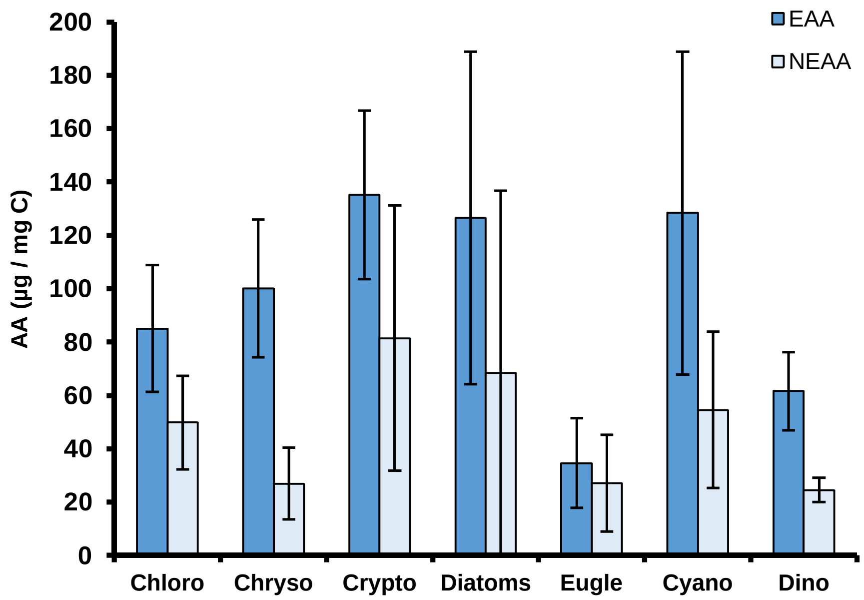
A)
FA (µg / mg C)
Total ω-3
Total ω-6
Chloro
Chryso
Crypto
Diatoms
Eugle
Cyano
Dino
B)
FA (µg / mg C)
EPA
DHA
C)
Sterols (µg / mg C)
Sterols with low threshold
Sterols with high threshold

D)



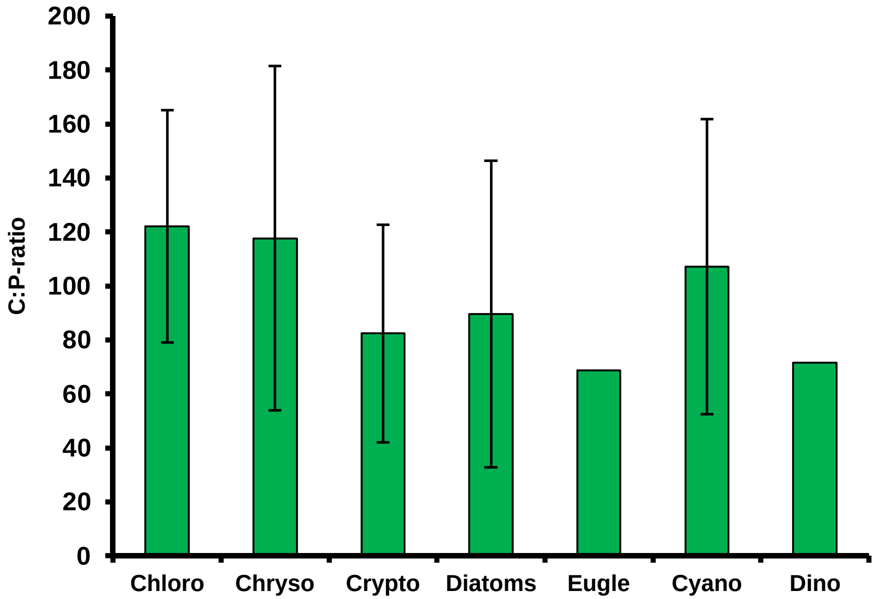
Protein%
80
70
60
50
40
30
20
10
0
a-c
b,c
c
a,b
a-c
b,c
a
Chloro
Chryso
Crypto
Diatoms
Eugle
Cyano
Dino

E)



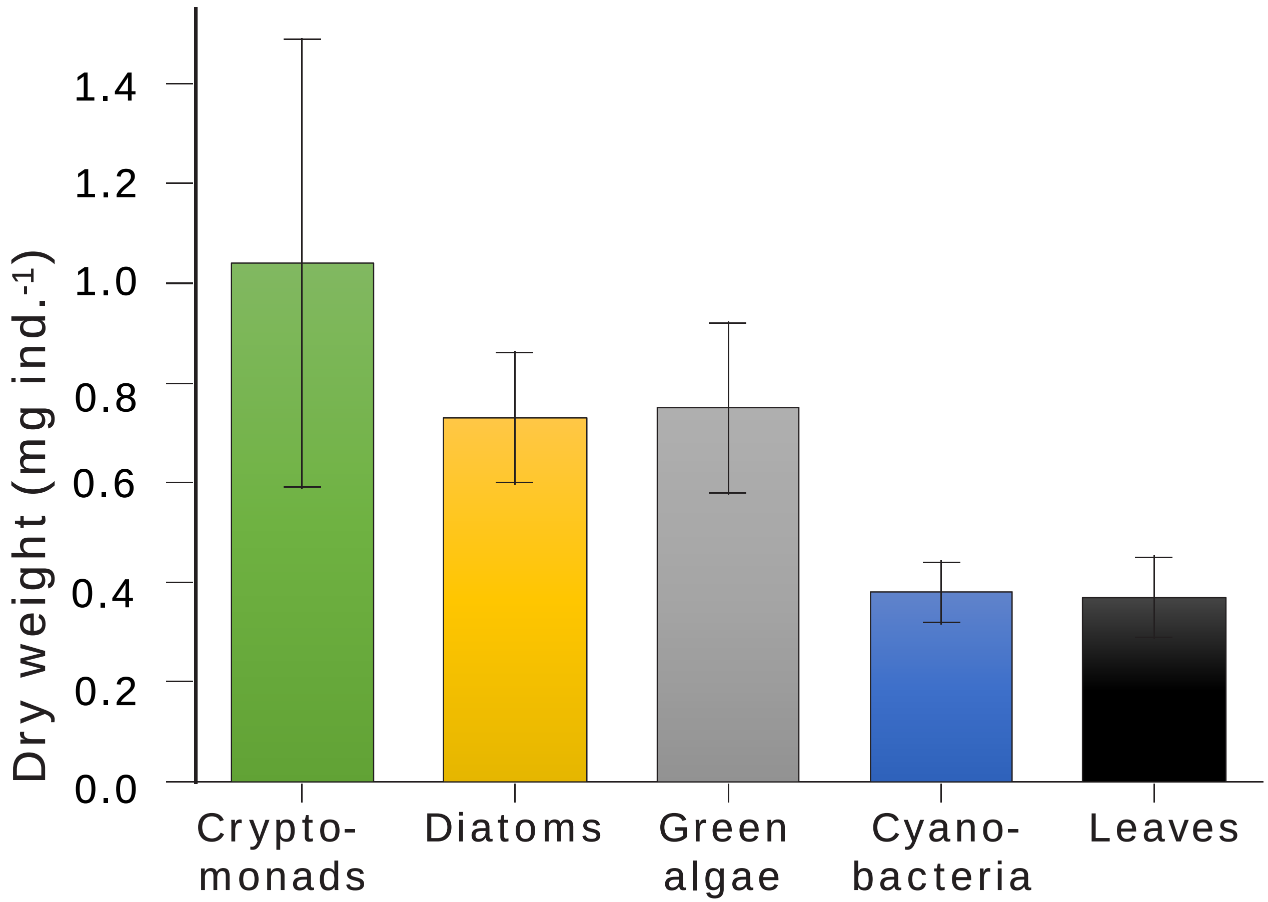
AA (µg / mg C)
200
180
160
140
120
100
80
60
40
20
0
EAA
NEAA
Chloro
Chryso
Crypto
Diatoms
Eugle
Cyano
Dino

F)

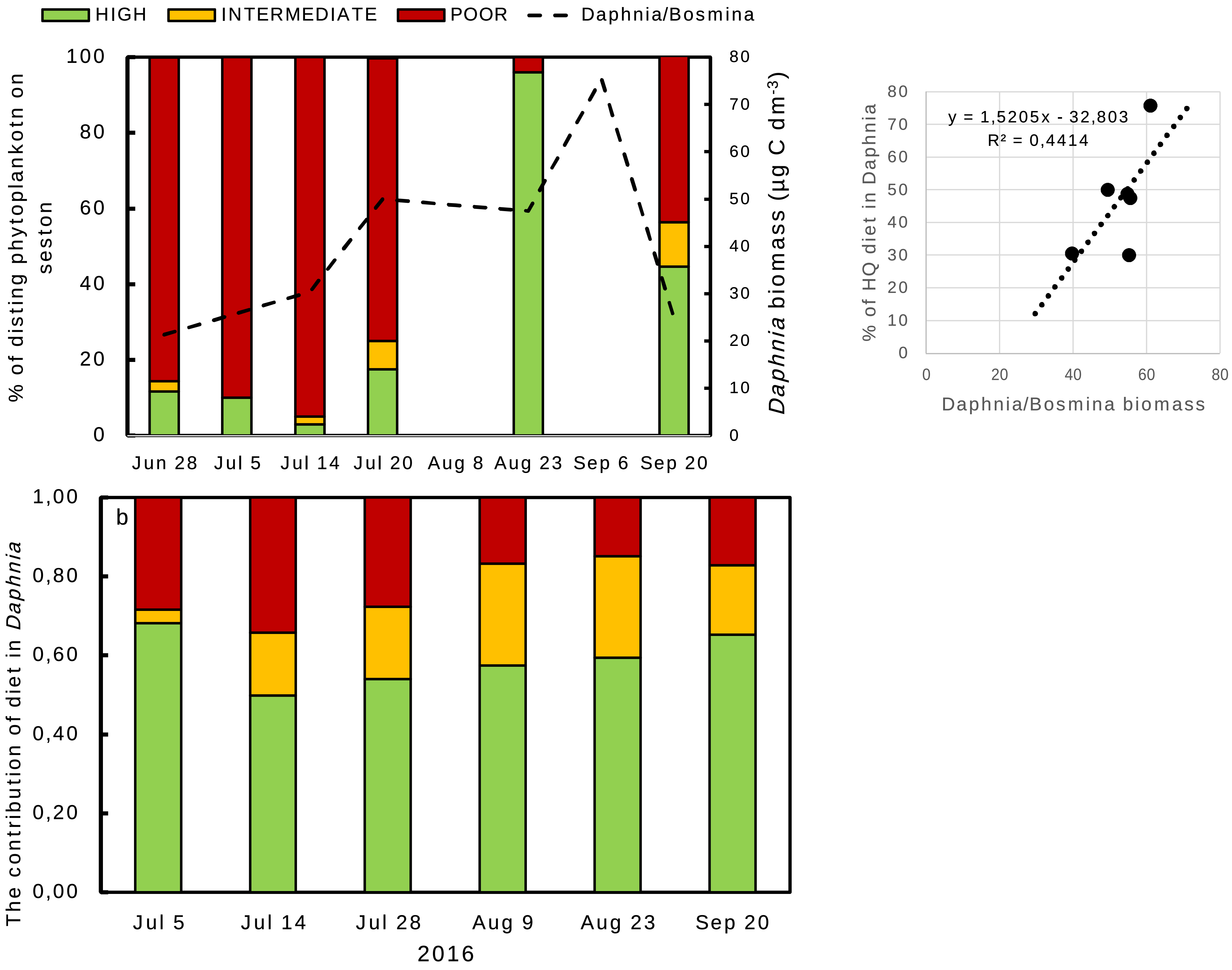


C:P-ratio
200
180
160
140
120
100
80
60
40
20
0
Chloro
Chryso
Crypto
Diatoms
Eugle
Cyano
Dino

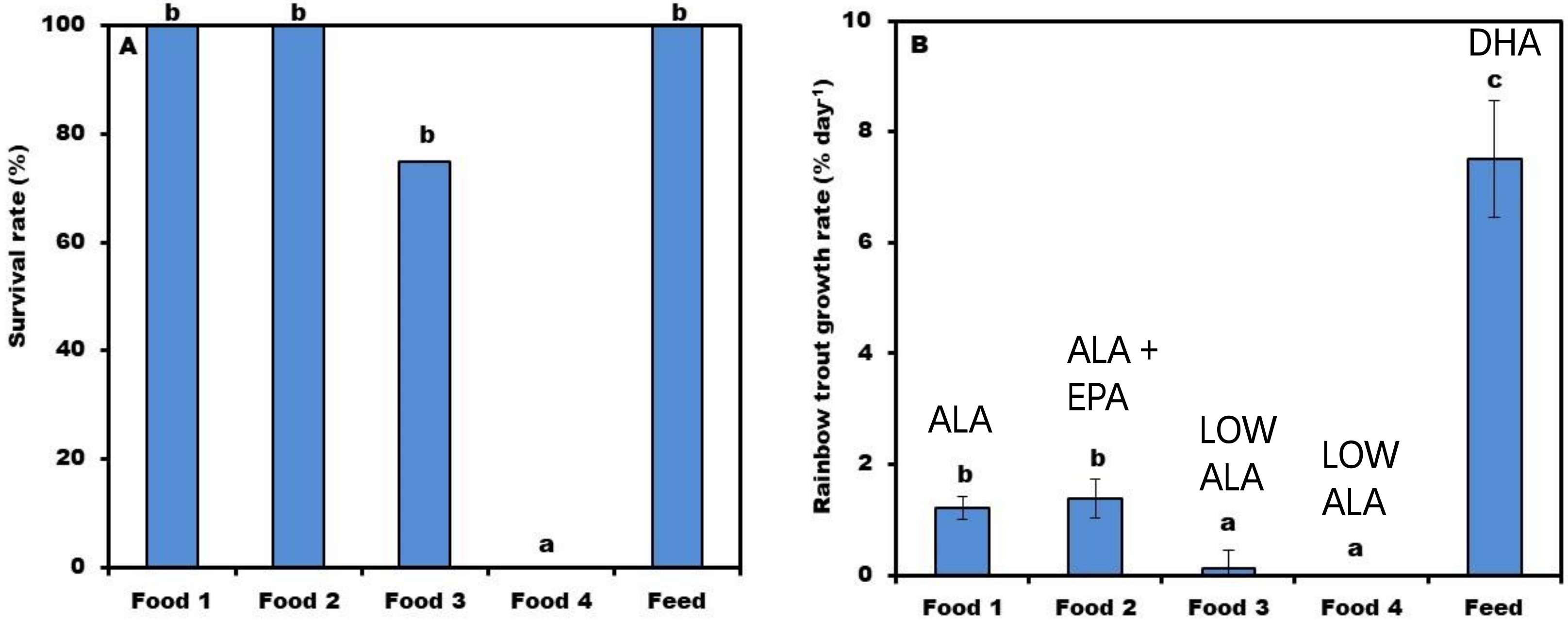
Zooplankton growth is regulated by w-3 and sterol content of phytoplankton.



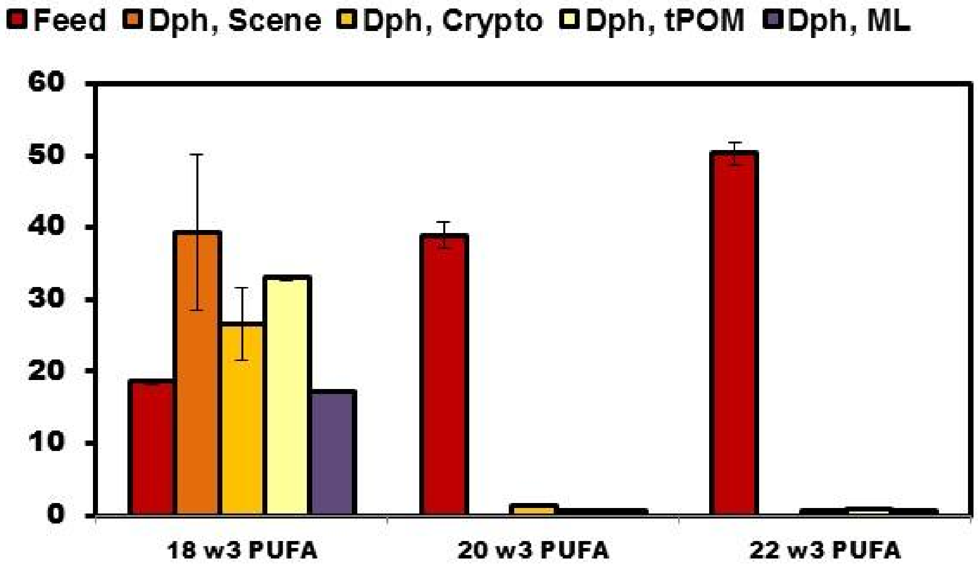
Brett et al. 2009. PNAS vol. 106 no. 50 21197-21201.



HIGH
INTERMEDIATE
POOR
Daphnia/Bosmina
% of disting phytoplankotn on seston
Daphnia biomass (µg C dm-3)
100
80
60
40
20
0
80
70
60
50
40
30
20
10
0
Jun 28
Jul 5
Jul 14
Jul 20
Aug 8
Aug 23
Sep 6
Sep 20
y = 1,5205x - 32,803
R² = 0,4414
% of HQ diet in Daphnia
Daphnia/Bosmina biomass
b
1,00
0,80
0,60
0,40
0,20
0,00
The contribution of diet in Daphnia
Jul 5
Jul 14
Jul 28
Aug 9
Aug 23
Sep 20
2016

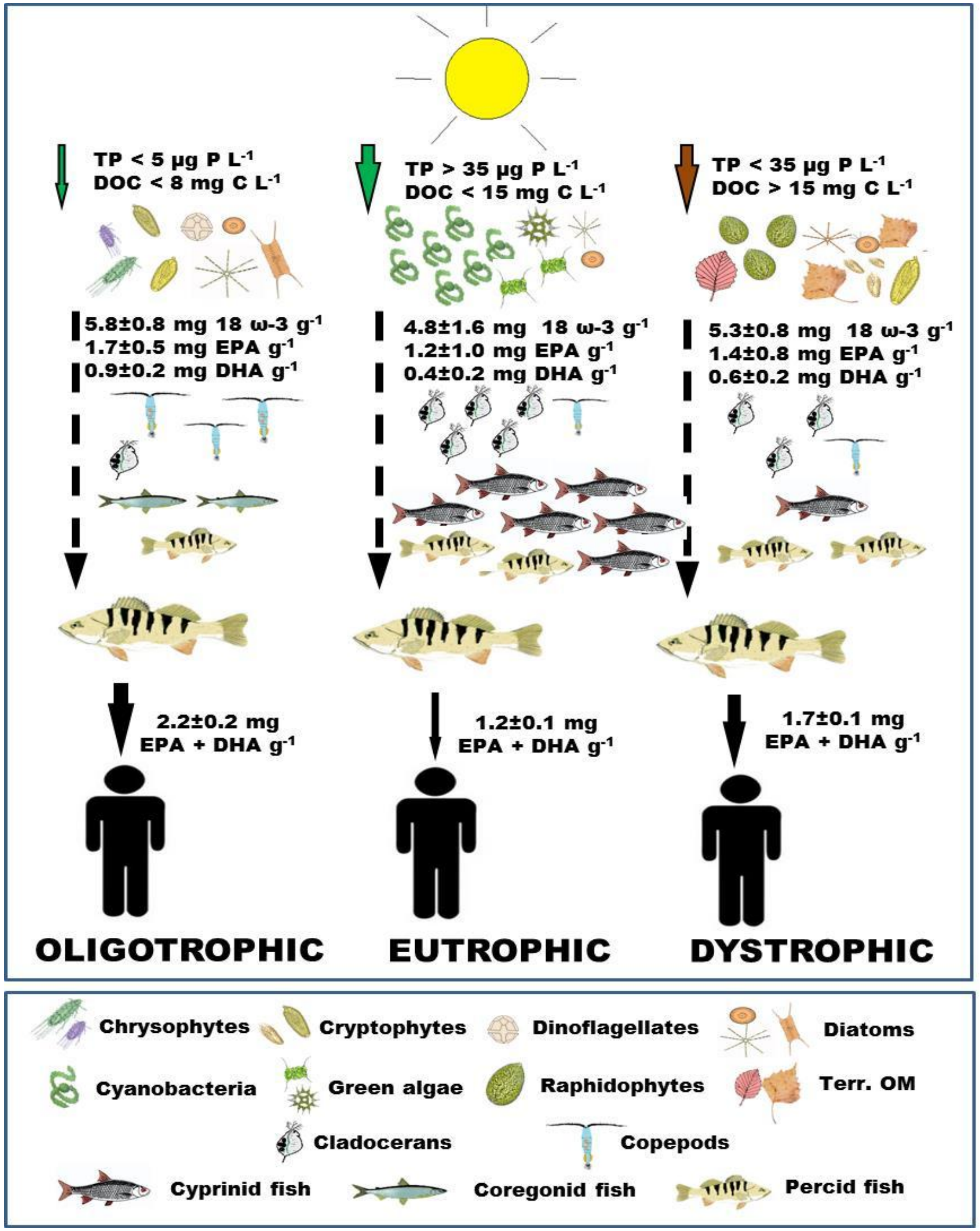


Taipale et al. Ecol and Evol 2018.



- Fish require DHA (and ARA) for disease resistance, neural tissue and eye development, pigmentation and reproduction (Sargent et al. 1999).

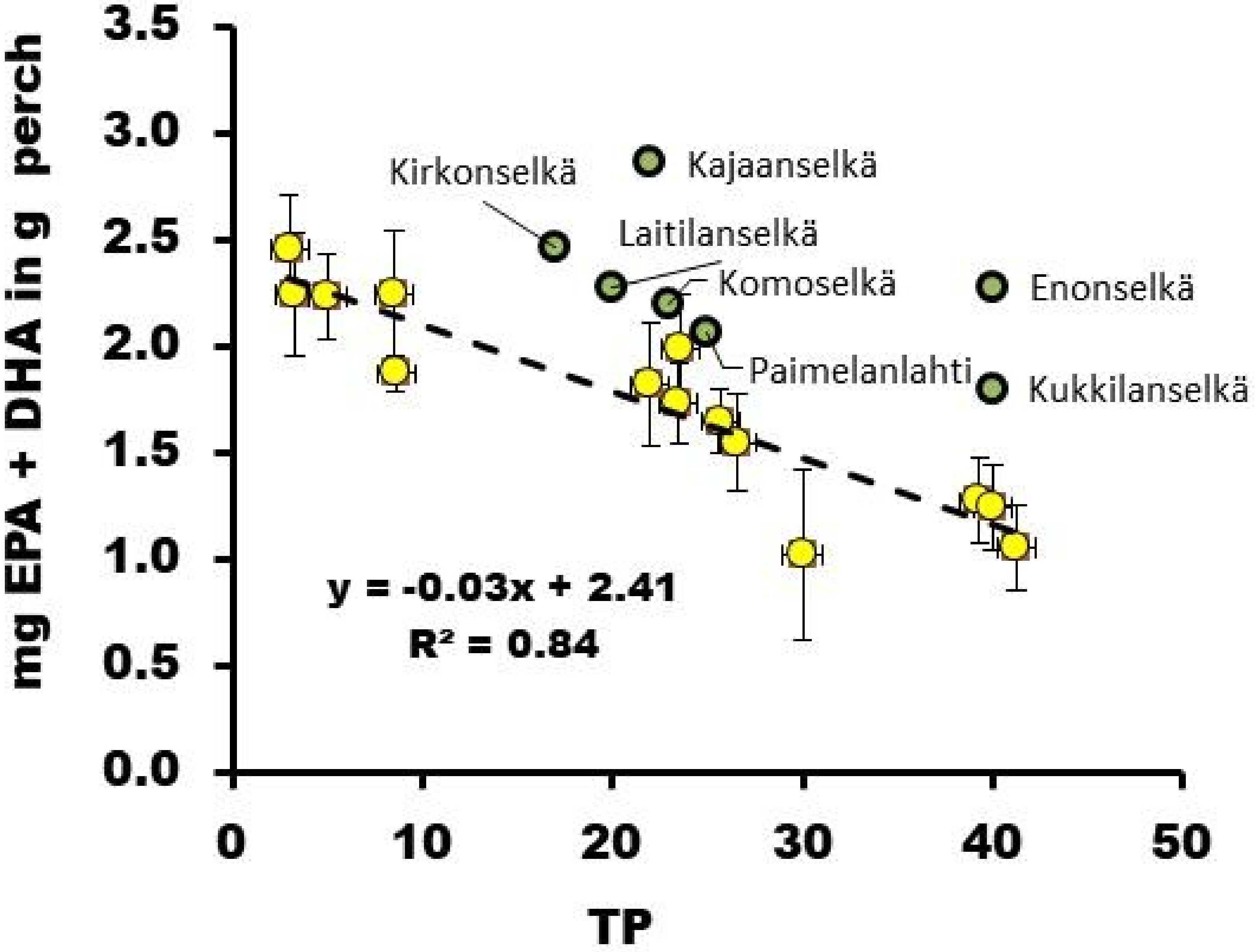
- Juvenile rainbow trout were not able to grow on *Daphnia* with low ALA content and grew moderately with high ALA.



- **The ω-3 FA is transferred via herbivorous zooplankton and planktivorous fish to piscivorous fish (in this case large perch).**

- **TP and DOC concentration influence phytoplankton structure and synthesis of ω-3 FA .**

- **The EPA and DHA content in individual perch is the highest in the oligo-mesotrophic lakes. Thus, a person should eat 1.9 and 1.5 times more perch from eutrophic and dystrophic lakes compared with those from oligotrophic lakes to achieve the daily recommended intake of EPA and DHA.**

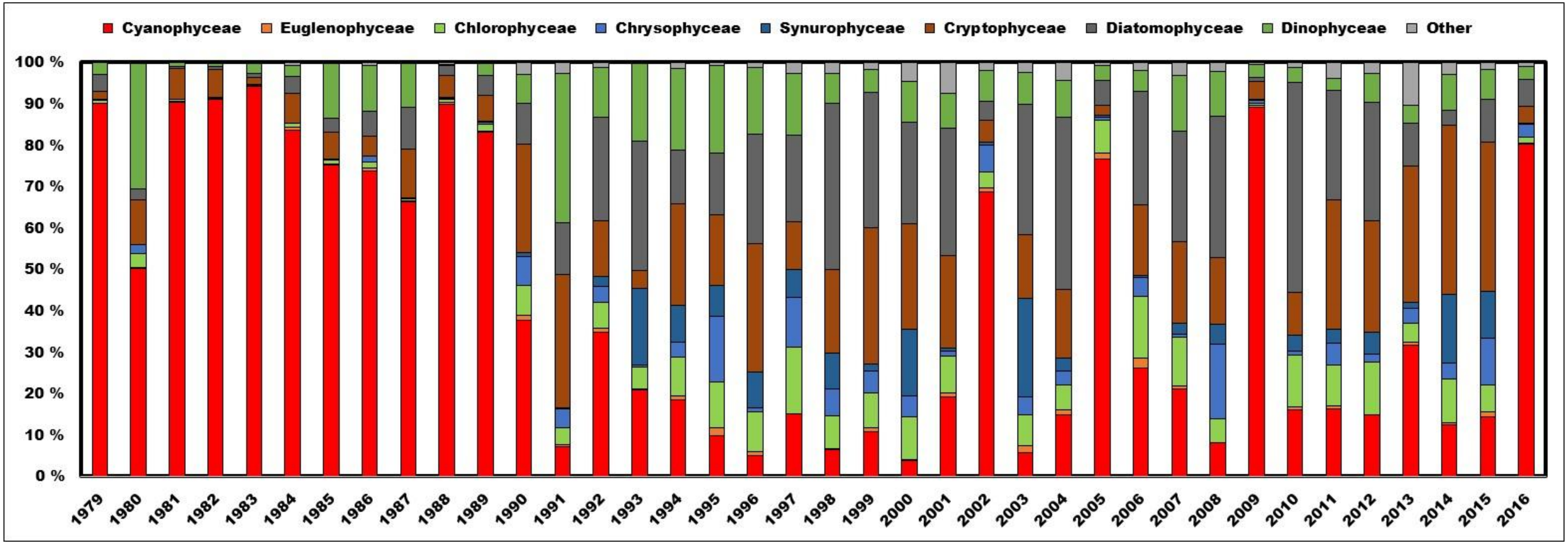


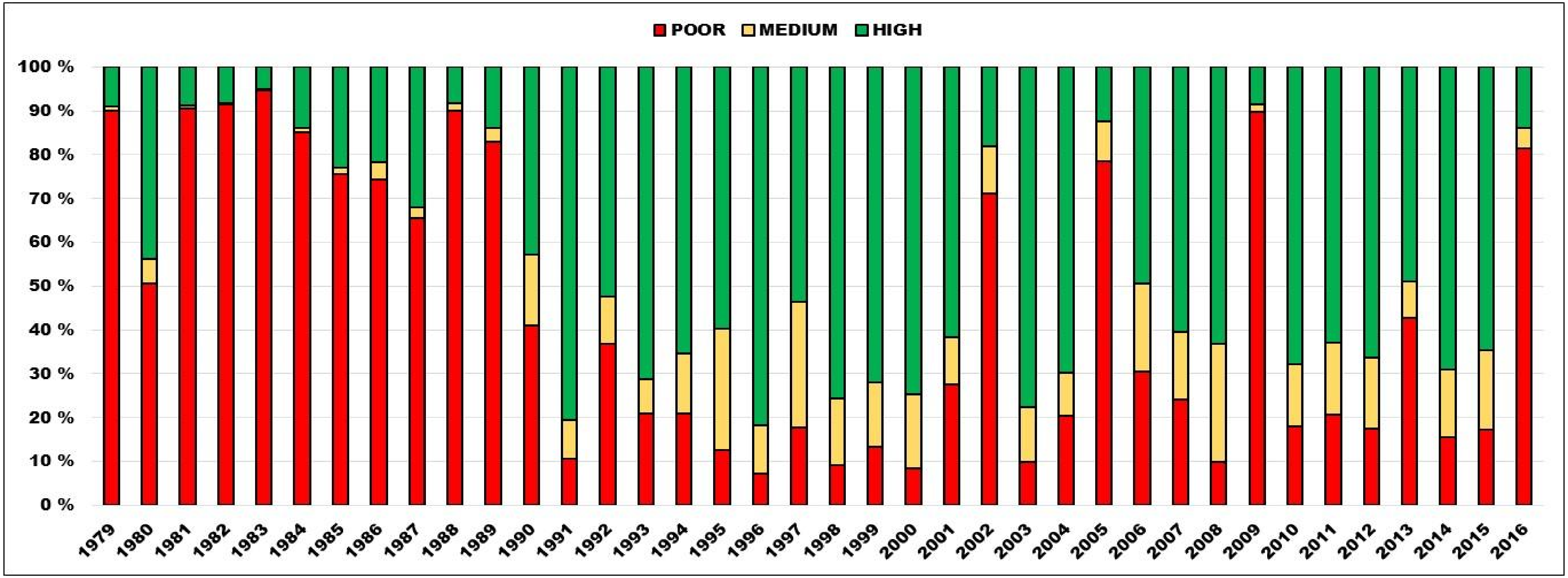
Taipale et al. 2016 Environ Intern doi. 10.1016/j.envint.2016.08.018.

1. HOW BIOMANIPULATION AND HYPOLIMENTIC AEROTATION INFLUENCE PHYTOPLANKTON COMPOSITION?

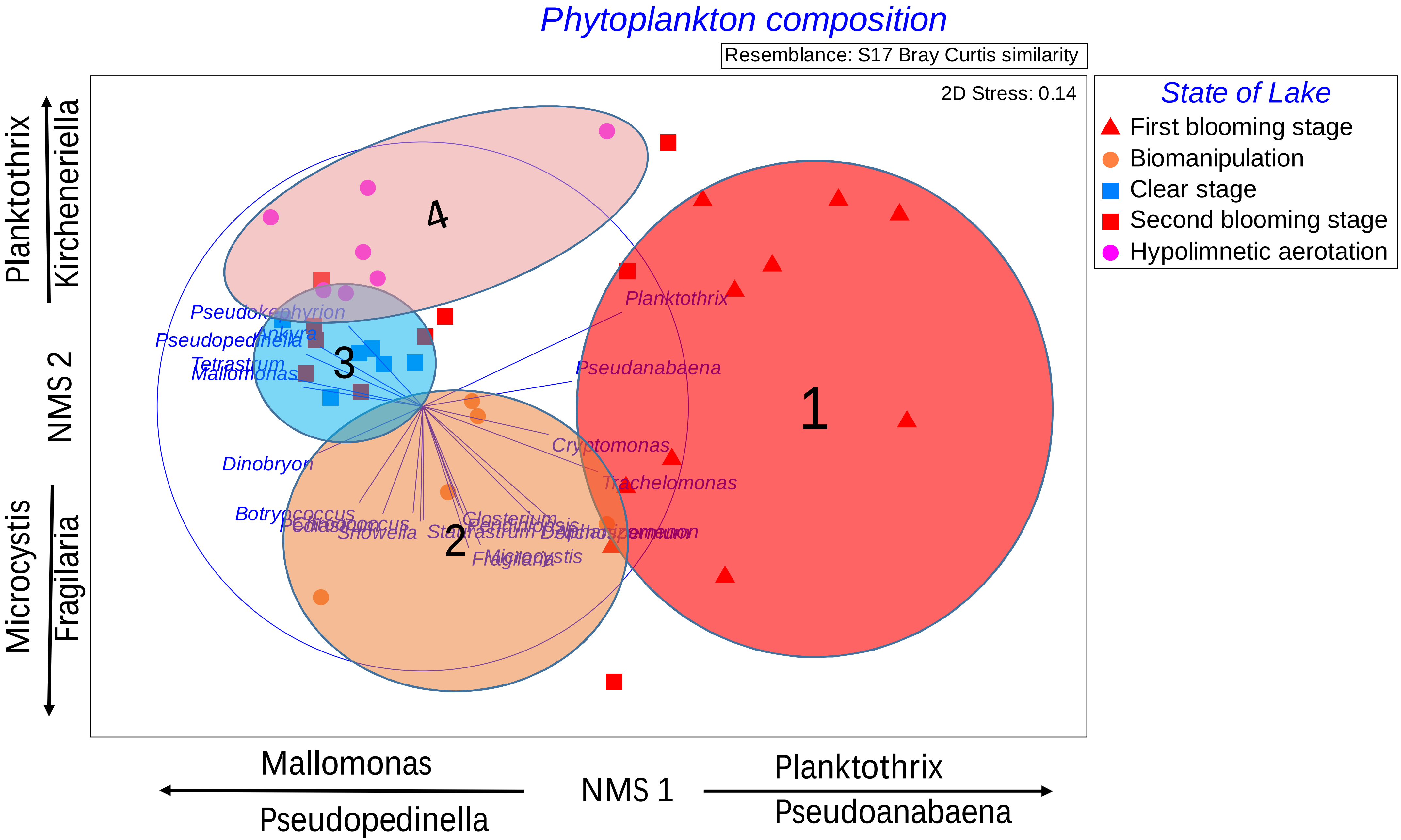
2. DOES THEY ENHANCE EPA- AND DHA-SYNTHESIZING PHYTOPLANKTON TAXA?

- Phytoplankton composition from Lake Vesijärvi 1979-2016
- Using modern statistical test: non-metric multidimensional scaling (NMS), permutational multivariate analysis of variance (PERMANOVA), similarity percentages (SIMPER) and test of functional similarity (PERMDISP).
- The sestonic w-3, EPA, DHA and sterol content was calculated based on phytoplankton biomass and laboratory cultures of distinct phytoplantkon taxa.

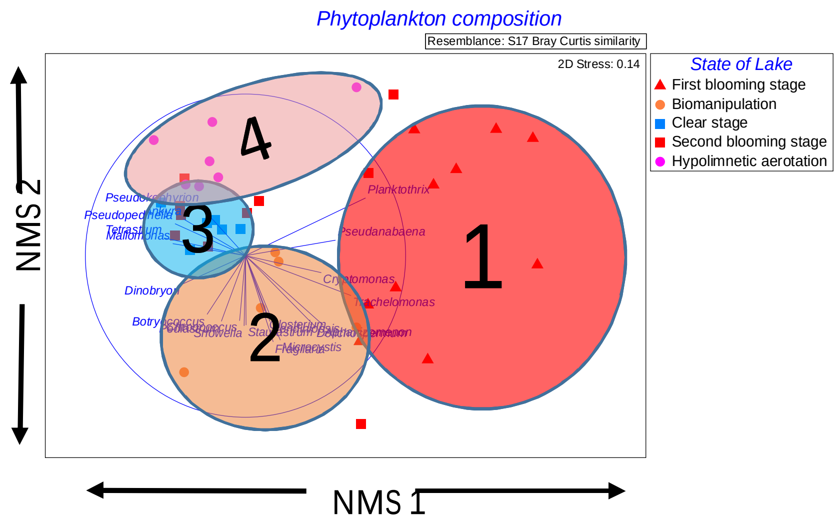

Cyanophyceae
Euglenophyceae
Chlorophyceae
Chrysophyceae
Synurophyceae
Cryptophyceae
Diatomophyceae
Dinophyceae
Other
0 %
10 %
20 %
30 %
40 %
50 %
60 %
70 %
80 %
90 %
100 %
1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

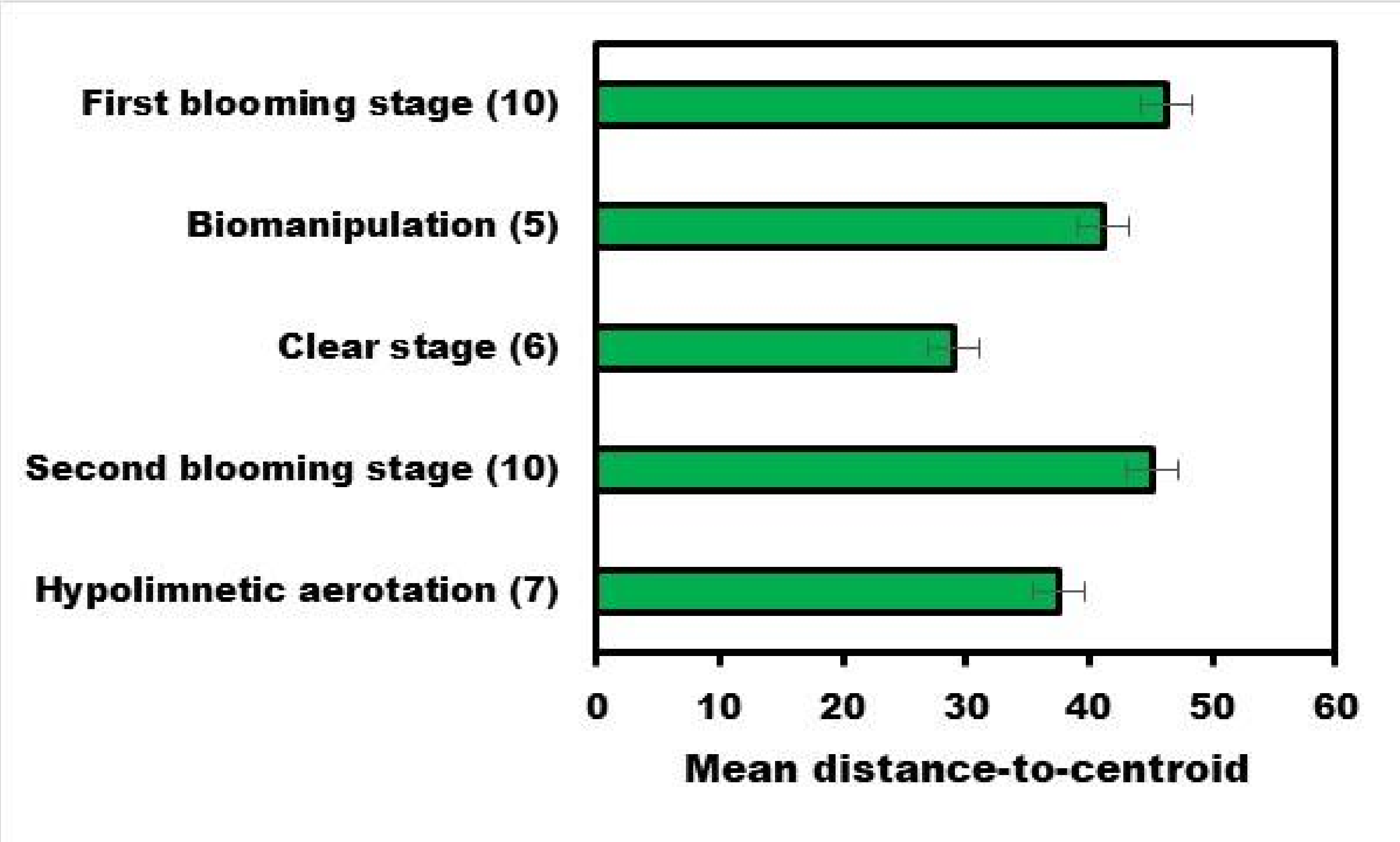

POOR
MEDIUM
HIGH
0 %
10 %
20 %
30 %
40 %
50 %
60 %
70 %
80 %
90 %
100 %
1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Non-metric Multi-Dimensional Scaling



Permutational Analysis of Multivariate Dispersions (PERMIDISP) was used to evaluate dispersion within each stage.





Similarity Percentage Analysis (SIMPER)

Group First blooming stage					
Average similarity: 32.50					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Planktothrix	307.0	11.9	0.8	36.5	36.5
Aphanizomenon	151.7	6.1	0.7	18.7	55.1
Cryptomonas	40.7	3.9	2.1	12.1	67.2
Dolichospermum	101.3	3.1	0.8	9.4	76.6
Pseudanabaena	152.7	2.1	0.4	6.3	83.0
Microcystis	19.5	0.9	0.6	2.8	85.8
Peridiniopsis	21.2	0.8	0.4	2.6	88.4
Rhodomonas	8.4	0.6	1.8	1.9	90.3

Group Biomanipulation					
Average similarity: 34.23					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cryptomonas	40.58	7.66	1.38	22.37	22.37
Dolichospermum	31.96	4.5	0.63	13.15	35.52
Microcystis	28.71	3.94	1.36	11.52	47.03
Tabellaria	13.38	2.24	1.06	6.54	53.57
Fragilaria	7.49	2.13	2.88	6.22	59.79
Snowella	6.72	1.61	1.77	4.72	64.51
Ceratium	9.2	1.6	1.39	4.67	69.18
Rhodomonas	7.63	1.41	1.04	4.12	73.3

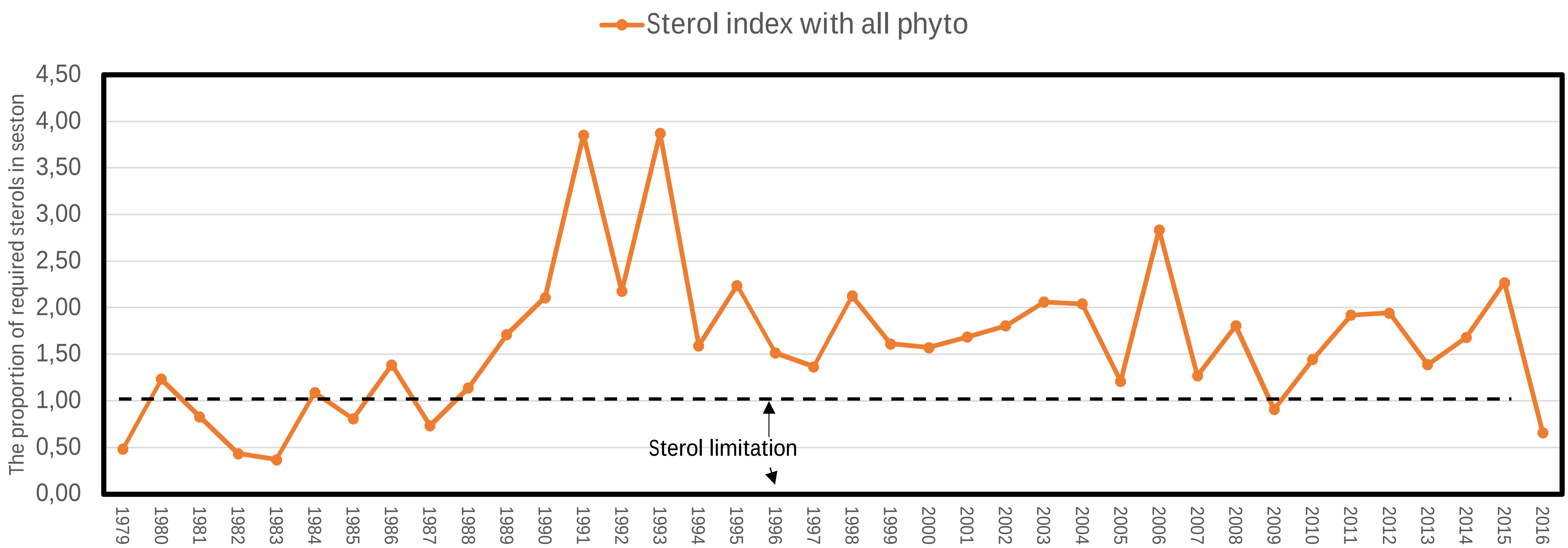
Group Clear stage					
Average similarity: 55.45					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Tabellaria	22.59	10.61	1.49	19.14	19.14
Cryptomonas	19.82	10.3	1.89	18.58	37.71
Rhodomonas	11.03	5.06	1.83	9.12	46.83
Mallomonas	7.69	3.74	1.94	6.74	53.57
Ceratium	5.53	3.73	2.84	6.73	60.31
Peridiniopsis	10.96	3.29	0.68	5.92	66.23
Snowella	5.72	2.95	1.85	5.32	71.55
Asterionella	3.46	1.81	1.44	3.26	74.81
Uroglena	5.86	1.7	0.83	3.06	77.87
Dolichospermum	5.82	1.64	1.23	2.96	80.83
Fragilaria	2.79	1.4	2.33	2.53	83.36
Stephanodiscus	1.98	1	1.17	1.8	85.16
Peridinium	1.56	0.86	2.81	1.56	86.72
Dinobryon	1.57	0.75	1.43	1.35	88.07
Oocystis	1.46	0.71	2.35	1.29	89.36
Synura	2.07	0.6	0.78	1.09	90.45

Group Hypolimnion aerotation					
Average similarity: 42.43					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Rhodomonas	14.4	10.99	1.66	25.91	25.91
Cryptomonas	8.81	6.89	1.73	16.23	42.14
Dolichospermum	7.36	4.58	1.75	10.81	52.94
Asterionella	6.16	2.67	0.88	6.3	59.24
Mallomonas	4.46	2.39	0.99	5.64	64.88
Planktothrix	20.44	2.11	1.01	4.98	69.86
Ceratium	2.29	1.37	1.12	3.23	73.09
Tabellaria	11.27	1.37	0.59	3.22	76.31
Gymnodinium	2.09	1.19	0.9	2.8	79.11
Uroglena	2.72	1.02	1.05	2.41	81.51
Aulacoseira	2.09	0.96	1.04	2.25	83.76
Stephanodiscus	1.16	0.73	1.17	1.73	85.49
Fragilaria	1.16	0.51	1.46	1.2	86.69
Woronichinia	0.98	0.47	1.3	1.1	87.79
Pseudopedinella	0.53	0.44	2.23	1.04	88.83
Pediastrum	0.71	0.41	1.34	0.98	89.8
Microcystis	0.75	0.38	1.77	0.9	90.7

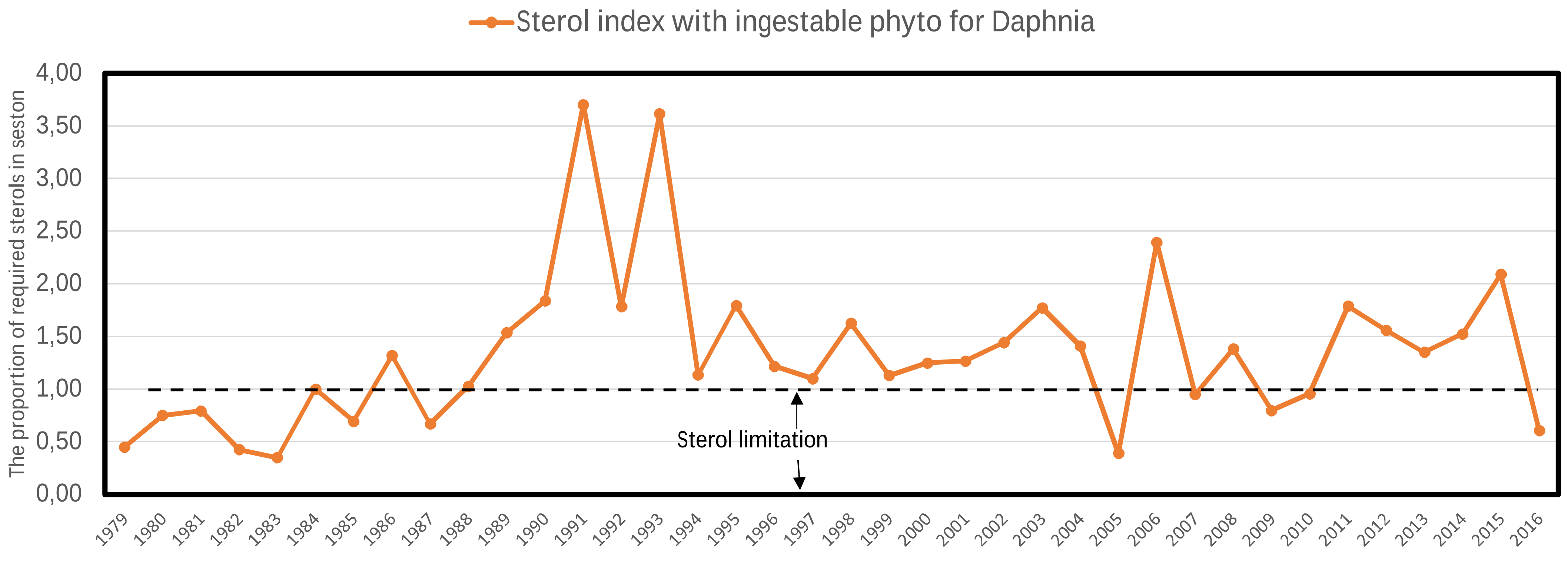
Groups First blooming stage & Clear stage						
Average dissimilarity = 85.86						
	Group First blooming stage	Group Clear stage				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Planktothrix	307	0	27.7	1.08	32.26	32.26
Aphanizomenon	152	0	16.71	0.81	19.46	51.72
Pseudanabaena	153	0	10.45	0.71	12.18	63.89
Dolichospermum	101	5.82	7.91	0.86	9.22	73.11
Peridiniopsis	21	10.96	2.93	0.93	3.41	76.52
Microcystis	20	0.71	2.74	0.69	3.19	79.71
Ceratium	19	5.53	2.61	0.37	3.04	82.76
Cryptomonas	41	19.82	2.53	1.3	2.94	85.7
Tabellaria	2	22.59	2.5	1.31	2.91	88.61
Woronichinia	8	0.63	1.09	0.58	1.27	89.87
Aulacoseira	7	0.69	0.85	0.74	0.99	90.87

Groups Biomanipulation & Clear stage						
Average dissimilarity = 64.76						
	Group Biomanipulation	Group Clear stage				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Aphanizomenon	45.9	0	7.81	0.5	12.05	12.05
Dolichospermum	31.96	5.82	6.97	1.35	10.76	22.81
Cryptomonas	40.58	19.82	6.58	1.13	10.16	32.98
Peridiniopsis	24.71	10.96	6.48	0.74	10.01	42.99
Microcystis	28.71	0.71	5.98	1.3	9.23	52.22
Tabellaria	13.38	22.59	3.72	1.18	5.74	57.96
Aulacoseira	8.64	0.69	2.55	0.52	3.94	61.9
Synura	6.91	2.07	2.3	0.61	3.55	65.45
Peridinium	6.86	1.56	1.76	0.54	2.72	68.17
Rhodomonas	7.63	11.03	1.73	1.24	2.67	70.84
Uroglena	7.4	5.86	1.72	1.24	2.66	73.5
Woronichinia	7.03	0.63	1.53	0.84	2.37	75.87
Ceratium	9.2	5.53	1.34	0.8	2.08	77.95
Mallomonas	3	7.69	1.27	1.45	1.95	79.9
Fragilaria	7.49	2.79	1.18	1.77	1.82	81.72

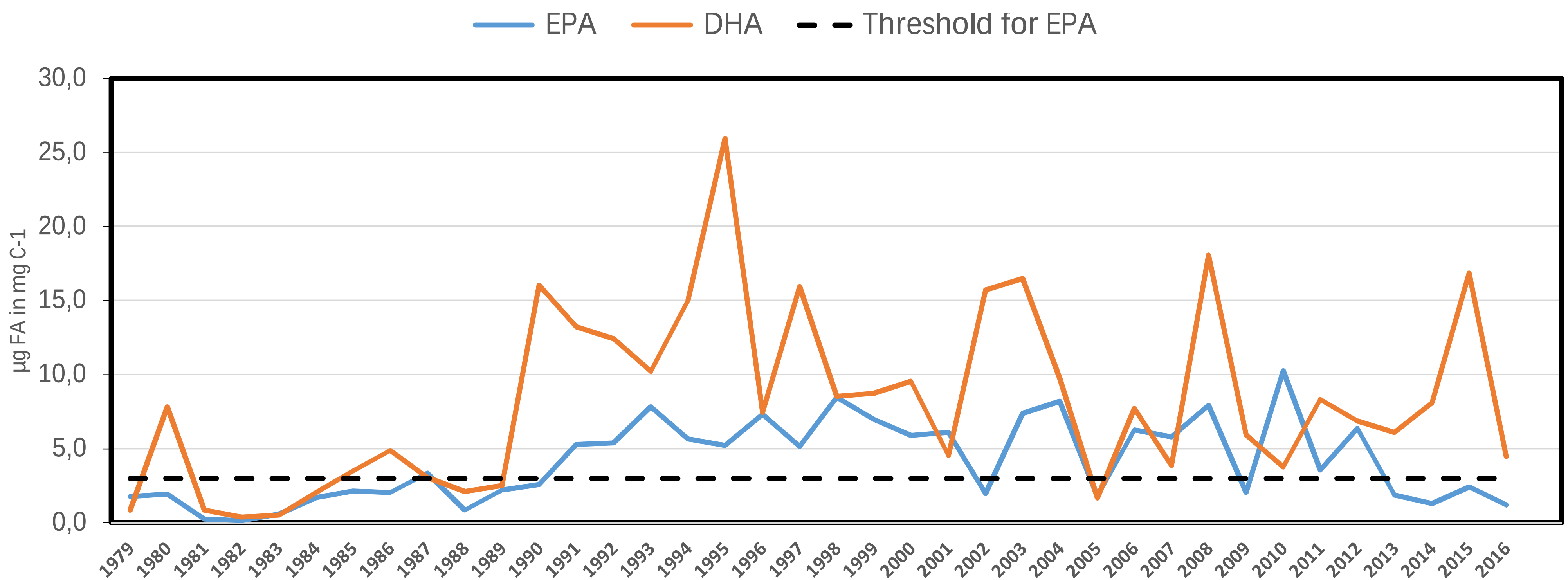
Groups Clear stage & Hypolimnion aerotation						
Average dissimilarity = 59.55						
	Group Clear stage	Group Hypolimnion aerotation				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Tabellaria	22.59	11.27	9.98	1.51	16.77	16.77
Planktothrix	0	20.44	7.21	0.52	12.11	28.87
Cryptomonas	19.82	8.81	5.44	1.32	9.13	38
Peridiniopsis	10.96	0	4.7	1.13	7.89	45.9
Rhodomonas	11.03	14.4	3.88	1.23	6.51	52.4
Dolichospermum	5.82	7.36	2.87	1.17	4.82	57.23
Uroglena	5.86	2.72	2.47	0.97	4.16	61.38
Snowella	5.72	0.61	2.41	1.39	4.04	65.43
Mallomonas	7.69	4.46	2.26	1.47	3.8	69.23
Asterionella	3.46	6.16	2.21	1.27	3.71	72.94
Ceratium	5.53	2.29	1.57	1.58	2.63	75.57
Fragilaria	2.79	1.16	0.94	1.24	1.58	77.15
Synura	2.07	0.49	0.91	0.99	1.53	78.68
Eudorina	1.89	0.99	0.82	1.08	1.38	80.05
Sphaerocystis	1.45	0	0.78	0.53	1.31	81.36
Aulacoseira	0.69	2.09	0.74	1.42	1.24	82.6
Gymnodinium	1.13	2.09	0.72	1.69	1.21	83.81
Stephanodiscus	1.98	1.16	0.64	1.3	1.08	84.89
Aphanizomenon	0	1.49	0.61	0.77	1.03	85.91
Dinobryon	1.57	0.57	0.57	1.07	0.95	86.87
Peridinium	1.56	0.63	0.52	1.38	0.87	87.74
Oocystis	1.46	0.36	0.5	1.29	0.83	88.57
Trachelomonas	1	0.31	0.4	1.15	0.68	89.24
Woronichinia	0.63	0.98	0.38	1	0.64	89.88
Dictyosphaerium	0.56	0.39	0.35	0.82	0.59	90.47

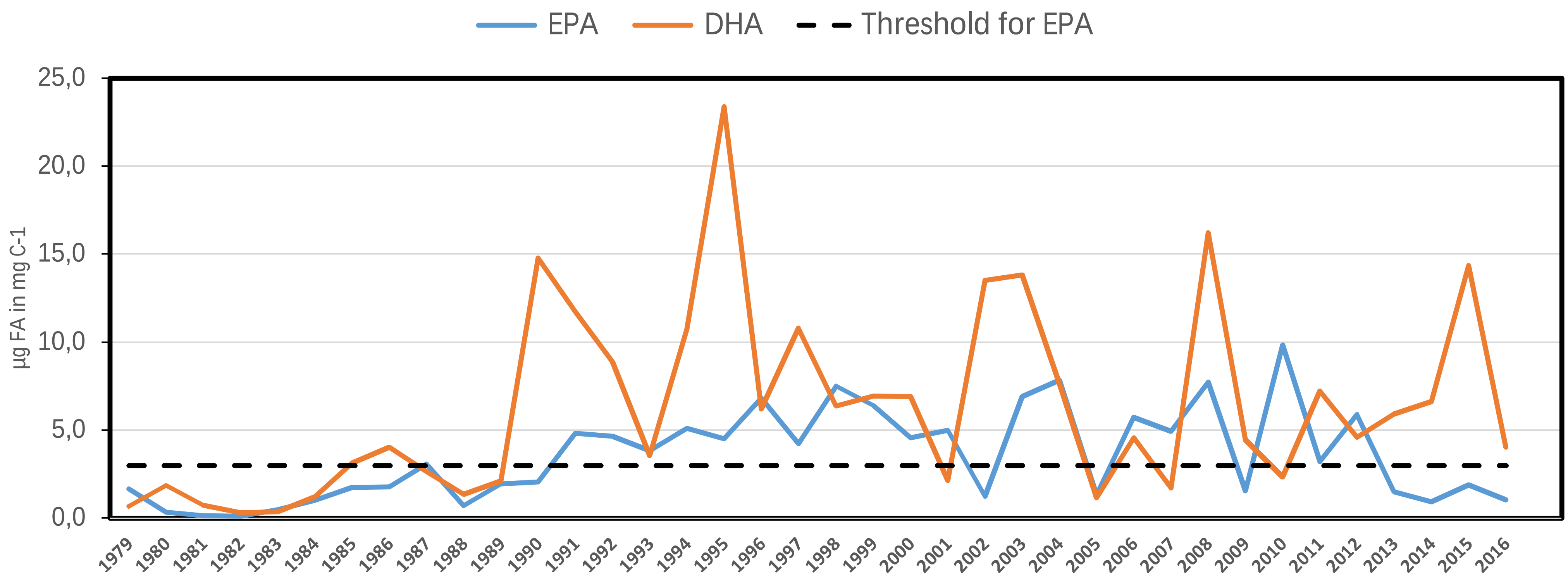


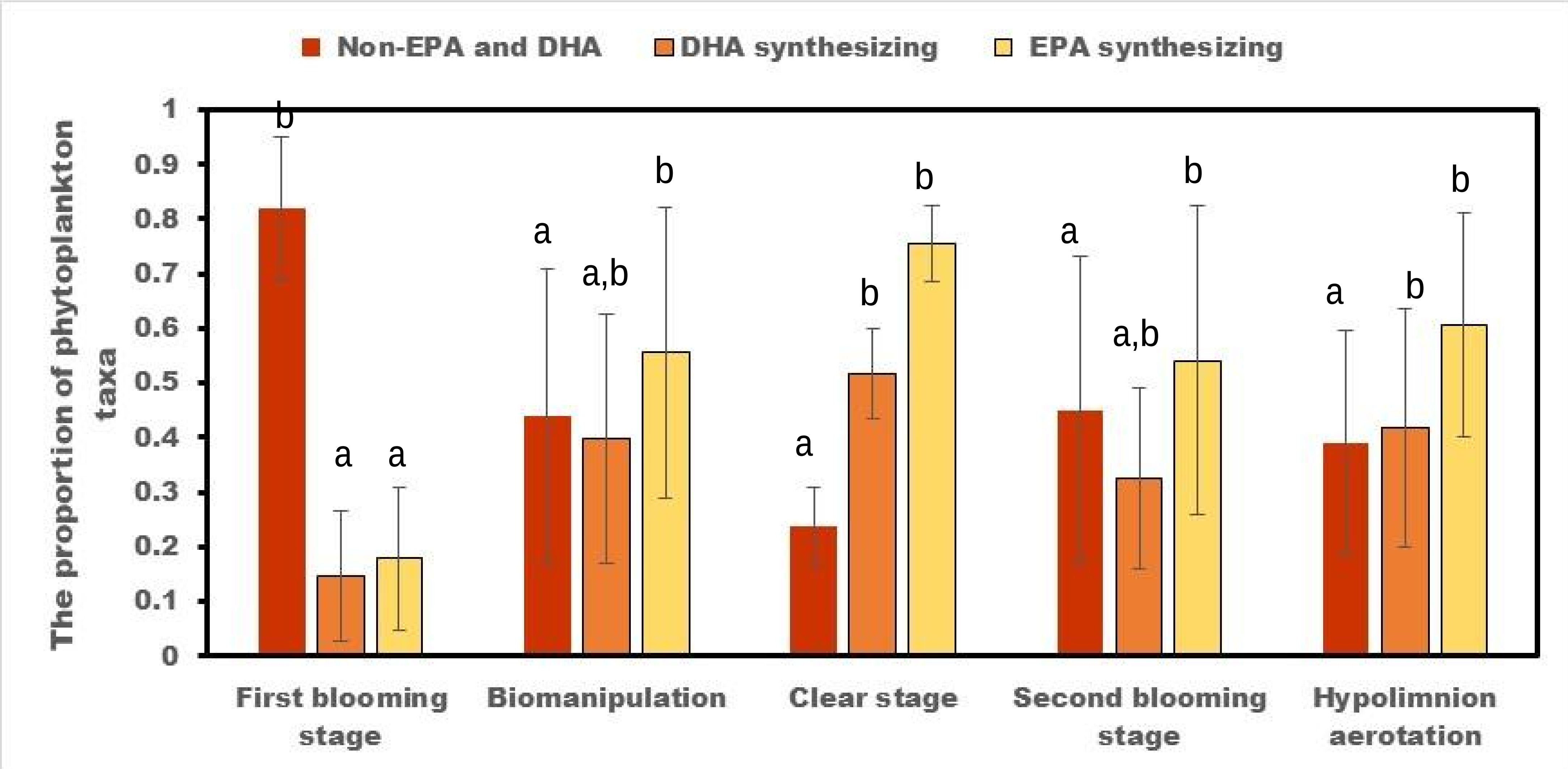
Sterol index with all phyto
The proportion of required sterols in seston
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Sterol limitation
1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016



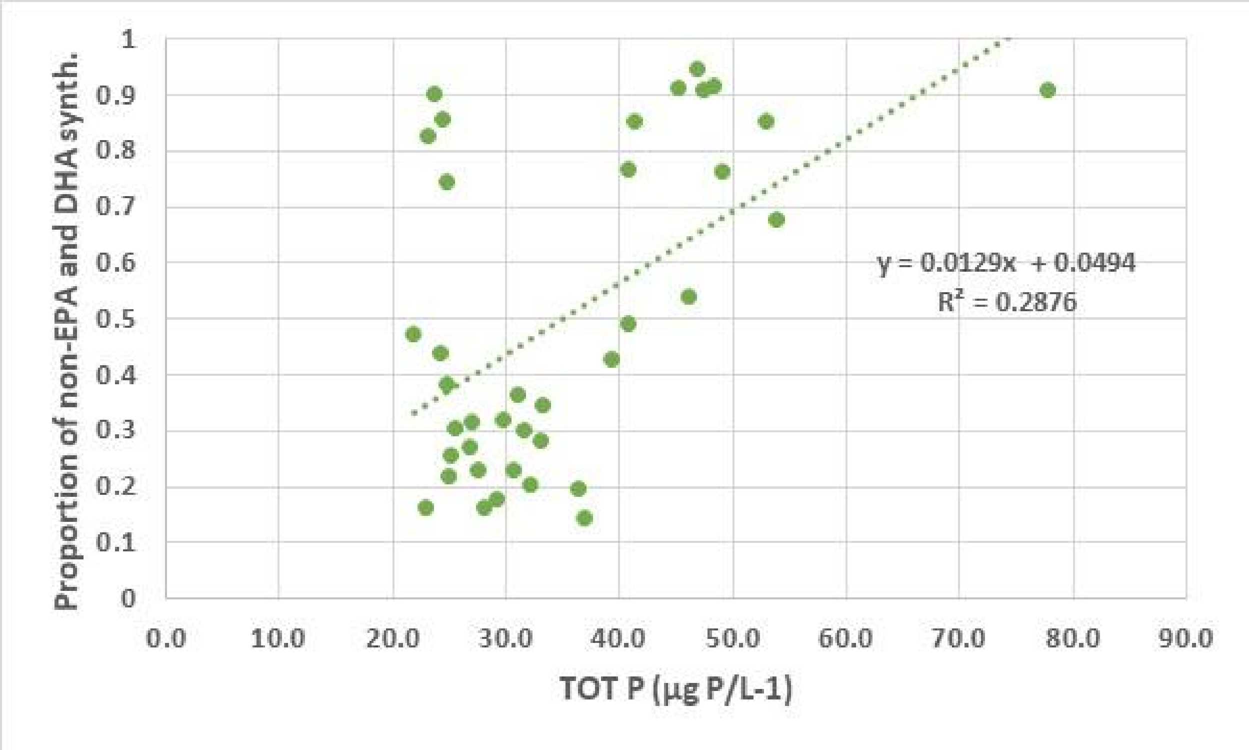
Sterol index with ingestable phyto for Daphnia
The proportion of required sterols in seston
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Sterol limitation
1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016


EPA
DHA
Threshold for EPA
µg FA in mg C-1
30,0
25,0
20,0
15,0
10,0
5,0
0,0
1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

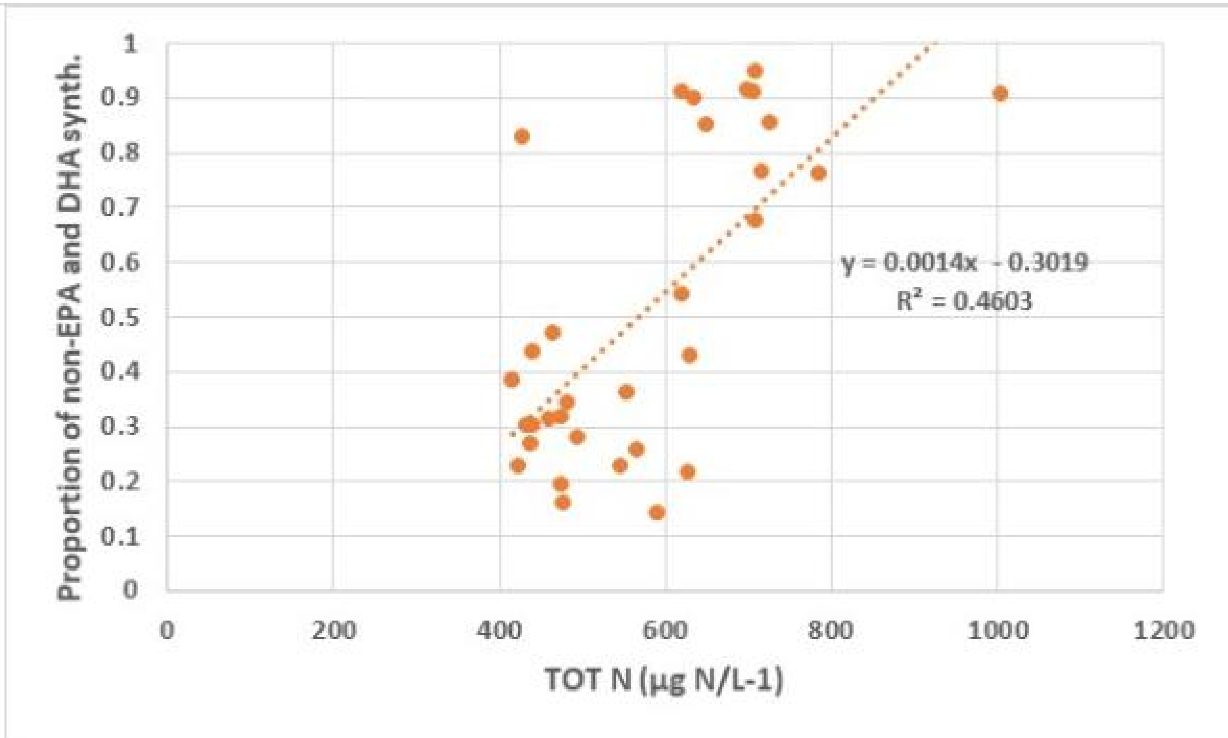

EPA
DHA
Threshold for EPA
µg FA in mg C-1
25,0
20,0
15,0
10,0
5,0
0,0
1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016



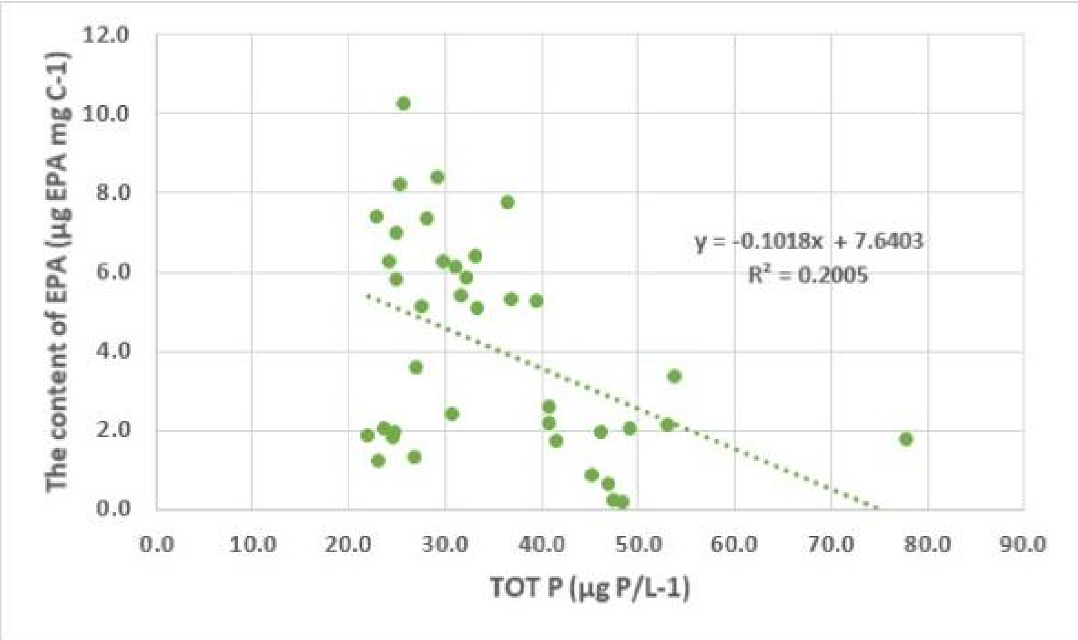
Non-EPA and DHA
DHA synthesizing
EPA synthesizing
The proportion of phytoplankton taxa
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
b
a
a
a
a,b
b
a
b
b
a
a,b
b
a
b
b
First blooming stage
Biomanipulation
Clear stage
Second blooming stage
Hypolimnion aerotation

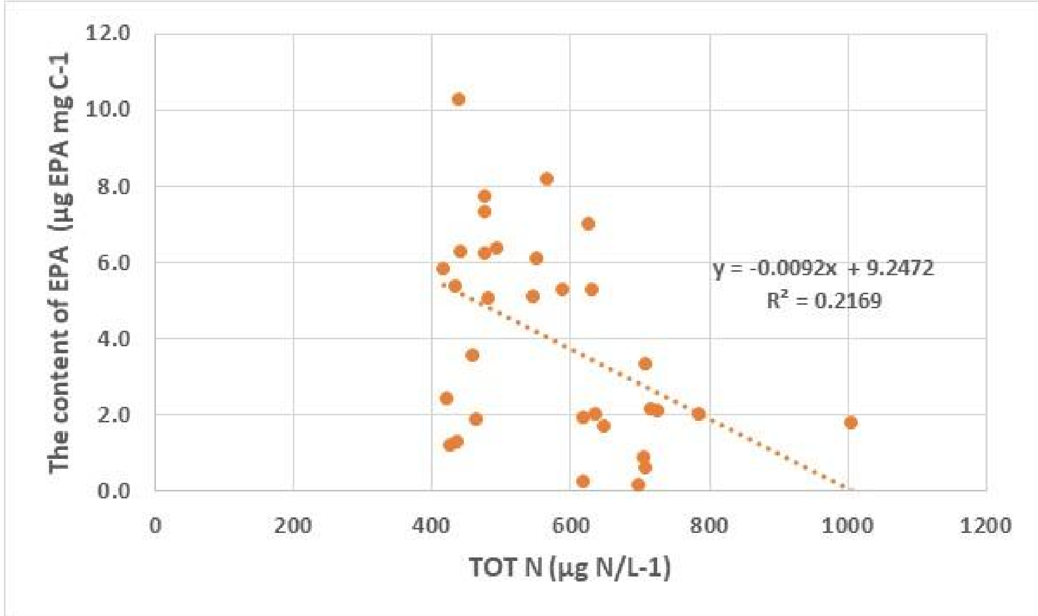


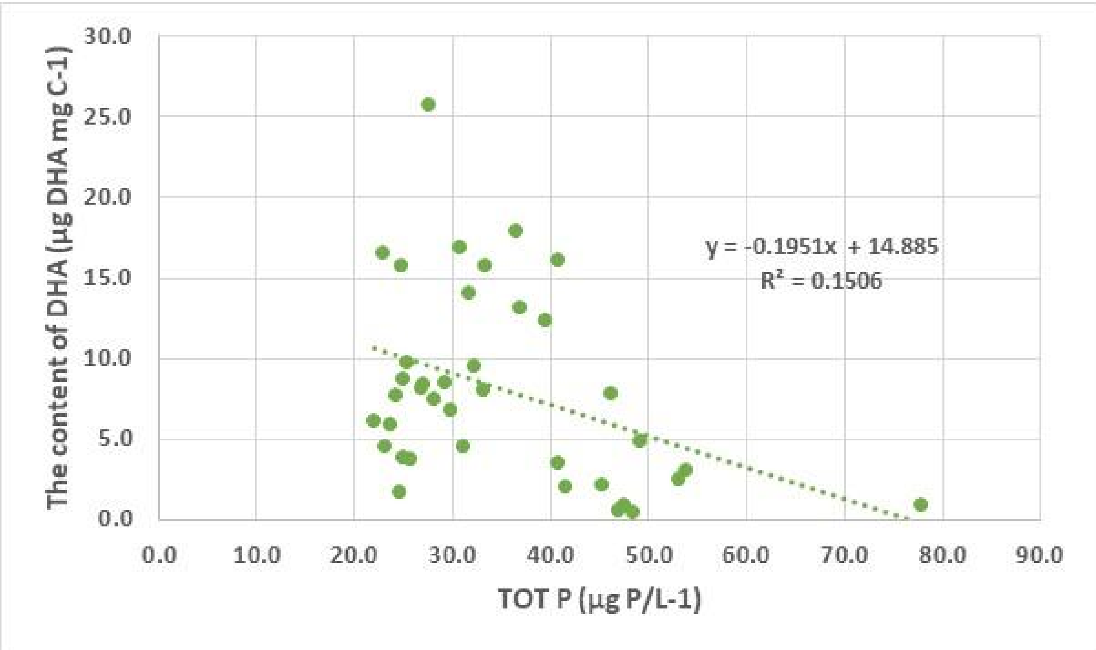
Proportion of non-EPA and DHA synth.
TOT P (µg P/L-1)
y = 0.0129x + 0.0494
R² = 0.2876

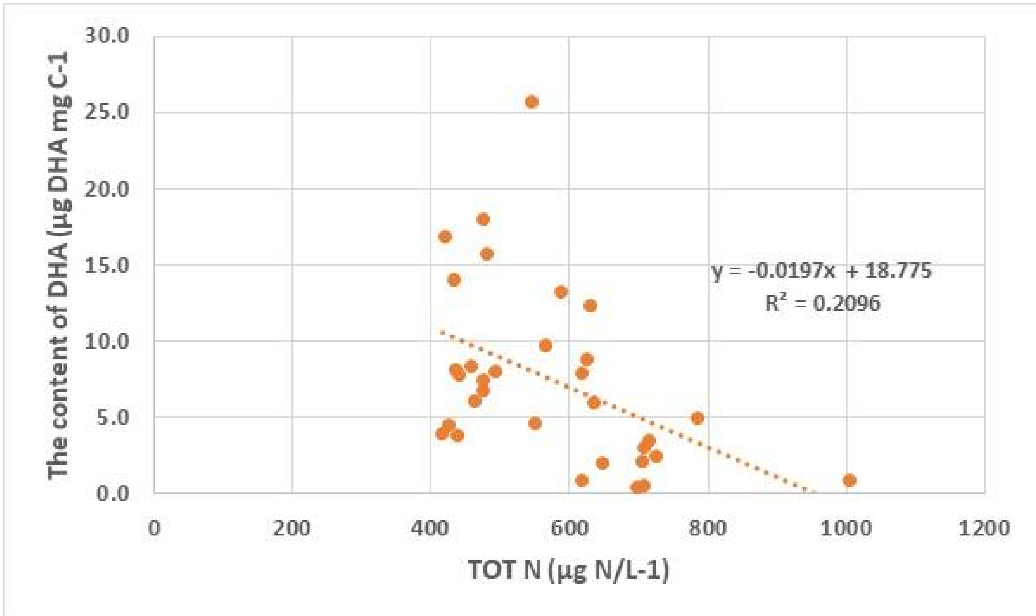


Proportion of non-EPA and DHA synth.
TOT N (µg N/L-1)
y = 0.0014x - 0.3019
R² = 0.4603


y = -0.1018x + 7.6403
R² = 0.2005
The content of EPA (µg EPA mg C-1)
TOT P (µg P/L-1)

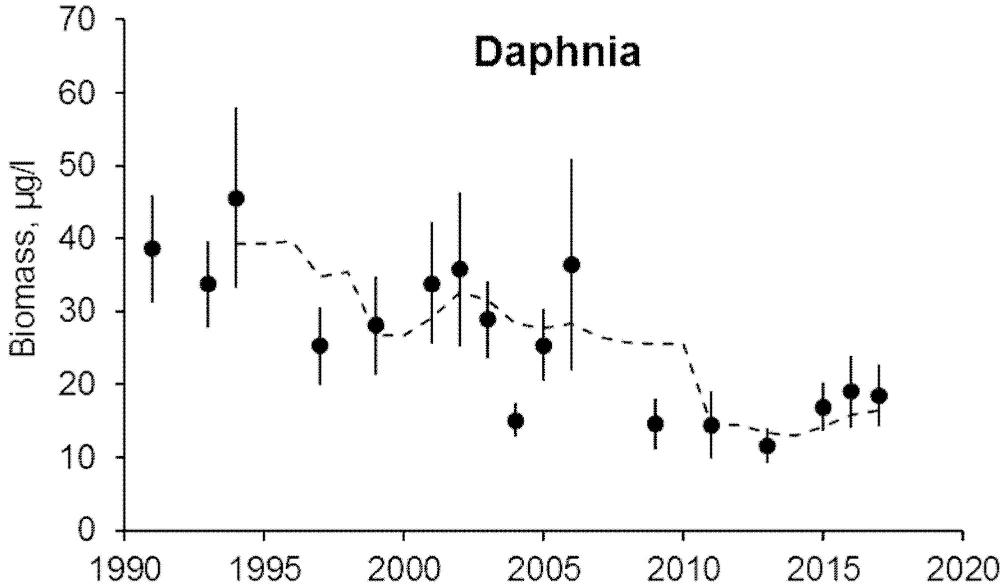

y = -0.0092x + 9.2472
R² = 0.2169
The content of EPA (µg EPA mg C-1
TOT N (µg N/L-1)

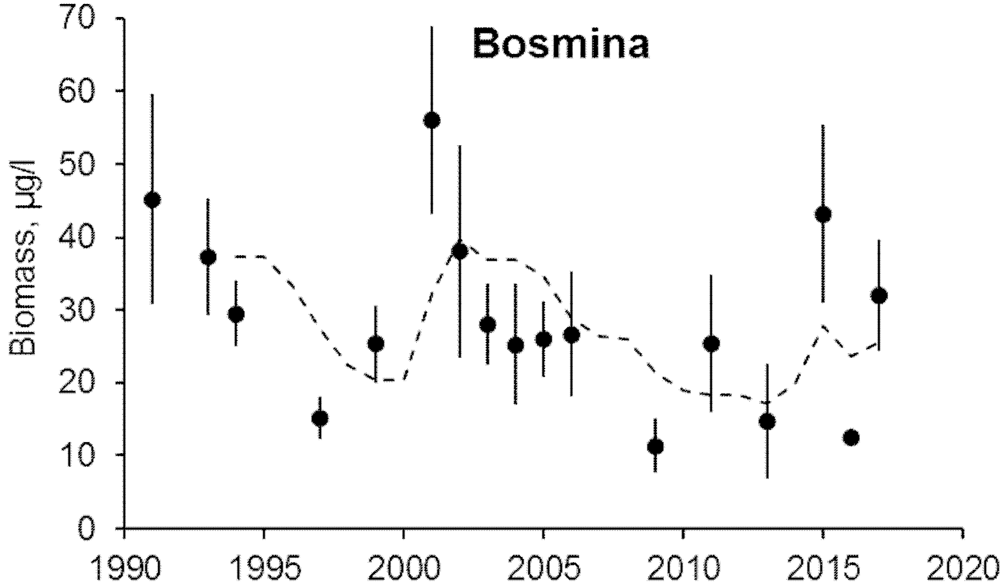

y = -0.1951x + 14.885
R² = 0.1506
The content of DHA (µg DHA mg C-1)
TOT P (µg P/L-1)


y = -0.0197x + 18.775
R² = 0.2096
The content of DHA (µg DHA mg C-1
TOT N (µg N/L-1)

CLADOCERA

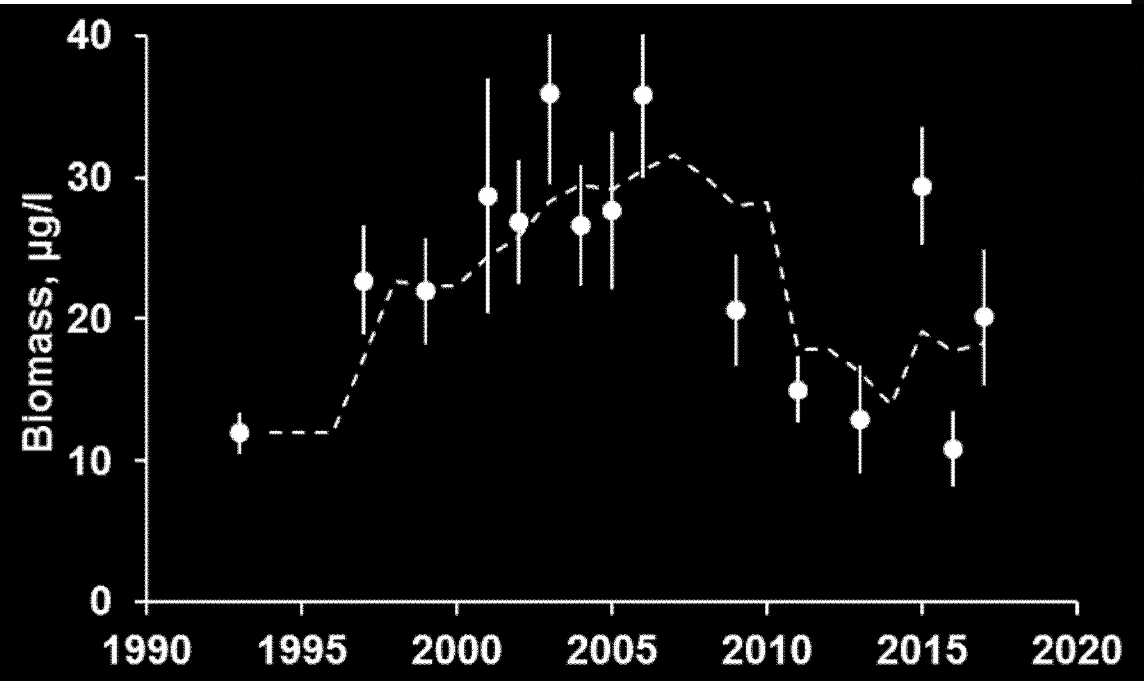
June-August average (±SE) biomass with 5-year moving average

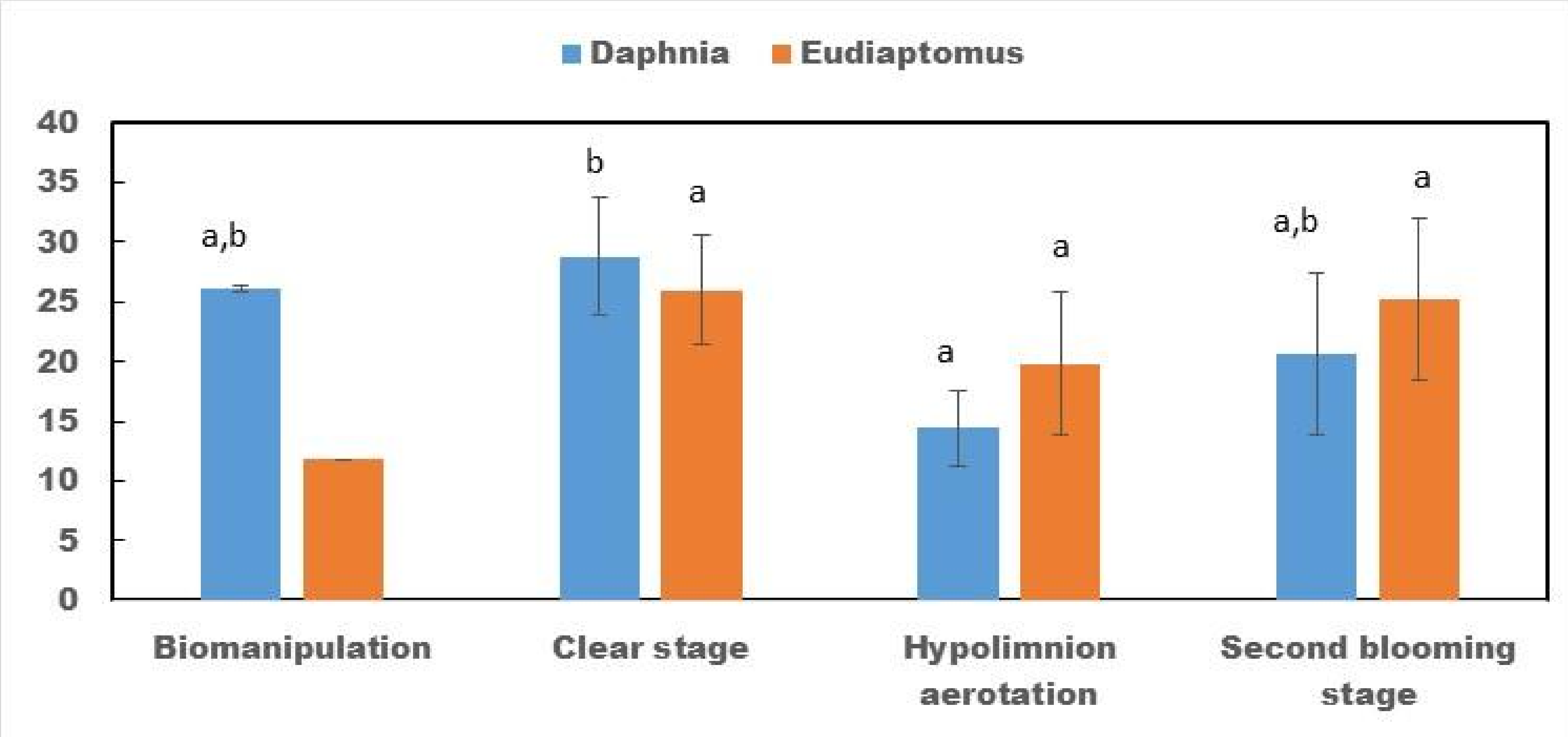




EUDIAPTOMUS

June-August average (±SE) biomass with 5-year moving average




Daphnia
Eudiaptomus
40
35
30
25
20
15
10
5
0
a,b
b
a
a
a
a,b
a
Biomanipulation
Clear stage
Hypolimnion aerotation
Second blooming stage

CONCLUSIONS

- AFTER BIOMANIPULATION (CLEAR STAGE) PHYTOPLANKTON COMMUNITY WAS STABLE AND CHARACTERIZISED BY OLIGOTROPHIC SPESIES
- DURING HYPOLIMNETIC AEROTATION PHYTOPLANKTON COMMUNITY DIFFERED FROM ANY PREVIOUS STAGE HAVING DIVERSE AFFECT ON PHYTOPLANKTON COMMUNITY: CYANOBACTERIA AND RHODOMONAS INCREASED
- THE PROPORTION OF NON-EPA AND NON-DHA SYNTHESIZING PHYTOPLANKTON TAXA WERE MOST ABUNDANT ON FIRST BLOOMING STAGE AND LOWEST IN CLEAR-STAGE.
- THE PROPORTION OF EPA AND DHA -SYNTHESIZING PHYTOPLANKTON TAXA WERE LOWEST IN FIRST BLOOMING STAGE AND MOST ABUNDANT IN CLEAR-STAGE, HOWEVER, THERE WAS NOT STATISTICAL DIFFERENCE BETWEEN CLEAR-STAGE, SECOND BLOOMING STAGE AND HYPOLIMNETIC AEROTATION.
- BIOMASS OF DAPHNIA WAS HIGHEST IN CLEAR STAGE AND LOWEST DURING HYPOLIMNETIC AEROTATION, BUT BIOMASS OF EUDIAPTOMUS DID NOT DIFFER BETWEEN STAGES.