What Does a Stream Ecologist Need to Know About Fatty Acids?

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Saturated Fatty Acids (SAFAs); e.g. Stearic acid (18:0)

Monounsaturated Fatty Acids (MUFAs); Oleic acid (18:1ω9)

Poly Unsaturated Fatty Acids (PUFAs)

ω6 family

Linoleic acid (LA; 18:2ω6)

γ-Linolenic acid (γ-LA; 18:3ω6)

Arachidonic acid (ARA; 20:4ω6)

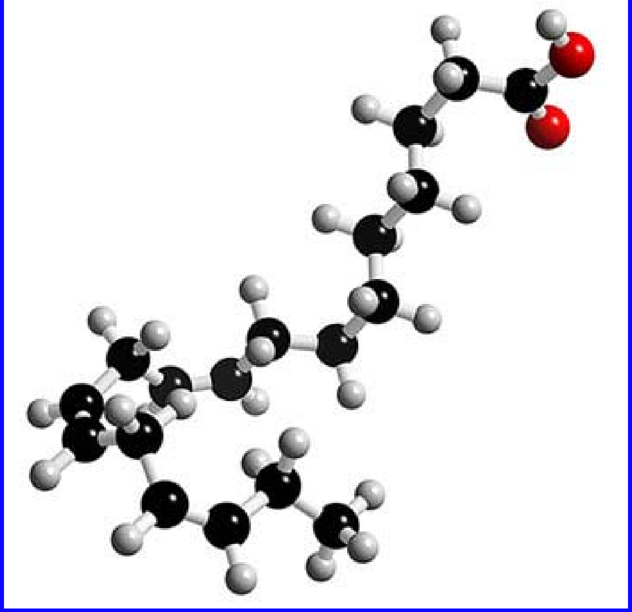
ω3 family

α-Linolenic acid (α-LA; 18:3ω3)

Stearidonic acid (SDA; 18:4ω3)

Eicosapentaenoic acid (EPA; 20:5ω3)

Docosahexaenoic acid (DHA; 22:6ω3)



"Essential Fatty Acids" (EFAs)

The ω6 and ω3 families

Highly unsaturated fatty acids (HUFAs)

ARA, EPA and DHA

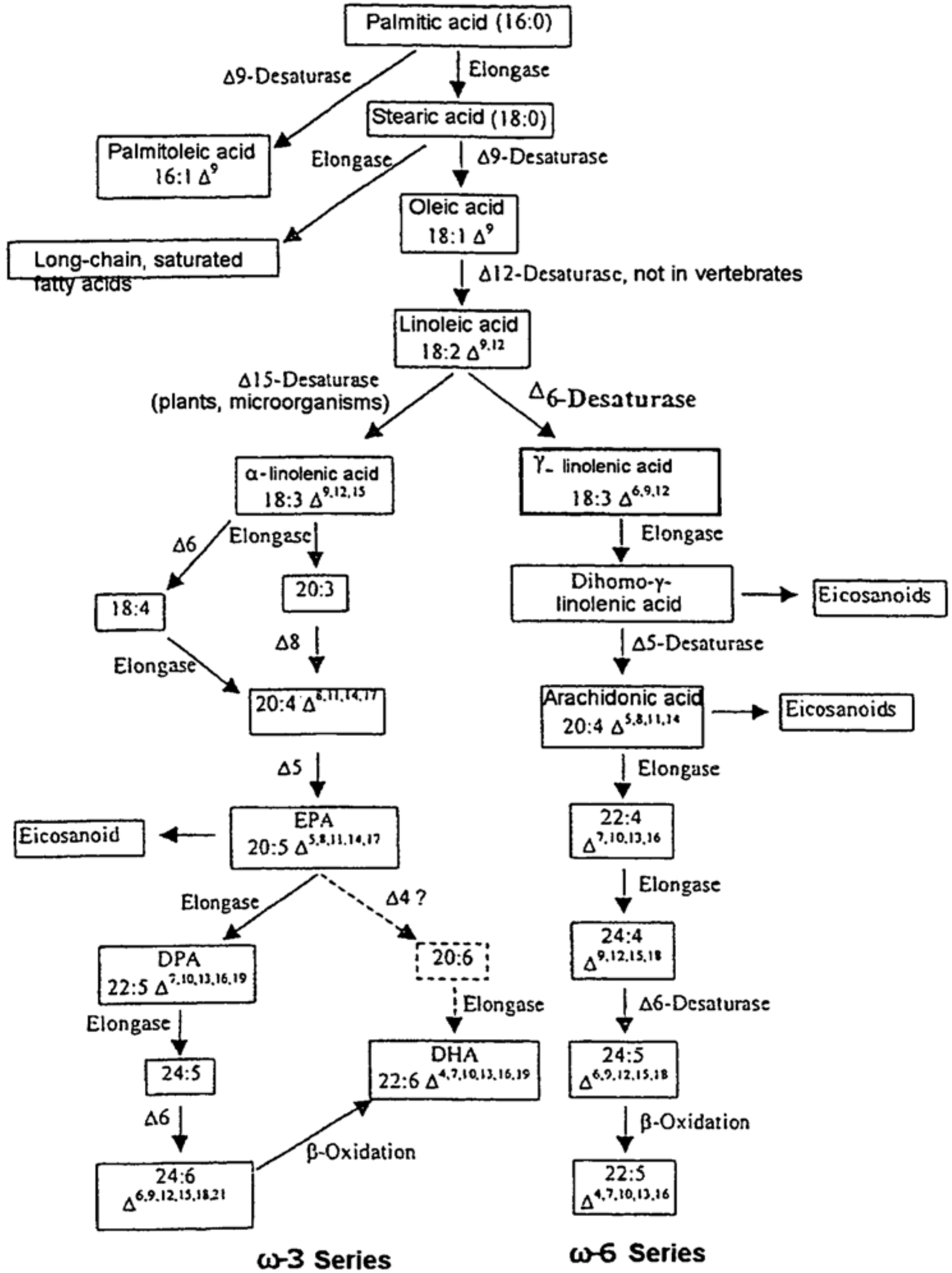
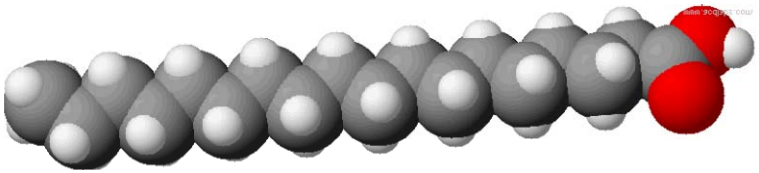
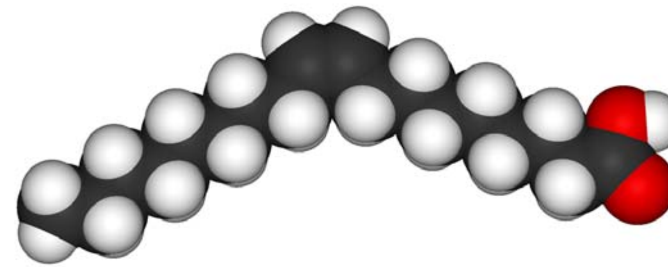


Figure 1 General pathway of PUFA biosynthesis in eukaryotes

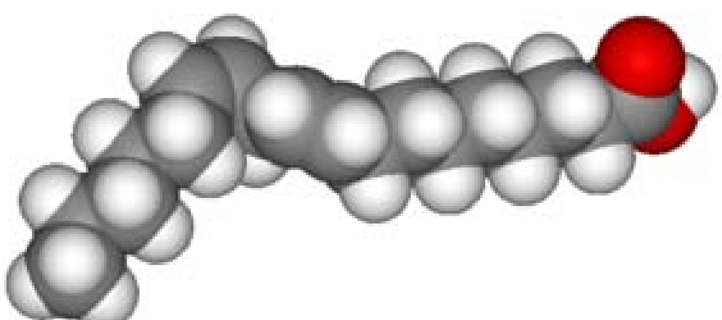
Stearic acid (18:0)
melting point = 70 °C



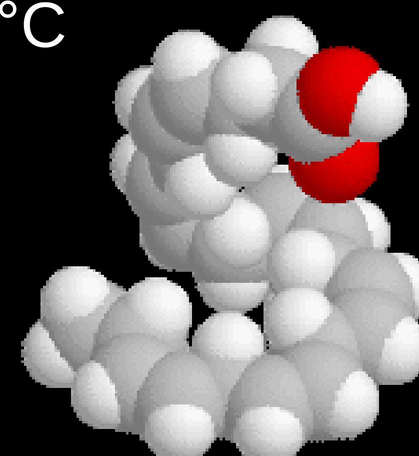
Oleic acid (18:1ω9)
melting point = 14 °C



α-linolenic acid (18:3ω3)
melting point = -11 °C



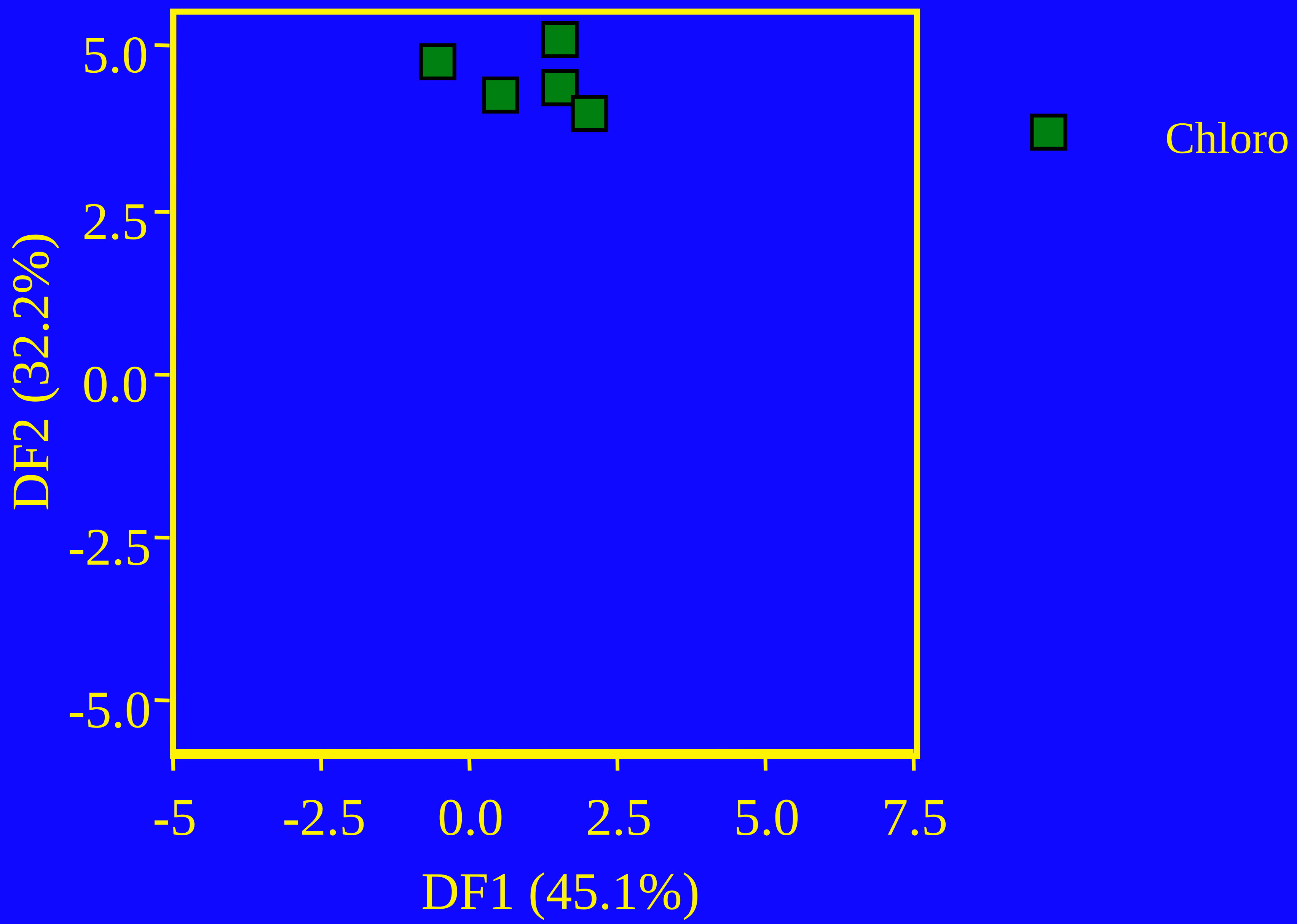
DHA (22:6ω3)
MP = -45 °C



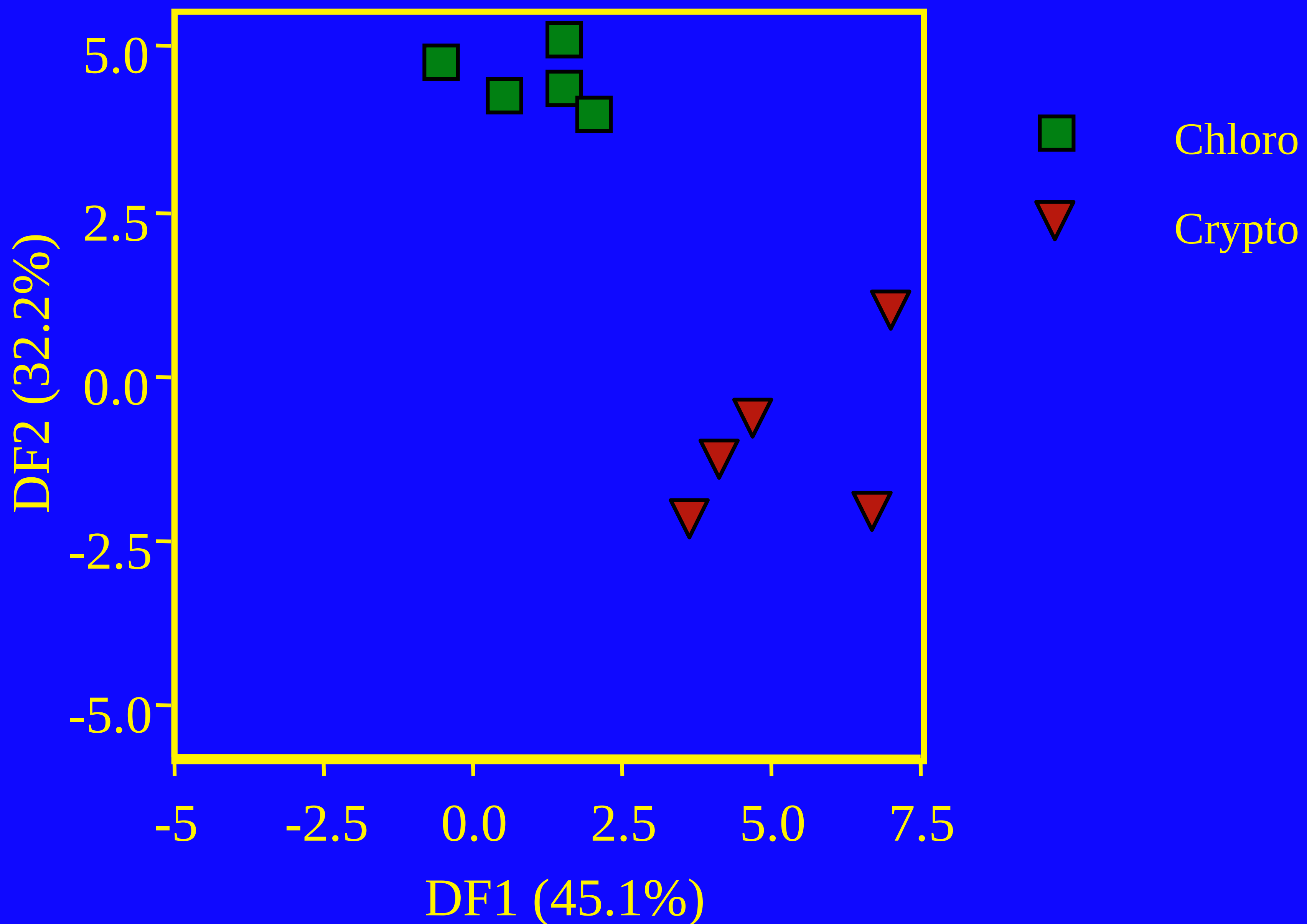
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

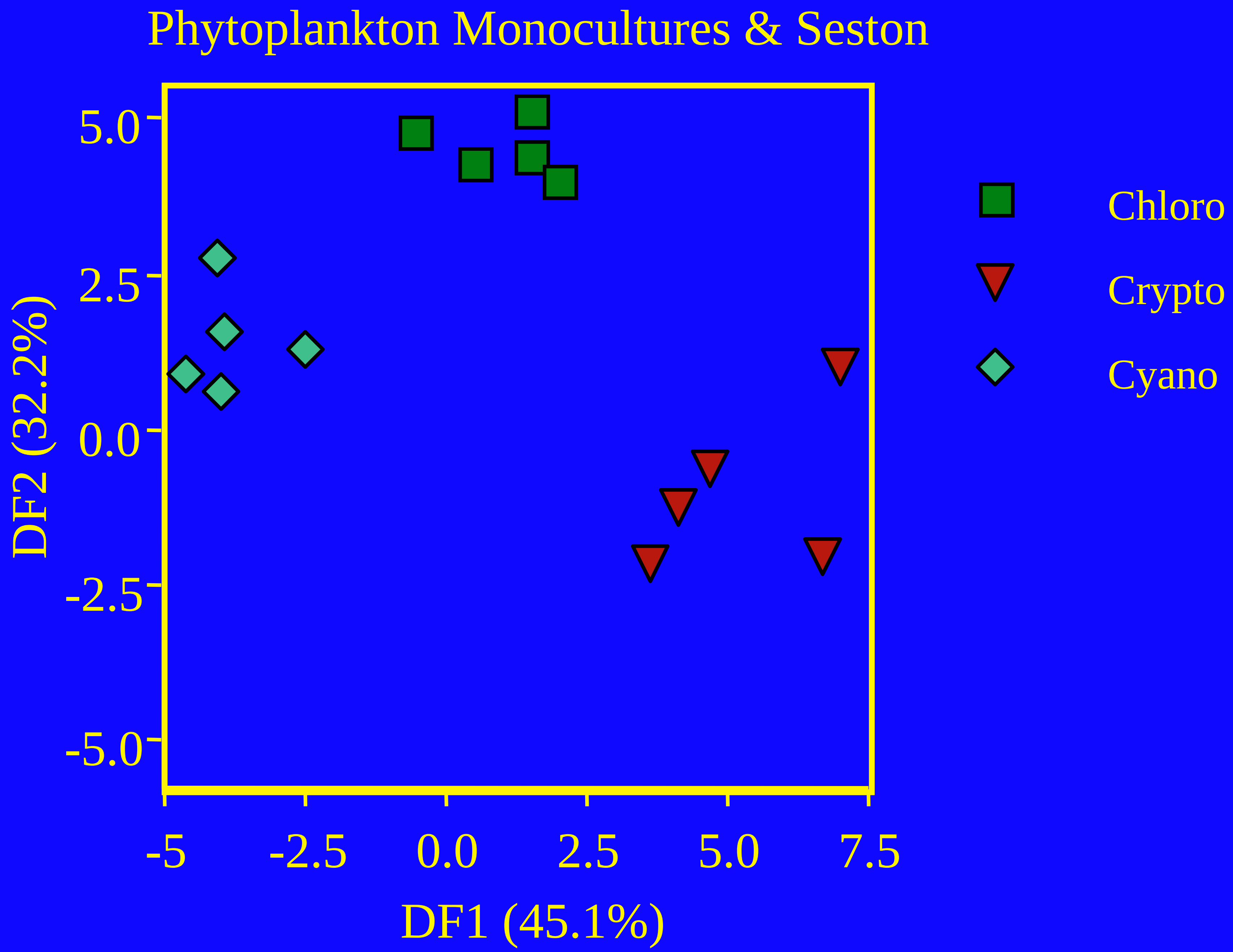
Group	n	SAFA	MUFA	16 PUFA	18 n-6	18 n-3	20 n-6	20 n-3	22 n-3	n-3:n-6
Cyanophytes	9	58.6 ± 18.5	24.8 ± 16.6	0.0 ± 0.0	7.2 ± 6.5	7.0 ± 10.2	1.0 ± 2.4	0.6 ± 1.2	0.7 ± 2.1	1.0 ± 1.0
Chlorophytes	11	32.5 ± 9.5	27.3 ± 12.5	0.0 ± 0.0	14.4 ± 5.6	25.5 ± 9.7	0.2 ± 0.3	0.1 ± 0.2	0.0 ± 0.0	1.9 ± 0.9
Cryptophytes	9	28.4 ± 9.8	9.9 ± 5.1	0.1 ± 0.4	3.3 ± 2.4	39.7 ± 10.4	0.1 ± 0.2	15.1 ± 6.1	2.9 ± 1.8	16.8 ± 8.2
Bacillariophytes	6	23.8 ± 11.0	40.3 ± 12.8	9.1 ± 5.8	2.0 ± 1.8	2.9 ± 3.1	2.3 ± 1.7	16.9 ± 8.2	2.5 ± 3.0	7.6 ± 4.8

Phytoplankton Monocultures & Seston

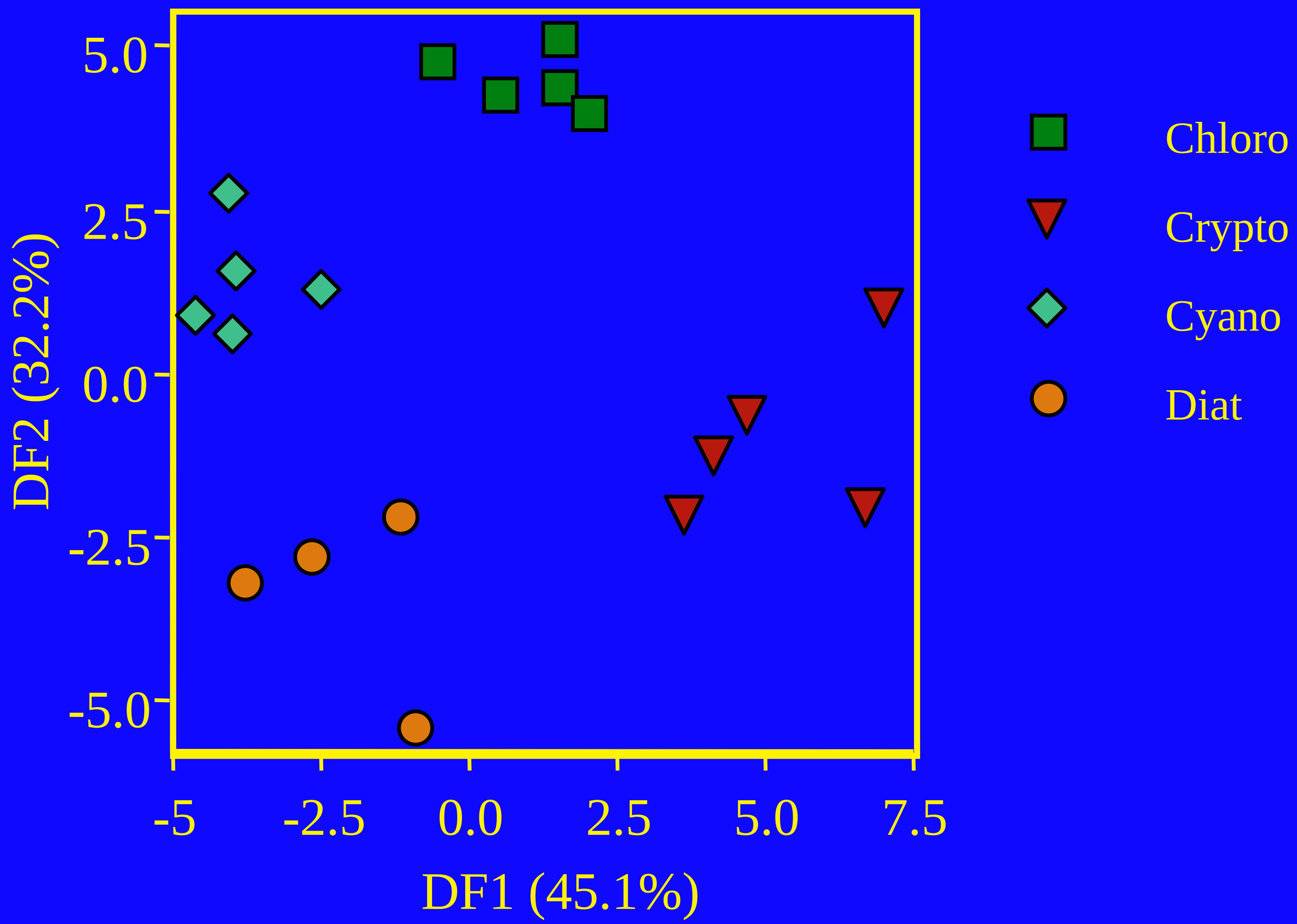


Phytoplankton Monocultures & Seston

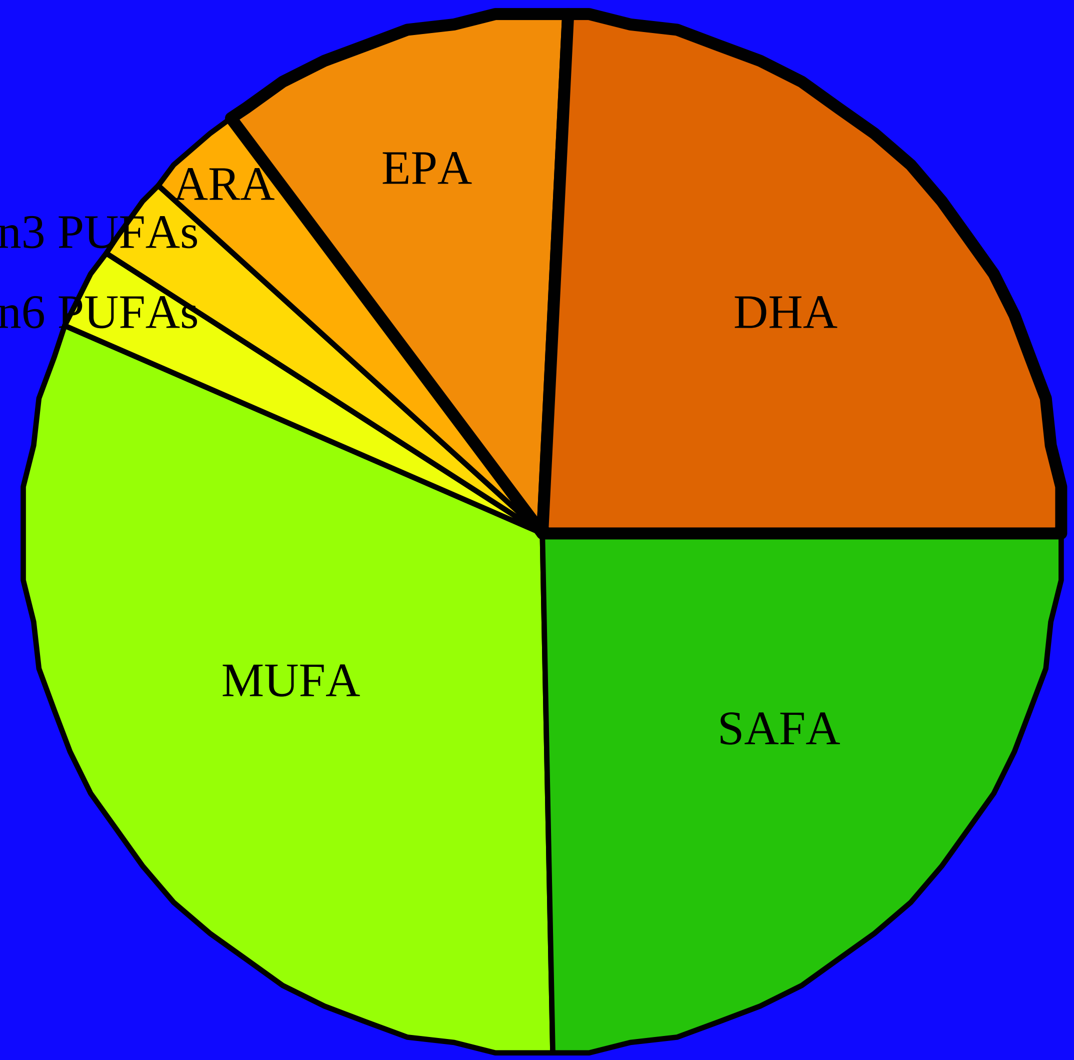


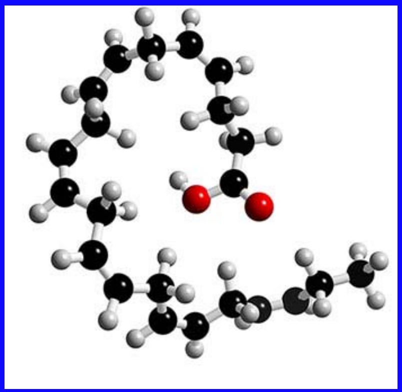

Phytoplankton Monocultures & Seston
DF2 (32.2%)
5.0
2.5
0.0
-2.5
-5.0
-5
-2.5
0.0
2.5
5.0
7.5
DF1 (45.1%)
Chloro
Crypto
Cyano

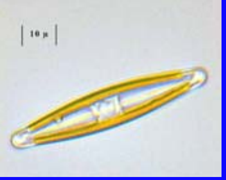
Phytoplankton Monocultures & Seston



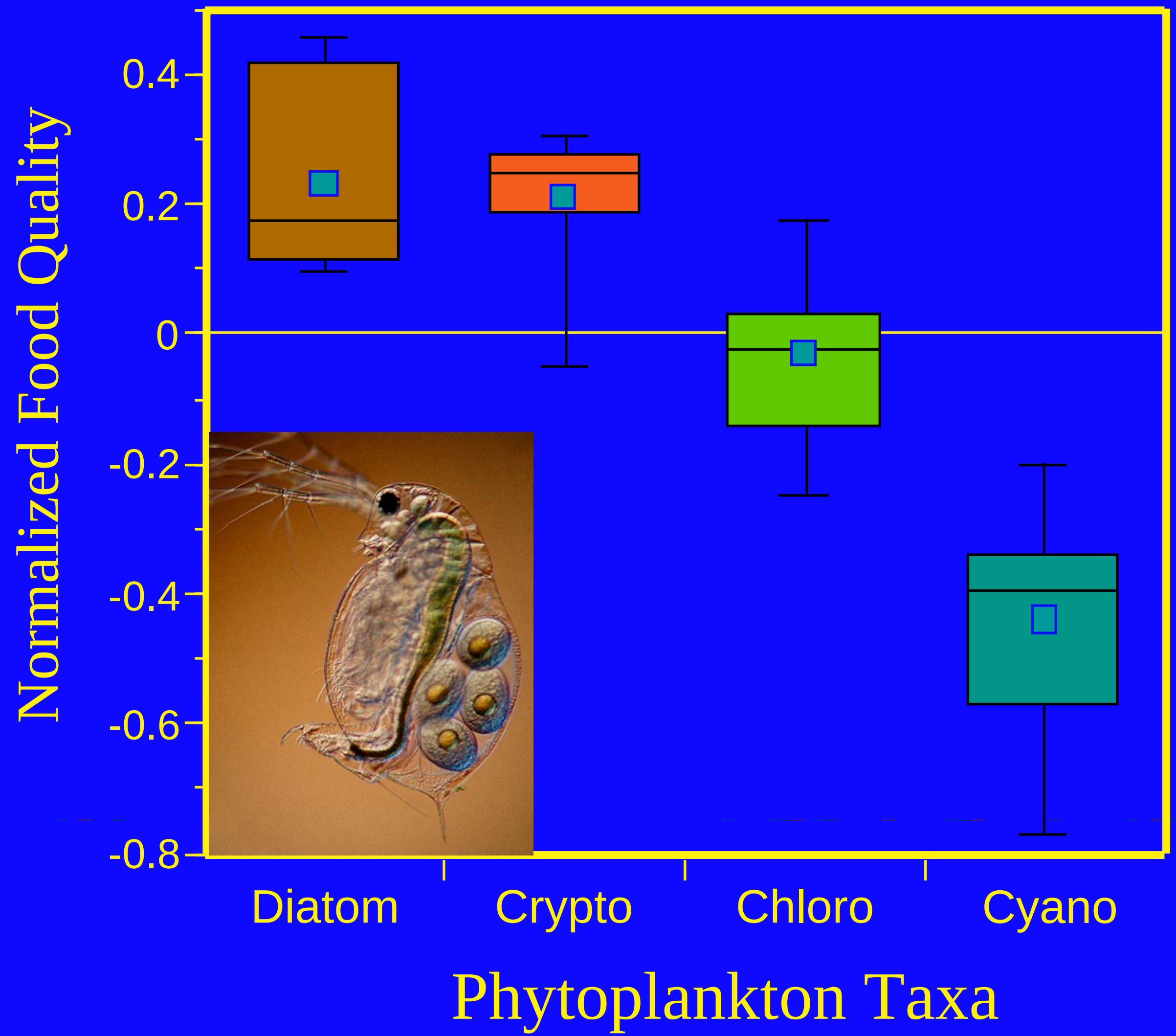
“the gold standard: the ideal diet for fish larvae is the yolk of eggs or yolk sac larvae”; Sargent et al. 1999; Aquaculture 179: 217-





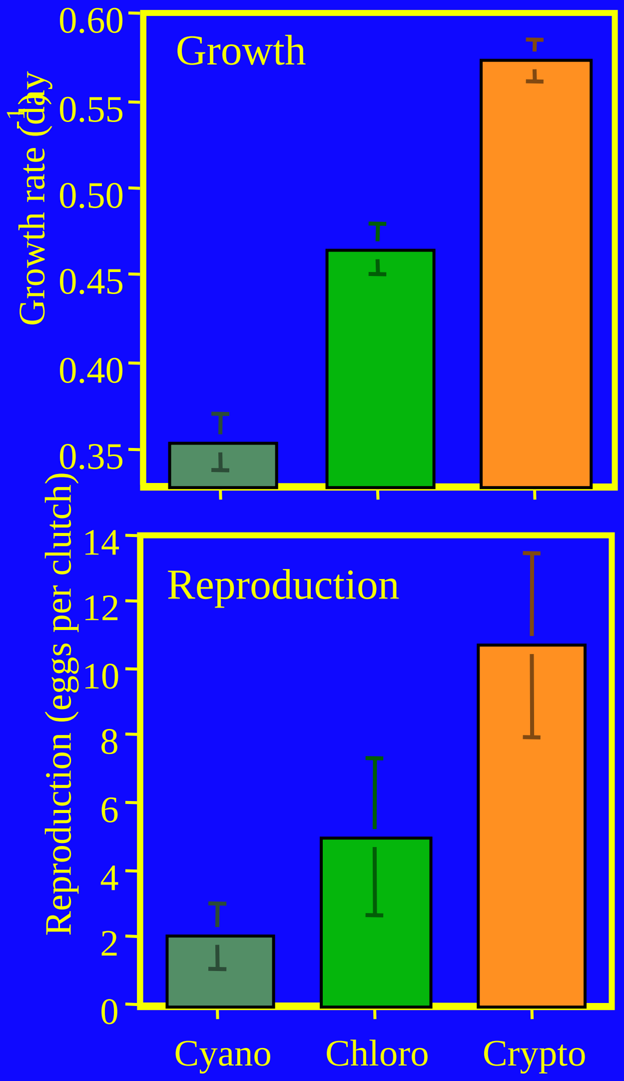


Normalized food quality by algae taxa



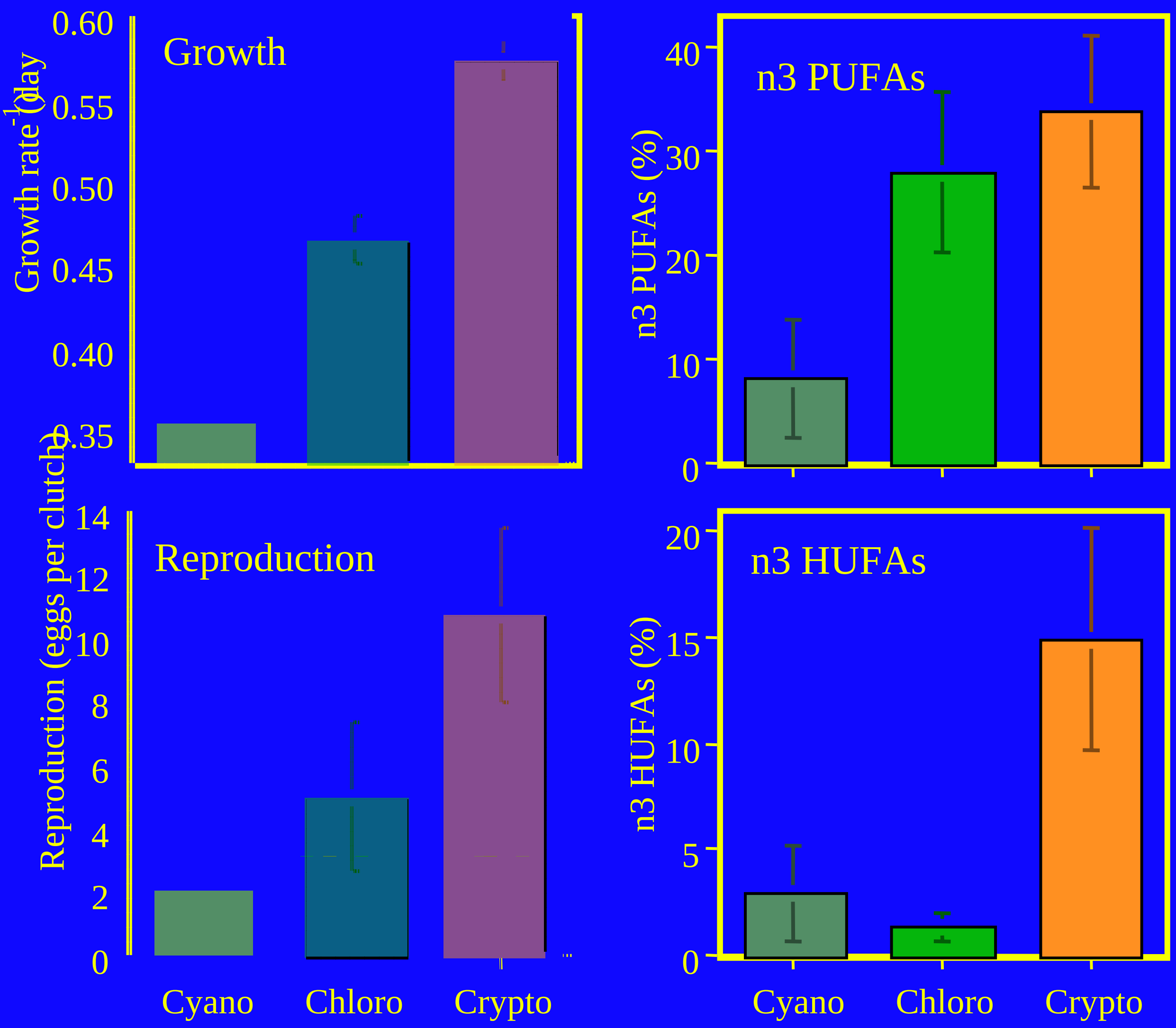
L&O 47: 1564-

Daphnia growth and biochemical composition responses to different food types



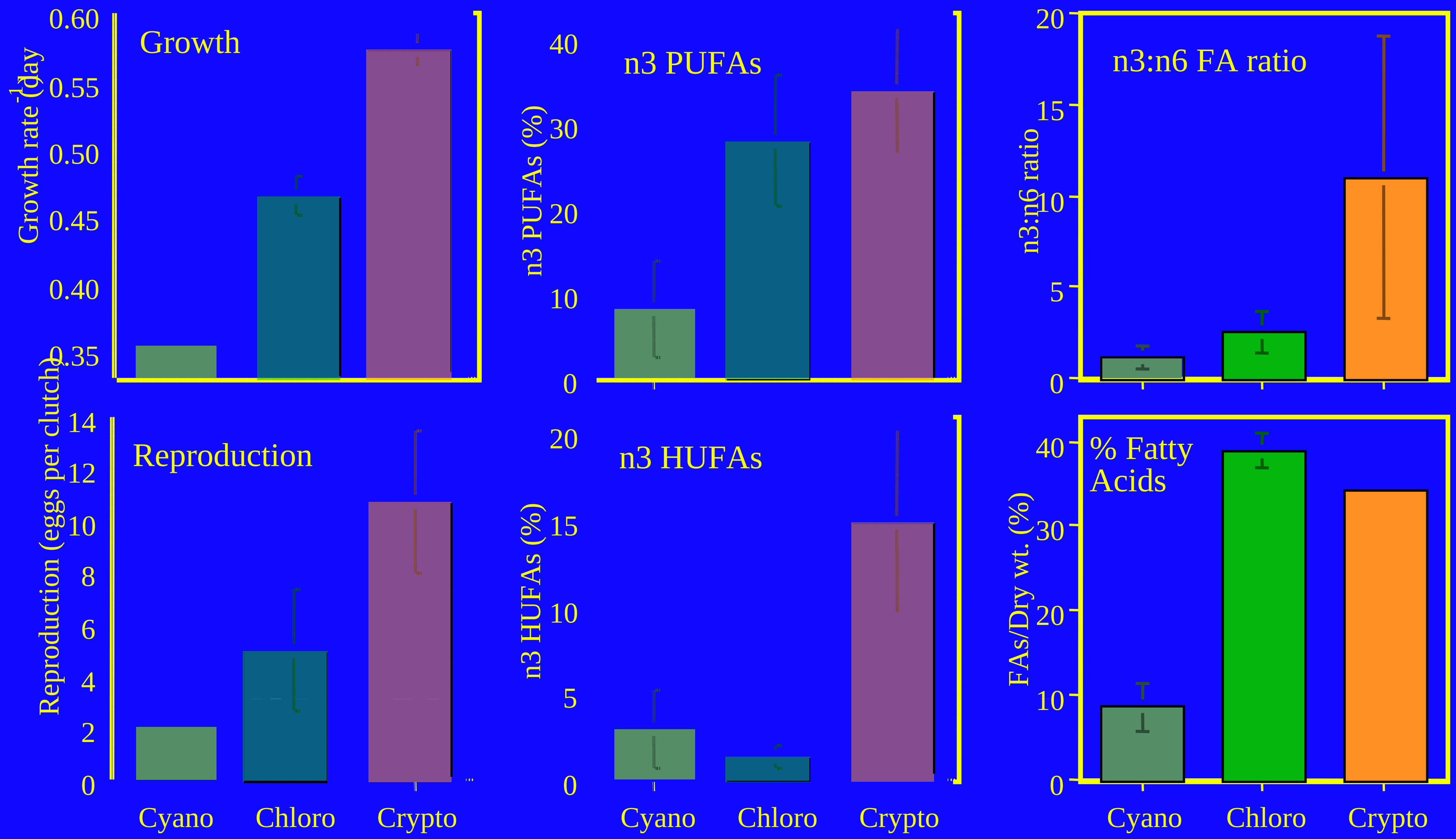
L&O 51: 2428-, Burns et al. ASLO 2006

Daphnia growth and biochemical composition responses to different food types



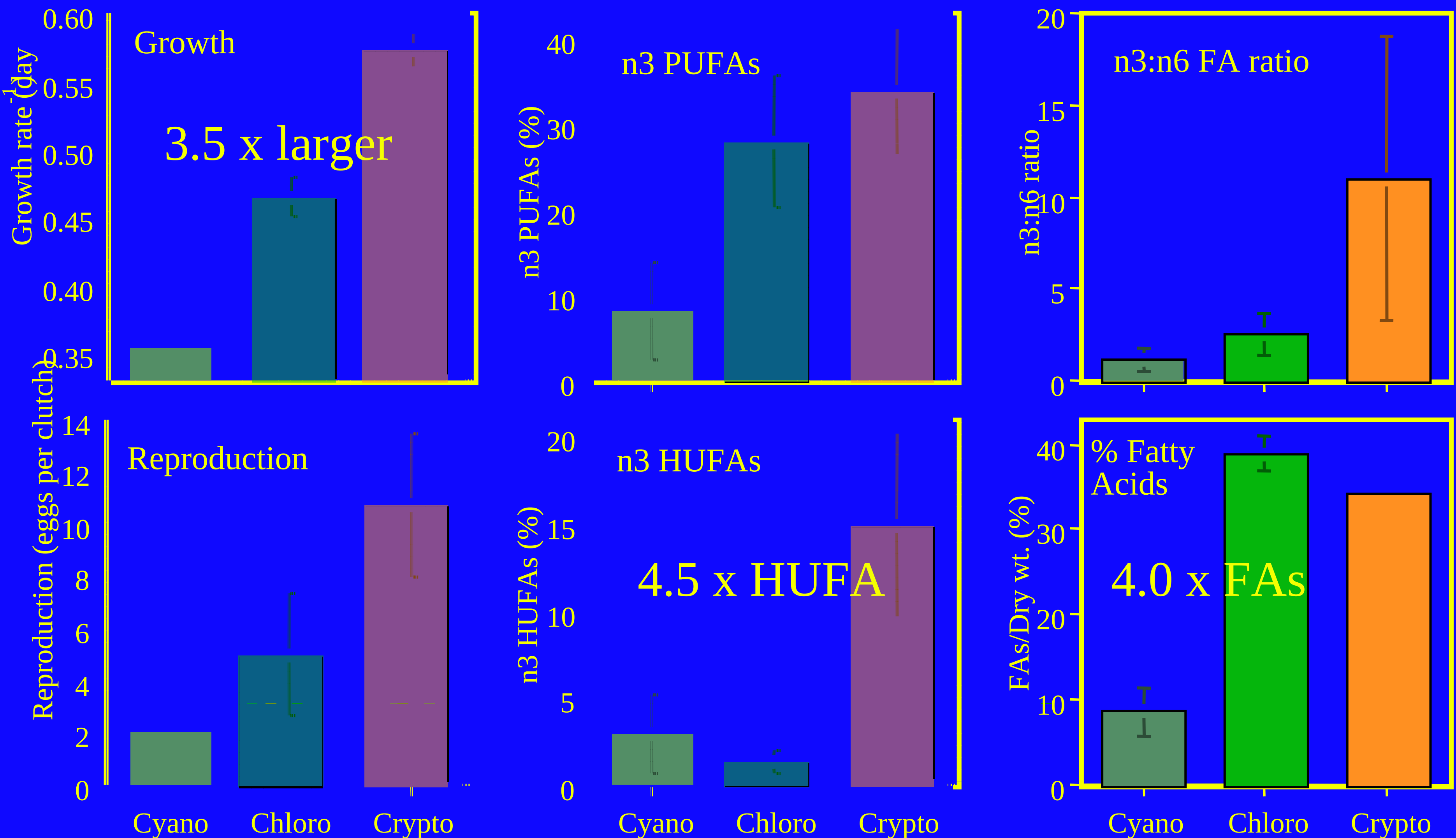
L&O 51: 2428-, Burns et al. ASLO 2006

Daphnia growth and biochemical composition responses to different food types



L&O 51: 2428-, Burns et al. ASLO 2006

Daphnia growth and biochemical composition responses to different food types



L&O 51: 2428-, Burns et al. ASLO 2006

Outline - Controls on Zooplankton Fatty Acid Content

1) Taxonomic affiliation

2) Diet

3) Temperature

4) Food ration/starvation

5) Biochemical transformations

6) Homeostasis

The Pioneers and the Examples

Farkas & Herodek 1964 J Lipid Res 3: 369-

Lee, R.F. et al. 1971 Marine Biology 9: 99-

Farkas et al. 1984 Lipids 19: 436-

Bourdier & Amblard 1989 J Plankton Res 11, 1201-

Goulden & Place 1990 J Exp Zool 256, 168-

Graeve et al. 1994 J Exp Mar Biol Ecol 182, 97-

Weers et al. 1997 Freshwater Biol 38: 731-

Taxonomic differences in zooplankton fatty acid composition

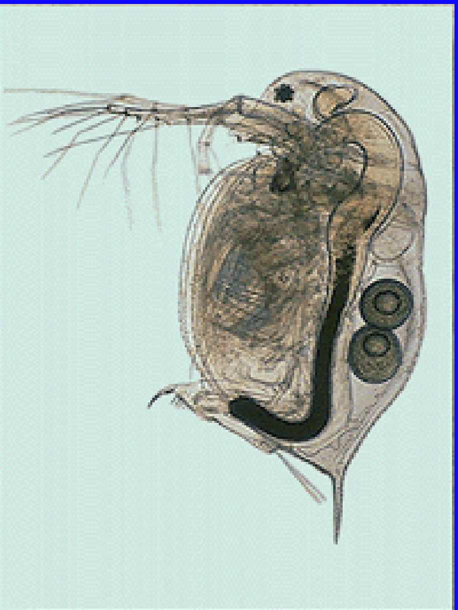
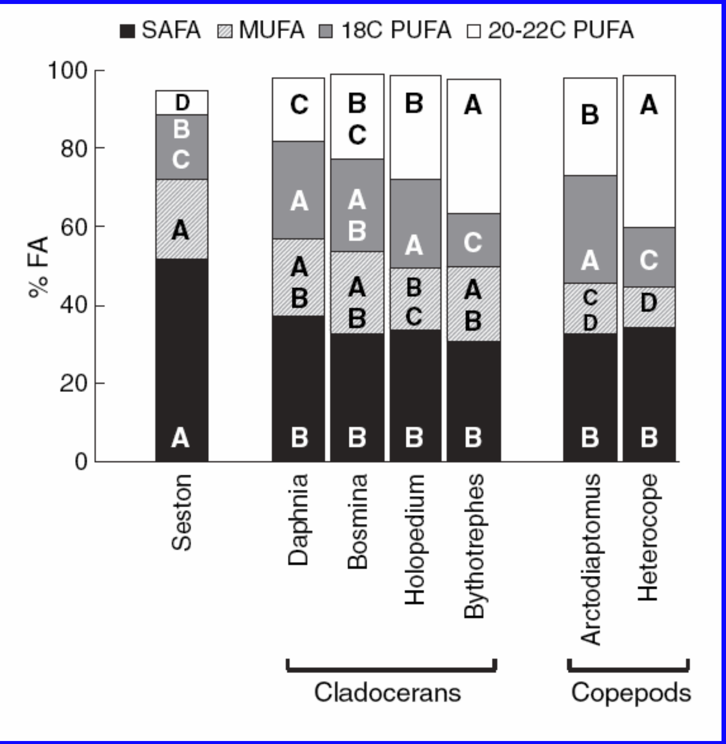
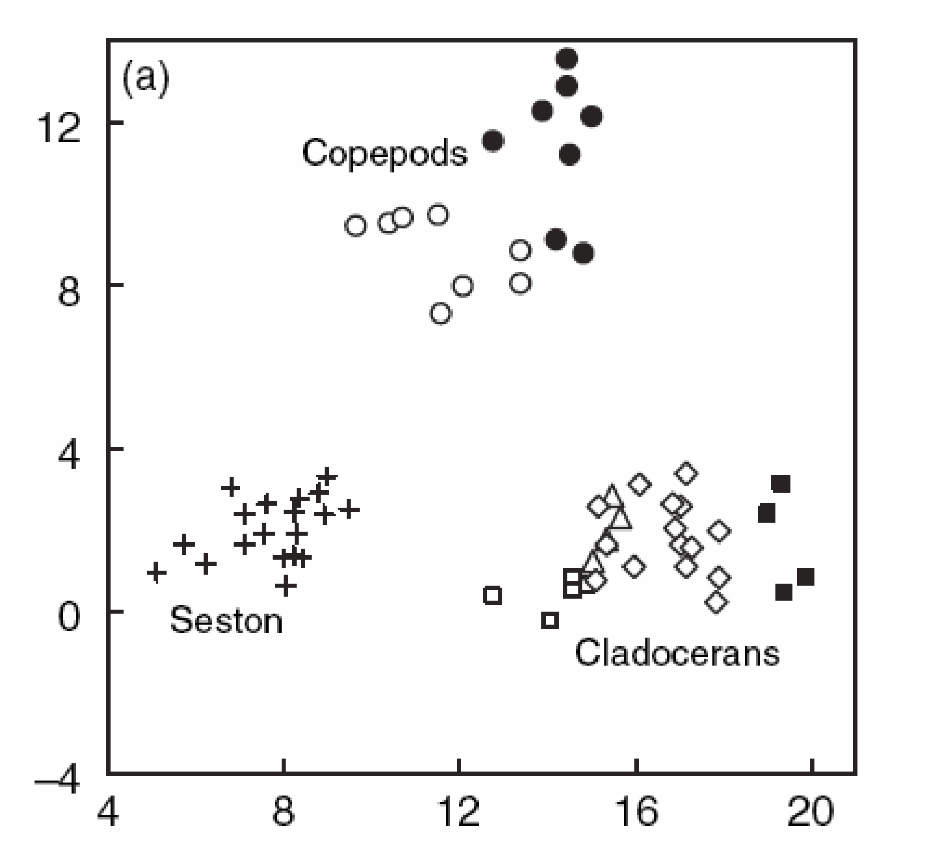


Photo by Carol Eunmi Lee

Persson and Vrede 2006

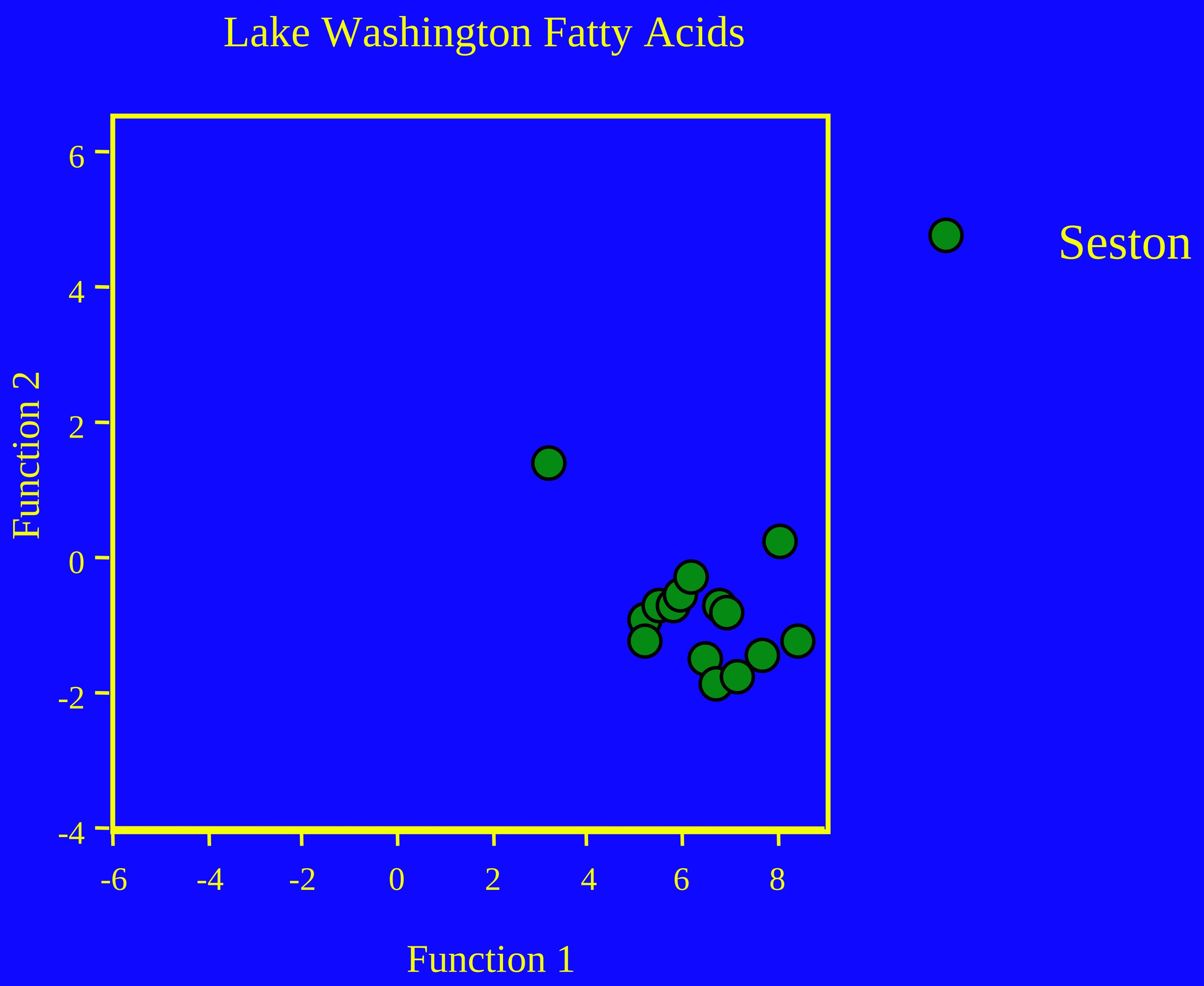




1) Zooplankton have more PUFA than seston and carnivorous zooplankton have more PUFA than herbivorous zooplankton

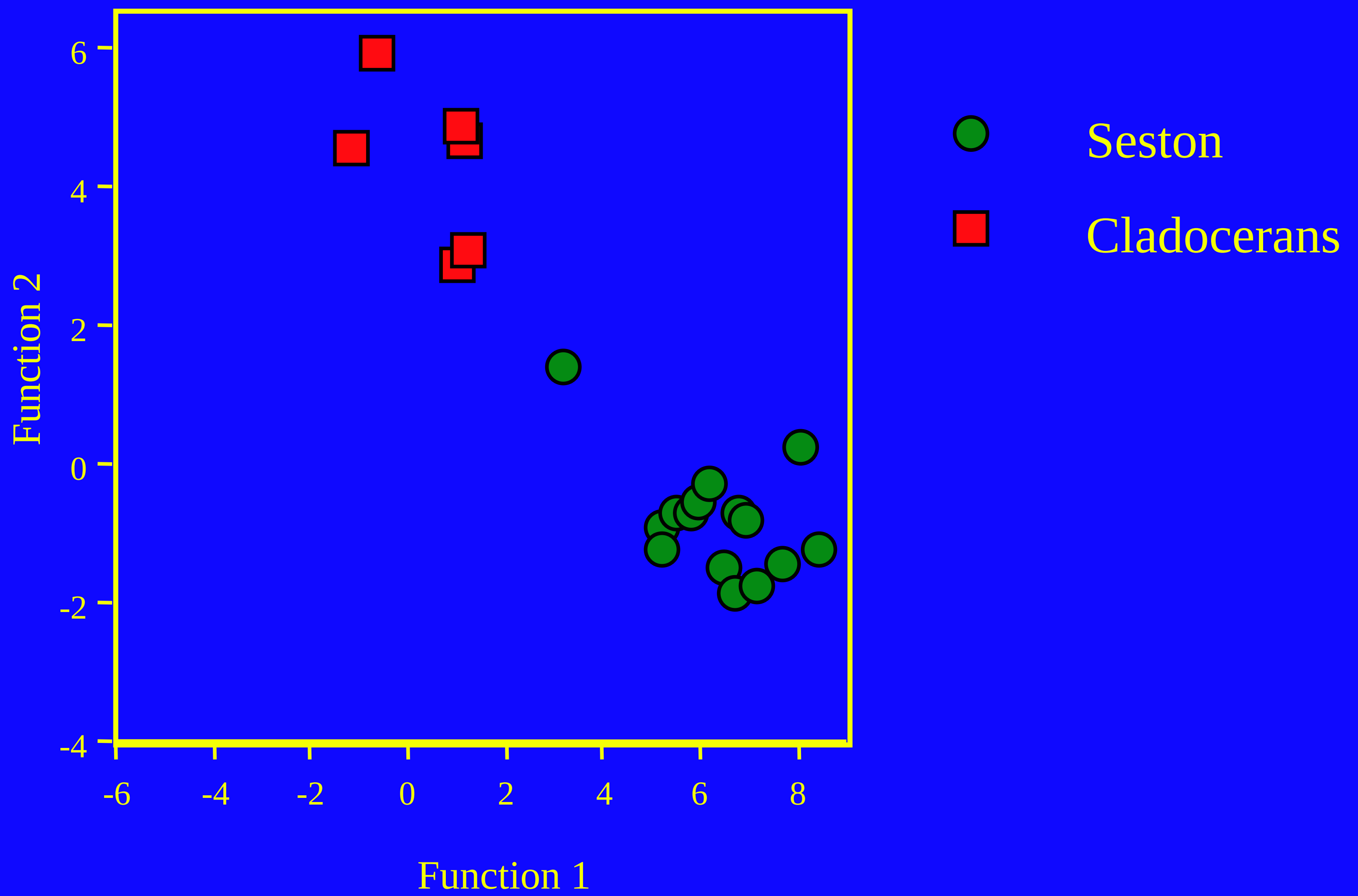
2) Cladocerans accumulate EPA, whereas copepods accumulate EPA and <u>especially DHA</u>

FWB 51: 887-



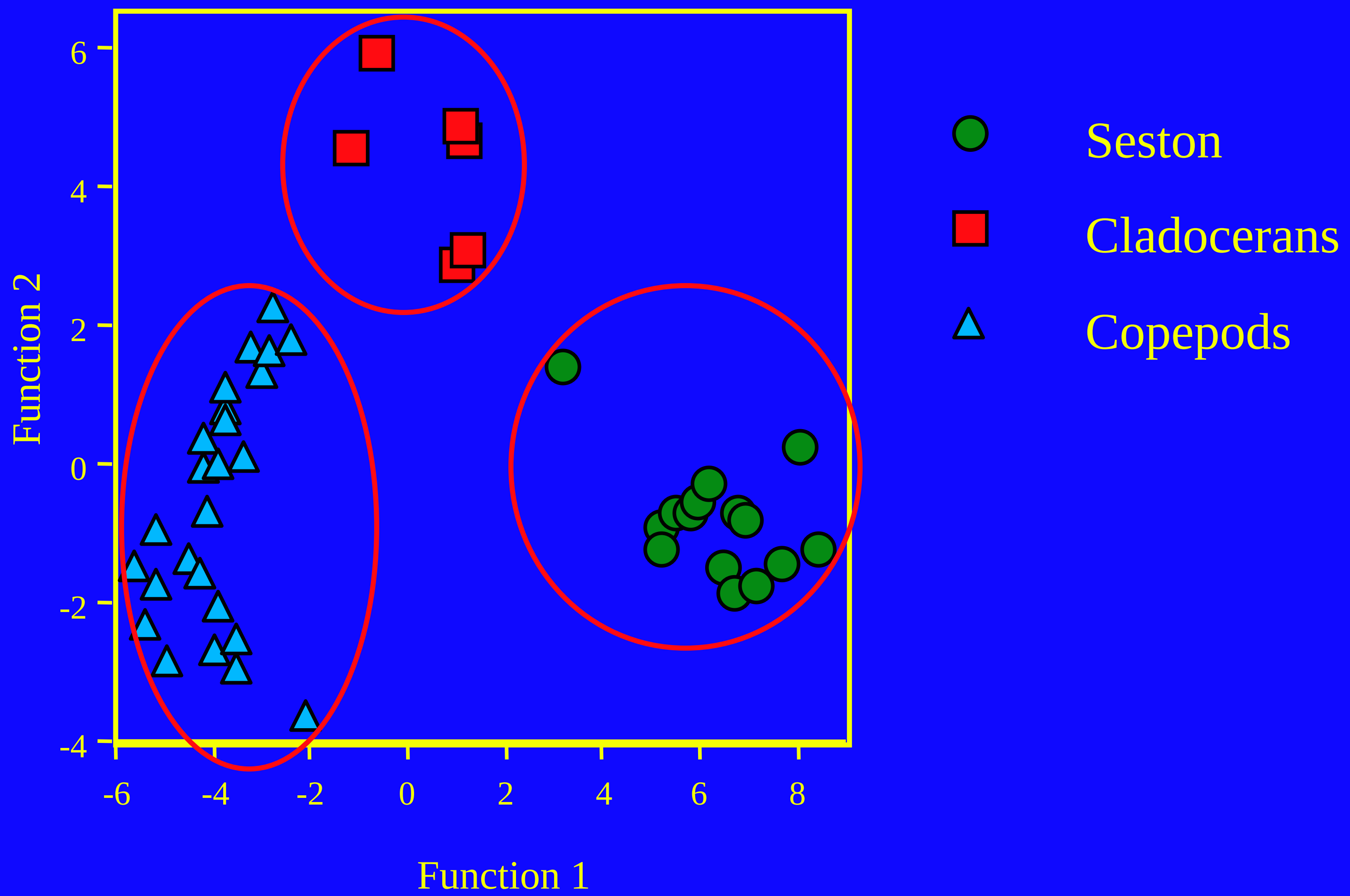
Ravet et al., unpub.

Lake Washington Fatty Acids



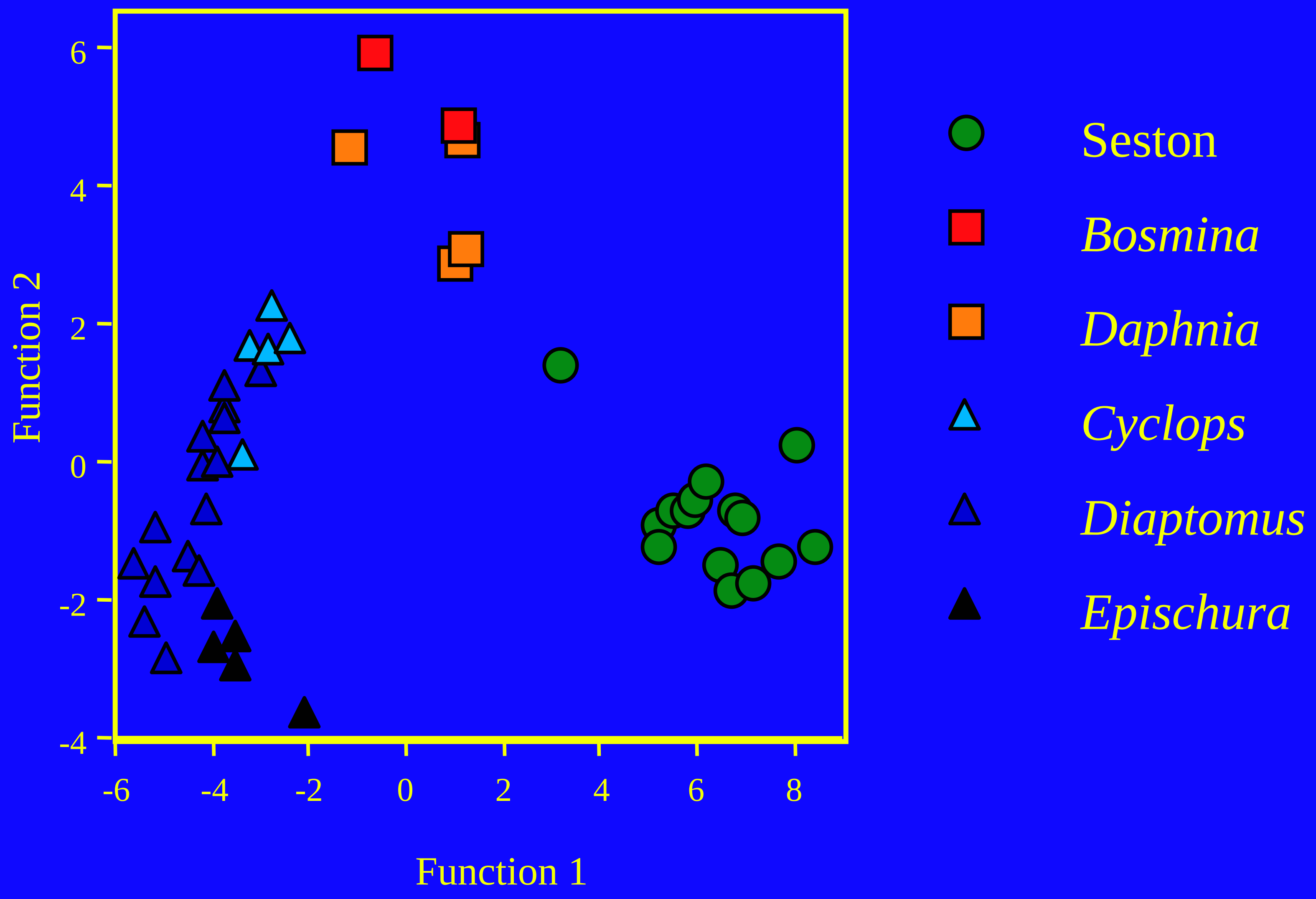
Ravet et al., unpub.

Lake Washington Fatty Acids

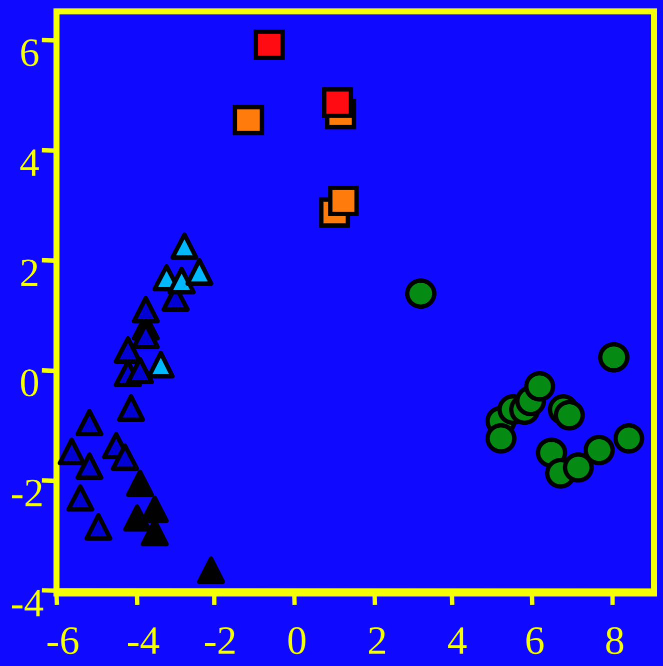


Ravet et al., unpub.

Lake Washington Fatty Acids



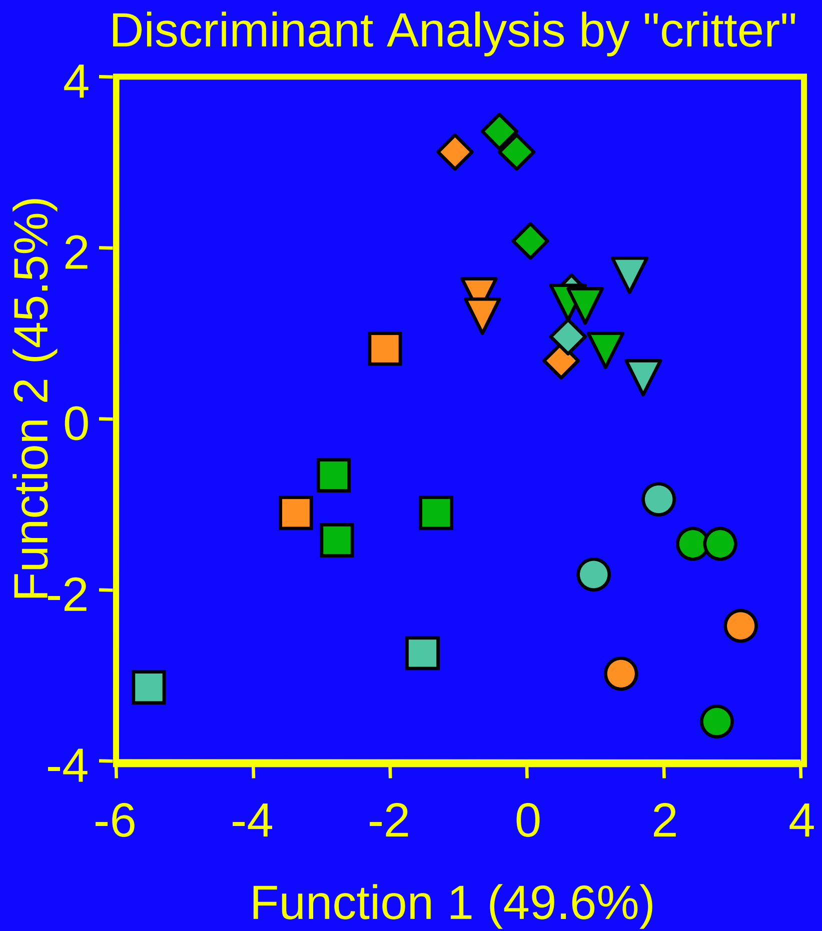
Ravet et al., unpub.



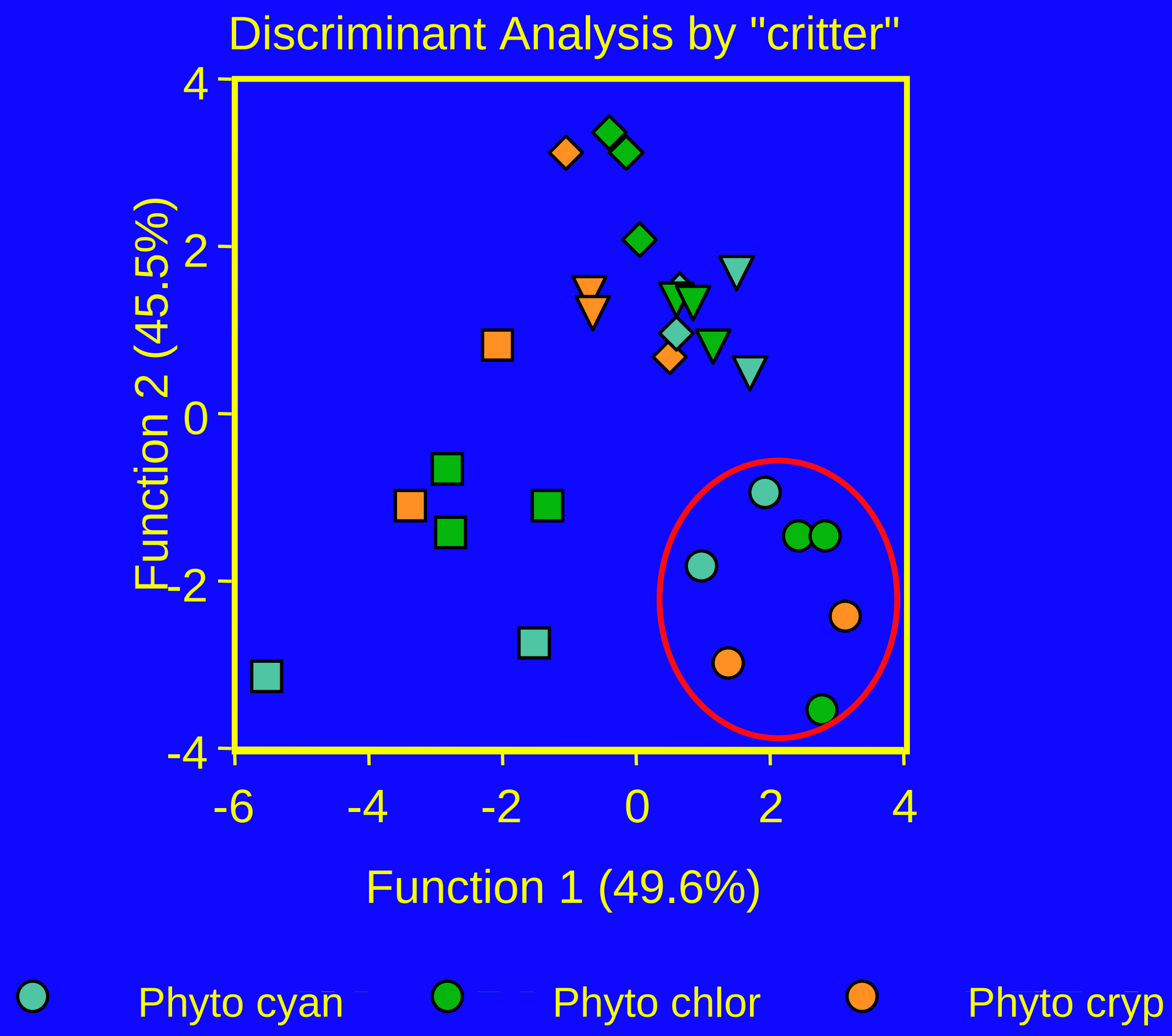
Zooplankton tended to accumulate much higher proportions of ω3 PUFA than their diets.

Copepods preferentially accumulated DHA, cladocerans accumulated EPA, and both copepods and cladocerans accumulated 18 carbon chain ω3 PUFAs.

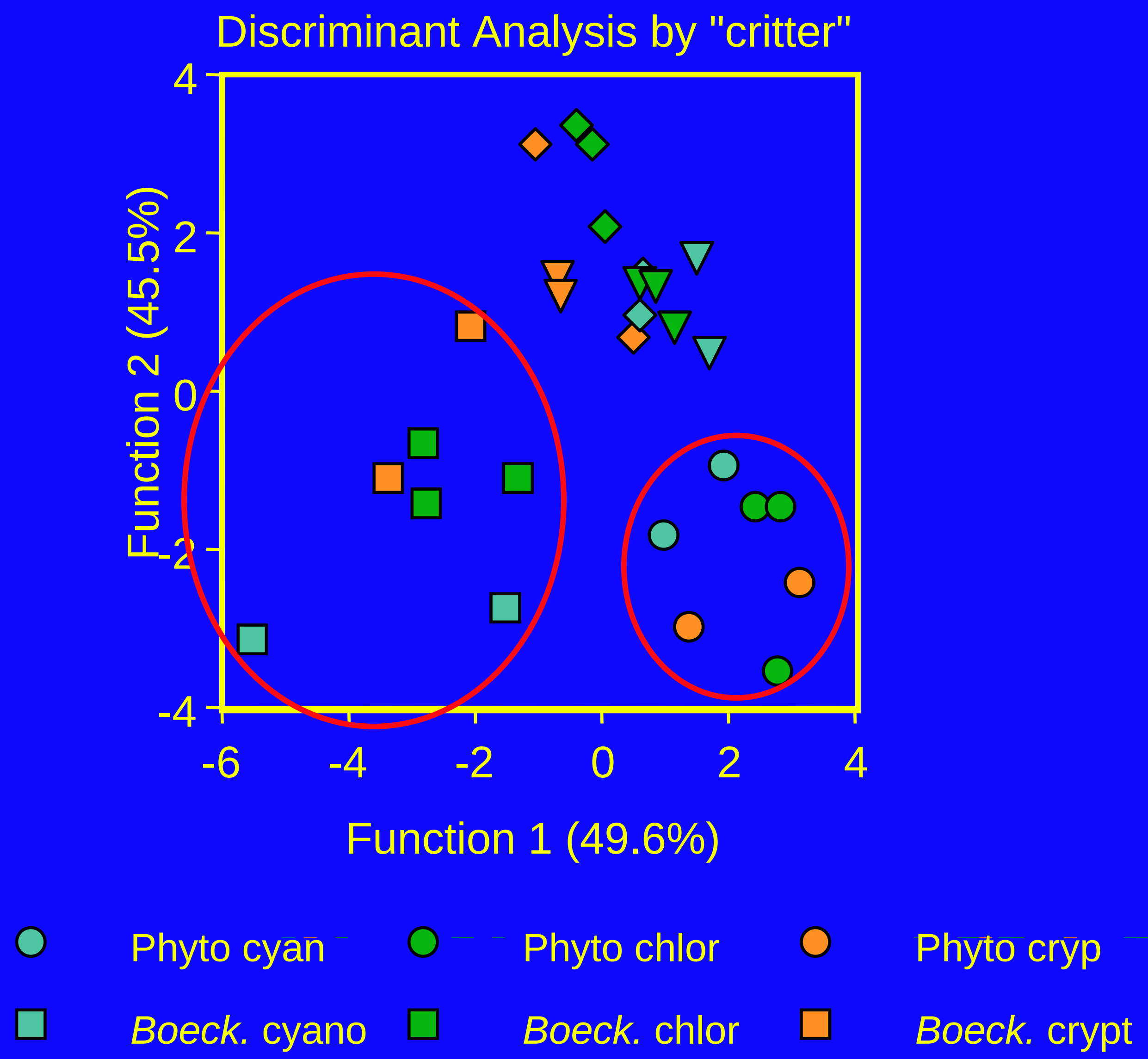
Ravet et al., unpub.



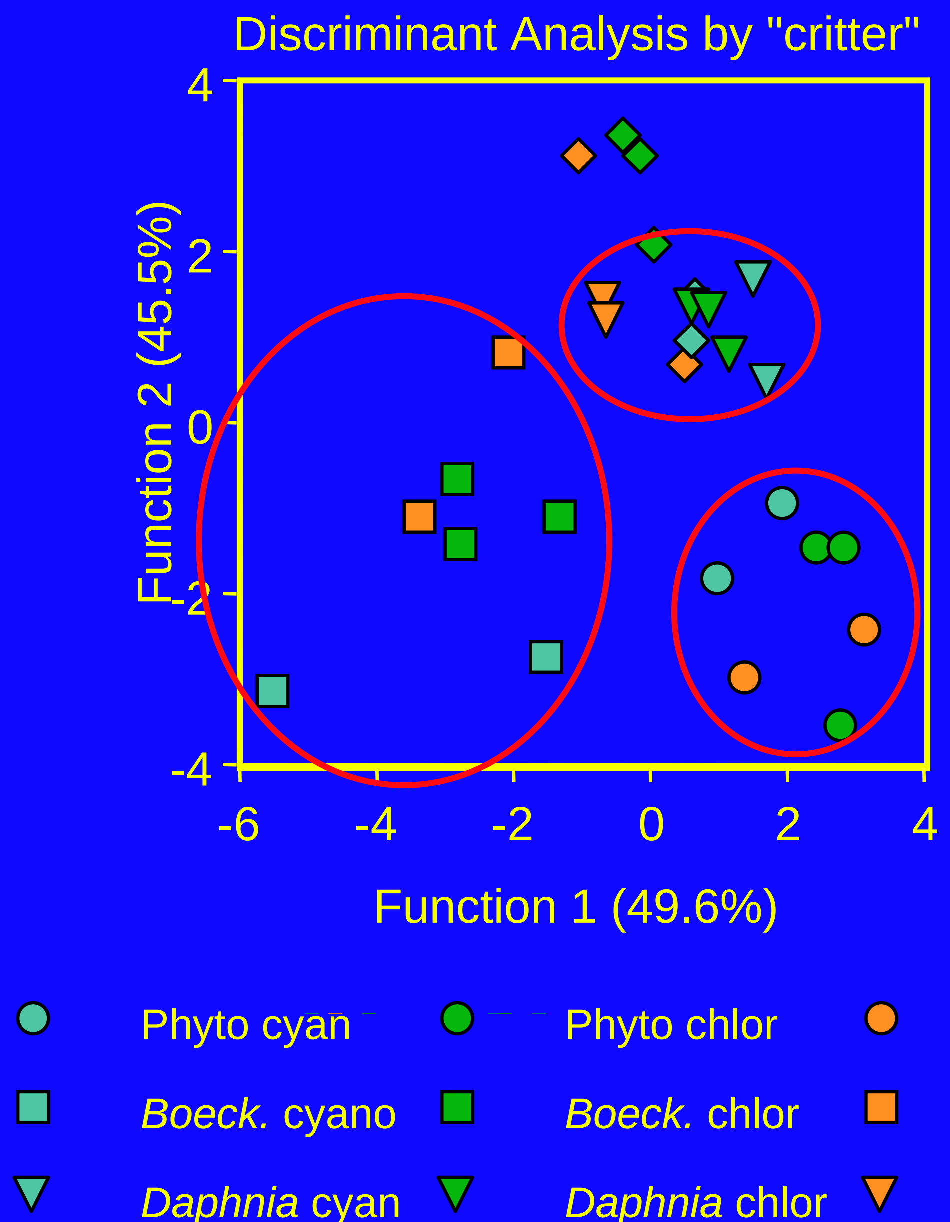
Burns et al., SIL 2007



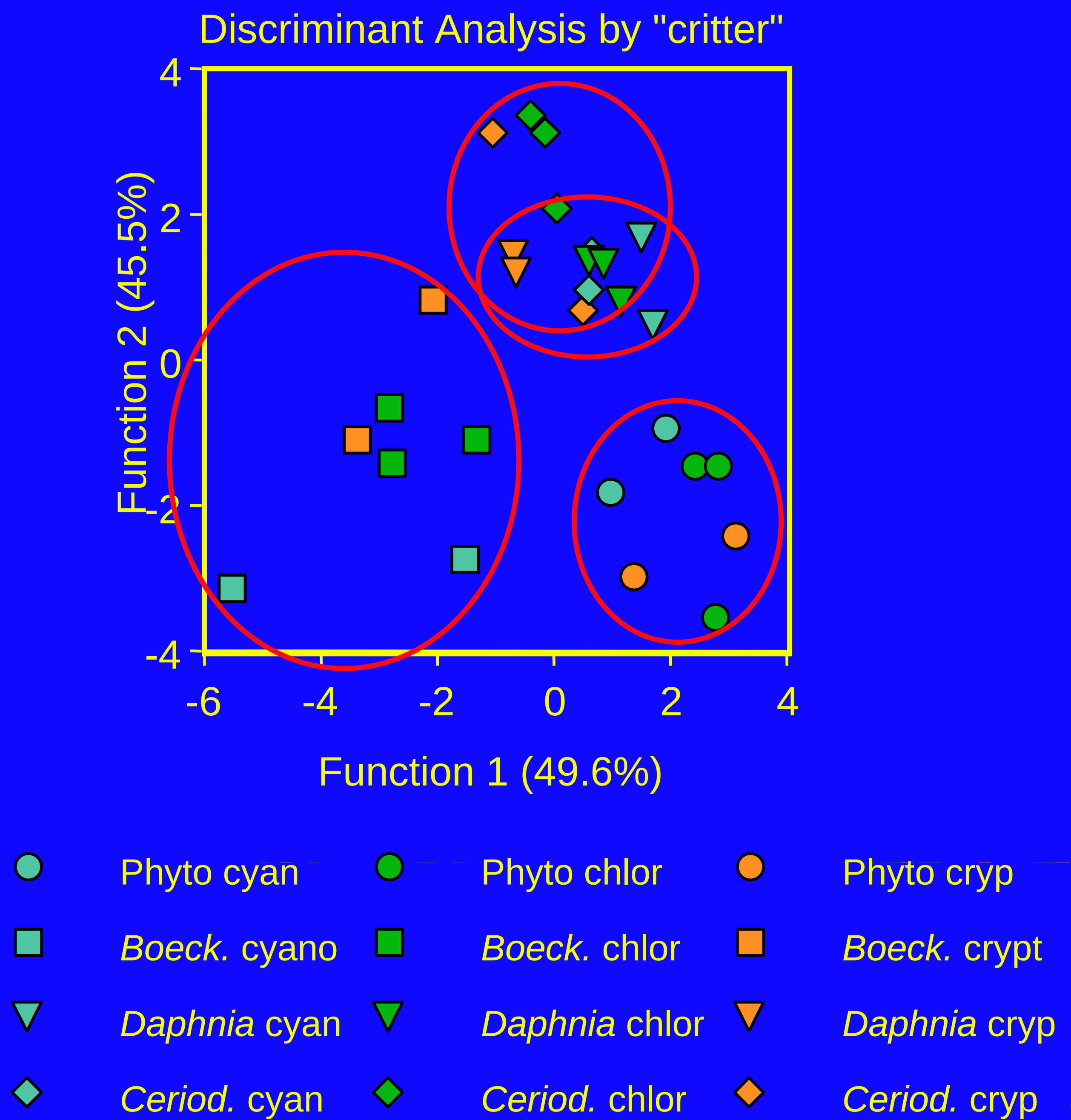
Burns et al., SIL 2007



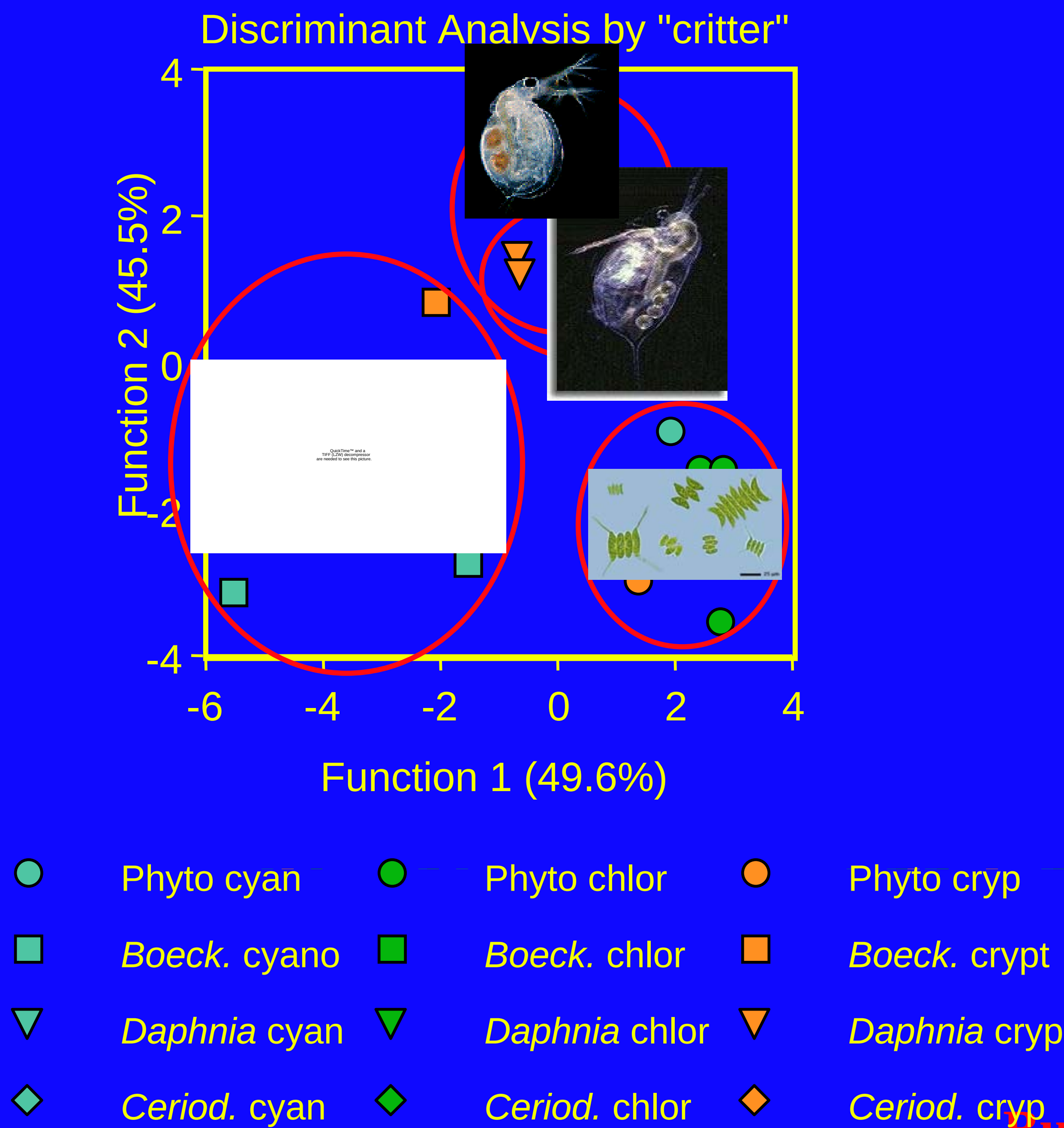
Burns et al., SIL 2007



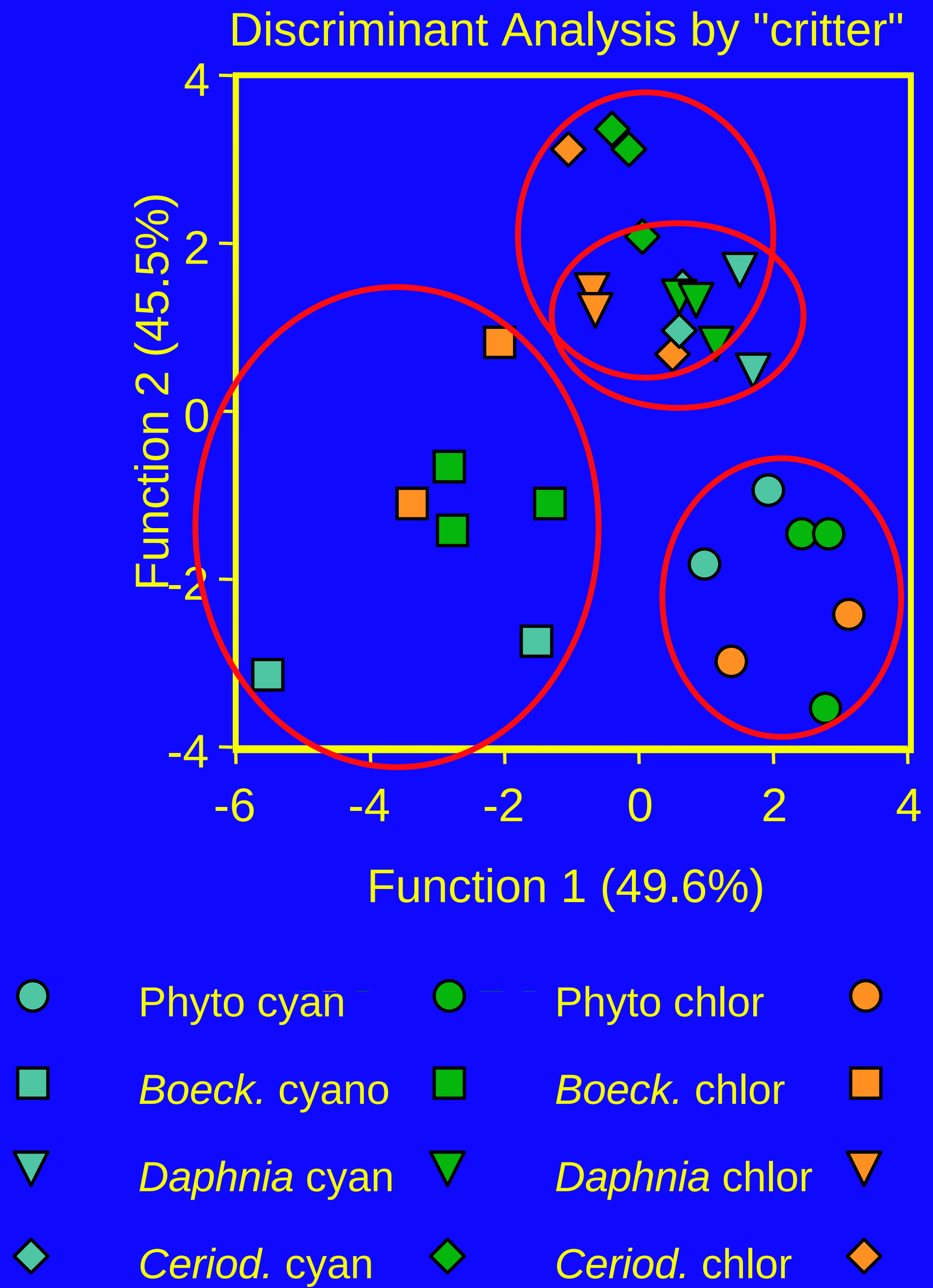
Burns et al., SIL 2007



Burns et al., SIL 2007



Burns et al., ASLO 2006



- 89% correctly classified
- Discrimination due to 20n3, 22n3 & %FAs
- Misclassification between *Daphnia & Ceriodaphnia*

Burns et al., ASLO 2006

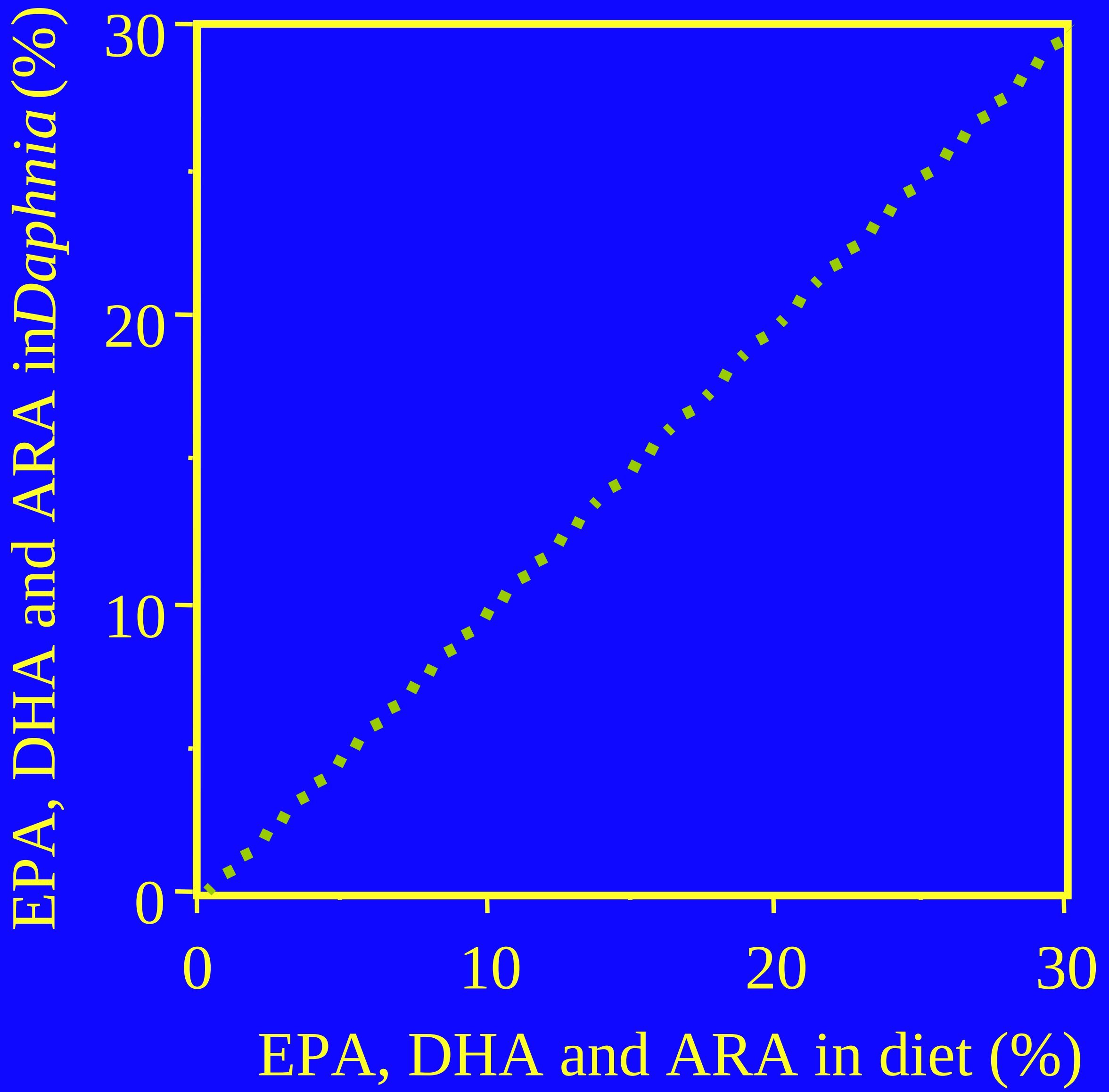
Taxonomic conclusions

Cladocerans accumulate almost exclusively EPA, whereas copepods accumulate both EPA and DHA - but predominantly DHA. **Why?**

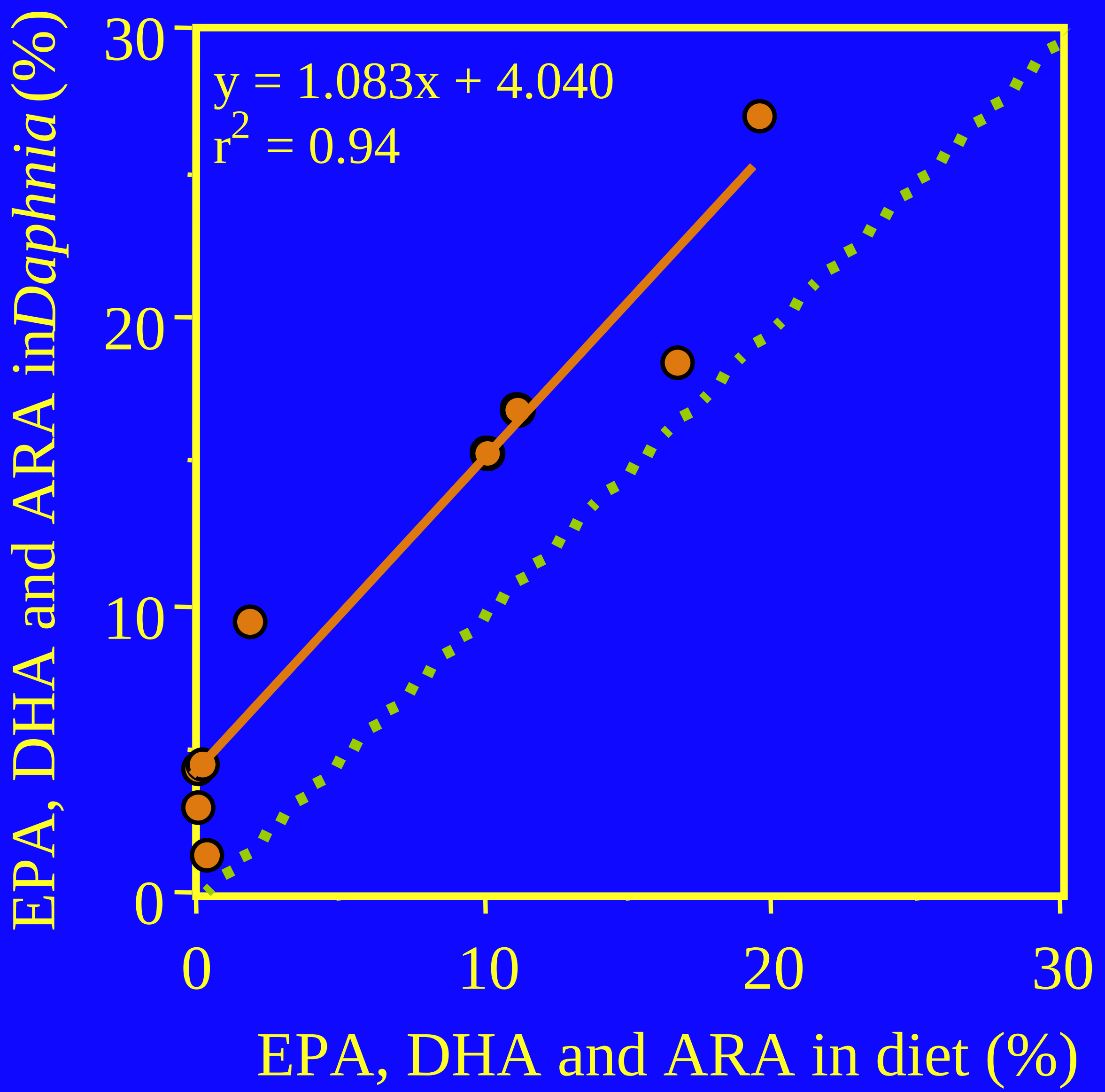
Persson and Vrede suggested this is because cladocerans were fast (growing/reproducing) but "dumb", whereas copepods are slow and "sensitive".

BUT why can't DHA be used as a substrate to support fast growth/reproduction & why can't EPA be used to form sensory tissues? Furthermore, do copepods actually have more sensory tissue than cladocerans?

Dietary control of fatty acid composition

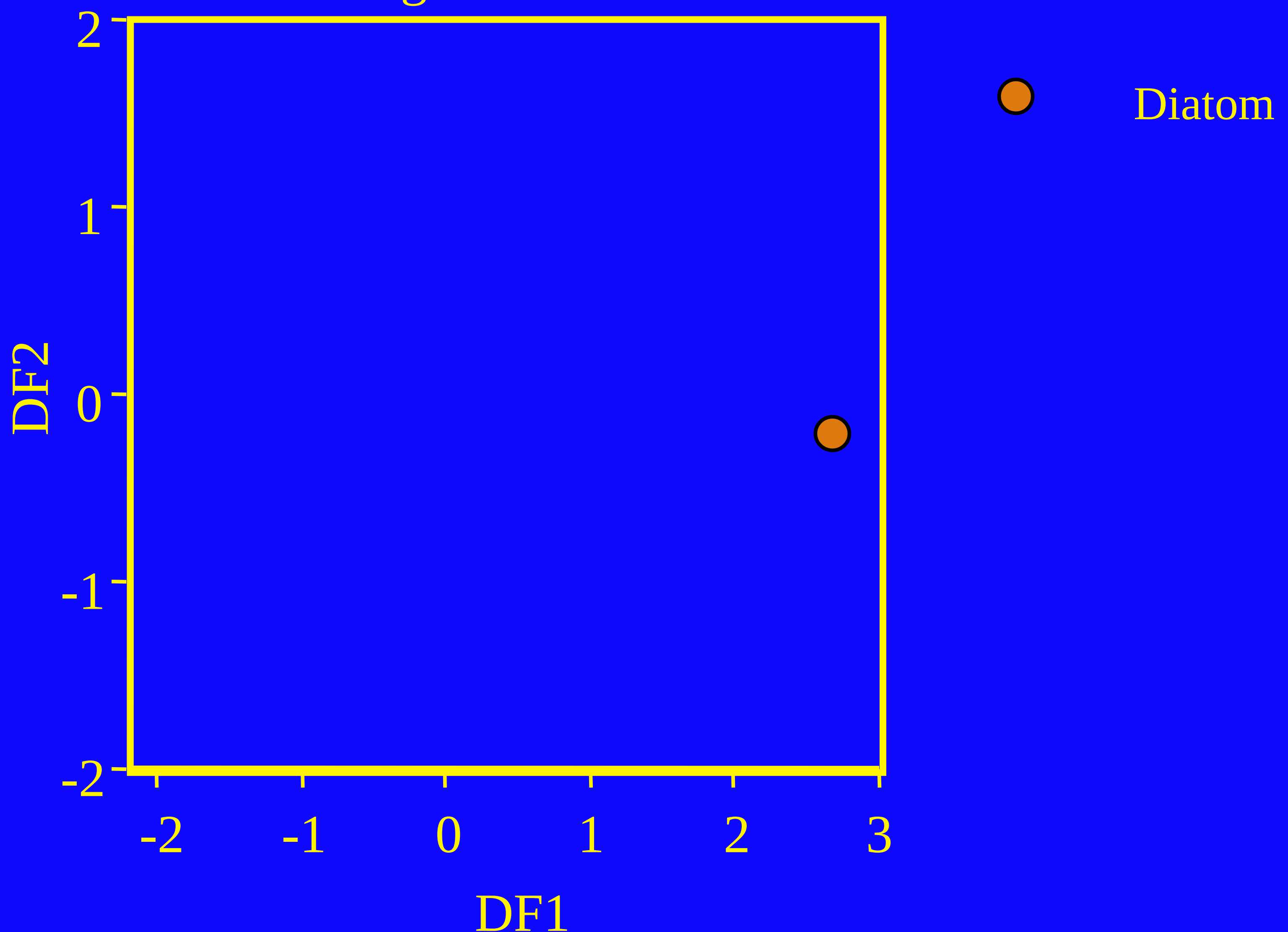


L&O 51: 2428-, 2006

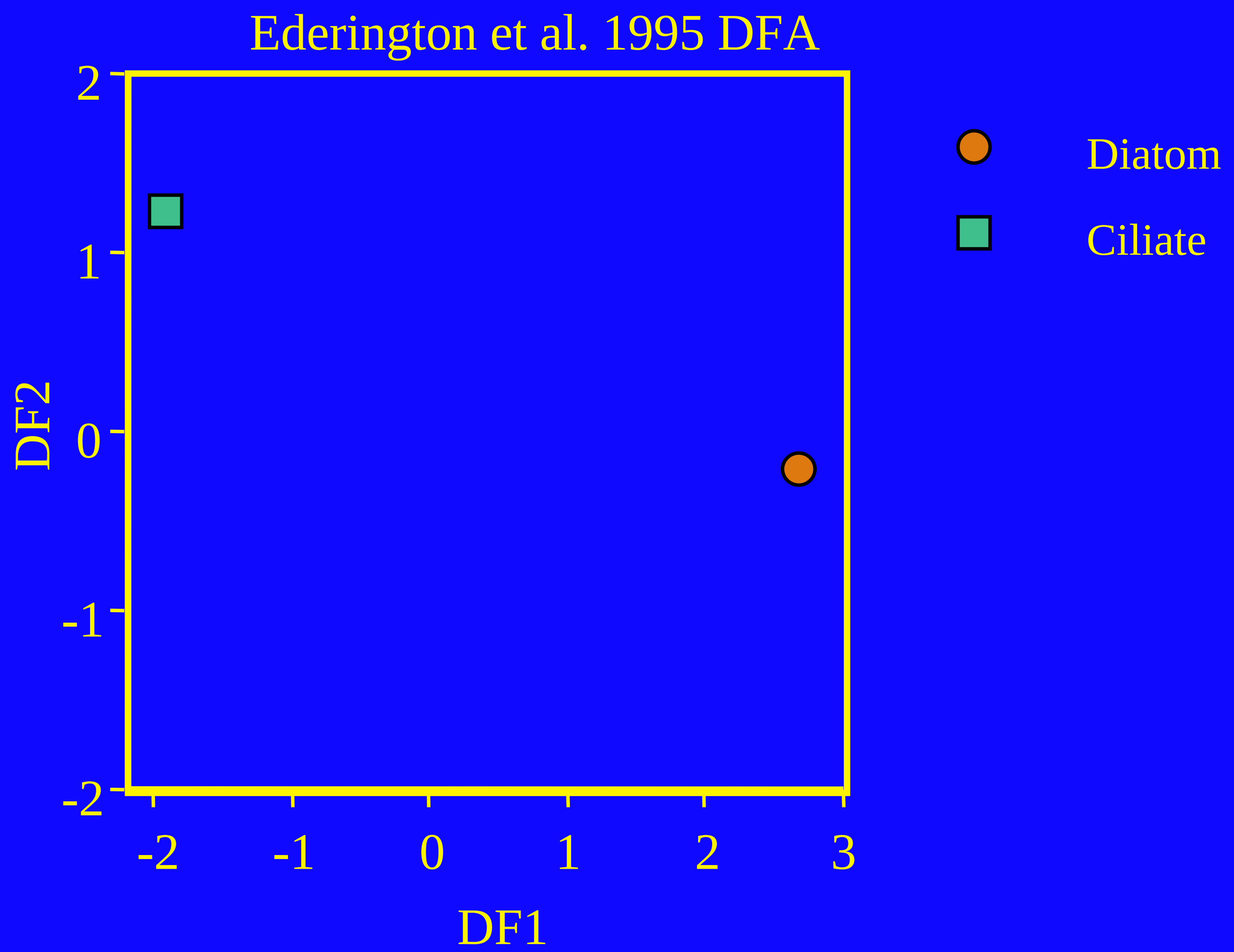


L&O 51: 2428-, 2006

Ederington et al. 1995 DFA

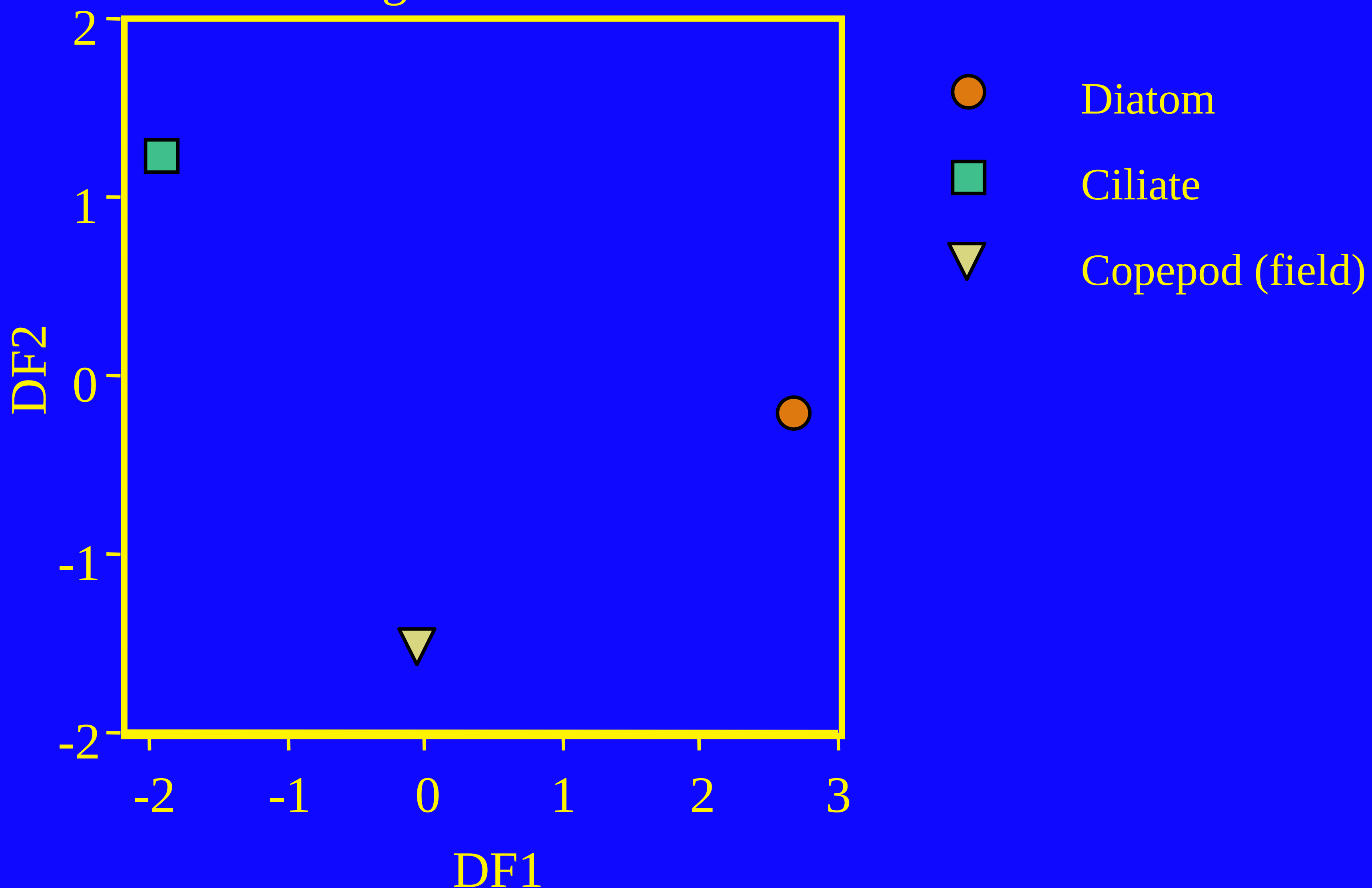


L&O 40: 860-


Ederington et al. 1995 DFA
2
1
0
-1
-2
DF2
-2
-1
0
1
2
3
DF1
Diatom
Ciliate

L&O 40: 860-

Ederington et al. 1995 DFA



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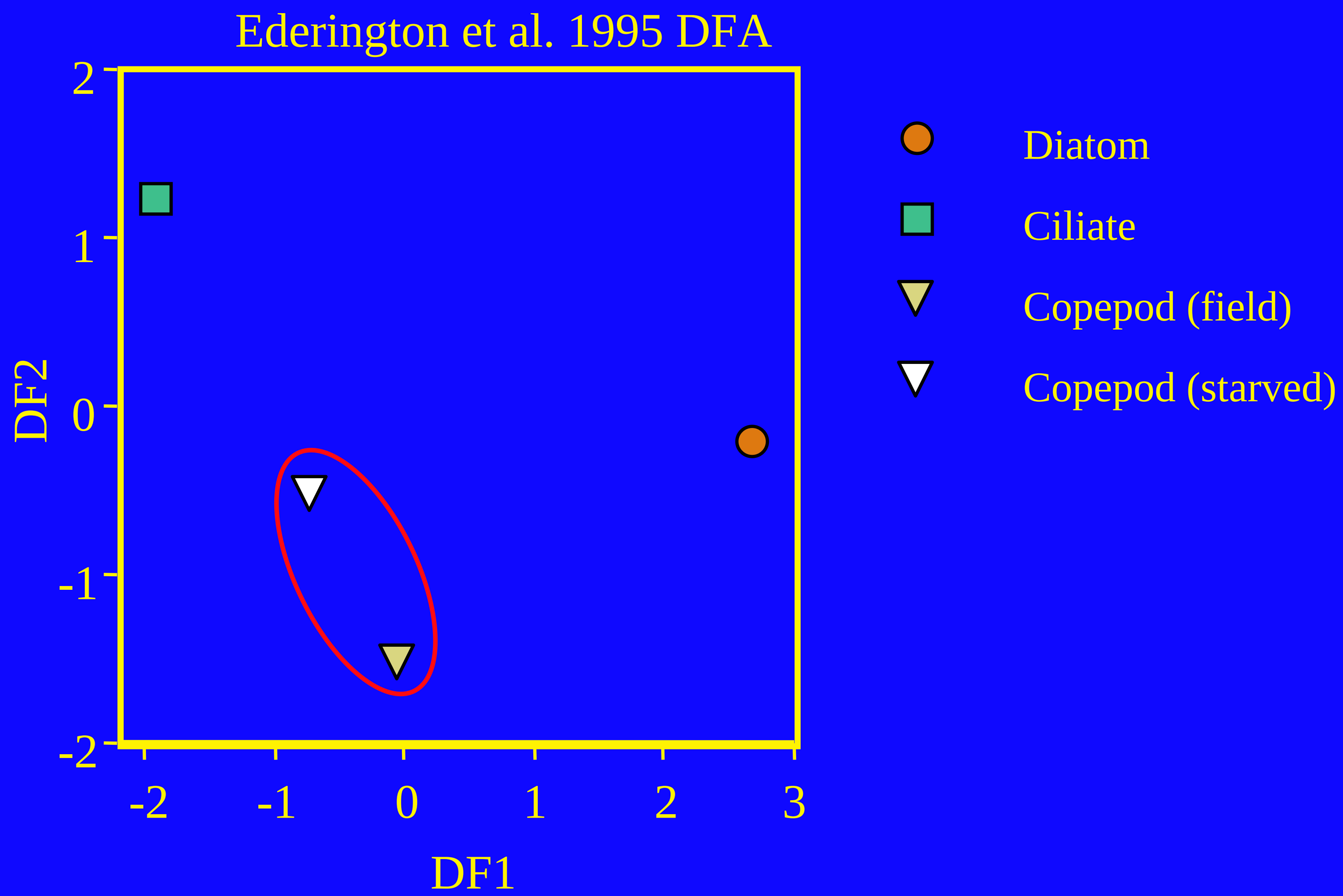
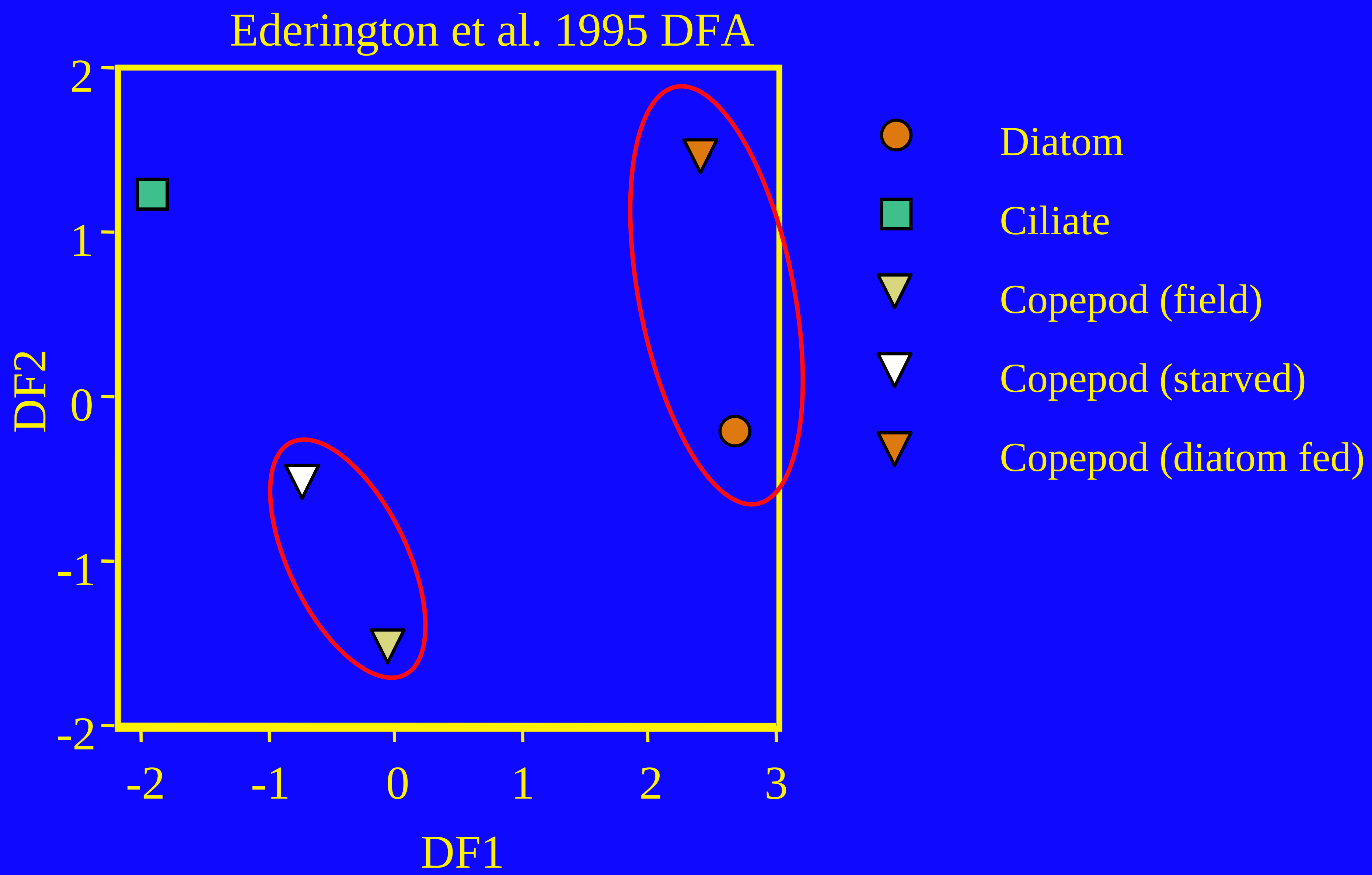
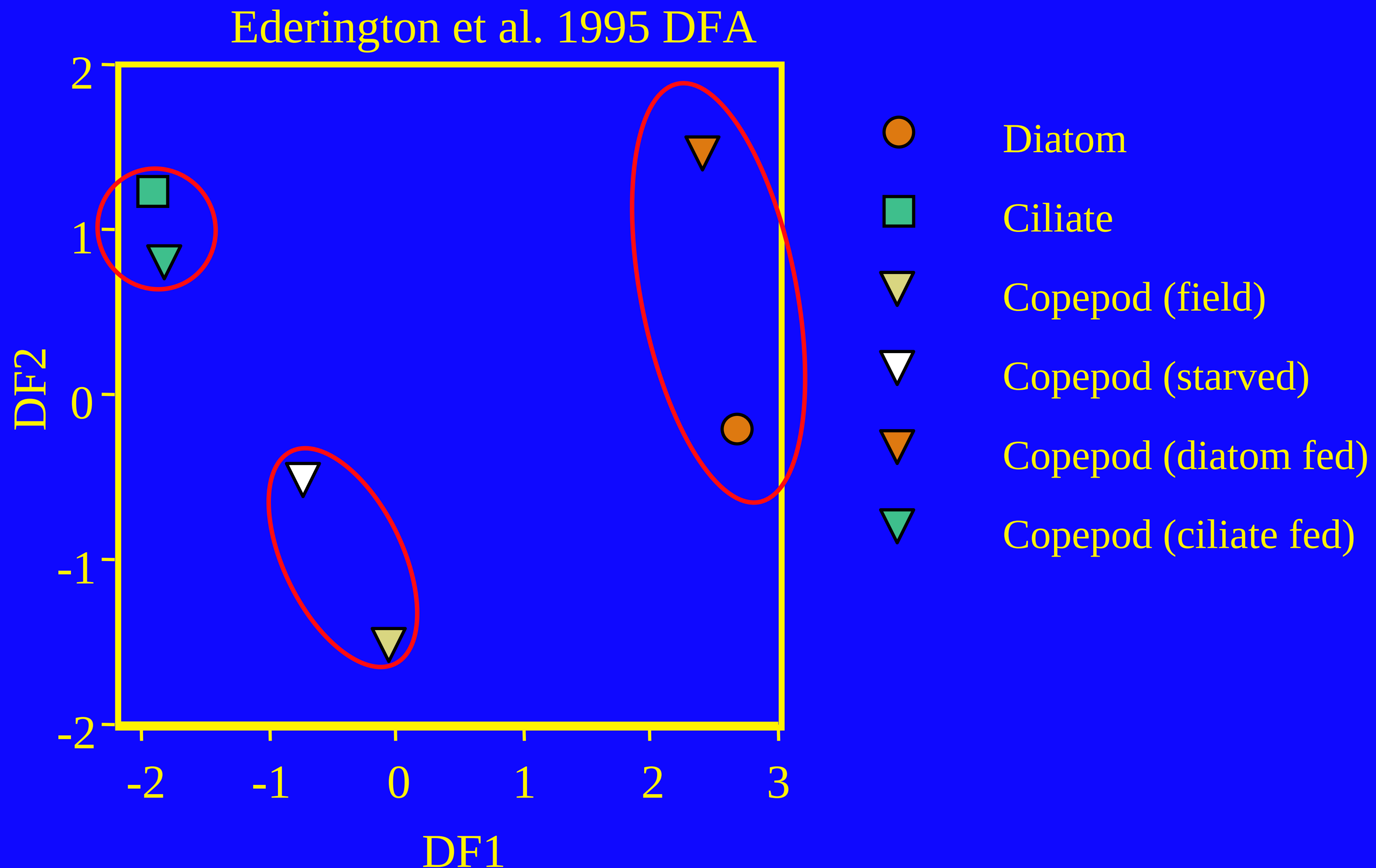

Ederington et al. 1995 DFA
2
1
0
-1
-2
DF2
-2
-1
0
1
2
3
DF1
Diatom
Ciliate
Copepod (field)
Copepod (starved)

L&O 40: 860-



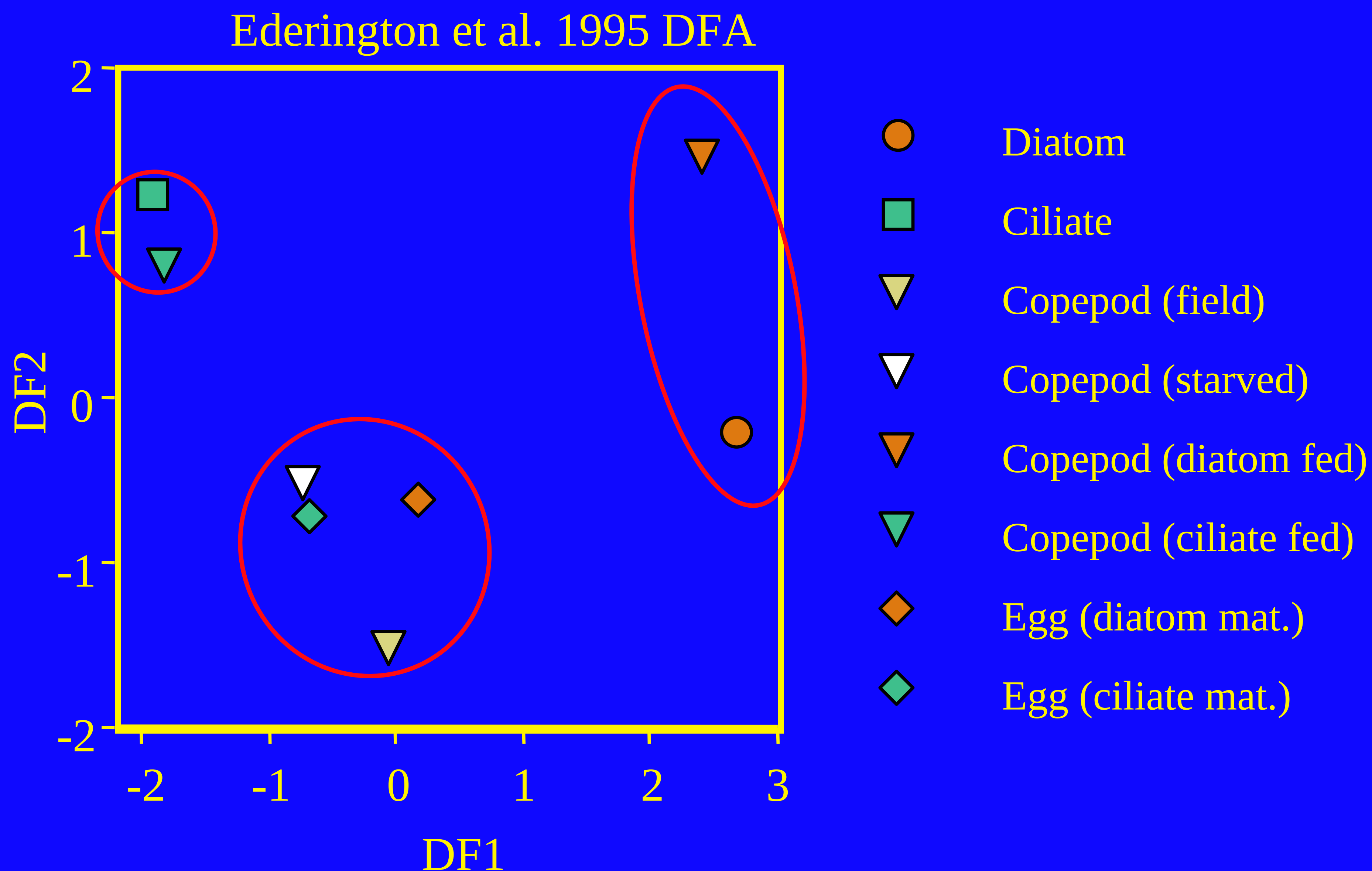
Ederington et al. 1995 DFA
2
1
0
-1
-2
DF2
-2
-1
0
1
2
3
DF1
Diatom
Ciliate
Copepod (field)
Copepod (starved)
Copepod (diatom fed)

L&O 40: 860-



Ederington et al. 1995 DFA
2
1
0
-1
-2
DF2
-2
-1
0
1
2
3
DF1
Diatom
Ciliate
Copepod (field)
Copepod (starved)
Copepod (diatom fed)
Copepod (ciliate fed)

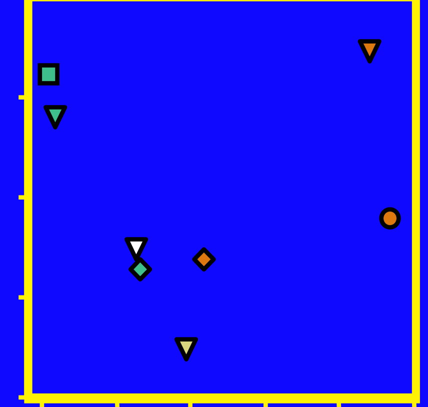
L&O 40: 860-



Ederington et al. 1995 DFA
DF2
2
1
0
-1
-2
-2
-1
0
1
2
3
DF1
Diatom
Ciliate
Copepod (field)
Copepod (starved)
Copepod (diatom fed)
Copepod (ciliate fed)
Egg (diatom mat.)
Egg (ciliate mat.)

L&O 40: 860-

Conclusions from Ederington data



1) *Acartia* had high 16:0 and 18:0 irrespective of diet

2) Diatoms and *Acartia* fed diatoms & their eggs had high EPA

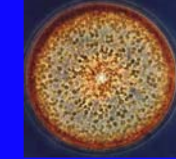
3) Ciliates and *Acartia* fed ciliates & their eggs had high 18:1ω11 and 22:0

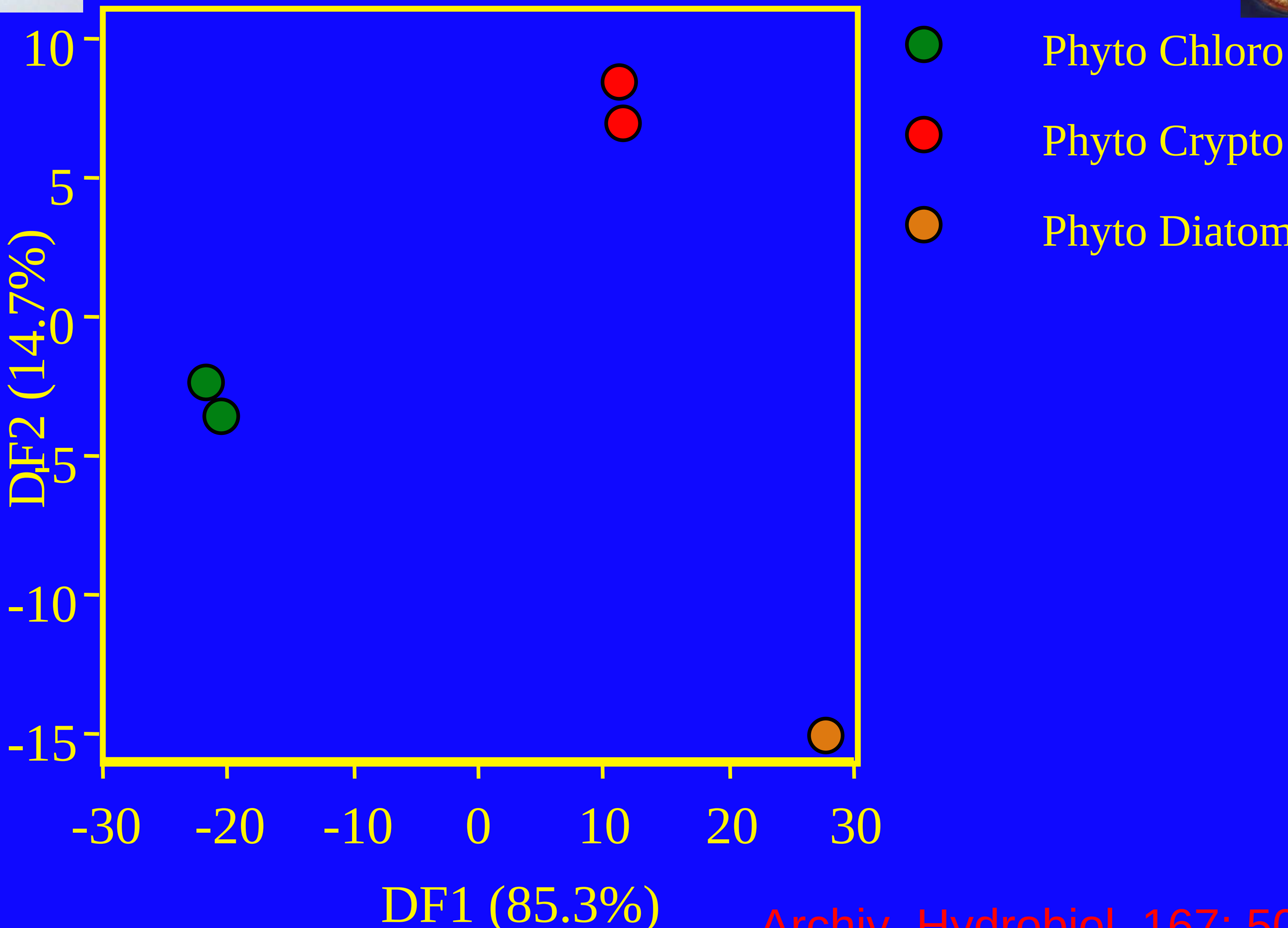
4) The FA composition of *Acartia* was much more strongly influenced by diet than was the FA composition of their eggs

Caveat: These were only 4 day incubations

L&O 40: 860-

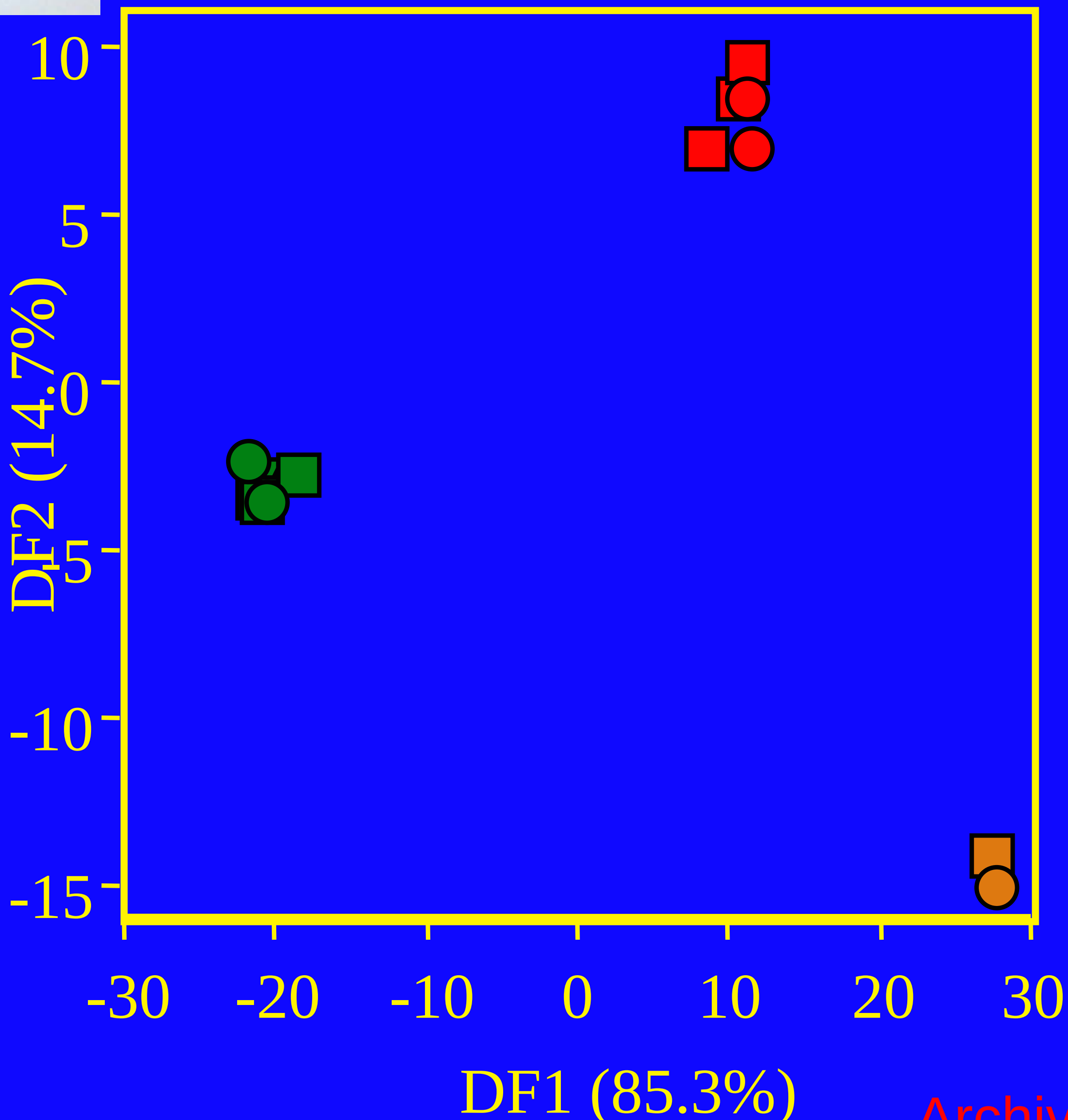
Müller-Navarra 2006





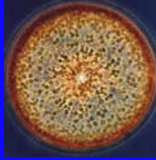
Archiv. Hydrobiol. 167: 501-

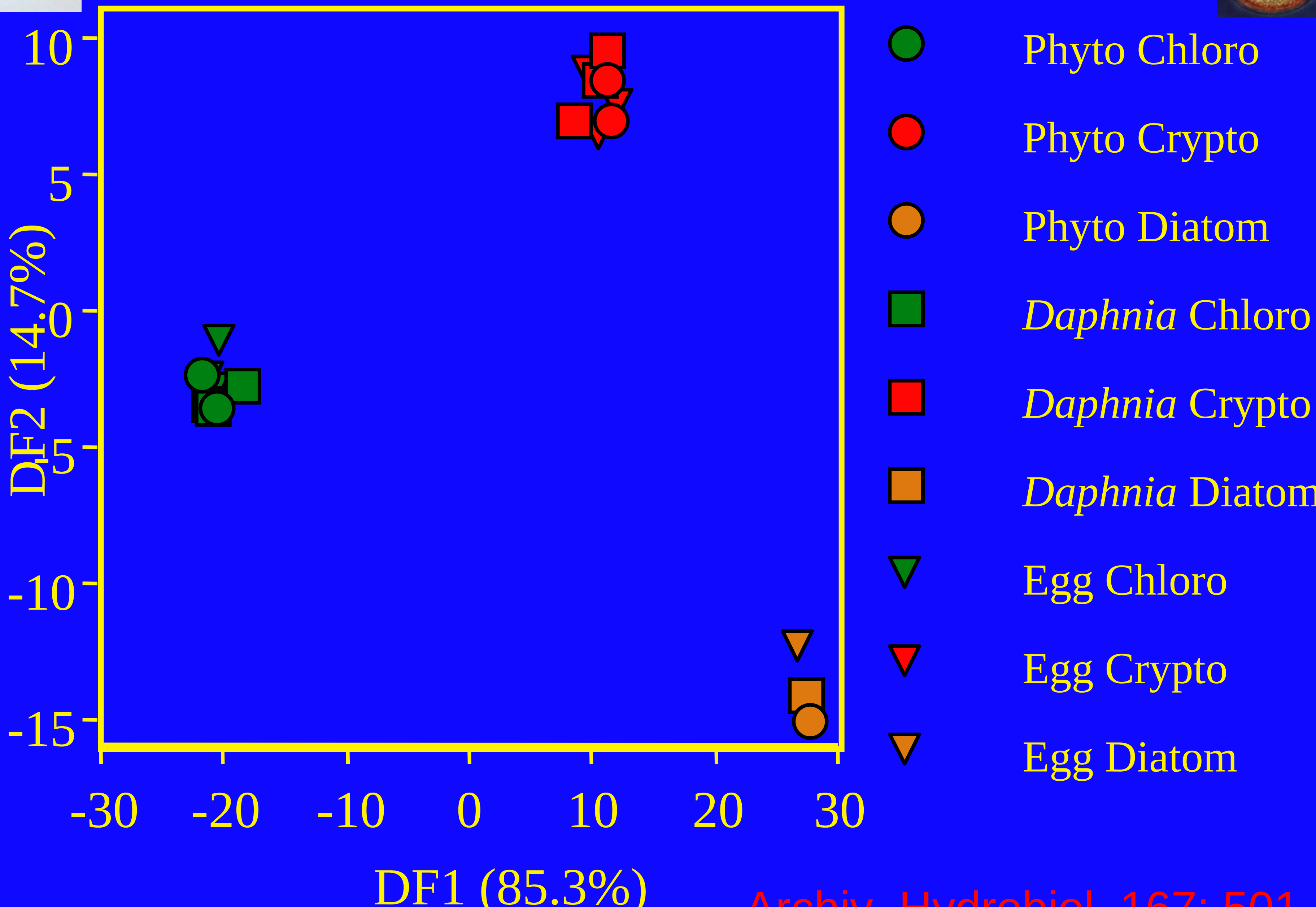
Müller-Navarra 2006



Archiv. Hydrobiol. 167: 501-

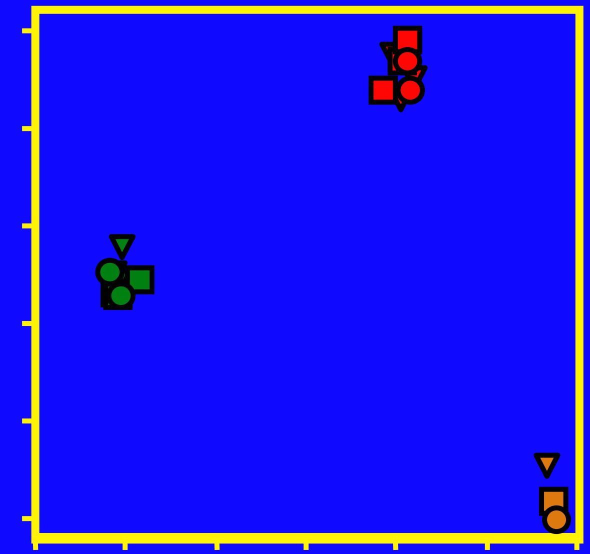
Müller-Navarra 2006





Archiv. Hydrobiol. 167: 501-

Conclusions from M-N 2006 data

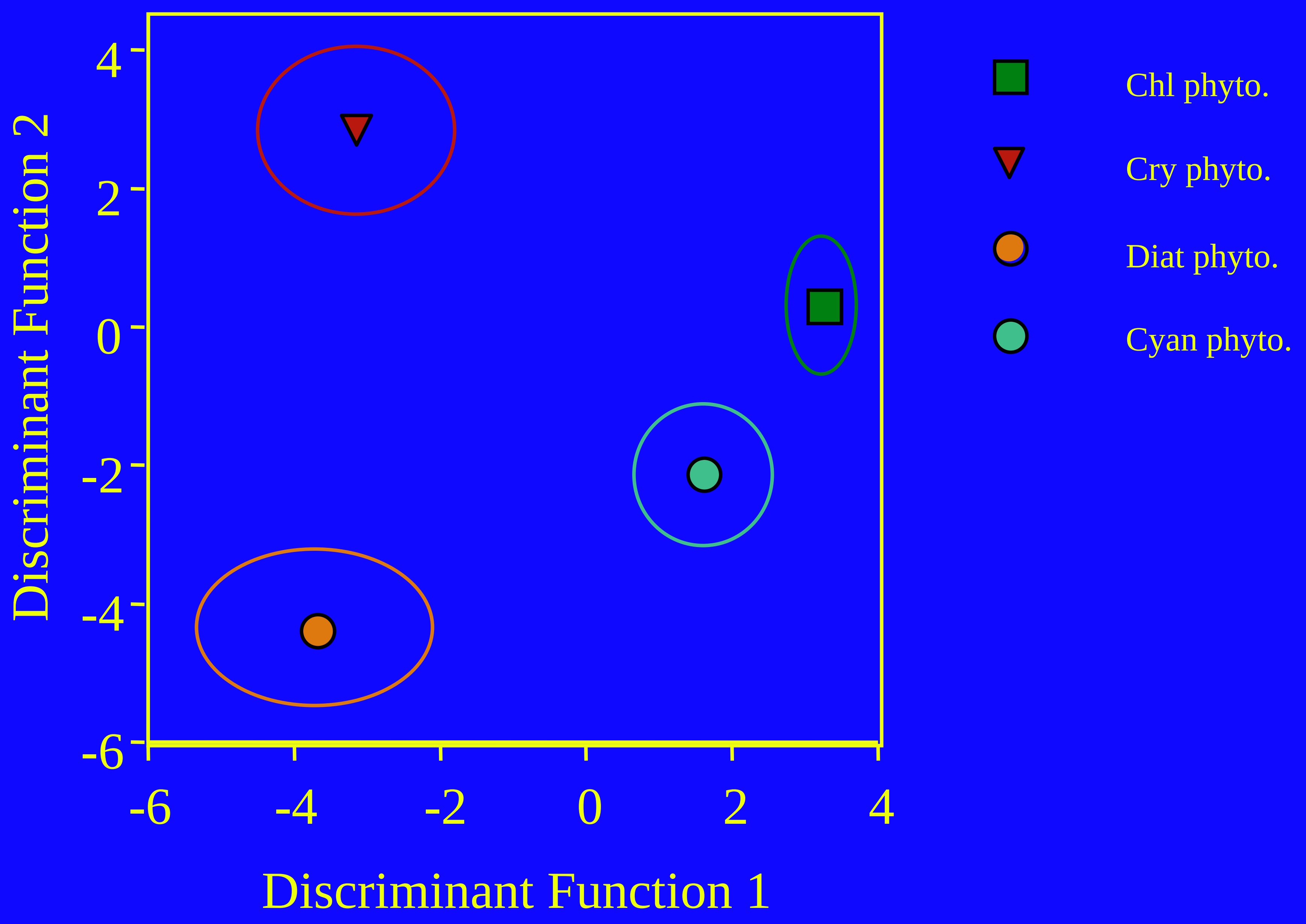


1) The 18:2ω6, 18:3ω3, 18:4ω3, and EPA content and ω3:ω6 ratio of the diet was very strongly correlated with that of the *Daphnia* somatic tissues and eggs

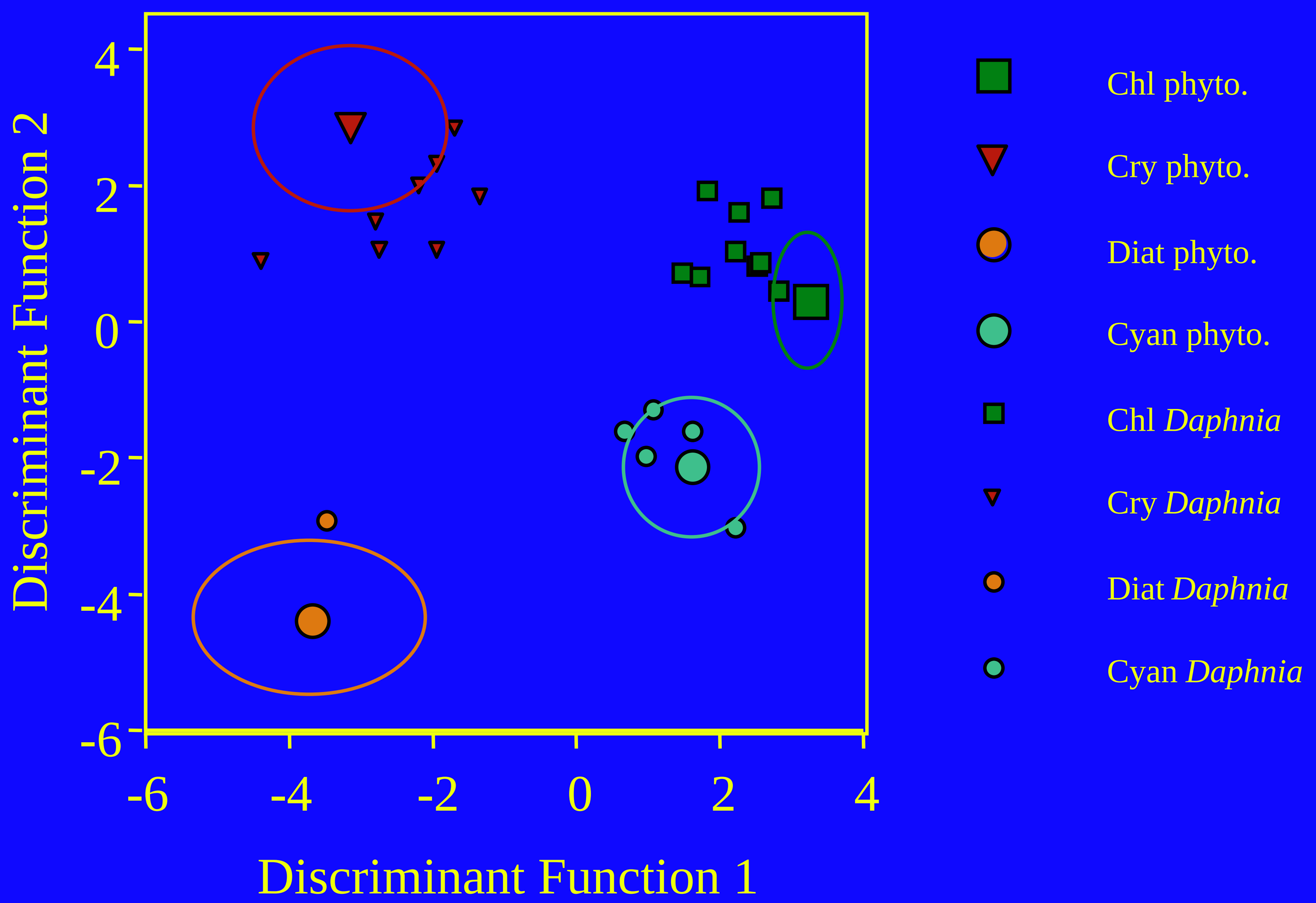
2) Somatic tissues and eggs have significantly more 18:1ω7 and ARA, and significantly less DHA than the diets

3) *Daphnia* eggs had significantly more 18:3ω3 and 18:4ω3, higher ω3:ω6 ratios and a higher total fatty acid content than does the somatic tissue

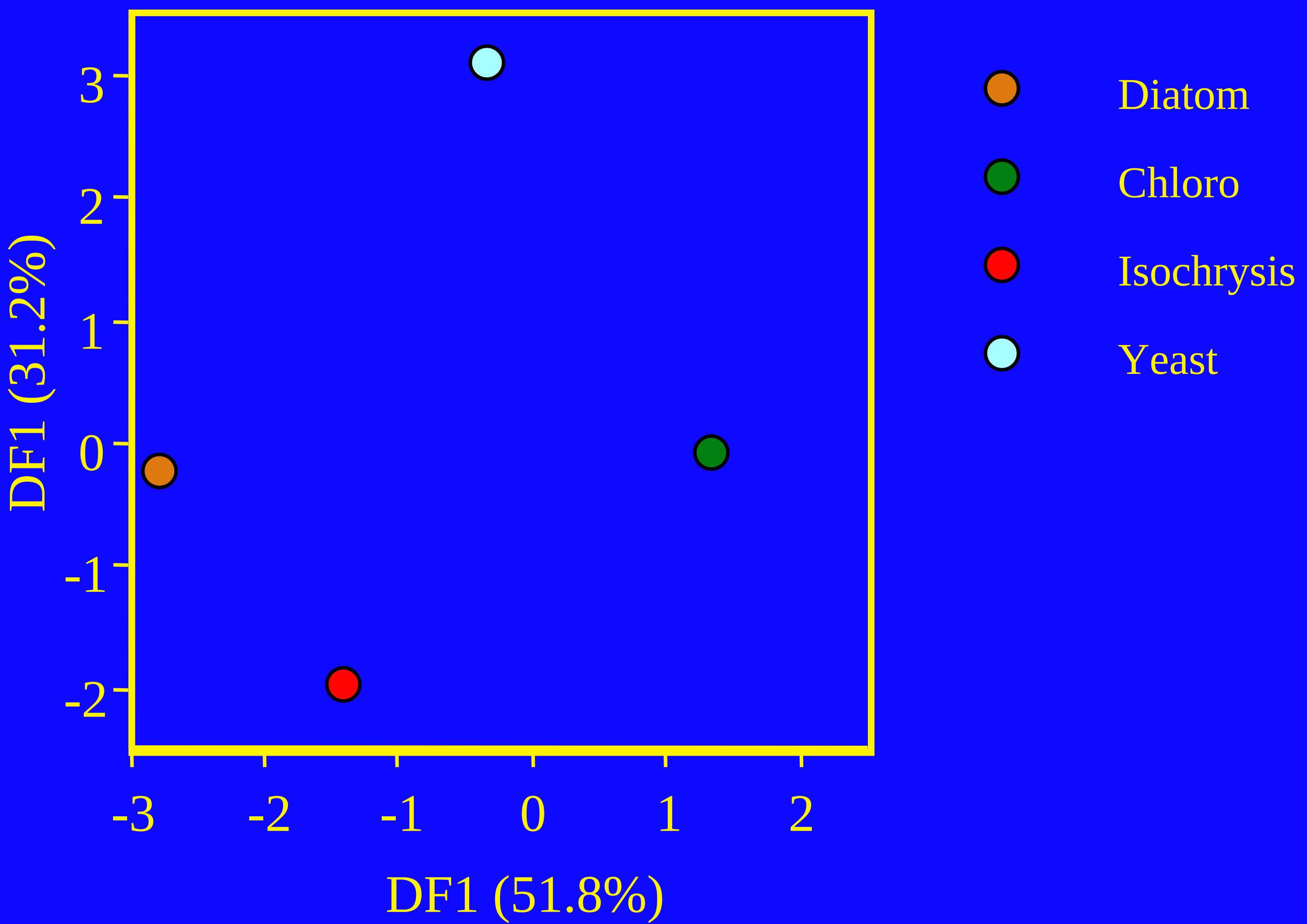
Archiv. Hydrobiol. 167: 501-



Discriminant Function 2
4
2
0
-2
-4
-6
-6
-4
-2
0
2
4
Discriminant Function 1
Chl phyto.
Cry phyto.
Diat phyto.
Cyan phyto.

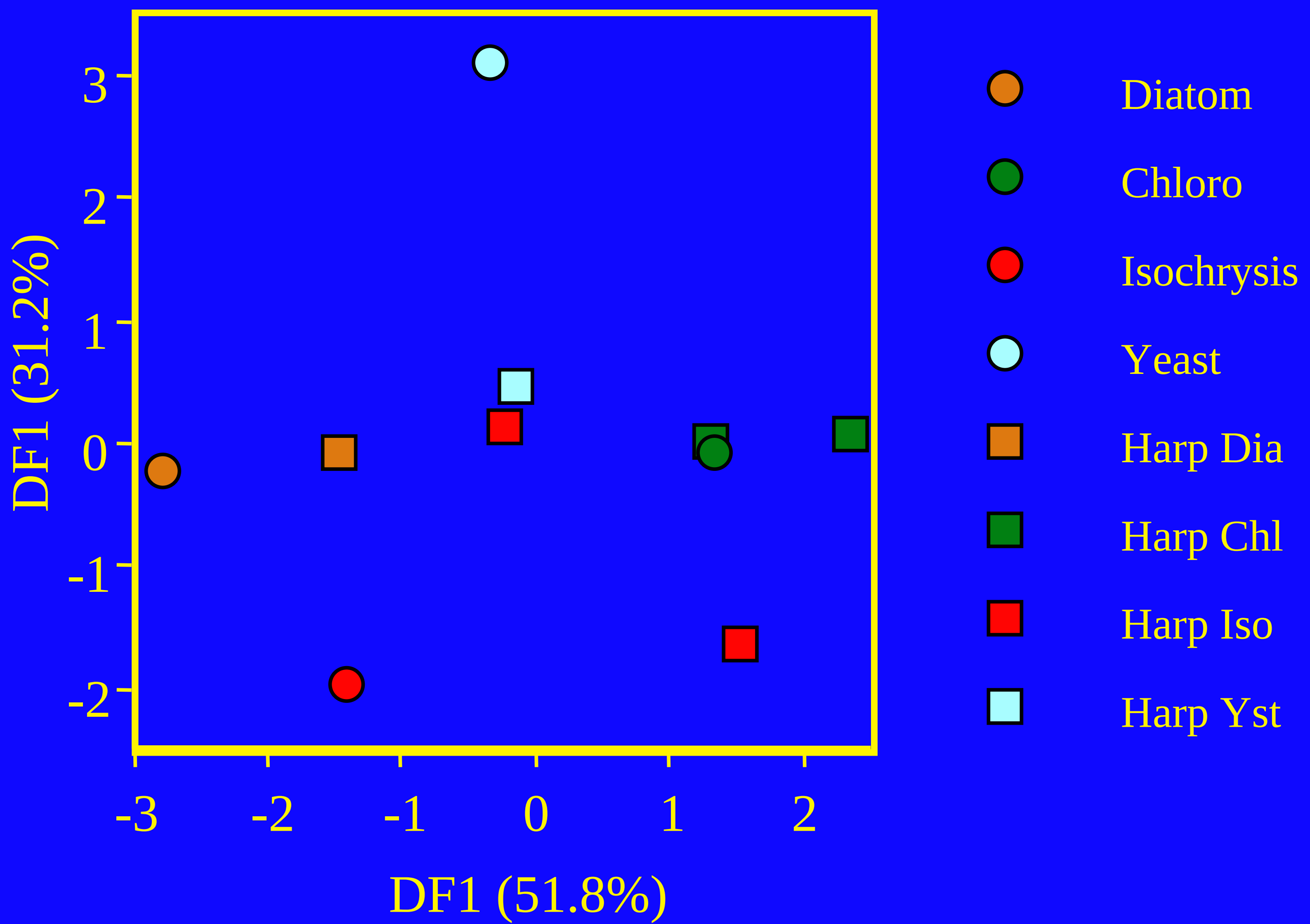

Discriminant Function 2
4
2
0
-2
-4
-6
-6
-4
-2
0
2
4
Discriminant Function 1
Chl phyto.
Cry phyto.
Diat phyto.
Cyan phyto.
Chl *Daphnia*
Cry *Daphnia*
Diat *Daphnia*
Cyan *Daphnia*

Nanton and Castell 1998



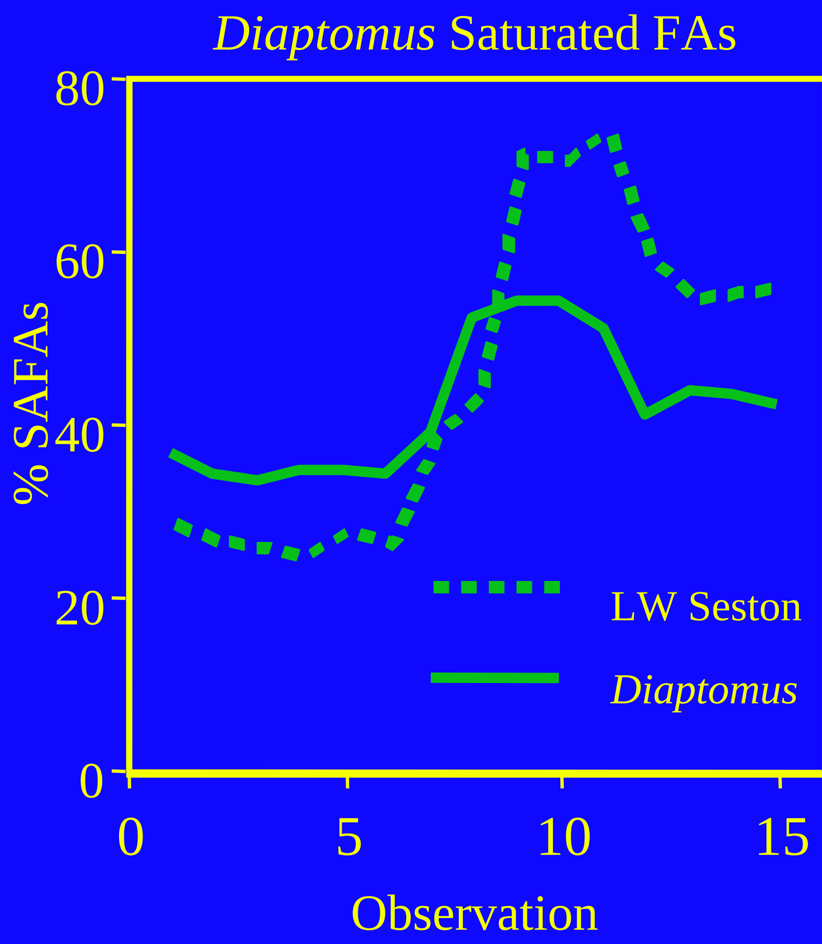
Aquaculture 163: 251-

Nanton and Castell 1998



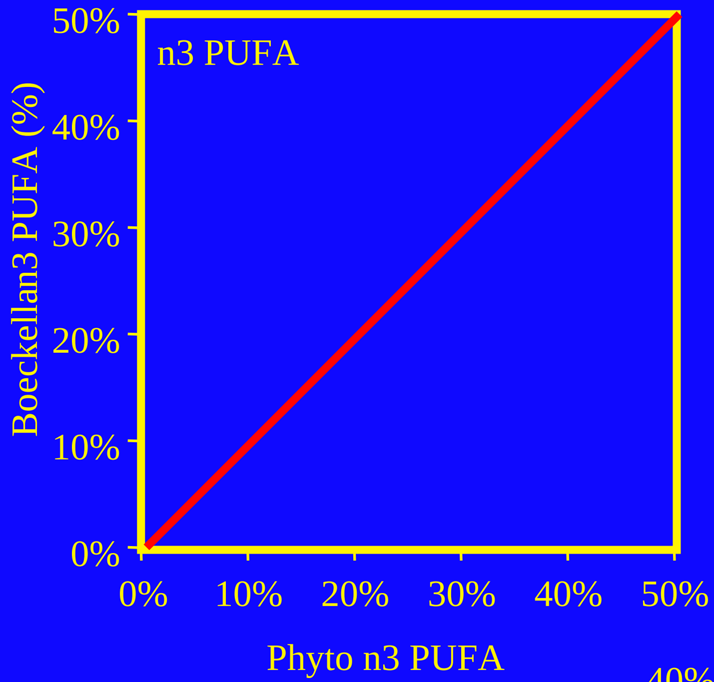
Aquaculture 163: 251-

Dietary control of fatty acid composition with homeostasis

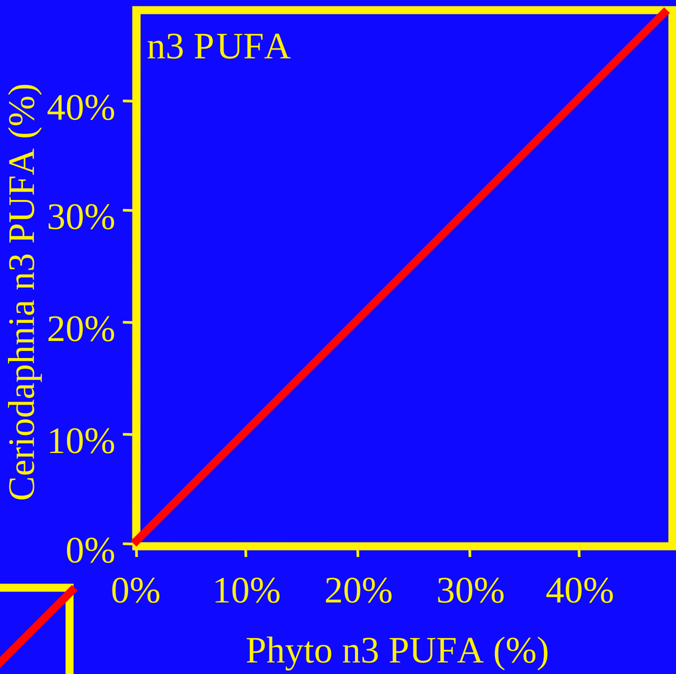


Ravet et al., unpub.

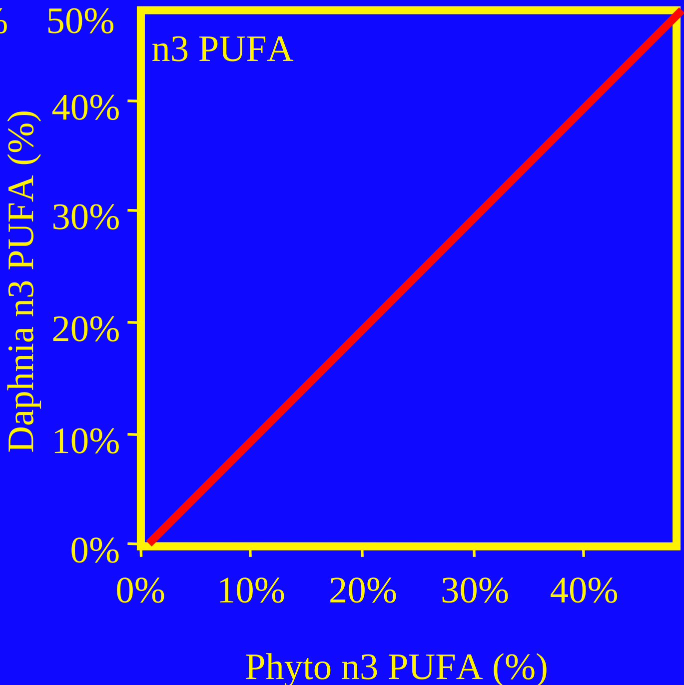
Boeckella



Ceriodaphnia

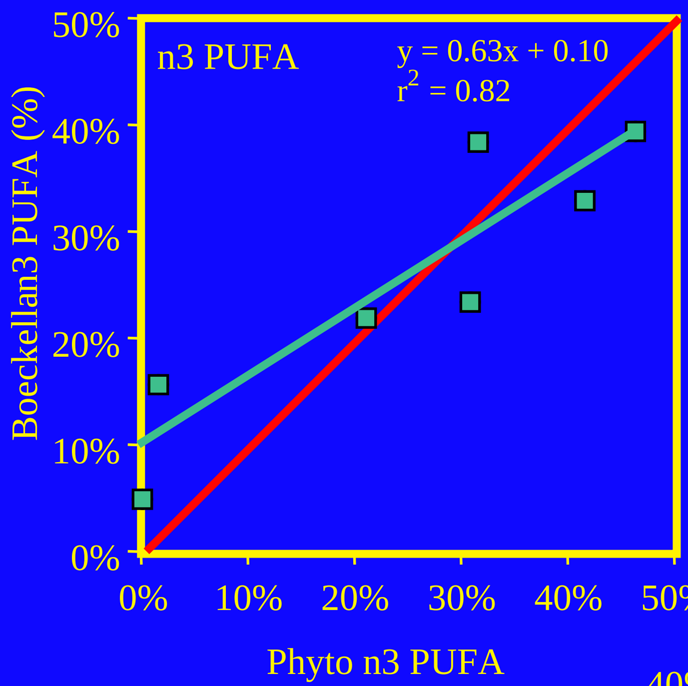


Daphnia

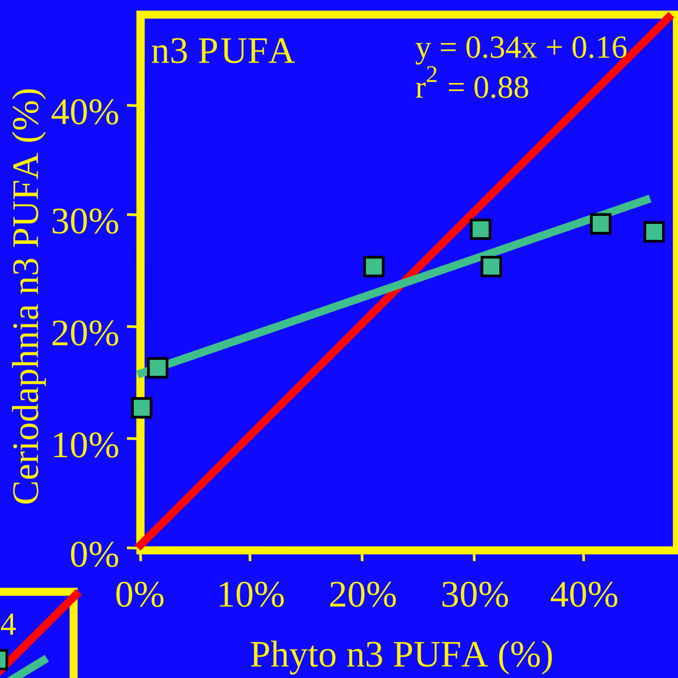


Burns et al., SIL 2007

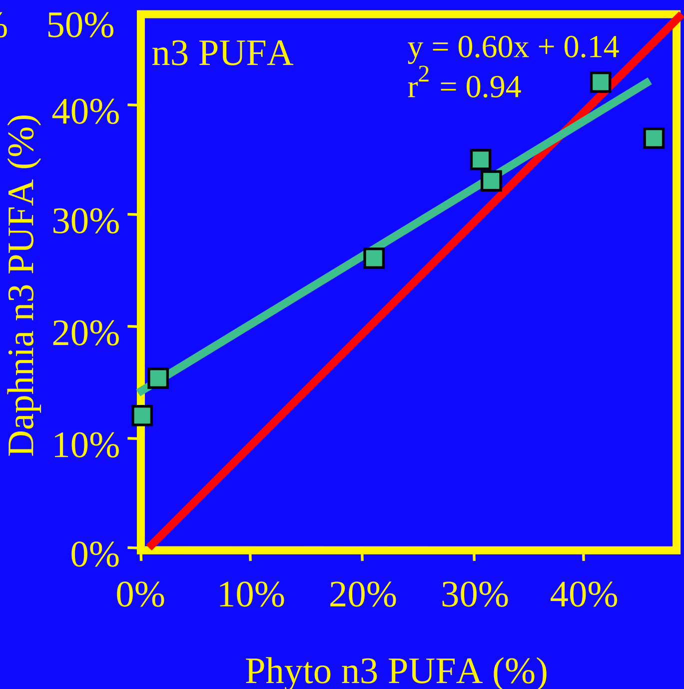
Boeckella



Ceriodaphnia

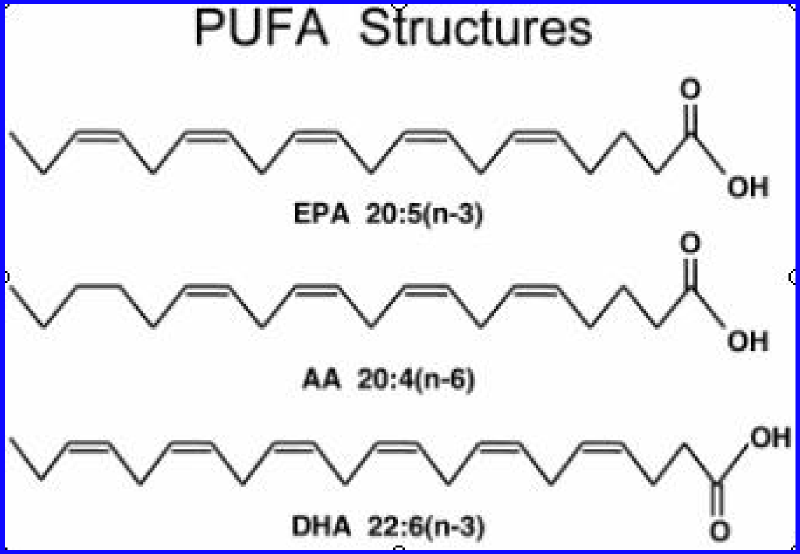


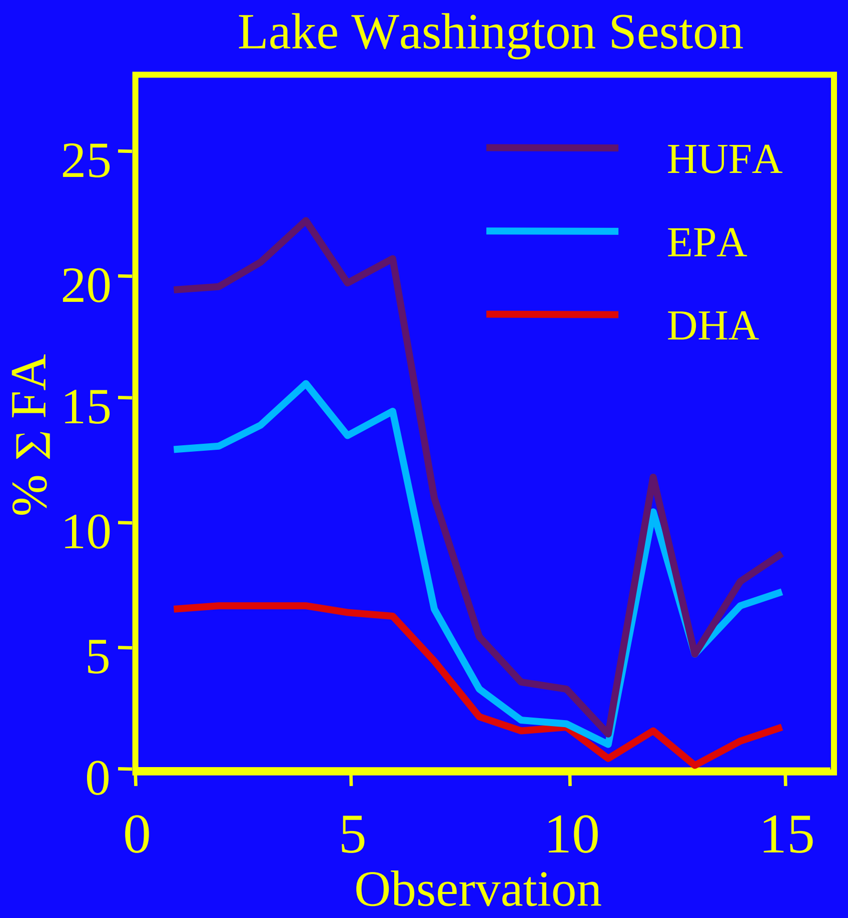
Daphnia



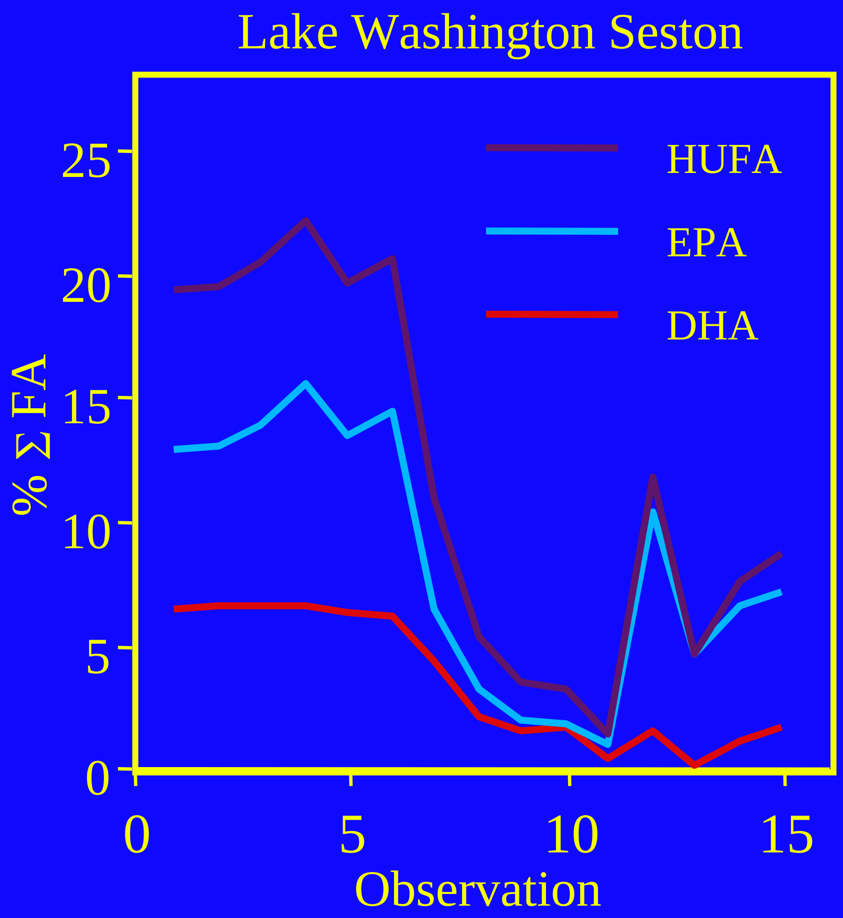
Burns et al., SIL 2007

Biochemical transformations



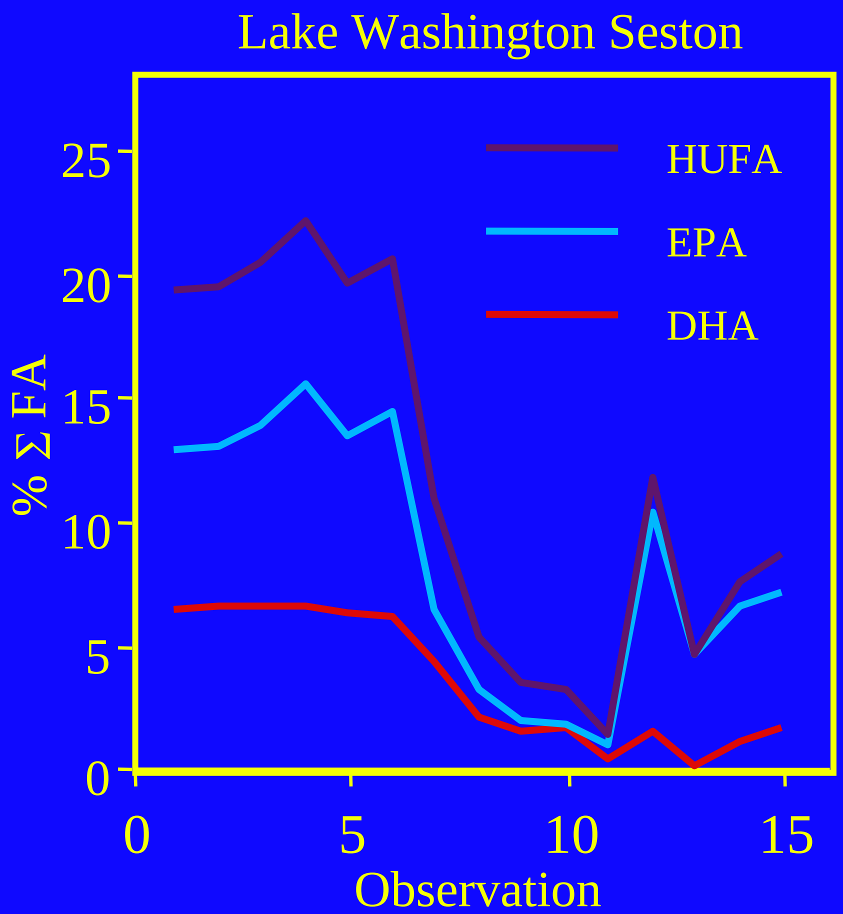


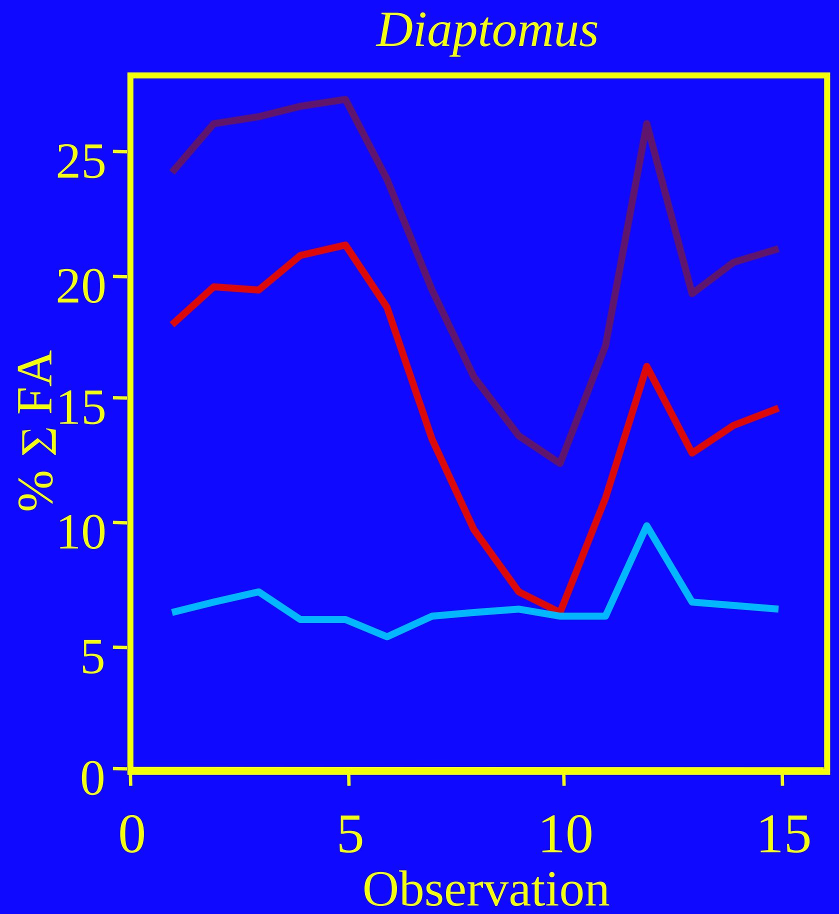
Ravet et al., unpub.



Seston HUFA is dominated by EPA

Ravet et al., unpub.

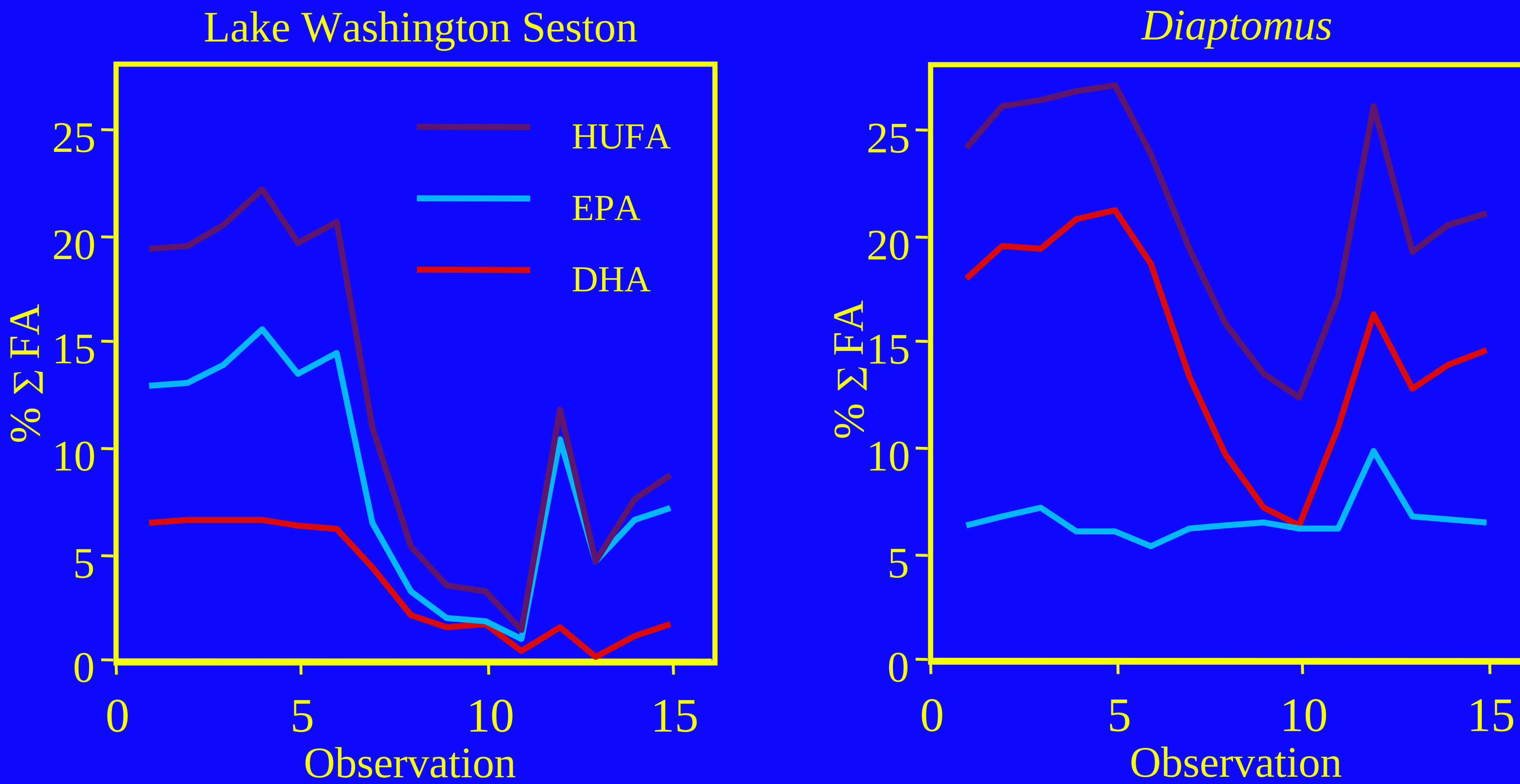




Seston HUFA is dominated by EPA

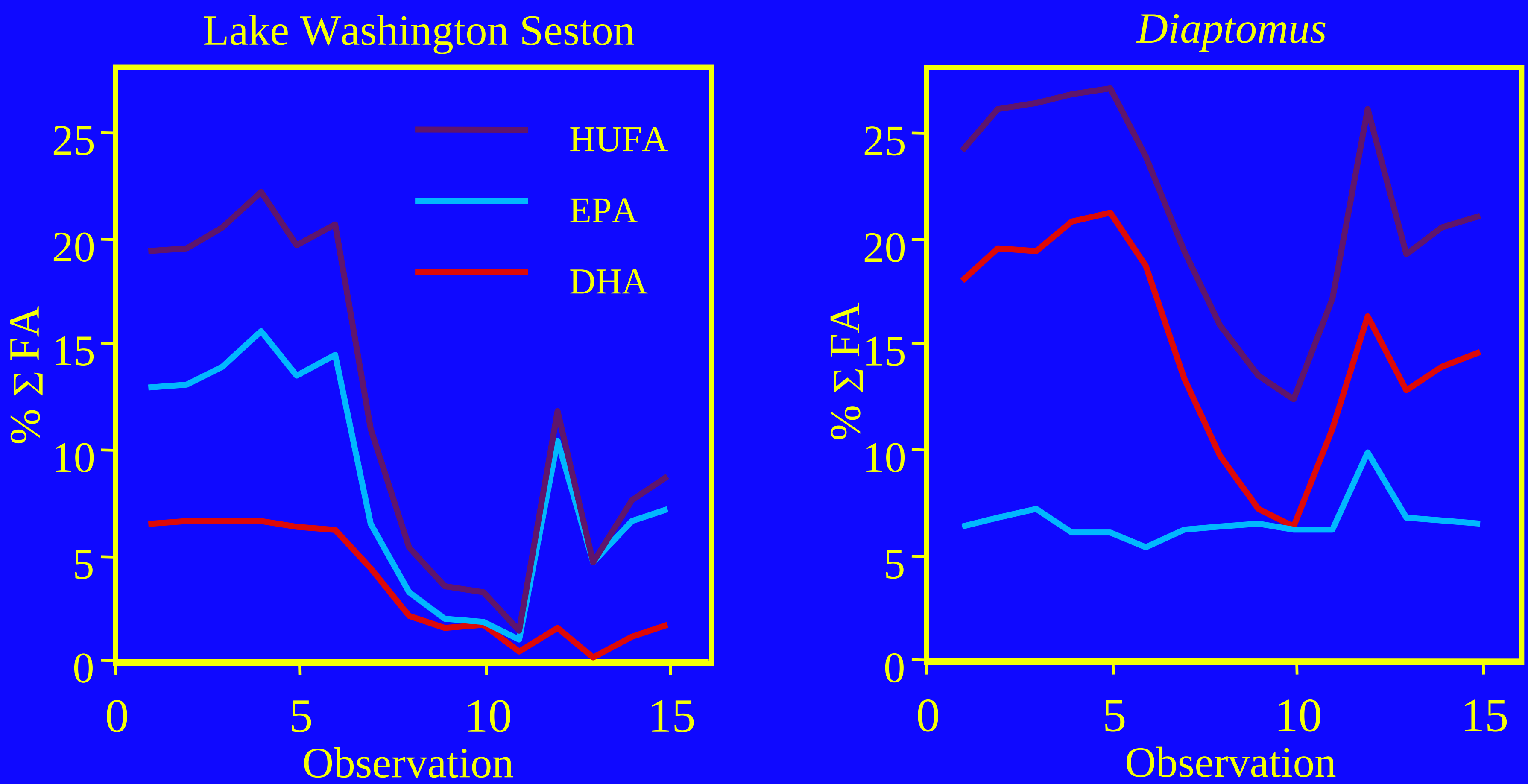
Diaptomus HUFA is dominated by DHA

Ravet et al., unpub.



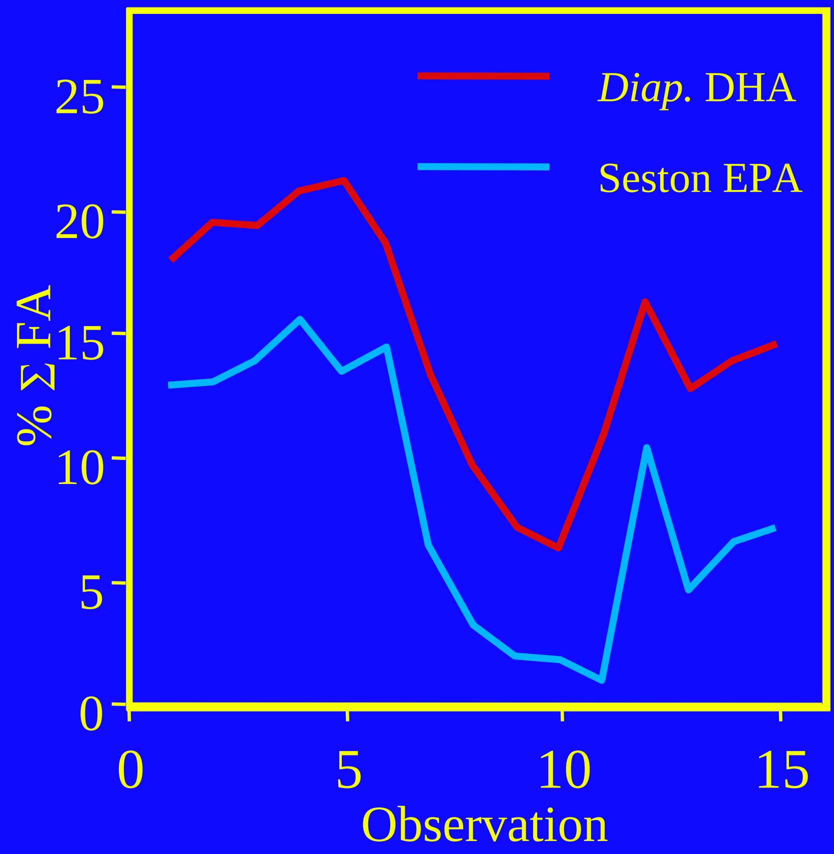
r^2		Seston EPA	Seston DHA	Seston HUFA
Diaptomus	EPA	0.01		
Diaptomus	DHA		0.62	
Diaptomus	HUFA			0.78

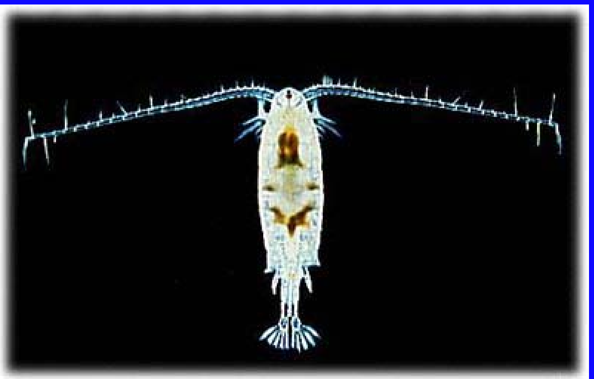
Ravet et al., unpub.



r^2		Seston EPA	Seston DHA	Seston HUFA
Diaptomus	EPA	0.01	0.06	0.00
Diaptomus	DHA	0.91	0.62	0.86
Diaptomus	HUFA	0.87	0.50	0.78

Ravet et al., unpub.





Ravet et al., unpub.

Cold adaptation and zooplankton fatty acid composition: the homeoviscous response

Schlechtriem et al. 2006

TABLE 1
Effects of Growth Temperature on FA Composition (% of total identified FAME) of *Daphnia pulex* Fed *Ankistrodesmus falcatus*

		DA22		DA11	
	A. falcatus	Mean	SE	Mean	SE
11:0	nd	nd		0.3	0.2
12:0	0.6	0.2	0.0[a]	1.0	0.2[a]
14:0	0.3	1.4	0.1[a]	1.7	0.1[a]
15:0	0.1	0.8	0.0[a]	0.5	0.0[b]
16:0	20.4	18.6	0.5[a]	19.1	0.6[a]
16:1n-7	1.0	3.3	0.1[b]	13.0	0.4[a]
17:0	0.1	0.9	0.0[a]	1.1	0.0[a]
18:0	0.5	8.1	0.5[a]	6.2	1.7[a]
18:1n-9*t*	nd	0.1	0.0[a]	0.1	0.0[a]
18:1n-9*c*	11.6	19.2	0.5[b]	23.2	0.5[a]
18:2n-6*c*	15.9	14.3	0.3[a]	6.8	1.2[b]
20:0	nd	0.3	0.1	nd	
18:3n-6	1.4	1.2	0.0[a]	0.7	0.0[b]
20:1n-9	nd	0.1	0.0	nd	
18:3n-3	44.3	22.4	0.3[a]	11.3	0.2[b]
21:0	nd	0.1	0.0	nd	
20:2	nd	1.8	0.2	nd	
22:0	2.4	0.5	0.1	nd	
20:3n-6	nd	0.1	0.0[a]	0.1	0.0[a]
22:1n-9	nd	0.3	0.0	nd	
20:3n-3	nd	0.2	0.0	nd	
20:4n-6	nd	2.7	0.3[a]	2.1	0.1[a]
24:0	0.9	0.2	0.0	nd	
20:5n-3	nd	3.1	0.2[a]	12.7	0.4[b]
24:1n-9	0.2	0.3	0.3	nd	
Σn-3	44.3	25.6	0.3[a]	24.0	0.6[a]
Σn-6	17.4	18.2	0.5[a]	9.7	1.3[b]
ΣSAFA	25.4	31.0	1.0[a]	30.0	2.2[a]
ΣMUFA	12.9	23.3	0.4[b]	36.3	0.4[a]
ΣPUFA	61.7	45.7	0.5[a]	33.7	1.8[b]

[a]Results are means ± SE. Values within a row with a different superscripted letter are significantly different ($P < 0.05$). nd = not detected. DA22, *Daphnia pulex* cultured at 22°C; DA11, *D. pulex* cultured at 11°C; SAFA, saturated FA; MUFA, monounsaturated FA.

Lipids 41: 397-

Schlechtriem et al. 2006

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21:0	nd	0.1	0.0	nd	
20:2	nd	1.8	0.2	nd	
22:0	2.4	0.5	0.1	nd	
20:3n-6	nd	0.1	0.0[a]	0.1	0.0[a]
22:1n-9	nd	0.3	0.0	nd	
20:3n-3	nd	0.2	0.0	nd	
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24:0	0.9	0.2	0.0	nd	
20:5n-3	nd	3.1	0.2[a]	12.7	0.4[b]
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1) **When cold adapted** 18:2ω6 **and** 18:3ω3 **go down,**

2) 16:1ω7 **and EPA go up**

3) **Farkas et al. (1984, Lipids 19: 436-) previously noted this response for copepod FAs which became enriched with DHA during cold adaptation**

Lipids 41: 397-

Schlechtriem et al. 2006

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20:3n-6	nd	0.1	0.0[a]	0.1	0.0[a]
22:1n-9	nd	0.3	0.0	nd	
20:3n-3	nd	0.2	0.0	nd	
20:4n-6	nd	2.7	0.3[a]	2.1	0.1[a]
24:0	0.9	[illegible]	0.0	nd	
20:5n-3	nd	3.1	0.2[a]	12.7	0.4[b]
24:1n-9	0.2	0.3	0.3	nd	
Σn-3	44.3	25.6	0.3[a]	24.0	0.6[a]
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2) 16:1ω7 and EPA go up

3) Farkas et al. (1984, Lipids 19: 436-) previously noted this response for copepods FAs which became enriched with DHA during cold adaptation

4) Evidence of 18:3ω3 conversion to EPA

Lipids 41: 397-

Starvation impacts on fatty acid composition

Schlechtriem et al. 2006

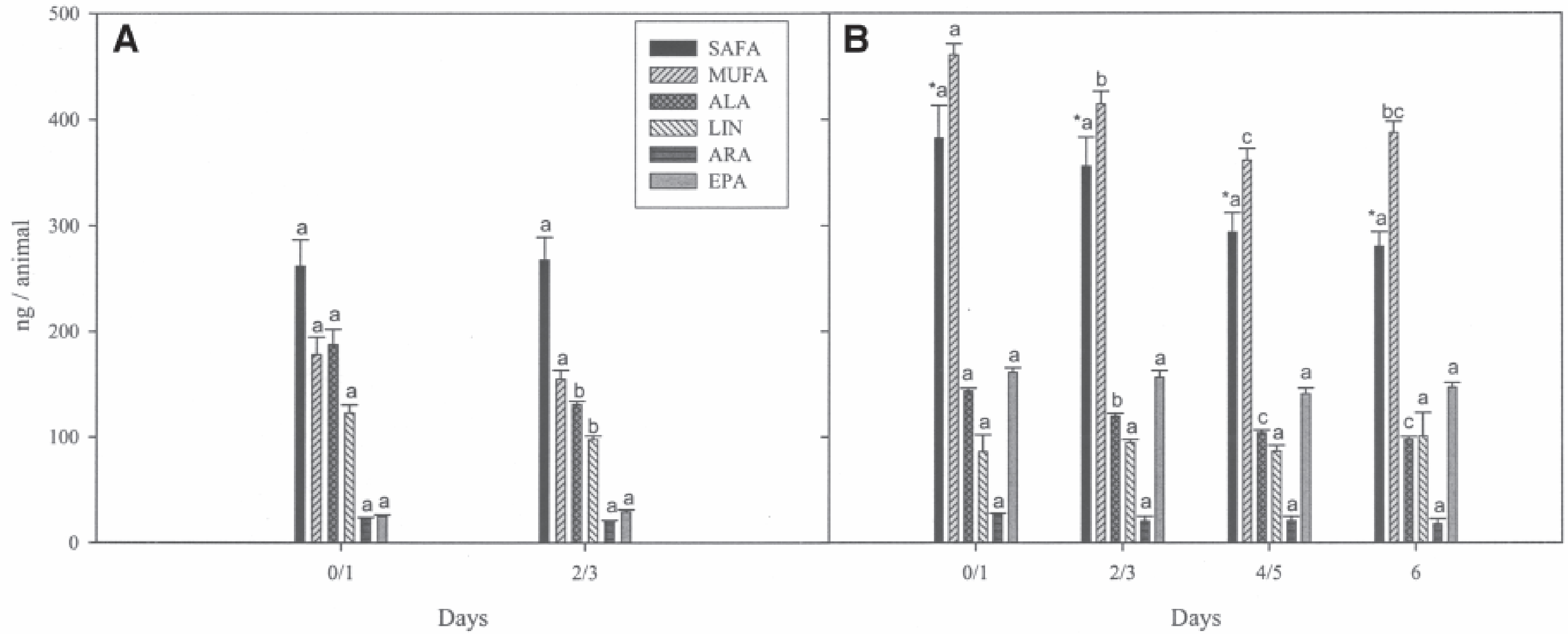
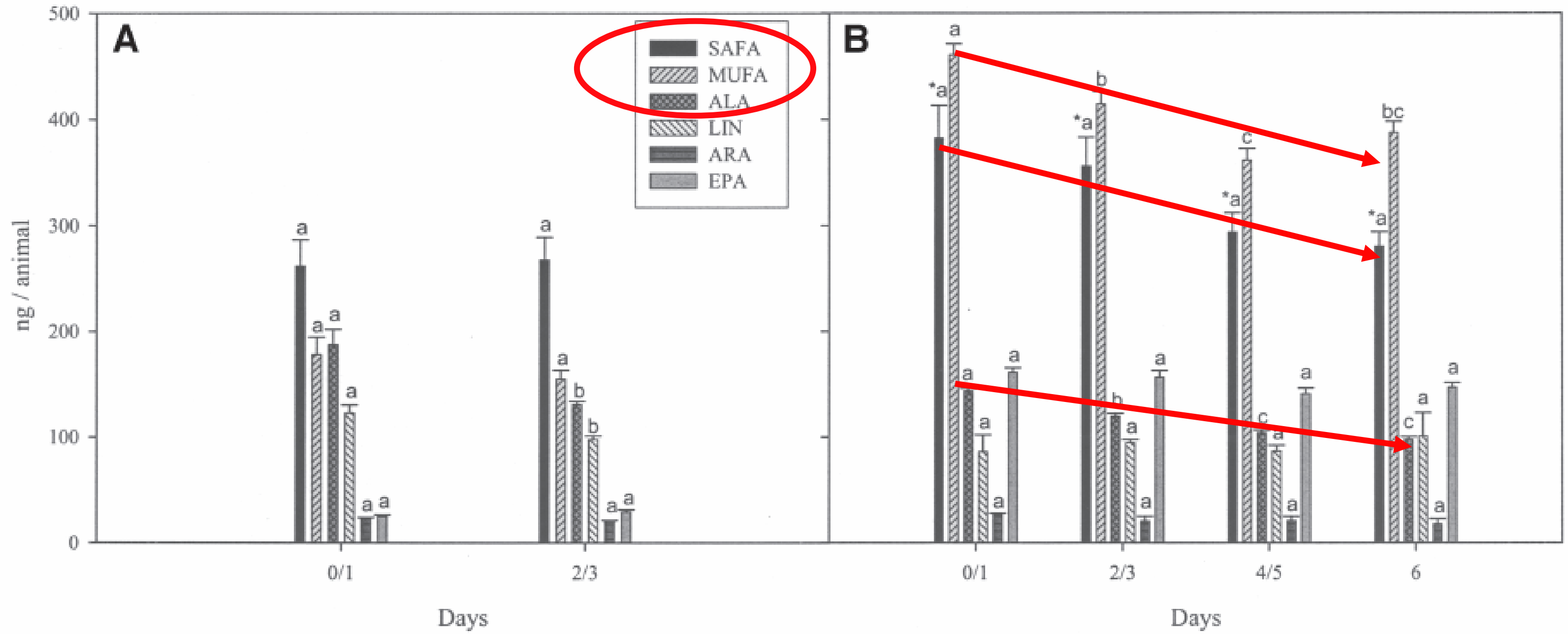


FIG. 1. Temporal trajectories of FA in fasting *Daphnia pulex* kept at (A) 22 and (B) 11°C. Results are means ± SE. Significant differences between means were determined by one-way ANOVA followed by Tukey's multiple comparison test. Values of the same FA with a different superscripted letter are significantly different ($P < 0.05$). An asterisk indicates that there was a statistically significant difference ($P = 0.031$), but the power of the performed test (0.56) was below the desired power of 0.80. ALA, α-linolenic acid; ARA, arachidonic acid; LIN, linoleic acid; MUFA, monounsaturated FA; SAFA, saturated FA.

Lipids 41: 397-

Schlechtriem et al. 2006



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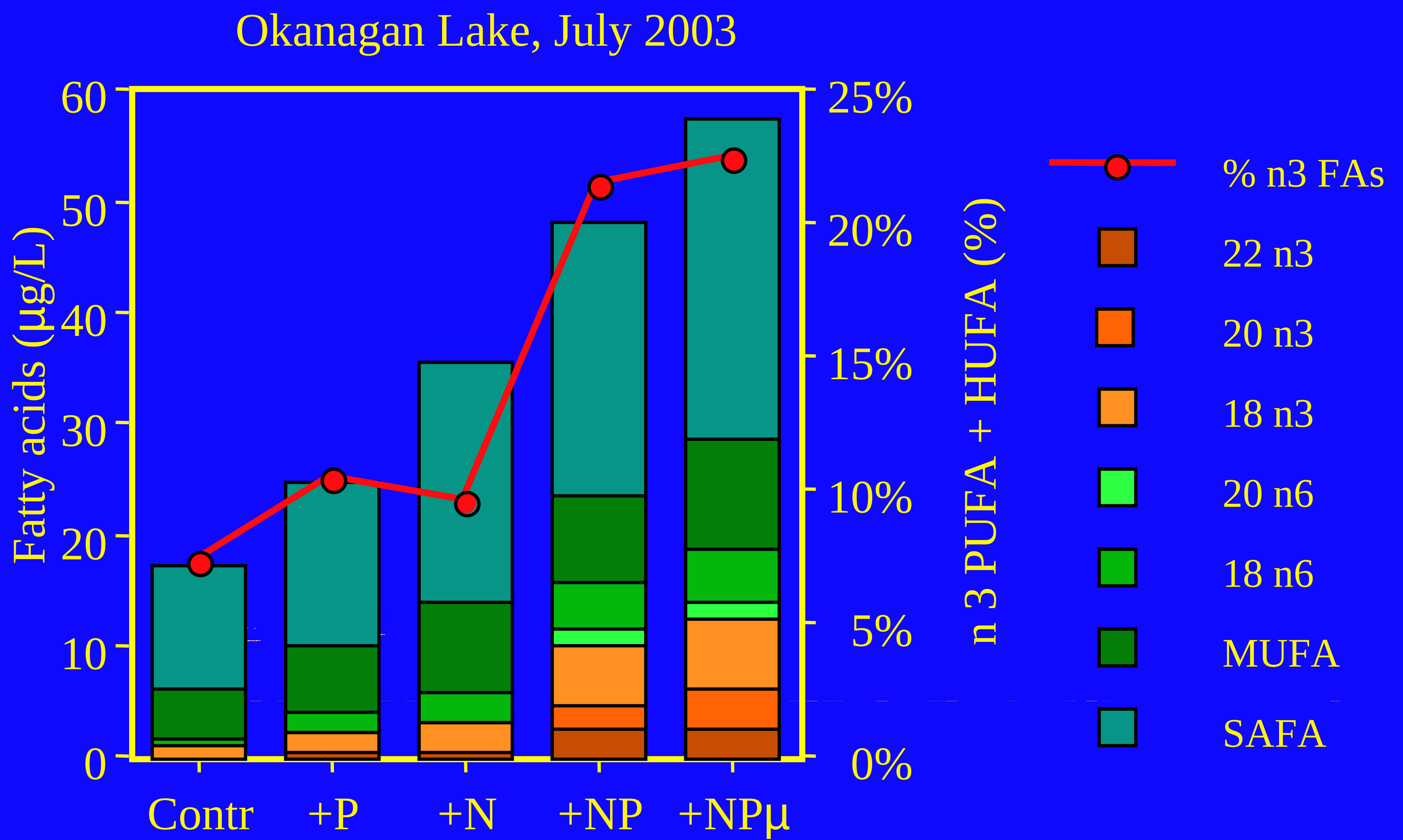
4) When starved SAFA, MUFA and 18:3ω3 are metabolized, &

5) 18:2ω6, ARA and EPA are conserved

Lipids 41: 397-


Okanagan Lake, July 2003
Fatty acids (µg/L)
n 3 PUFA + HUFA (%)
0
10
20
30
40
50
60
0%
5%
10%
15%
20%
25%
Contr
+P
+N
+NP
+NPµ
% n3 FAs
22 n3
20 n3
18 n3
20 n6
18 n6
MUFA
SAFA

Conclusions:

1) Copepods and cladocerans have distinct fatty acid profiles

2) Diet strongly influences the FA composition of zooplankton, especially the PUFAs and HUFAs

3) Despite strong dietary control, many zooplankton FAs stay within much narrower ranges than their diets

4) Copepods increase their DHA content and cladocerans increase their EPA content at lower temperatures

5) During starvation zooplankton selectively retain HUFA such as EPA and ARA

6) There is clear evidence of bioconversions of PUFA (e.g. 18:3ω3) to more physiologically important HUFAs like EPA and DHA