

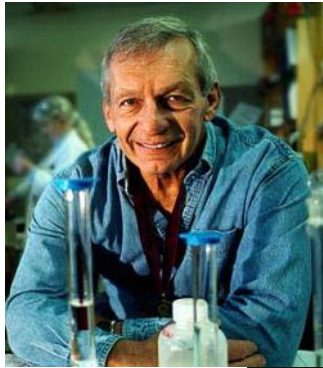
“Zooming in” on Scotland’s eutrophic loch management needs

Bryan Spears, Laurence Carvalho, Bernard Dudley &
Linda May

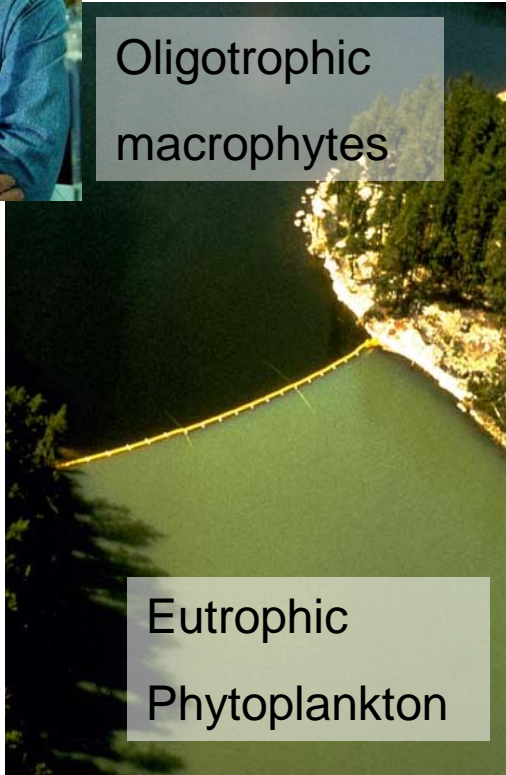
1 Centre for Ecology & Hydrology – Edinburgh

- A large proportion of Scottish lochs may not conform to the TP:Chl restoration approach
- Complexity of management increases from multi-lake to lake-specific scale
- Water quality is governed by multiple interacting drivers that are difficult to control



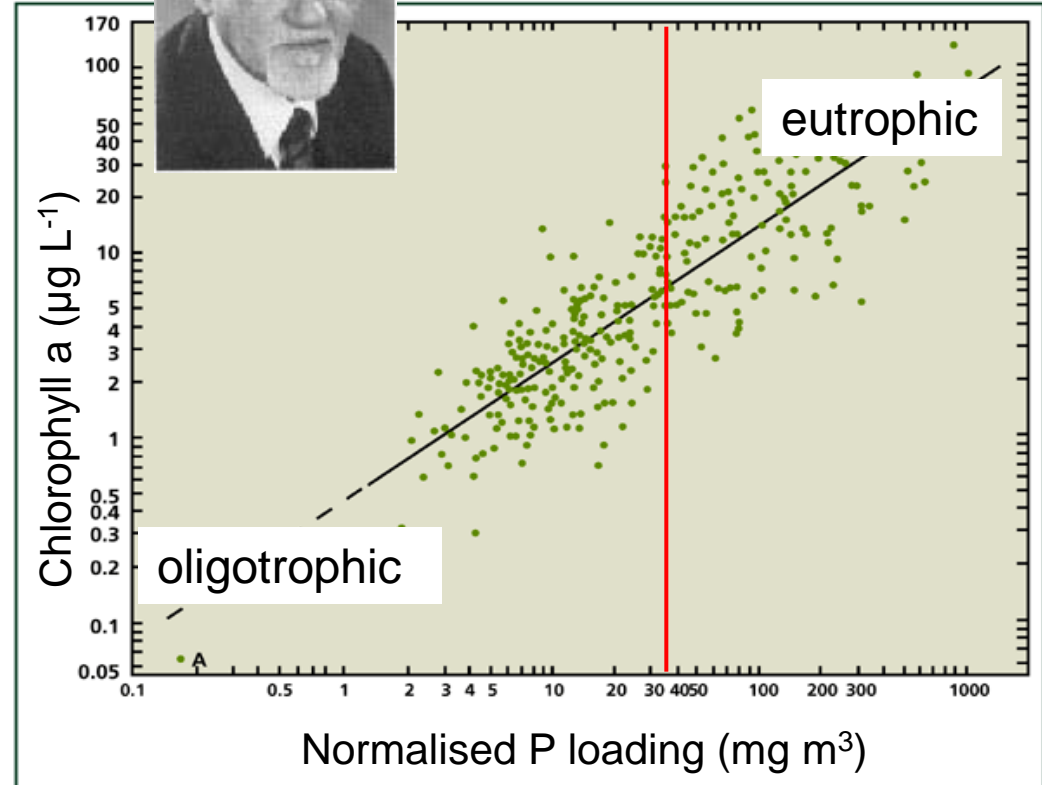
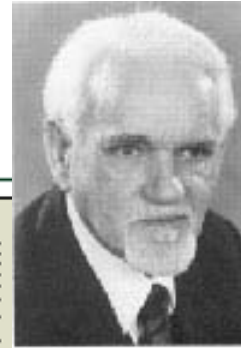


Oligotrophic
macrophytes



Eutrophic
Phytoplankton

Schindler, D. (1977) Science. 195, 260-262

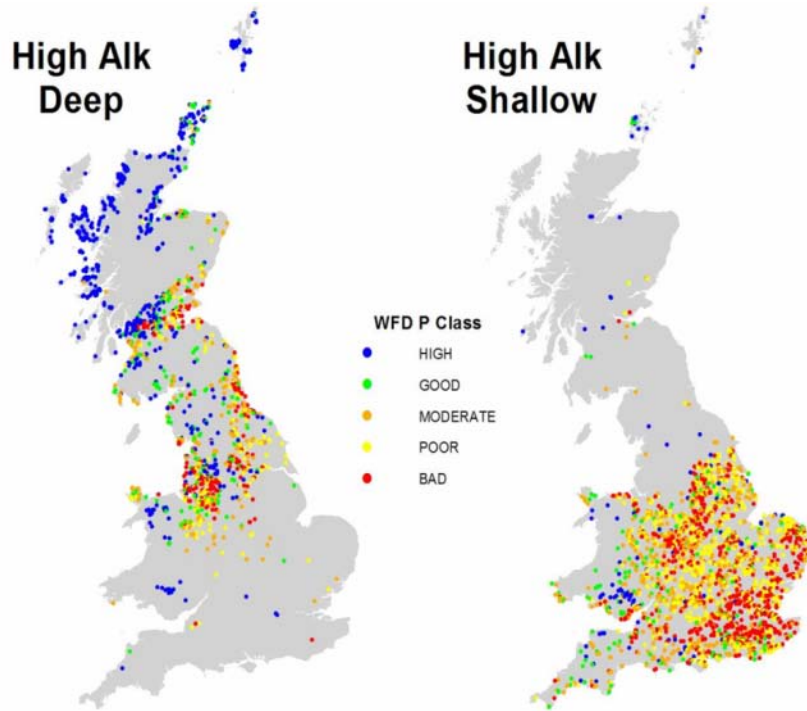


Vollenweider R.A. (1968) OECD (updated)

<i>Loch type</i>	H/G		G/M	
	<i>TP</i>	<i>Chl</i>	<i>TP</i>	<i>Chl</i>
HAVS	23	8.6	32	16.5
HAS	17	4.6	23	7.5
LAVS	9	4.1	14	7.9
LAS	7	3.2	10	5.5
LAD	5	3.2	9	4.8
MAVS	16	8.3	23	15.3
MAS	11	4.7	16	7.2
MAD	8	4.4	13	6.7

Table 1. Details of lake types used to categorise lakes

Type	Abbreviation	Determinand
Alkalinity types		
High	HA	Alkalinity > 1.0 mEq l ⁻¹
Moderate	MA	Alkalinity 0.2–1.0 mEq l ⁻¹
Low	LA	Alkalinity < 0.2 mEq l ⁻¹
Depth types		
Deep	D	Mean depth > 15.0 m
Shallow	S	Mean depth 3.0–15.0 m
Very shallow	VS	Mean depth < 3.0 m

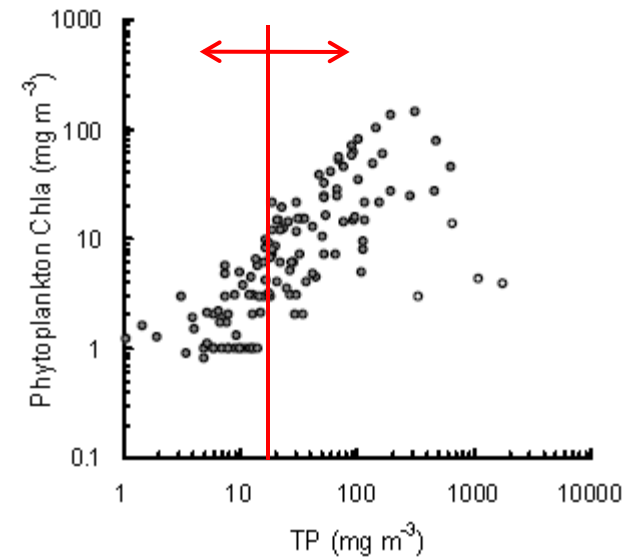


High Alkalinity - Deeper

England 72% at risk
Wales 34% at risk
Scotland 23% at risk

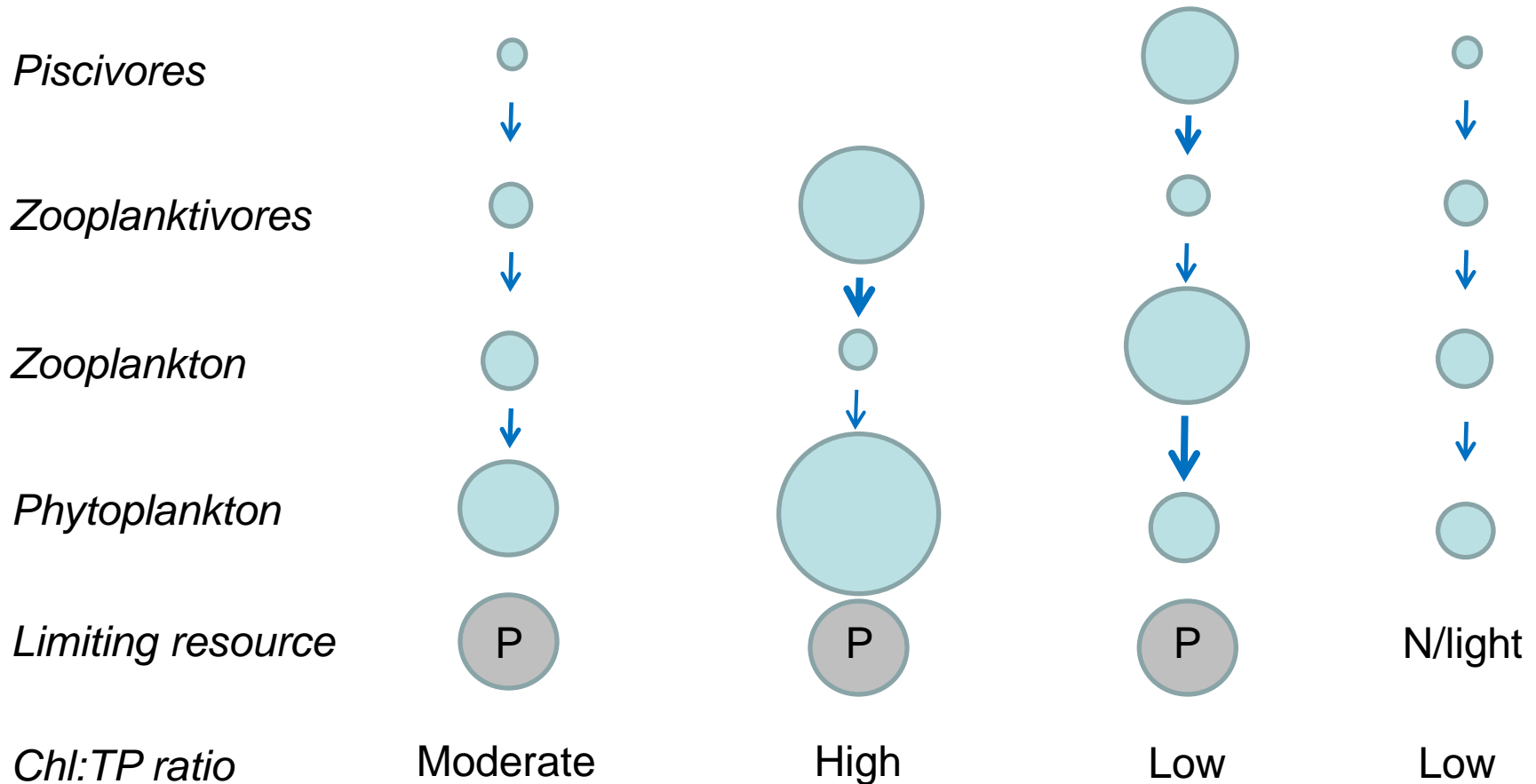
High Alkalinity - V Shallow

England 91% at risk
Wales 61% at risk
Scotland 29% at risk

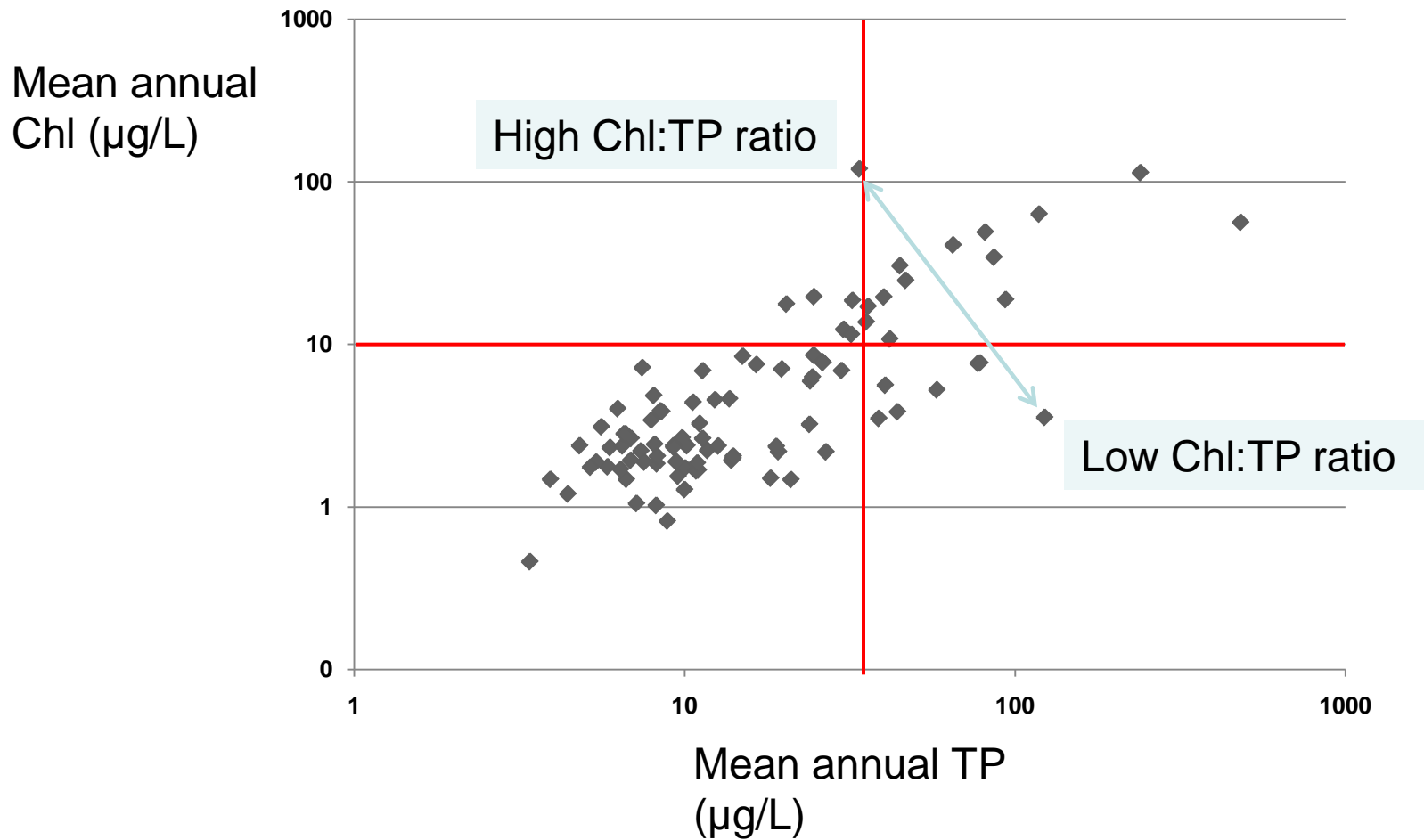


"Cascading trophic interactions and nutrient loading models are complimentary, not contradictory."

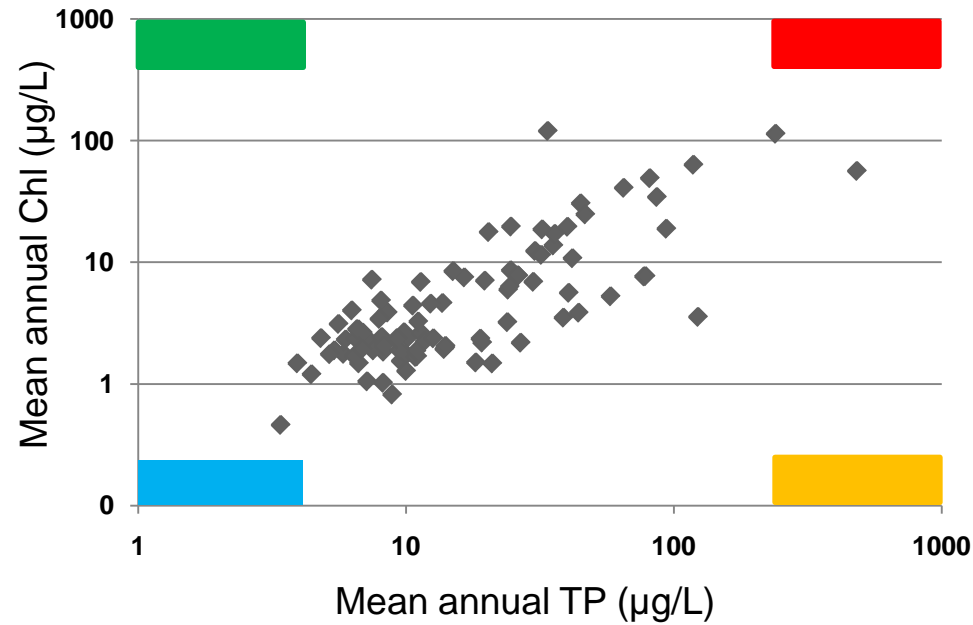
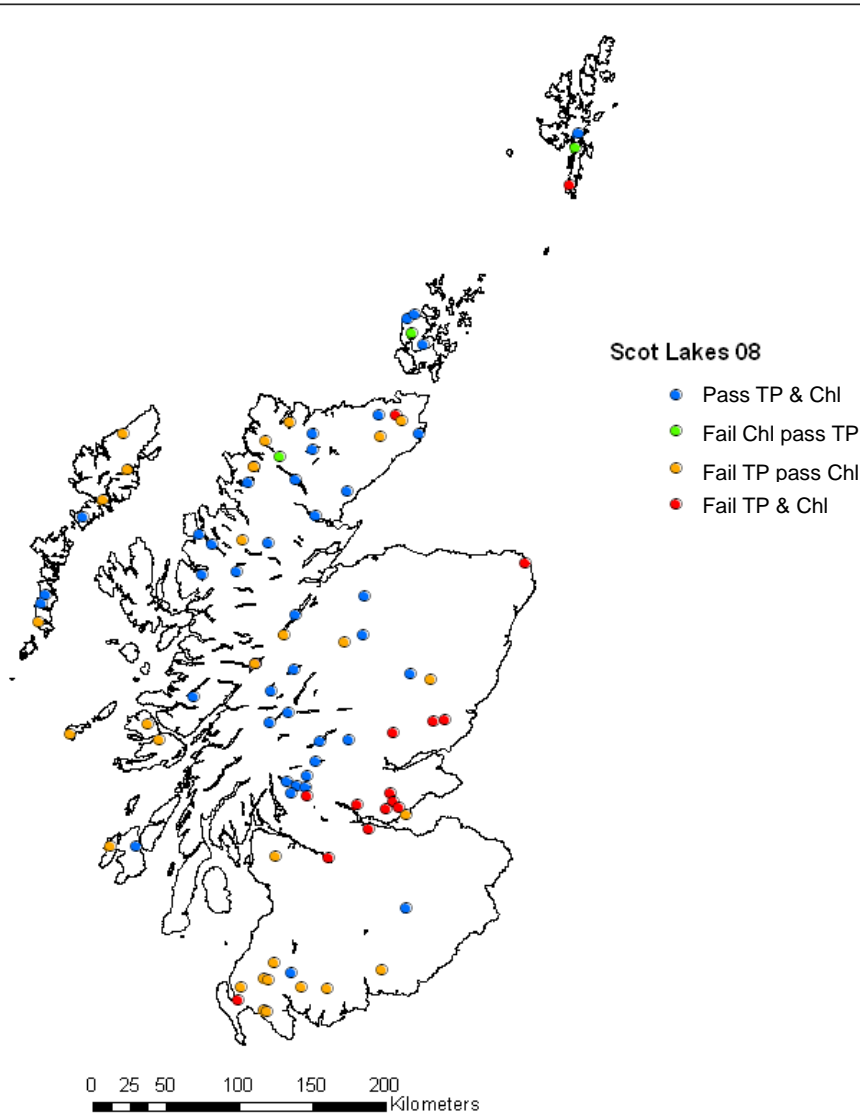
Stephen Carpenter et al., 1985, BioScience



	WFD Lake type							
	All	HAS	HAVS	LAD	LAS	LAVS	MAD	MAS
No. of lakes	92	15	12	16	30	8	3	7



- At the **national scale**, what proportion of lochs failed TP but passed chlorophyll WFD standards (i.e. low Chl:TP ratio lochs) in 2008?
- Does the ratio of Chl:TP vary across **WFD lake type**?
- Can we explain variations in Chl:TP ratio at the **lake specific scale**?
- What are the implications for the restoration of eutrophic lochs?



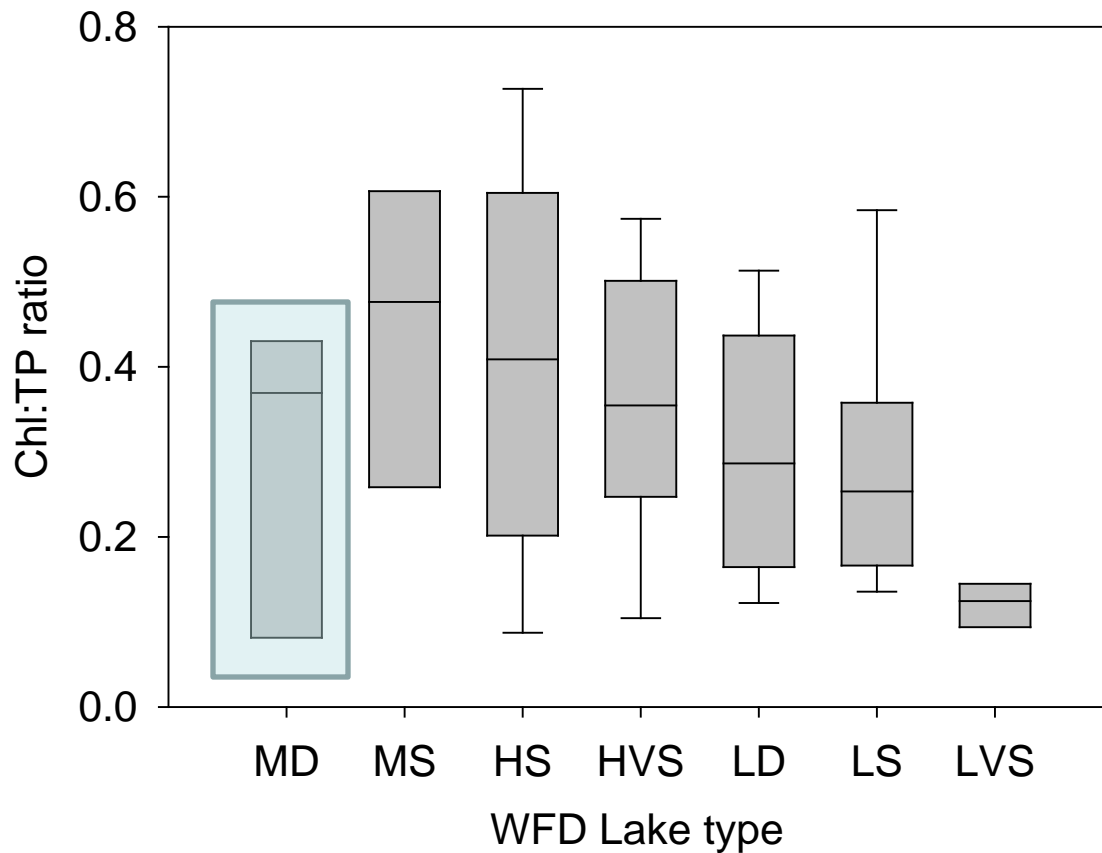
low TP; low Chl - 45 %

low TP; high Chl - 2 %

high TP; low Chl - 35 %

high TP; high Chl - 18 %

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High algae per unit TP

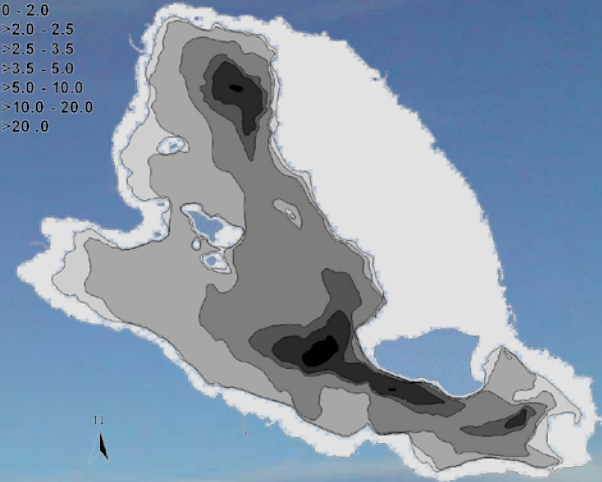


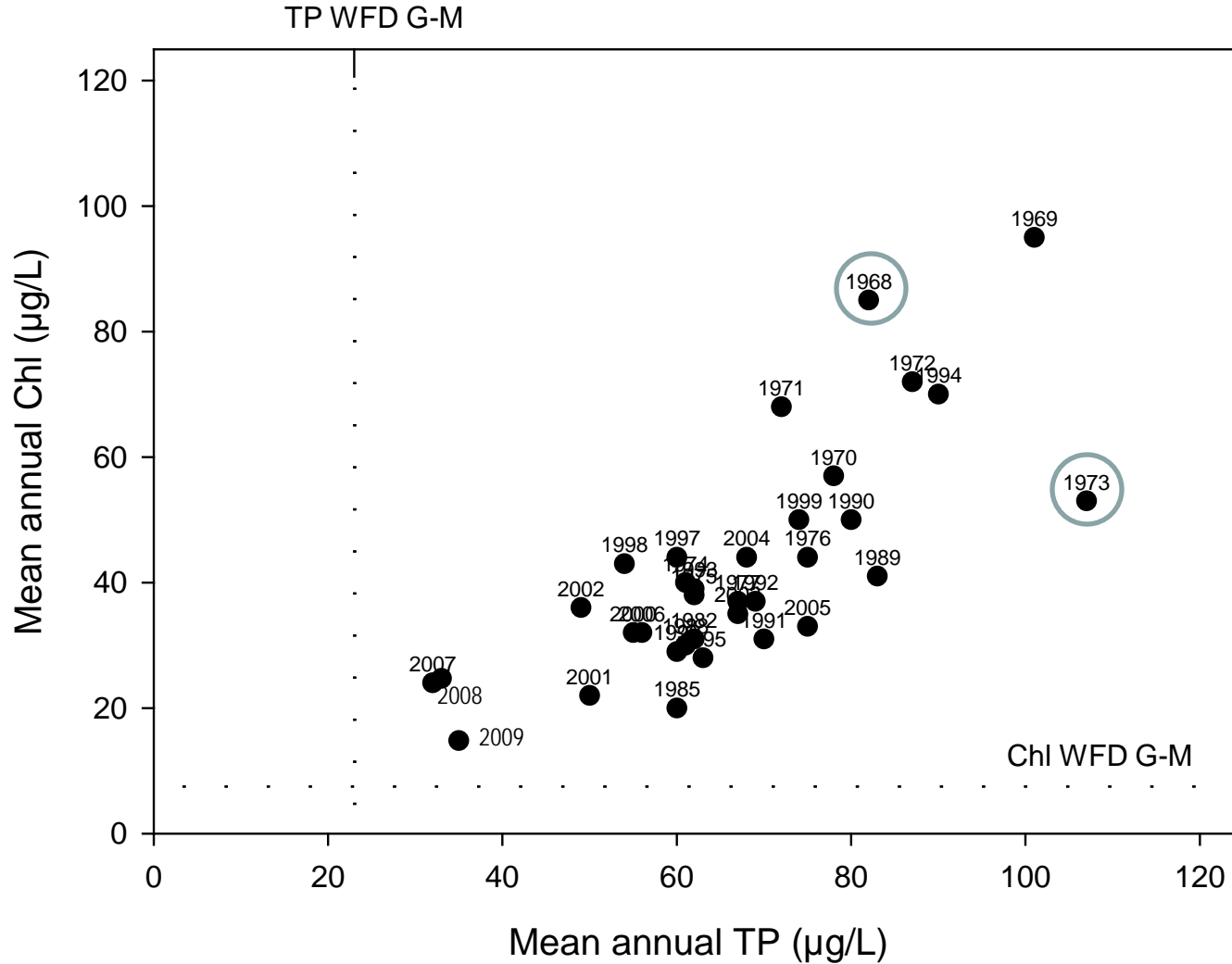
Low algae per unit TP

More chlorophyll per unit phosphorus as lakes get deeper?
More chlorophyll per unit phosphorus as alkalinity increases?

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County – P&K
Altitude – 106 m
Surface area – 1371 ha
Mean depth – 3.9 m
WFD type - HAS

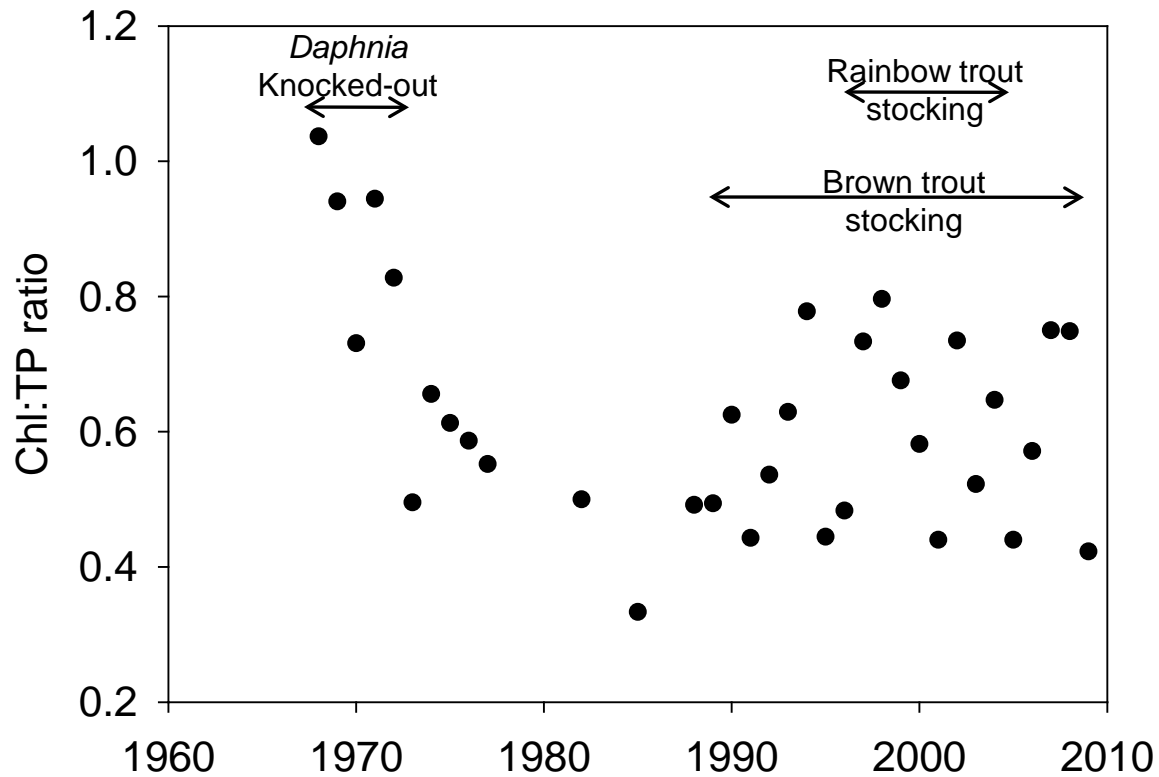
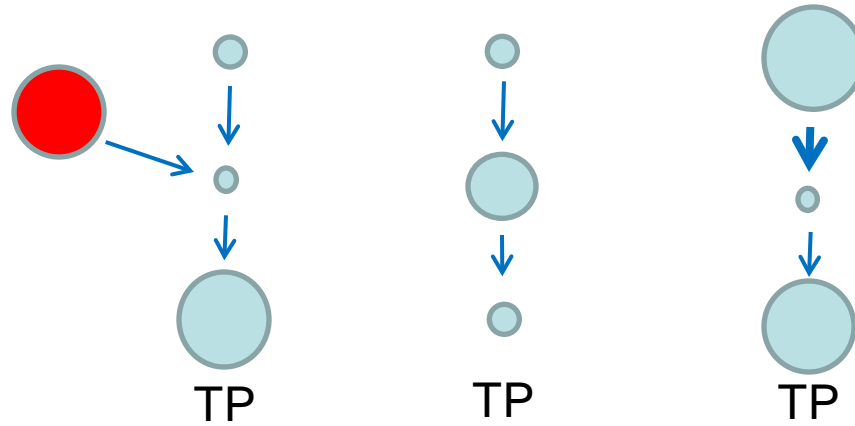




Zooplanktivores

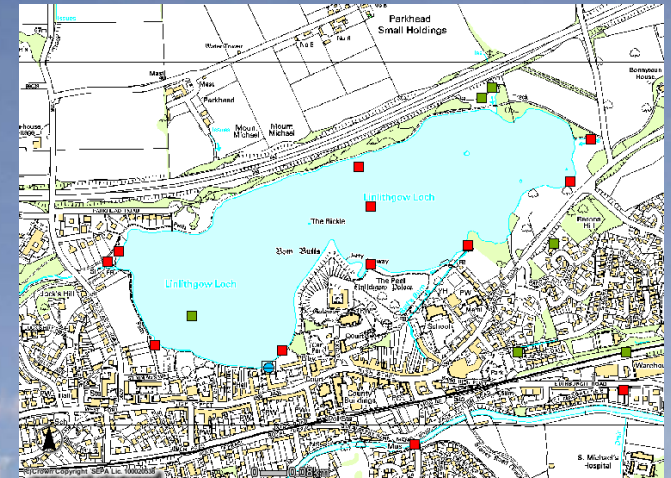
Zooplankton

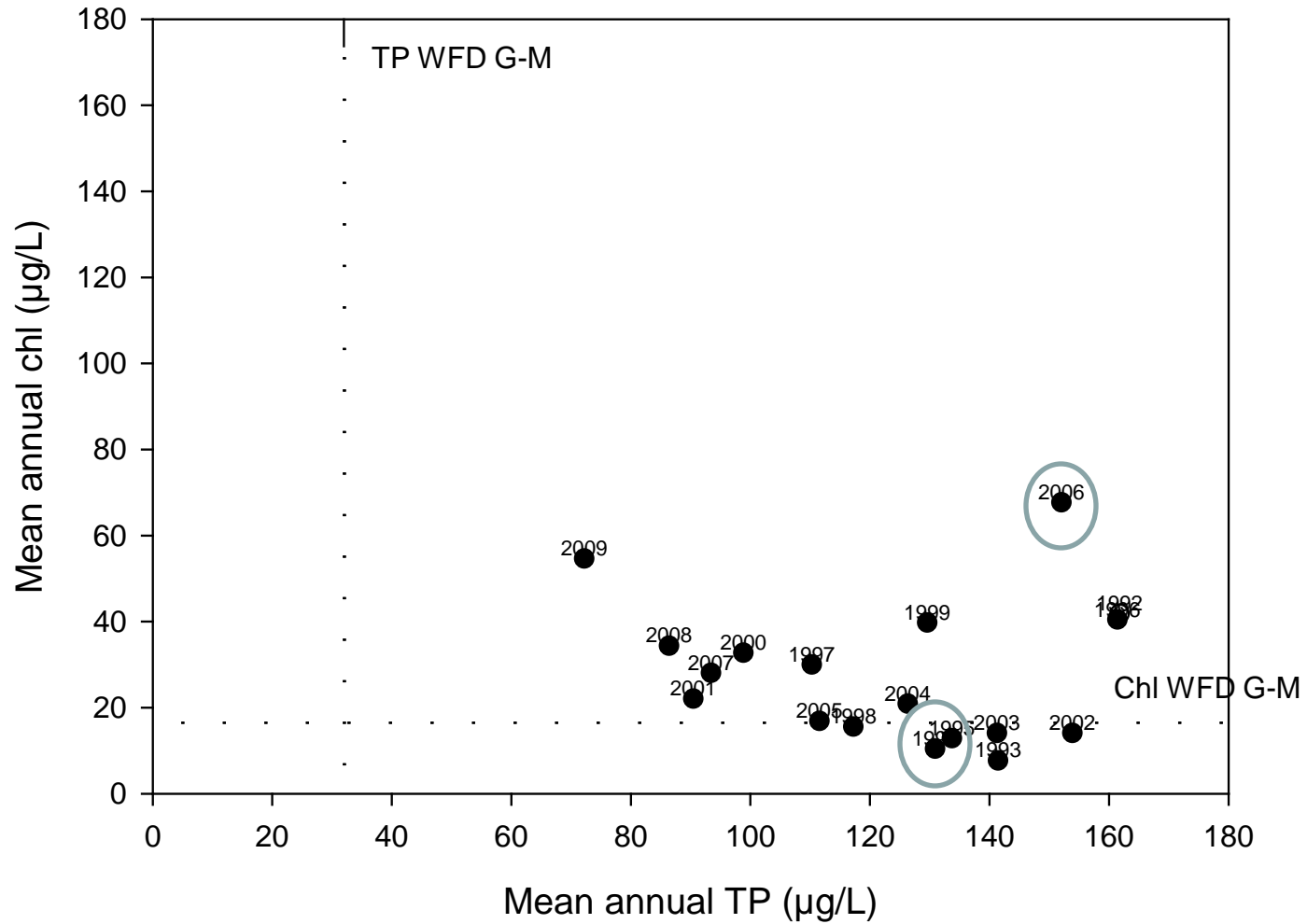
Phytoplankton



Linlithgow Loch – an N limited loch?

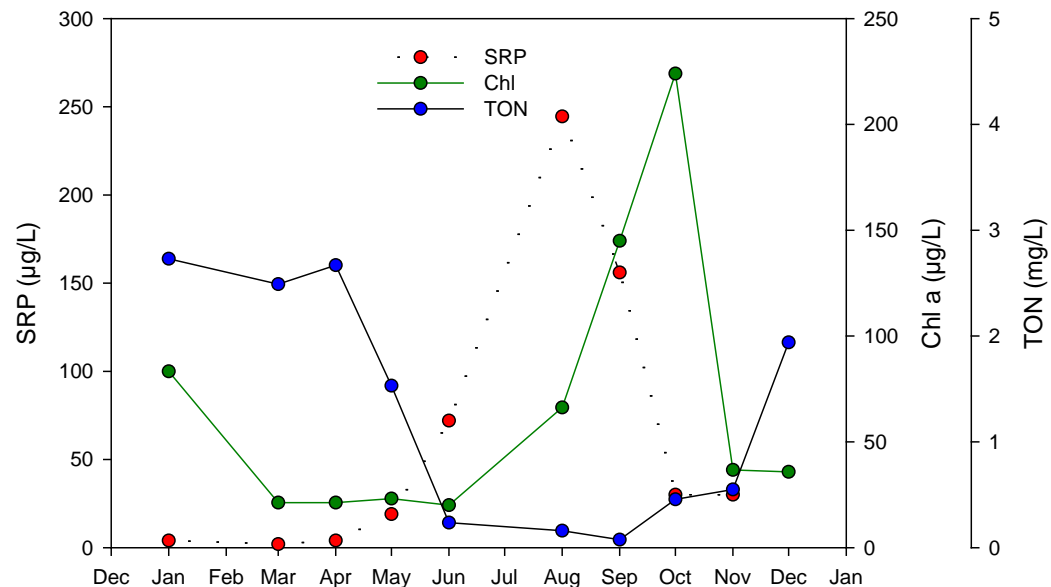
County – West Lothian
Altitude – 48 m
Surface area – 40.6 ha
Mean depth – 2.3 m
WFD type - HAVS





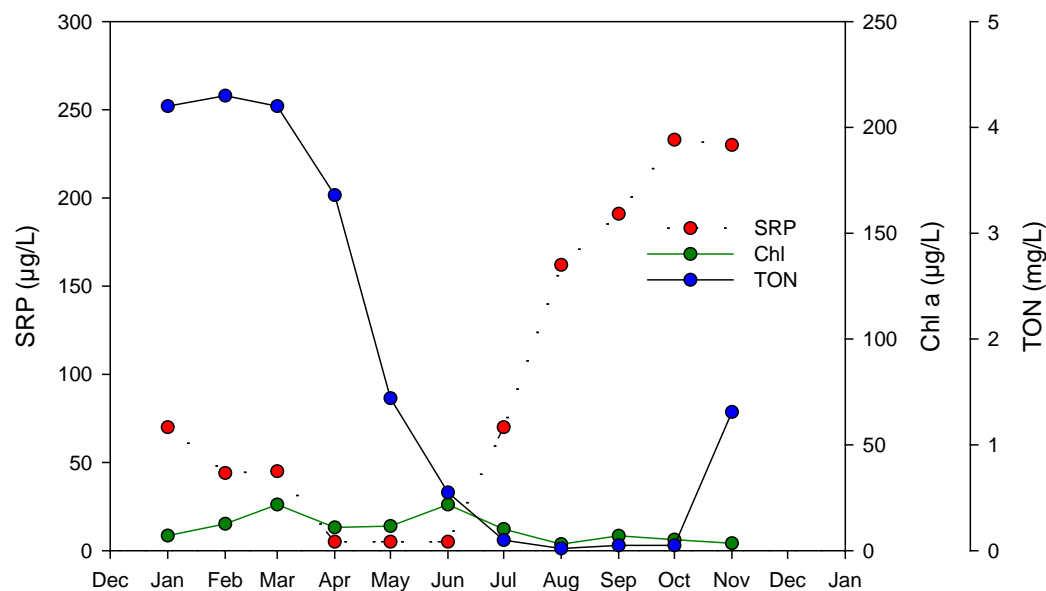
2006 – High TP: High Chl

phytoplankton growth unchecked by N and P

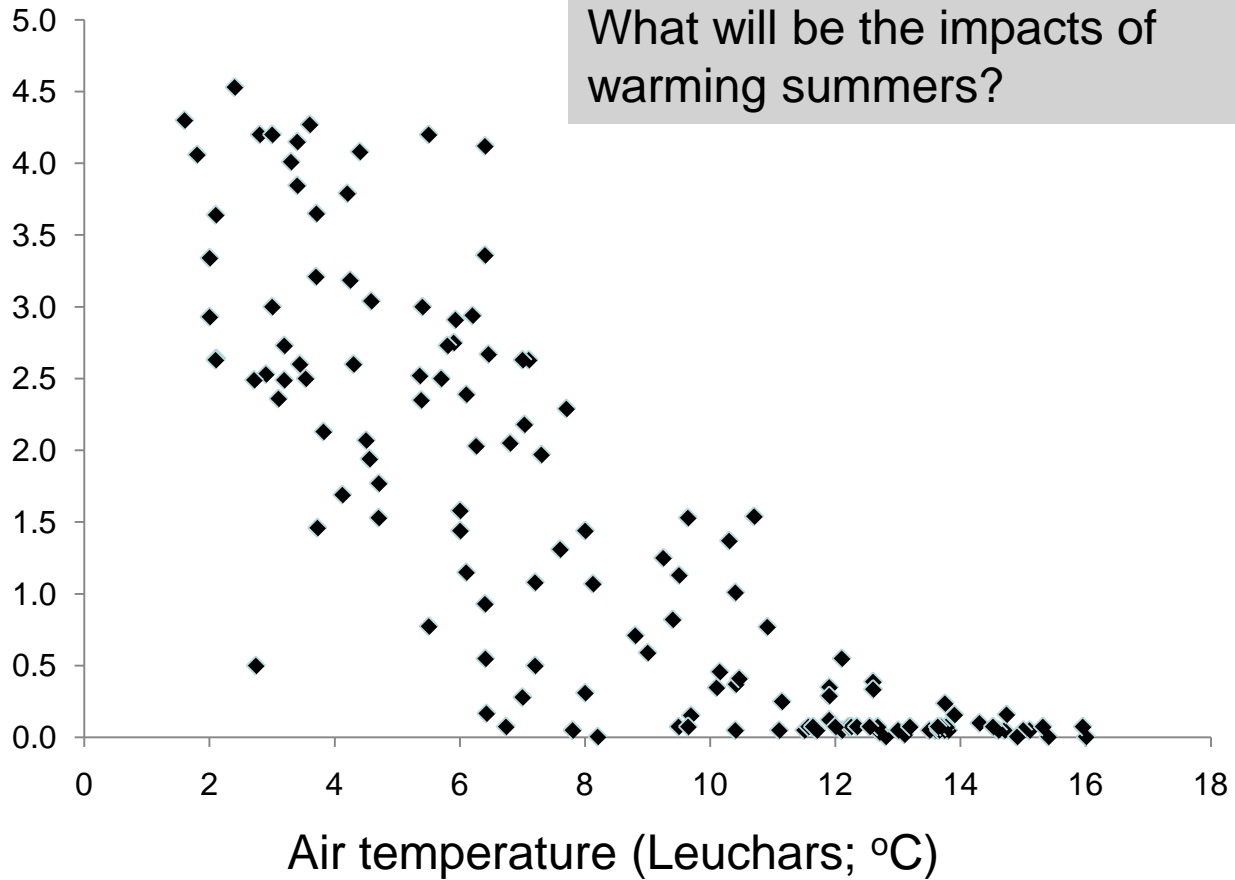


1994 – High TP: Low Chl

phytoplankton controlled by N limitation?

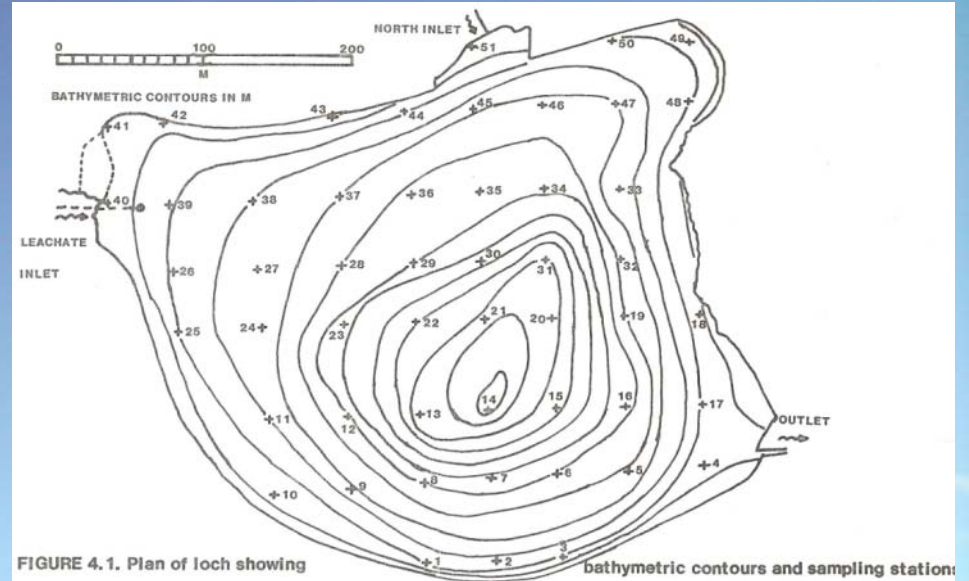


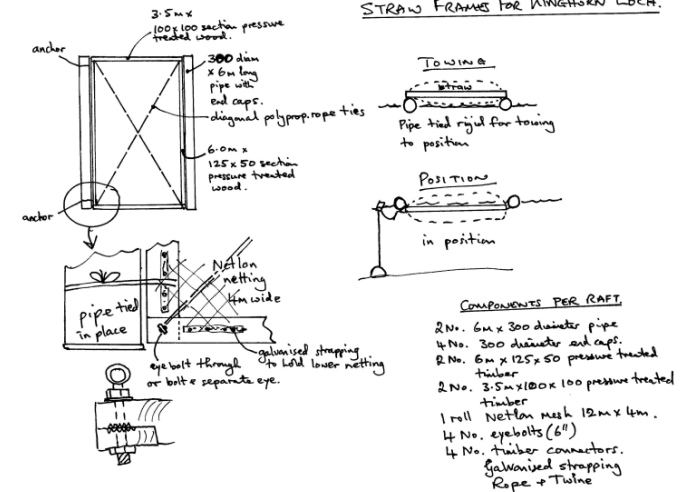
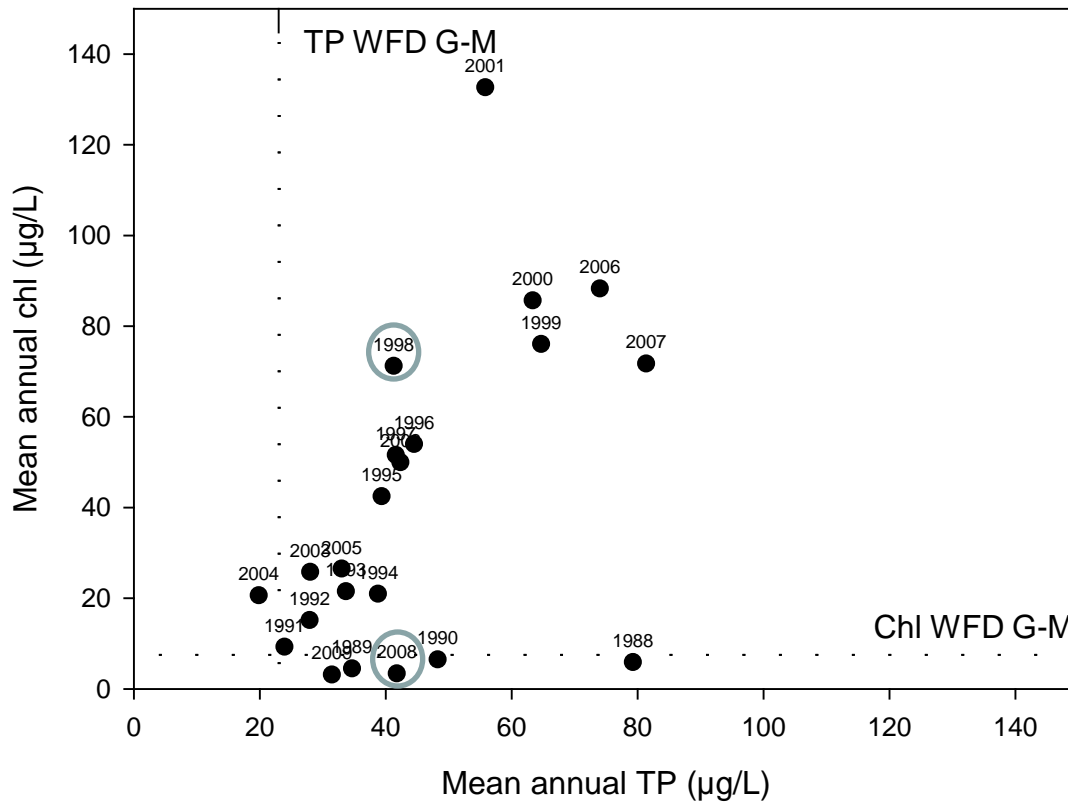
TON concentration
(mg/L)



Denitrification/biological uptake

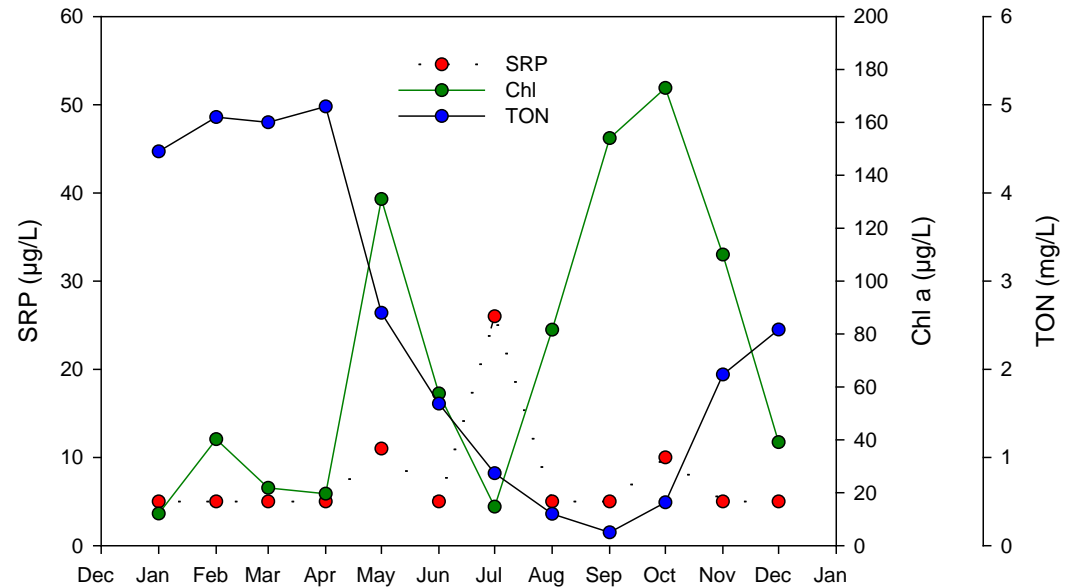
County – Fife
Altitude – 67 m
Surface area – 11.3 ha
Mean depth – 4.7 m
WFD type - HAS





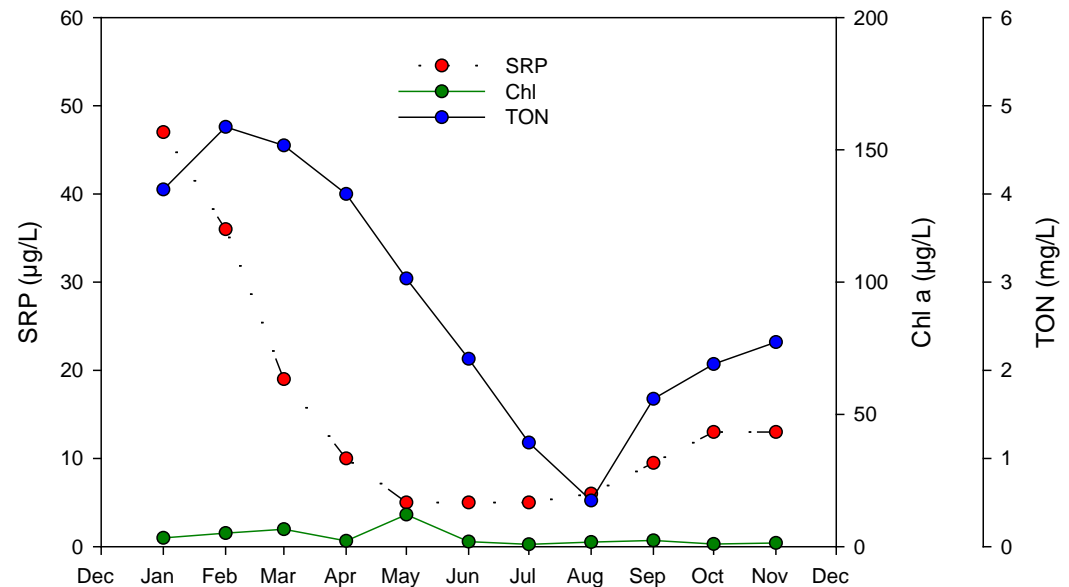
1998 - High TP: High Chl

Phytoplankton growth limited by P

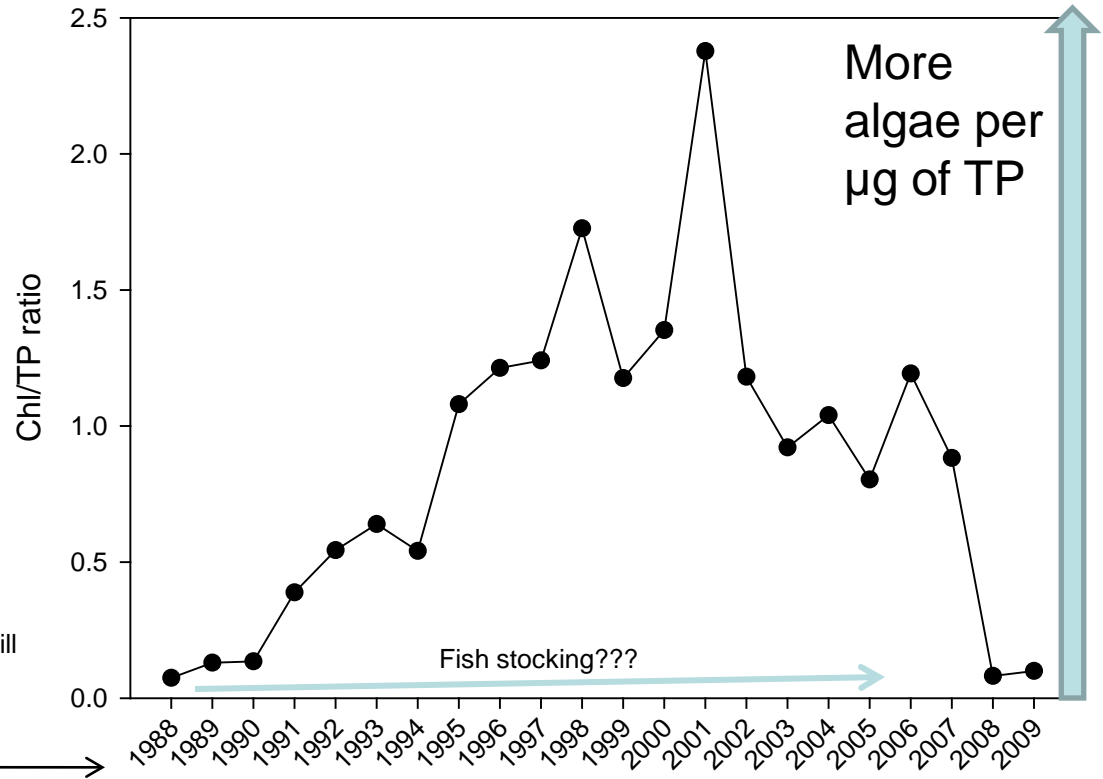


2008 - High TP: Low Chl

Phytoplankton growth unchecked by N or P



Kinghorn Chl:TP



Disposal of Red Mud [1947-1980]; high arsenic, vanadium, SRP, NaOH; no macrophytes; low macroinverts.; extreme water level fluctuation [1983-1985]; diversion of waste water from landfill site [1983]; pH recovery [1984]; brown trout trial [1985]; pike, roach, perch, carp, rainbow trout, brown trout.

Clear water and establishment of macrophytes

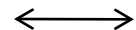
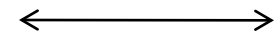
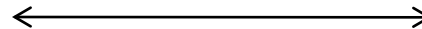
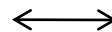
Increased occurrence of algal blooms [spring-autumn]

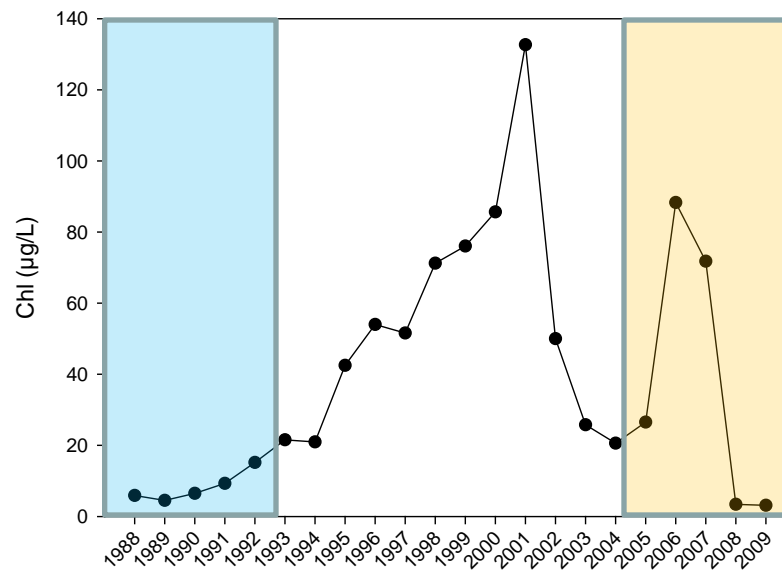
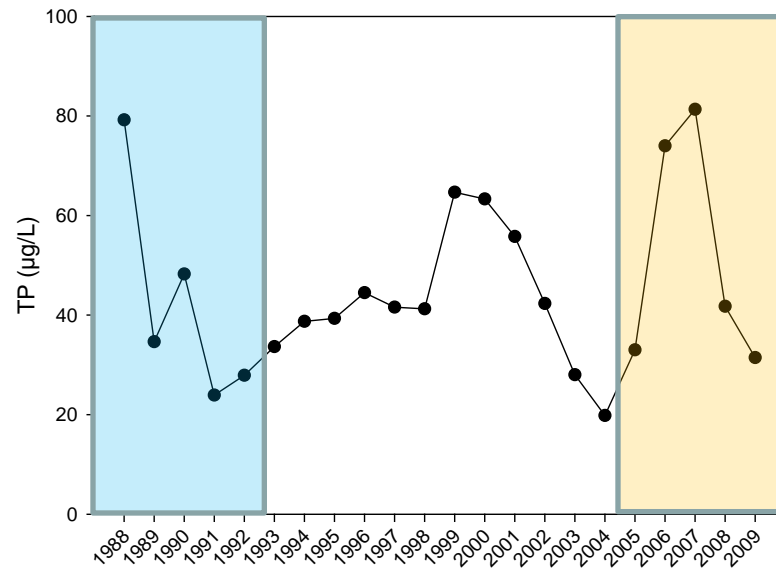
Barley straw (low dose in shallows) trialled in shallows to control algae

Barley straw (2 open water rafts) trialled

Barley straw (6 open water rafts) continued

Blanket weed becoming a problem [summer-autumn]





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- The Chl:TP ratio varies with WFD lake type
- All lakes may not respond as expected to reductions in external P load and N load should also be considered
- Climate change may strengthen the likelihood of N limitation in shallow lakes
- Have to consider biological, physical and chemical interactions when designing lake restoration programmes

Lake meta-analysis: Harry Hoser (RIZA)

Linlithgow Loch: Viv Grey (SNH); Jill Gillard & Mervyn MacGregor (SEPA), Martin Gray (Historic Scotland); Graeme Hedger and Chris Alcorn (WLC); Chris McDonald and Carole Christian (SAC)

Kinghorn Loch: Tim Foster & Alistair Morrison (SEPA); Ron Edwards (Fife Council and Kinghorn Loch Users Group); Saul Gardiner (Scottish Carp Group)

Loch Leven: Loch Leven Estates; SNH; SEPA.