Lake level fluctuations, ecological attributes and fish productivity in African lakes and reservoirs

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On behalf of:

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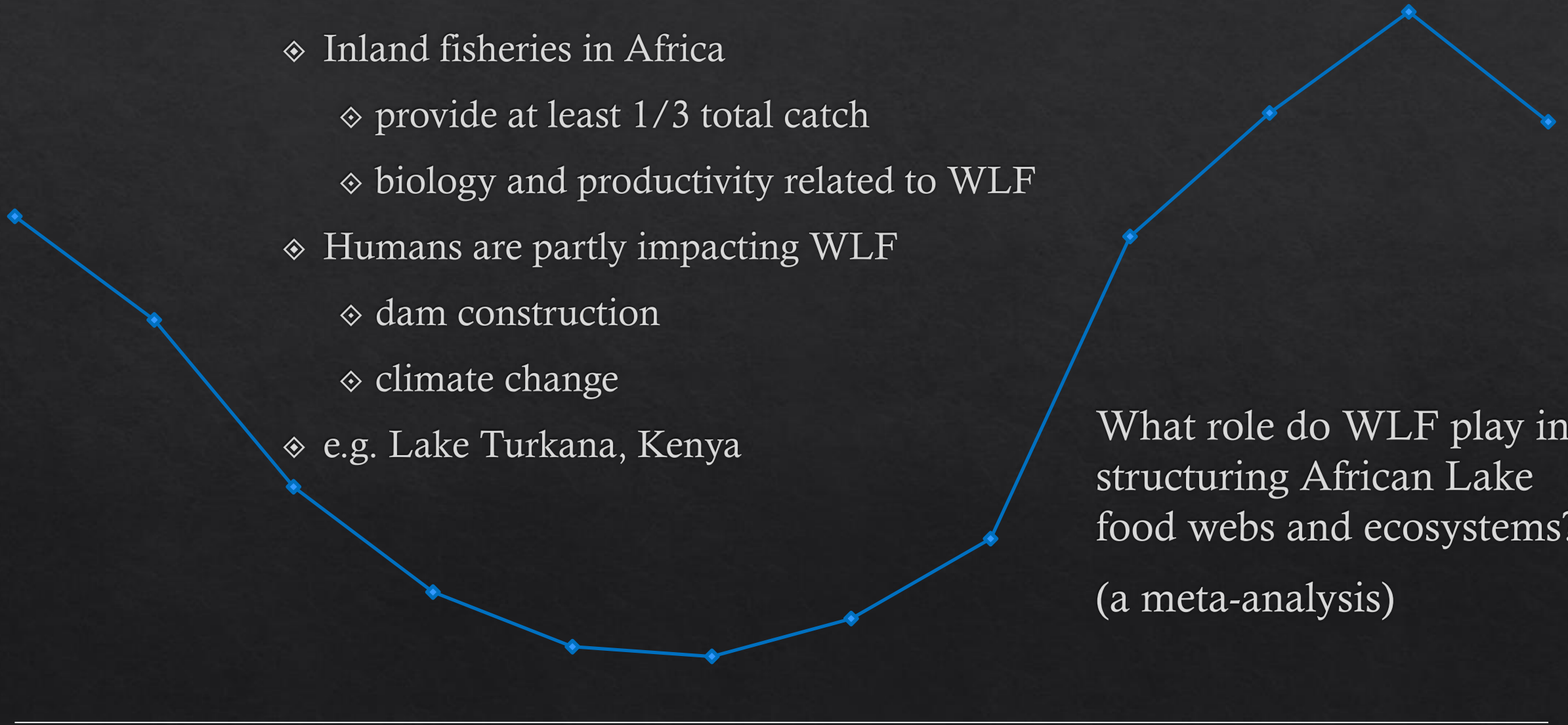
AFRICAN GREAT LAKES CONFERENCE 2017

Water Level Fluctuations (WLF) and African Lakes

- Inland fisheries in Africa
  - provide at least 1/3 total catch
  - biology and productivity related to WLF
- Humans are partly impacting WLF
  - dam construction
  - climate change
- e.g. Lake Turkana, Kenya



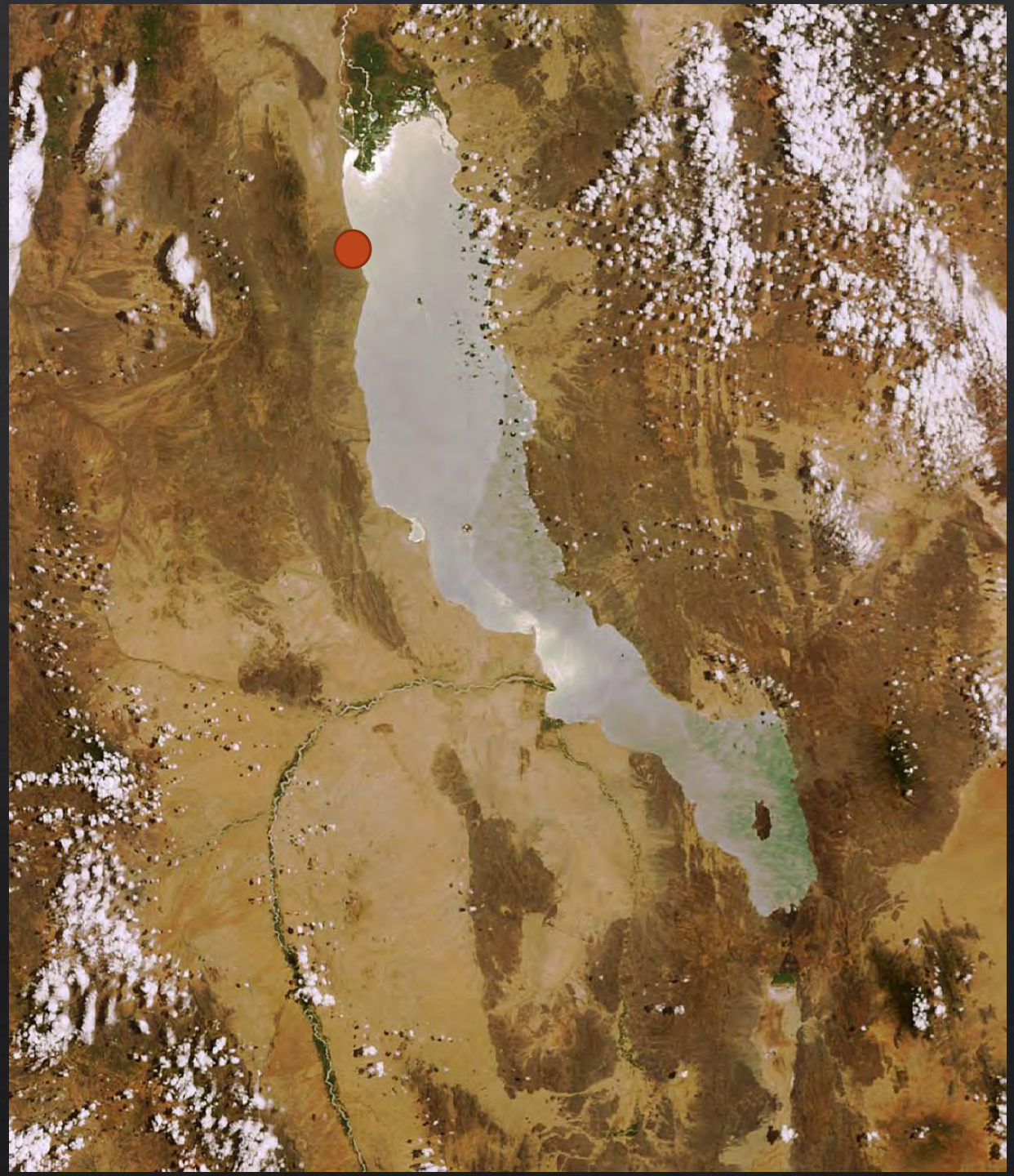
What role do WLF play in structuring African Lake food webs and ecosystems?

(a meta-analysis)

Lake Turkana

The worlds largest dessert lake

35 years ago I started my “African voyage” in Turkana with the Danish Volunteer Service (DVS)




Abandoned aquaculture plant
The fish factory called the New mountain
Kalokol
Turkana alias "Norkana"
Ferguson's Gulf
Image © 2009 TerraMetrics
© 2009 Google
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Google


A hot dessert


… and a salty lake


... and some tough
nomadic people


… all they miss is water


… but sometimes there are droughts

… and then there is hunger


… but the lake was full of fish

We brought in a boat

We built a fish factory (The new mountain)

We built roads to transport the fish

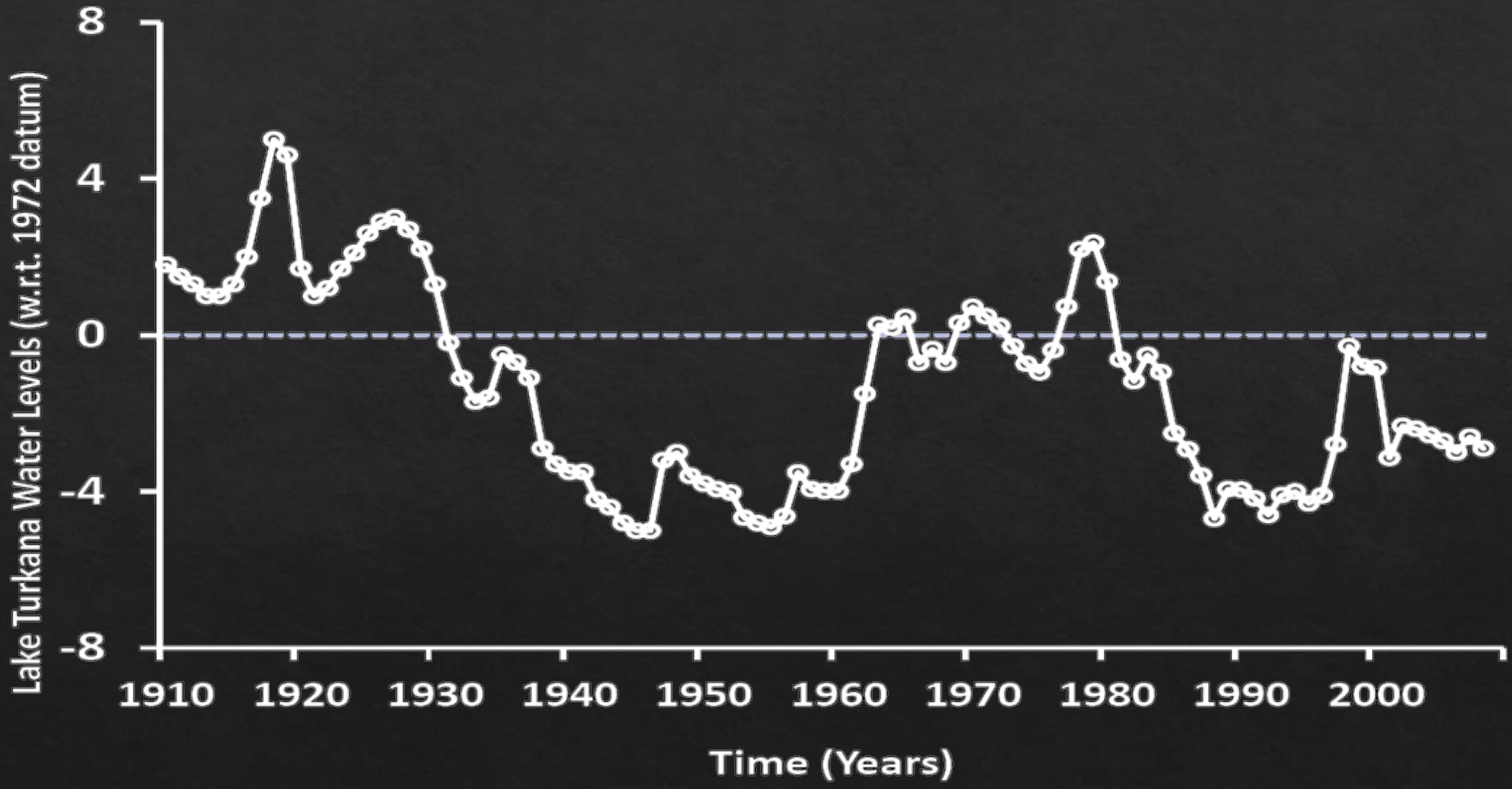
We built a pier to land the fish

..but the lake shrunk and the fish disappeared

..and the boats stranded

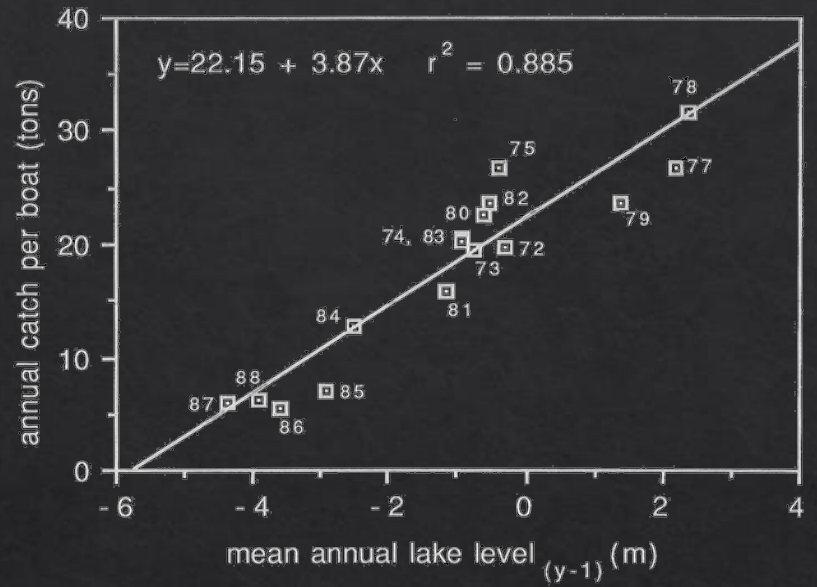

Kalokol
Ferguson’s gulf
dried up
Image © 2012 GeoEye
© 2012 Google
Image © 2012 DigitalGlobe
3°32'49.82" N 35°52'46.59" E elev 373 m

Oops. Lake level changes? ….in a tropical dessert ?

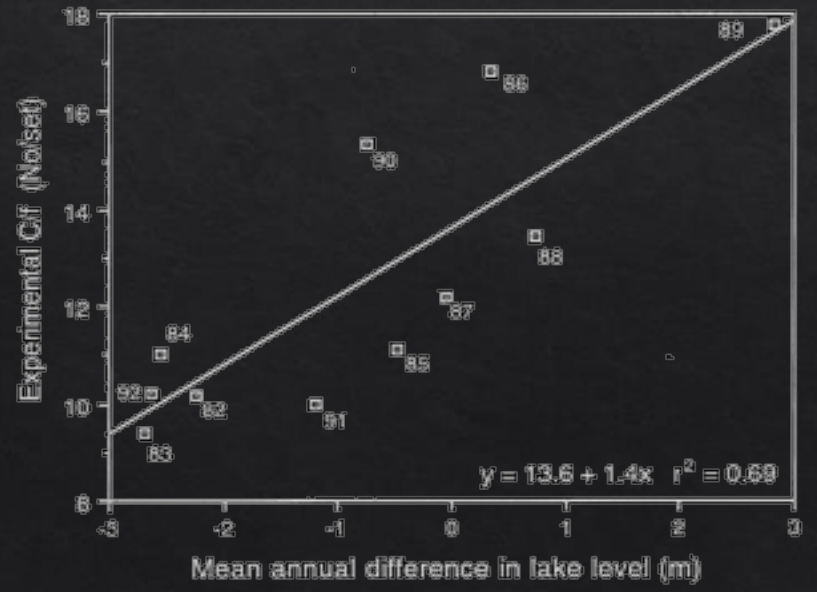


Catch, effort and water levels

Fish productivity



Lake Turkana
1972-1988
Kolding (1989)



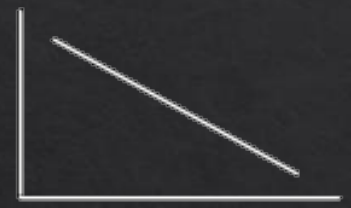
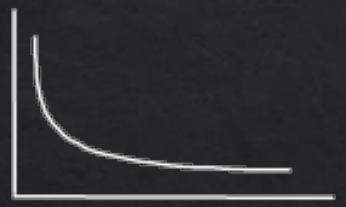
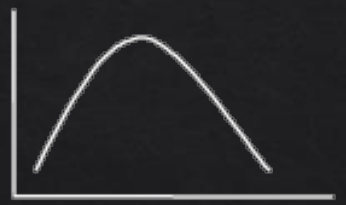
Lake Kariba
1982-1992
Karenge & Kolding (1993)

Lake level changes

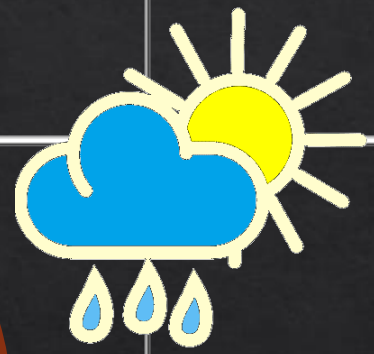
- Strong association between productivity and WLF ?

Principal Components – Physical Characteristics

Fish productivity

	Climatic	Morphological	Edaphic	Hydrologic
	Latitude Altitude			
		Area Depth Volume		
			Nutrient loading	Size, duration and variability of flood pulse

MEI



Kolding and van Zwieten 2012

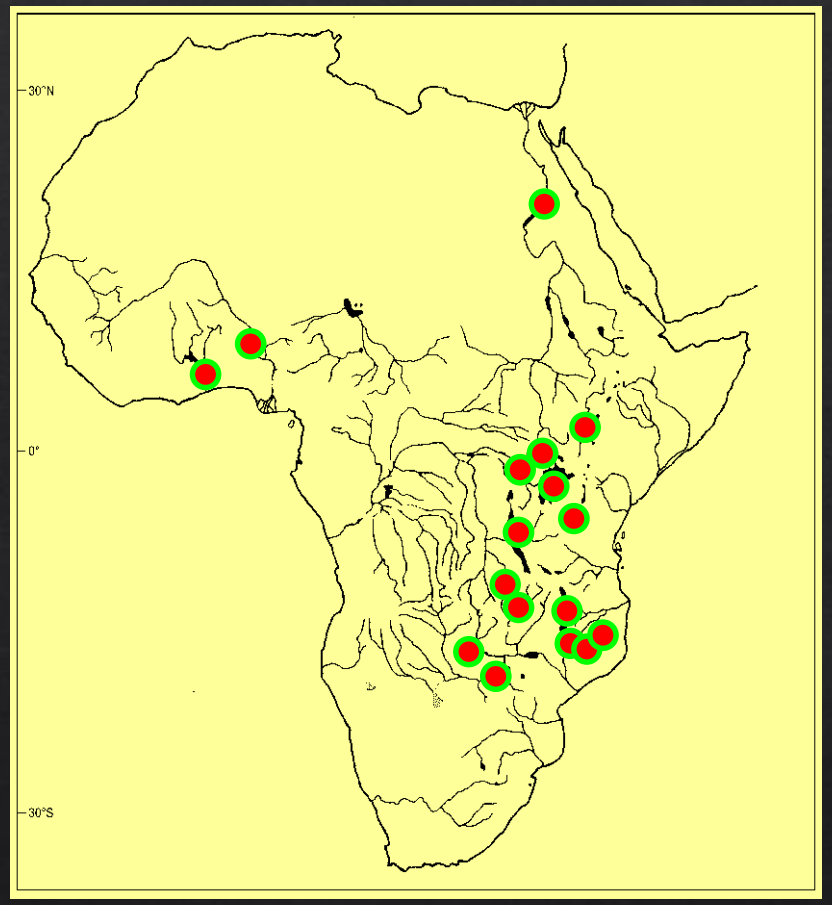
Relative Lake Level Fluctuation Index (RLLF) …

$$\mathrm{RLLF} = \frac{\textit{mean lake level amplitude}}{\textit{mean depth}} \cdot 100$$

- …encapsulates the morphological, edaphic and hydrological driving forces for productivity into a single quantity.
- … is a dynamic extension of the MEI index that only incorporated morphological and edaphic factors
- … builds on the 'flood pulse' concept (Junk et al. 1989) and the 'flood pulse advantage' (Bayley 1991)
- …has a seasonal (RLLFs) and a long-term (RLLFa) dimension

Kolding and van Zwieten 2012

Yield (production) is highly correlated with RLLF

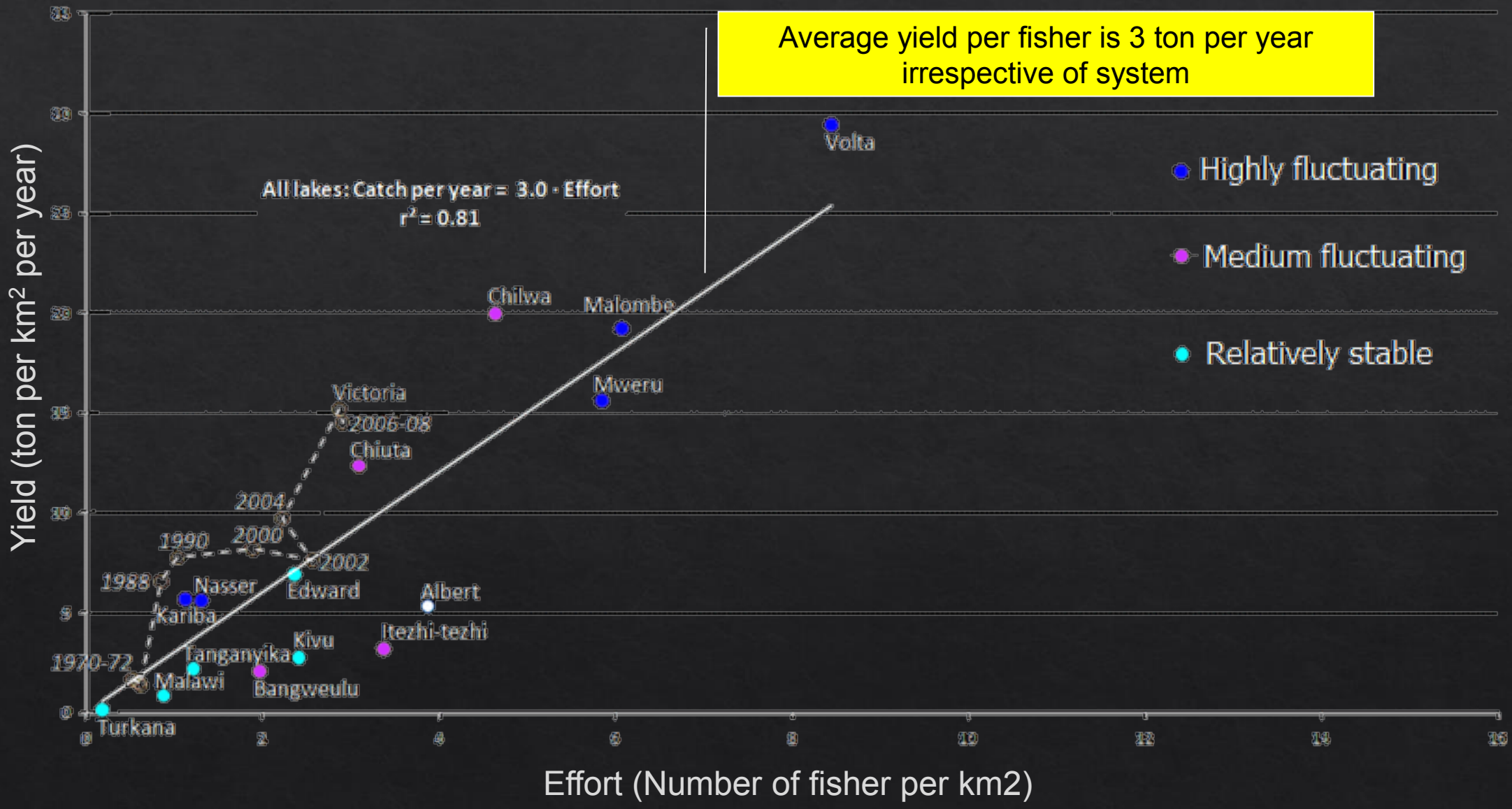


17 lakes and reservoirs in Africa.

Effort is highly correlated with RLLF

Kolding and van Zwieten 2012

Effort self-regulated by productivity



Kolding and van Zwieten 2012

15 African Lakes with Ecopath models

15 African Lakes, 19 models: Ayamé, Victoria (x2), Ihema, Turkana (x2), Naivasha, Nakuru (x2), Chad, Awassa, Tanganyika (x2), Malawi, Kivu, Tana, Hayq, Kariba, and George

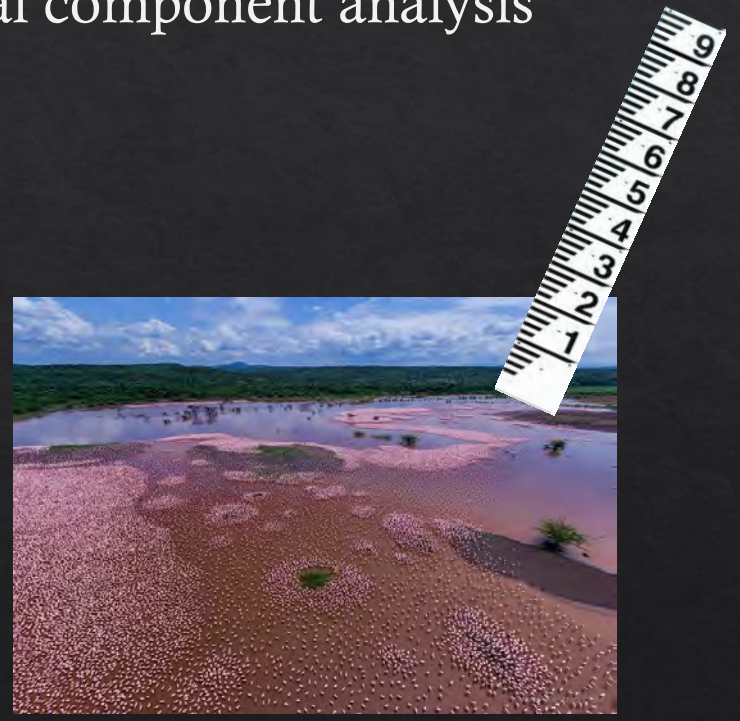
Relative Lake Level Fluctuations

Hypothesis: RLLFs+a will be negatively correlated with ecosystem maturity (sensu Odum 1969), as measured by a variety of food web characteristics.

Statistical tools: changepoint analysis, linear models, principal component analysis

$$\mathbf{RLLF} = \frac{\boldsymbol{Amplitude}}{\boldsymbol{Mean\ Depth}} \times \mathbf{100}$$

Lake Tanganyika
RLLFa- 0.04
RLLFs- 0.13
Internal Mixing

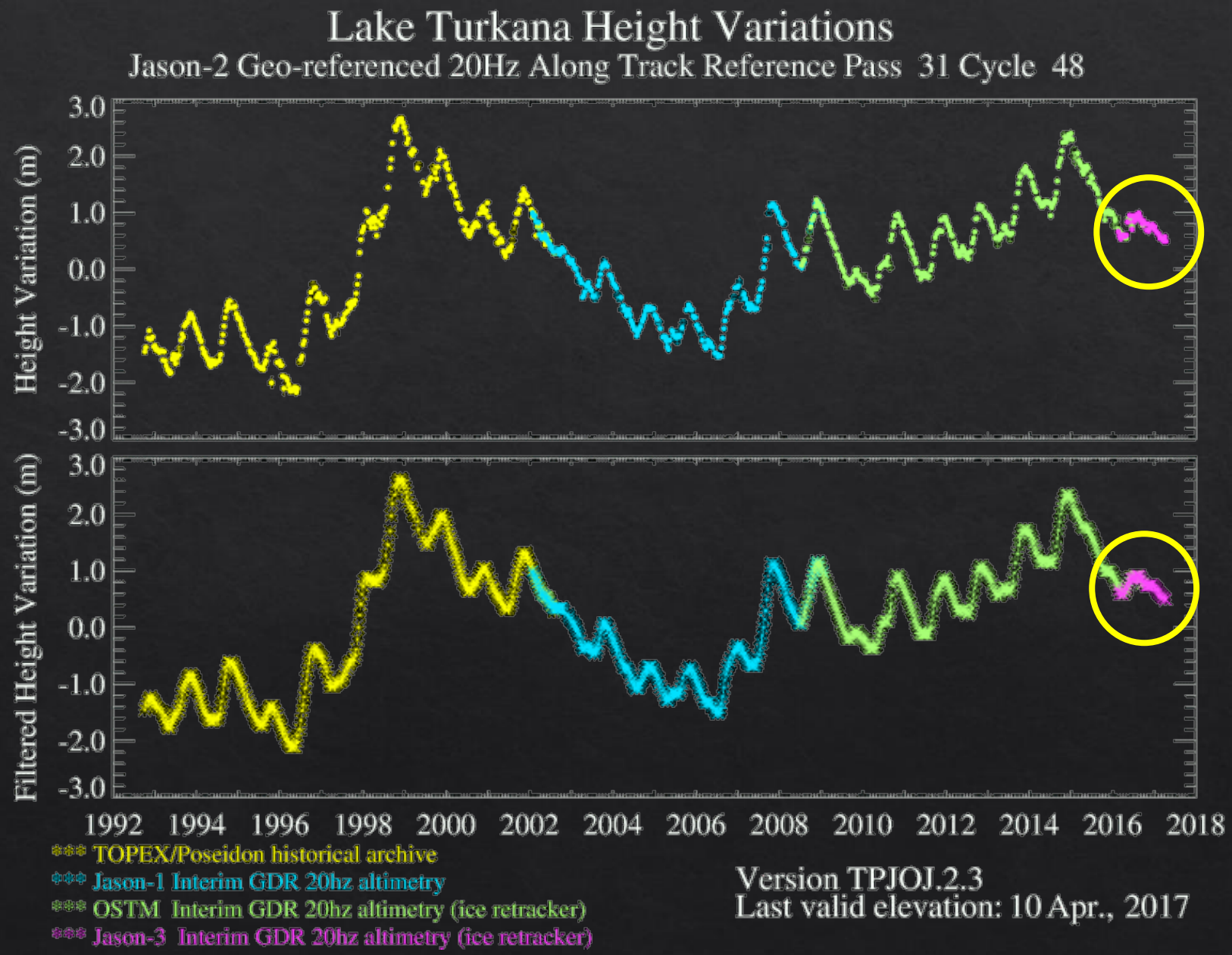


Lake Nakuru
RLLFa- 19.01
RLLFs- 33.14
External Inputs

Kolding and van Zwieten 2012

G-REALM http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/

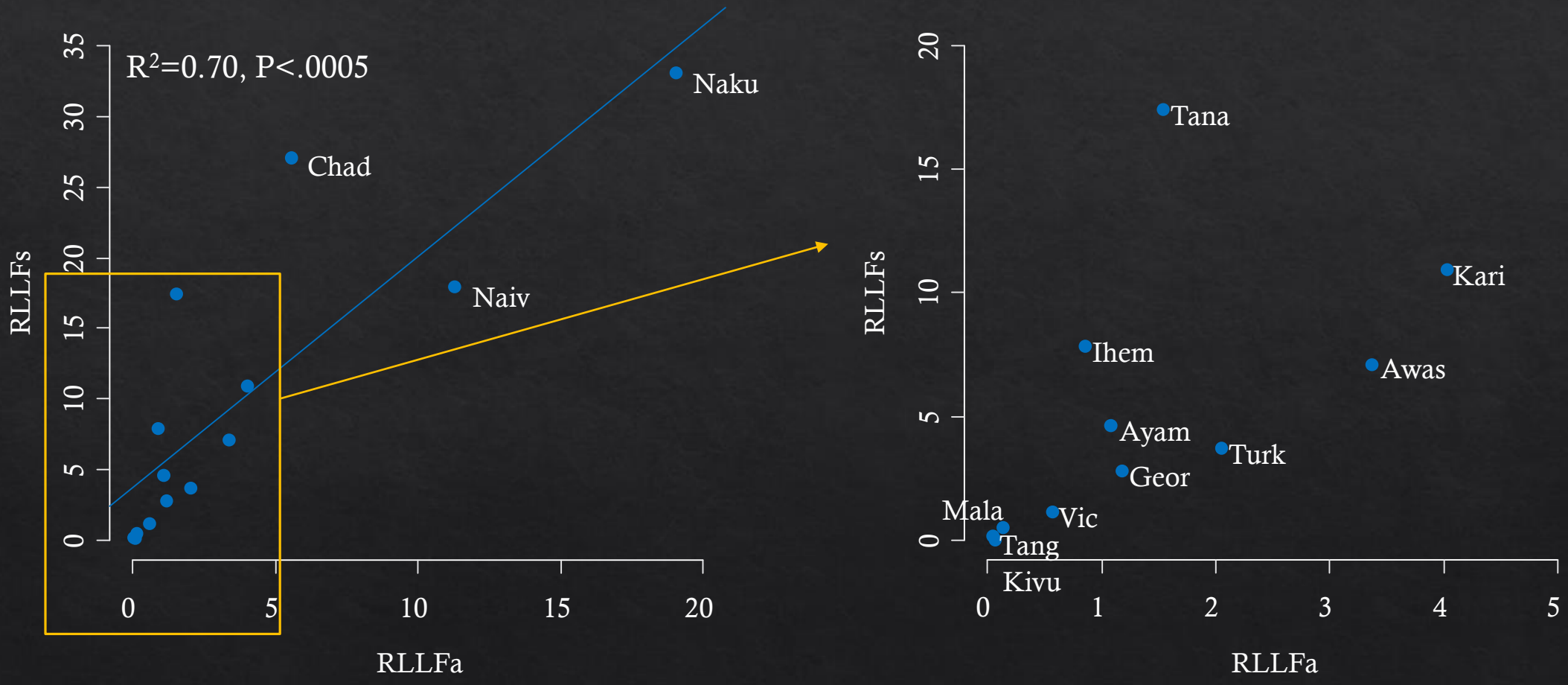
Lake level products at 10day resolution



RLLFs = 3.75

RLLFa = 2.05

Seasonal and Annual Lake Level Fluctuations



Ecology and Food Web Parameters - Ecopath

RLLF
+
Other Physical

Fishery/Other Characteristics

- Catch/Area (⬇M,⬆RLLF)
- MTL_c (⬆M, ⬇RLLF)
- % Catch Tilapia
- %PP Macrophytes

Community Energetics

- PP (⬇M,⬆RLLF)
- PP/B (⬇M,⬆RLLF)
- PP/R (⬇ M,⬆RLLF)
- B/Throughput (⬆M, ⬇RLLF)

Overall Stability

- Schrodinger Ratio (R/B) (⬆M, ⬇RLLF)

Community Structure

- #TL (⬆M,⬇RLLF)
- #Species (⬆M, ⬇RLLF)
- SOI (⬇M,⬆RLLF)

Life History

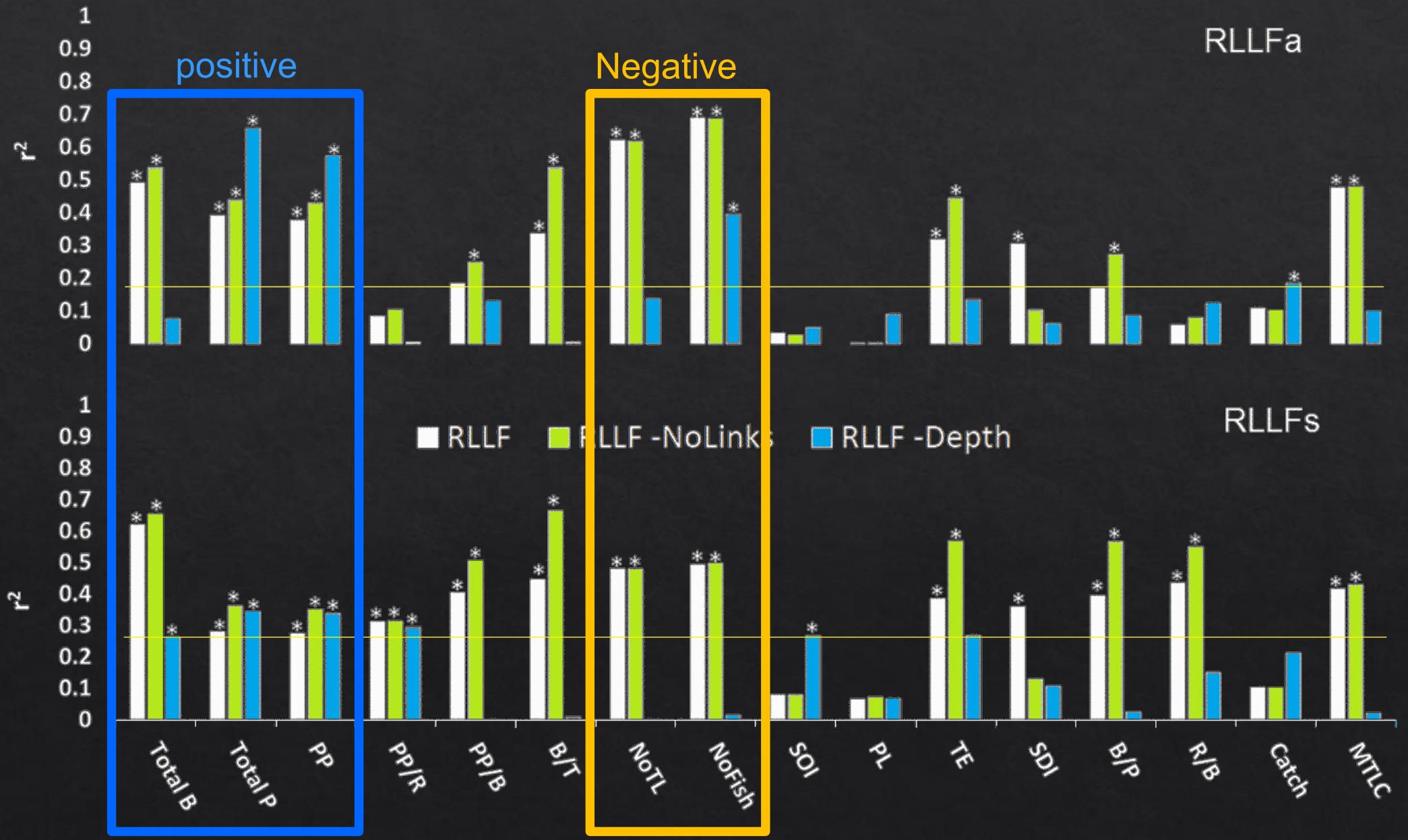
- P/B ≈Organism Size (⬆M, ⬇RLLF)

Nutrient Cycling

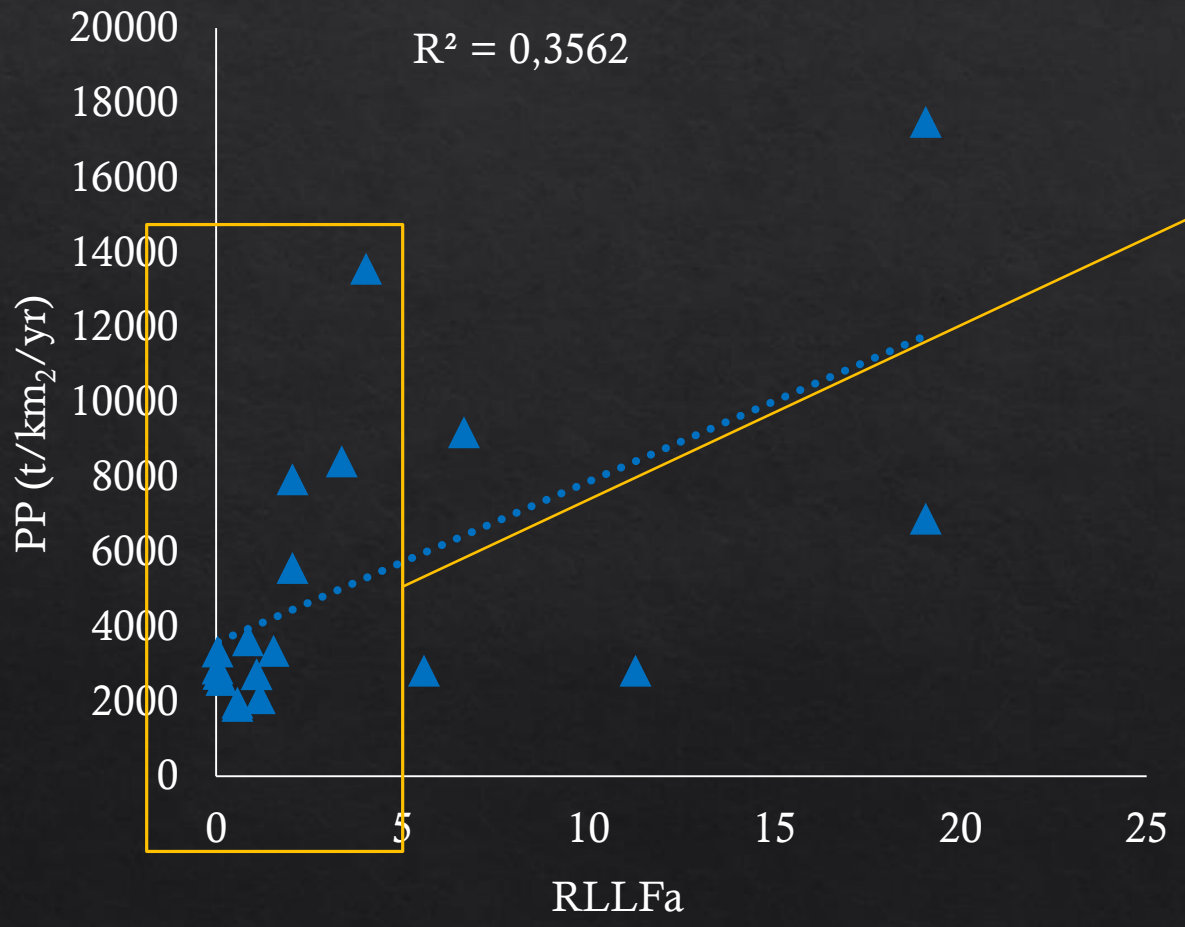
- PL (⬆M, ⬇RLLF)
- TE (⬆M,⬇RLLF)
- SDI (⬆M,⬇RLLF)

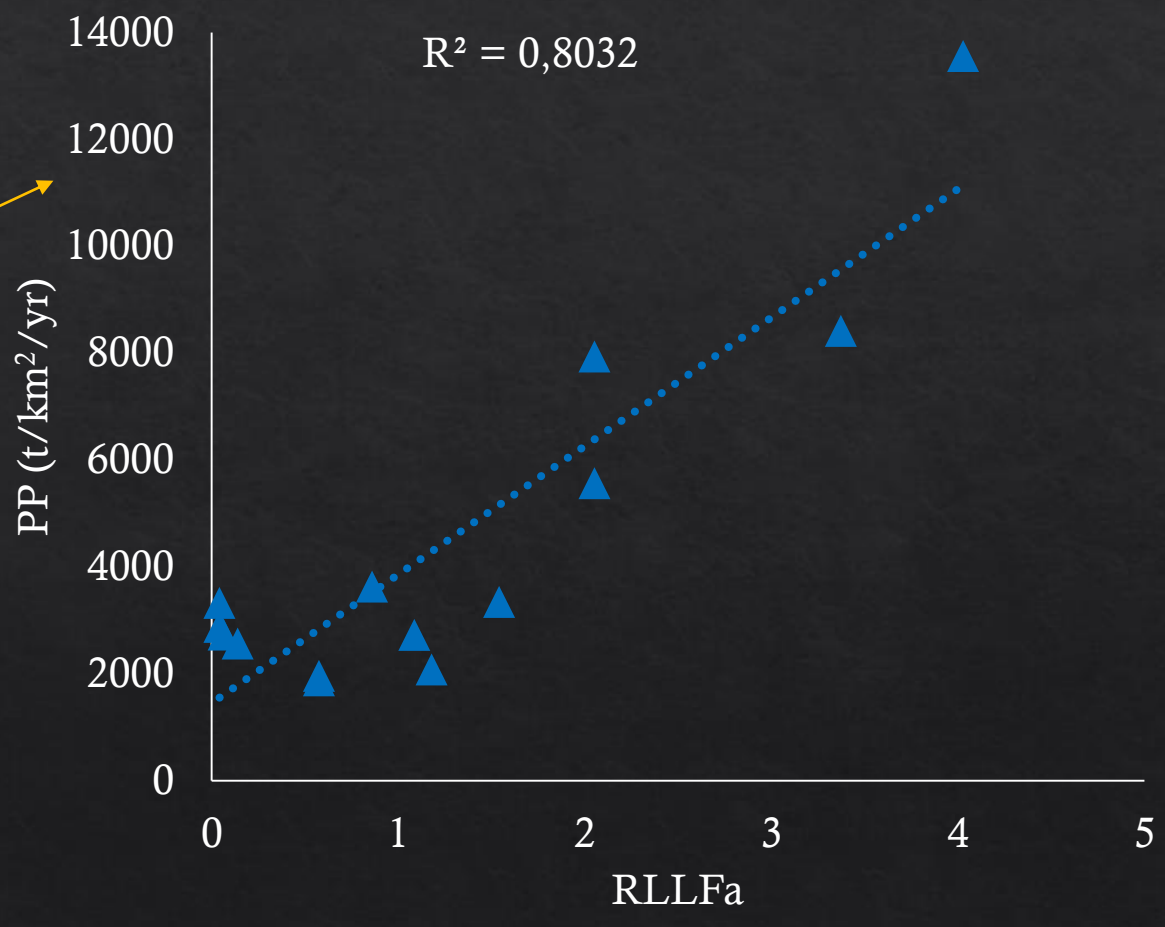
Odum 1969, Christensen and Pauly 1993, Christensen 1995, VanderZaden and Fetzer 2007, Kolding and van Zwietin 2012

Linear relationships RLLF and ecological attributes



Primary productivity (PP) and RLLF





PCA + Food Web Characteristics

PC1

RLLFs, RLLFa

Mean Depth

Volume

Residence time

10/17 FW parameters

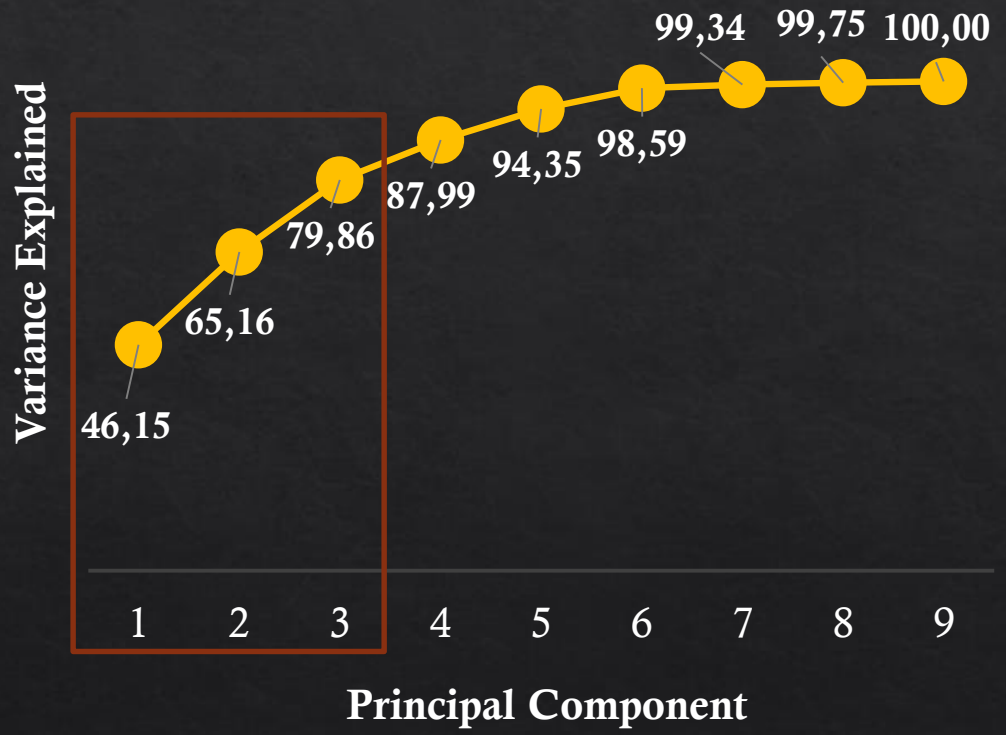
PC2

RLLFa

Altitude

Residence time

Catchment area



PC3

Latitude

RLLFs, RLLFa,

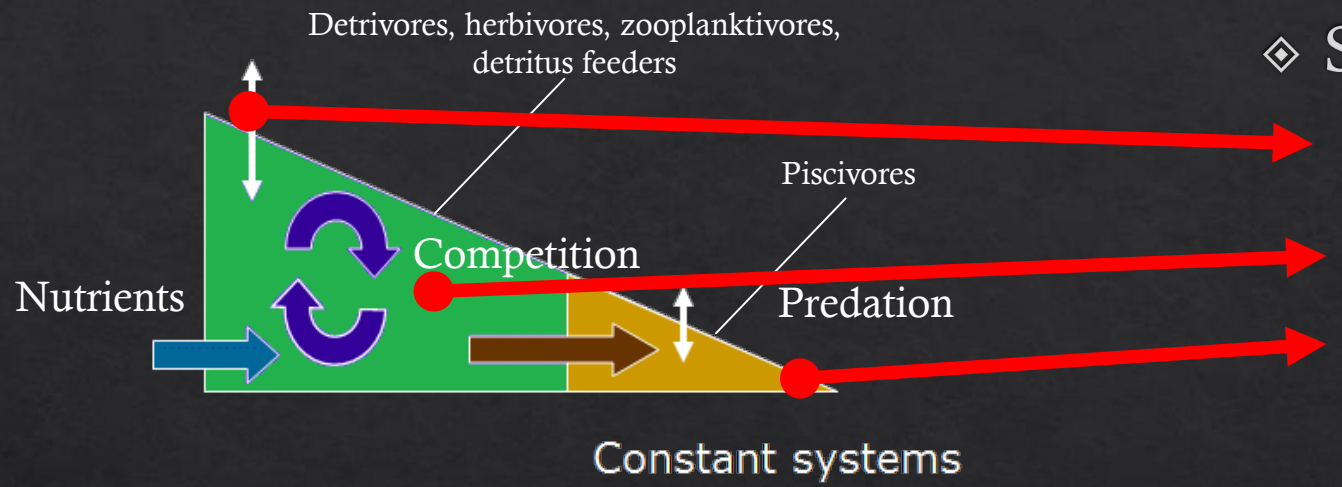
Catchment area

4/17 FW parameters

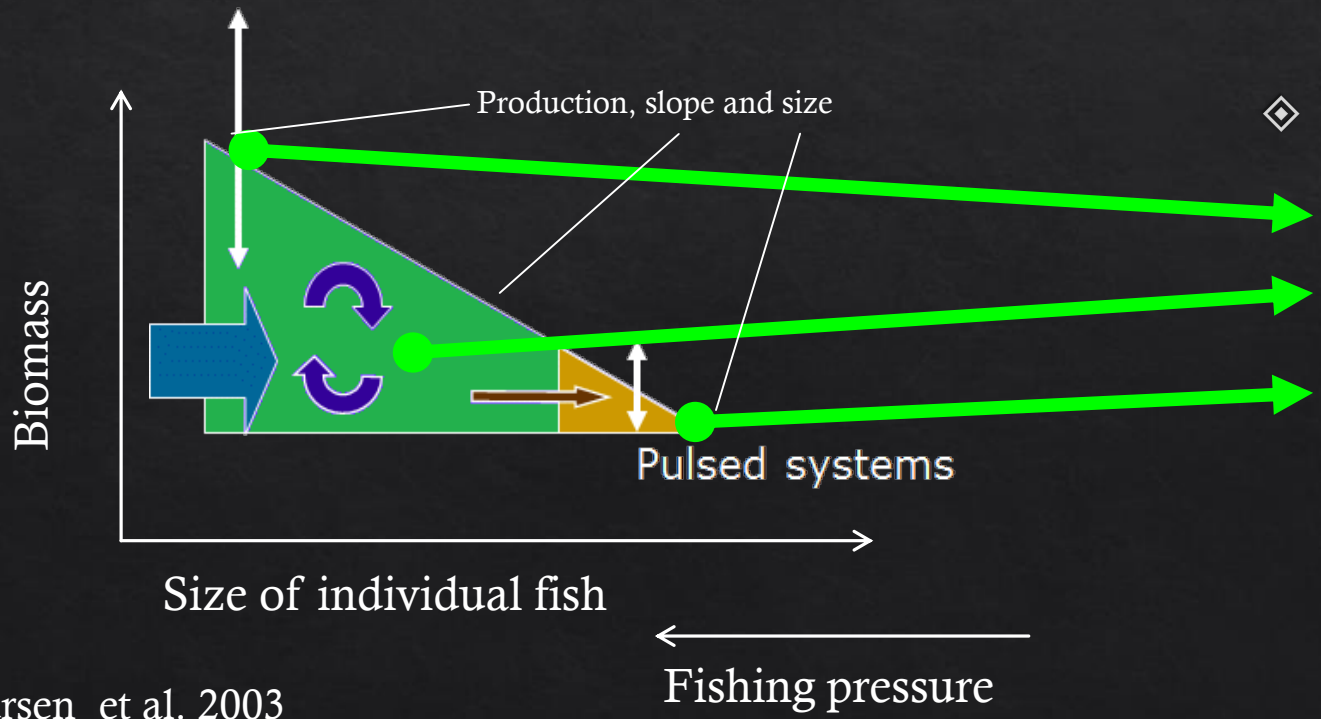
Negative

Positive

Stability-Maturity-Disturbance and biological implications…



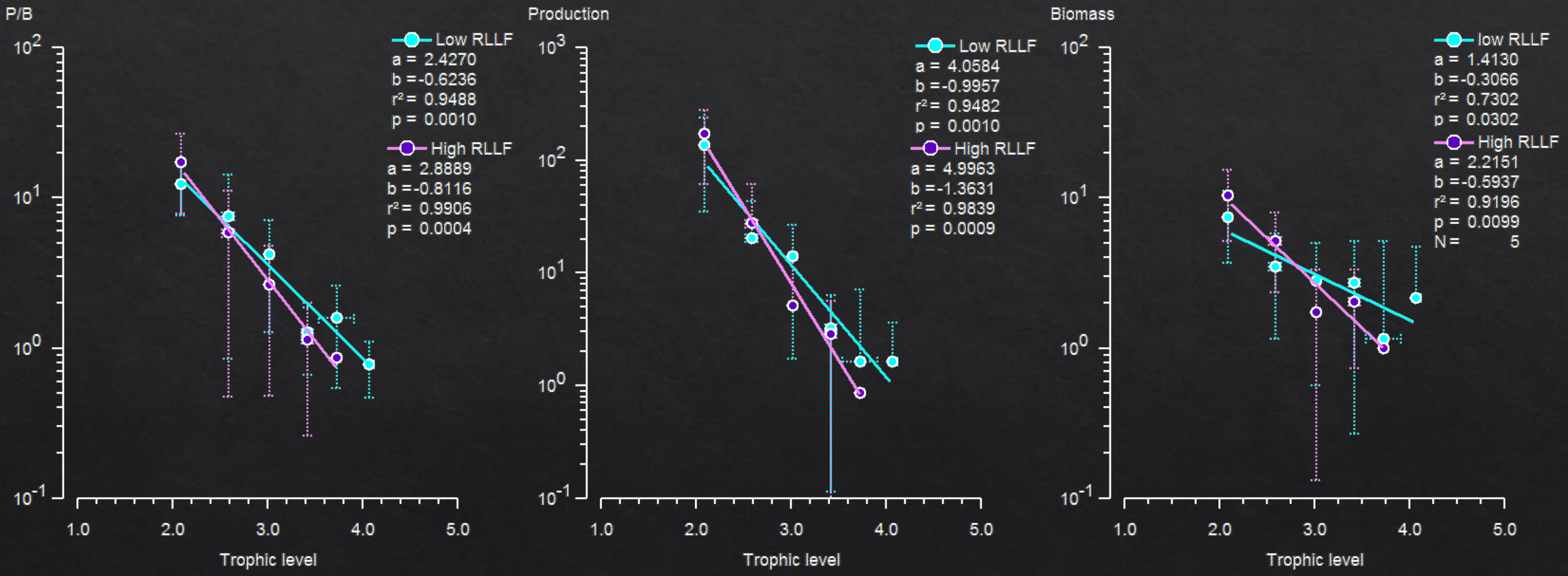
- Stable systems (RLLFa < 2.5)
  - Low productivity
  - High diversity
  - K-selected community
  - Vulnerable



- Pulsed Systems (RLLFa > 2.5)
  - High productivity
  - Low diversity
  - *r*-selected community
  - Resilient

Jul-Larsen et al. 2003

Observed attributes with low (<2.5) and high RLLF systems



Trophic level is a proxy for organism size (Jennings et al. 2001)

Kolding et al. 2016

Summary/Conclusions

- $RLLF_s$ and $RLLF_a$ explain more of the variation in ecological attributes than any combination of the other physical characteristics in African lakes
- There is a complex, but generally negative relationship between RLLF and ecosystem maturity (sensu Odum 1969). Mature systems are stable systems.
- RLLF in a system has strong implications for:
  - Productivity (PP and P)
  - Biomass (B/Throughput, PP/B)
  - Diversity, Food web structure and efficiency (#TL, #Species, TE, SOI)
  - Life history of organisms (B/P)
  - Vulnerability and resilience of the ecosystem

Questions?

Asante Sana

Conference Organizers

Natasha Gownaris, Konstantine Rountos,
Les Kaufman, Kamazima Lwiza, Ellen Pikitch

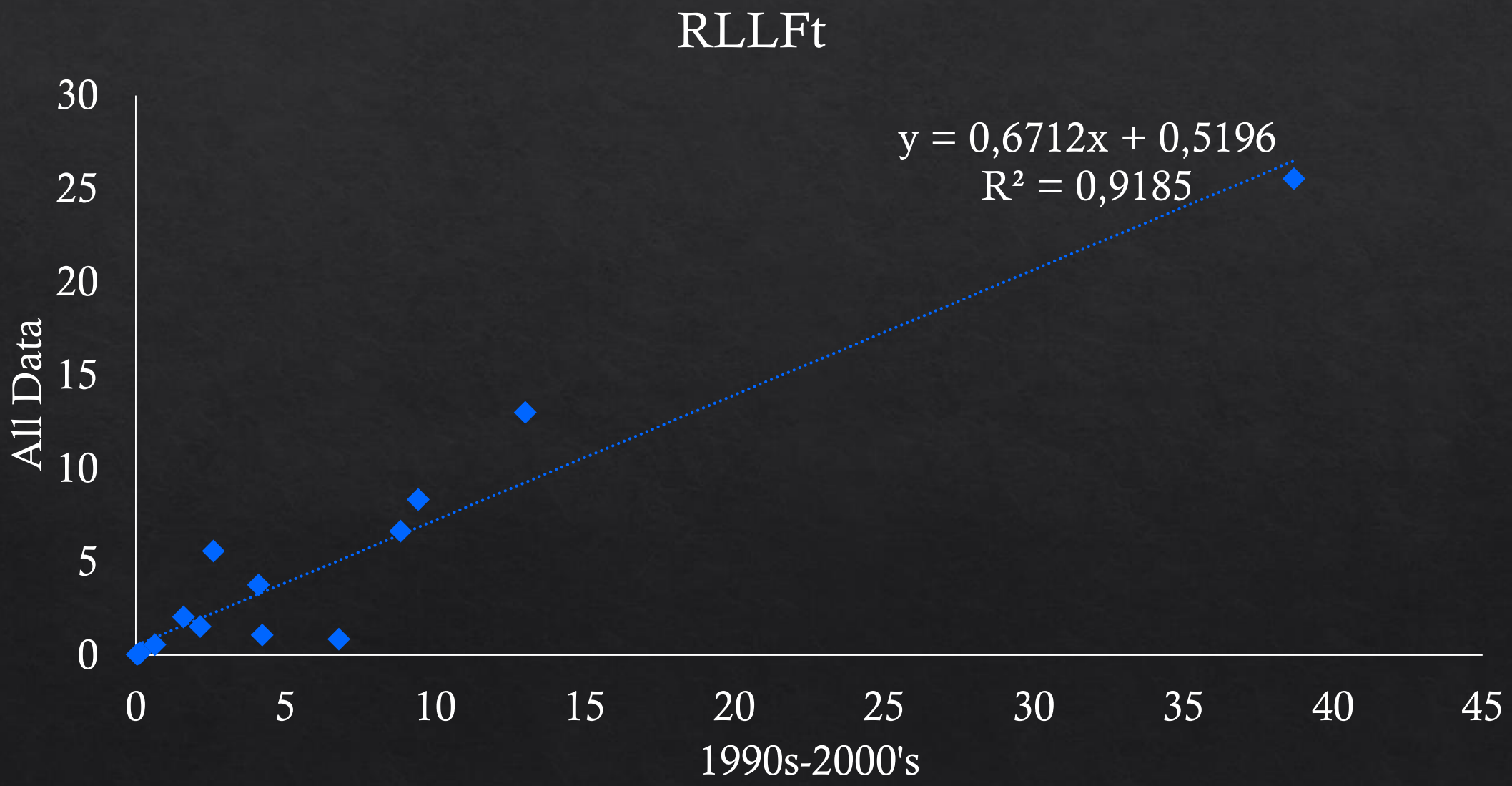
Ecosystem Maturity, Odum 1969

Ecosystem attributes	Developmental stages	Mature stages
Community energetics		
1. Gross production/community respiration (P/R ratio)	Greater or less than 1	Approaches 1
2. Gross production/standing crop biomass (P/B ratio)	High	Low
3. Biomass supported/unit energy flow (B/E ratio)	Low	High
4. Net community production (yield)	High	Low
5. Food chains	Linear, predominantly grazing	Weblike, predominantly detritus
Community structure		
6. Total organic matter	Small	Large
7. Inorganic nutrients	Extrabiotic	Intrabiotic
8. Species diversity—variety component	Low	High
9. Species diversity—equitability component	Low	High
10. Biochemical diversity	Low	High
11. Stratification and spatial heterogeneity (pattern diversity)	Poorly organized	Well-organized
Life history		
12. Niche specialization	Broad	Narrow
13. Size of organism	Small	Large
14. Life cycles	Short, simple	Long, complex
Nutrient cycling		
15. Mineral cycles	Open	Closed
16. Nutrient exchange rate, between organisms and environment	Rapid	Slow
17. Role of detritus in nutrient regeneration	Unimportant	Important
Selection pressure		
18. Growth form	For rapid growth ("r-selection")	For feedback control ("K-selection")
19. Production	Quantity	Quality
Overall homeostasis		
20. Internal symbiosis	Undeveloped	Developed
21. Nutrient conservation	Poor	Good
22. Stability (resistance to external perturbations)	Poor	Good
23. Entropy	High	Low
24. Information	Low	High

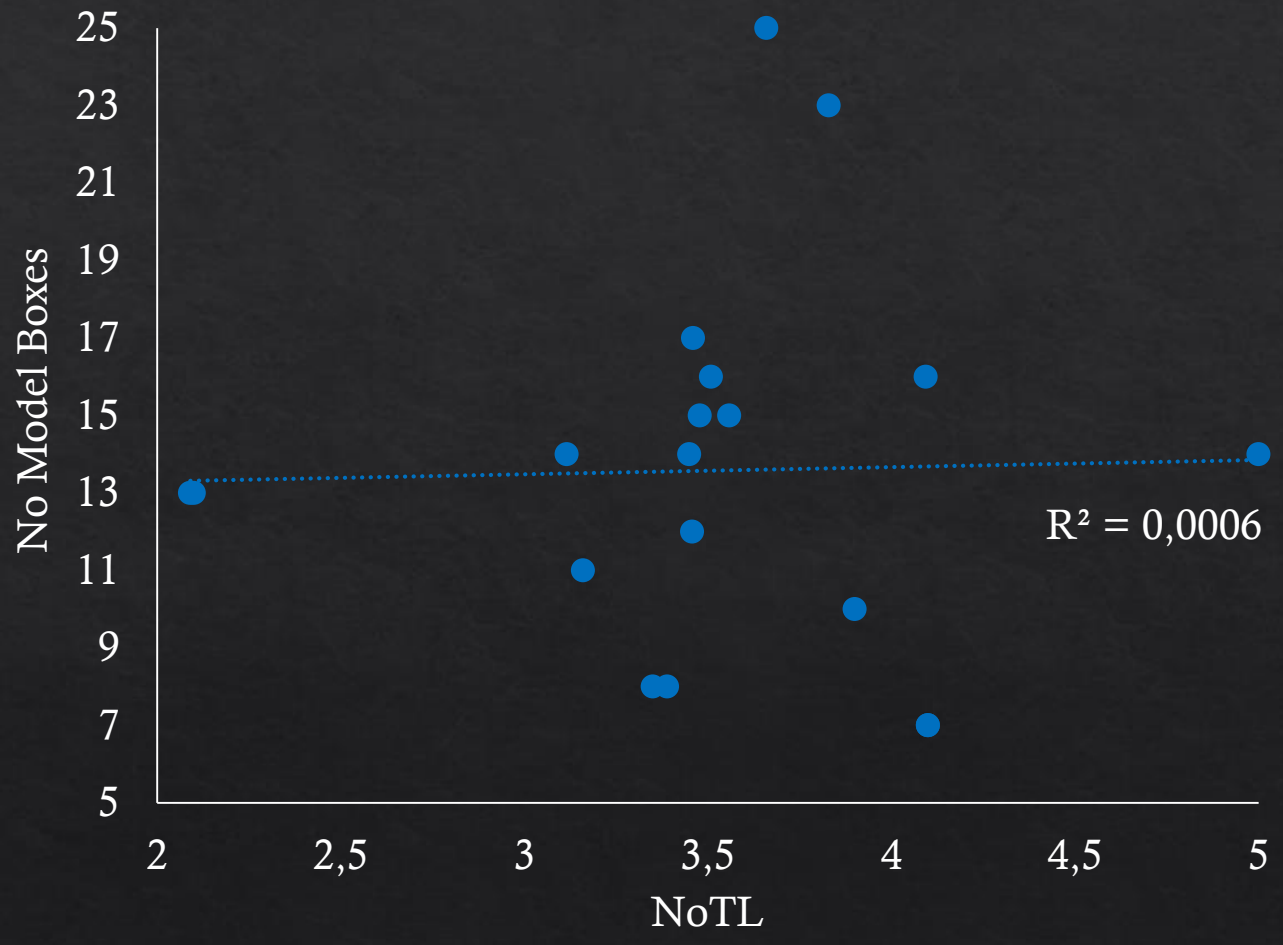
RLLF Data

System	Country	Years Used- Annual	Years Used- Seasonal	RLLF-a	RLLF-s	Year of Model Data
Lake Victoria	Kenya, Tanzania, Uganda	1900-1989; 1993-2014	1900-1989; 1993-2014	0.57	1.14	1970's-1980's and 2005
Lake Turkana	Kenya	1889-1989; 2003-2014	1993-2014	2.05	3.72	1970's-1980's
Lake George	Uganda	2000-2010	2000-2010	1.18	2.81	1970's-1980's
Lake Awassa	Ethiopia	1970-1999	1970-1990	1.08	4.61	1990's
Lake Naivasha	Kenya	1900-1992; 1993-2002; 2008-2014	1900-1992; 1993-2002; 2008-2014	8.34	14.91	1970's-1990's
Lake Ihema	Rwanda	2003-2010	2003-2010	0.86	7.86	1970's-1990's
Lake Nakuru	Kenya	1956-1975; 1990-2000	1956-1975; 1990-2000	25.55	29.11	1970's-1980's
Lake Malawi	Malawi, Mozambique and Tanzania	1922-2014	1922-2014	0.14	0.51	1970's-1990's
Lake Kivu	DRC and Rwanda	1945-1973; 2003-2008	1945-1973; 2003-2008	0.06	0.14	2002-2003; some from 1990's
Lake Tanganyika	DRC, Tanzania, Burundi, Zambia	1909-1992; 1993-2014	1909-1992; 1993-2014	0.04	0.13	1970's-1980's
Lake Chad	Chad	1954-1977; 1993-2014	1954-1977; 1993-2014	5.58	27.06	1970's
Lake Hayq	Ethiopia	1975-1991	1998-2012	6.66		1990's
Lake Ayamé	Côte d'Ivoire	2003-2010	2003-2010	13.02	56.80	1980's-1990's
Lake Tana	Ethiopia	1960-2014	1960-2014	1.54	17.45	1990's-2000's
Lake Kariba	Zambia-Sinzongwe Area	1962-2014	1962-2014	3.77	12.26	1970's-1990's

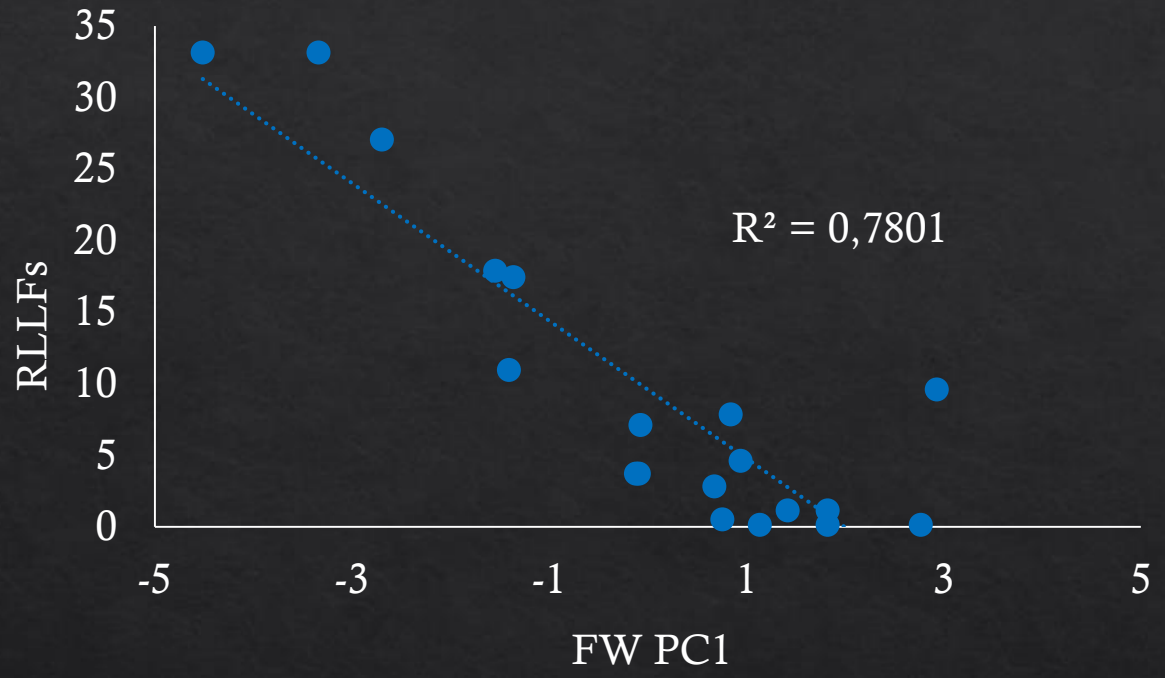
1990’s-2000’s/All Data

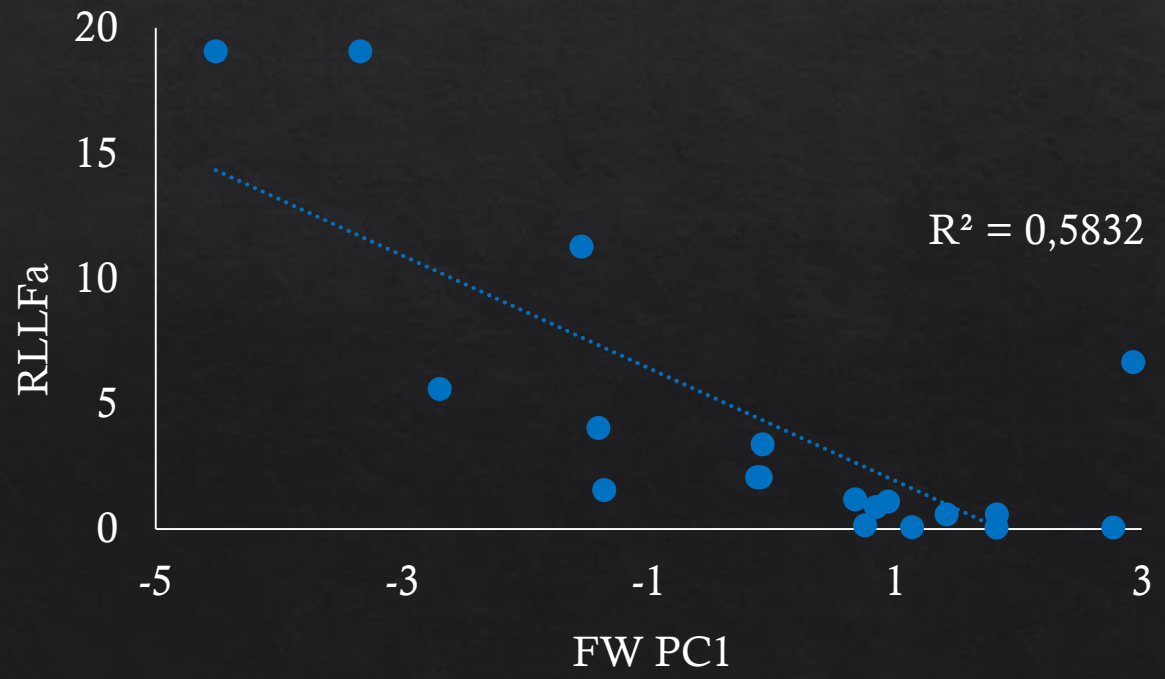


NoTL vs. Model Boxes

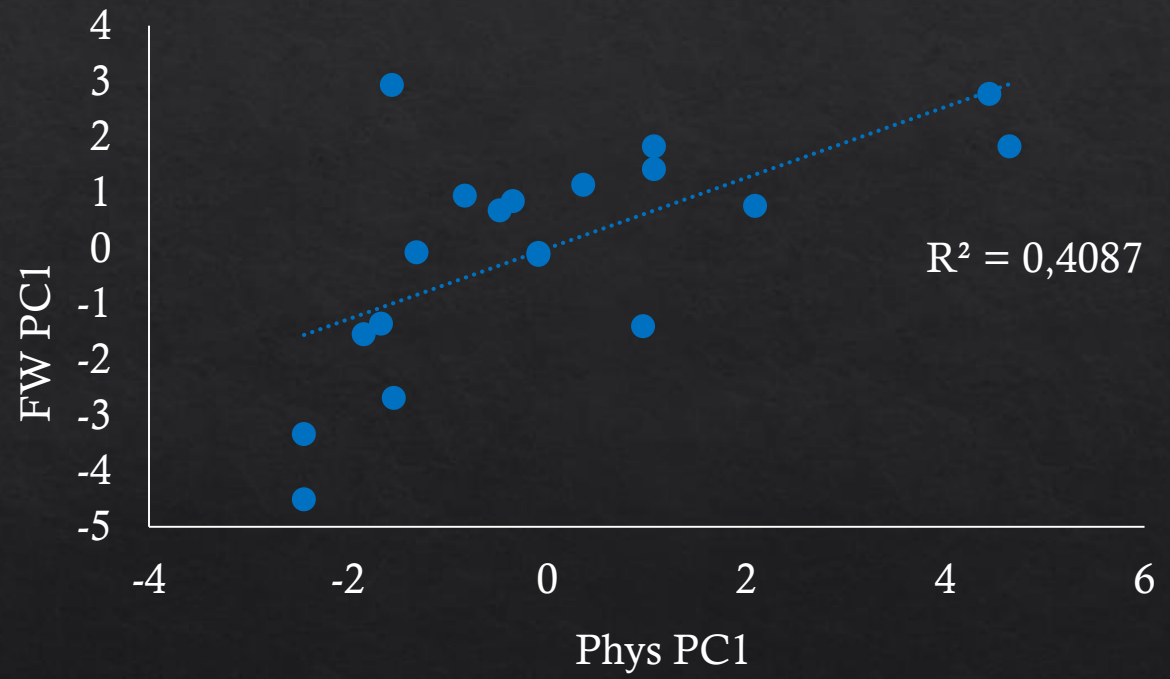


RLLFs and RLLFa vs. FW PC1

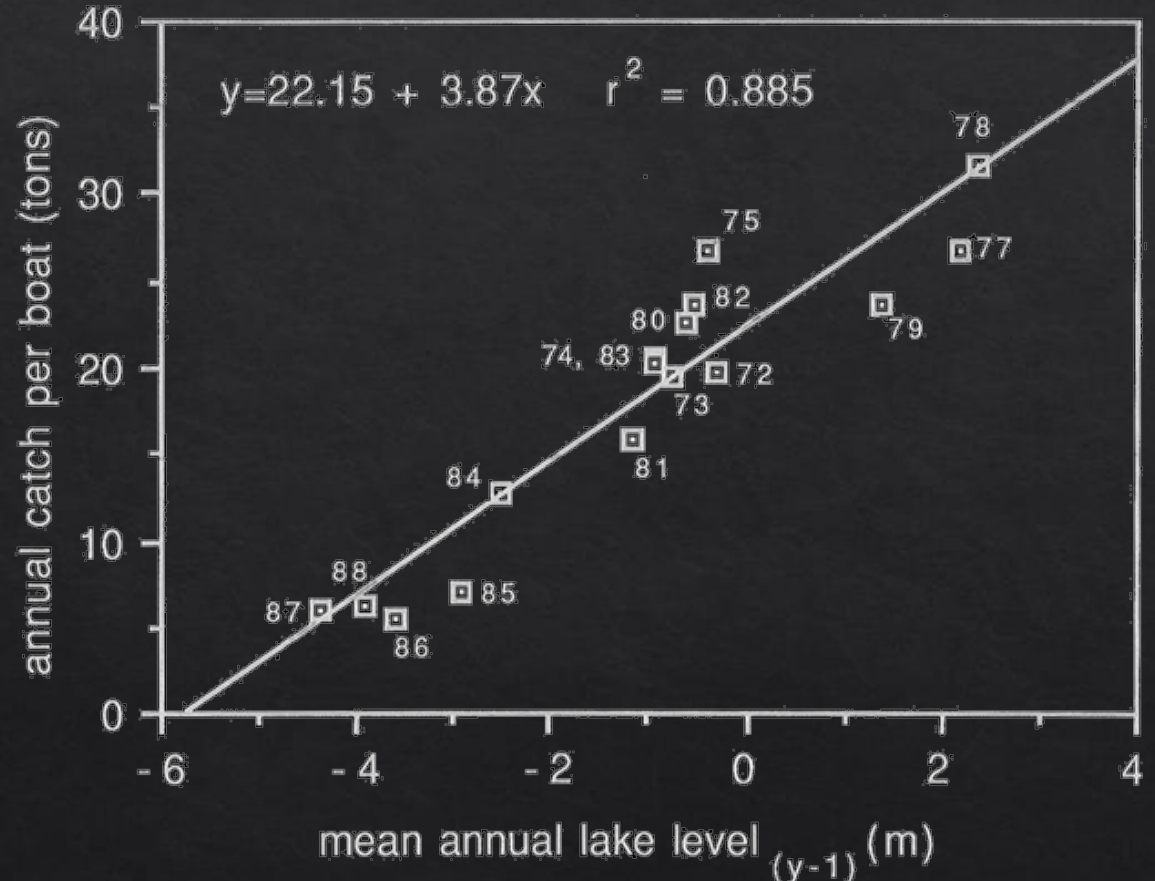




FWPC1 vs. PhysPC1

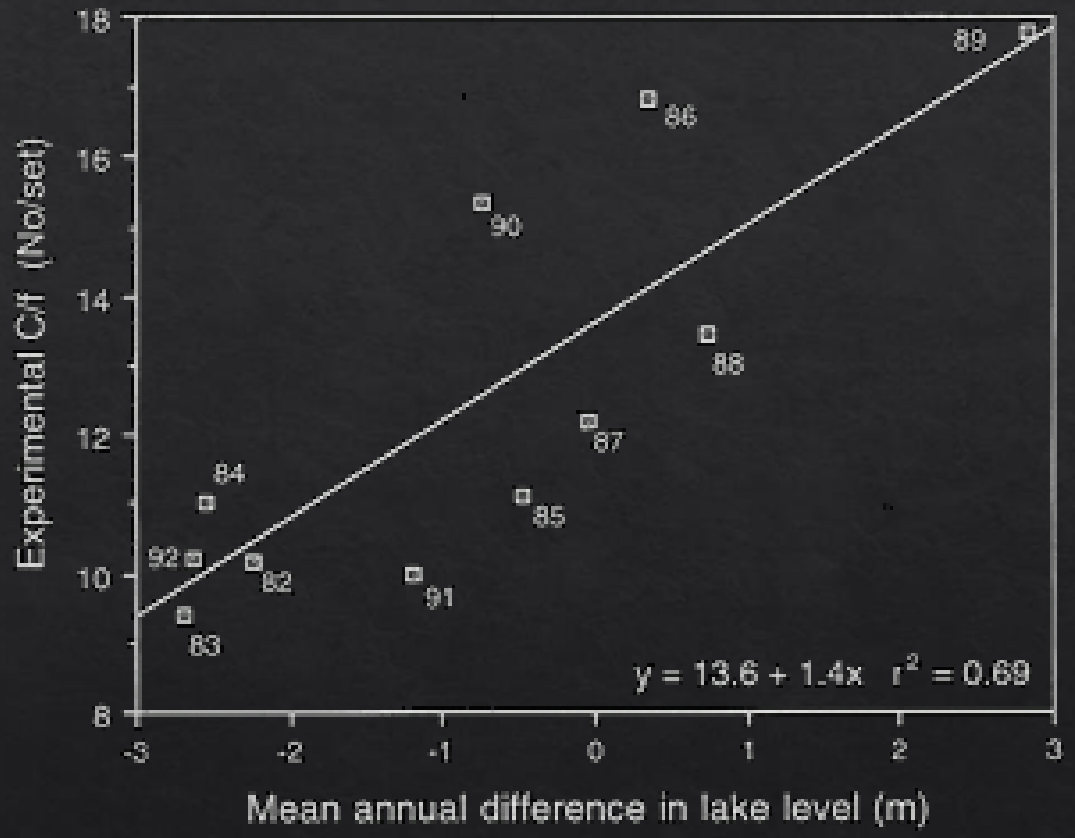


Is production is related to water levels?



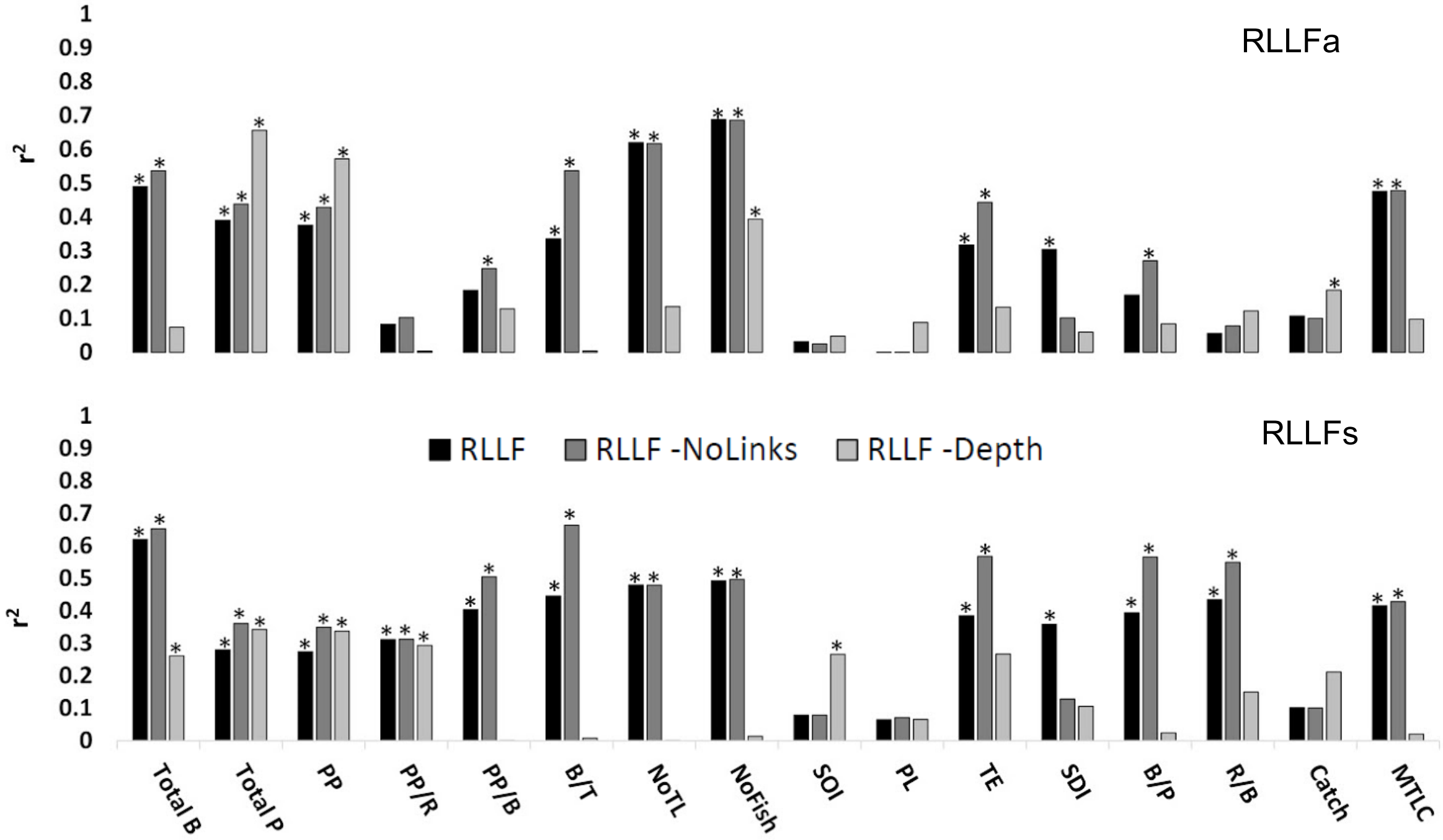
Lake Turkana 1972-1988

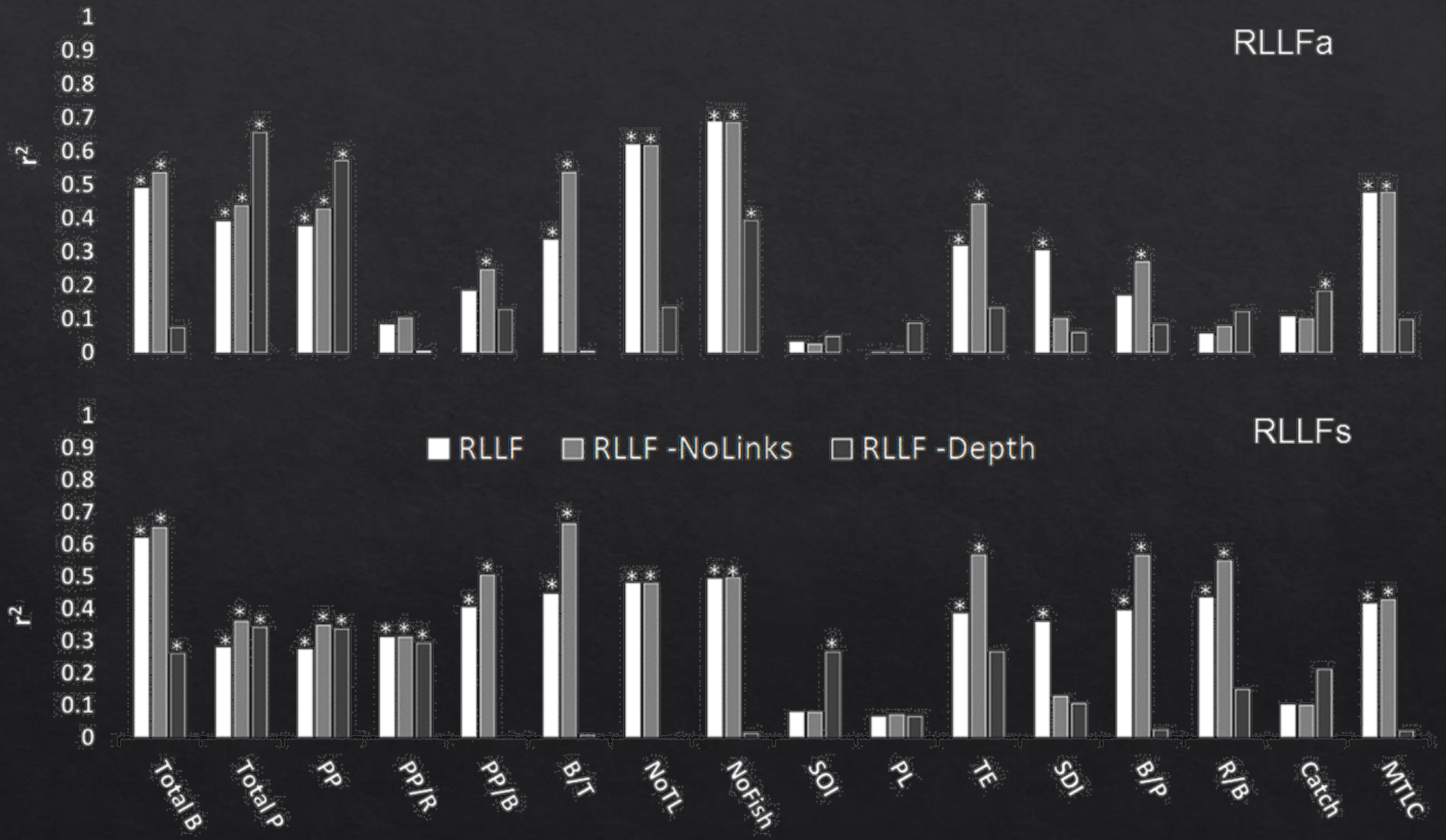
Kolding (1989)



Lake Kariba 1982-1992

Karenge & Kolding (1993)


RLLFa
RLLFs
RLLF
RLLF -NoLinks
RLLF -Depth
r2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Total B
Total P
PP
PP/R
PP/B
B/T
NoTL
NoFish
SOI
PL
TE
SDI
B/P
R/B
Catch
MTLC


RLLFa
RLLFs
RLLF
RLLF -NoLinks
RLLF -Depth
r²
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Total B
Total P
PP
PP/R
PP/B
B/T
NoTL
NoFish
SOI
PL
TE
SDI
B/P
R/B
Catch
MTLC