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European Regional Development Fund

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Interreg South Baltic

IMTA. Aquaponics with African catfish

University of Rostock
Aquaculture & Sea-Ranching
Faculty of Agricultural and Environmental Sciences

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Contents of the presentation:

- Introduction to IMTA & Aquaponics
- Applied technologies in Aquaponics
- Application of Aquaponics

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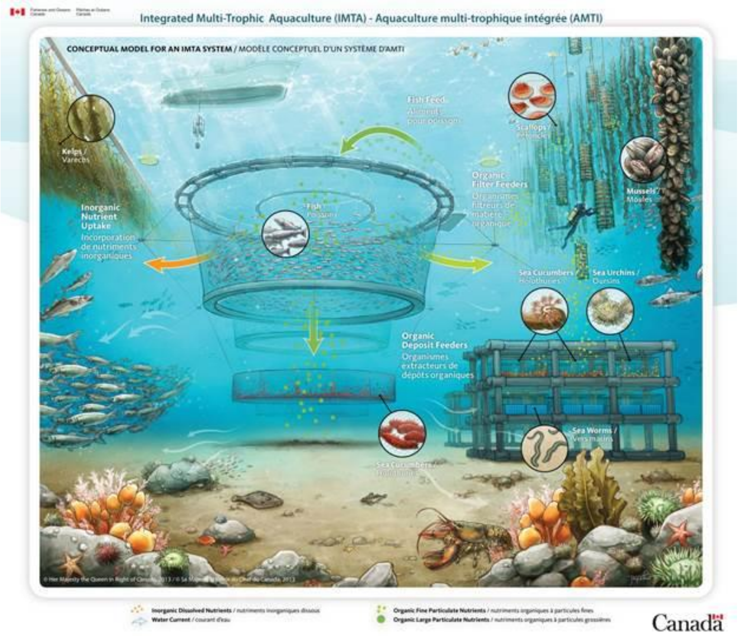
- **IMTA** = *Integrated Multitrophic Aquaculture*

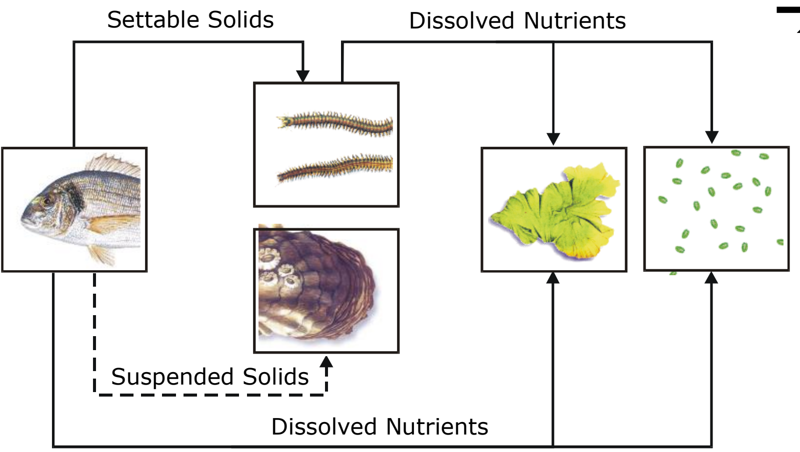


Aquaculture in Canada, 2013

→ Combination of different organisms that can be cultivated, but which feed at different trophic levels

→ All organisms are harvestable and market-able and thus enhance nutrient efficiency and the profitability of production

- **IMTA** = *Integrated Multitrophic Aquaculture*



→ Primary culture organism – the organism whose biotic and abiotic needs, serve as the basis for determining the water parameters as well as the feeding regime in an aquaculture production

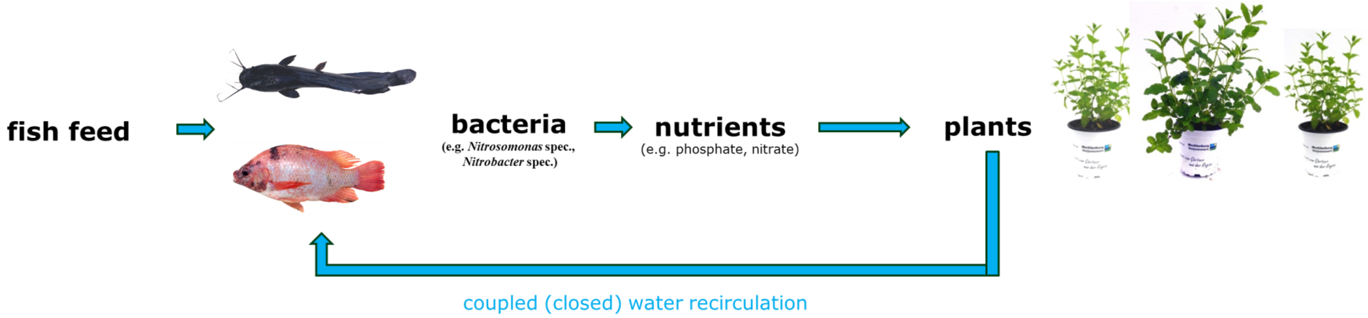
→ Secondary culture organism - the organisms that are used as recyclers of accumulating excess nutrient excretions of the primary organism

- **Aquaponic** = Aquaculture + Hydroponic
- **Aquaculture** = Production of aquatic organisms such as fish, crayfish, mussels, shrimps

  → effluent water with unused nutrients
- **Hydroponics** = Soil less plant production such as tomatos, herbs and other commercial plants,

  → integrated plant cultivation

"The aquaponic cycle"



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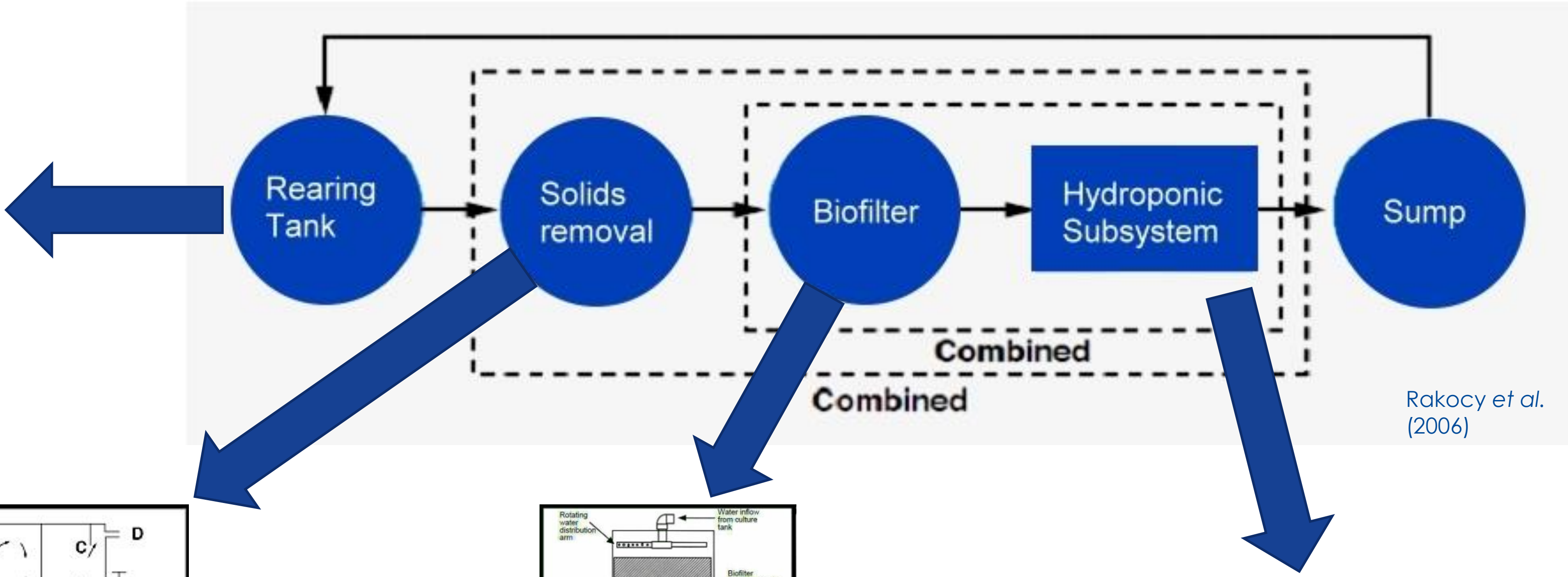
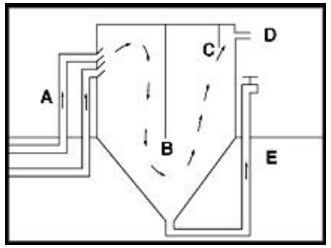
Schematic Overview of Aquaponic – Recirculation Systems

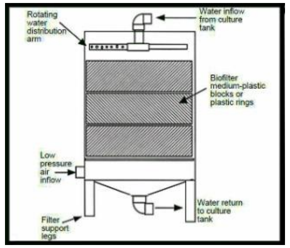
Fish feed (unused nutrients) → Nitrification → Plant nutrients (mostly Nitrate, Phosphate)



Fish - Tank



Mechanical Filtration
(e.g. Clarifier)



Biofilter
(e.g. Trickling Filter)

There are different Hydroponic Subsystems →

Traditional Hydroponic Subsystems

- "**Aggregate Systems**": e.g Gravel, Expanded Clay, Sand as mechanical filter and nutrient buffer → "Ebb and Flow System"

Ebb- and Flow System
(Aquaculture and Sea Ranching, UROS)

- "**Floating Raft System**": Plants are swimming on nutrient enriched water by rafts

Raft System (Blaze, 2010)

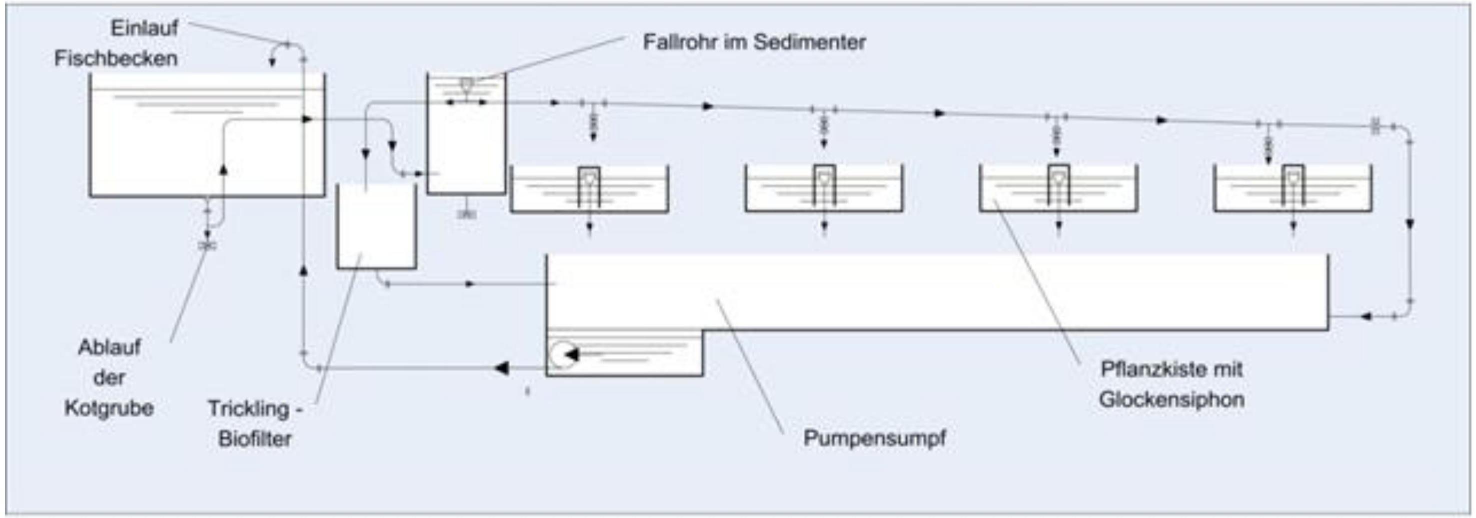
- "**Nutrient Film Technique**" (NFT): Plant roots bathing in channels of thin recirculating nutrient film

NFT - System (Blaze, 2011)

- "**Aeroponics**": Dispersed nutrients to the roots with sprays

An new initiative at University Rostock

- Warm water Aquaponics and Hydroponics (from M.Sc., to PhD, to research papers)



- Impressions of the first system




- The FishGlassHouse (at dawn)

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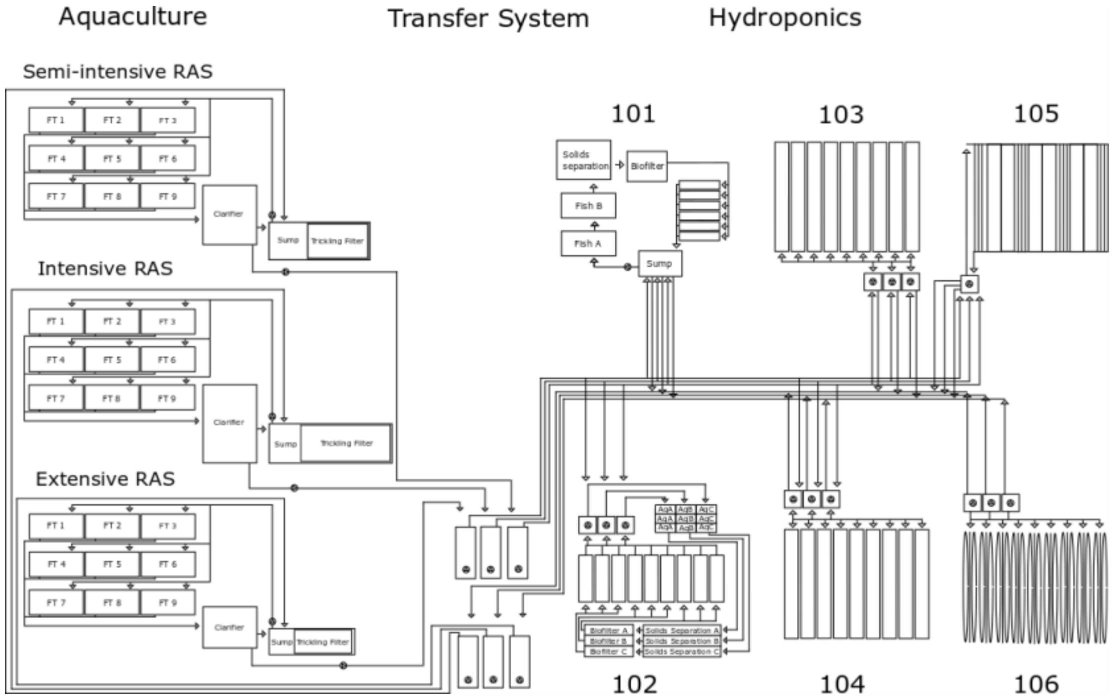
The FishGlassHouse at the University of Rostock



Sampling strategies at the FishGlassHouse

Factor	Variables	Results
Stocking density Extensive: max. 50 kg, 35 fish m^{-3} Semi-intensive: max. 100 kg, 70 fish m^{-3} Intensive: max. 200 kg, 140 fish m^{-3} Feed input & RAS management strategy Run-in, Batch, Staggered	What did we test ? **1.Nutrient dynamics** **2.Growth** (FCR and SGR) **3.Mortality** **4.Plant performance** in commercial ebb-flow system **5.Fish product quality**	1. Propotionate (K) and disproportionate dynamics caused by denitrification (N) and precipitation, (P, Ca, Mg, Fe), changing over time in dynamic catfish RAS production 2. Stocking density ↑ : FCR ↓, SGR → 3. Stocking density ↑ : Survival ↓ (Oxygen) 4. N and K limiting on growth and quality of mint and basil in substrate cultuvation 5. Maintenance ↑ : Product quality (fish) ↑
Selective nutrient addition (P, K) to 1.Process water of the fish 2.Culture water of the plants	Effects on **1.FCR, SGR, survival, welfare in fish** **2.Plant performance**	1.P possible in the range of 40 mg/l 2.K possible in the range of 200 – 400 mg L^{-1} *Bassalo et al. (2017)*

- Outcome: recommendations to commercial catfish farmers

- FishGlassHouse: coupled, decoupled and gardening

Nutrient fluxes in aquaponics – the problems…

- Aquaponic systems often small scale
- Different designs make comparisons difficult
- Commercial fish production focus on fish and commercial plant production on hydroponics
- Different plant species react differently on different fish species in coupled aquaponics
- How to compensate and control the nutrient composition under fish process water use in decoupled systems

→ **What happens inside commercial aquaculture systems with relevance to subsequent plant production ?**

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What happens with the fish inside the water?

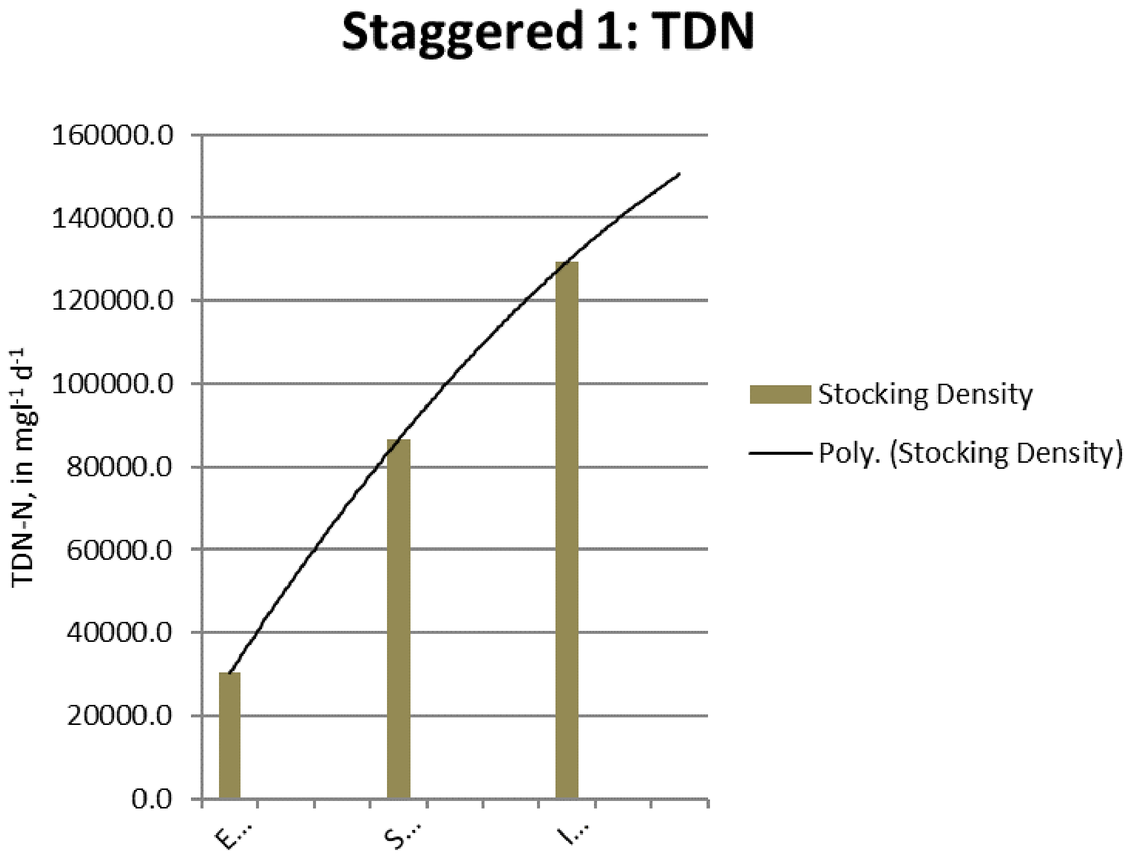
Management	Stocking density	Production phase				
		Run in	Batch	Staggered I	Staggered II	Staggered III
Feed	Extensive	196.2	1657.8	2180.7	2106.3	1378.4
in g d^{-1} (dry matter)	Semi-intensive	485.2	2917.0	4341.0	4234.4	2717.4
	Intensive	835.4	6309.1	8622.0	8421.8	5352.9
Maintenance	Extensive	0.3	1.7	1.7	1.2	0.3
Clarifer cleanings $week^{-1}$	Semi-intensive	1.7	2.6	3.8	4.7	2.7
	Intensive	1.9	2.1	2.7	5.1	2.7
Water exchange	Extensive	110.9	472.7	526.8	248.5	43.3
in l day^{-1}	Semi-intensive	368.3	887.8	1191.1	1247.7	490.8
	Intensive	465.7	810.6	1271.0	1647.2	694.0

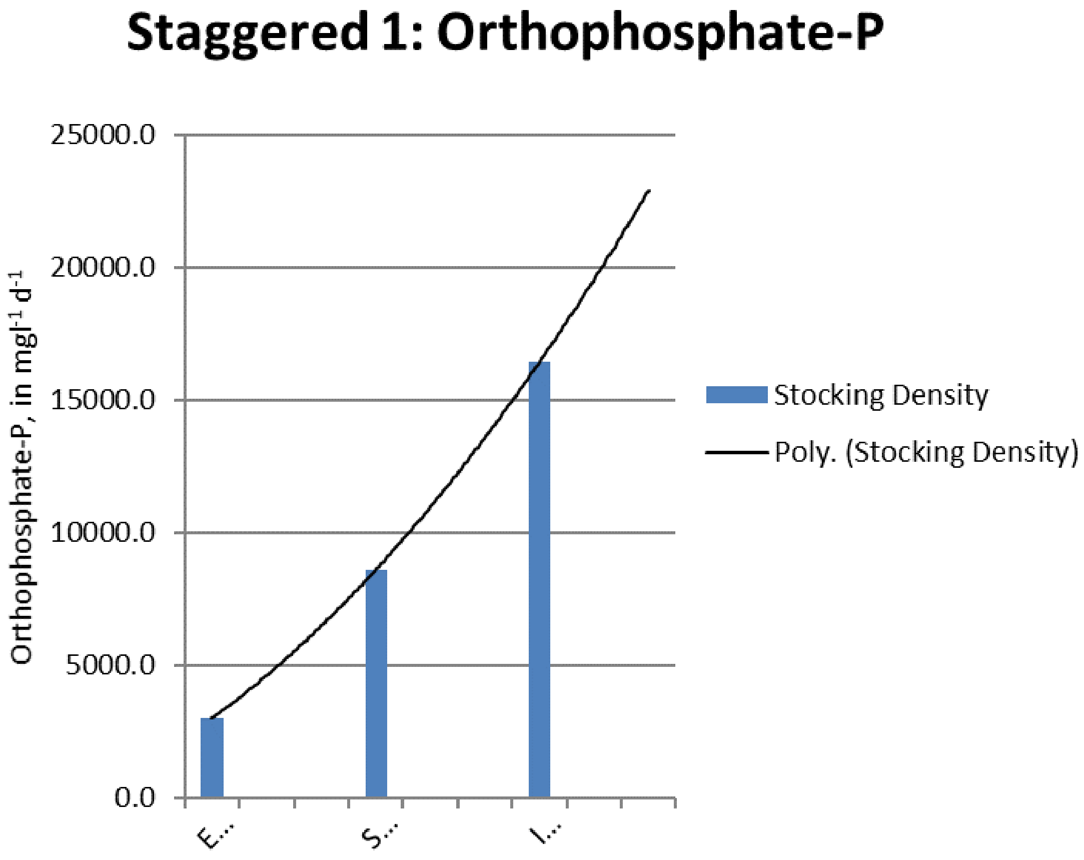
- Growth ?
- Mortality?

Depends the mortality on the applied stocking density?

Fish cohorts	Production phase	Intensity	Initial weight	Final weight	Total growth	FCR	Survival
			mean fish^{-1}, in g n=9 tanks	mean fish^{-1}, in g n=9 tanks	mean tank^{-1}, in kg n=9 tanks	mean tank^{-1} n=9 tanks	mean tank^{-1}, in % n=9 tanks
1, 2, 3	Run in/batch	Extensive	275	1527	41	0.94	96.2
		Semi-intensive	275	1497	80	0.94	95.1
		Intensive	275	1459	146	0.96	89.8
			mean fish^{-1}, in g n=3 tanks	mean fish^{-1}, in g n=3 tanks	mean tank^{-1}, in kg n=3 tanks	mean tank^{-1} n=3 tanks	mean tank^{-1}, in % n=3 tanks
4	Staggered 1	Extensive	51	1791	47	1.14	78.1
		Semi-intensive	51	1781	109	1.01	90.0
		Intensive	51	1715	200	1.07	86.4
			mean fish^{-1}, in g n=3 tanks	mean fish^{-1}, in g n=3 tanks	mean tank^{-1}, in kg n=3 tanks	mean tank^{-1} n=3 tanks	mean tank^{-1}, in % n=3 tanks
5	Staggered 2	Extensive	47	1607	52	0.89	96.2
		Semi-intensive	47	1593	104	0.89	96.7
		Intensive	47	1628	199	0.94	90.2
			mean fish^{-1}, in g n=3 tanks	mean fish^{-1}, in g n=3 tanks	mean tank^{-1}, in kg n=3 tanks	mean tank^{-1} n=3 tanks	mean tank^{-1}, in % n=3 tanks
6	Staggered 3	Extensive	40	1492	49	0.87	96.2
		Semi-intensive	40	1541	93	0.91	88.6
		Intensive	40	1561	172	0.97	81.4

Nutrient fluxes under different stocking densities





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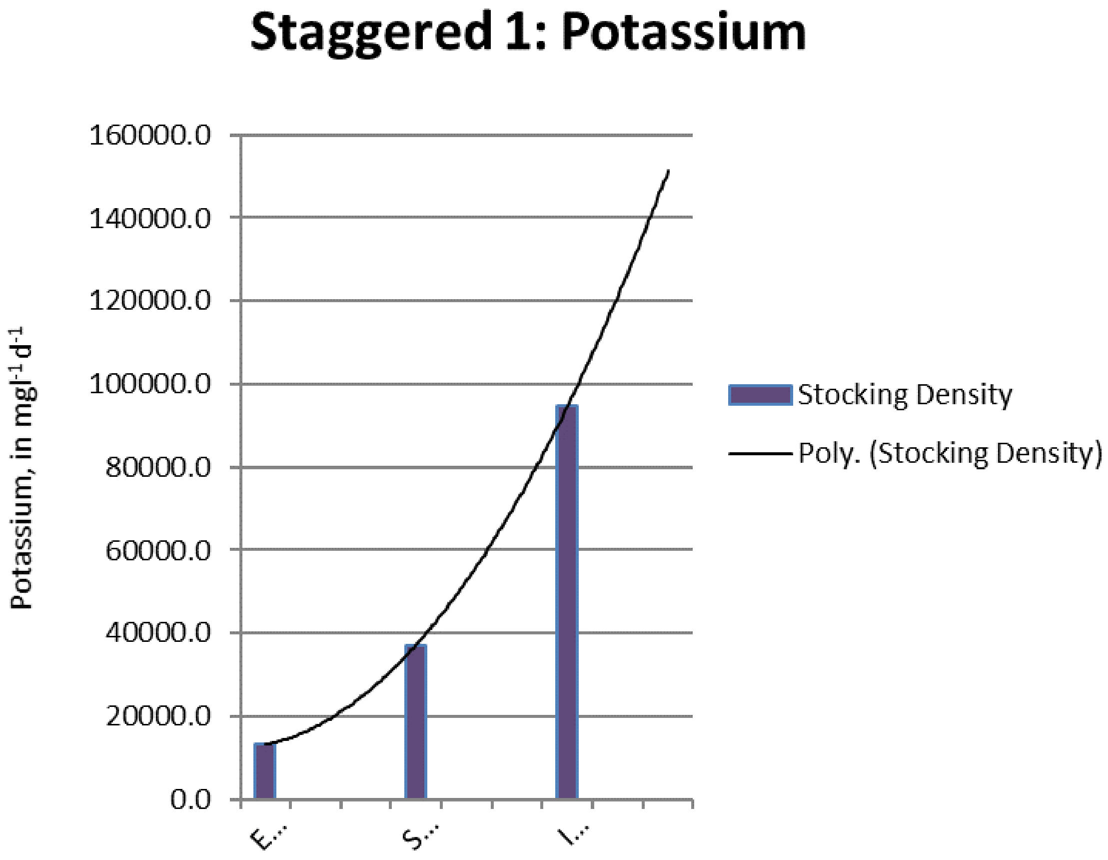
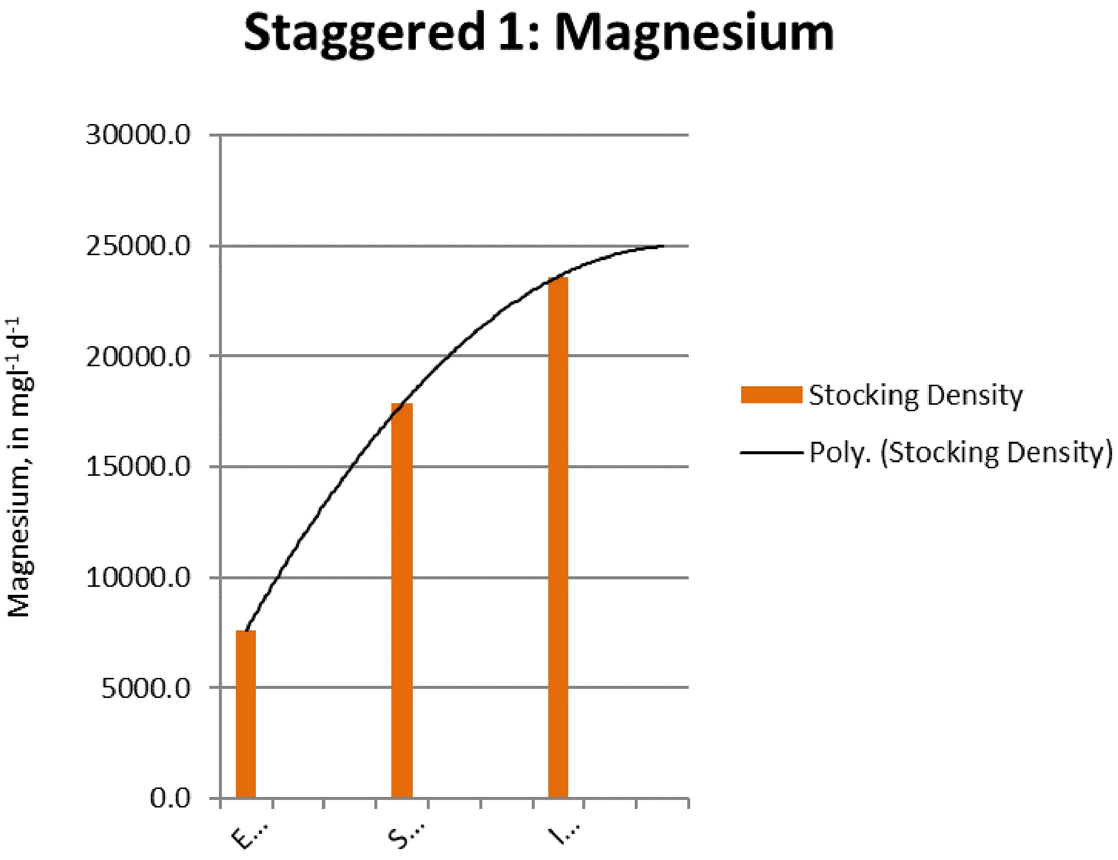
Nutrient fluxes under different stocking densities





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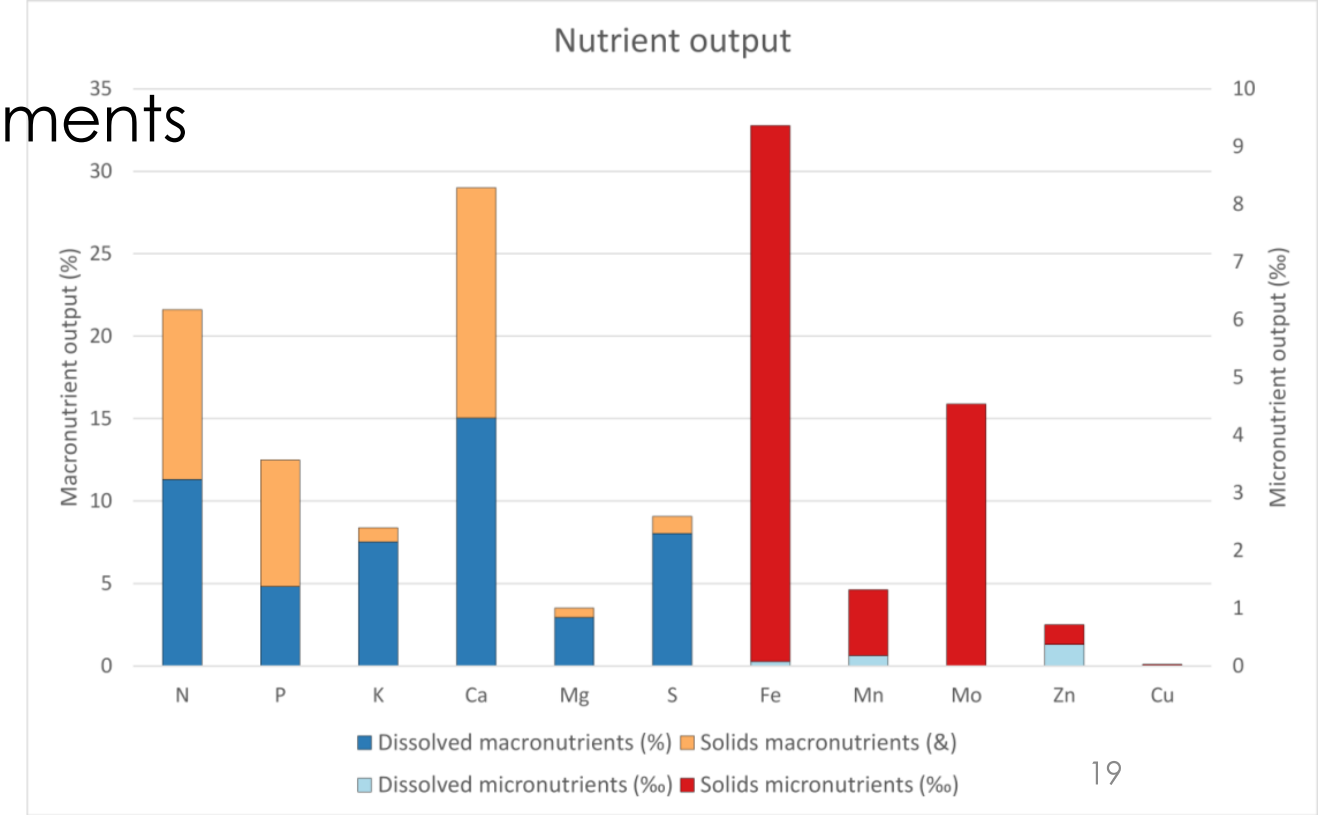
Sediment compositon under commercial conditions

- N underlies unaerobic processes in the sediments (N_2 production)
- Ca and Mg and precipitation of P depends on water exchange rates
- Fe, Mn, Mo attached to the sediments



Sludge for biogas production (?)

Element	Optimal (mg L^{-1})	Minimal (mg L^{-1})	Measured (Range, mg L^{-1})
Co	0.120	0.060	0.003–0.005
Ni	0.015	0.006	0.006–0.020
Se	0.018	0.008	0.002–0.006
Mo	0.150	0.050	0.005–0.013
Mn	-	0.005–50	0.107–0.995
Fe	-	1–10	1.37–7.81

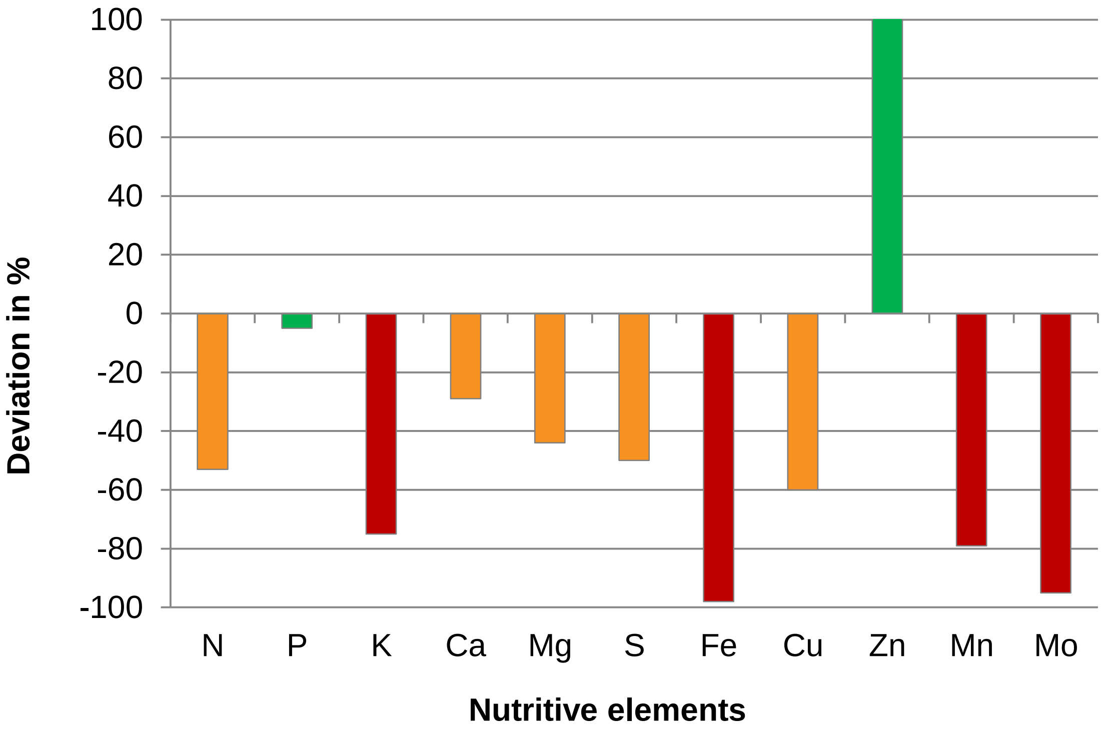
Ratios	Recommendation (FNR, 2016)	Measured (Average)
C:N:P:S ratio	600:15:5:3	112:13:8:3
C:N ratio	10–30:1	8–9:1

- Deviations of RAS sludge from recommended element concentrations and element ratios for anaerobic digestion (FNR, 2016).

→ Should be used as a co-substrate (needs additional C input)

Process water vs hydroponic fertilizer in the case of aquaponics

- Low overall nutrient concentrations in the process water
- High deficiencies of K (loss through water exchange), Fe , Mo and Mn (sediments)
- Direct use for undemanding plants
- Nutrient adjustment required for demanding plants

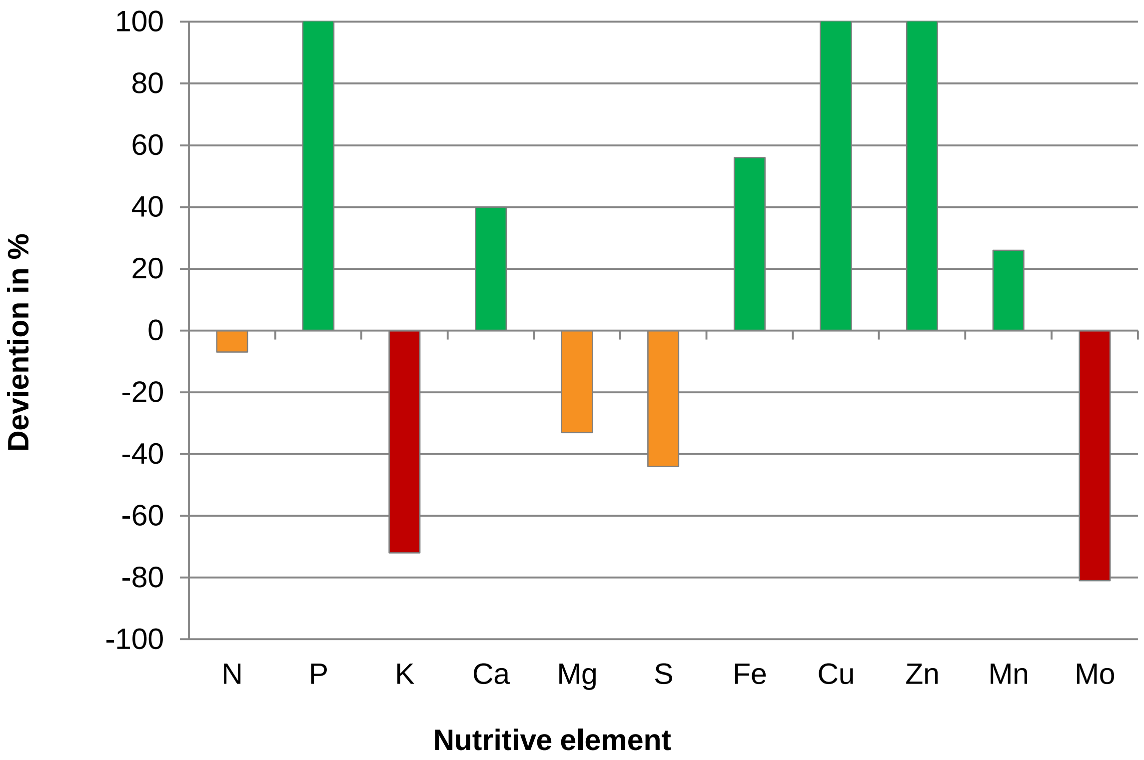


Deviations from recommended hydroponic fertilizer concentrations from Hoagland and Aarnon (1938), Hewitt (1966), Cooper (1979) and Steiner (1984) (Table 2 in Trejo-Téllez & Gómez-Merino, 2012).

Process water vs hydroponic fertilizer in the case of aquaponics

- Compared to process water: high P Ca, Fe, Cu, Mn concentrations
- Deficiencies of K and Mo
- U : P ratio < than in average in P-fertilizer

→ **In combination with process water the nutrient profile can be improved**



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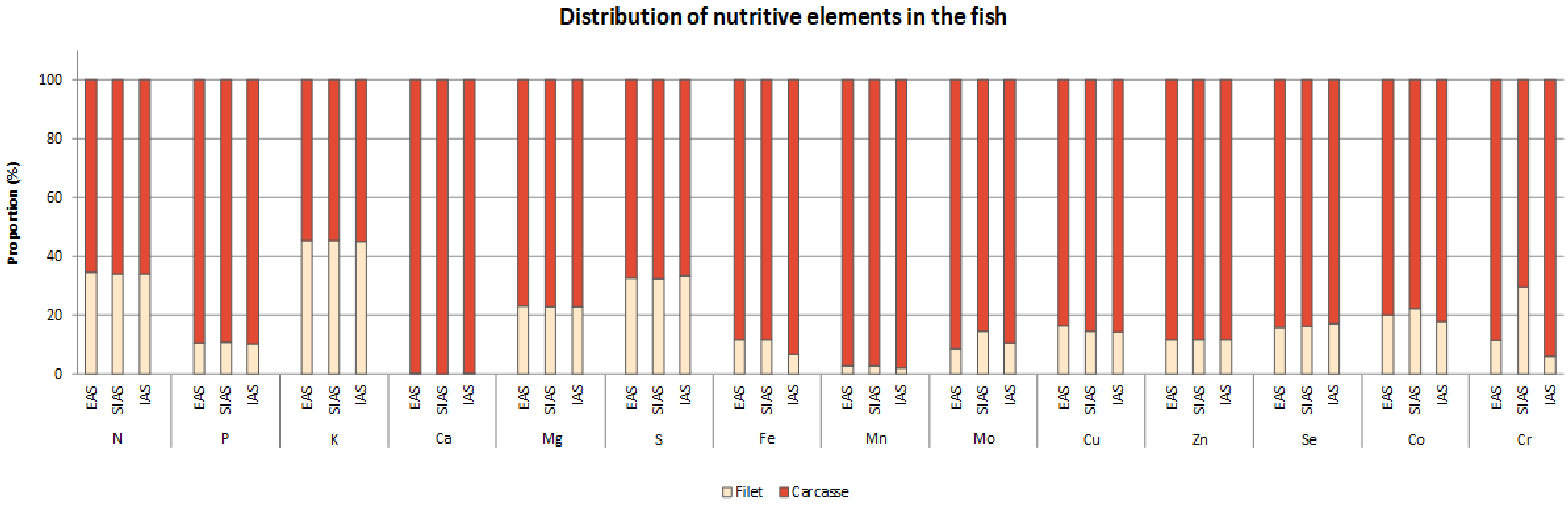
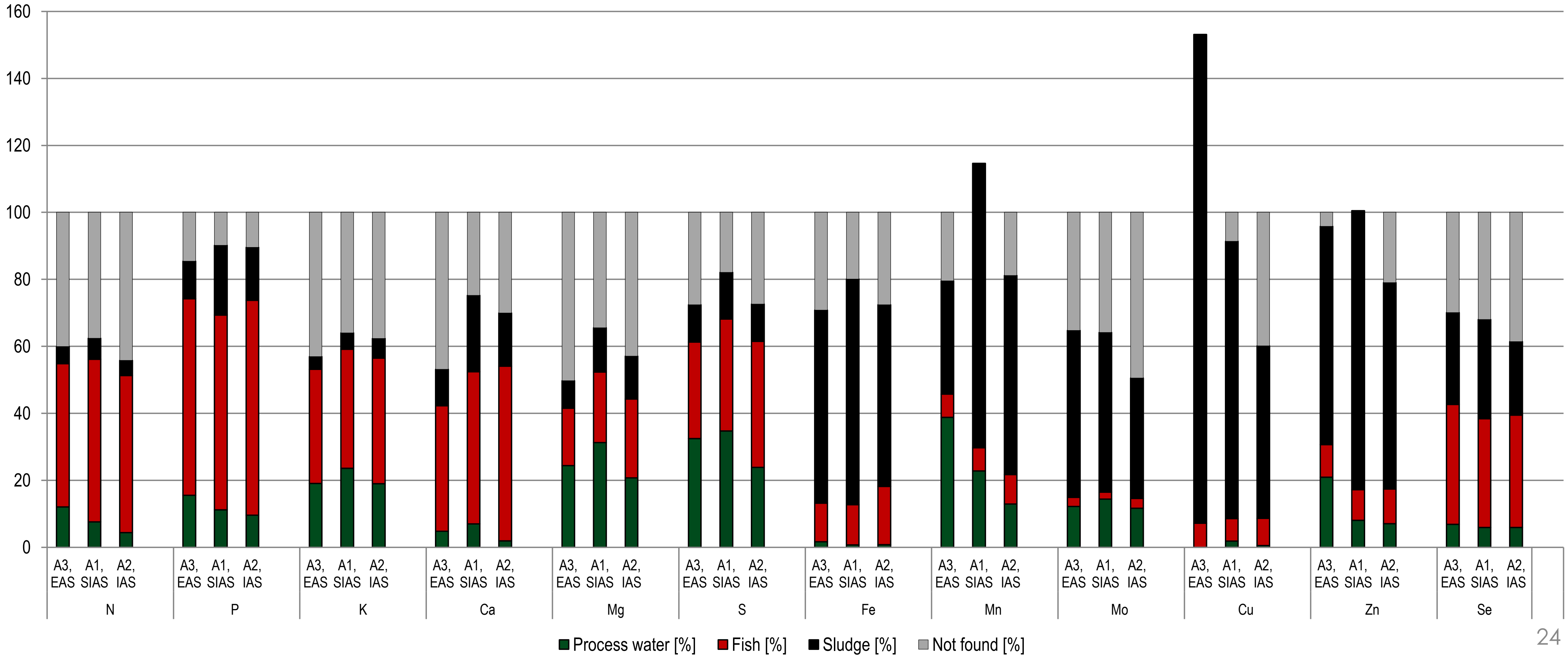
How much nutrients are retained by the fish



• And the rest ???


160
140
120
100
80
60
40
20
0
A3, EAS
A1, SIAS
A2, IAS
N
P
K
Ca
Mg
S
Fe
Mn
Mo
Cu
Zn
Se
Process water [%]
Fish [%]
Sludge [%]
Not found [%]

The RAS and the Fish, …. and what we do not know!(?)

- **Process water:** Low nutrient overall concentrations, deficient in K, Fe, Mn and Mo → **Nutrient adjustment required**
- **Sludge:** Much too low C content for the solely use in biogas production. Contains plant essential nutrients lacking in the process water (P, Ca, Fe, Cu, Mn)
  → **Successful use in aquaponics farming appears possible**
- **Carcass:** High energy content and concentrations of valuable nutrients (P, Ca, Mg, N)
  → **Reuse potential e.g. application as animal feeds**
- **Phosphorous:** 84–89% of input P was recovered, most of it remaining in the carcass (52.85%). Rest inside bacteria ?. U:P ratio inside the sludge lower than in commercial P-fertilizer

Products (e.g. ornamental plants – ivy - different strains)

Palm et al. (2019) In Aquaponics Food Production Systems (eds. Goddek et al.)

	sale category		
ivy-variations	**very good [%]**	**good [%]**	**bad [%]**
bright ivy (total 159 plants)	**50.3**	**44.0**	**5.7**
control (total 59)	47.5	49.2	3.4
extensive (total 49)	53.1	39.0	8.2
intensive (total 51)	51.0	43.1	6.0
dark ivy (total 634 plants)	**20.0**	**43.5**	**36.4**
control (total 218)	10.1	60.0	30.3
extensive (total 207)	32.4	44.0	24.0
intensive (total 209)	18.2	26.3	55.5

→ **bright ivy achieved a plant quality of 94.3% without fertilization, dark ivy only 63.5%.**

Products and markets (gardening plant species)

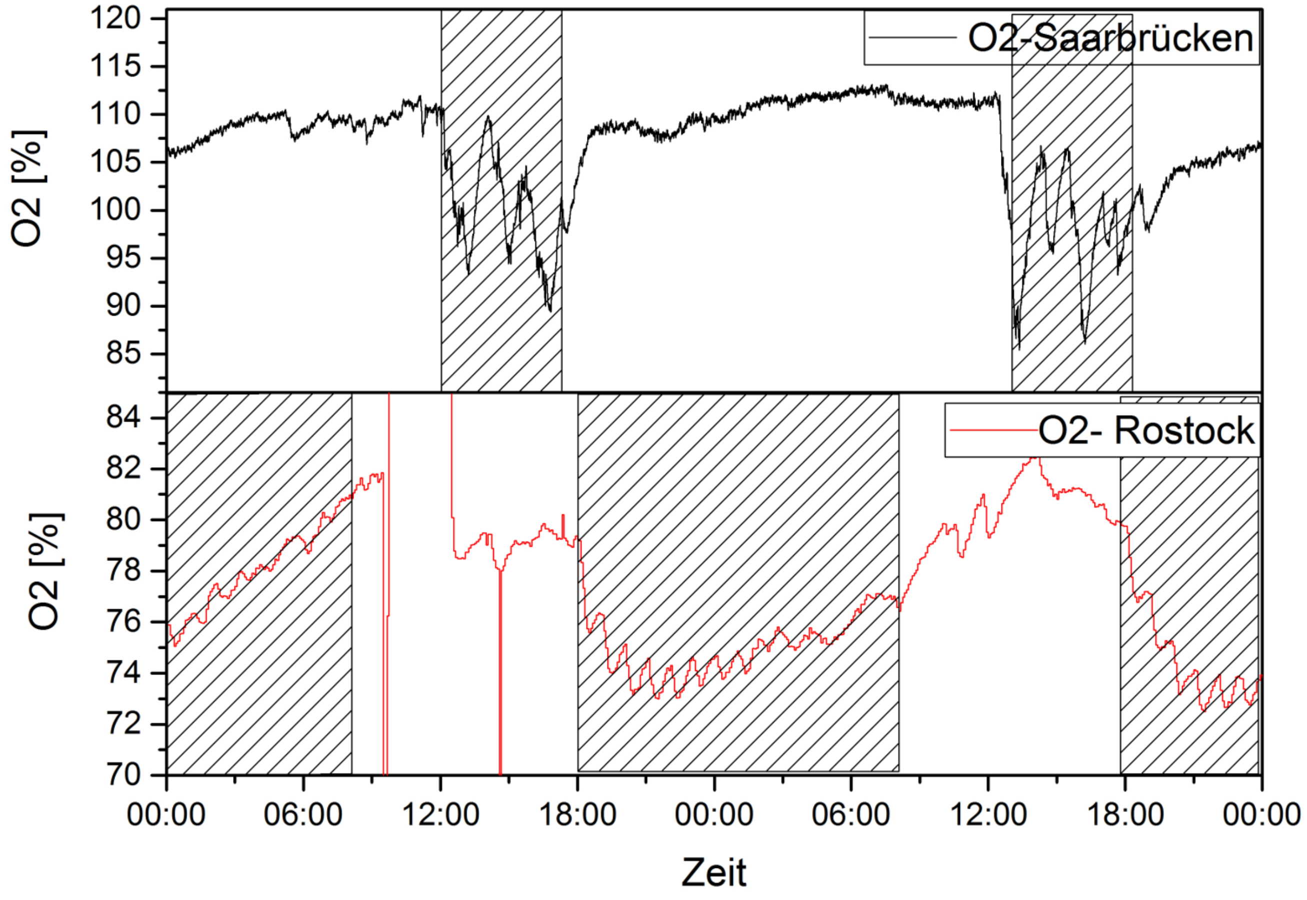


Palm et al. (2019)
In Aquaponics Food Production Systems (eds. Goddek et al.)

Resulting recommendation of gardening plant species for aquaponic farming with the use of 50% or the regular fertilizer and soil

Common name	Latin name	Applicable in aquaponics	Mark	Nutrient regime
Beans	*Phaseolus vulgaris*	yes	1	extensive
Peas	*Pisum sativum*	no	2	intensive
beet	*Beta vulgaris*	no	2	both
Tomatoes	*Solanum lycopersicum*	no	2.3	both
Lamb's lettuce	*Valerianella locusta*	yes	1	both
Radish	*Raphanus sativus*	yes	1	both
Wheat	*Triticum aestivum*	no	2	both
Lettuce	*Lactuca sativa*	yes	1	intensive

The fish…



Oxygen contents inside the tanks, comparison of

Dicentrachus labrax

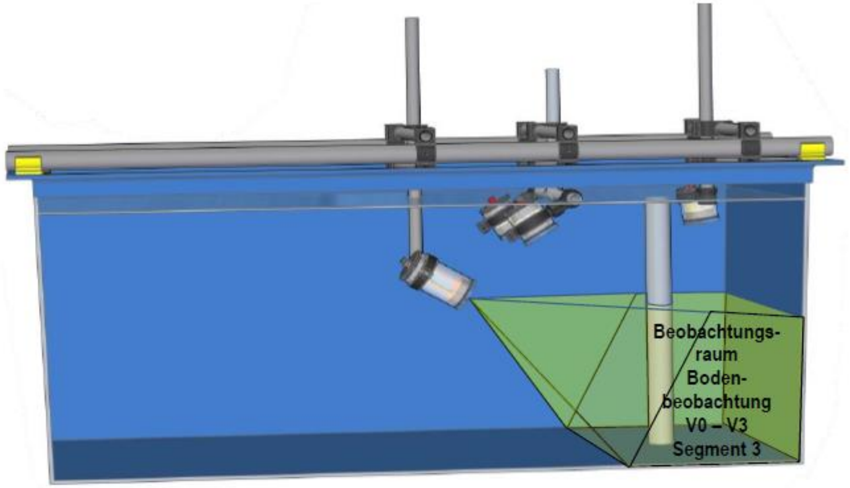
Clarias gariepinus

Fish and Welfare: What happens inside the water?

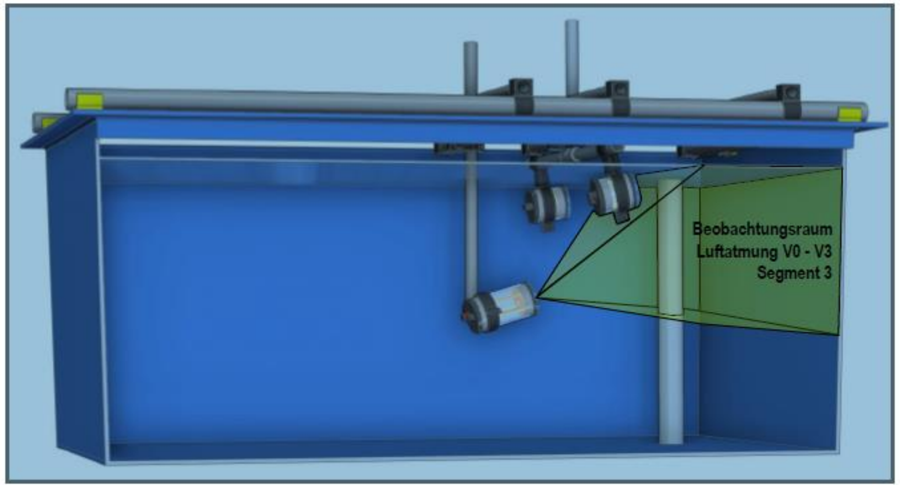
- Under water camera system for fish surveillance under complete darkness

Fish and Welfare: What happens inside the water?

- The number of bite wounds coincides with the fish behavior inside the fish tanks



Berchtold 2020



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Fish and Welfare: What happens inside the water?

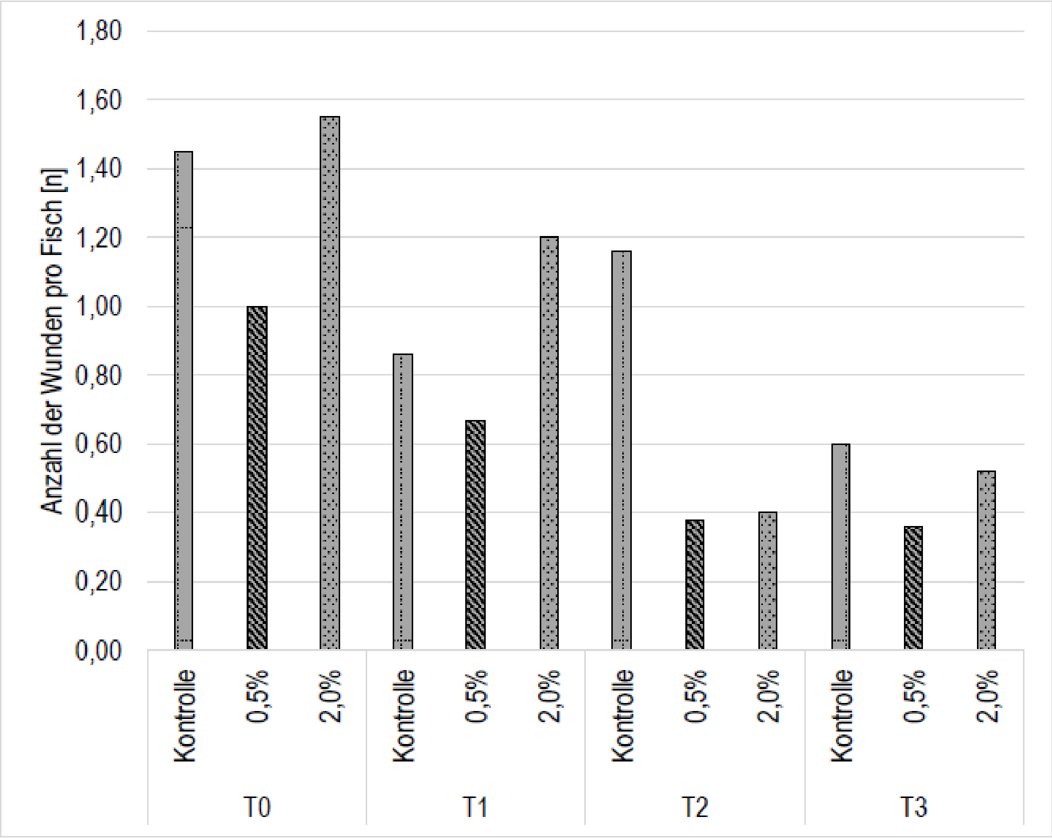
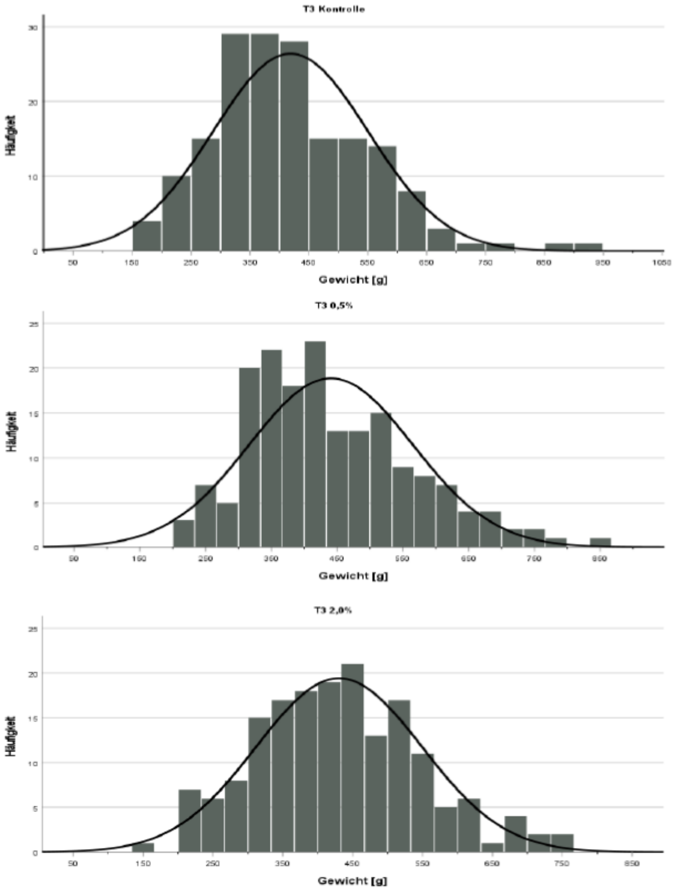


Abbildung 42 Durchschnittliche Anzahl der Bisswunden zu den Zeitpunkten T0 bis T3.



Verhalten
Agonistisches Verhalten
Luft atmen
Fluchtversuche
Ruhen
Stereotypes Verhalten
Schwimmen
Neugier

Berchtold 2020

Aquaponics under urban conditions

Addition of 4 further loops:

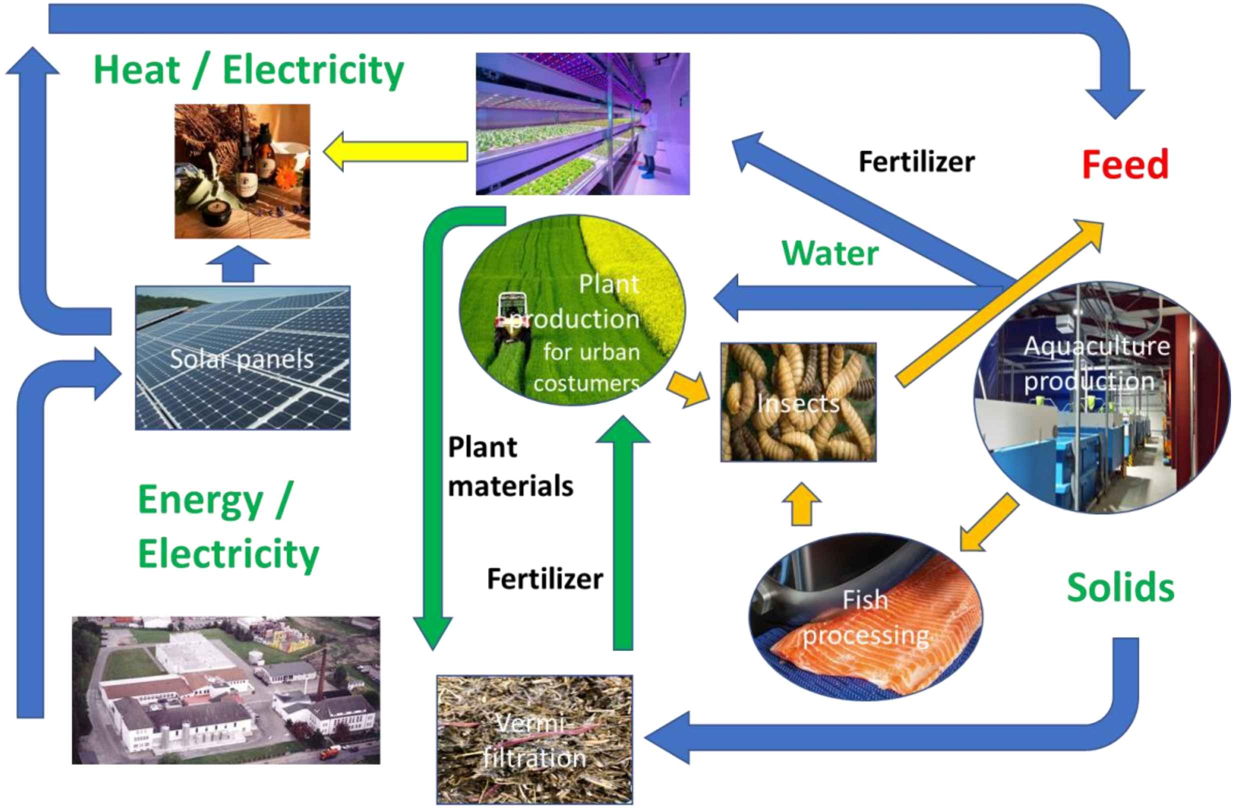
a) insects vs pigs
b) compost/worms vs biogas
c) cosmetics
d) education

Palm 2021

Output:
- Cosmetics
- Crops (berries)
- Herbs
- Fish (Filet)
- Insect proteins
- Electricity
- Heat
- Compost
- Education

Input:
- Seed
- Fertilizer (-)
- Water (-)
- Feed (Fish)

Wastes:
- Depending on dimensions



Lessons learned (part I)

- We are able to understand a fish cultivation system

  → **But** …this needed some time

- The physiology and life history of fish strongly influences nutrient dynamics
- We do NOT KNOW (so far) the role of the microorganisms or the micro-sediments in RAS as nutrient carriers to the aquaponical produced plants
- We are NOT (YET) ABLE to explain the aquaponic effect on Fish Welfare

Lessons learned (part II)

- Aquaponics requires
  - a) perfect match of fish and plant species
  - b) additional fertilizers (and/or) pH-adjustment with an additional control of fish welfare
- Sediments of African catfish are not suitable for solely use in biogas production or vermifiltration without additional C or substantial increase of dry matter content
- With low accumulation of nutrients in sediments and waters, both can be applied in aquaponics farming, with or without additional fertilizers

Perspectives (part I)

- Aquaponics as a concept must become integrated into education programmes as well as regular agricultural practices in order to minimize environmental impact of food production
- Aquaculture in Germany is stagnating. Aquaponics is a possible way to increase production output and increase acceptance for aquaculture products
- Aquaponics should sideline further aquaculture developments, increasing aquaculture output combined with product diversification and minimal resource useage

Thanks to the Aquaculture and Sea-Ranching team and your attention

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