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Fishmeal Replacement by Duckweed and its Effects on Growth and Feed Utilization in Rainbow Trout Fry

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Aquaculture and Fisheries in a global context

- 2011:
  - Aquatic food production (aquaculture and fisheries):
  - 144 Mio. t.
  - Terrestrial food production:
  - 3982 Mio. t.

3.6% of global **food** supply
1.2% of global **food energy** supply (kJ)
1.5% of global **lipid** supply
6.7% of global **protein** supply
3.5% of global **feed** supply

Table 3 Global production and utilization of major primary food commodities derived from agriculture and aquatic food production systems in 2011 (values given in 1000 tonnes; data compiled from FAO, 2014c)

Primary food commodity	Total	Food	Feed	Processing	Seed	Waste	Other
Cereals	2,345,593	1,014,082	818,85	89,175	66,918	100,781	228,641
Vegetables	1,087,504	935,189	52,562	611	0	92,94	536
Starchy roots	798,175	437,922	177,249	14,712	35,711	78,068	52,378
Oilcrops	550,913	48,218	35,568	422,535	11,099	13,183	13,652
Fruits	629,018	510,073	5,543	55,318	0	60,12	1,884
Pulses	68,336	47,092	13,244	0	3,966	3,478	710
Treenuts	15,483	15,423	0	0	0	456	67
Terrestrial meat	296,607	290,648	75	453	0	882	1,79
Eggs	70,682	61,563	74	0	4,697	3,291	710
Milk	739,111	621,61	78,961	101	101	18,622	16,752
Total agricultural foods	**6,601,421**	**3,981,820**	**1,182,125**	**582,906**	**122,391**	**371,821**	**317,189**
Fish and seafood	149,508	129,908	23,445	466	466	0	3,868
Other aquatic products	23,127	14,287	159	0	0	0	8,799
Total aquatic products	**172,635**	**144,196**	**23,604**	**466**	**466**	**0**	**12,666**

Bolded values indicate an aggregate volume:
- Total agricultural foods represent the sum of cereals, vegetables, starchy roots, oil crops, fruits, pulses, tree nuts, terrestrial meat, eggs and milk
- Total aquatic products represent the sum of fish and seafood and other aquatic products.

Tacon & Metian 2015

Why rainbow trout?

- Rainbow trout is the most important food fish in Switzerland (~60% of production volume)
- Rainbow trout globally among most important high price fish
  - (2018: 850.000 t globally, CH: 1300 t)
- Rainbow trout is a carnivorous fish species (trophic level 4 in nature)
- To increase sustainability, «feed trophic level» needs to be reduced (Olsen 2011)
- To some degree, results might be transferred to salmon due to similar physiology

Proteinsources for aqua feeds

Source	Estimated annual production	Plant or animal derived
Fishmeal	4-6 mio. t., approx. 1/3 from trimmings	Animal derived, aquatic, can include other animals such as shrimp or krill
Soy-based (meal, concentrate, isolate)	~352 mio. t. global production, most important protein source in aquaculture	Plant derived, competition to human consumption
Wheat	~772 mio. t. global harvest, utilized in fish feed either as wheat flour (starch → binder) or processed as protein source (wheat gluten)	Plant-derived, can be consumed directly, as animal feed for pigs/poultry almost without processing
Maize/Corn	1135 mio. t. global harvest, utilization as source for starch or oil, infrequently as protein source (mais gluten/zeine → meat colour turns yellowish)	Plant-derived, can be consumed directly or without processing fed to pigs and poultry
Animal by-products	Assumption: 10% of slaughter weight Cows: 66 mio. t. Chicken: 109 mio. t. pigs: 120 mio. t. 295 Mio. t. = 29.5 Mio. t. available	Largely varying quality, not centralized except for large slaughterhouses, administrative obstacles (BSE), sometimes bad digestibility (feather meal)

Environmental issues

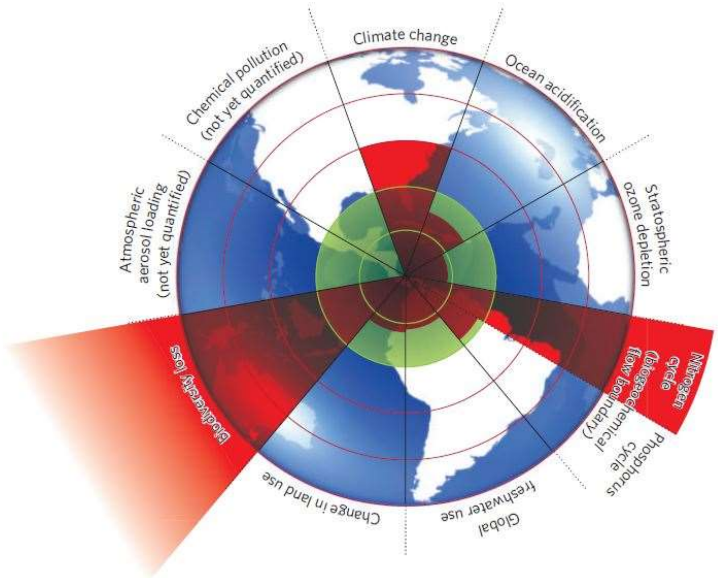
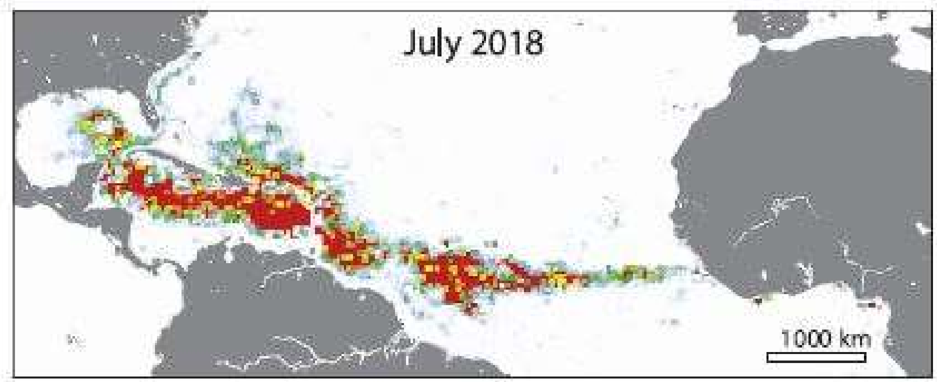


Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

„Planetary Boundaries“, Rockström et al. 2009



„Great Atlantic Sargassum Belt/Sargassum Brown Tides“, Wang et al. 2019

- Associated external costs for soy-production:
- 10 billion US$ import value in 2008 into EU
- Environmental damage: 120 billion US$

Boerema et al. 2016

Waldbrände in Südamerika über drei Tage im August 2019 (24.-26.8.2019). Die roten Punkte geben nicht die reale Größe von Bränden wieder, sondern markieren Gitterzellen, in denen Feuer registriert wurden. Grün: Schutzgebiete.

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Alternative feed ingredients

- Demand for true alternatives!

- Large-scale N and P emissions and subsequent eutrophication of agricultural areas and groundwaters

- High N and P uptake efficiencies could counter emissions from agriculture
  - E.g. *Pangasianodon* sp. in Mekong delta region: 2008 only due to emissions created by *Pangasianodon* sp. : 50000 t N and 16000 t P

- Duckweed shows high growth rates and high protein contents (up to 40%)

Feed formulation

- Control diet: 40% fish meal, 28.8% wheat gluten → 52.5% crude protein, 17.5% crude lipids
- Test diets: 12, 24 or 35% of fishmeal protein replaced by duckweed protein
- Dried duckweed (DWD) or fermented duckweed (DWF)
- Maximum duckweed content: DWF35 = 28.4% of dry matter
- Feed mixed dry and pelleted with household meat grinder
- Feed afterwards broken and sieved for 0.8-1.2 mm fraction

Experimental setup

- Experiment conducted in April/May during Corona

- 15 initial fish per aquarium
- Initial individual body mass: 1.49 g
- 1 week adaptation with standard feed
- Average water temperature: 16.8 °C
- Average oxygen saturation: 90%
- Feed allowance: 5% during first 3 weeks, in 4th week 3%
- Feeding regime: hand feeding, during week 3x/day, during weekend 2x/day
- 2x/week water quality analysis (O_2, NH_4, NO_2, pH)
- Every Monday group weighing and re-calculation of feed allowance

Experimental system

Experimental system

Results

	Control	DWD12	DWD24	DWD35	DWF12	DWF24	DWF35
Initial (g)	1.47 ± 0.05	1.51 ± 0.05	1.47 ± 0.02	1.47 ± 0.06	1.53 ± 0.03	1.48 ± 0.05	1.48 ± 0.06
Final (g)	6.81 ± 0.37	6.99 ± 0.37	6.35 ± 0.20	5.81 ± 0.52	6.93 ± 0.29	6.41 ± 0.37	6.22 ± 0.22
Body mass gain (%)	465 ± 15.6	463 ± 15.6	431 ± 9.04	396 ± 26.8	455 ± 13.8	433 ± 33.4	420 ± 11.5
SGR (% d^{-1})	4.39 ± 0.10	4.37 ± 0.10	4.17 ± 0.06	3.93 ± 0.20	4.33 ± 0.09	4.18 ± 0.23	4.10 ± 0.08
FCR	1.11 ± 0.04	1.11 ± 0.03	1.16 ± 0.01	1.26 ± 0.07	1.12 ± 0.03	1.19 ± 0.07	1.20 ± 0.03

Conclusion

- Preliminary conclusions → statistics not performed yet
- Very good performance over the whole experiment
  - (no really „bad performance“)
- 40% Fishmeal is for frty and fingerlings typical, 52.5% protein is on the low side
- Replacement of poultry by-product meal with wheat gluten → no more foaming
- Very few differences between treatments, very parallel growth
- Only in highes fish meal substitution levels differences → dried duckweed appears to have worst performance contrary to carps (fermented duckweed worst performance)


Thank you for your attention

› Nutrient content of plants depends on nutrient content in substrate:

Table 3: The influence of the concentration of N in culture water on crude protein in duckweed (*Spirodela spp*) grown on diluted effluent from a piggery. The P levels varied from 0.2-6.1 mg P/litre (Leng *et al* 1994)

N in water (mg/litre)	Total samples	N*6.25 (% in DM) 5-20	20-25	25-30	30-35	35-40
		Number in each N*6.25 range				
0-5	7	3	3			
5-10	13	3	4	3	3	2
10-15	12		2	2	2	6
15-20	3					3
20-25	2				1	1
25-30	2					2
30-35	0					
35-40	0					
40-45	2					2

Table 4: The relationship between the quantity of P in duckweed and the concentration of P in water. Values below 1.5 mg P/litre of water are Sutton and Ornes (1975); the higher values are from research in this Centre (Stambolie and Leng 1994)

P in water (mg/litre)	Total samples	P (mg/g DM) 0-2	2-4	4-6	6-8	8-10	10-12	12-14
		Number in each P range						
0-0.5	6	3	3					
0.5-1.0	1	0	0	1				
1.0-1.5	2	0	0	0	0	1	0	2
1.5-2.0	2	0	0	0	0	0	0	2
2.0-2.5	3	0	0	0	0	1	0	2
2.3-3.0	1	0	0	0	0	0	0	1

from Leng et al. (1995)

- Extreme biomass growth compared to terrestrial crops

Table 1: Some reported yields of duckweed dry matter under a variety of growth conditions

Location	DM Yield (tonnes/ha/yr)	Source
SUB OPTIMUM ENVIRONMENT		
Thailand	10-11	Hassan and Edwards (1992), Landolt & Kandeler (1987)
Israel	10-17	Porath *et al* (1979)
Russia	7-8	Landolt and Kandeler (1987)
Uzbekistan	7-15	Landolt and Kandeler (1987)
Germany	16-22	Landolt and Kandeler (1987)
India	22	Landolt and Kandeler (1987)
Egypt	10	Landolt and Kandeler (1987)
Southern States - USA	2-23	Culley and Epps (1973), Rusoff *et al* (1980), Reddy and DeBusk (1985), Landolt and Kandeler (1987)
NEAR OPTIMUM ENVIRONMENT		
Southern States - USA	27-79	Mestayer *et al* (1984)
Israel	36-51	Oran *et al* (1987)

from Leng et al. (1995)

Xu et al. 2012:
Soybean yield **2.33 t** DM ha^{-1} a^{-1} with **38% CP** → **0.89 t** soybean protein yield ha^{-1} a^{-1}

Duckweed yield **27.3 t** DM ha^{-1} a^{-1} with **26.5% CP** → **7.23 t** duckweed protein ha^{-1} a^{-1}