THE CONSERVATION FUND

America's Partner in Conservation

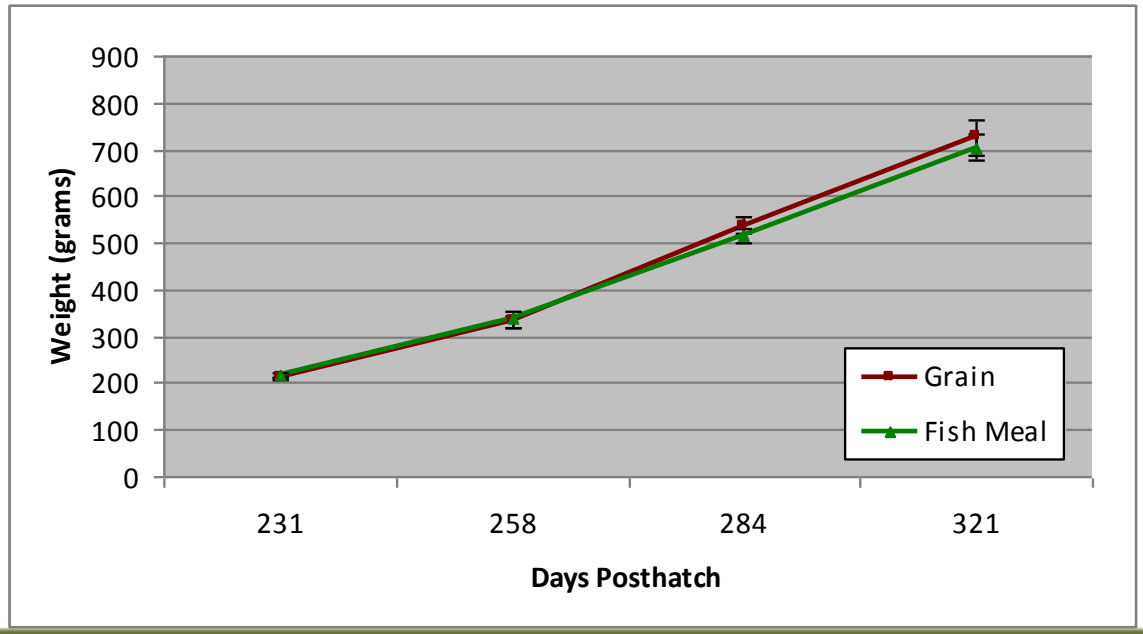
Comparing the effects of feeding a fishmeal-free vs. a fishmeal-based diet on Atlantic salmon performance, water quality, & waste production rates in low exchange recirculating aquaculture systems

John Davidson, Frederic Barrows,
Christopher Good, Brett Kenney, and Steven Summerfelt

4th Conference on Recirc. Aquaculture
Sunndalsøra, Norway
October 25-26, 2016

Background

- The aquaculture industry has been shifting from use of fishmeal to alternative protein ingredients over past several decades
- Newly developed diets with complete fishmeal replacement now result in equal growth performance for many cultured species such as rainbow trout
- Davidson et al., 2013 Aquacultural Engineering 52, 45-57.



THE CONSERVATION FUND
America's Partner in Conservation

Land-Based Salmon Grow-out

1. KUTERRA (Canada)	**2. Golden Eagle Aqua** (Canada)	**3. Spring Salmon** (USA)	**4. Bell Aqua** (USA)
5. Freshwater Institute (USA)	**6. Sustainable Blue** (Canada)	**7. BDV** (France)	**8. Langsand Laks** (Denmark)
9. Danish Salmon (Denmark)	**10. Jurrasic Salmon** (Poland)	**11. Xinjiang Ehe** (China)	**12. Shandong Oriental OT** (China)

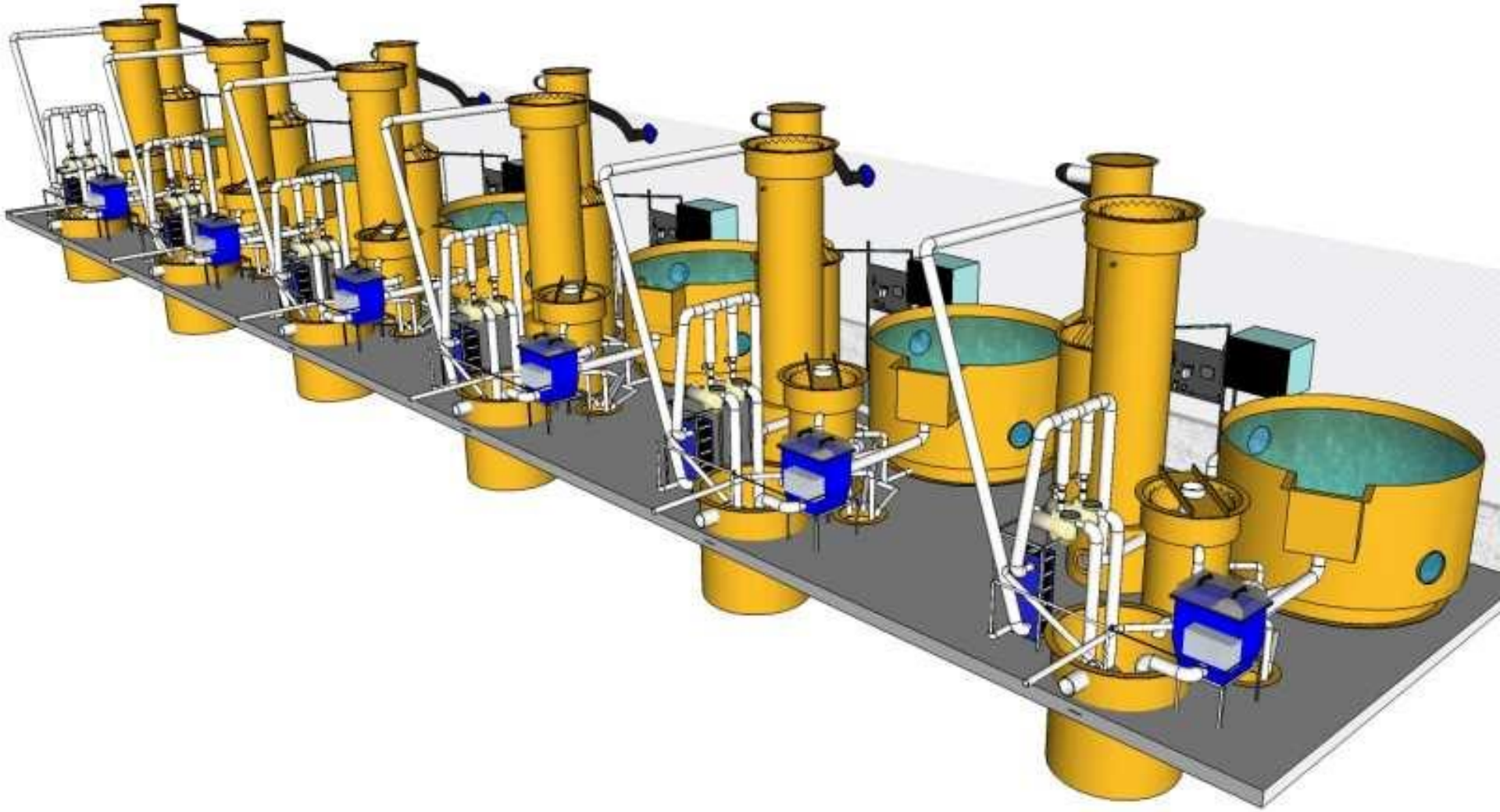
(Facilities harvesting fish or at least with eggs stocked)

Study Objectives

- Are alternative protein (fishmeal-free) diets suitable for use in RAS?
  - Water Quality
  - Waste Load Flushed

- Do alternative protein (fishmeal-free) diets result in comparable salmon performance?
  - Growth Metrics, Feed Conversion
  - Fillet Attributes

6 Replicated RAS



Recirculating System (9.5 m^3)

- 5.3 m^3 dual-drain tank
- Radial flow settler
- Drum filter (60 µm screens)
- Pump sump
- 1-HP centrifugal pump
- Heat exchanger/ inline heater
- Fluidized sand biofilter
- Low head oxygenator (LHO)
- CO_2 stripping column

Experimental Design

- 6-month study conducted to compare two diets
- 220 post-smolt Atlantic salmon (281 ± 5 g) stocked per RAS
- Fishmeal-based (FM) diet delivered to 3 RAS
  Fishmeal-free (FMF) diet delivered to 3 RAS
- Protein/fat ratio of each diet was 42/27
- FM diet similar to standard commercial salmon diet
- FMF diet had replacement proteins: mixed-nut meal & poultry byproducts
- Fish oil equalized to provide equal omega-3 fatty acids

Methods

- All RAS operated with relatively "low" water exchange rates
  - No continuous flushing, water exchange via backwash only
  - Enough flushing to maintain NO_3-N $\leq$ 75 mg/L
  - Average system HRT – approximately 13 days
  - Appx. 7-8% of system volume flushed daily

- Feed delivered via automated feeders
  - 24 equally spaced feedings, around-the-clock
  - Feed amounts kept relatively equal per RAS
  - Feed adjusted per RAS based on observations of wasted feed and feeding response

Controlled Water Quality

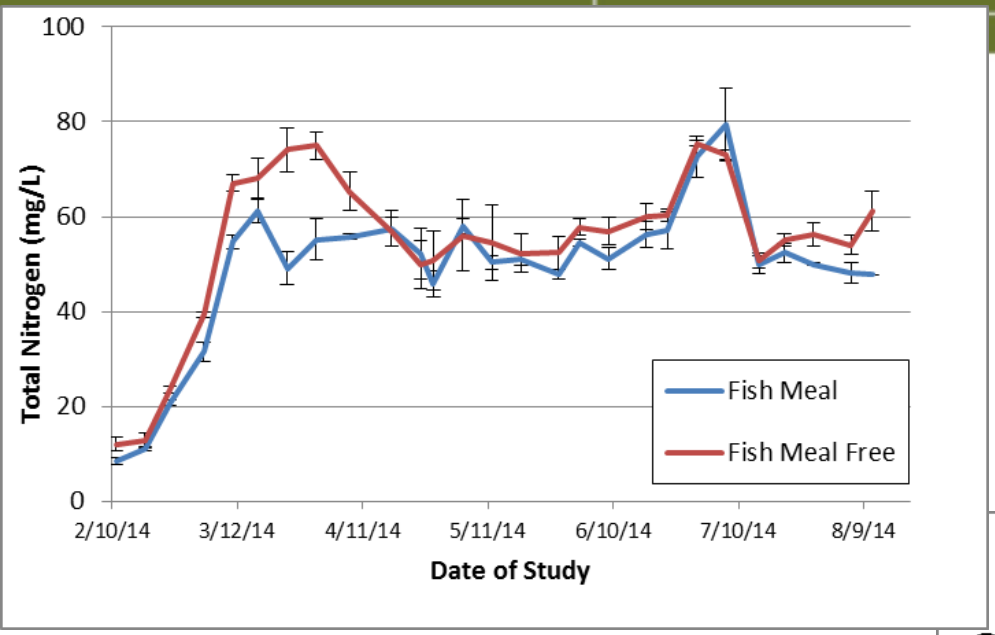
(mg/L)	FM	FMF
Alkalinity	208 ± 2	206 ± 2
CO_2	3.2 ± 0.0	3.6 ± 0.3
pH	8.11 ± 0.01	8.09 ± 0.00
Temp. (^oC)	15.2 ± 0.02	15.2 ± 0.04
DO	10.0 ± 0.04	10.0 ± 0.04

Water Quality

(mg/L)	FM	FMF	(mg/L)	FM	FMF
TAN	0.14 ± 0.01	0.17 ± 0.01	TSS	1.7 ± 0.1	1.3 ± 0.2
NO_2-N	0.028 ± 0.015	0.053 ± 0.037	BOD	0.91 ± 0.09	0.88 ± 0.12
NO_3-N	57 ± 1	65 ± 2	Color	25 ± 2	20 ± 2
TN	49 ± 1	54 ± 1	UVT (%)	79.2 ± 0.5	80.5 ± 1.1
TP	0.085 ± 0.02	4.26 ± 0.13	Heterotr. Bacteria	493 ± 121	437 ± 83

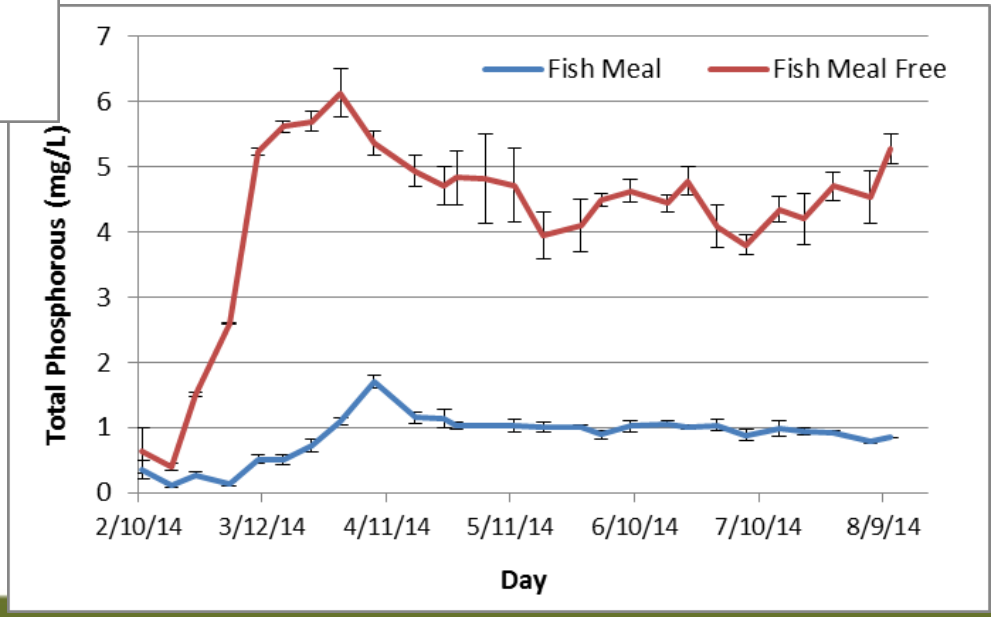
THE CONSERVATION FUND
America's Partner in Conservation

Nitrogen and Phosphorous with Time



- Phosphorous inclusion
  - Fishmeal - 0.96%
  - Fishmeal free - 1.41%
- FMF supplemented with extra dicalcium phosphate due to lower ADC of mixed-nut meal

- Total nitrogen similar between diets over study duration
- Protein inclusion
  - Fishmeal - 42.3%
  - Fishmeal-free - 42.1%



Dissolved Metals/Nutrients

	2.5 Months		5 Months	
(mg/L)	FM	FMF	FM	FMF
Calcium	105 ± 2	100 ± 2	94 ± 1	85 ± 1
Copper	0.031 ± 0.001	0.030 ± 0.003	< det	< det
Magnesium	13.0 ± 0.1	13.2 ± 0.2	10.8 ± 0.1	10.5 ± 0.1
Potassium	4.0 ± 0.1	9.0 ± 0.7	3.9 ± 0.3	6.3 ± 0.1
Phosphorous	1.0 ± 0.1	5.3 ± 0.4	0.9 ± 0.1	4.3 ± 0.1
Sodium	80 ± 6	132 ± 18	36 ± 4	53 ± 3
Zinc	0.072 ± 0.005	0.079 ± 0.002	0.014 ± 0.008	0.022 ± 0.005

Waste Production per kg Feed

	Month 2		Month 4		Month 6	
	FM	FMF	FM	FMF	FM	FMF
TSS	0.164 ± 0.019	0.231 ± 0.020	0.250 ± 0.029	0.349 ± 0.012	0.287 ± 0.052	0.322 ± 0.057
TP	0.006 ± 0.001	0.008 ± 0.000	0.006 ± 0.001	0.010 ± 0.000	0.007 ± 0.001	0.009 ± 0.001
TN	0.016 ± 0.002	0.018 ± 0.002	0.023 ± 0.001	0.025 ± 0.003	0.022 ± 0.004	0.024 ± 0.001
BOD	0.055 ± 0.006	0.076 ± 0.005	0.054 ± 0.005	0.082 ± 0.005	0.065 ± 0.003	0.080 ± 0.007

Waste Production

	Month 4 (Mid Study) kg waste/kg feed			
	FM Diet		FMF Diet	
	Drum Filter BW	RF Settler Flush	Drum Filter BW	RF Settler Flush
TSS	0.167 ± 0.015 66.5 %	0.084 ± 0.022 33.5 %	0.171 ± 0.021 49.9 %	0.172 ± 0.015 51.1%
TP	0.004 ± 0.001 67.2 %	0.002 ± 0.000 32.8 %	0.006 ± 0.001 61.2 %	0.004 ± 0.000 38.8%
TN	0.020 ± 0.001 87.0 %	0.003 ± 0.000 13.0 %	0.019 ± 0.002 76.0 %	0.006 ± 0.000 24.0 %
BOD	0.035 ± 0.001 62.5 %	0.021 ± 0.007 37.5 %	0.045 ± 0.007 57.0 %	0.034 ± 0.002 43.0 %

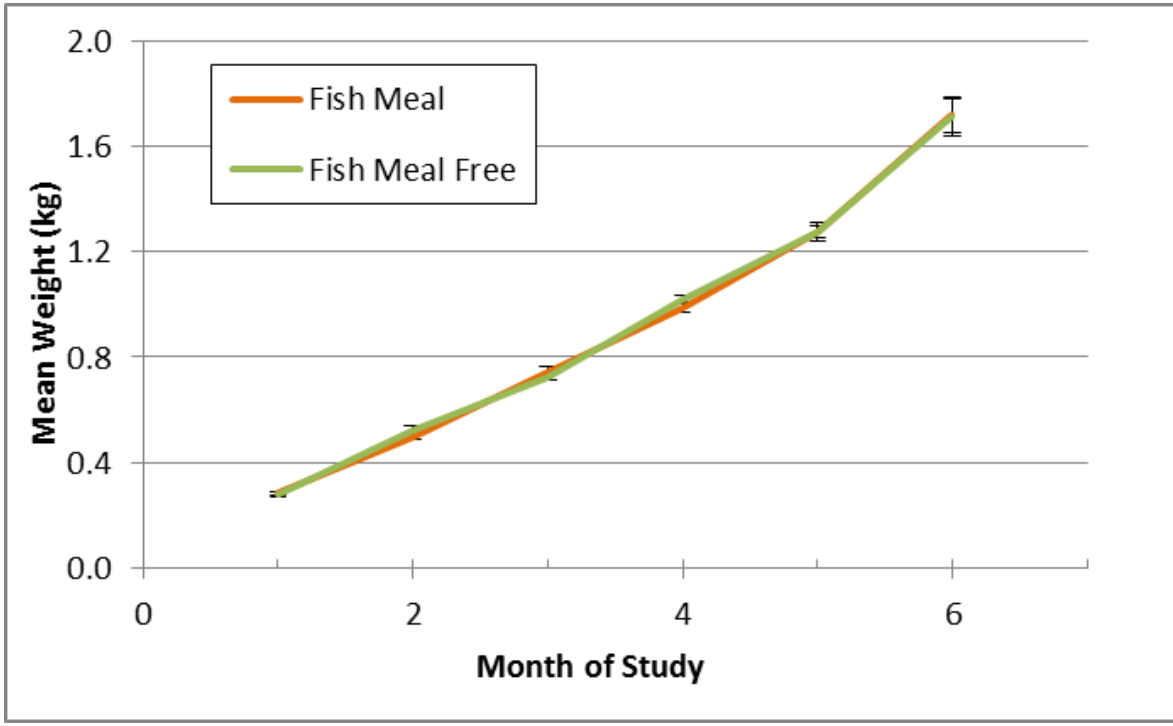
Growth Performance and Survival

- Atlantic salmon mean weights at study's end
  - FM Diet - 1.72 ± 0.06 kg
  - FMF Diet - 1.72 ± 0.07 kg

- Condition factor
- FM Diet - 1.28 ± 0.02
- FMF Diet - 1.25 ± 0.01

- FCR
- FM Diet - 0.87 ± 0.03
- FMF Diet - 0.90 ± 0.06

- Survival
- FM Diet - 99.7 ± 0.3 %
- FMF Diet - 99.8 ± 0.2 %



Blood Chemistry

I-Stat Measures	End of Study		
	FM	FMF	P-value
Chloride (mmol/L)	137 ± 0.62	Non-detect	-
Glucose (mg/dL)	85.0 ± 1.55	80.6 ± 1.48	0.054
Hematocrit (%PCV)	40.8 ± 2.13	34.3 ± 1.31	0.028
Hemoglobin	13.9 ± 0.73	11.7 ± 0.44	0.029
pCO2 (mm Hg)	40.8 ± 0.87	36.9 ± 1.13	0.025
pO2 (mm Hg)	9.14 ± 0.73	11.5 ± 0.88	0.093
Potassium (mmol/L)	2.88 ± 0.12	3.27 ± 0.10	0.067

Processing Attributes

	Immature ("Premium")		Mature Males	
	FM	FMF	FM	FMF
Mean Weight (kg)	1.74 ± 0.06	1.95 ± 0.07	1.34 ± 0.04	1.51 ± 0.04
GSI (%)	0.28 ± 0.03	0.32 ± 0.10	5.8 ± 0.2	6.6 ± 0.1
CF	1.28 ± 0.01	1.23 ± 0.03	1.18 ± 0.02	1.13 ± 0.01
HOG Yield (%)	91.6 ± 0.2	91.2 ± 0.6	89.1 ± 0.4	89.5 ± 0.2
Butterfly Yield (%)	73.7 ± 0.2	70.7 ± 1.1	68.8 ± 1.5	66.6 ± 0.3
Skin-On/Trim Yield (%)	60.7 ± 0.1	58.4 ± 0.9	52.9 ± 0.3	52.5 ± 0.6
Skin-Off/Trim Yield (%)	55.8 ± 0.2	53.4 ± 0.9	47.9 ± 0.3	47.5 ± 0.6

Whole Body Proximate Composition

	Immature ("Premium")		Mature Males	
	FM	FMF	FM	FMF
Mean Weight (kg)	1.70 ± 0.08	1.67 ± 0.03	1.51 ± 0.10	1.47 ± 0.13
% Moisture	64.5 ± 0.70	63.7 ± 0.49	69.2 ± 0.50	69.1 ± 0.15
% Protein	17.9 ± 0.18	17.4 ± 0.32	19.4 ± 0.10	18.8 ± 0.34
% Fat	17.3 ± 0.54	18.0 ± 0.19	11.1 ± 0.66	11.6 ± 0.48
% Ash	1.88 ± 0.05	2.12 ± 0.03	1.94 ± 0.02	2.35 ± 0.02

Conclusions

- Aquafeeds that utilized no fishmeal and substituted sustainable alternative protein ingredients (mixed-nut meal and poultry byproduct) resulted in equal post-smolt Atlantic salmon performance in RAS
- Water quality was maintained within limits for optimal fish performance
- Aquafeeds can be designed to be RAS-specific and minimize phosphorous discharge or…
- Aquafeeds can be designed for aquaponics with over-supplemented phosphorous to support vegetable production.

Acknowledgements

- All research supported by the Agriculture Research Service of the United States Department of Agriculture, under Agreement No. 59-1930-5-510.

- Opinions, conclusions, and recommendations are of the authors and do not necessarily reflect the view of the USDA.

- All experimental protocols were in compliance with Animal Welfare Act (9CFR) and have been approved by the Freshwater Institute Animal Care and Use Committee.

- Special thanks to Karen Schroyer, Susan Glenn, Brianna Taylor, Katelyn Walters, Natalie Monacelli, and Christina Russell for water quality, to Clayton Raines, Heather Dailey, and Wells Larson for technical assistance, and to Susan Slider at West Virginia University for fillet quality analyses.