

A large Atlantic salmon is the central focus, swimming towards the right. It has a silvery body with dark spots and a reddish-orange head. Several other salmon are visible in the background, swimming in the same direction. The entire scene is framed within a circular border, which is set against a dark green background.

Optimizing Atlantic Salmon Product Quality from Land-Based Closed Containment Systems

John Davidson, Thomas Waldrop, Kevin Schrader, Brett Kenney, Gary Burr, William Wolters, and Steven Summerfelt

- Superior quality of end product from closed containment aquaculture is critical!!!
- Consumers are paying attention to details and the **story** behind the seafood that they eat
- Strive for final product that consumers will choose again and again
- Color, clean flavor, texture, freshness, sustainably produced health benefits, etc.



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Fillet Quality: Net Pen (Commercial) vs. Closed Containment



- Salmon purchased through Blue Circle Seafood as Head-on-gutted (HOG) product
- Originated from European net pen facilities
 - 6 from Norway
 - 6 from Scotland
- Certified as organic
- Fillet quality assessed at West Virginia University with Dr. Brett Kenney and associates
- Two trials comparing commercial salmon to Freshwater Institute salmon

Fillet Quality: Net Pen vs. Closed Containment

Trial 1	Norway Organic	Scotland Organic	Freshwater Institute
Days from Harvest	6	5	<1 day
Rigor	Post Rigor	Post Rigor	Pre-Rigor
HOG Weight (kg)	4.66 ± 0.09	7.18 ± 0.08 *	3.84 ± 0.17
Fillet Temp (°C)	3.0 ± 0.5 *	-1.5 ± 0.2	0.0 ± 0.4

Fillet Quality: Net Pen vs. Closed Containment

Trial 1 Fillet Yield from HOG	Norway Organic	Scotland Organic	Freshwater Institute
HOG Weight (kg)	4.66 ± 0.09	7.18 ± 0.08	3.84 ± 0.17
Butterfly Fillet Yield (%)	81.9 ± 1.7	81.6 ± 0.2	82.2 ± 0.4
Skin-Off Fillet Yield (%)	64.2 ± 0.4 *	63.0 ± 0.3	62.6 ± 0.5 *
Fillet Thickness (mm)	29.5 ± 0.4 *	35.1 ± 0.6	36.3 ± 0.8 *

Fillet Quality: Net Pen vs. Closed Containment

Trial 1 Proximate Analysis	Norway Organic	Scotland Organic	Freshwater Institute
% Moisture	61.9 ± 0.99	63.6 ± 0.99	63.1 ± 0.55
% Protein	19.0 ± 0.47	19.6 ± 0.29	20.0 ± 0.20
% Fat	19.9 ± 1.38 *	17.2 ± 1.31	15.2 ± 0.70 *
% Ash	1.10 ± 0.02	1.19 ± 0.03	1.18 ± 0.02

<div> <div>THE CONSERVATION FUND</div> <div>America's Partner in Conservation</div> </div>		Fillet Quality: Net Pen vs. Closed Containment			
Trial 1 Fatty Acids	Commercial 1	Commercial 2	Norway Organic	Scotland Organic	Freshwater Institute
Total Omega-3 (mg/ g)	19.0	32.6	10.0 ± 0.82	10.5 ± 0.65	21.6 ± 2.76 *
Total Omega-6 (mg/ g)	9.8	5.9	7.32 ± 0.90	5.56 ± 0.47	10.44 ± 1.29
Omega 3: 6 Ratio	2.15	5.52	1.39 ± 0.06	1.91 ± 0.07	2.10 ± 0.13 *
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Fillet Quality: Net Pen vs. Closed Containment

- **EWOS Dynamic Red**
 - Protein/Fat - 44/29
 - Commercially Available
- **Use of alternative oils could reduce Omega-3 and change Omega 3:6 ratio**
 - Feeds are available
 - Research is ongoing
 - Need to maintain health benefits
- **We must develop feed specifically for closed containment RAS!!**



Fillet Quality: Net Pen vs. Closed Containment

Trial 1 Cook Yield Texture	Norway Organic	Scotland Organic	Freshwater Institute
AK Cook Yield (%)	88.9 ± 0.4	88.6 ± 0.4	91.4 ± 0.2 *
VB Cook Yield (%)	88.7 ± 0.5	88.1 ± 0.2	90.7 ± 0.2 *
AK Shear (g/g wt)	333 ± 20	364 ± 11	387 ± 33
VB Shear (g/g wt)	38.2 ± 4.1 *	22.5 ± 2.4	23.4 ± 2.4

Fillet Quality: Net Pen vs. Closed Containment

Trial 1 Fillet Color	Norway Organic	Scotland Organic	Freshwater Institute
L (lightness)	43.5 ± 1.4	41.9 ± 0.9	39.1 ± 1.1
A (orange-red)	13.4 ± 0.8	9.1 ± 0.6 *	12.9 ± 0.6
B (yellowish)	17.8 ± 1.7	12.8 ± 0.9	15.5 ± 0.5

Fillet Quality: Net Pen vs. Closed Containment

Trial 2	Norway Organic	Scotland Organic	Freshwater Institute
Days from Harvest	7	7	<1 day
Rigor	Post Rigor	Post Rigor	Pre-Rigor
HOG Weight (kg)	4.42 ± 0.12	4.34 ± 0.15	4.80 ± 0.15
Fillet Temp (°C)	-1.8 ± 0.2	-2.0 ± 0.1	-1.2 ± 0.4

Fillet Quality: Net Pen vs. Closed Containment

Trial 2 Proximate Analysis	Norway Organic	Scotland Organic	Freshwater Institute
% Moisture	59.0 ± 1.0 *	61.9 ± 0.7	62.0 ± 0.3
% Protein	18.7 ± 0.4	18.2 ± 0.1	19.8 ± 0.3 *
% Fat	21.9 ± 1.5	19.1 ± 0.9	17.0 ± 0.3 *
% Ash	1.06 ± 0.03	1.01 ± 0.02	1.14 ± 0.02

Fillet Quality: Net Pen vs. Closed Containment

Trial 2 Fillet Yield from HOG	Norway Organic	Scotland Organic	Freshwater Institute
HOG Weight (kg)	4.42 ± 0.12	4.34 ± 0.15	4.80 ± 0.15 *
Butterfly Fillet Yield (%)	85.0 ± 0.4	84.0 ± 0.2	82.5 ± 0.4 *
Skin-Off Fillet Yield (%)	66.7 ± 0.5	66.1 ± 0.3	63.3 ± 0.6 *
Belly Flap Thickness (mm)	14.1 ± 0.3	13.2 ± 0.4	15.8 ± 0.4 *
Fillet Thickness (mm)	24.7 ± 0.6	26.3 ± 0.7	34.3 ± 1.2 *



SalmoFan™ Lineal

For salmonids pigmented with CAROPHYLL® Pink (astaxanthin)

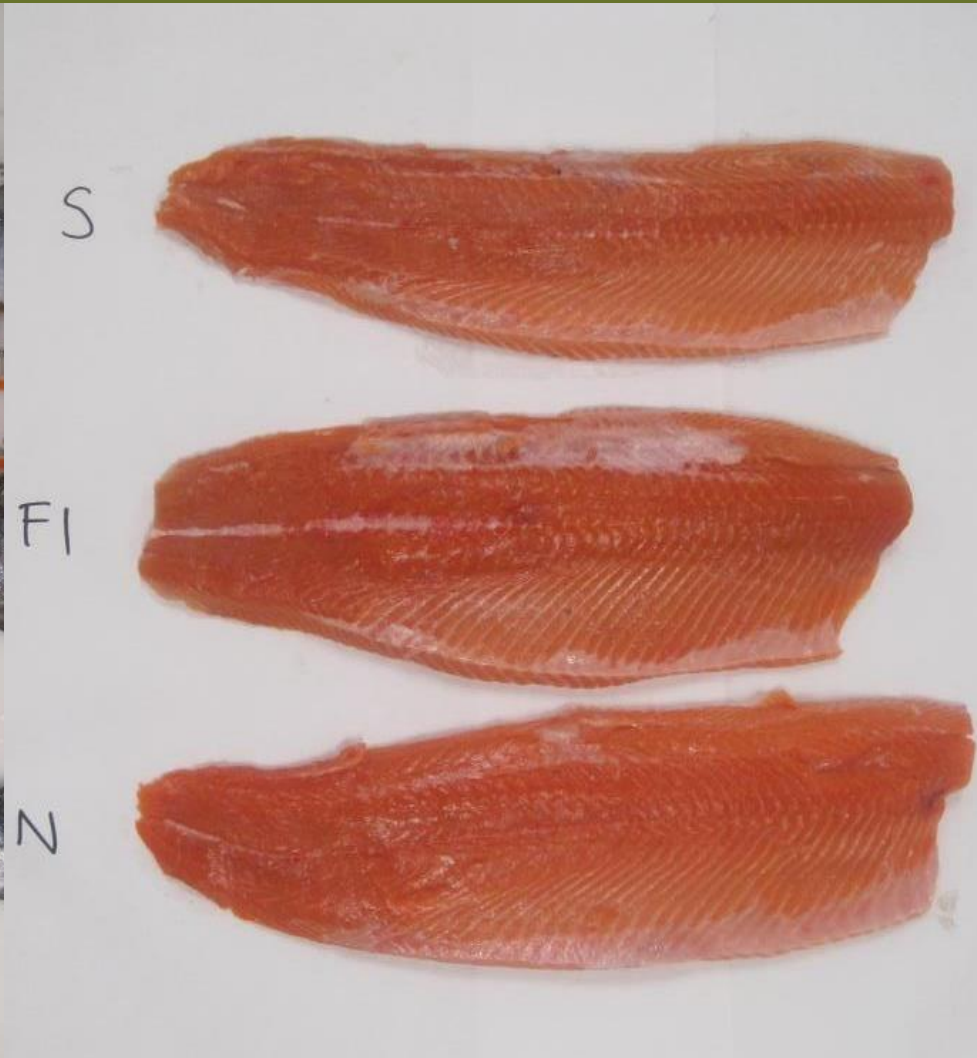
Centimeter
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**Visceral Fat
Coating Organs**

Fillet Quality: Net Pen vs. Closed Containment

Trial 2 Fillet Color	Norway Organic	Scotland Organic	Freshwater Institute
L (lightness)	41.90 ± 0.49	41.15 ± 1.15	38.49 ± 0.79
A (orange-red)	13.36 ± 0.41 *	9.99 ± 0.40	9.18 ± 0.58 *
B (yellowish)	15.49 ± 0.58	11.87 ± 0.58	11.86 ± 0.96

Fillet Quality: Net Pen vs. Closed Containment



Fillet Quality: Net Pen vs. Closed Containment

Trial 2 Cook Yield Texture	Norway Organic	Scotland Organic	Freshwater Institute
AK Cook Yield (%)	90.9 ± 0.2	90.2 ± 0.3	91.0 ± 0.4
VB Cook Yield (%)	89.9 ± 0.4	89.4 ± 0.2	90.6 ± 0.3 *
AK Shear (g/g wt)	349 ± 23	289 ± 28	394 ± 21
VB Shear (g/g wt)	32.2 ± 3.5	30.8 ± 3.4	18.6 ± 1.3 *

Fillet Quality: Net Pen vs. Closed Containment Summary

➤ **Freshness**

- If processed pre-rigor domestic closed containment salmon can reach final product stage same day as harvest
- Imported commercial salmon best case 5-7 days from harvest

➤ **Quality Control**

- Domestic closed containment salmon have inherent quality control due to shorter chain of custody
- Imported salmon require frequent icing

➤ **Skin Color**

- Closed containment salmon had darker pigmented skin
- Culture/ purging in light blue tanks could provide silvery appearance

Fillet Quality: Net Pen vs. Closed Containment Summary

➤ **Composition**

- Compare fairly well with high quality commercial salmon
- Closed containment salmon tended to have lower fat levels
- Excess fat deposition in viscera and belly flap
- We need to develop feeds that are specific to RAS!

➤ **Fillet Color**

- Trial 1 color was comparable to best; Trial 2 color slightly lighter
- Variable fillet color? Need to explore how to improve!

➤ **Fillet Thickness**

- Closed containment salmon had greater fillet thickness
- Is this is desirable trait?

Fillet Quality: Net Pen vs. Closed Containment Summary

➤ **Fatty Acids**

- Freshwater Institute salmon compare well with some of the highest quality salmon available on market.
- Feed makes a difference. Organic certified salmon have lower Omega-3 levels.
- Trial 2 results pending

➤ **Fillet Yield**

- Slightly lower fillet yields likely due to belly flap loss

➤ **Cook Yield/Texture**

- Closed containment salmon fillets appeared firmer as raw product
- Closed containment salmon had significantly greater cook yield
- Softer cooked fillet.....possible positive perception by consumer??

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Depuration Techniques to Mitigate Off-Flavor

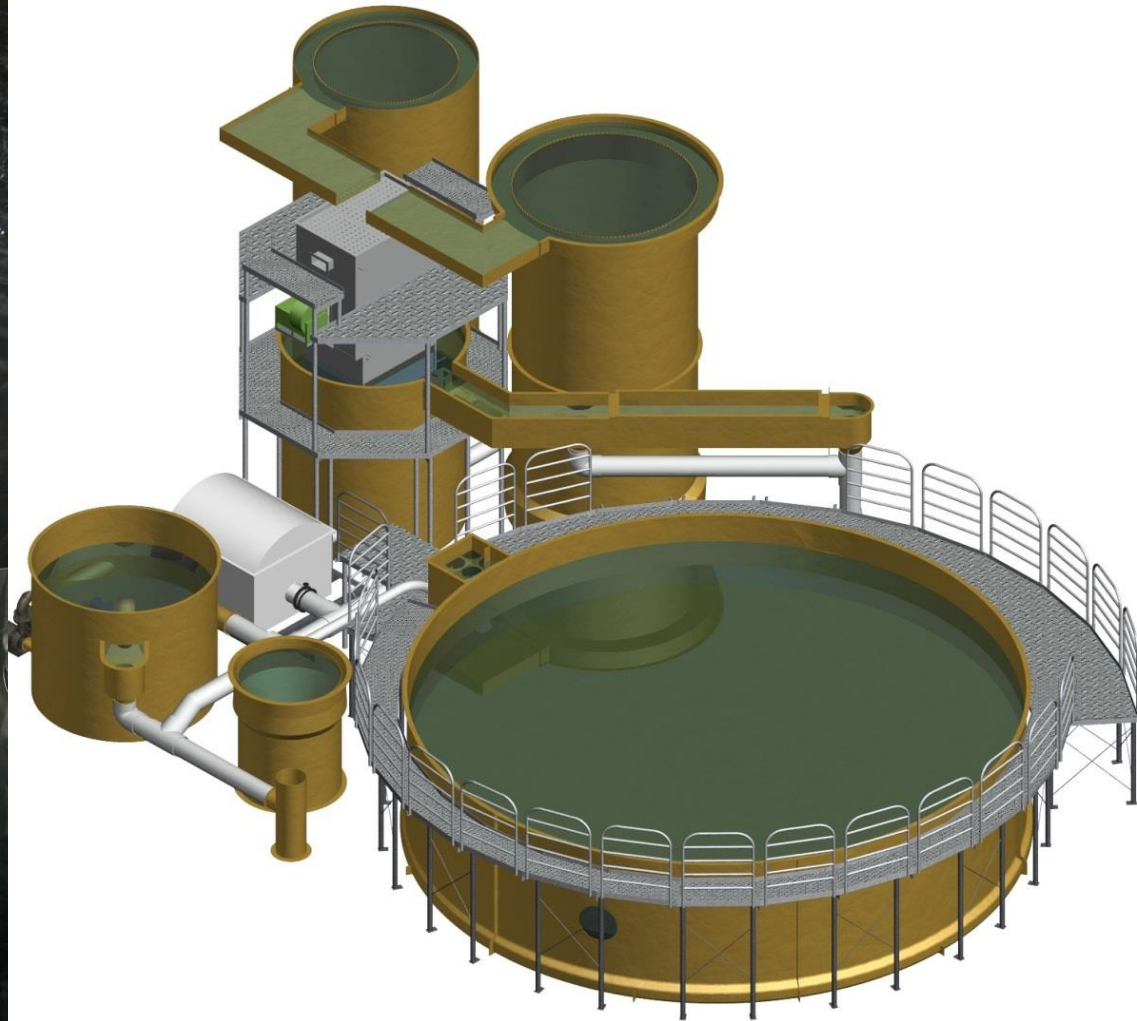


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Depuration Techniques to Mitigate Off-Flavor

- Many advantages of RAS, but one drawback
 - Bioaccumulation of off-flavor compounds within fish flesh
 - Create earthy or musty taste
- Caused by microbial metabolites produced by actinomycetes and cyanobacteria
 - 2-Methylisoborneol (MIB)
 - Geosmin
- Off-flavor not reported for salmon cultured in ocean net pens
- For RAS to be viable technology, methods for off-flavor removal are necessary!

150 m³ Commercial Scale Grow-out RAS



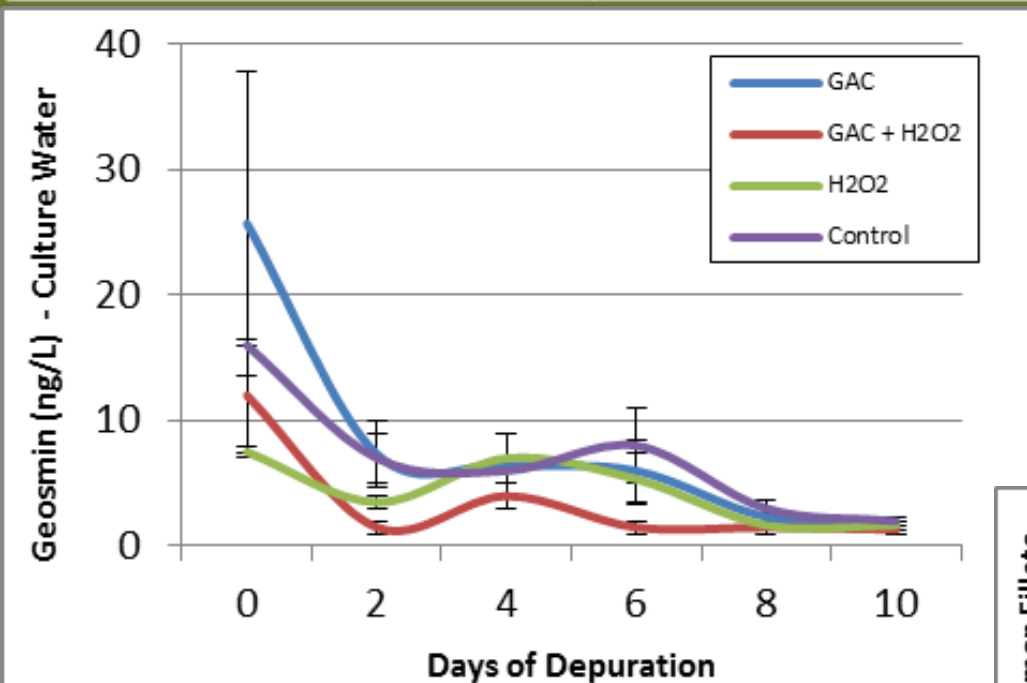
Salmon Depuration Experimental Design - Trial 1 and 2

Experimental Tanks per Treatment	Granular Activated Carbon (GAC)	Hydrogen Peroxide
3	✓	✓
3	✓	
3		✓
3		

0.5 m³ Experimental Partial Reuse Systems

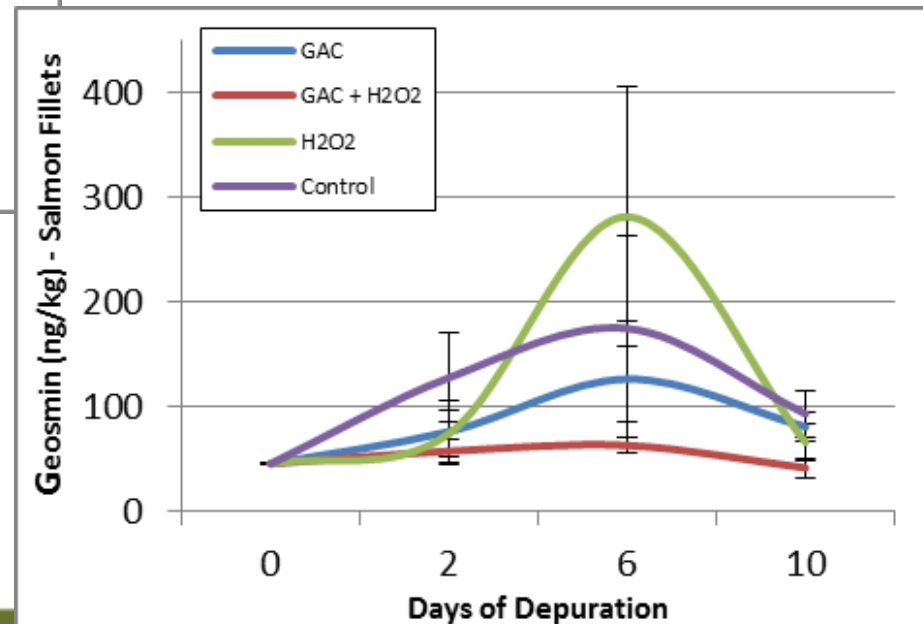


Geosmin - Culture Water/ Salmon Fillets – Trial 1

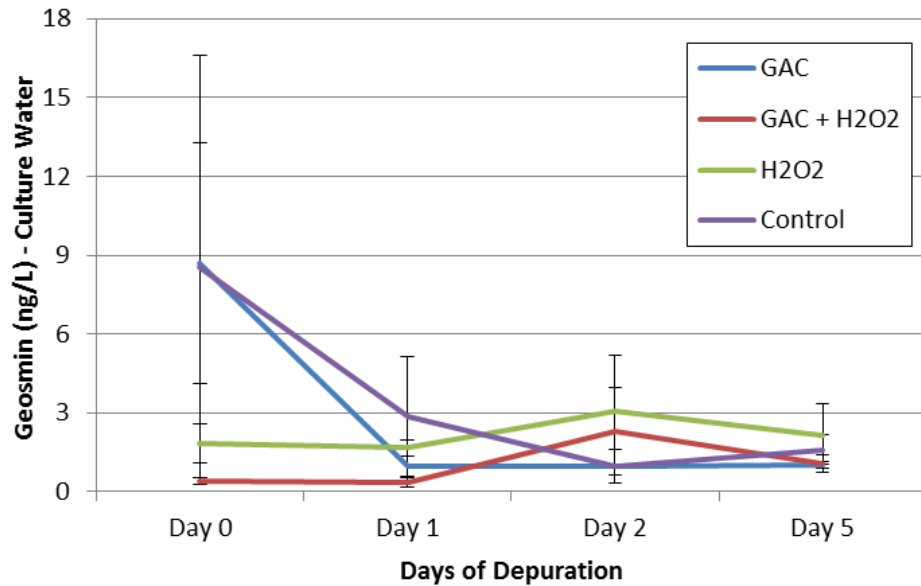


- Geosmin concentrations in water declined over 10-day period

- Geosmin in fillets increased for all treatments except GAC + H₂O₂
- Increase in off-flavor would not be expected in clean, biofilm-free depuration system

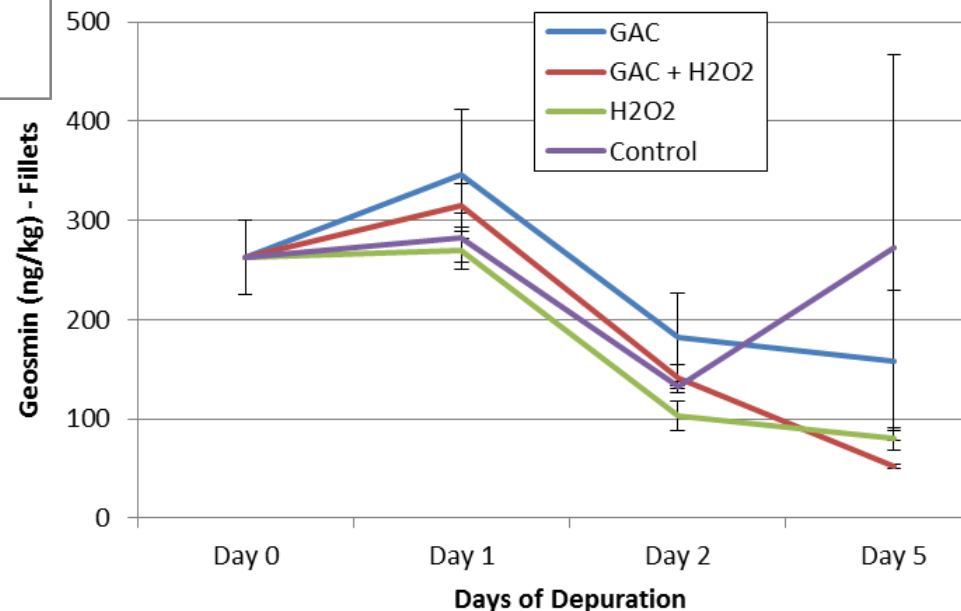


Geosmin - Culture Water/ Salmon Fillets – Trial 2



- Lowest geosmin in salmon harvested from H₂O₂ and GAC + H₂O₂ treated systems

- Disinfection techniques allowed us to start with less geosmin!!!



Depuration Techniques - Conclusions

- **Thorough pre-cleaning is critical so that depuration systems are clean/ biofilm-free to begin**
- **Off-flavor concentrations in fillets can increase in “dirty” depuration systems with biofilm on walls of unit processes**
- **GAC combined with H_2O_2 disinfection appears to be best treatment option, but H_2O_2 disinfection alone was just as effective**

- **Communication with industry indicates aeration columns and media within can harbor off-flavor producing bacteria**

- **Third study was conducted**
 - 6 Systems with aeration media inside stripping column
 - 6 Systems without aeration media inside stripping column
 - Systems treated with and without hydrogen peroxide
 - Results are pending

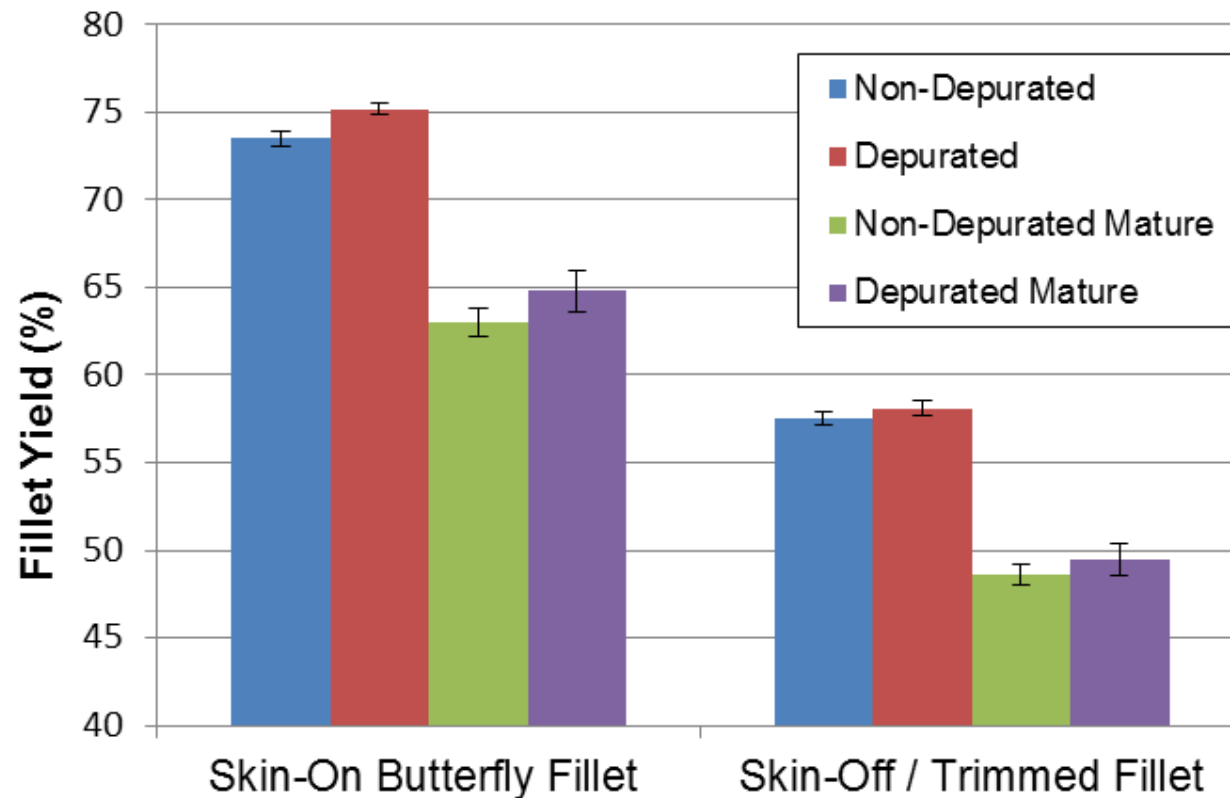
Fillet Quality (Depurated vs. Non-Depurated)

Color Score on Salmo™ Fan 28-30

- No significant difference in fillet color between non-depurated and 10-day depurated salmon
- No difference in percentage fat of fillet measured during proximate analysis
- No difference in fatty acid content



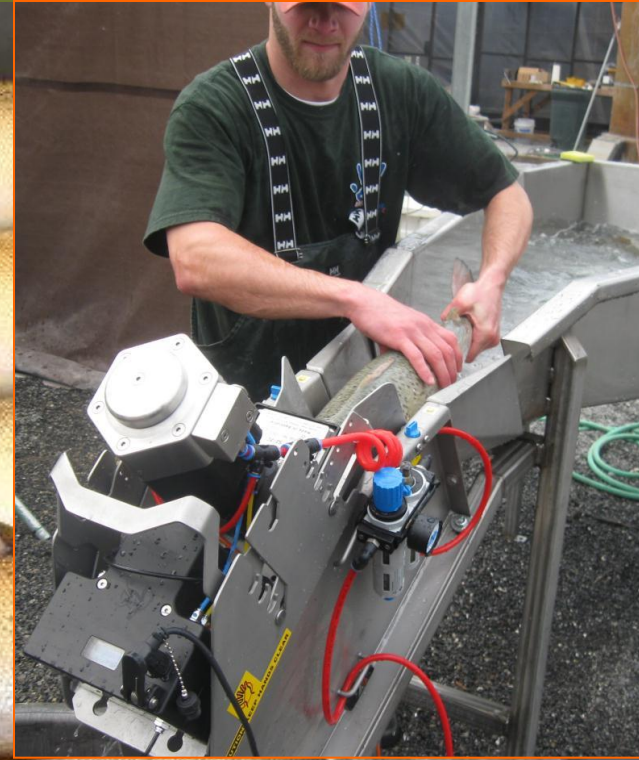
Atlantic Salmon Fillet Yield (Depurated vs. Non-Depurated)



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Evaluation of Humane Slaughter Techniques



Humane Slaughter Techniques Study Methods

➤ Two trials

1. Humane Stunner Technology with/ without bleeding vs. Carbon Dioxide and Ice Slurry with/ without bleeding

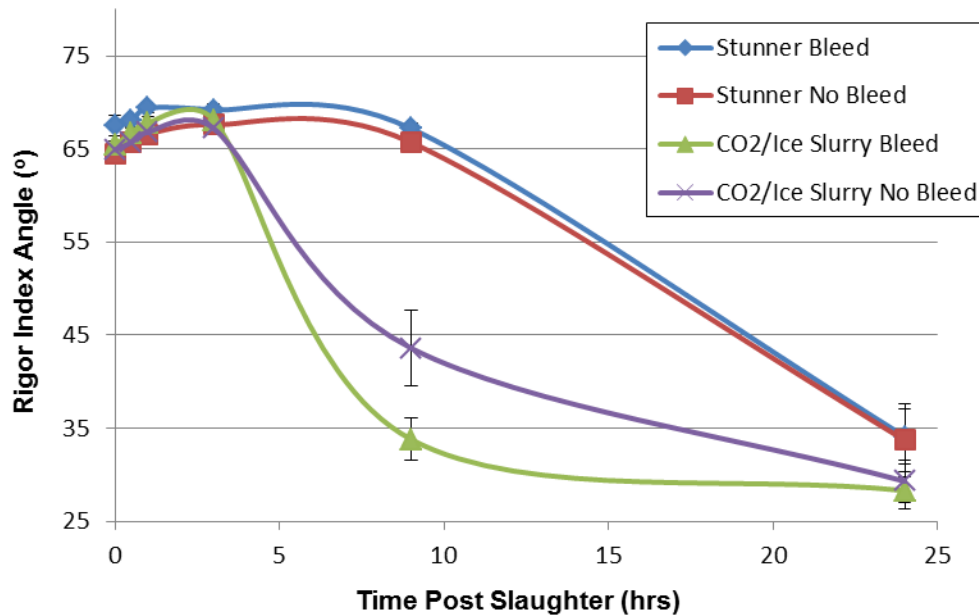
- All processing done post-rigor or when fish were still slightly in rigor

2. Humane Stunner Technology vs. Carbon Dioxide and Ice Slurry with bleeding Pre Rigor vs. Post-Rigor Quality

- ## ➤ Six salmon randomly selected/ euthanized using each technique
- Males and obviously mature fish excluded
 - 4-6 kg fish targeted
 - 10-11 Day depuration period

Rigor Onset and Resolution

Trial 1



➤ Depuration

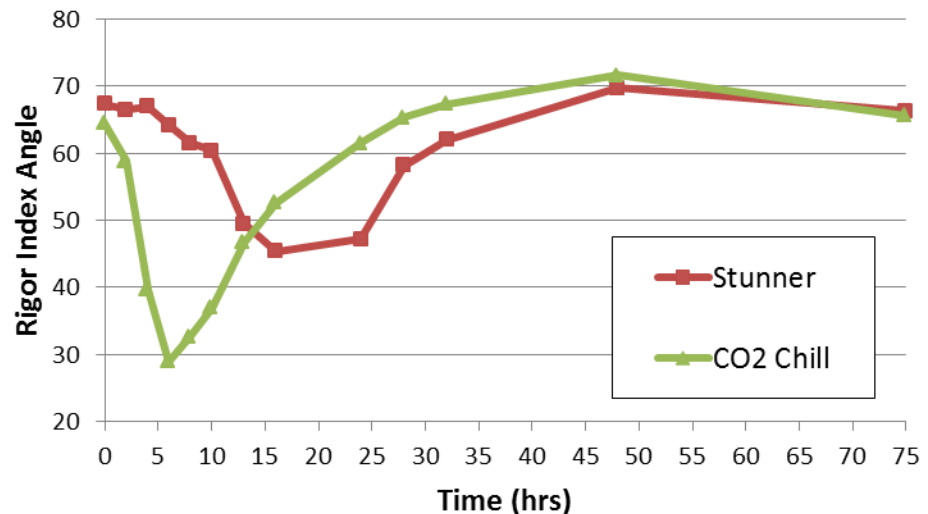
- Trial 1 – 10 day
- Trial 2 – 11 day

➤ Evisceration

- Trial 1- Gutted at processor
- Trial 2 – Gutted immediately

- Window up to 8-10 hrs for pre-rigor processing
- Gutting immediately might speed rigor resolution

Trial 2



Trial 2 - Pre-Rigor vs. Post-Rigor

	HOG Yield (%)	Butterfly Fillet Yield (%)	Skin-Off Fillet Yield (%)	Color (A)
Stunner Pre-Rigor	90.9 ± 1.1	74.2 ± 0.8	57.0 ± 0.8 *	9.90 ± 0.62
Stunner Post-Rigor	88.2 ± 0.8	71.5 ± 0.8	54.2 ± 0.9 *	10.55 ± 0.83
CO ₂ Chill Pre-Rigor	89.0 ± 1.1	73.4 ± 1.2	56.2 ± 1.1	11.03 ± 0.23
CO ₂ Chill Post-Rigor	87.8 ± 0.6	71.5 ± 0.5	54.0 ± 0.7	10.89 ± 0.48

Trial 2 - Pre-Rigor vs. Post-Rigor

	AK Cook Yield (%)	VB Cook Yield (%)	AK Shear Texture (g/ g wt)	VB Shear Texture (g/ g wt)
Stunner Pre-Rigor	88.3 ± 1.9	87.0 ± 2.0	467 ± 57	27.1 ± 4.2
Stunner Post-Rigor	88.8 ± 0.4	88.0 ± 0.4	404 ± 18	31.3 ± 1.0
CO ₂ Chill Pre-Rigor	87.9 ± 0.9	87.3 ± 1.2	425 ± 25	28.6 ± 3.0
CO ₂ Chill Post-Rigor	88.0 ± 0.3	87.4 ± 0.4	395 ± 18	33.3 ± 3.2

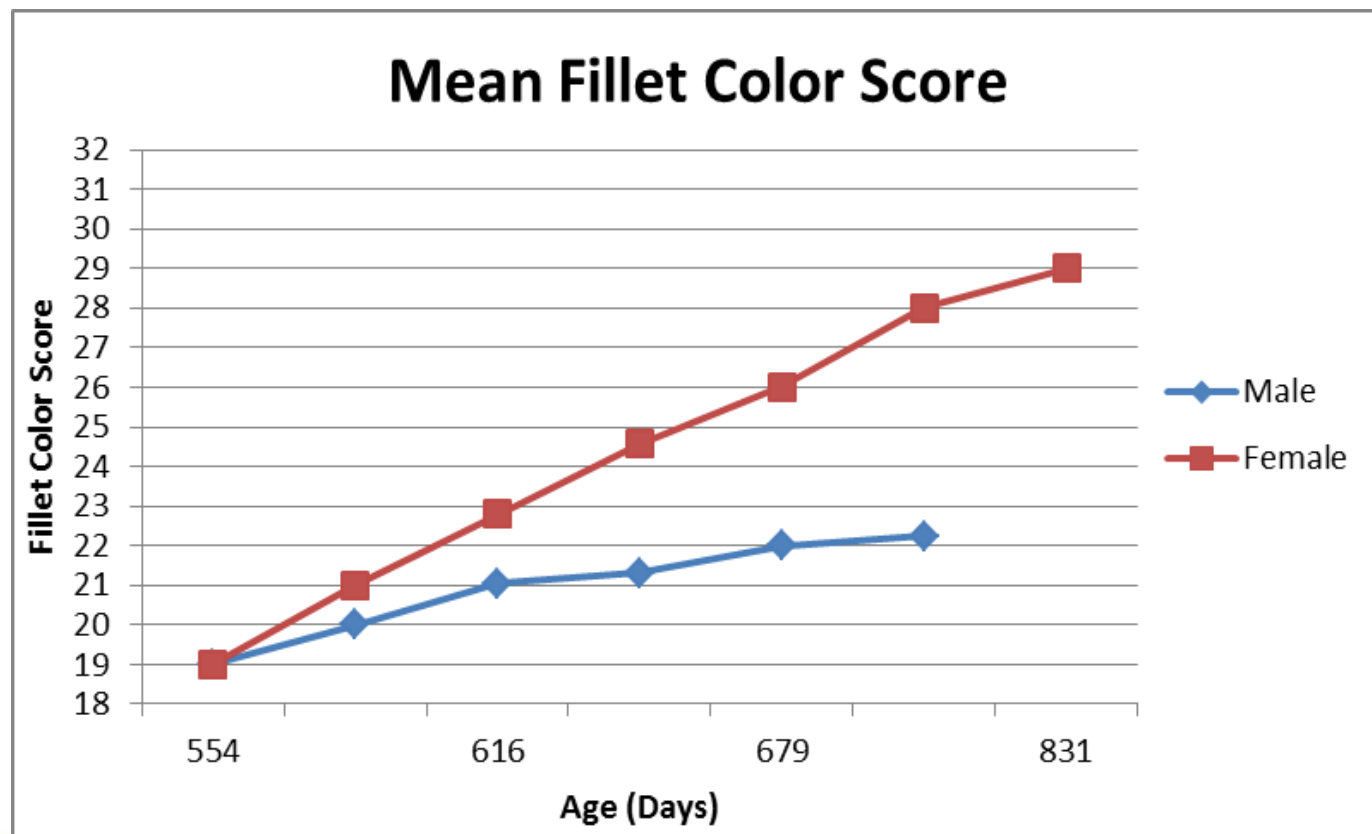
- **Humane stunning technology improves fillet attributes**
 - Less struggle = lower ATP use and less lactic acid
 - Less fluctuation of flesh pH
 - Slower onset to rigor provides window for pre-rigor processing
- **Bleeding did not impact most fillet quality parameters**
 - Processor (Dr. Brett Kenney) commented that bled fish cleaner to work with and likely less potential for bacterial spoilage
- **Pre-rigor processing appears to offer increased fillet yield**

Other Product Quality News and Considerations

- Fillet color increases steadily with time when feeding a diet containing astaxanthin pigment. It is not instantaneous!!

- Feed contained 30 ppm pigments

- Lighter, less optimal fillet color of male salmon



- Marketing research using optimal depuration techniques indicates success!

- 2012 - Blind taste tests - 2 panels of seafood professionals in Seattle indicated preference for Freshwater Institute closed containment salmon vs. commercially available ocean-raised salmon
 - Cooked flavor
 - Cooked smell
 - Cooked texture

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Freshwater Institute Salmon Albion & Safeway



Up to 60% Premium \$\$!!!

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Fillet Quality Advantages of Closed Containment Salmon

- Freshness!!!
 - Land-based closed containment systems offer inherent advantage (locate near major retail markets, reduce carbon footprint)
 - Salmon can be on consumer's plate within a few days from harvest
 - Pre-rigor processing (up to 10 hours post harvest) could be considered to speed time to final product
- Closed Containment salmon compare well with high quality commercial salmon
- Environmentally Friendly / Sustainable
 - Waste capture, No antibiotics used, No fish escapement, etc.

Potential Improvements Future Research

- Fillet Color
 - Can we increase consistency?
 - Is some of the pigment being assimilated in the visceral fat?
 - Genetics?
 - All female cohort would likely be helpful relative to color

- Utilization of fat/ too much fat deposited in viscera
 - Must develop diets specific to the increased metabolism of Atlantic salmon cultured in RAS

Acknowledgements

- Research supported by Tides Canada, the Gordon Betty Moore Foundation, and the Atlantic Salmon Federation.
- All experimental protocols were in compliance with Animal Welfare Act (9CFR) and have been approved by the Freshwater Institute Animal Care and Use Committee.
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Bon Appetit!!

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