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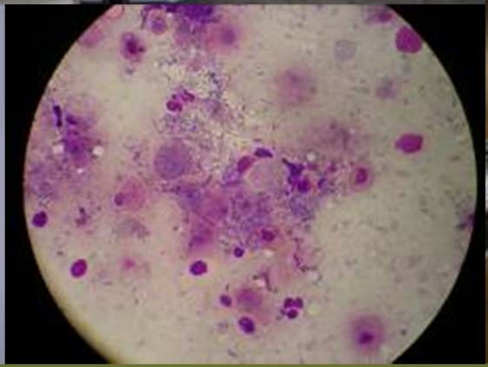
Fish Health & Welfare in Closed Containment Systems



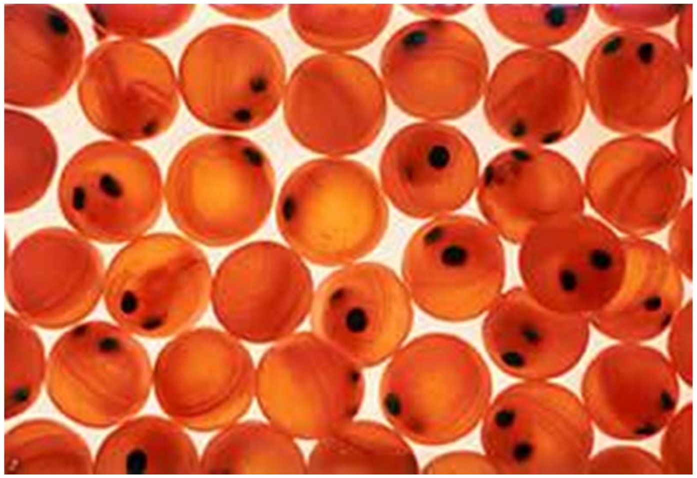
Christopher Good

Aquaculture Innovation Workshop, Jan 17-18, 2010

Advantages of Closed Containment

With biosecure source water and specific pathogen-free eggs:

- **No vaccinations required**
- **Reduction or elimination of antibiotic and chemotherapeutant usage**
- **More environmental control to reduce stress**



Advantages of Closed Containment

Avoids <u>obligate pathogens</u>:

- **Viruses**
  - **IPNV**
  - **IHNV**
  - **VHSV**
- **Bacteria**
  - ***Aeromonas salmonicida***
  - ***Renibacterium salmoninarum***
- **Parasites**
  - ***Ichthyophthirius multifiliis***
  - ***Myxobolus cerebralis***

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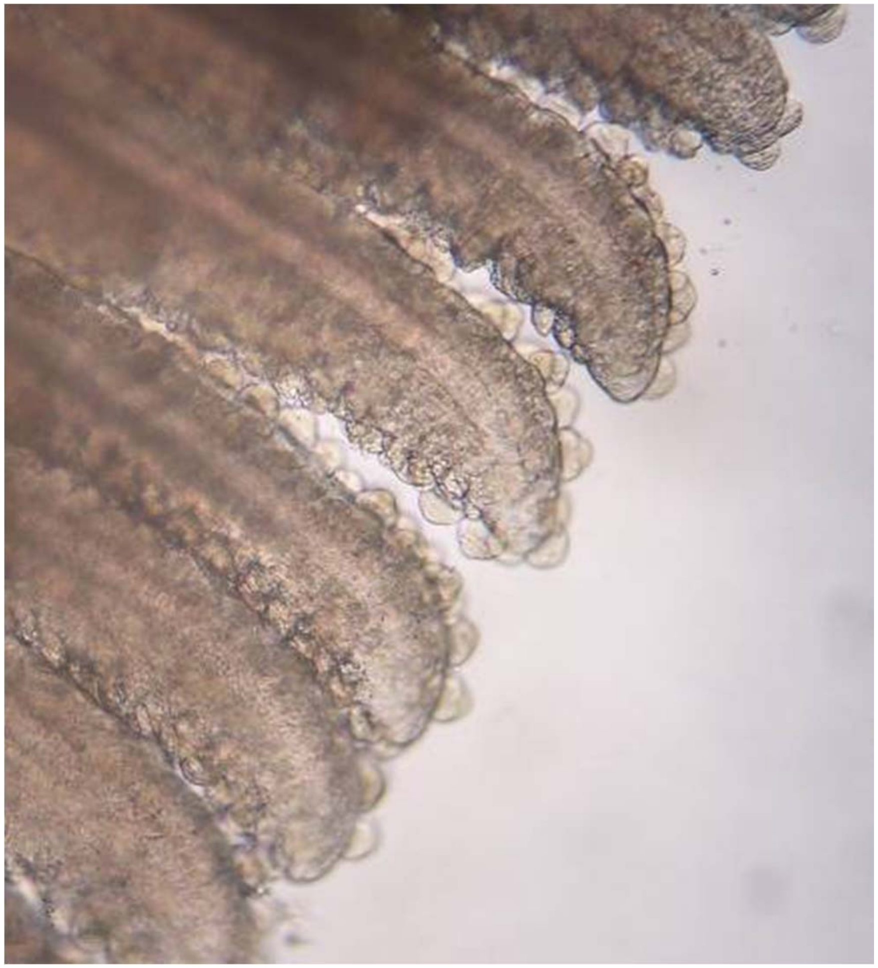
Advantages of Closed Containment

Opportunistic pathogens still need to be considered:

- Bacterial gill disease
- Columnaris
- Fungal infections
- Protozoans

Control conditions to prevent opportunists from gaining "upper hand"



Stress Reduction

Stress Physiology

- Stressful stimuli result in increased circulating **cortisol** levels
- Elevated cortisol leads to immunosuppresion:
  - Decreased serum bactericidal activity
    - Complement, lysozyme
  - Impaired phagocytosis
  - Decreased white cell count
  - Decreased antibody production

Stress Reduction

Types of stress

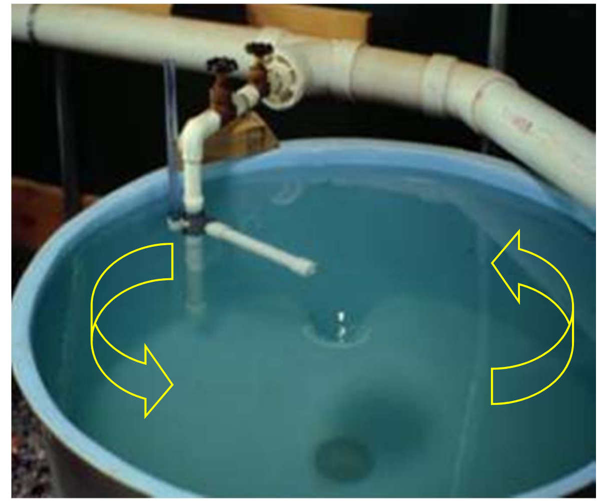
- **Chemical**
  - Poor diet, suboptimal water quality
- **Biological**
  - Pathogens, aggression, crowding
- **Physical**
  - Light, sound, temperature
- **Husbandry**
  - Handling, transport, treatments

Stress Response:

- Depends on the **magnitude** and **duration**
- Stressors are often **cumulative**

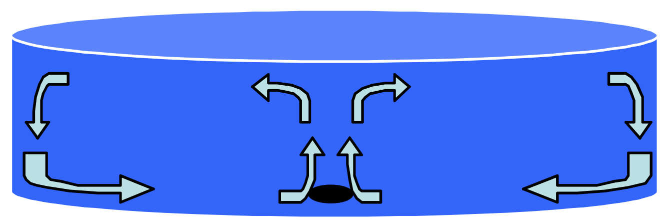
Environmental Management: Circular Tanks

- Tank hydraulics can be optimized
- Solids flushing can be very rapid, < 1-3 min
  - Tanks are self-cleaning
  - Fresh fecal pellets are flushed before they breakdown
  - Solids are not stored in the culture tank primary flow



primary rotating flow

secondary radial flow



Environmental Management: Circular Tanks

Outcomes:

Excellent **solids control** and **uniform water quality** throughout tanks

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Circular Tanks Without Rotation

Water Quality: **RAS**

Important Parameters

- Dissolved Oxygen
- Dissolved Carbon Dioxide
- Ammonia/Nitrite/Nitrate
- Temperature
- pH

Dissolved Oxygen

- Maintaining optimal DO critical in intensive recirculation systems
- O_2 poorly soluble in water
- Max. DO rarely exceeds 10-12 mg/L in H_2O
- For resting salmonids:
  - 5-20 L H_2O/kg body wgt/hour irrigation rate
  - 40-60/minute ventilation rate
    - Energy cost: at least 10% of O_2 consumed

Dissolved Oxygen

- DO consumption rates:
  - Approx. 100 mg O_2/kg body wgt/hour (resting)
  - As high as 800 mg O_2/kg body wgt/hour (actively swimming)
- 85-100% saturation of O_2 required to maintain maximum growth rates in salmonids
- Pure oxygen can be added to system water through low-head oxygenators
  - **Can maintain tank H_2O at saturation**

Dissolved CO_2

- Salmonids produce 0.96 – 1.10 g CO_2 per gram of O_2 consumed
- Inverse relationship of CO_2 with pH
- Long-term exposure to elevated CO_2
  - Decreased hemoglobin oxygen binding capacity (Bohr effect)
    - Increased ventilation, elevated blood pressure
  - Reduced growth rate
  - Higher FCR
  - Nephrocalcinosis
- Also, increased solubility of toxic metals at lower water pH

Dissolved CO_2

- Growth of salmonids significantly reduced at ≥30 mg CO_2 / L
- Maximum limit < 20 mg CO_2 / L
  - Recent review suggests 10 mg CO_2 / L max for Atlantic salmon

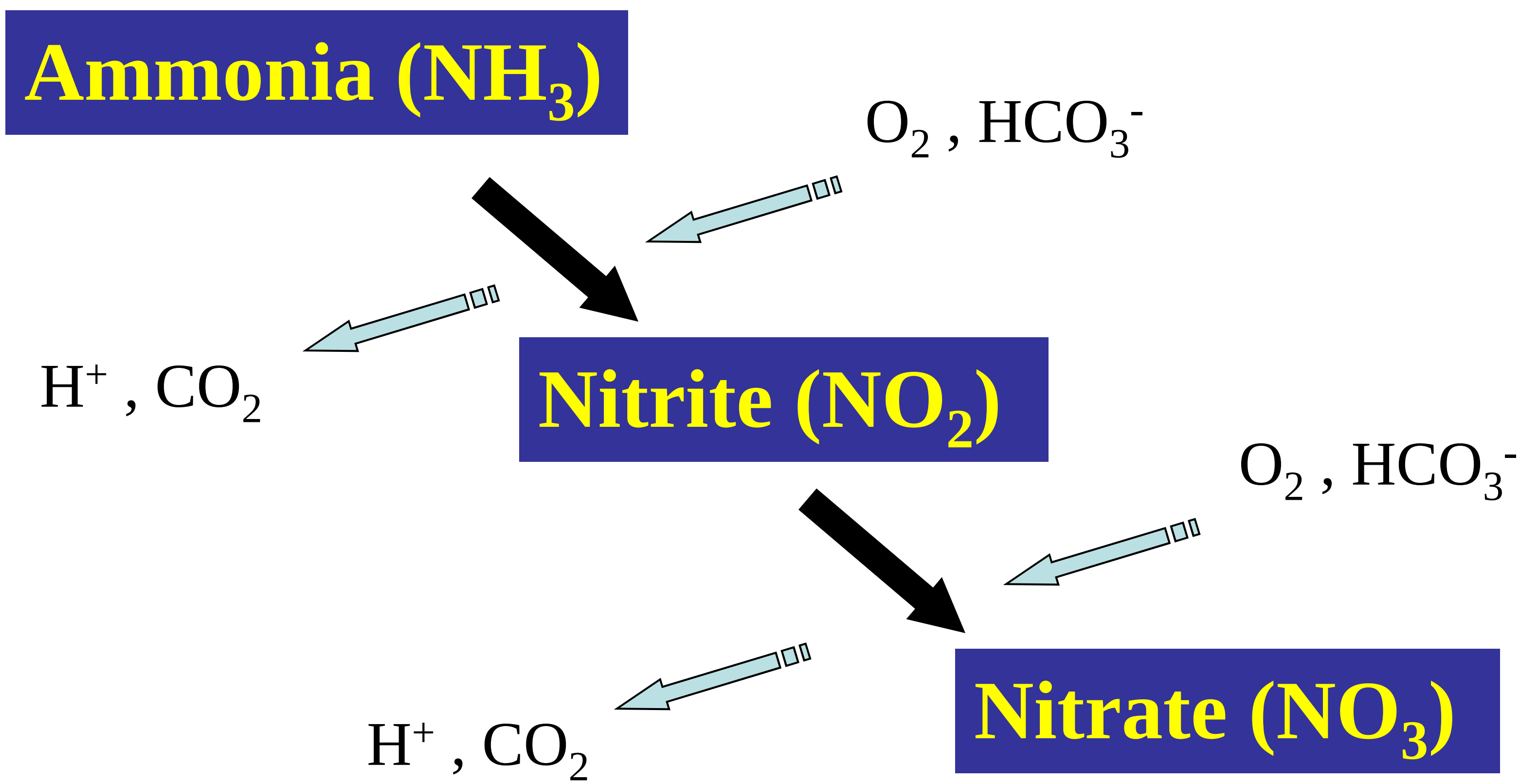
Ammonia • Nitrite • Nitrate

$$NH_3 + H^+ + OH^- \leftrightarrow NH_4^+ + OH^-$$

- **Ammonia:** end product of protein catabolism
  - Excreted through gills
  - Rate of nitrogen excretion increases with feeding rate
  - Unionized: NH_3 (most toxic)
    - Direct effects on central nervous system
    - Gill damage
    - Osmoregulatory disruption
  - Ionized: NH_4
  - Balance of unionized vs. ionized: pH dependent

Ammonia • Nitrite • Nitrate

BIOFILTRATION



Ammonia • **Nitrite** • Nitrate

- Nitrite ions taken up through gills, bind to hemoglobin to produce methemoglobin
  - Reduction of blood oxygen transport capacity
  - "Brown blood disease"
- Nitrite toxicity influenced by bicarbonate, potassium, sodium, calcium, and most importantly chloride
  - LC_{50} nitrite: 0.24–12.20 mg/L depending on chloride concentration
  - Chloride cells in gills do not distinguish chloride from nitrite
- Recommended limit: <1 mg/L
  - <0.1 mg/L in soft water

Ammonia • Nitrite • **Nitrate**

- Very low toxicity, and not normally a concern
- Literature: Mortalities occur when levels exceed 1000 mg/L
- Causes non-specific osmoregulatory failure
- Recent evidence at FWI that near-zero exchange RAS (with elevated nitrate) are associated with mortality, deformities, and erratic swimming

Temperature

- Ectothermic animals
- Increased T = increased metabolism
- Directly effects fish physiological processes:
  - Respiration rate
  - Feed efficiency and assimilation
  - Growth
  - Behavior
  - Reproduction
- Different pathogens thrive at different temperatures

Temperature

- Water temperature manipulation very important during early life stages of Atlantic salmon:
  - Egg incubation at >8ºC can induce skull and vertebral deformities in fry
  - Increased rearing temperature associated with increased vertebral deformities by 60g in size
    - 12ºC – 2%
    - 14ºC – 13%
    - 16ºC – 15%
    - 18ºC – 22%   Baeverfjord et al.

pH

- 6.5 – 8.5 recommended range
- 4.8 > pH > 9.2 can damage and kill salmonids
- pH also has a significant influence on toxicities of e.g. ammonia, hydrogen sulfide, and heavy metals
- In RAS, biofiltration gradually consumes the pH-buffering capacity (i.e. alkalinity) of system water
- Therefore, very important to monitor changes and add sodium bicarbonate when necessary

Environmental Management: Density

- Maximum biomass for a given flow rate determined by:
  - Fish metabolic rate e.g. oxygen consumption
  - Water quality e.g. DO, waste treatment or dilution
- Increased density, in general
  - Reduced feed intake
  - Reduced FCR
  - Reduced growth
  - Reduced body and fin condition
  - Increased risk of clinical disease outbreaks

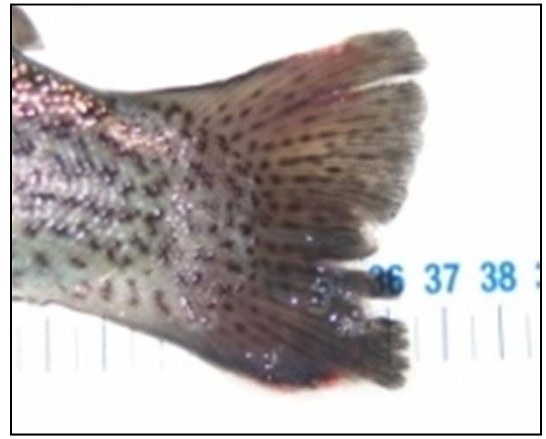
Environmental Management: Density

- Inconsistent findings in the scientific literature
- For Atlantic salmon, no consistent density effect up to around 80 kg/m^3
- Some studies report reduced growth at densities higher than 80 kg/m^3

Environmental Management: Density

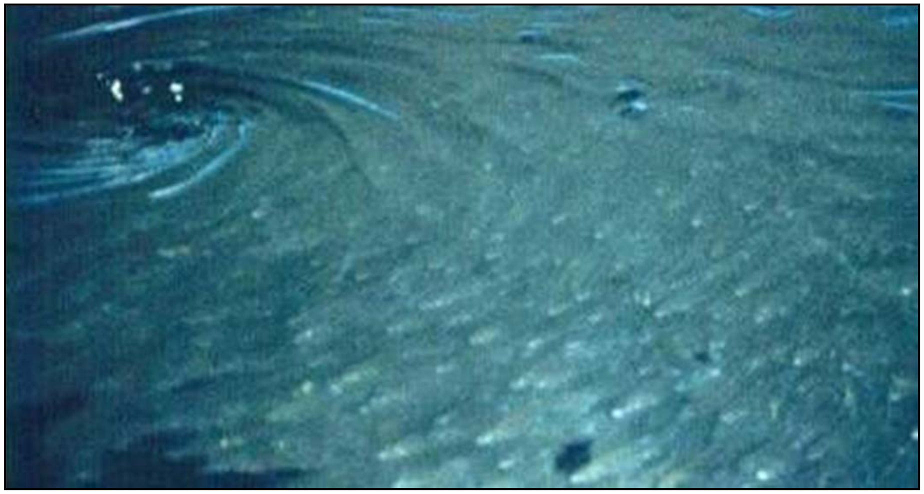
Fin Erosion

- Common welfare index
- For rainbow trout, optimum densities lie between 40 - 80 kg/m^3
- Need further research on this and other welfare indices for Atlantic salmon



Environmental Management: Optimum Swimming Velocity

- Optimum swimming velocity in circular tanks
  = (0.5 to 2.0) x (fish body length)/second



- Velocities in a 'donut-shaped' region about tank center are reduced:
  - allows fish to select a variety of swimming speeds

Environmental Management: Optimum Swimming Velocity

- Advantages of ideal swimming speed:
  - Increased growth rate & protein synthesis
  - Less aggression
  - Enhanced immune function
  - Improved flesh texture

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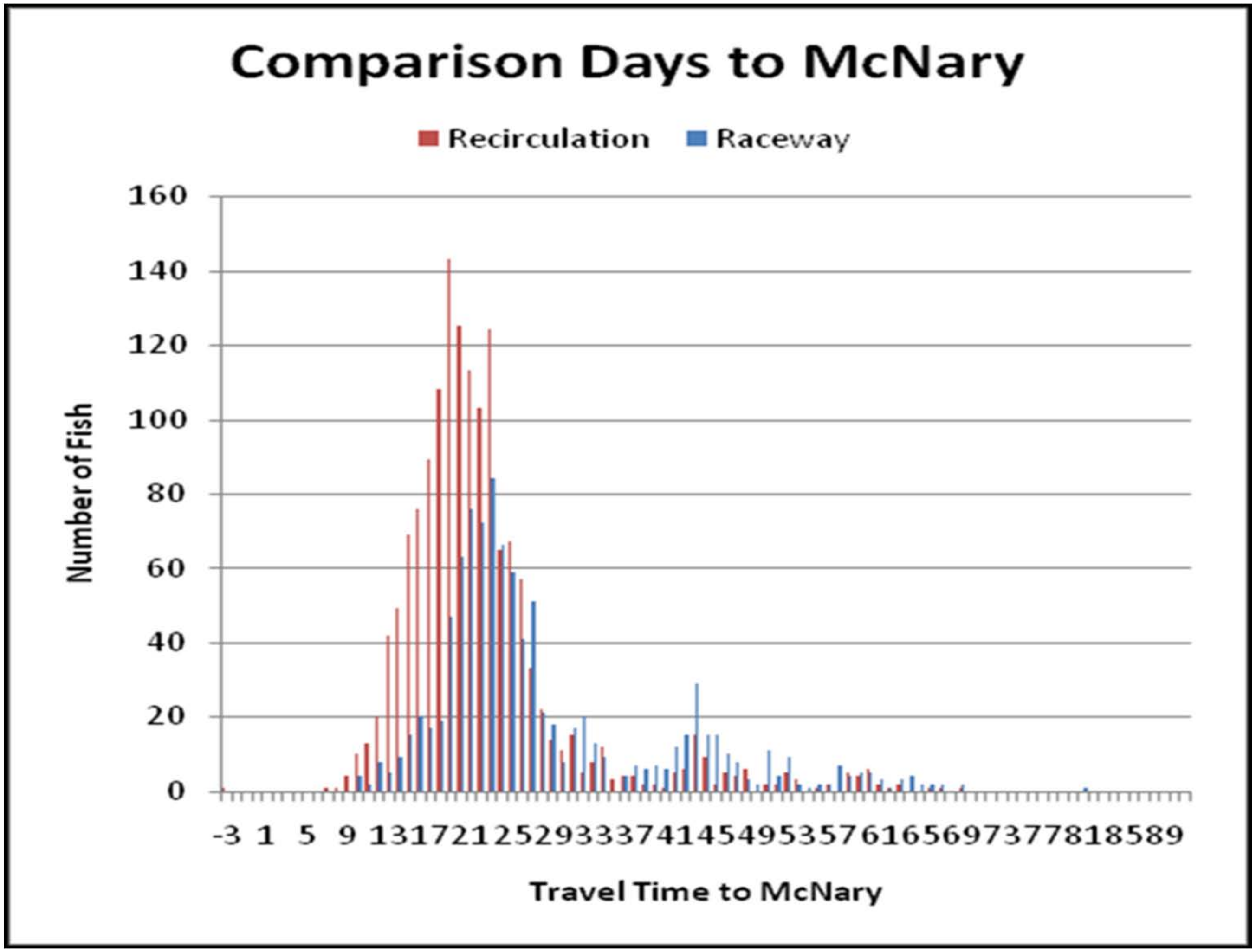
Environmental Management: Optimum Swimming Velocity

Downstream migration of Chinook salmon

Exercised fish out-migrated faster and in greater numbers than raceway fish



Atlantic salmon *Salmo salar* growout in freshwater closed-containment systems:

(1) effects of high and low dissolved carbon dioxide

(2) effects of strain and photoperiod manipulation

(3) effects of swimming speed and dissolved oxygen

STUDY 1

Long-term effects of
high (20 mg/L) and low (10 mg/L) carbon dioxide exposure on Atlantic salmon

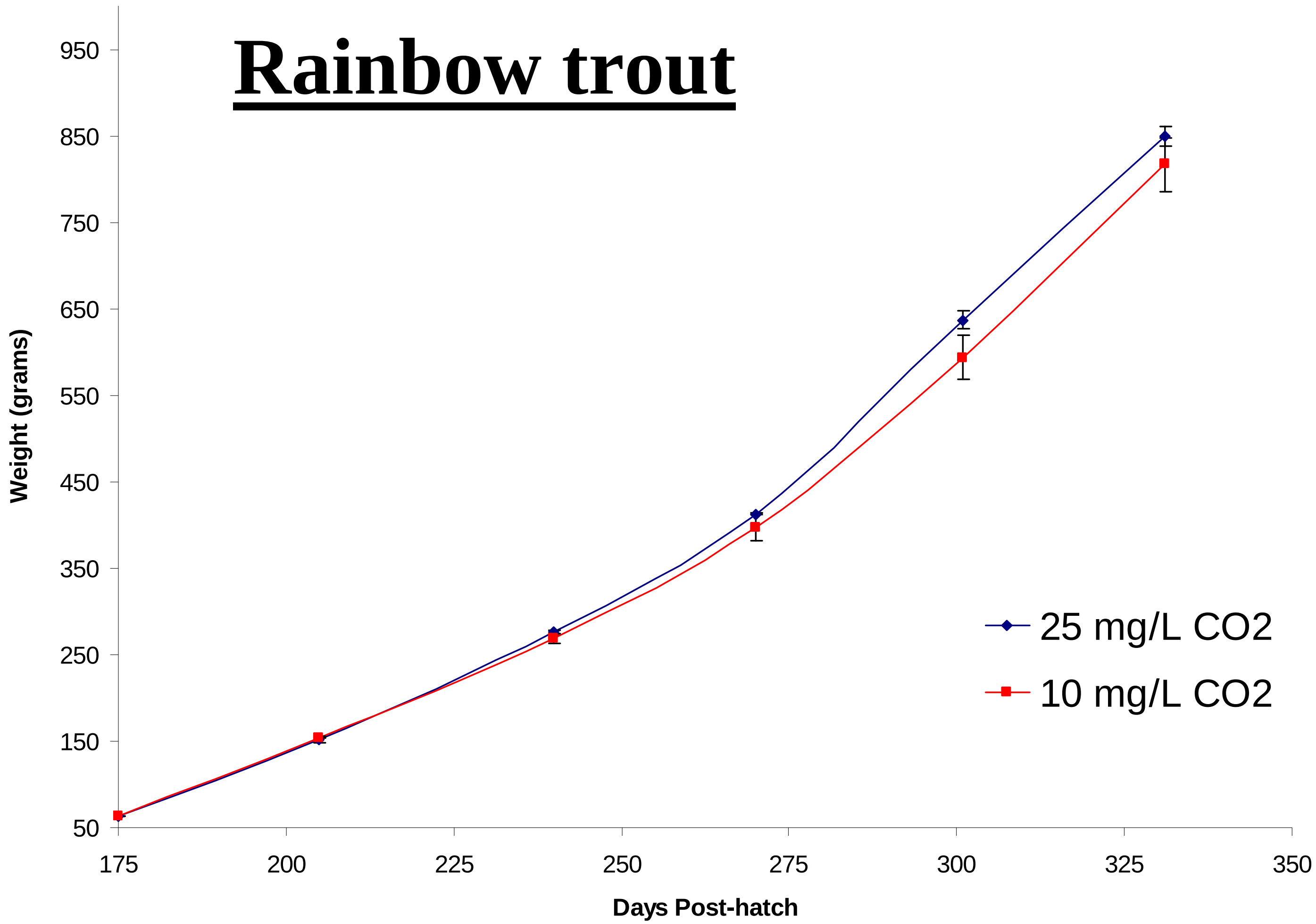
Aside from fish health implications….

Economic Considerations

- Decreasing tank CO_2 concentrations requires pumping more water flow & installing a larger stripping unit (cascade column or aerated basin)
  - increases fixed costs
  - increases variable costs to pump water

Current Research at The Freshwater Institute

Similar study completed with rainbow trout (Good et al. 2010 *Aquacultural Engineering*)



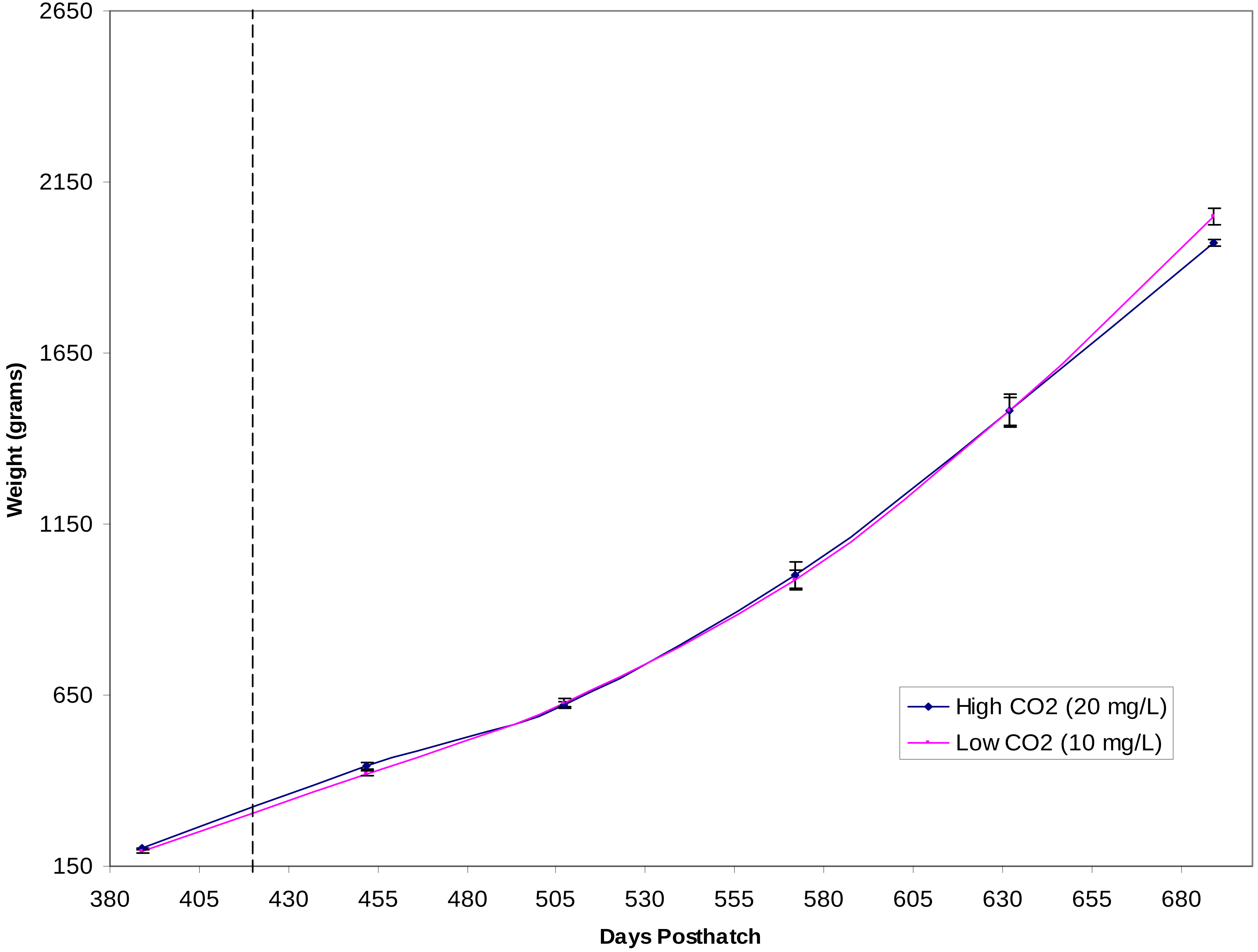
Atlantic salmon: Ongoing Data Collection

- Bi-monthly length/weight sampling
- Daily mortalities
- Gill tissue and plasma collected at increasing intervals
- Kidney tissue collected for histopathology evaluation

Current Research at The Freshwater Institute

December 2010

- Age: 689 d post-hatch
- High CO_2: 1974 ± 10 g
- Low CO_2: 2050 ± 23 g
- CO_2 beginning to show effects on fish growth



2650
2150
1650
1150
650
150
Weight (grams)
380
405
430
455
480
505
530
555
580
605
630
655
680
Days Posthatch
High CO2 (20 mg/L)
Low CO2 (10 mg/L)

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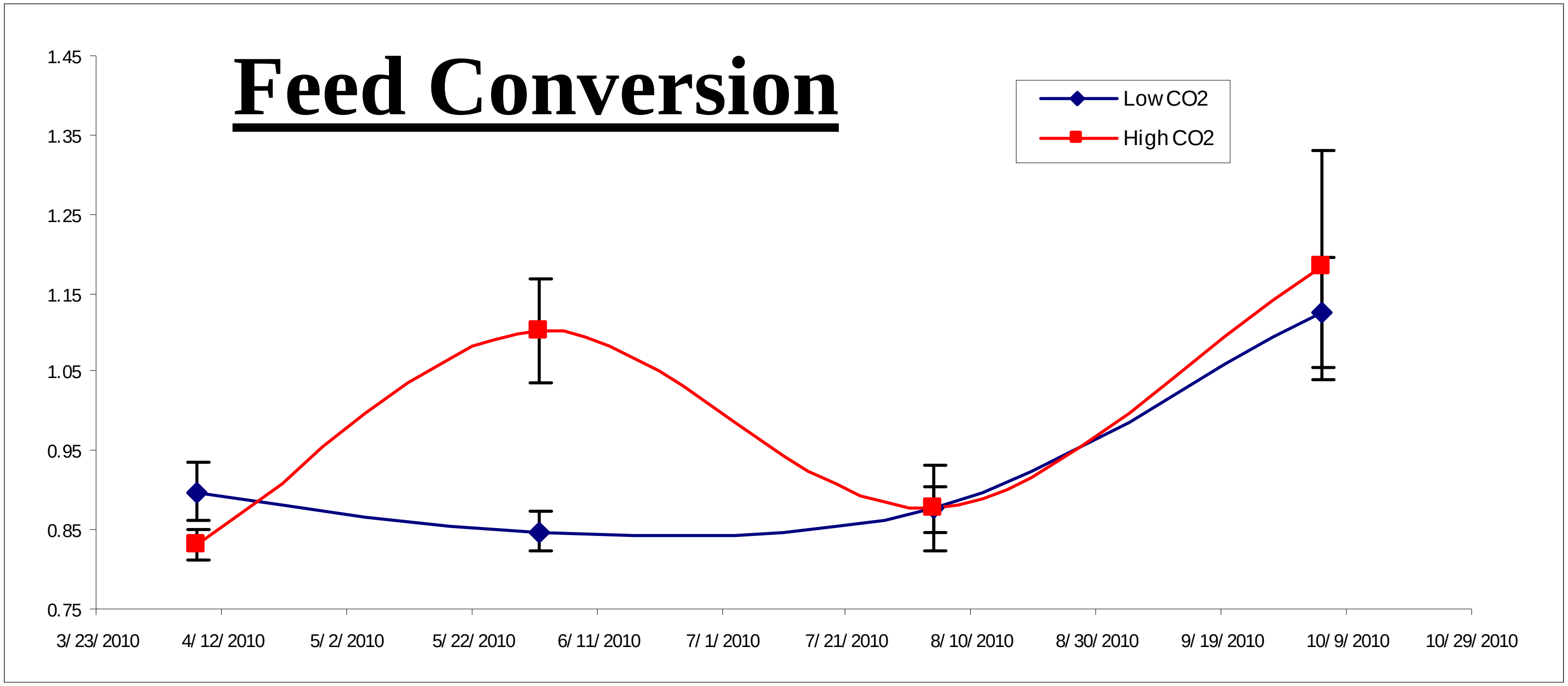
Current Research at The Freshwater Institute



	4/8/10	6/2/10	8/4/10	10/5/10	Grand
Low CO_2	0.90	0.85	0.88	1.12	0.94
High CO_2	0.83	1.10	0.88	1.18	1.00

End-of-study sampling:

- Multiple tissue histopathology
- Blood gas and chemistry
- Fin indices
- RT-PCR of gill tissue for carbonic anhydrase and Rhcg mRNA

STUDY 2

Effects of strain and photoperiod manipulation on Atlantic salmon

Objectives

- Determine how Atlantic salmon strain and photoperiod manipulation (to produce smoltification) influence growth, processing attributes, and sexual maturity to 26 months post-hatch in freshwater RAS.

Materials and Methods

- 2X2 Factorial study
- Two Atlantic salmon strains:
  1. St. John's
  2. Gaspe
- Two early rearing light regimes:
  1. Continuous light
  2. Continuous light with S_0 winter
     - 12h light, 12h dark for six weeks, then return to constant light

Current Research at The Freshwater Institute

- Three 10 m^3 culture tanks in one freshwater reuse system
- Both strains and photoperiod treatment fish co-mingled within each tank for n=3 replication

Results so far…

- Performance differences for both strain and lighting regime are already apparent
- Gaspe strain outperforming St. John's
- Salmon the underwent S_0 winter are statistically ($p<0.05$) larger within Gaspe strain

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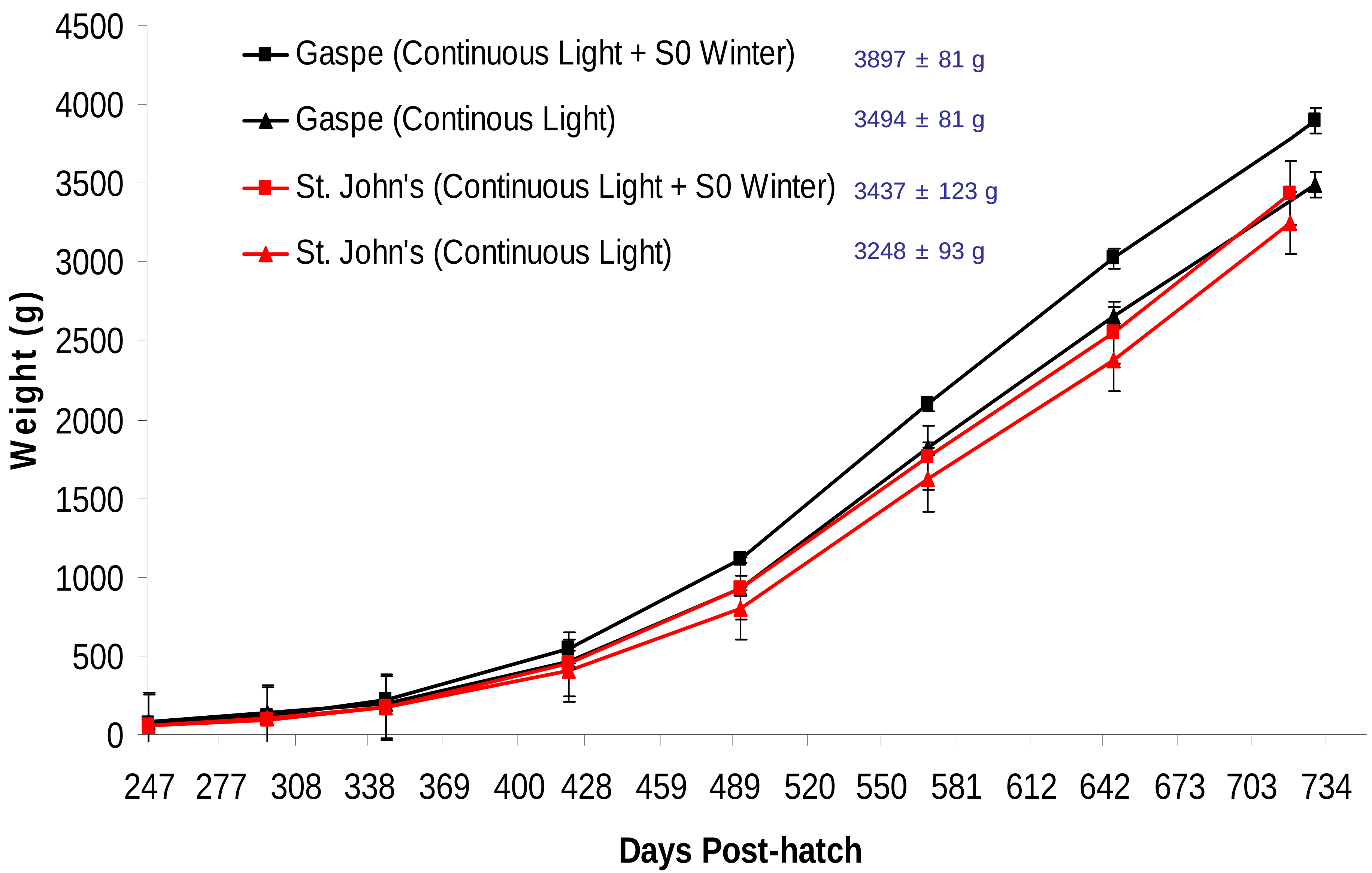
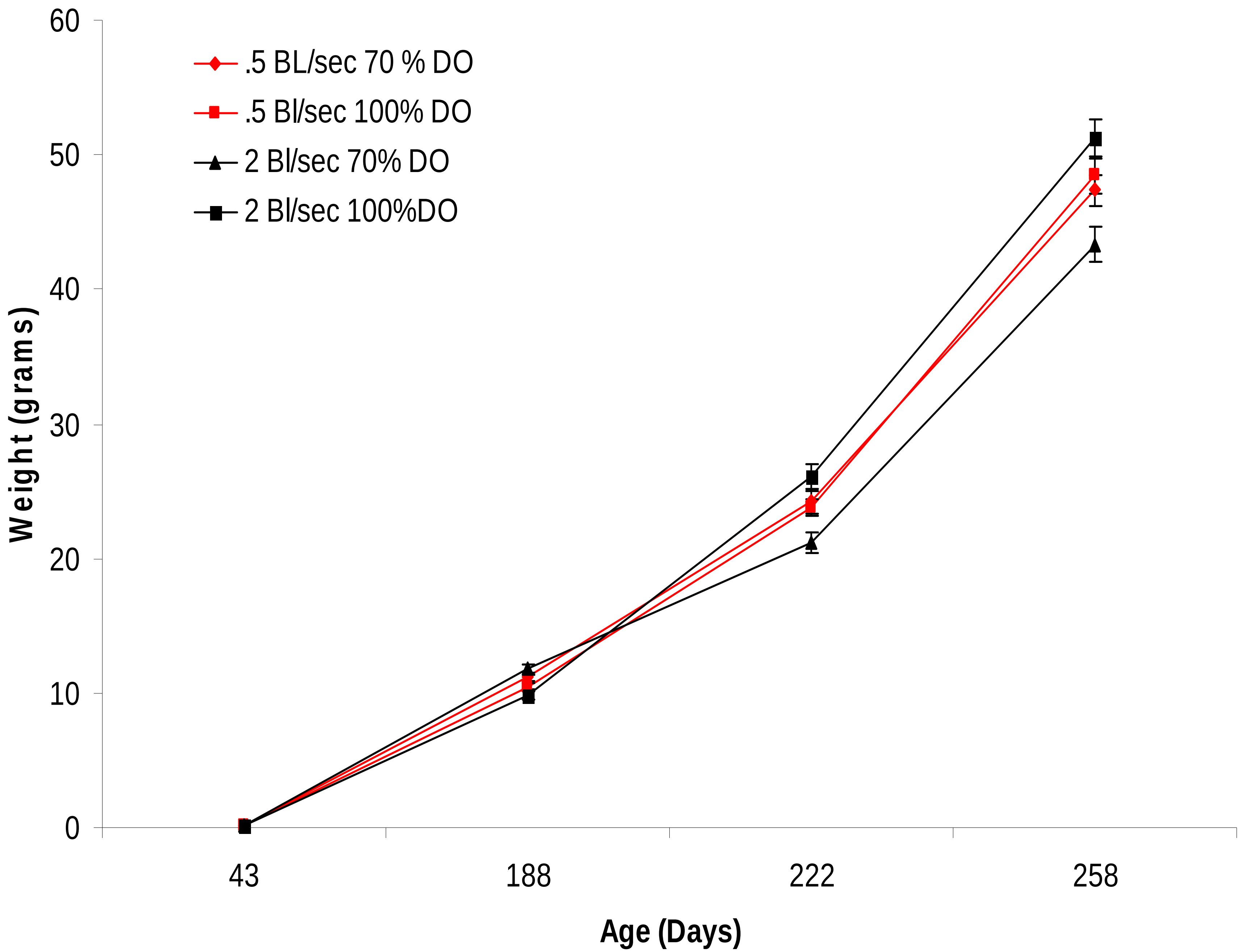


Further Data Collection

- Gill ATPase analysis
- Plasma growth hormone assays
- Histopathology
- Blood gas / chemistry
- Processing attributes: fillet yield, fillet proximate analyses, fatty acid profiles, visceral indices, gonadal indices
  - 22-, 24-, and 26-months post hatch

STUDY 3

Effects of swimming speed (2 BL/s vs. 0.5 BL/s) and dissolved oxygen (100% vs. 70% saturation) on Atlantic salmon



60
50
40
30
20
10
0
.5 BL/sec 70 % DO
.5 Bl/sec 100% DO
2 Bl/sec 70% DO
2 Bl/sec 100%DO
Weight (grams)
43
188
222
258
Age (Days)

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

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