

Dietary mineral supply in Atlantic salmon – impact on skeletal development

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Nutritional aspects of vertebral deformities

- **No limit** to the number of potential nutritional factors
- In commercial diets, **mineral supply** is the most likely **limiting factor**
- **Phosphorus deficiency** impairs bone formation
- Mineral supply (**dietary level X bioavailability**) is a challenge in fast growing animals of any species
- **Unpredictable dietary supply** in formulated diets
 - Vegetable ingredients impairs absorption
 - Unforeseen variation in availability in fish meal
- Potential **interaction** between dietary minerals and reduced water quality in impact on bone mineralisation

- Minerals were suspected to be a cause of skeletal malformations early on (mid 1990-ies)
- A study from 1993-1994 demonstrated that a restricted dietary supply of P caused impaired bone development both in freshwater and seawater (Baeverfjord et al., 1998)
- Temperature took over as the number one causal factor as experimental research progressed
- After temperature adjustments were implemented by industry, the focus on mineralization as a possible second factor resurfaced

The unpredictability of dietary P supply

- Digestibility of P depends on source
- Required dietary content depends on digestibility and feed conversion ratio (kg feed/kg weight gain, FCR)
- **Whole body P content in fish with normal bone mineralization ~4000 mg/kg.**

Dietary P content mg/kg (%)	Digestibility of P %	FCR (kg feed/ kg weight gain)	Available P mg/kg per kg weight gain
12 000 (1,2 %)	50	1	6000
12 000 (1,2 %)	30	0,8	2880

2002-2005:

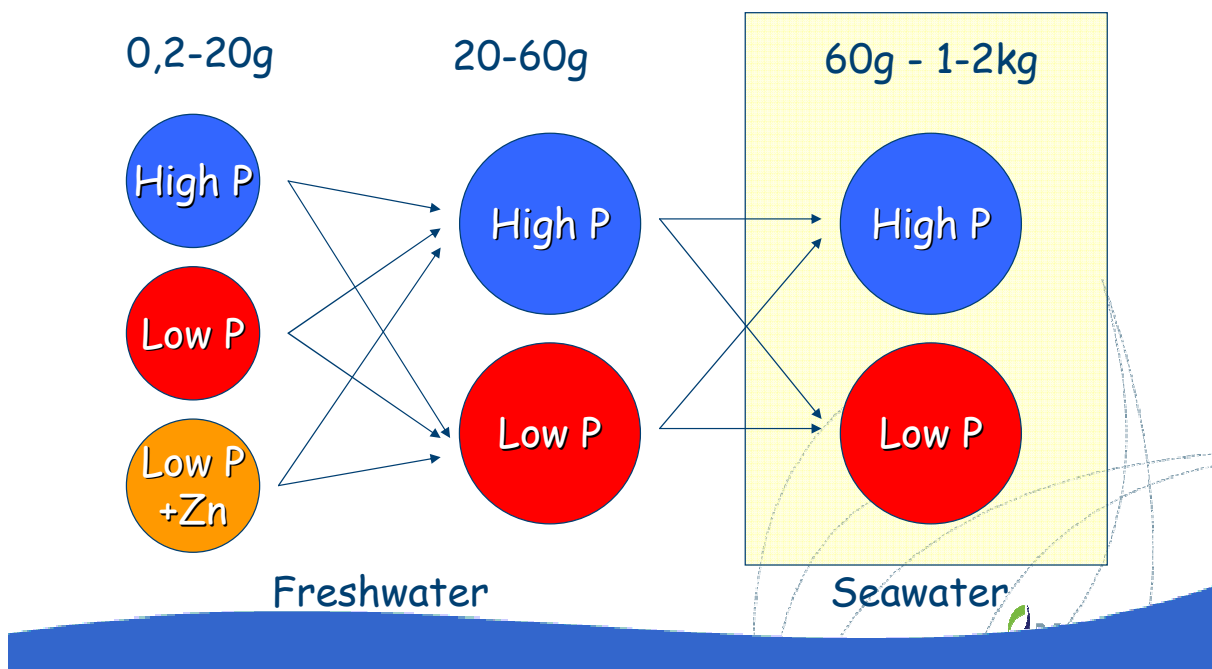
Deformities of vertebral column and jaw in Atlantic salmon
Effects of genetic susceptibility, mineral nutrition and production temperature

- Funded by Fiskeri- og Havbruksnæringens Forskningsfond (FHF), the Norwegian industry research foundation
- Study supported by
 - AquaGen: Supplied egg groups selected for genetic disposition
 - Ewos Innovation: Experimental feeds



Long term experiment:

Restricted dietary phosphorus supply in salmon - Effects on skeletal development



Diets:

	Phosphorus (P) %	Zinc (Zn) mg/kg
High P	1,7-1,8	140-190
Low P	1,0-1,2	140-190
Low P + Zn	1,0-1,2	50-80

Low P: P levels comparable to published requirements
Low Zn: Zn levels " " "

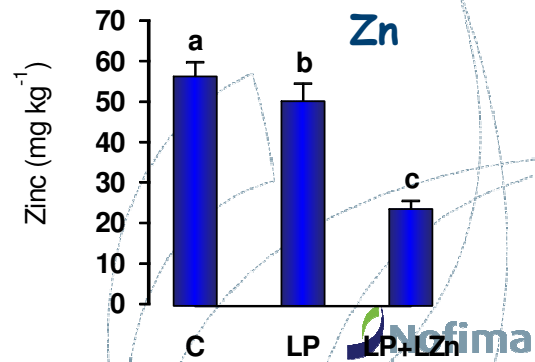
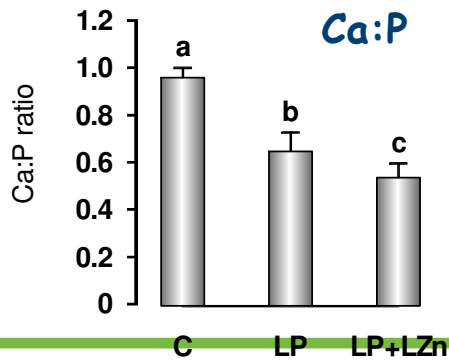
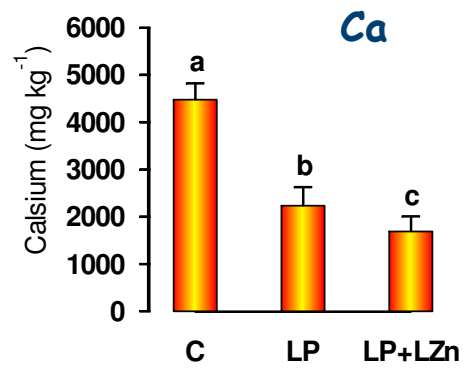
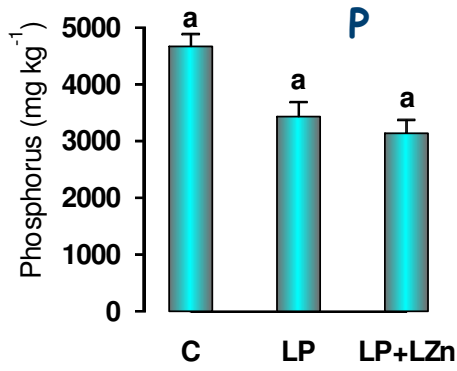
If digestibility 50% and FCR 1,0: Sufficient
If digestibility 30% and FCR 0,8: Marginal deficiency



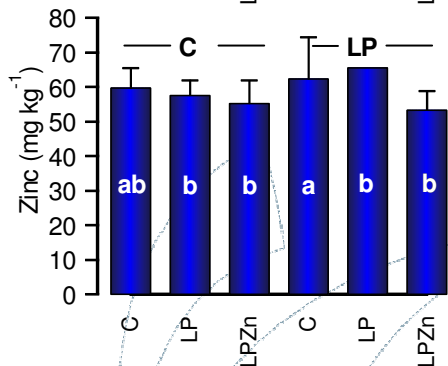
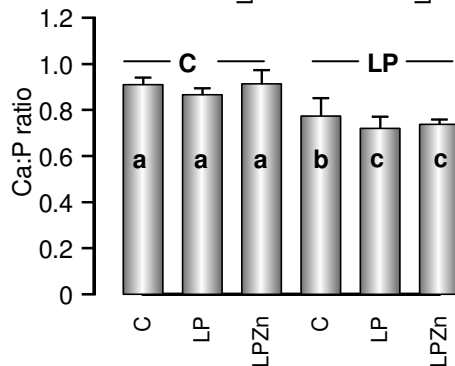
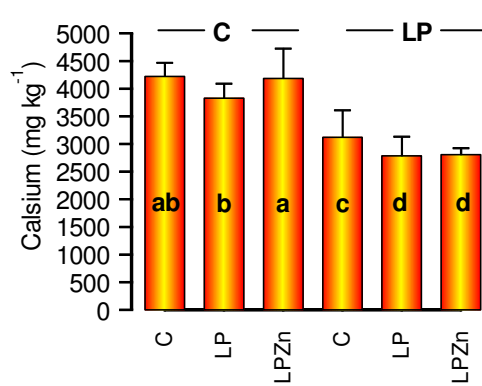
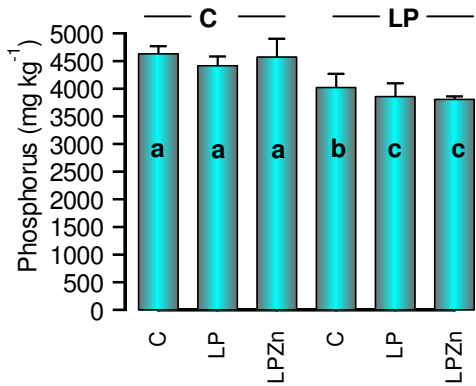
5g



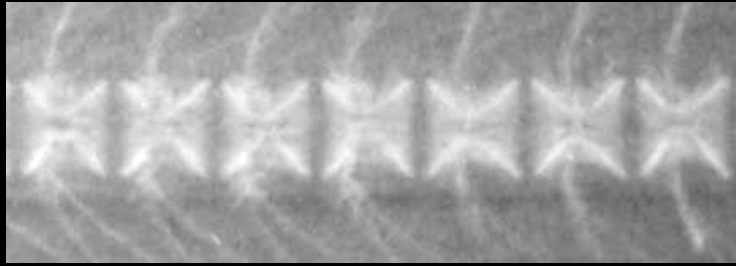
Whole body mineral content at 20g



Whole body mineral content at smolt transfer (60-80g)



20g



High P



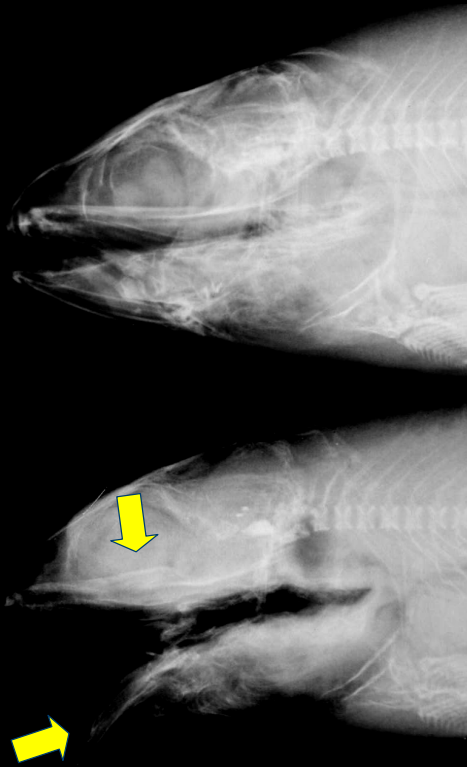
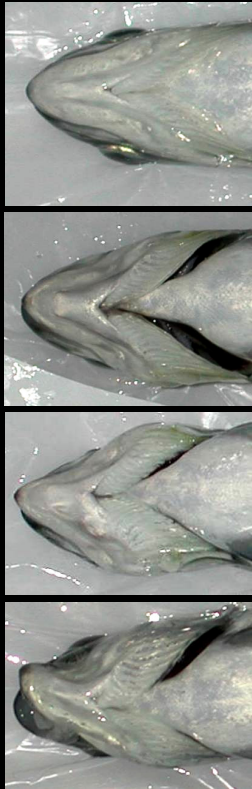
Low P



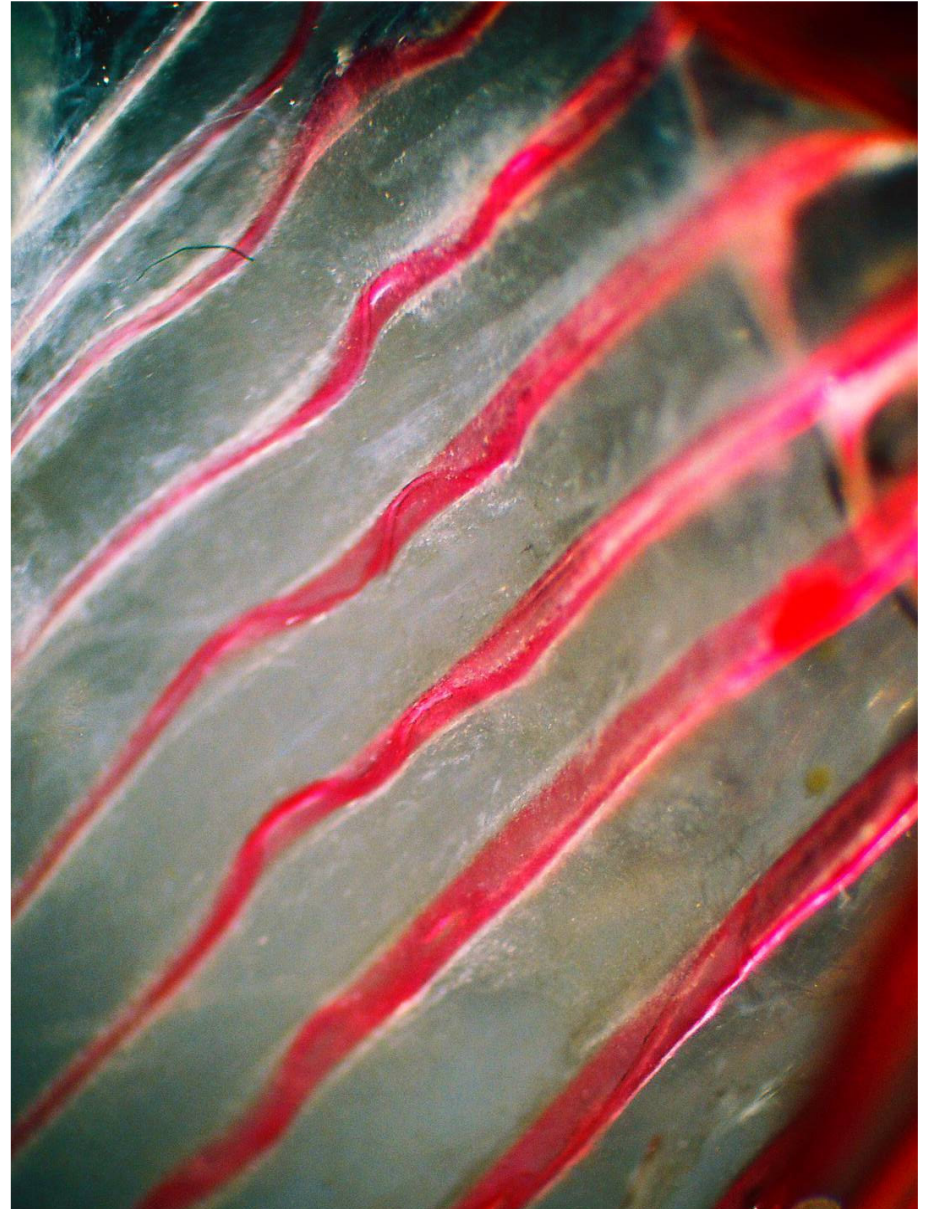
Low P
+ Zn

 Nofima

60g



 Nofima





End of seawater rearing:
• Abnormally soft fish
• Short fish



Summary, long term P study:

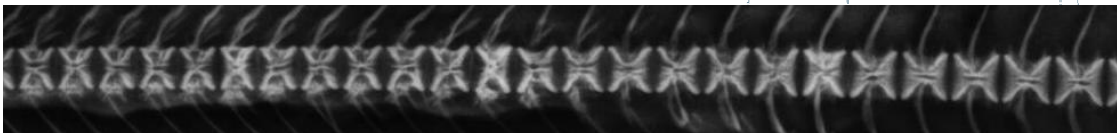
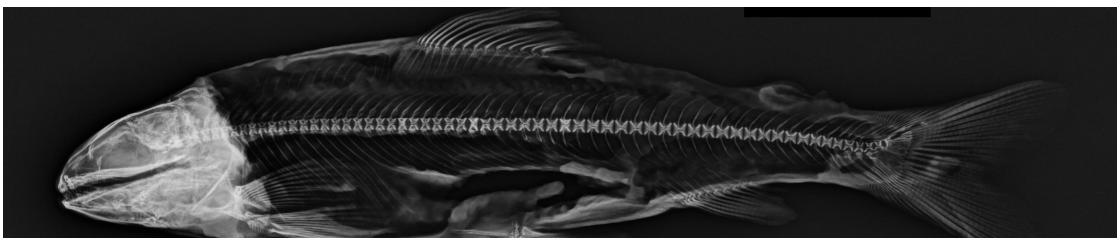
- Even a moderate P deficiency may induce long term effects
- P deficiency is aggravated by low Zn
- Periods of negative P balance may induce irreversible structural changes in bones, even though mineral content will return to normal if supply is increased
- The early juvenile stages are most vulnerable, but..
- The skeletal structures are susceptible to mineral deficiency throughout freshwater and seawater stages

- Long term effects of undermineralisation include
 - Malformations of the lower jaw
 - Platyspondylia of the spinal column

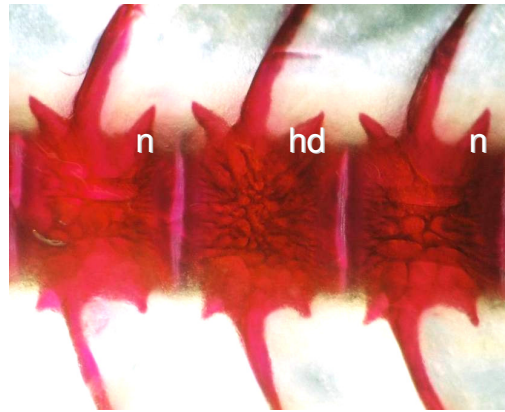


Hyper dense vertebrae in Atlantic salmon parr

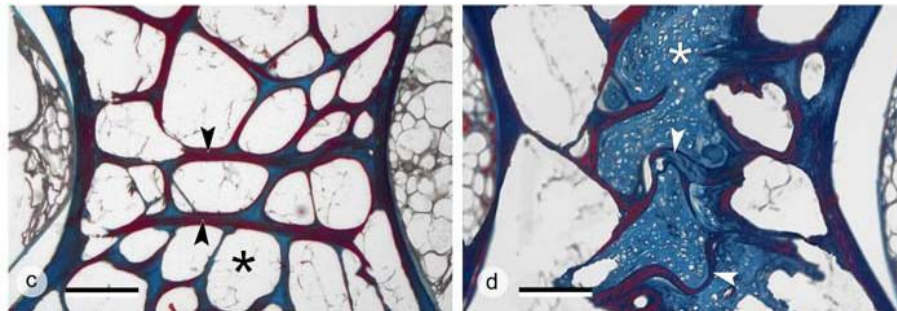
- Experiment with graded levels of phytic acid (Denstadli m.fl., 2006)
- Phytic acid in high levels led to reduced levels of Ca og P in fish
- Presence of hyper dense vertebra at start of experiment



Structure of hyper dense vertebrae



(Whole mount staining, Alizarin red)



Normal

Hyperdense

(Masson's Trichrome)

Helland *m. fl.*, 2006



Restricted dietary levels of phosphorus and zinc induces specific skeletal deformities in juvenile Atlantic salmon (*Salmo salar* L.)

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FINE FISH - Improving sustainability of European fish aquaculture
by control of infections (EU - FP7-CT-2015-01245)

Background and objective

- Previous experiments demonstrated the importance of adequate supply of P and Zn for preventing skeletal deformities in long term development
- Ca and P levels are low in a significant number of samples
 - Ca or P < 3500 mg kg⁻¹, Ca and P should be > 4000 mg kg⁻¹
 - Ca << P, should be Ca > or = P
- Zn levels are low in commercial samples
 - Whole body Zn values of 30 mg kg⁻¹ are typical, and lower values are commonly observed
 - Reference values are in the range of 40 – 60 mg kg⁻¹
- Mg levels are highly variable in samples of commercially reared fish
- In the present study, the specific effects of restricted P and Zn supply during early juvenile development was examined.
- The potential effects of reduced dietary Mg supply was also addressed

Objective:

To determine the specific effects of restricted, suboptimal dietary supply of P, Zn and Mg during early skeletal development

- First feeding experiment A. salmon
- Start weight 0,2g (start of exogenous feeding)
- Final weight 25-30g
- Feeding period 20 weeks
- 4 diets x 3 replicates = 12 tanks
- Continuous feeding, continuous light, flow through water supply
- Sampling of fish at 1g, 5g and 25g (end of feeding experiment)
- Chemical contents and radiography
- Analyses of gene expression (not presented here)

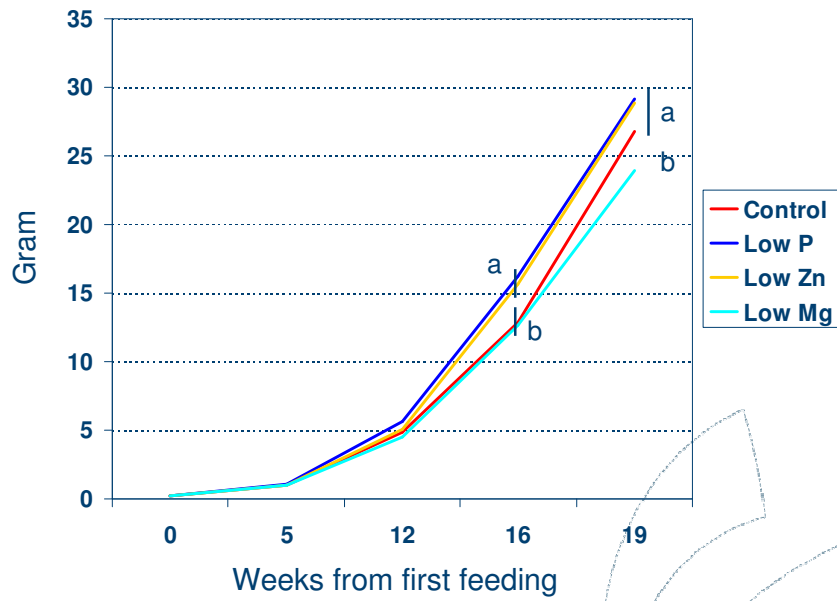
Diets

- Four diets with differing mineral contents were made by Nofima marine Bergen (then Fiskeriforskning Bergen)
- The basic diet was formulated to contain
 - 53 % protein
 - 18 % lipid
 - 10 % carbohydrate
- Mineral content was differentiated by excluding mineral supplementation selectively for P, Zn and Mg
- Diets were aimed at producing **subclinical mineral deficiency** comparable to the lower end of commercial values
- Four different particle sizes were produced per diet, from the same basic feed batch

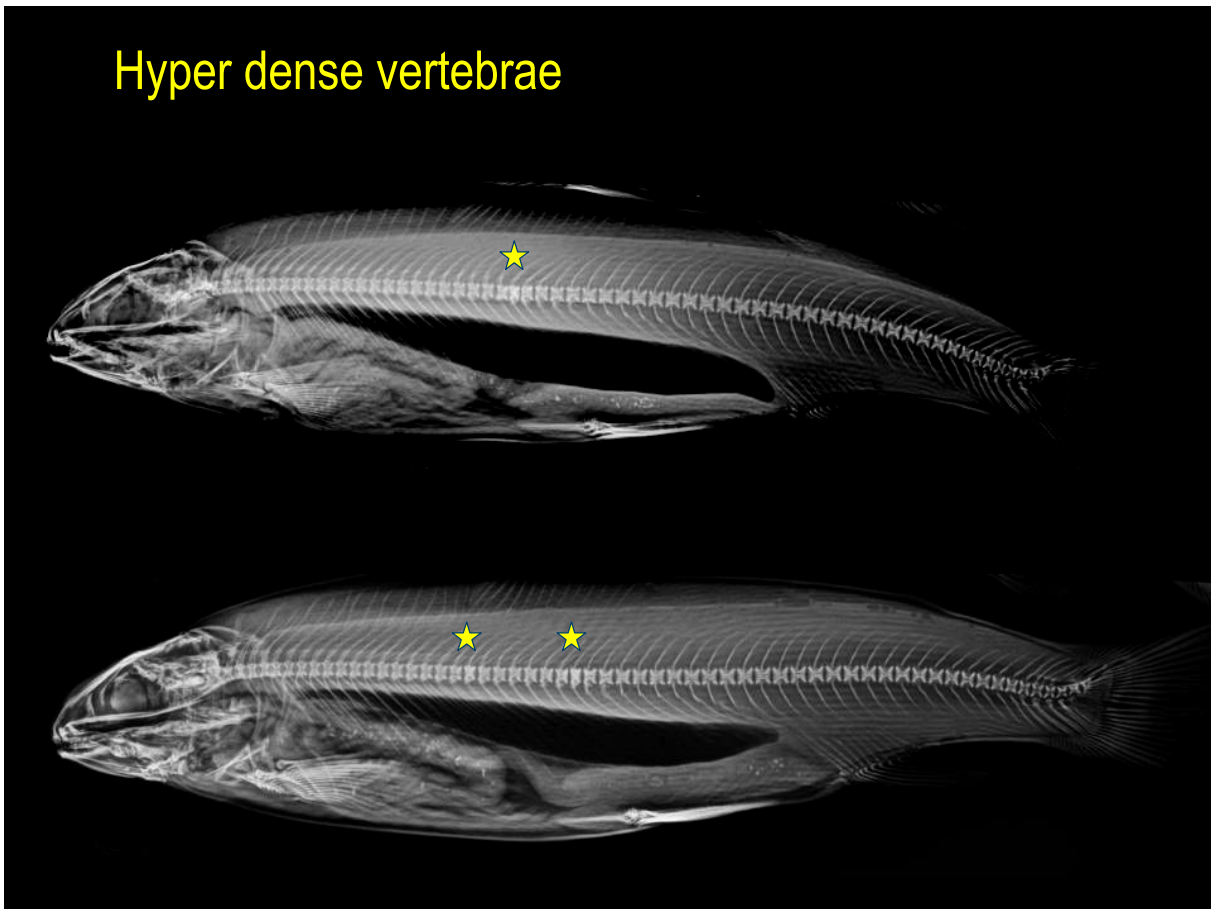
Mineral analyses of experimental diets

Diet	P (mg kg ⁻¹)	Ca (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Mg (mg kg ⁻¹)
Control	16500	15600	194	2375
Low P	13300	13200	181	2350
Low Zn	16800	15500	85	2440
Low Mg	15900	14800	182	1860

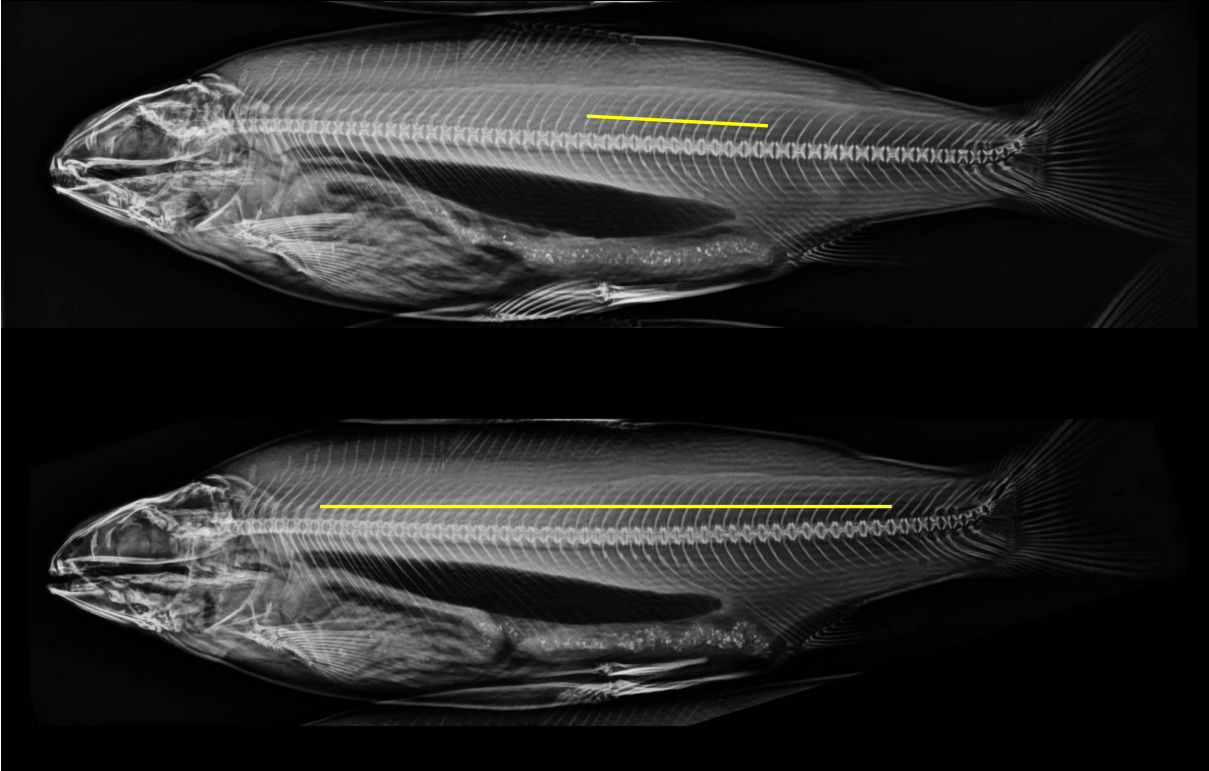
Growth of *A. salmon* juveniles fed diets differing in mineral contents



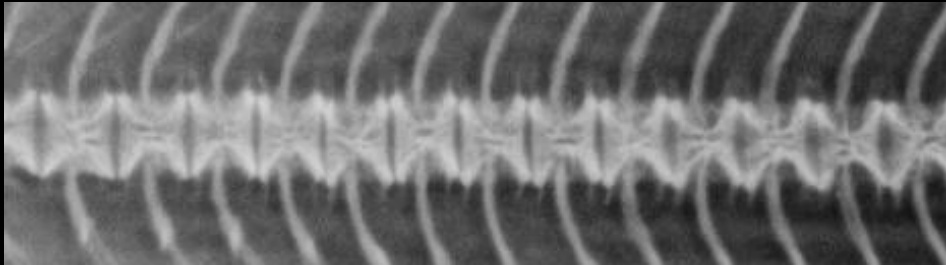
Hyper dense vertebrae



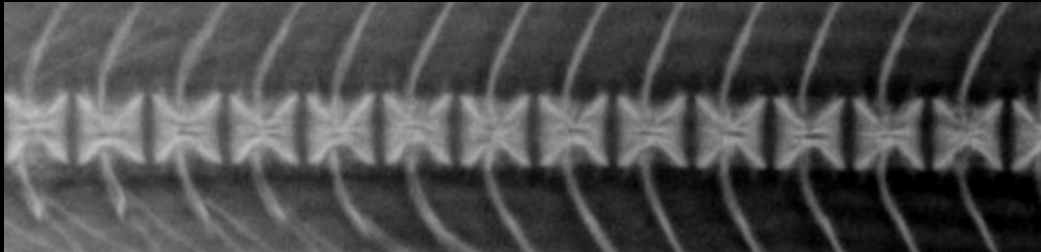
Compressed vertebrae



Detail of compressed vertebrae



Compressed



Normal

Hyper dense versus compressed vertebrae

- Hyper dense vertebrae were observed in all dietary treatments except control
- The observations confirm that **hyper dense vertebrae can be used as indicator for disturbances in early mineralization**
- Highest number of fish with hyper dense vertebrae observed in low P groups
- Low P groups were particularly low in Ca and P around 1g size
- **Compressed vertebrae were typical for Zn deficiency**
- The observations are comparable to older studies of "short body dwarfism" related to Zn deficiency in other species
- Zn deficiency was consistent in low Zn groups throughout the experiment
- **Early-life subclinical hypomineralization was previously linked to development of late-onset platyspondylia**

Fate of HD-vertebrae

- High density vertebrae (HD-vertebrae) were identified in 20 fish on X-ray at seawater transfer.
- HD-vertebrae were seen in fish from all diet groups
- At harvest, same vertebrae were identified, X-rayed and sampled for histology
- Of 20 HD vertebra identified at seawater transfer
 - 10 were normal by termination of experiment
 - 10 were developed into fusions at termination

Conclusions, P, Zn and Mg

- Dietary phosphorus supply may still be a limiting factor for normal skeletal development in *A. salmon* early rearing. The low P diet in this experiment was higher in P than many samples of commercial diets
- Supply of Zn in diets for juvenile salmon should receive more attention. The estimated Zn requirement of 37-67 mg kg⁻¹ feed is clearly too low.
- Low dietary Mg may interfere with mineralization, although how and why remains unanswered by this study



Summary and recommendations

- Minerals most important dietary factors, in particular P and Zn
- Still reason for concern about mineral supply from commercial feeds
- Present and future challenges
 - Reduced mineral availability with vegetable meals
 - Variable and unpredictable availability of minerals from fish meals
- Subclinical mineral deficiency does not affect growth
- Morphological effects are delayed
- Mineral status can be assessed through chemical analyses of fish
- Remember that mineralization is dynamic
- You will see the full effect of undermineralization only as the fish approach harvest size

