The functional genomics of rapid evolutionary changes between domesticated and wild salmon populations

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Genomics and Conservation of Aquatic Resources
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The issue:

. The aquaculture industry has become a major supplier of fish and shellfish worldwide.

. Over 40% of all fish directly consumed by humans worldwide are farmed.

. Growth of some aquaculture sectors has been especially dramatic.

. Global production of farm salmon quadrupled over the last 10 years.

. Over 90% of this farm product is Atlantic salmon (Salmo salar), a species nearly depleted in the wild.
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The issue:

. Atlantic salmon are farmed both within their native range (northern Europe, eastern North America) and beyond (western North America, Chile, Tasmania).

. The production of farmed salmon in the North Atlantic reached $> 800,000$ t.

. Total annual catch of wild salmon in the North Atlantic declined to 2000 t.

. Atlantic salmon raised on farms now far outnumber wild Atlantic salmon returning to rivers
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The issue:

- About two million farm salmon escape each year into the North Atlantic.

- 20% to 40% of the Atlantic salmon caught in the open ocean fisheries between 1989 and 1996 was of farmed origin.

- Farm salmon represent on average 11% to 35% of the “wild” spawning populations in Norway, with some populations exceeding 80%.

- About 500 000 farmed salmon escaped from one Norwegian farm during a storm in August 2005: their weight (1300 t) exceeded total annual wild salmon harvest in coastal and river fisheries.
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**Biological consequences of farm salmon escapes:**

- Risks of competition with wild fish for mates, space, and prey
- Risks of feral stock establishment
- Risks of pathogen transmission
- Risks associated with genetic interactions

All of these risks may potentially affect the evolutionary trajectory of wild salmon
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**Evolutionary change associated with genetic interactions:**

- Farmed salmon have been under artificial selection for 30 years:
  - Growth
  - Sexual maturity
  - Bacteria resistance
  - Fat content
  - Flesh colour
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Evolutionary change associated with genetic interactions:

- When reared in common environment, farm fish show:
  - Increased growth rate
  - Increased aggressiveness
  - Risk-taking behavior
  - Offspring less fit in nature
  - Different morphology
Evolutionary change associated with genetic interactions:

- The genomic bases for rapid phenotypic change in farm salmon is unknown...

- Yet, such knowledge is crucial for accurately addressing the following question:

How much will interbreeding between farm and wild salmon populations change the genetic makeup of wild salmon?
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Evolutionary changes strongly depend on alterations in gene regulation ...

“… We suggest that evolutionary changes in anatomy and way of life are more often based on changes in the mechanisms controlling the expression of genes than on sequence changes in proteins.”

Evolution at two levels in humans and chimpanzees
Marie-Claire C King and Allan C. Wilson
Use microarrays technology to detect genetic differences in gene transcription profiles between the progeny of two salmon breeding strains (one Canadian and one Norwegian) and that of their respective wild populations of origin (river St-John, Canada and river Namsen, Norway), all grown in controlled conditions.
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Gene expression:
3,500 genes compared on DNA chips
(1) RNA → (2) RT-PCR → cDNA
(3) Marked amplified cDNA
Ind 1  Cy5  Ind 2  Cy3
(4) Hybridization on microarray containing gene probes
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- Forty full-sib families were created from wild and farmed genitors of Canada and Norway.

- Fry sampled and total RNA was extracted from whole individuals.

- Transcription profiles of wild and farm salmon fry: Norway: 20, Canada: 26 compared directly on microarrays (3500 genes).
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- 68 and 74 genes showed significant difference in levels of gene expression in progeny of wild and farmed populations from Canada and Norway.
- This represents about 1.5% of all significant genes screened. (roughly 300 – 400 genes genomewide)
- The average magnitude of the differences observed in level of expression was 20%.
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Significant changes in expression observed for genes representing 16 physiological functions:

- Energy metabolism
- Chaperones
- Transcription regulation
- Protein synthesis
- Extra-cellular matrix
- Immunity
- Blood transport protein
- Signal transduction
- Cellular growth
- Development/Growth regulation
- Muscular function
- Metal ion transport/sequestration
- Digestive enzyme
- Lysosomal Enzyme
- Other
- Unknown

Percent of significant genes
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Several genes showed parallel patterns of change in expression in farmed versus wild fish in Canada and Norway:
- Similar genetic responses to similar selective pressures...
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Evidence of inadvertent selection:

- A 63% overexpression of Type I collagen in farmed salmon: a fish allergen that can induce hives in allergic humans.
- A 21% under-expression of metallothionein in farmed fish: involved in adaptation to heavy metal environments.

Five generations of artificial selection caused significant evolutionary changes in the expression of many genes in farmed salmon, some of which may be non-desirable, either from a production or a conservation perspective.
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1. The findings of this study indicate potential for negative secondary effect from evolutionary impacts on biological composition of ecosystems.
   - Hybridization will change expression of genes controlling important functions.

2. The findings of this research indicate that the human activities we have linked to evolutionary effect need to be further controlled or changed.
   - Adds to voices stressing that implementation of measures to considerably reduce the number of escaped farmed salmon and their reproduction in the wild is urgently needed.

3. The findings of this research indicate that changing conservation practices could reduce the negative evolutionary effects of the human activities we studied.
   - Strengthening policy measures and providing sufficient incentives to improve aquaculture practices could reduce the number of farm escapes and therefore mitigate negative evolutionary effects.
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4. Further research building on these findings...

Documenting differences of gene expression between pure and farm-wild hybrid salmon and link to fitness

… Christian Roberge’s poster!