



Atlantic Cod Genomics and Broodstock Development in Canada

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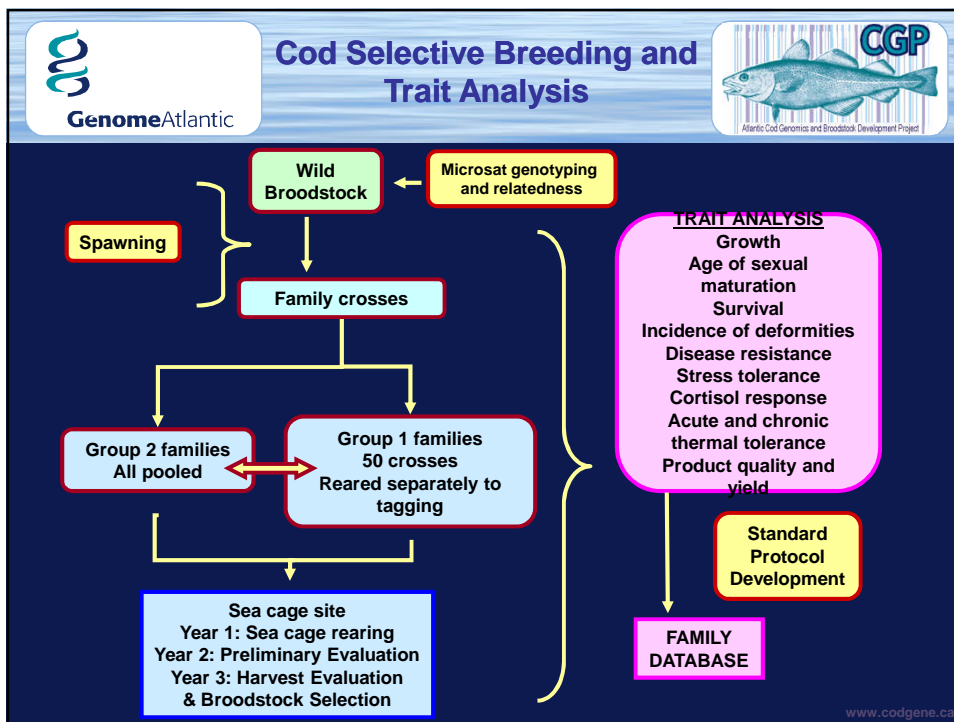
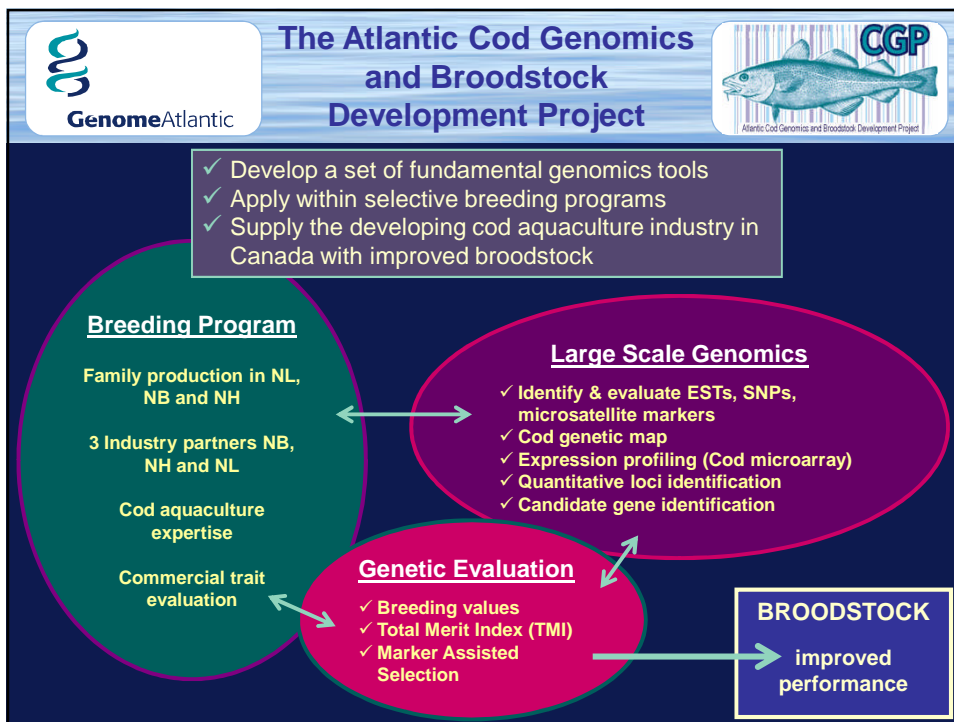
The Atlantic Cod Genomics and Broodstock Development Project




Why farm cod?

- ✓ Decline in wild cod populations resulted in fisheries closures throughout Atlantic Canada
- ✓ To supply stability to established salmon aquaculture industry (species diversification)


www.codgene.ca



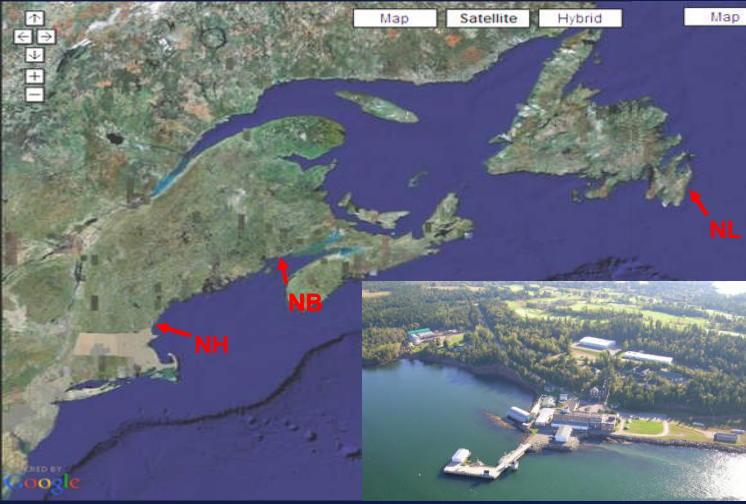


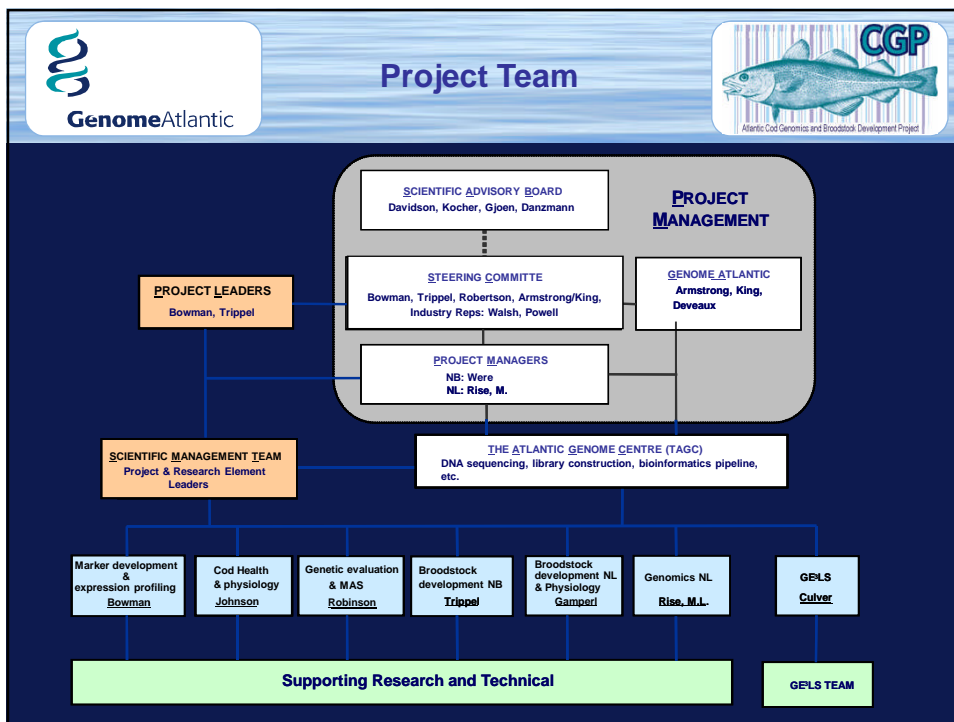
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Locations



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Generating Cod Families

- ✓ Two geographic regions (NB/NH, NL)
- ✓ Significant phenotypic and genetic variation detected in early rearing traits (e.g., high heritabilities for juvenile weight)

Acute and Chronic Thermal Tolerance

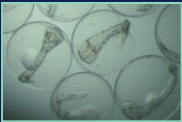



- ✓ Up to ~2°C difference, 18% variation due to family
- ✓ Expression evaluation of several immune genes

Thermal Biology of Haemoglobin Variants

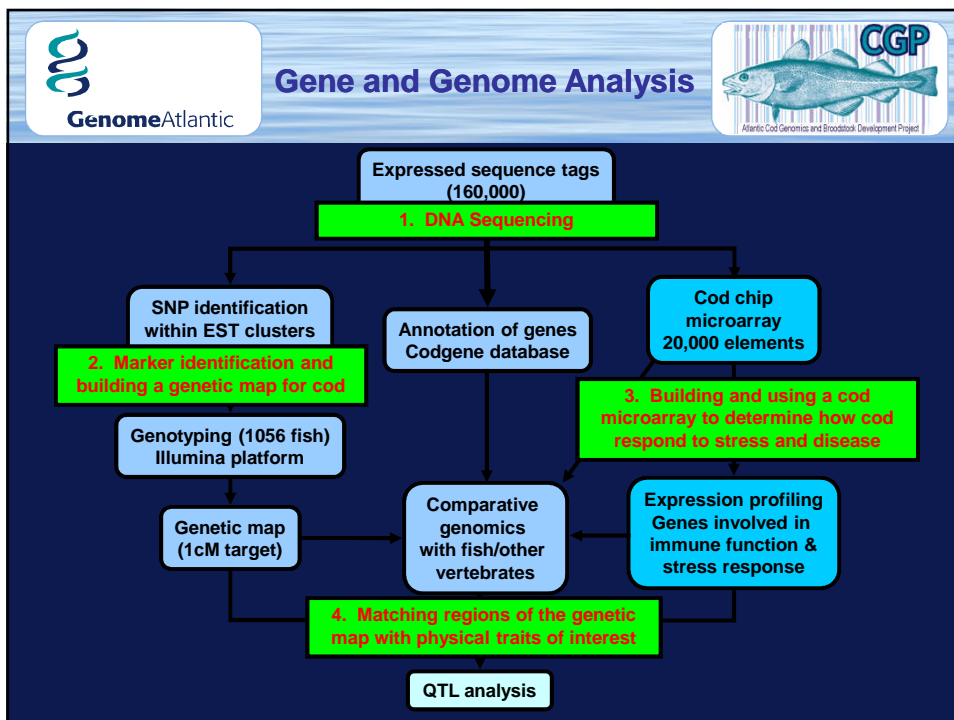
- ✓ Sea cage performance ongoing
- ✓ Hb typing not related to thermal or hypoxia tolerance or stress response (temperature challenge)



Variability in Cortisol Stress Response

- ✓ 'High' and 'low' responders
- ✓ Considerable variation between families

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cDNA Library Construction

- ✓ 21 normalized libraries, 19 SSH libraries
- ✓ 14 tissues
- ✓ 4 treatments & 4 developmental stages

DNA Sequencing

- ✓ >125,000 clones processed
- ✓ >150,000 sequences submitted to GenBank


Marker Identification

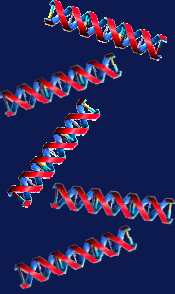
- ✓ >200 microsatellite markers tested
- ✓ >4,000 high quality/frequent SNPs

Microarray Development

- ✓ Contributing clones to Norwegian cDNA microarray
- ✓ CGP microarray construction underway

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GE³LS (Genomics Ethics Environment Economics Law Society)

- ✓ researching intellectual property protection
- ✓ status of selected broodstock under CA environmental law
- ✓ public benefit sharing and improved methods of consultation
- ✓ workshops related to these and other topics


Collaborations

- ✓ 15 national and four international agreements
- ✓ including genomics, disease resistance, reproductive biology
- ✓ >15,000 surplus cod provided for external collaborations
- ✓ >200,000 surplus cod provided to industry






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Broodstock Acquisition and Spawning





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		Female broodstock				
Male broodstock	H21		H30			
		H31		H32	H28	
			H29			
				H23		
				H24	H26	H27





- ✓ Berg and Henryon Design
- ✓ Partial Factorial
- ✓ Dams and Sires
- ✓ Full siblings
- ✓ Half siblings



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Early Rearing and Tagging of Families



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Year 1












Year 2 and Year 3

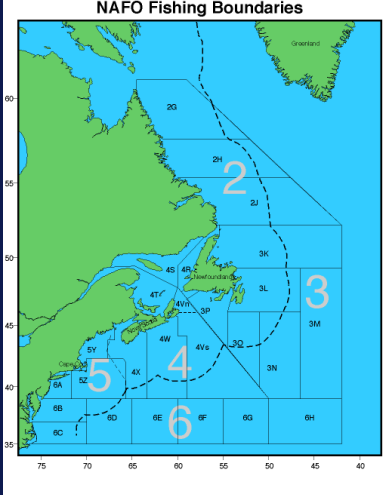
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Summary of YC1 Crosses




- 197 total crosses (2005/2006)
- 102 crosses evaluated in Group 1 or included in Group 2
 - ✓ **Group 1 NB/NH**
 - Cape Sable, 4X ($n = 39$ families)
 - New Hampshire Coast, 5Y ($n = 10$ families)
 - 15,622 progeny assessed at tagging
 - ✓ **Group 1 NL**
 - Petit Forte, 3Ps ($n = 14$ families)
 - 8,862 progeny assessed at tagging
 - ✓ **Group 2 NB/NH**
 - 54CS + 20 NH; 42 shared between Groups 1 & 2
 - Reared communally
 - $n \sim 41,532$ stocked into a single sea cage
- 24,484 progeny assessed



Source: <http://www.mar.dfo-mpo.gc.ca/>
www.codgene.ca



YC1 Preliminary Heritability Estimates




Heritabilities (standard errors) for Atlantic cod juveniles at PIT tagging

$h^2 = V_A/V_P$	NB	NH	NL
Weight (g)	0.445 (0.005)	0.541 (0.009)	0.450 (0.006)
Length (cm)	0.531 (0.004)	0.449 (0.010)	0.558 (0.004)


- ◆ $n = >20,000$ progeny included in the analysis
- ◆ 0.29 (± 0.27) and 0.52 (± 0.26) for body weight (Gjerde *et al.* 2004)
 $n = 6,112$ Atlantic cod (~ 200 dpf); two regions off Norway

Initial results demonstrate the possibility for improvement of important commercial production traits.



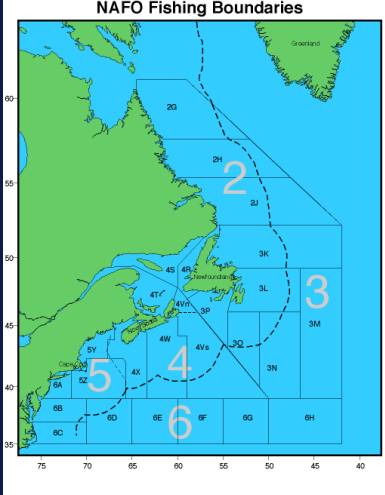
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Summary of YC2 Crosses




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- 232 total crosses (2006/2007)
- 77 crosses evaluated in Group 1
 - ✓ **Group 1 and Group 2 NB/NH (n = 155 crosses)**
 - 5Z/4X, GB/CS (n = 38 crosses)
 - 5Y, NH (n = 8 crosses)
 - 15,545 progeny assessed at tagging
 - ✓ **Group 1 NL (n = 72 crosses)**
 - 3L, Bay Bulls (n = 31)
 - 7,581 progeny assessed at tagging
- 23,126 progeny assessed




Source: <http://www.mar.dfo-mpo.gc.ca/>
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Analysis of Tagging Data



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	YC	Hatchery	Stock	nFish	nFam	nSires	nDams	nGroups
YC1	1	OSC	NL	8862	22	12	8	4
	1	SABS	NB	12355	39	25	22	8
	1	SABS	NH	3295	10	6	6	2
YC2	2	OSC	NL	7580	31	21	24	14
	2	SABS	NB	12770	38	22	23	8
	2	SABS	NH	2775	8	4	6	3
				47637	148	90	89	39

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Broodstock Acquisition and Spawning



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Year 1

↓

YC1

- ✓ PIT Tagged cod transported from the hatchery to three sea cages
 - ✓ 9998 tagged NBNH progeny into 2 sea cages in NB
 - ✓ 3062 tagged NL progeny into 1 sea cage in NL

↓

Year 2 and Year 3

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Year 2 Sea Cage Assessment



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**Fall/Winter 2007
Sea Cage and Laboratory Components**









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Year 2 Sea Cage Assessment




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$n = 7909, 1571$


- ✓ Body Weight
- ✓ Length
- ✓ Condition Factor
- ✓ Deformities

$n = 1259, 579$

- ✓ Carcass Weight (Carcass Index – CSI)
- ✓ Liver Weight (HSI)
- ✓ Gonad Weight (GSI)
- ✓ Gender (F/M)
- ✓ Maturation (five levels)




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Trait/Family Summary Statistics





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Traits	P-values	Mean Min-Max NL ($n = 14$)	Mean Min-Max NBNH ($n = 49$)
Wt	<0.0001	194-482 g	417-886 g
Lgt	<0.0001	25.0-33.1	30.2-37.8
CF	<0.0001	1.09-1.39	1.39-1.80
Carcass	<0.0001	208-393	722-311
Liver	<0.0001	21.3-52.9	113.2-29.9
Gonad	<0.0001	1.9-10.0	4.3-29.7
Maturity	<0.0001	2.3-3.4	2.0-3.7

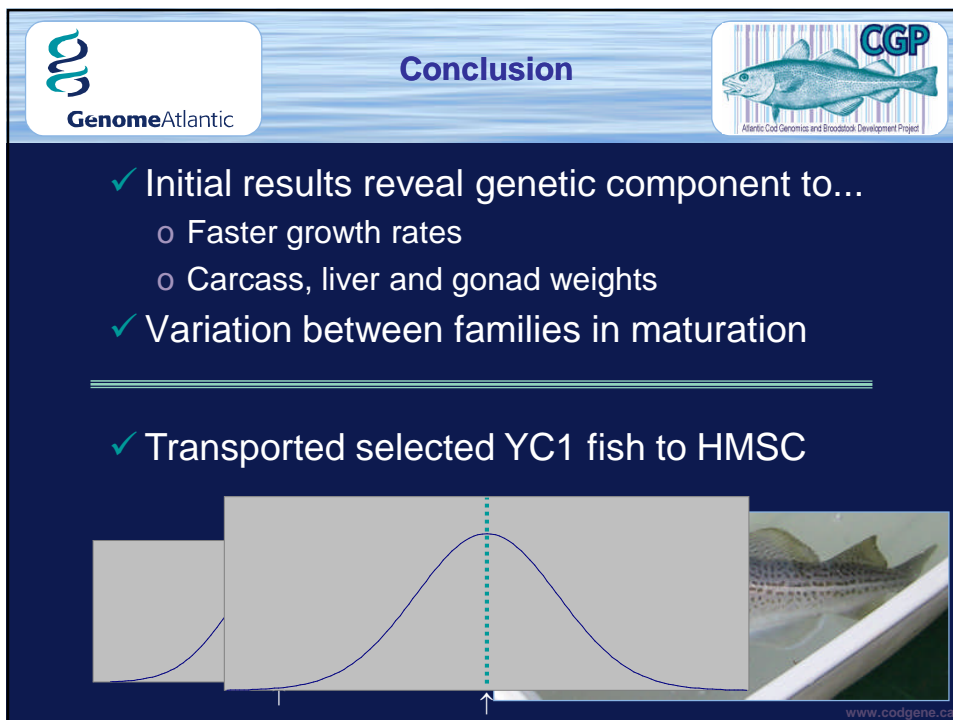
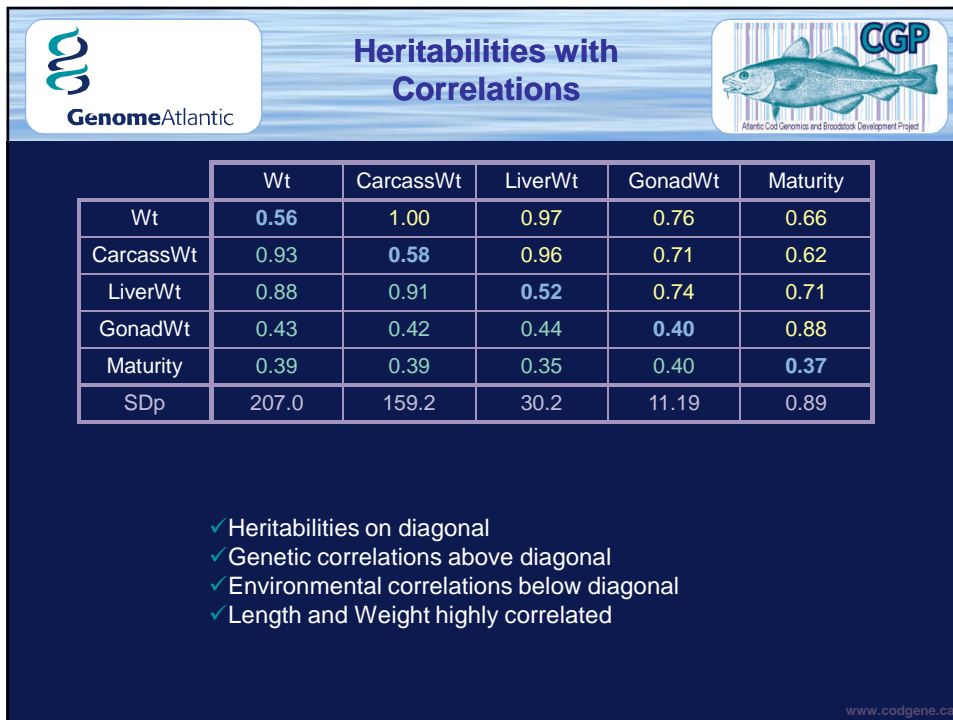
✓ Highly significant between family variation for all traits measured


	NL	NBNH
CSI	79.3-84.3	79.0-84.8
HSI	7.6-11.5	8.8-15.7
GSI	0.6-2.5	1.0-4.8

age not accounted for between geographic locations or sites within NB locations


→



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Identification of Elite Broodstock



- Physical traits are ranked based on economic or other criteria.
- Individuals are assigned a merit score based on their ranking.
- If genetic markers can be associated with important traits they can be used to identify individuals carrying that trait – particular benefit for traits that cannot be measured in live fish.

Genetic Information
QTL markers


Phenotypic information
Economic value of traits

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Index of total genetic merit
(TMI)


↓

Selection of elite broodstock

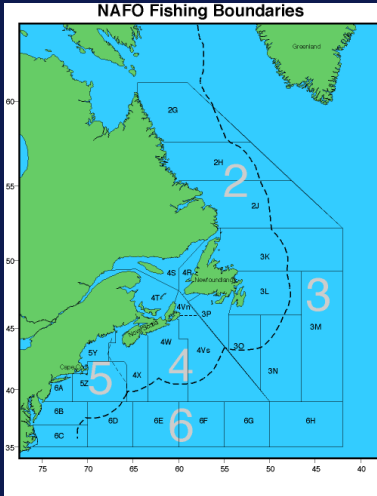


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Summary of YC3 Crosses



- 418 total crosses (2007/2008)
- 181 crosses evaluated in Group 1 or included in Group 2
 - ✓ **Group 1 and Group 2 NB/NH (n = 137 crosses)**
 - 50 families Group 1, 105 families Group 2 → F₁, F_{1.5}, F₂ progeny
 - 5Z, Georges Bank (2006 and 2007 wild caught; YC2 parents 2006 wild caught)
 - 4X, Cape Sable (2006 wild caught; YC2 parents 2006 wild caught)
 - 4X, F1/YC0, Bay of Fundy
 - 5Y, F1 2003 Broodstock Year
 - 5Y, F1 2004 Broodstock Year
 - 5Y, F1 2005 Broodstock Year
 - 5Y, NH 2008 wild caught (milt Group 2 only)
 - ✓ **Group 1 NL (n = 79 crosses)**
 - 3L, Smith Sound & YC2 parents from Bay Bulls (n = 44)



Source: <http://www.mar.dfo-mpo.gc.ca/>
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IN PROGRESS



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Atlantic Cod Genomics and Broodstock Development

Sharen Bowman, Genome Atlantic
Ed Trippel, St. Andrews Biological Station

Genome Canada Competition III


Total funding awarded including co-funding is \$18,186,076 for the period January 1, 2006 to December 31, 2009.

Project Summary

For many years, traditional fisheries in Atlantic Canada were major contributors to the cultural identity and economies of the region. Declining fish stocks brought many challenges to this industry and to the local communities dependent on the revenue it generated. The subsequent growth of the salmon aquaculture industry helped revitalize this region and now provides considerable benefits to the local economy. For example salmon farming in New Brunswick generated annual sales of over \$200 million in 2002 and generated one in four direct jobs in Charlotte County (New Brunswick, Agriculture, Fisheries and Aquaculture, 2002).





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- [Management Structure](#)
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The Atlantic Cod Genomics and Broodstock Development Project








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