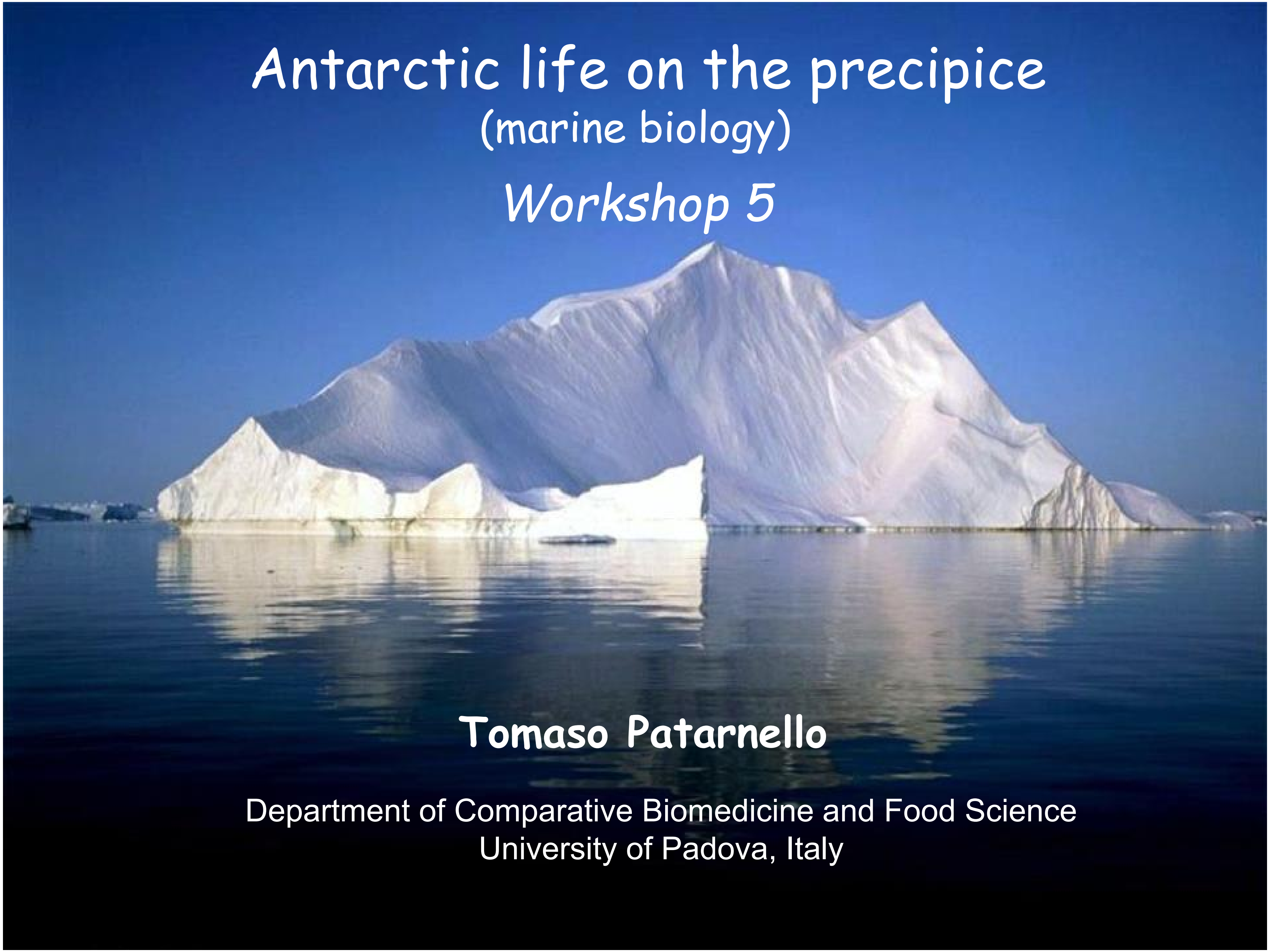
Antarctic life on the precipice
(marine biology)
Workshop 5



Tomaso Patarnello

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University of Padova, Italy

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50. What are the synergistic effects of multiple stressors and environmental change drivers on Antarctic and Southern Ocean biota?

51. How will organism and ecosystems respond to a changing soundscape in the Southern Ocean?' (*Cross-cuts 'Human'*)

52. How will next-generation contaminants affect Antarctic and Southern Ocean biota and ecosystems?

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s and range shifts of indigenous species change

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existing and future Southern Ocean

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59. How will linkages between marine and terrestrial systems change in the

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63. How can changes in the form and frequency of extreme events be used to improve biological understanding and forecasting? (*Cross-cuts 'Antarctic atmosphere'*)

64. How can temporal and spatial 'omic-level' analyses of Antarctic and Southern Ocean biodiversity inform ecological forecasting?

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66. How successful will Southern Ocean Marine Protected Areas be in meeting their protection objectives, and how will they affect ecosystem processes and resource extraction? (*Cross-cuts 'Human'*)

67. What *ex situ* conservation measures, such as genetic repositories, are required for the Antarctic and Southern Ocean? (*Cross-cuts 'Human'*)

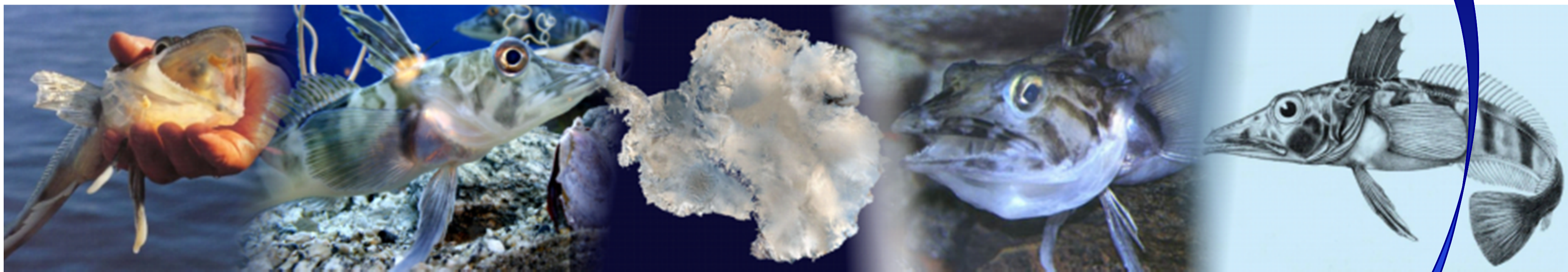
68. How effective are Antarctic and Southern Ocean conservation measures for preserving evolutionary potential? (*Cross-cuts 'Human'*)

Genomic basis of icefish adaptation to cold

- ✓ no hemoglobin
- ✓ no myoglobin expression in skeletal muscle

- ✓ remodeling of the cardio-vascular system
- ✓ high mitochondrial density

O_2



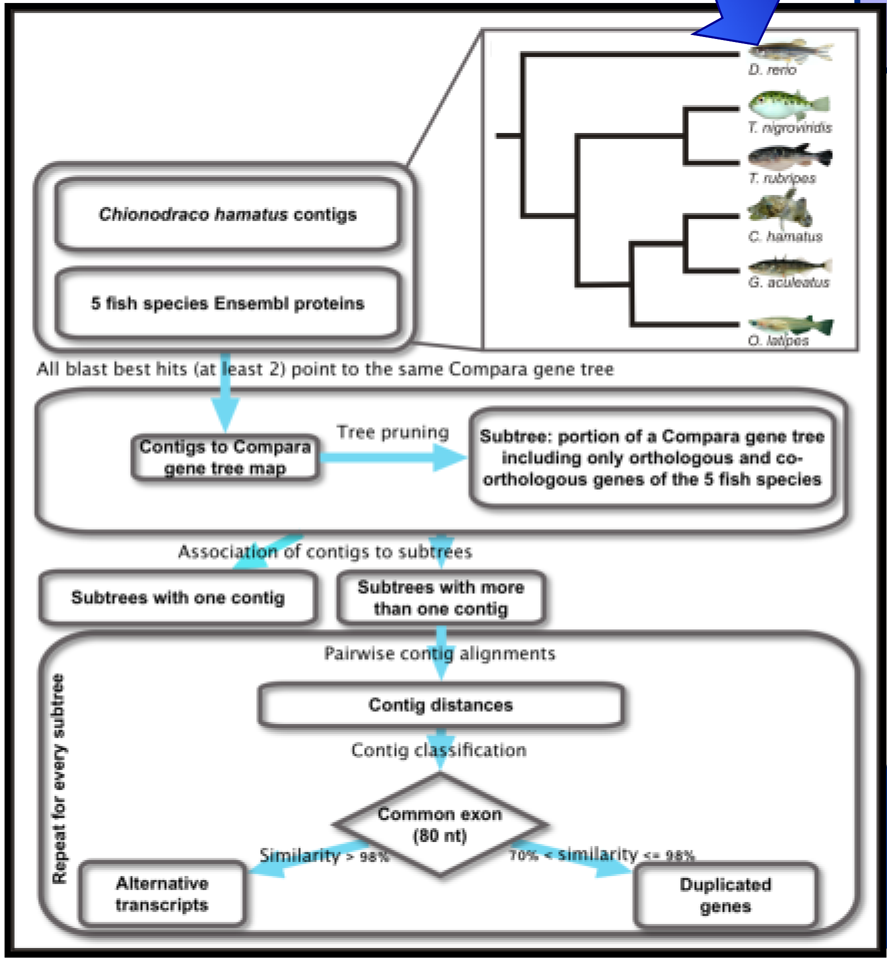
Increased request for structural and functional components of mitochondria ?

- **Kock** KH (2005a) Antarctic icefishes (Channichthyidae): a unique family of fishes: A review, Part I. *Pol Biol*, 28: 862-895.
- **O'Brien** KM, Mueller IA (2010) The unique mitochondrial form and function of Antarctic channichthyid icefishes. *Integr Comp Biol*, 50: 993-1008.
- **Ruud** JT (1954) Vertebrates without erythrocytes and blood pigment. *Nature*, 173: 848-850.
- **Sidell** BD *et al.* (1997) Variable expression of myoglobin among the hemoglobinless Antarctic icefishes. *PNAS*, 94: 3420-3424.

Genomic basis of icefish adaptation to cold

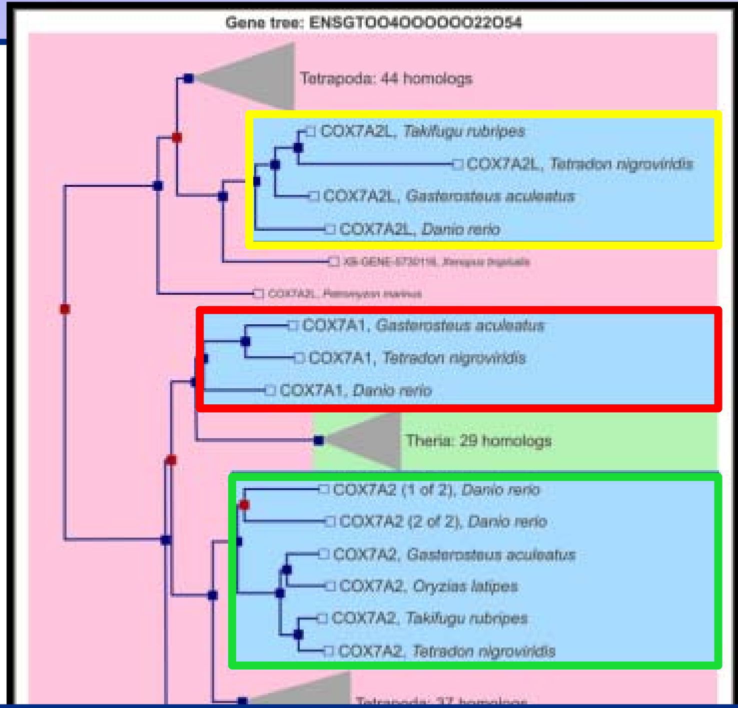
TRANSCRIPTOME

- ✓ Normalized, skeletal muscle
- ✓ ~340,000 good-quality 454-reads
- ✓ ~24,000 contigs (48% annotated)



BIOINFORMATIC PIPELINE

Transcripts were univocally assigned to groups of orthologous genes of **5 model fish** with sequenced genome

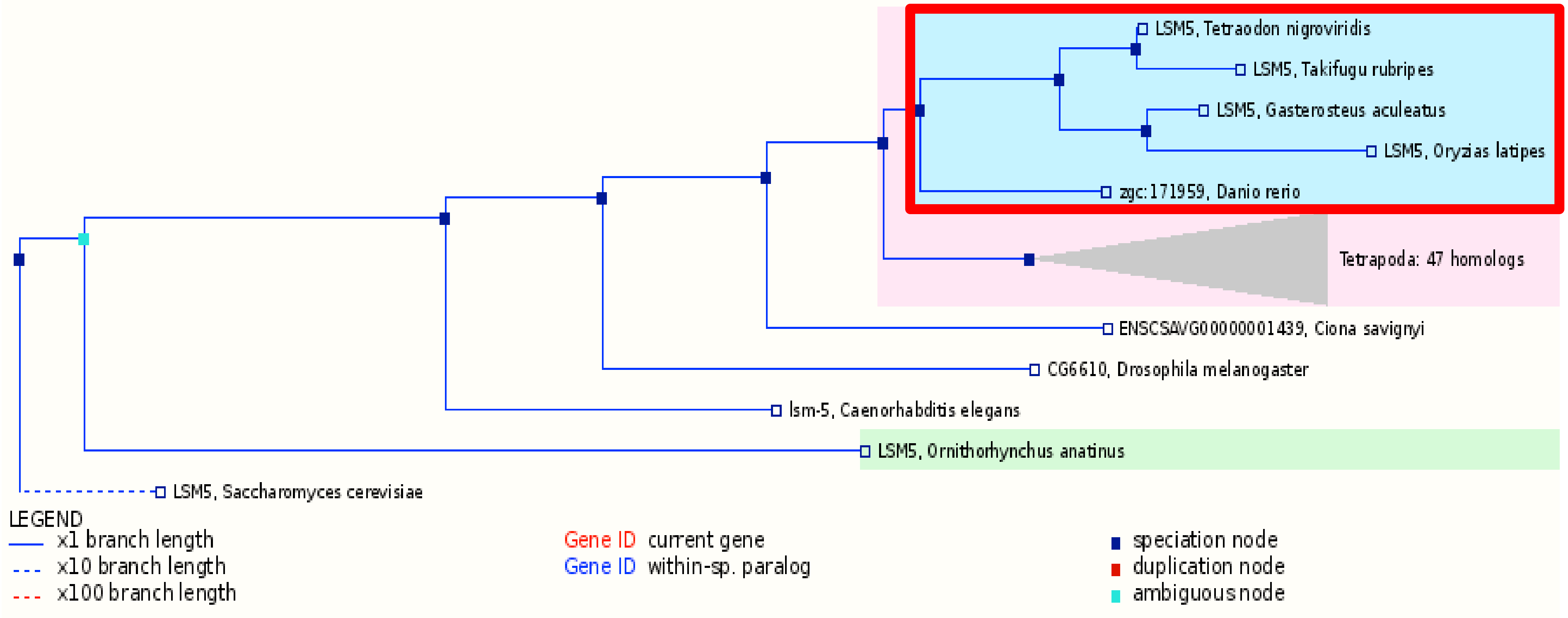


- ✓ the number of *C. hamatus* genes pointing to each orthologous group was recorded

Genomic basis of icefish adaptation to cold

Ch - 4 transcripts

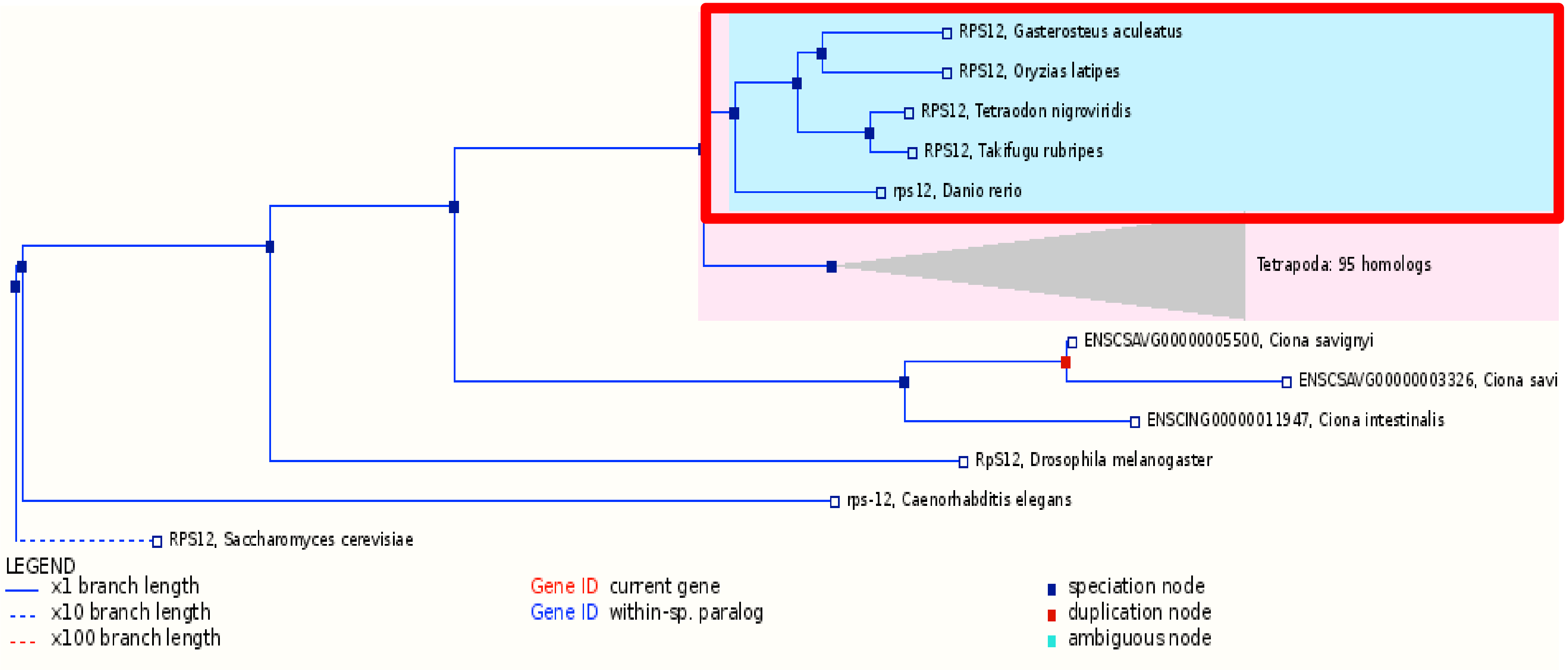
Tree	Ch	Dr	Ga	Ol	Tr	Tn
ENSGT00390000001455	**4**	1	1	1	1	1
LSM5 homolog, U6 small nuclear RNA associated						



Genomic basis of icefish adaptation to cold

Ch - 5 transcripts

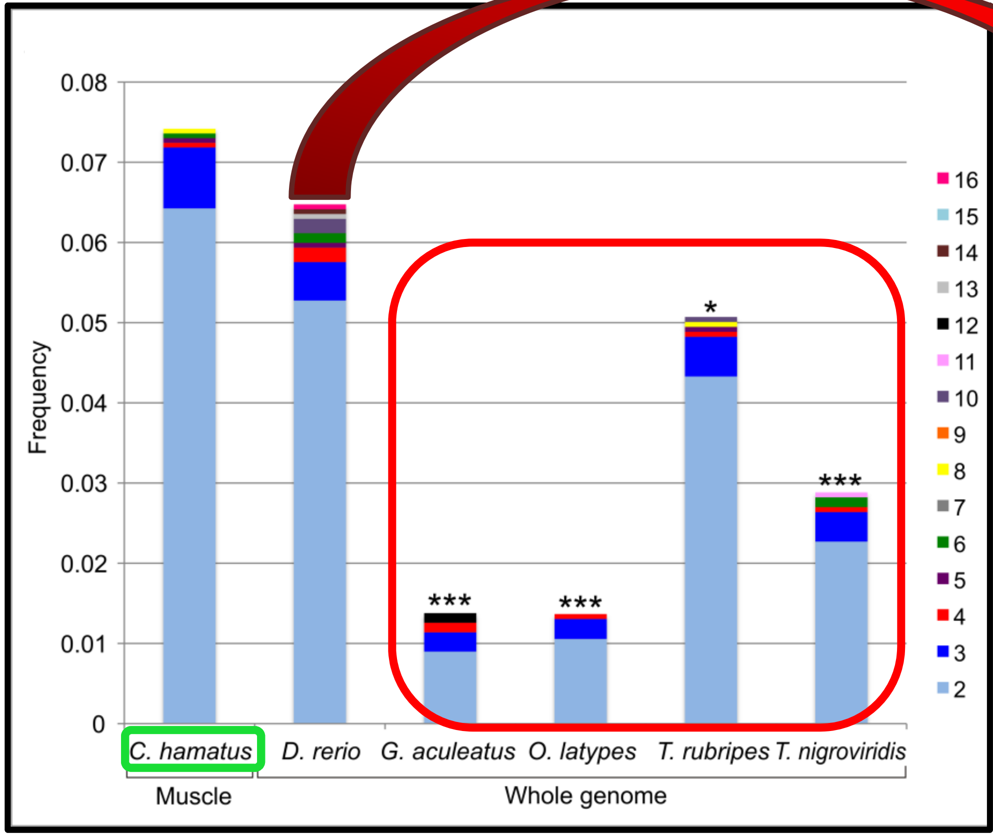
Tree	Ch	Dr	Ga	Ol	Tr	Tn
ENSGT00390000018318	**5**	1	1	1	1	1

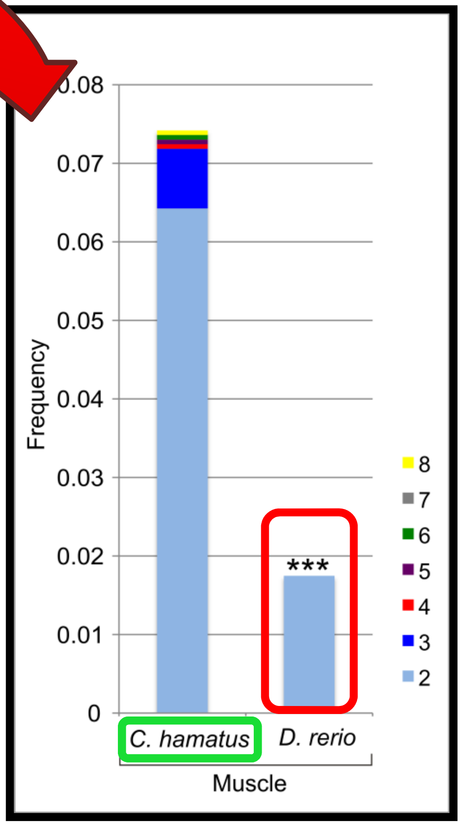


Genomic basis of icefish adaptation to cold

- ✓ 124 orthology groups with *C. hamatus* lineage-specific duplications
- ✓ 2 to 8 gene copies in each group (mean 2.3)

Statistical comparison of the proportion of lineage-specific duplicates found in *C. hamatus* and in each of the 5 model species





Test of equal proportions: ***p<0.001, **p<0.01, *p<0.05, after Bonferroni correction.

Genomic basis of icefish adaptation to cold

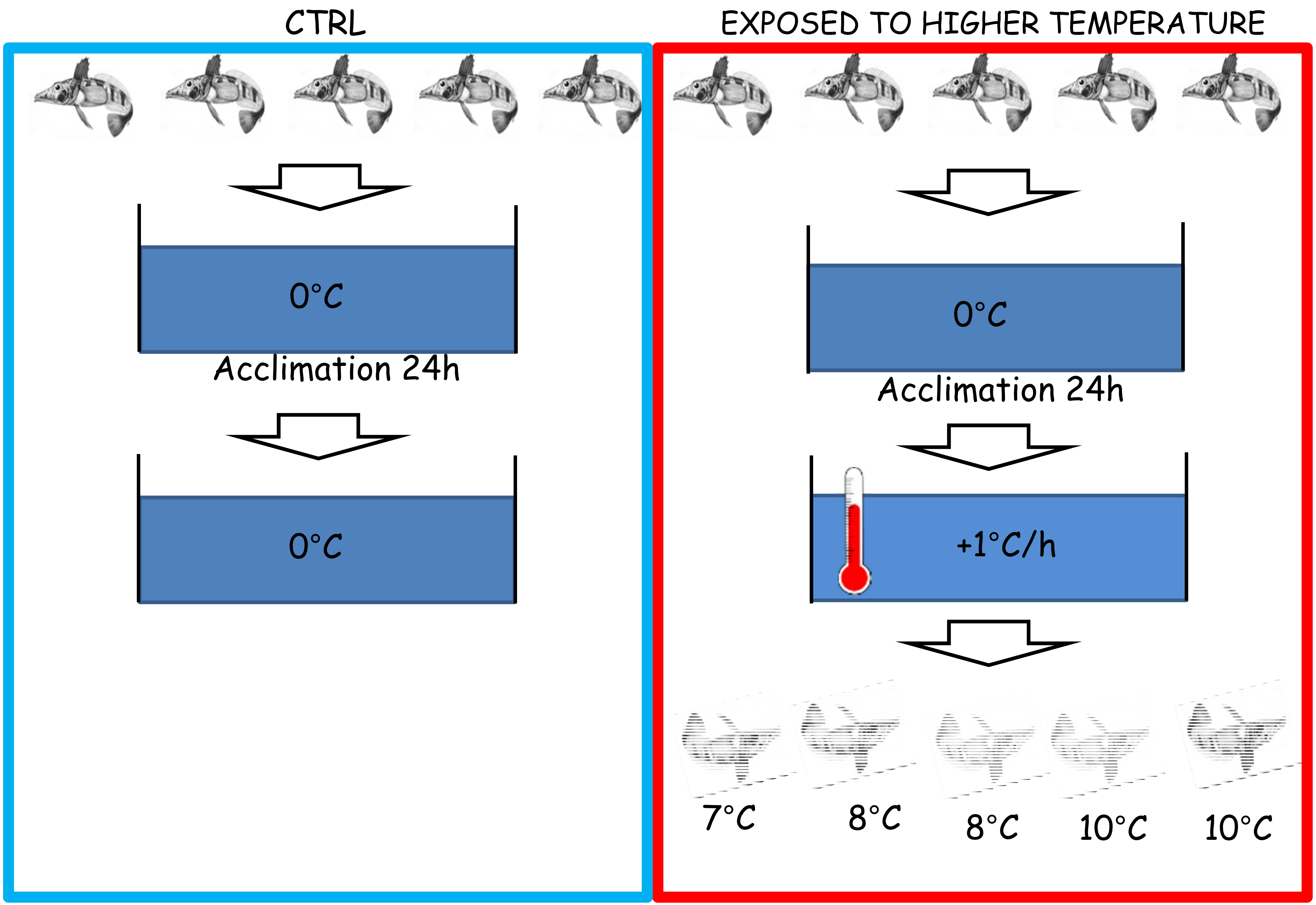
Functional enrichment of duplicated genes

- ✓ Enriched functional terms are related to:
  - protein translation
  - oxidative phosphorylation
  - organelle organization and biogenesis
- ✓ at least 34 out of 124 duplicated genes encode proteins with mitochondrial localization

Significant enrichment for mitochondrial proteins (p=0.0235)

- ✓ Confirm the **trend of genomic expansion** accompanying the evolutionary history of Antarctic notothenioids
- ✓ Suggest that the maintenance of duplicates in the icefish genome may be associated, at least in part, to a **selective pressure for increased mitochondrial density/function**

icefish transcriptomics and heat shock response



icefish transcriptomics and heat shock response

Gene expression analyses

control vs. exposed

⇩

102 transcripts down-regulates (in the exposed group)

107 transcripts up-regulates (in the exposed group)

Down-regulation
of several transcripts involved in **inflammatory and immune response**
(e.g. interleukin-6 receptor subunit alpha, c-type lectin domain family 4, chemokine 4, chemokine 13)

Up-regulation
of several transcripts involved in **Glycolysis / Gluconeogenesis.**

Potential impact of **mitochondrial and thermal stress on the bioenergetics and reserve respiratory capacity**.

in progress…

Whole genome sequencing of *Chionodraco hamatus* (*illumina + PacBio technology*)

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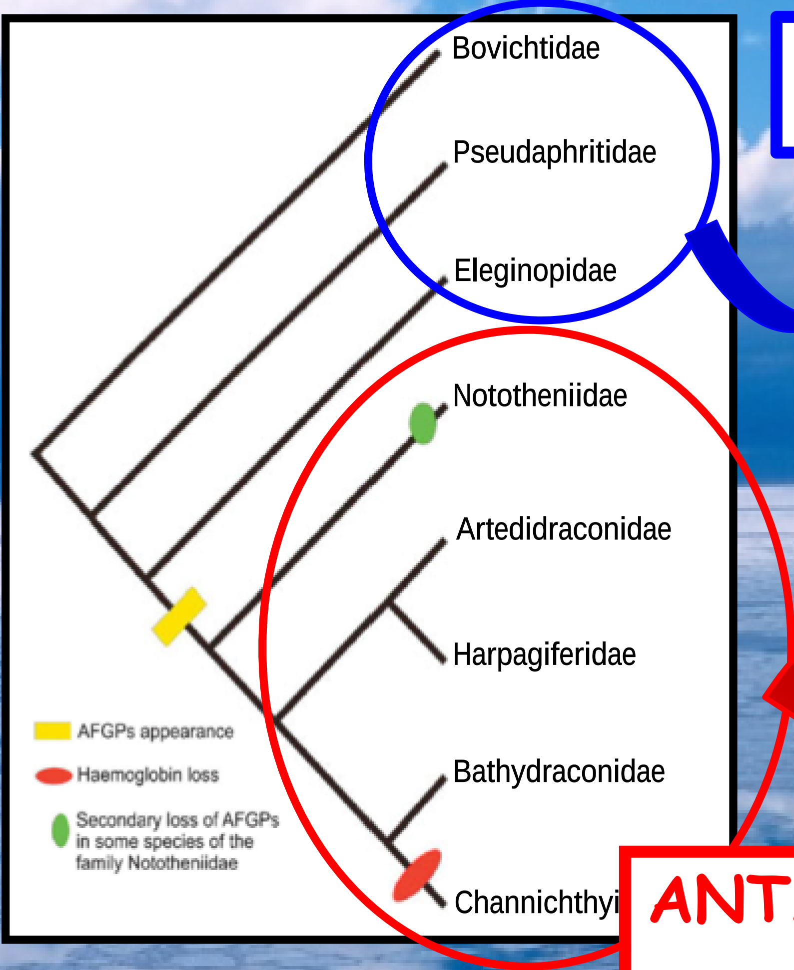
Suborder Notothenioidei (Perciformes)



Subantarctic (13 sp.)

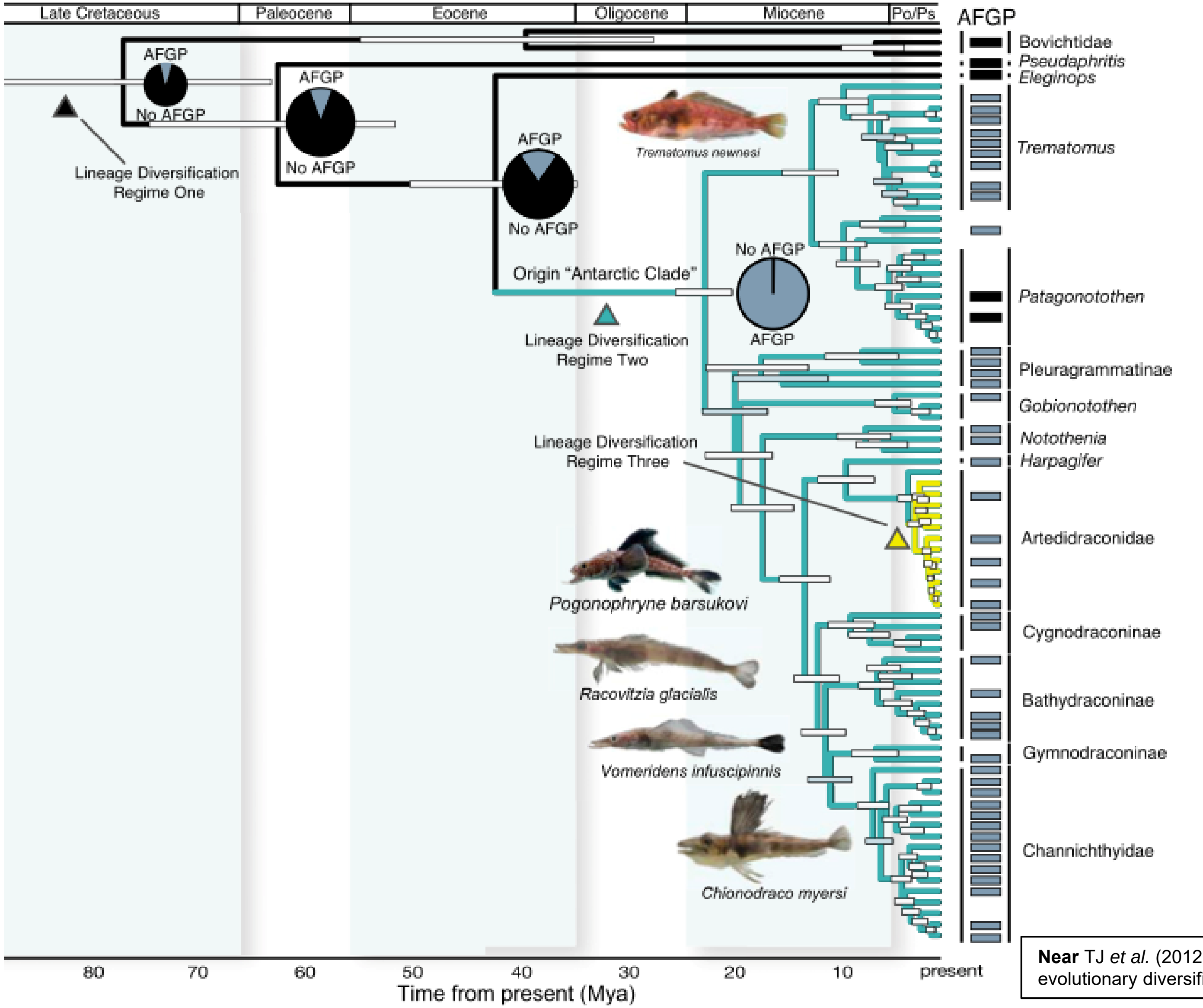
ANTARCTIC CLADE (121 sp.)

46% species diversity
91% biomass

- **Eastman** JT (2005) The nature of the diversity of Antarctic fishes. *Polar Biol,* 28: 93-107.
- **Lecointre** G (2012) Phylogeny and systematics of Antarctic teleosts: methodological and evolutionary issues. In: *Adaptation and Evolution in Marine Environments - The Impacts of Global Change on Biodiversity*, Vol 1 (eds di Prisco G, Verde C), pp 97-117. Springer, Berlin.
- **Patarnello** T *et al.* (2011) How will fish that evolved at constant sub-zero temperatures cope with global warming? Notothenioids as a case study. *Bioessays*, 33: 260-268.

Evolutionary history and adaptive radiation

Evolutionary history and dominance is linked to tectonic and paleo-climatic events



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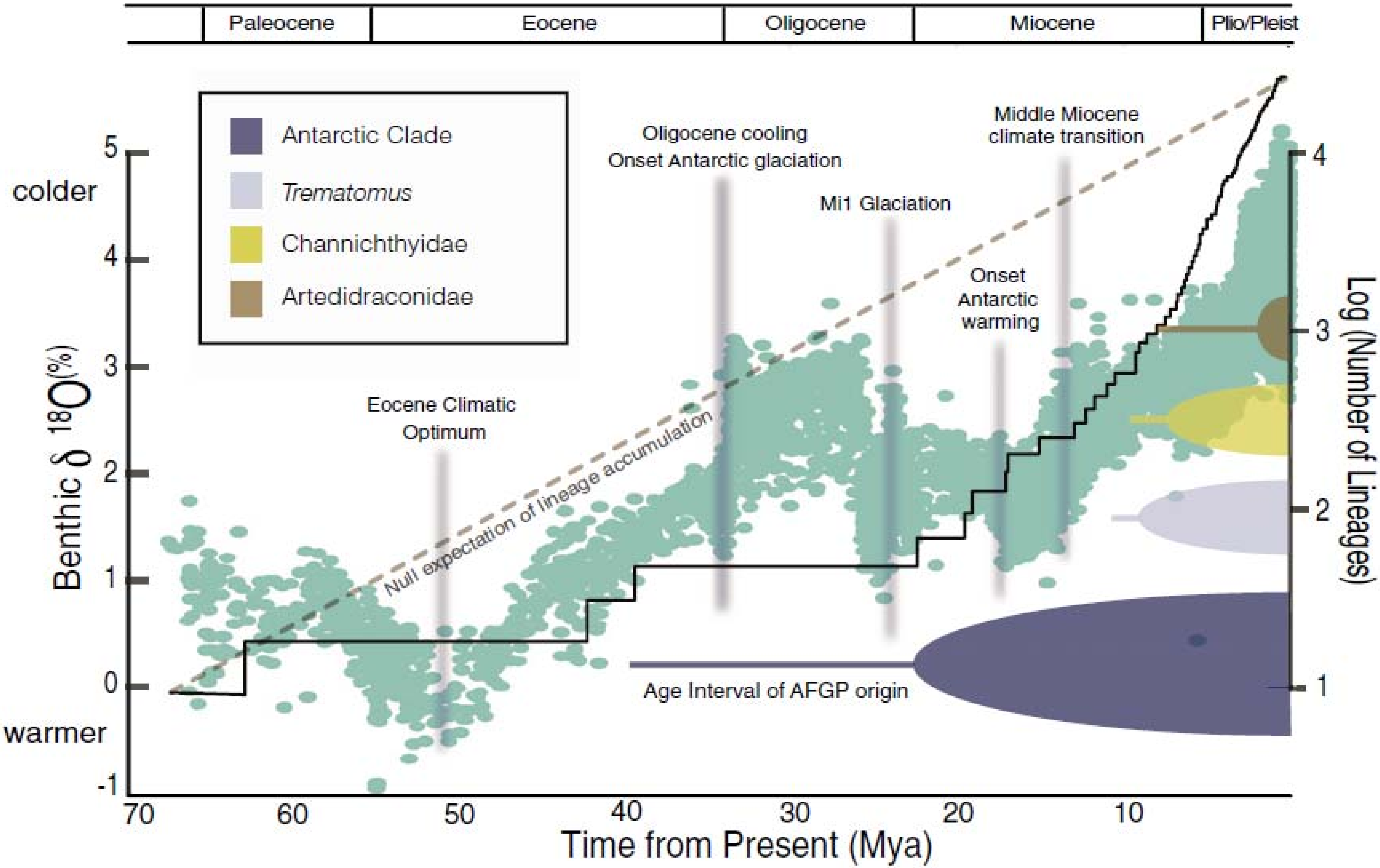
Evolutionary history and adaptive radiation



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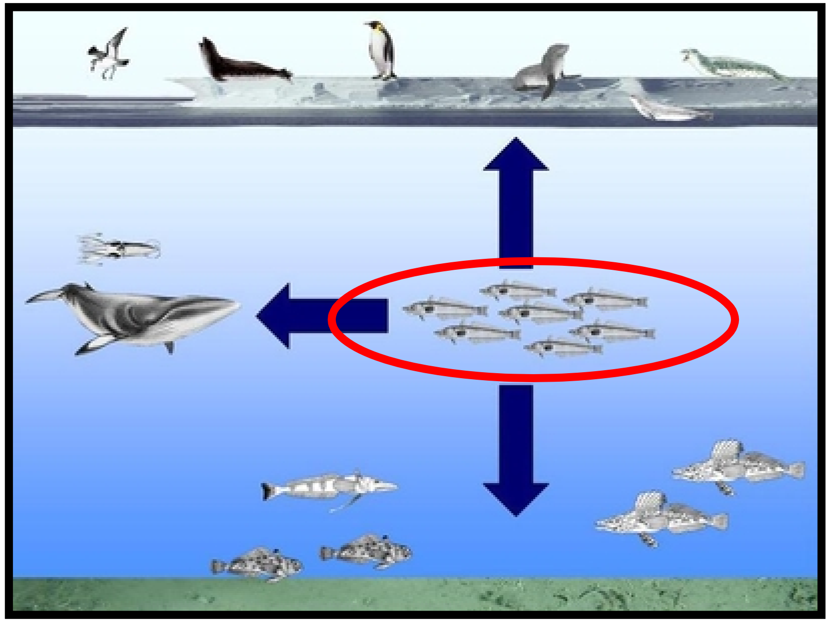
Population genetics: *Pleuragramma antarctica*



Pleuragramma antarctica
(Antarctic silverfish)

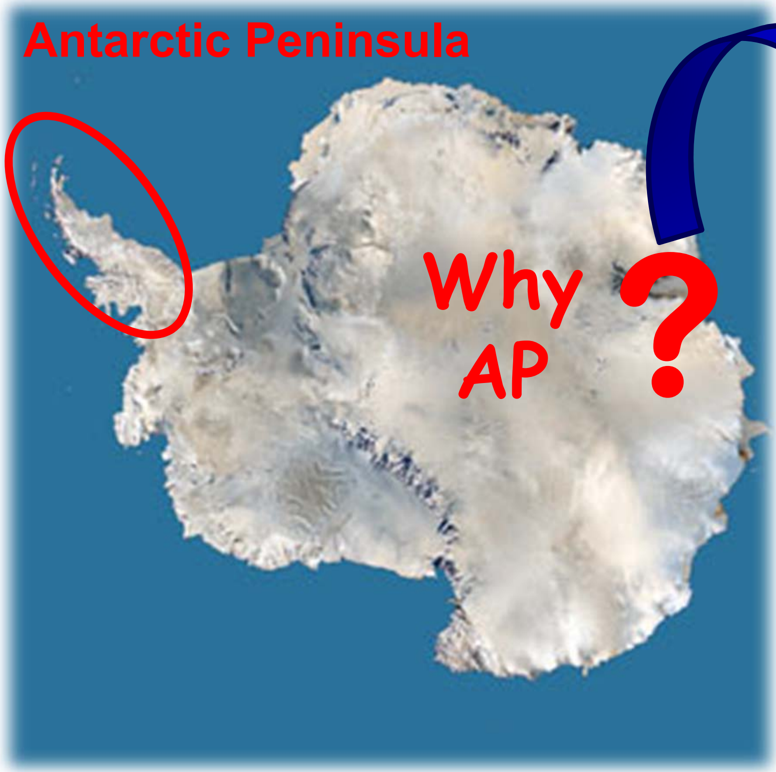
- circum-Antarctic distribution
- complete pelagic life-cycle
- dominant pelagic fish in many shelf areas (> 90% number, biomass)
- key role in the marine food web

- **La Mesa** M, Eastman JT (2011) Antarctic silverfish: life strategies of a key species in the high-Antarctic ecosystem. *Fish Fish*, 13: 241-266.
- **Vacchi** M *et al.* (2004) Early life stages in the life cycle of Antarctic silverfish, *Pleuragramma antarcticum* in Terra Nova Bay, Ross Sea. *Antarct Sci*, 16: 299-305.
- **Vacchi** M *et al.* (2012) A nursery area for the Antarctic silverfish *Pleuragramma antarcticum* at Terra Nova Bay (Ross Sea): first estimate of distribution and abundance of eggs and larvae under the seasonal sea-ice. *Polar Biol*, 35: 1573-1585.

P. antarctica: genetic variability and population structure

P. antarcticum population structure along the **Antarctic Peninsula** (AP)

- ✓ microsatellite markers
- ✓ otolith chemistry



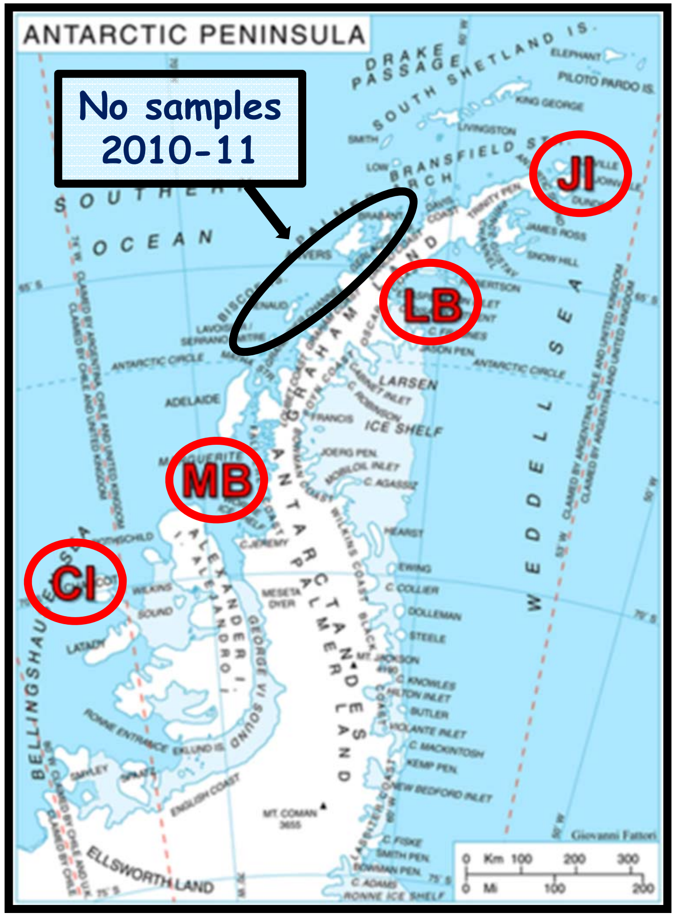
- ➢ Sea surface temperatures ↑ by **3°C** within the last 50 y
- ➢ Sea-ice melting
- ➢ Adélie penguins are ↓ at almost all locations on the AP
- ➢ *P. antarcticum* has almost disappeared from their diet

- ➢ **Ferguson** J, *et al.* (2011) Connectivity and population structure in *Pleuragramma antarcticum*. WG-FSA-11/19, CCAMLR.
- ➢ **Turner** J, *et al.* (2005) Antarctic climate change during the last 50 years. *Int J Climatol*, 25: 279-294.
- ➢ **Zazulie** N, *et al.* (2010) Changes in Climate at High Southern Latitudes: A Unique Daily Record at Orcadas Spanning 1903-2008. *J Clim*, 23: 189-196.

P. antarctica: genetic variability and population structure

9 population samples
(562 individuals)

Site	Year	Campaign	N
Charcot Island	2010	NBP 10-02 [a]	60
Marguerite Bay	2001	SO GLOBEC-Cruise 1 [c]	28
	2002	SO GLOBEC-Cruise 3 [c]	49
	2010	NBP 10-02 [a]	60
	2011	LMG Cruise 11-01, Palmer LTER [d]	83
Joinville Island	2007	ANTXXIII/8AWI [e]	34
	2010	NBP 10-02 [a]	148
	2012	ANT-XXVIII/4 AWI [e]	54
Larsen Bay	2007	ANTXXIII/8AWI [e]	46



P. antarctica: genetic variability and population structure

Genetic variability

- no difference (N_a, A_r, H_{obs}, H_{nb}) across samples (one-way ANOVA, $p > 0.05$)

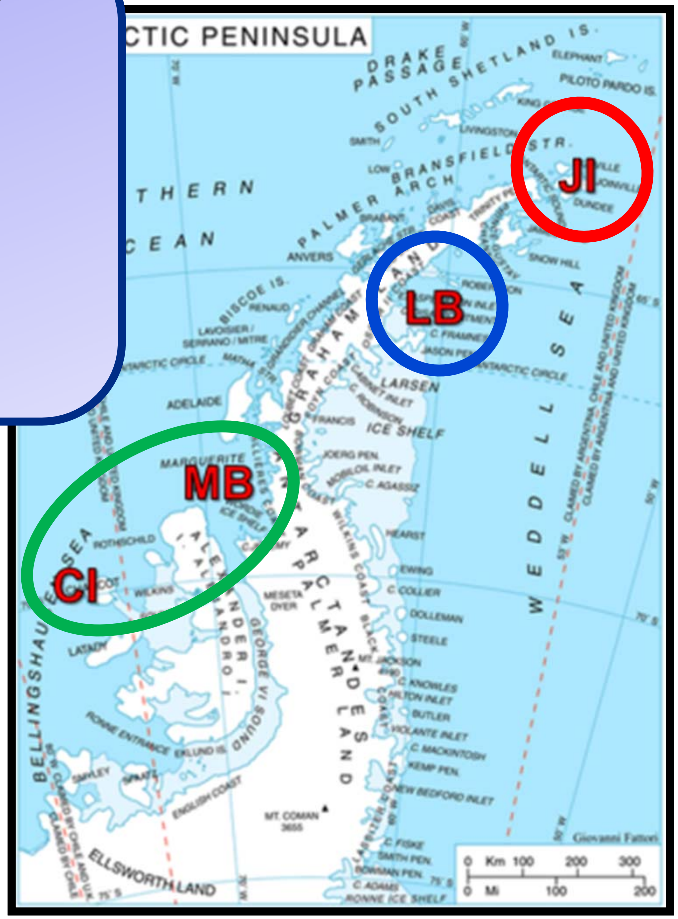
Population structure

F_{st} Index

- CI, MB -> no difference both on a temporal (01-02-10-11) and on a geographic scale
- JI -> no difference on a temporal scale (07-10-12)

  -> Fst values JI vs CI-MB tend to ↑ with time:
- LB07 -> differentiated from CI-MB

  (also from JI12 but not after Bonferroni correction, $\alpha_{corrected}$=0.005)

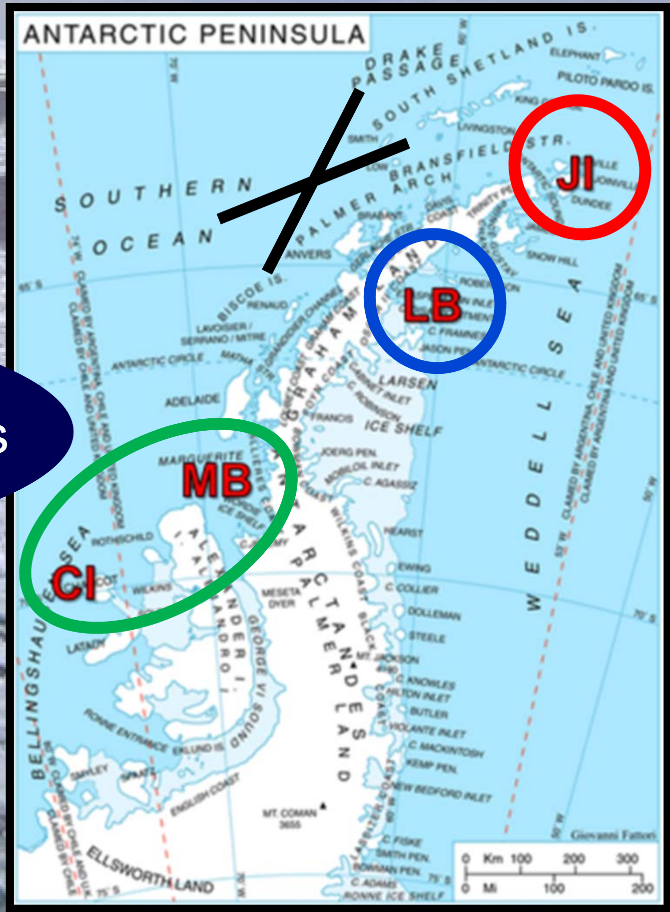


P. antarctica: **genetic variability and population structure**

in summary…

- apparent **disappearance** from the central western AP
- **population fragmentation** may **increase** with time
- similar level of genetic variation
  ➔ differentiation is **recent**

P. antarcticum has been affected by climate change with possible cascading effects on the Antarctic marine food web



Conclusions

The evolution of Antarctic fish genome was strongly driven by the sub-zero water temperature established in the Southern Ocean over million years.

The complex set of adaptations are often accompained by 'irreversible' genomic losses or gene amplifications

On the micro-evolutionary scale, the observed habitat fragmentation strongly reduces population connectivity and consequently genetic variation

Conclusions

These features, taken together with the unprecedented speed of rising temperatures, suggest that Antarctic fish might have little genetic potential to cope with global warming