

An ecophysiological approach to understand potential impacts of hypoxia on fisheries in the estuary and Gulf of St. Lawrence

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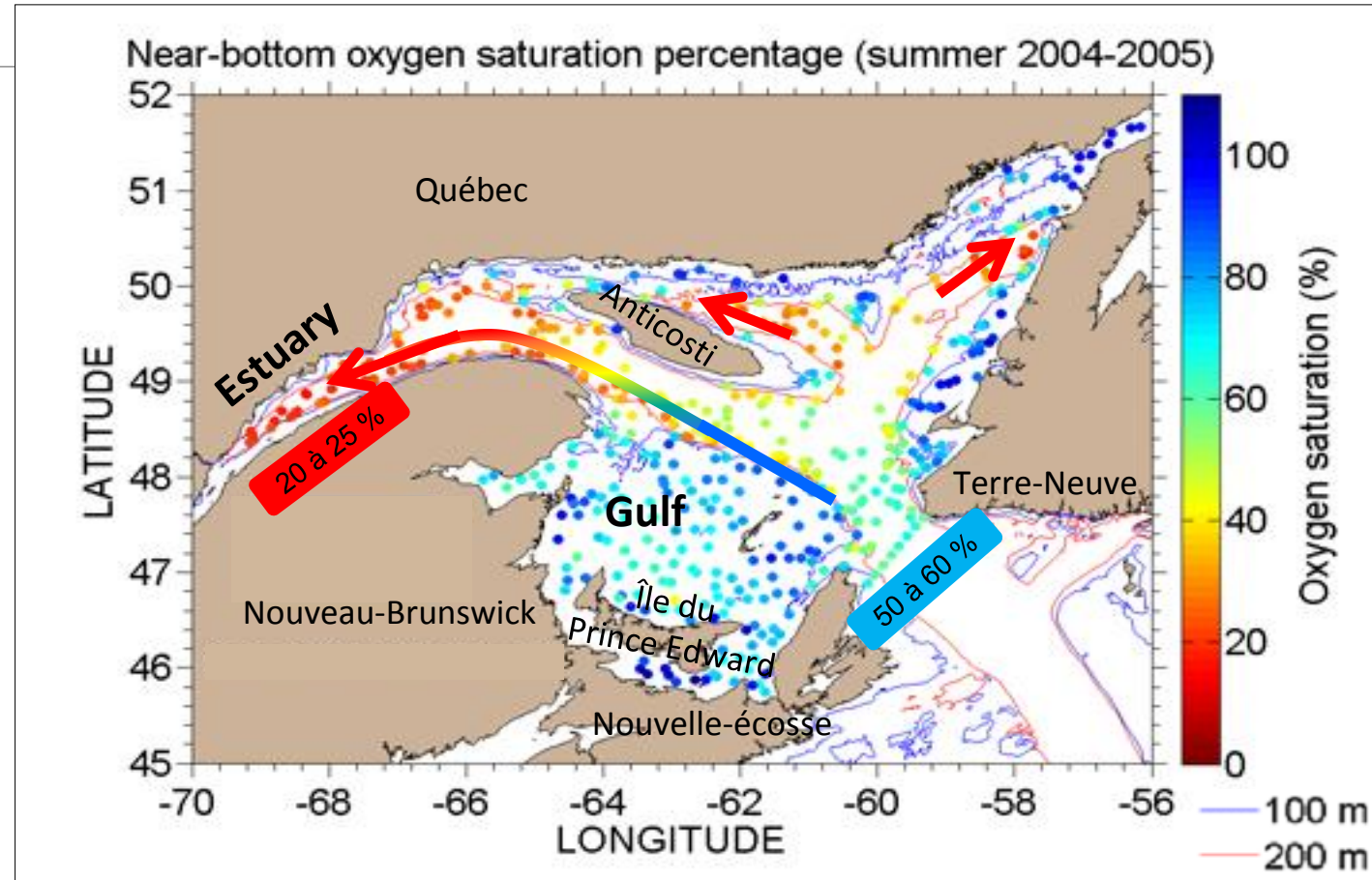
Background

Deep waters of the estuary and Gulf of St. Lawrence (EGSL) are **warm** and **hypoxic year-round**, and have been getting warmer and more hypoxic since 2012.



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From 1930 to 1980 : •↓ 50% O₂ saturation in the estuary

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We examined the effects of hypoxia on two species supporting important **fisheries** in the **EGSL**

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Greenland halibut



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200 – 300 meters

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Northern shrimp

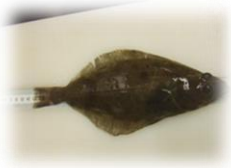


Water depth

200 – 300 meters

150 – 300 meters

Distribution in the EGSL



We used DFO data to evaluate the distribution in periods of low and high abundances.

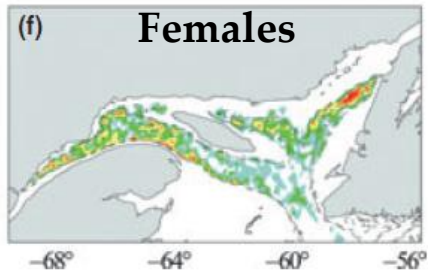
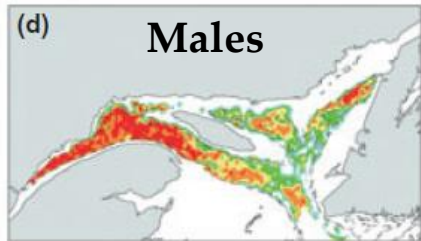
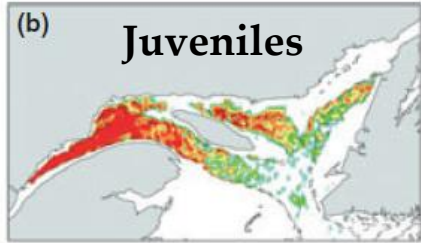
Summer multidisciplinary bottom-trawl surveys conducted annually from 1990 to 2010 by Fisheries and Oceans, Canada (DFO) and yearly sentinel fishery surveys conducted in collaboration with the industry from 1995 to 2010.

Distribution in the EGSL



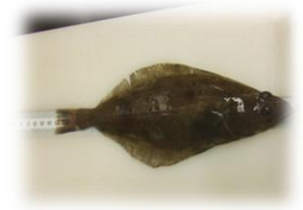
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High juvenile Greenland halibut densities were found even in severely hypoxic habitats



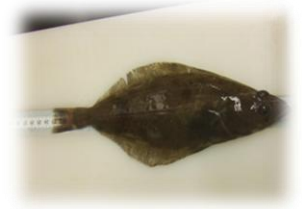
Distribution in periods of high abundance

Distribution in the EGSL



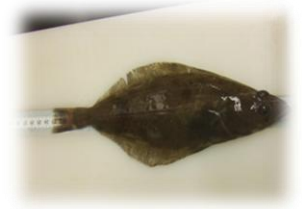
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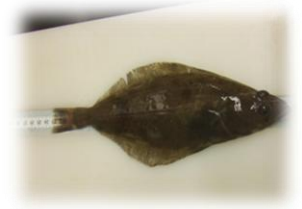
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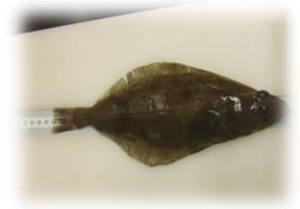
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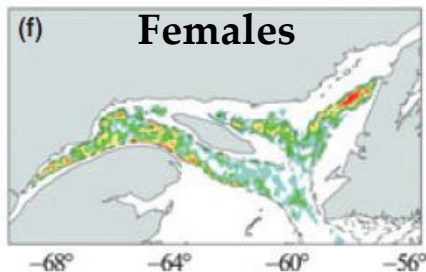
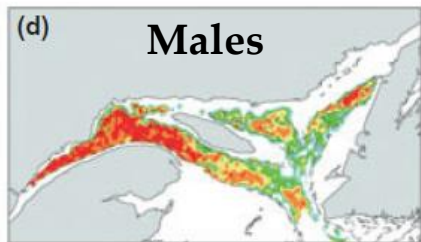
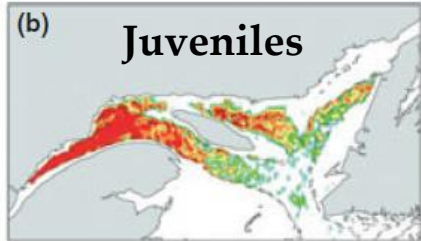
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- Possible negative effects associated with these hypoxic areas may be counterbalanced by possible advantages associated with higher food availability and/or refuge from predators.

Distribution in the EGSL



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Distribution at high densities



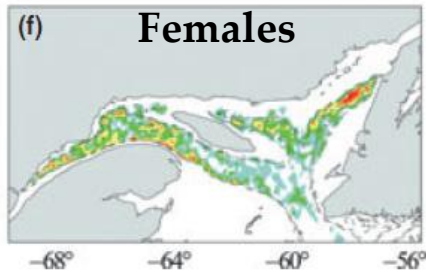
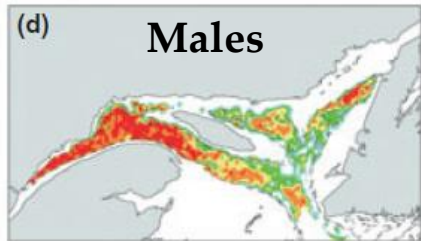
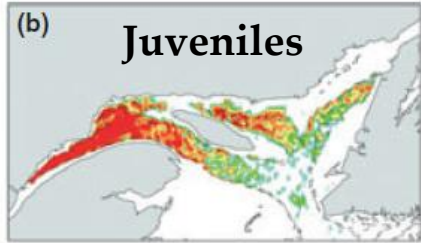
Protandric hermaphrodite species that reproduces first as a male, then changes sex and reproduces as a female for the rest of its life.

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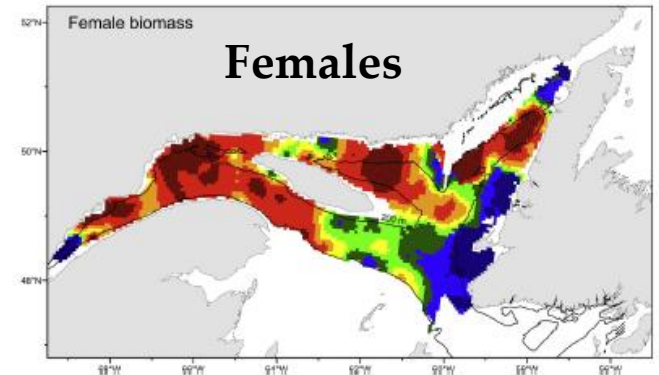
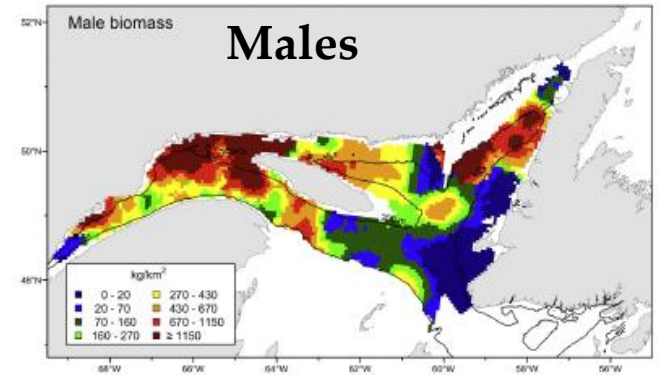
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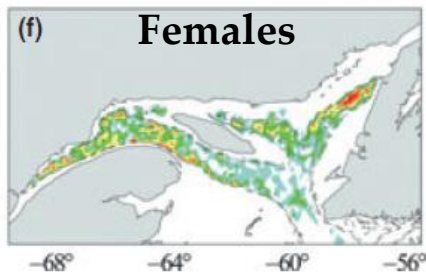
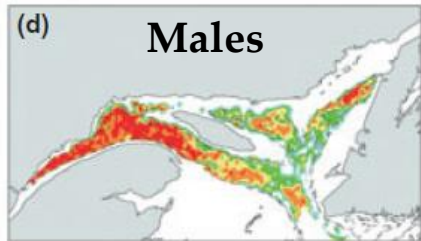
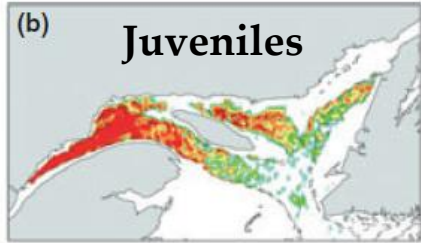


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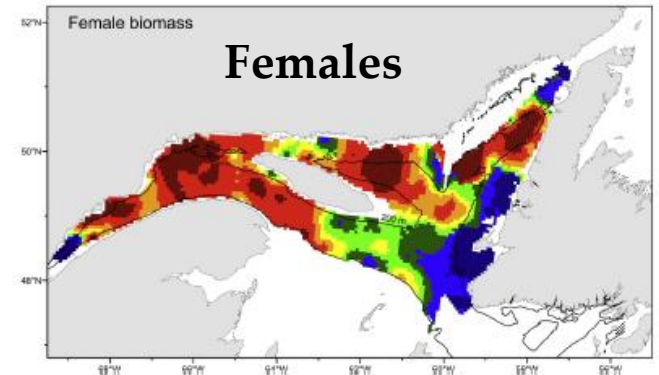
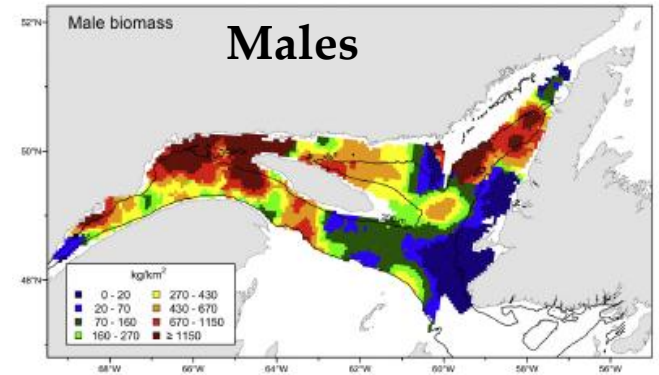


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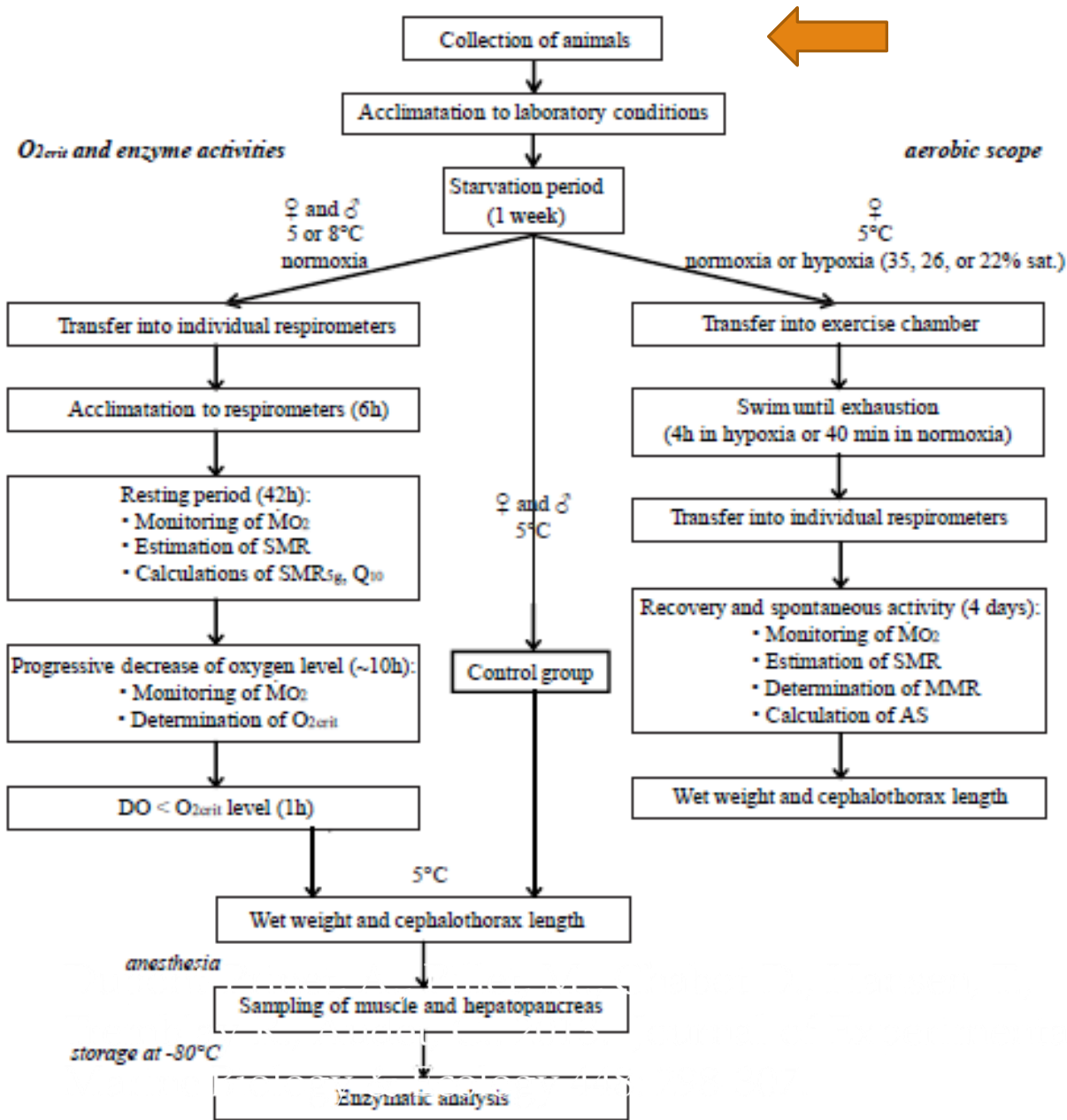


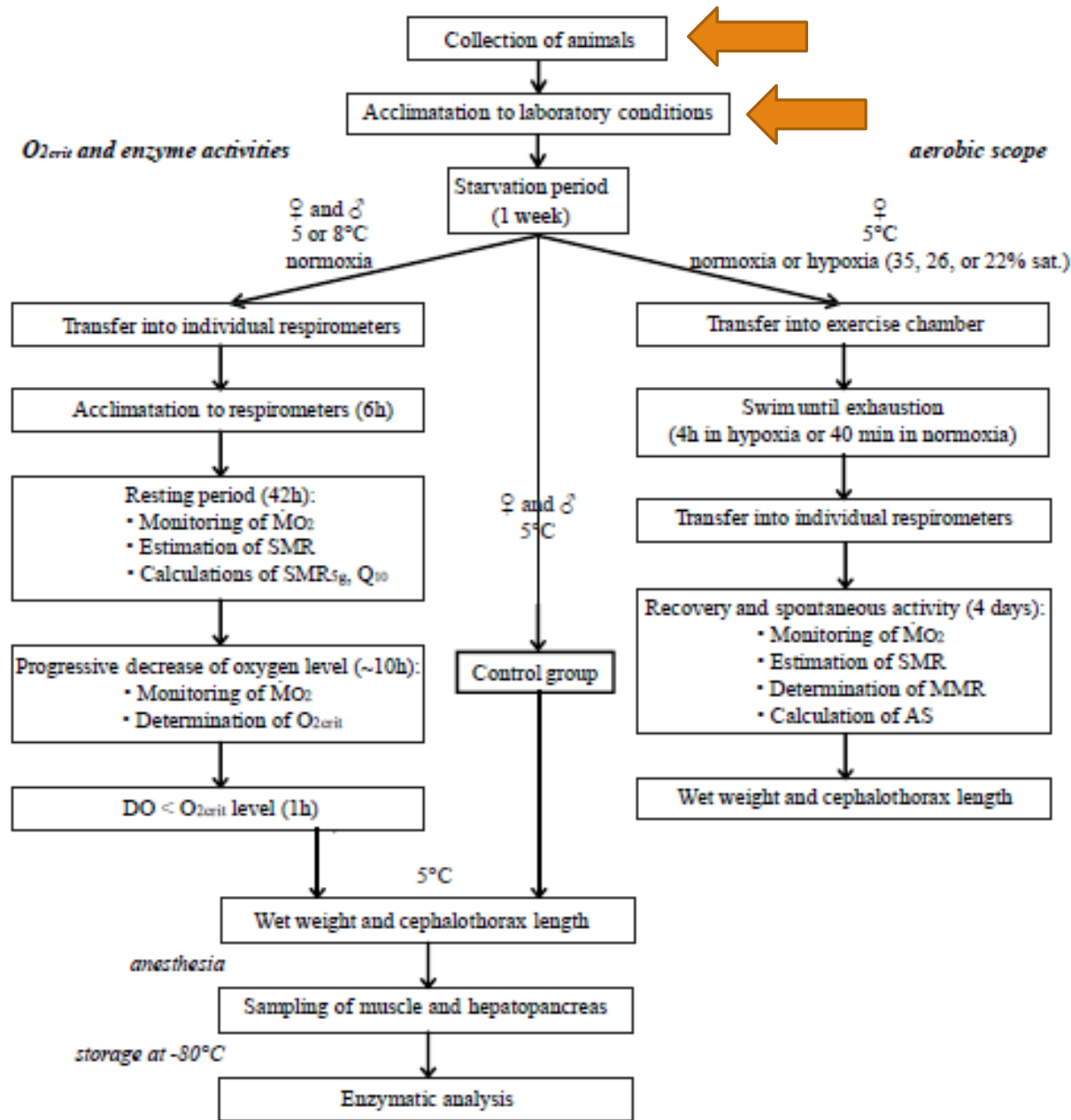
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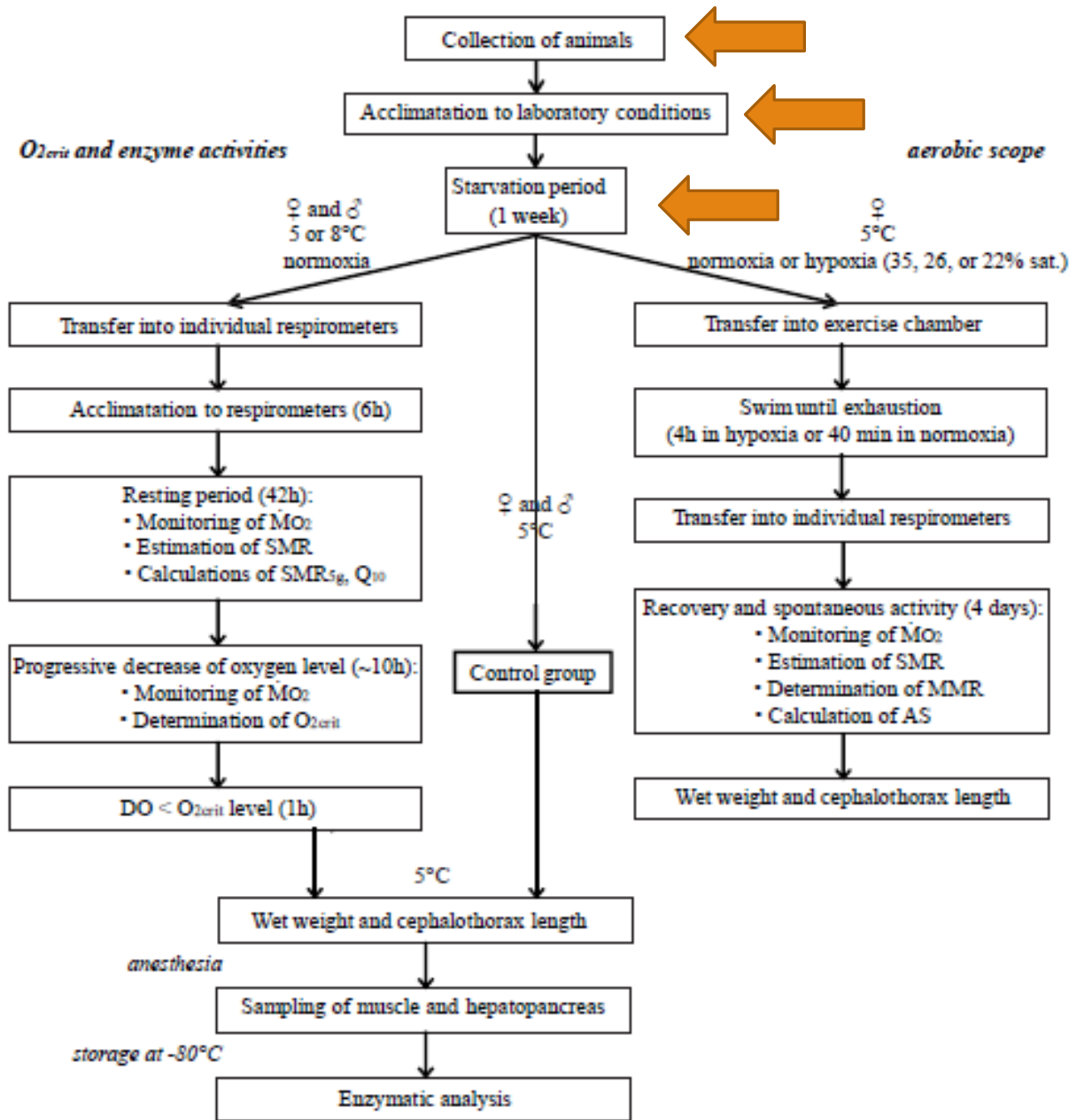
Frequently inhabits hypoxic areas (18-40% saturation) in the EGSL

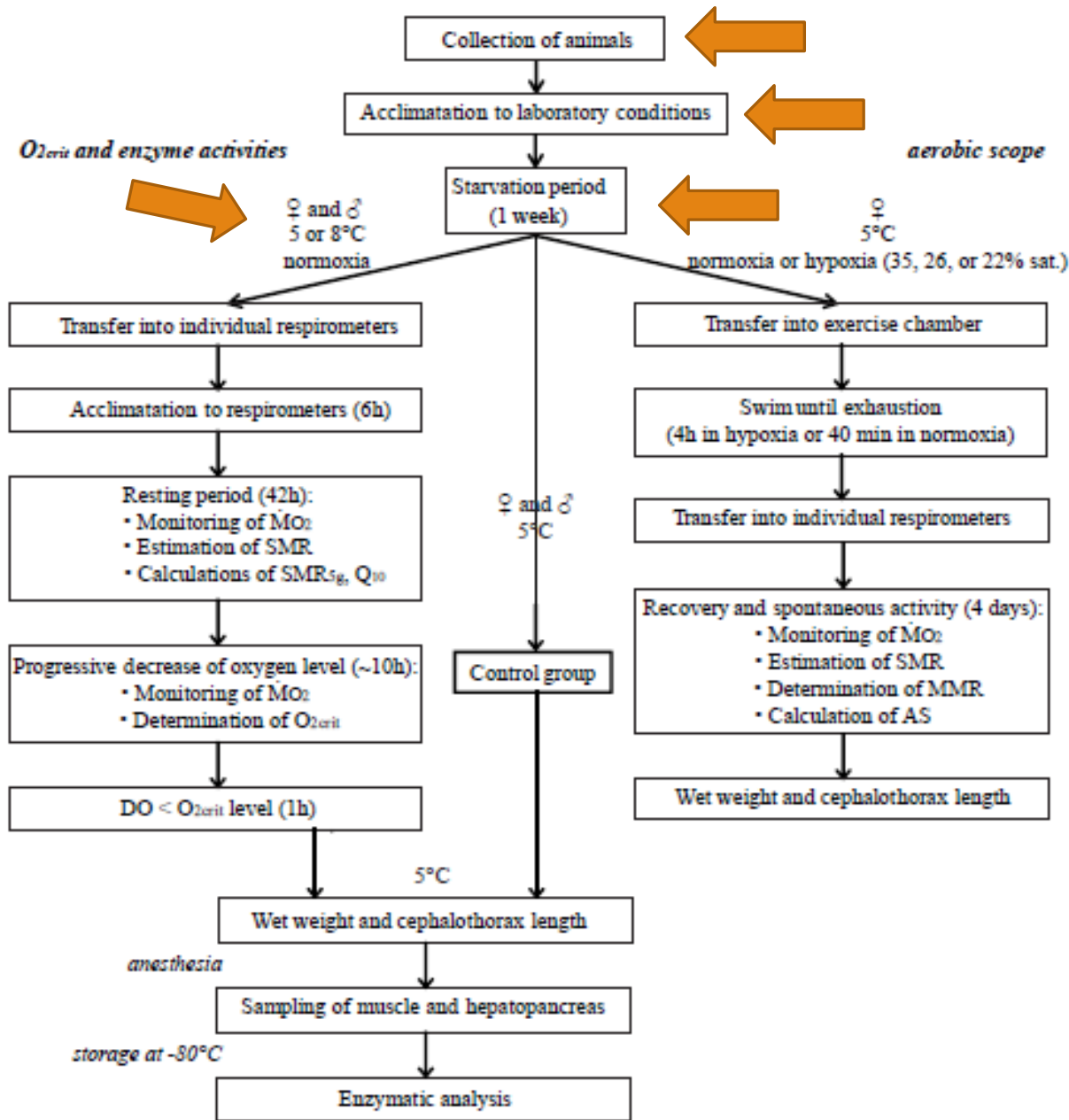


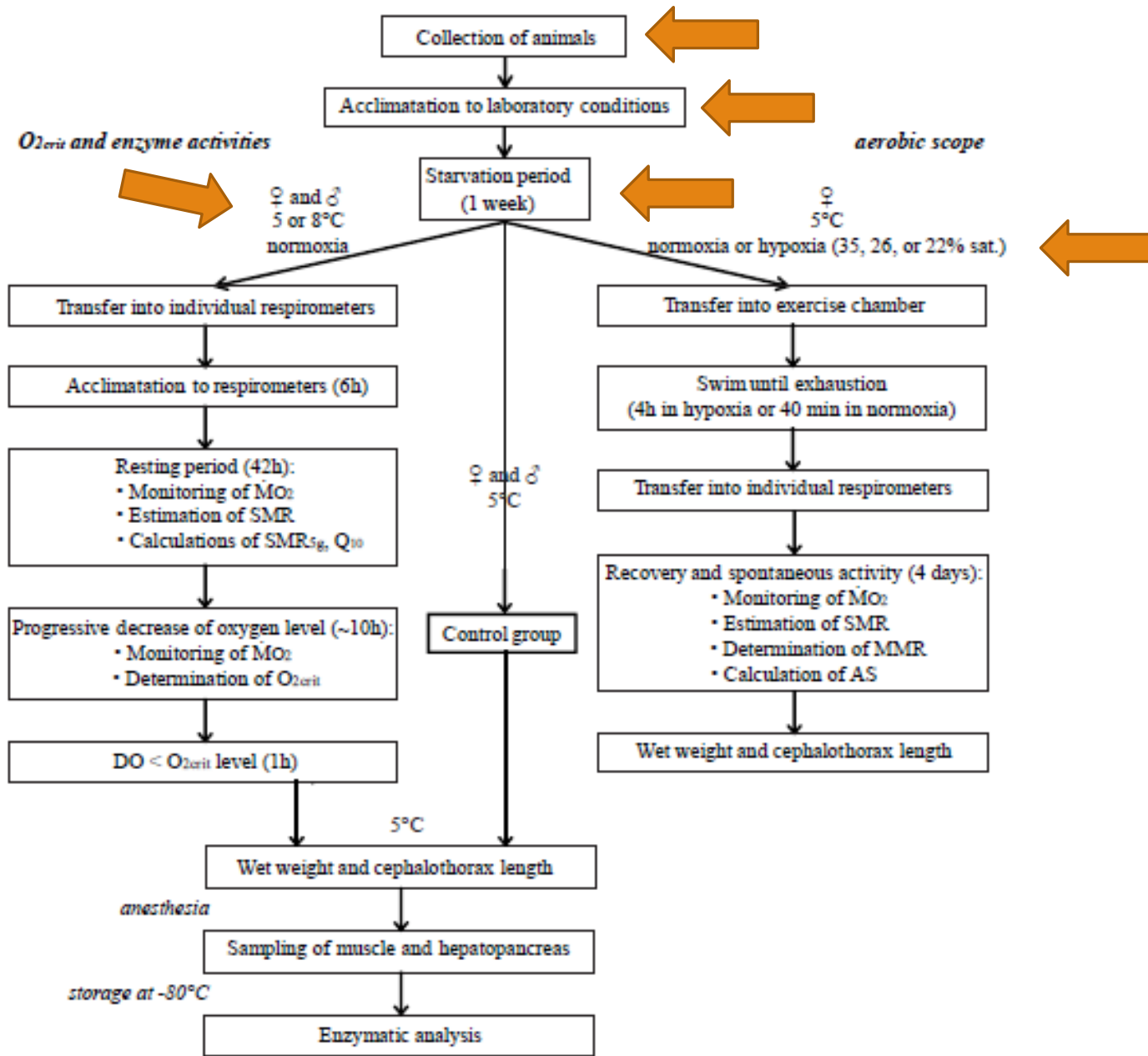
Experimental protocols

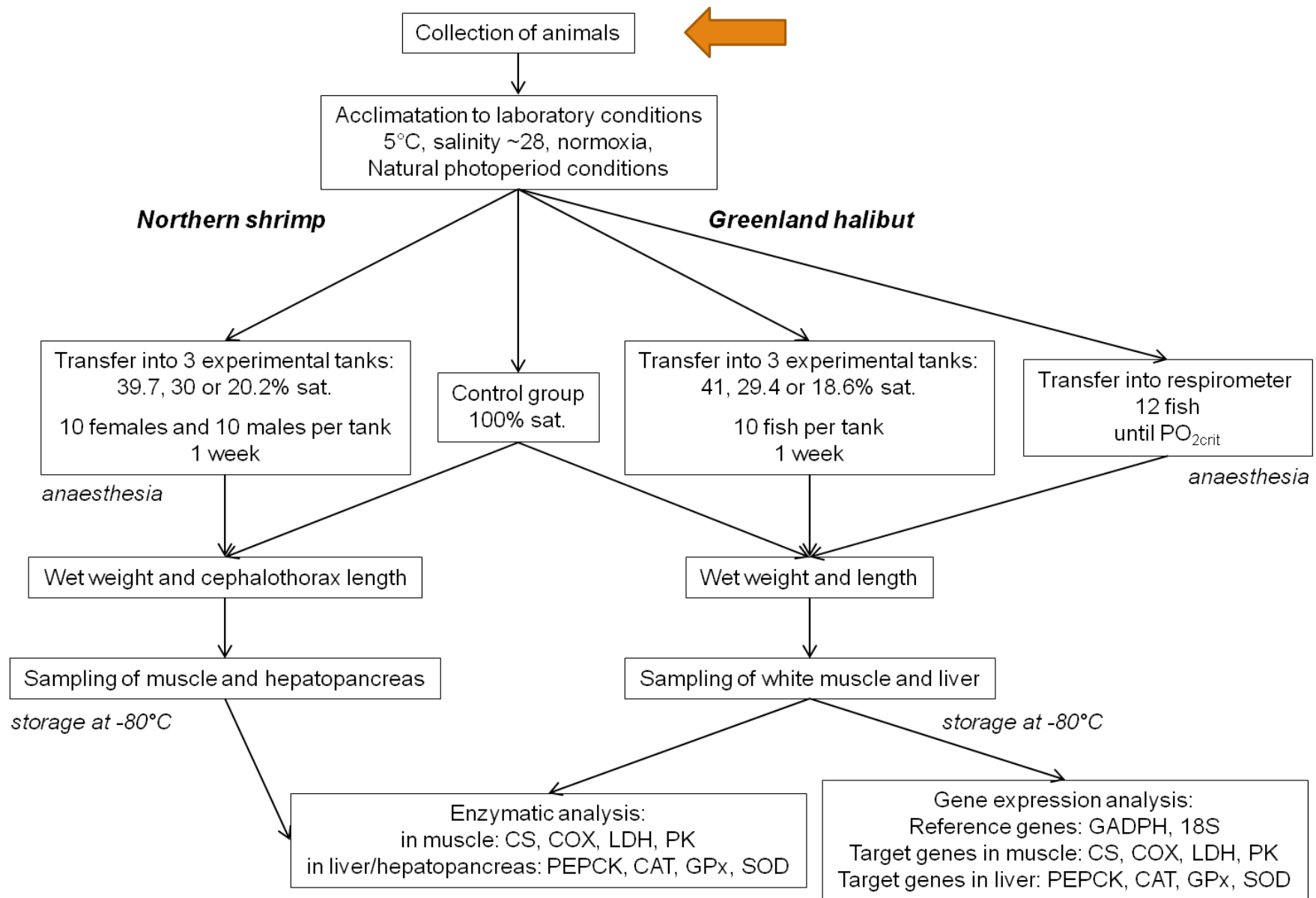


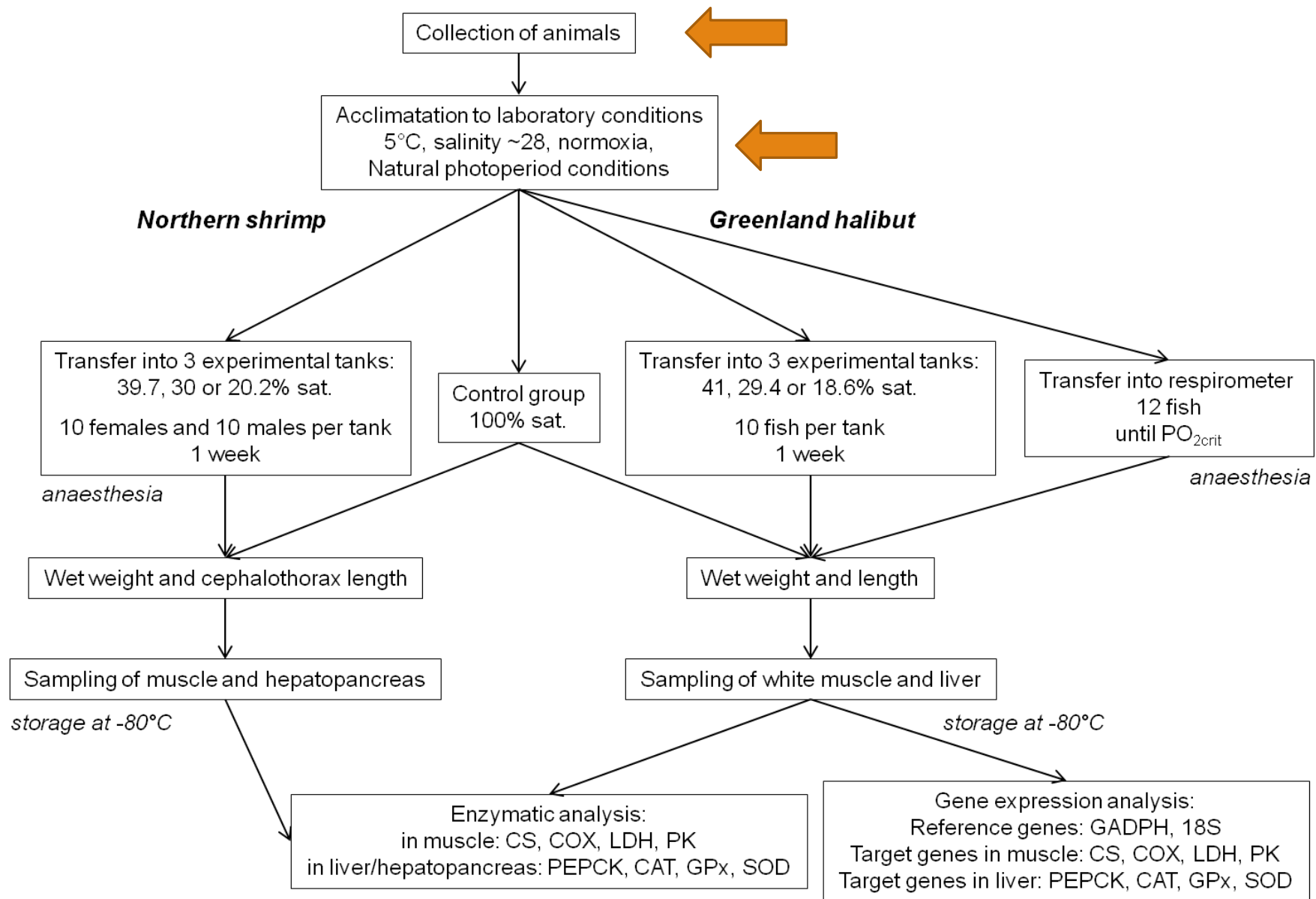


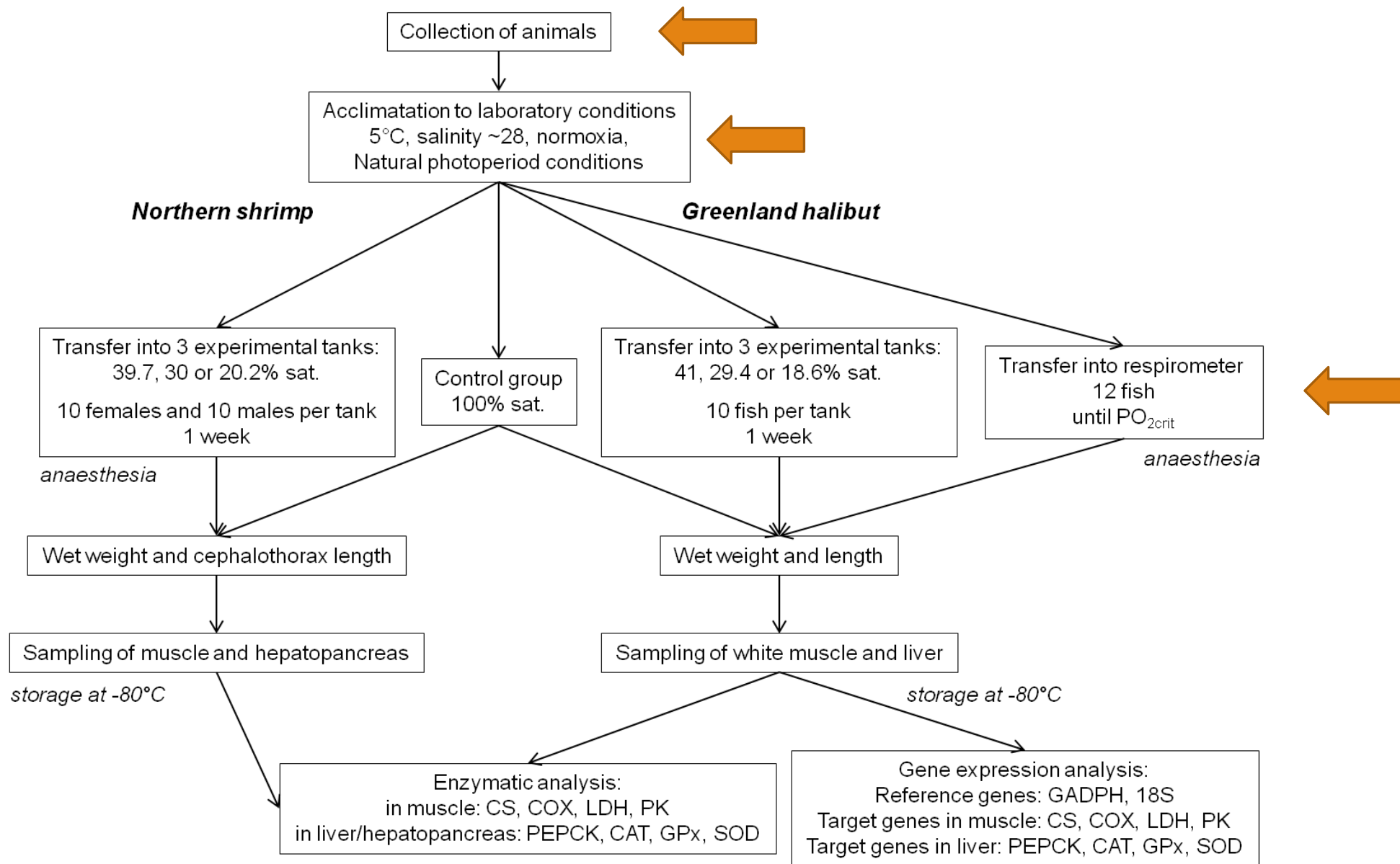


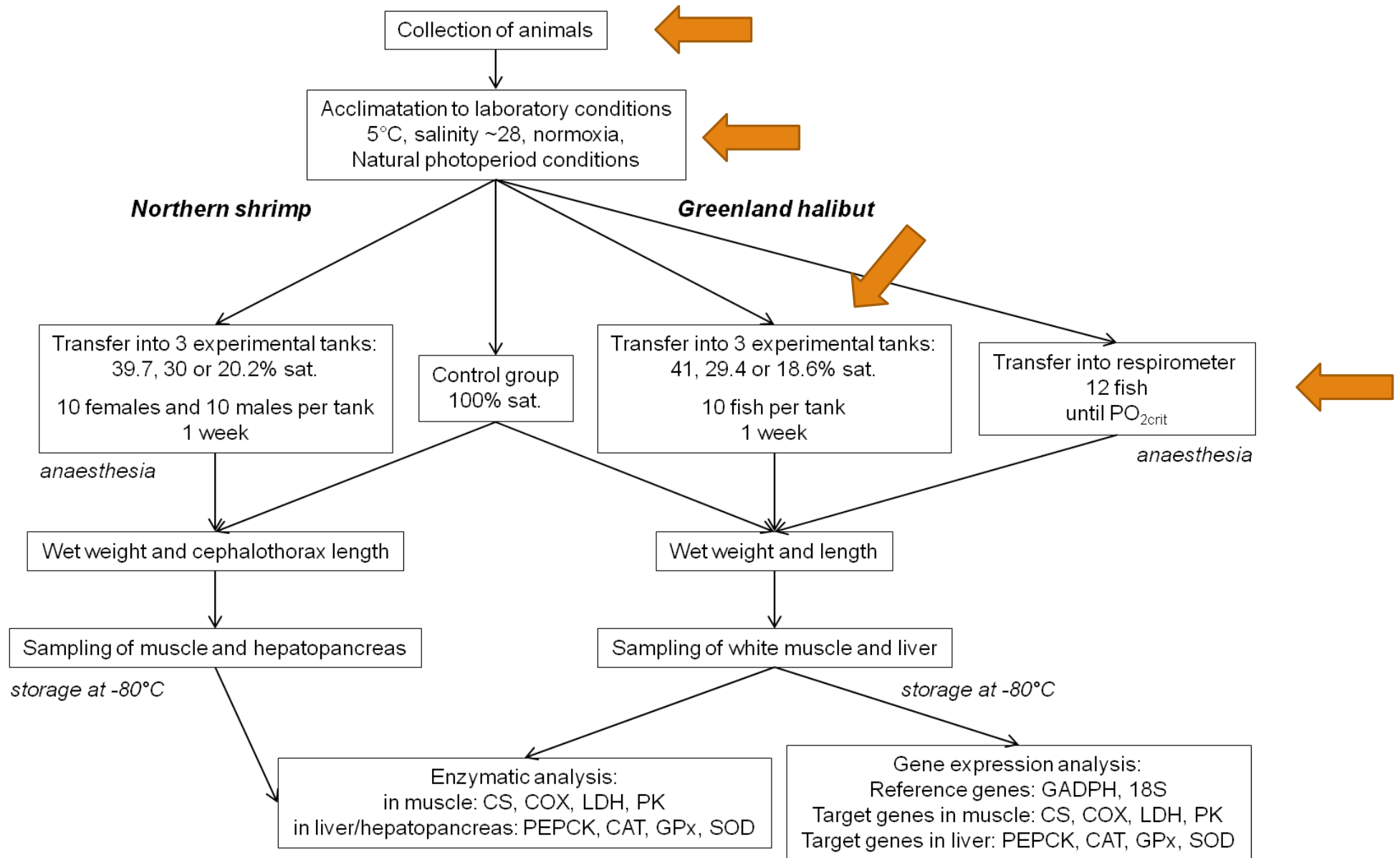


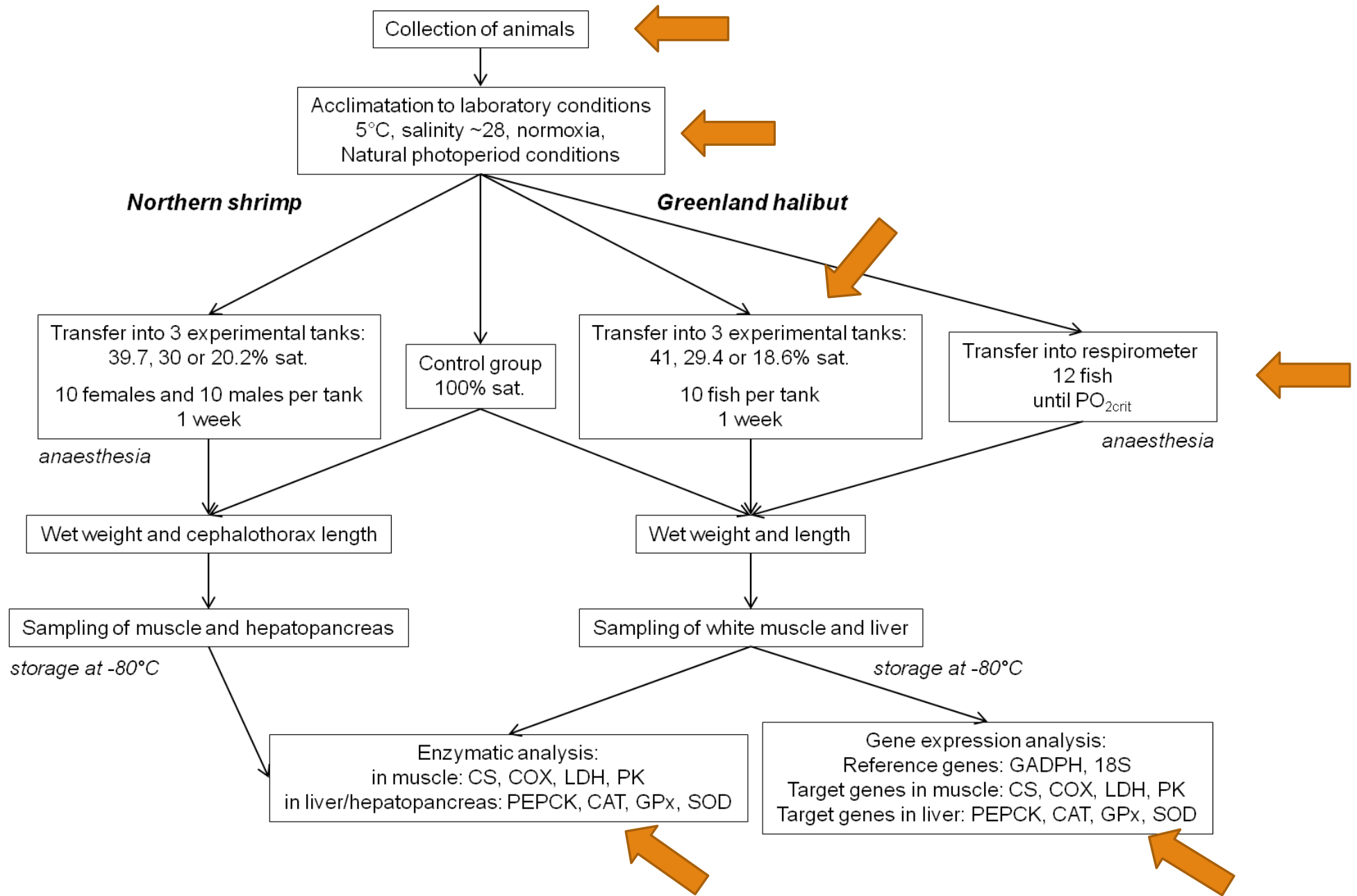












Severe hypoxia

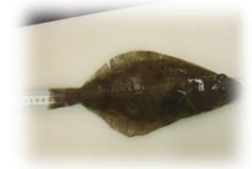


Table 1. Fork length (FL), mass, standard metabolic rate (SMR), and critical oxygen level (O_{2crit}) in adult ($N = 14$) and juvenile ($N = 12$) Greenland halibut (mean \pm SE).

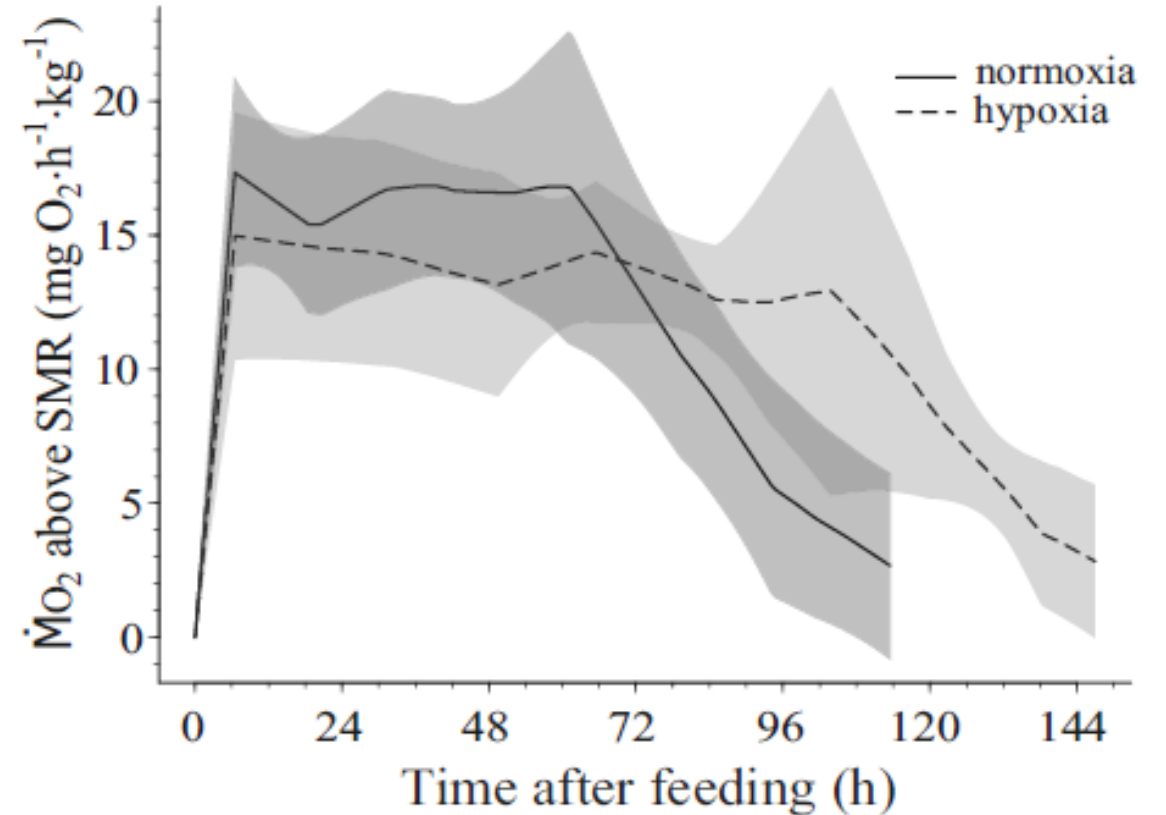
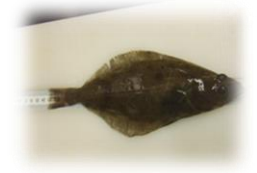
	Adults	Juveniles	<i>P</i>
FL (cm)	51 \pm 1.1	23 \pm 0.5	<0.001
Mass (g)	1465 \pm 114	91 \pm 6	<0.001
SMR (mg $O_2 \cdot h^{-1} \cdot kg^{-1}$)	18.02 \pm 0.84	36.20 \pm 1.53	<0.001
O_{2crit} (% sat.)	11.10 \pm 0.72	14.89 \pm 0.92	0.003

Note: *P* is the probability of a difference between adults and juveniles.

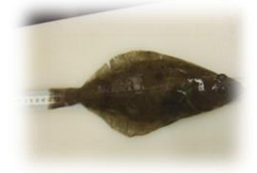
Juveniles were less hypoxia-tolerant than adults

Aerobic scope

Hypoxia **increased the duration of the digestive process**



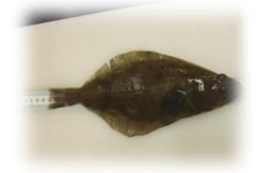
Aerobic scope



Hypoxia **reduced aerobic scope.**

	Dissolved oxygen			
	100%	28%	23%	19%
Fork length (cm)	21±0.2	21±0.6	21±0.7	21±0.6
Mass (g)	80±3	80±8	73±8	82±7
SMR (mg O ₂ ·h ⁻¹ ·kg ⁻¹)	38.79±1.33	29.60±2.17	31.83±4.12	32.00±1.94
MMR (mg O ₂ ·h ⁻¹ ·kg ⁻¹)	125.85±7.85b	68.41±5.23a	66.87±5.50a	56.38±2.81a
AS (mg O ₂ ·h ⁻¹ ·kg ⁻¹)	87.06±7.66c	38.81±3.82b	35.04±2.93ab	24.38±2.72a

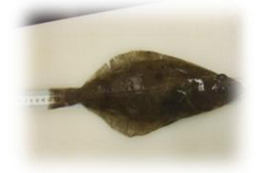
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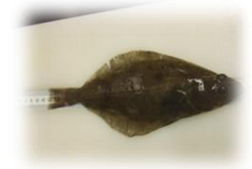
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Hypoxia tolerance

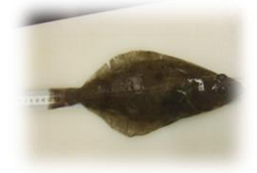


- Juvenile Greenland halibut proved to be less tolerant to hypoxia than adults

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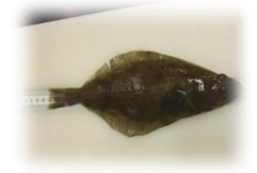
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Hypoxia tolerance

- Juvenile Greenland halibut proved to be less tolerant to hypoxia than adults
- Field values of DO can be as little as 3% sat. above the O_{2crit} of juvenile fish
- Our estimates of AS for juvenile Greenland halibut are comparable to those of other flatfishes

Severe hypoxia



Severe hypoxia (O_{2crit} determination) resulted in enhancement of antioxidant capacity in adults.

Table 1. Fork length (FL), mass, standard metabolic rate (SMR), and critical oxygen level (O_{2crit}) in adult ($N = 14$) and juvenile ($N = 12$) Greenland halibut (mean \pm SE).

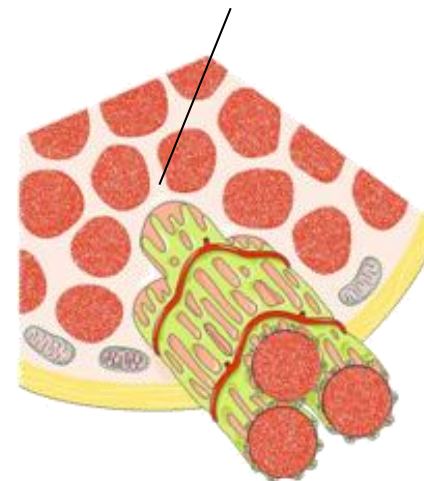
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Juveniles were less hypoxia-tolerant than adults

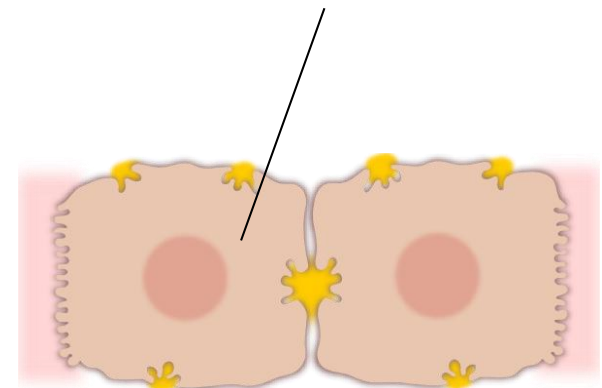
Muscle

↘ 33 % PEPCK

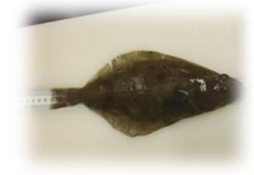


Foie

↗ 86 % SOD

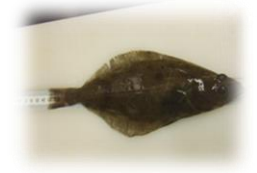


Antioxydant capacity



Juveniles showed a 37% reduced CAT activity in muscle tissue in acute hypoxia (not shown), and stable antioxydant capacity in chronic hypoxia.

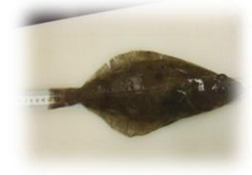
		DO	40%	30%	20%
N		100%	10	10	10
Mass		93.6 ± 1.7 ^a	152.6 ± 20.9 ^b	118.1 ± 14.5 ^{ab}	142.2 ± 13.4 ^{ab}
Length		22.7 ± 0.2	25.4 ± 1.1	23.9 ± 0.9	24.9 ± 0.6
Muscle	CS	2.27 ± 0.18	1.49 ± 0.24	1.88 ± 0.20 (9)	1.51 ± 0.21 (9)
	COX	b.d.	b.d.	b.d.	b.d.
	PK	43.07 ± 3.97 ^b	25.47 ± 1.88 ^a	21.11 ± 1.53 ^a	22.66 ± 3.52 ^a
	LDH	88.76 ± 7.77 ^b	39.81 ± 5.88 ^a	36.87 ± 2.95 ^a	36.91 ± 6.43 ^a
Liver	PEPCK	0.78 ± 0.04	0.71 ± 0.04	0.75 ± 0.03	0.67 ± 0.02
	GPx	1.52 ± 1.14	1.27 ± 0.14 (9)	1.03 ± 0.15	1.20 ± 0.16
	SOD	1409 ± 219 (9)	1162 ± 258	1557 ± 384	900.0 ± 182
	CAT	b.d.	b.d.	b.d.	b.d.



Antioxydant capacity

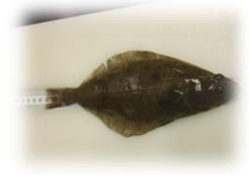
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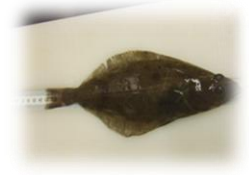
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- In juvenile Greenland halibut, no change in either GPx or SOD activity or in the relative expression of their respective genes was observed following chronic hypoxia exposure
- Hypoxia induced an up-regulation of CAT gene expression, but CAT activity remained so low that it was below the detection limit of the assay, suggesting a very minor role of this enzyme in this species

Hypoxia tolerance



In northern shrimp, **males were more hypoxia-tolerant** than females.

Sex effect < 0.01, for each comparison

	Sex	5 °C
N	F	8
	M	10
CT length	F	25.05 ± 0.24
	M	17.47 ± 0.82
Mass	F	10.19 ± 0.23
	M	3.83 ± 0.49
SMR	F	0.034 ± 0.002
	M	0.047 ± 0.004
SMR _{5g}	F	0.046 ± 0.002
	M	0.040 ± 0.003
O _{2crit}	F	15.5 ± 1.6
	M	9.0 ± 1.7
Q ₁₀	F	2.65
	M	1.71

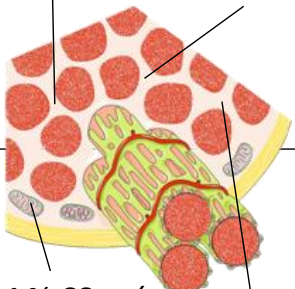
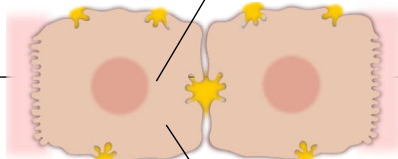
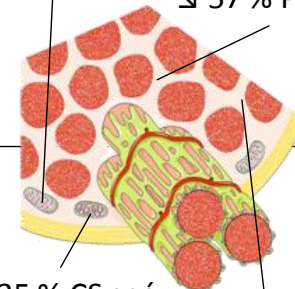
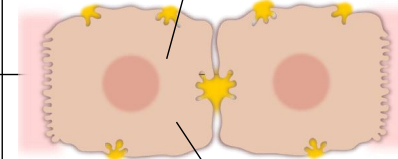
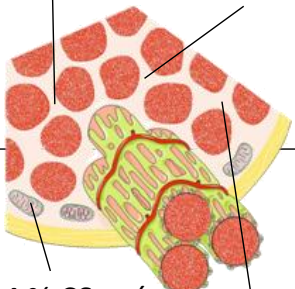
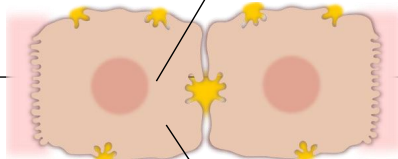
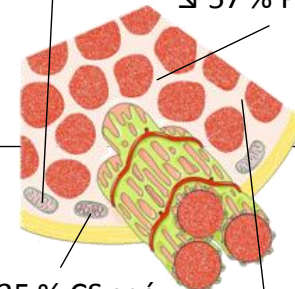
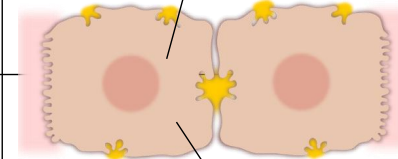
Hypoxia tolerance



Male and female northern shrimp showed an **increase in the antioxidant defense in presence of chronic hypoxia**

Males

Females

	Muscle	Hépatopancréas		Muscle	Hépatopancréas
Hypoxie aigüe	↘ 51 % PEPCK ↘ 70 % SOD 	↘ 52 % SOD ↗ 400 % GPx 	Hypoxie aigüe	↘ 27 % CS spé ↘ 26 % LDH ↘ 38 % PK ↘ 57 % PEPCK 	↘ 61 % SOD 
Hypoxie chronique	↘ 24 % CS spé ↘ 41 % CS ↘ 68 % LDH 	↗ 480 % GPx 	Hypoxie chronique	↘ 35 % CS spé ↘ 44 % CS ↘ 71 % LDH 	↗ 148 % GPx 

Hypoxia tolerance



- Males were more hypoxia tolerant than females



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- Despite the decrease in muscle SOD activity in severe hypoxia, muscle CAT activity remained comparable to what has been found in other marine species
- Our results show that O_{2crit} of males was far below environmental DO levels while O_{2crit} in females was 15% sat. at 5°C. This would imply that the most sensitive females may already face some habitat exclusion with an impact on shrimp recruitment.



Hypoxia tolerance

- Both male and female shrimp exposed to chronic hypoxia conditions had higher hepatopancreas GPx activity compared to those in normoxia

.



Hypoxia tolerance

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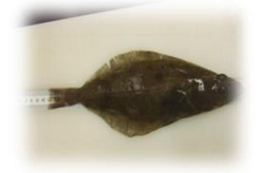
Hypoxia tolerance



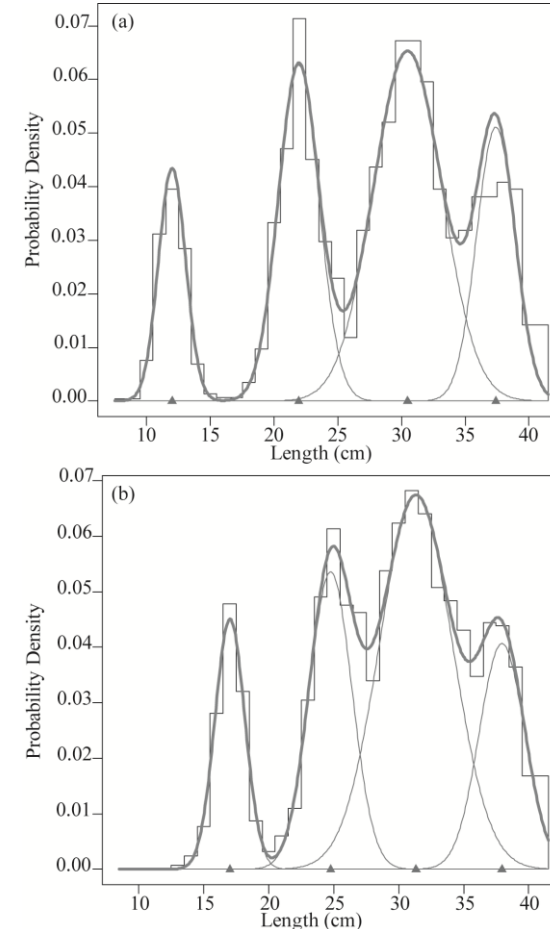
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- SOD was also enhanced, but only in males, which suggests that females were less able to prepare for reoxygenation than males
- Catalase activity was not detected in the hepatopancreas of either males or females, even though this enzyme has been shown to be present in the hepatopancreas of other shrimp species

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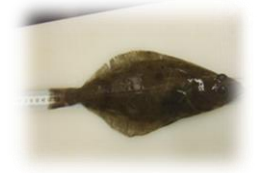
Juvenile Growth



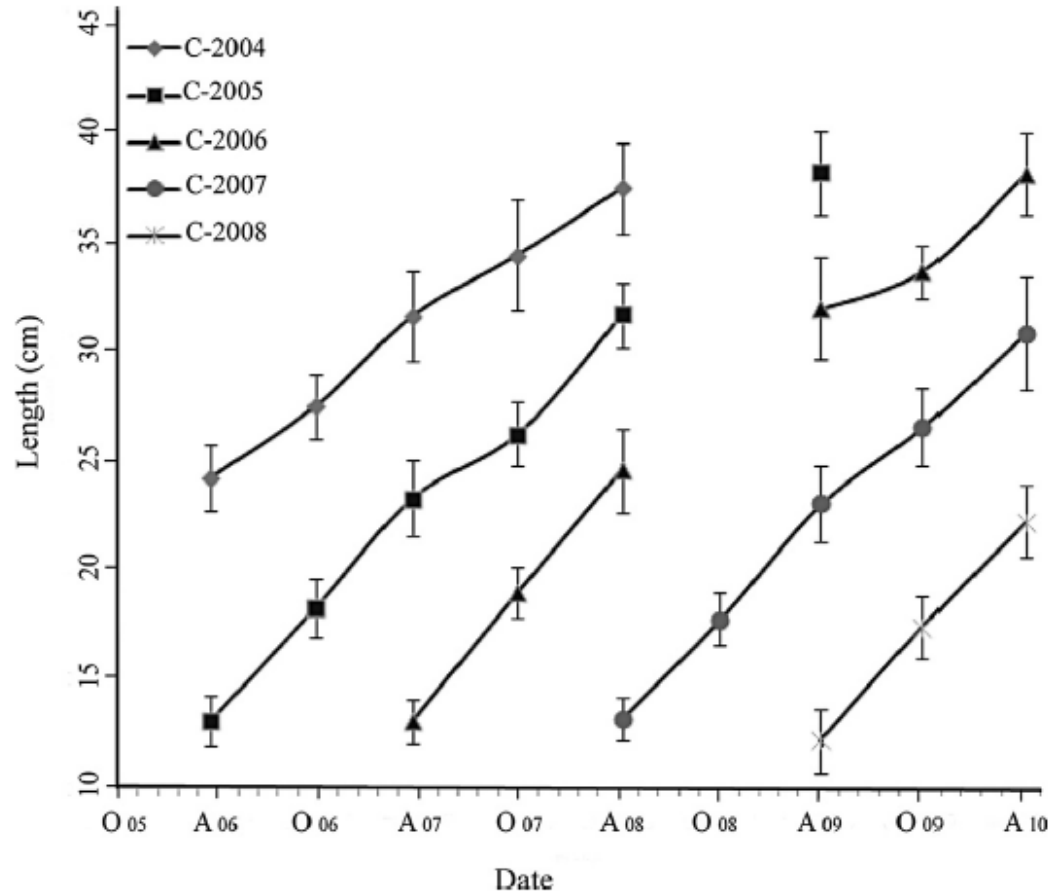
- The seasonal growth was estimated from an analysis of the length-frequency distributions of Greenland halibut in spring and fall surveys conducted in the St. Lawrence estuary from 2006 to 2010.
- We identified the different cohorts based on length-frequency analysis.



Juvenile Growth



- Our results indicate continuous growth in juveniles throughout the year
- The juveniles were mostly found at depths where the annual bottom temperature is stable and food access is constant.



Juvenile Growth

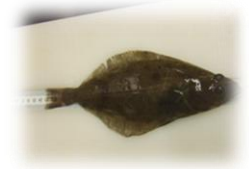


Table 3

Mean total lengths (cm) of 1- and 2-year-old juveniles and length increment between ages 1 and 2 for different populations of Greenland Halibut from published studies.

Zone, Time of year	Reference	Mean length (cm)		Length increment between ages 1 and 2
		1 year old	2 years old	
Coastal waters of western Spitsbergen	Haug and Gulliksen (1982)	13.7		7.6
Southern Labrador July	Bowering and Nedreaas (2001)	10.5–12.5	16.5–18.5	6–8
Newfoundland Autumn	Bowering and Nedreaas (2001)	8.5–10.5	16.5–18.5	
Northeast Atlantic June–August	Bowering and Nedreaas (2001)	12–14	21	7–9
Northeast Arctic October–January	Albert (2003)	13–15	21–23	
Hinlopen (Svalbard archipelago) December–January	Vollen et al. (2004)	10	17	
Disko Bay July–September	Sünksen et al. (2010)	13–15	20.5–25	
Estuary and Gulf of St. Lawrence August	Present study	15.8–18.7	24.8–29.5	8–12

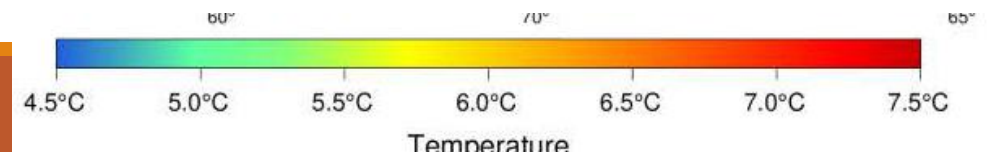
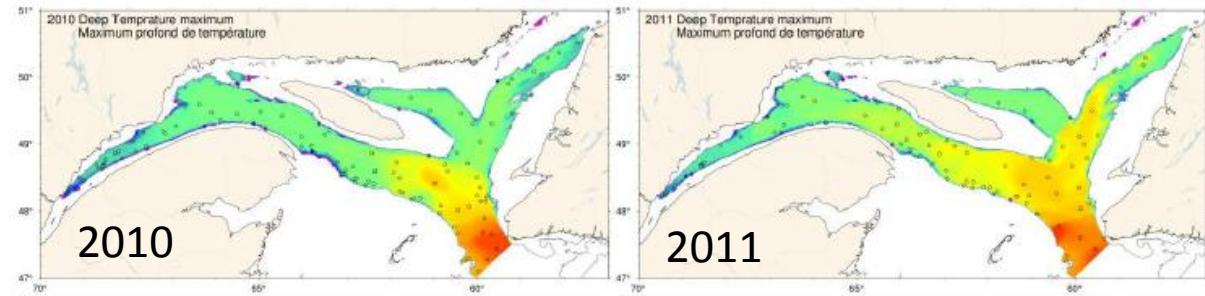
The **mean lengths** at ages 1 and 2 and **length increments** estimated from field data (annual surveys of DFO in the EGSL) were **higher** than those estimated in other populations of Greenland halibut

Overall conclusion

Even though both species are highly hypoxia tolerant, **present oxygen levels in the Estuary are close to the average lethal level of juvenile halibut and female shrimp**, and further drops due to climate changes, could result in loss of habitat, especially in the Estuary, **and especially if accompanied by warming.**

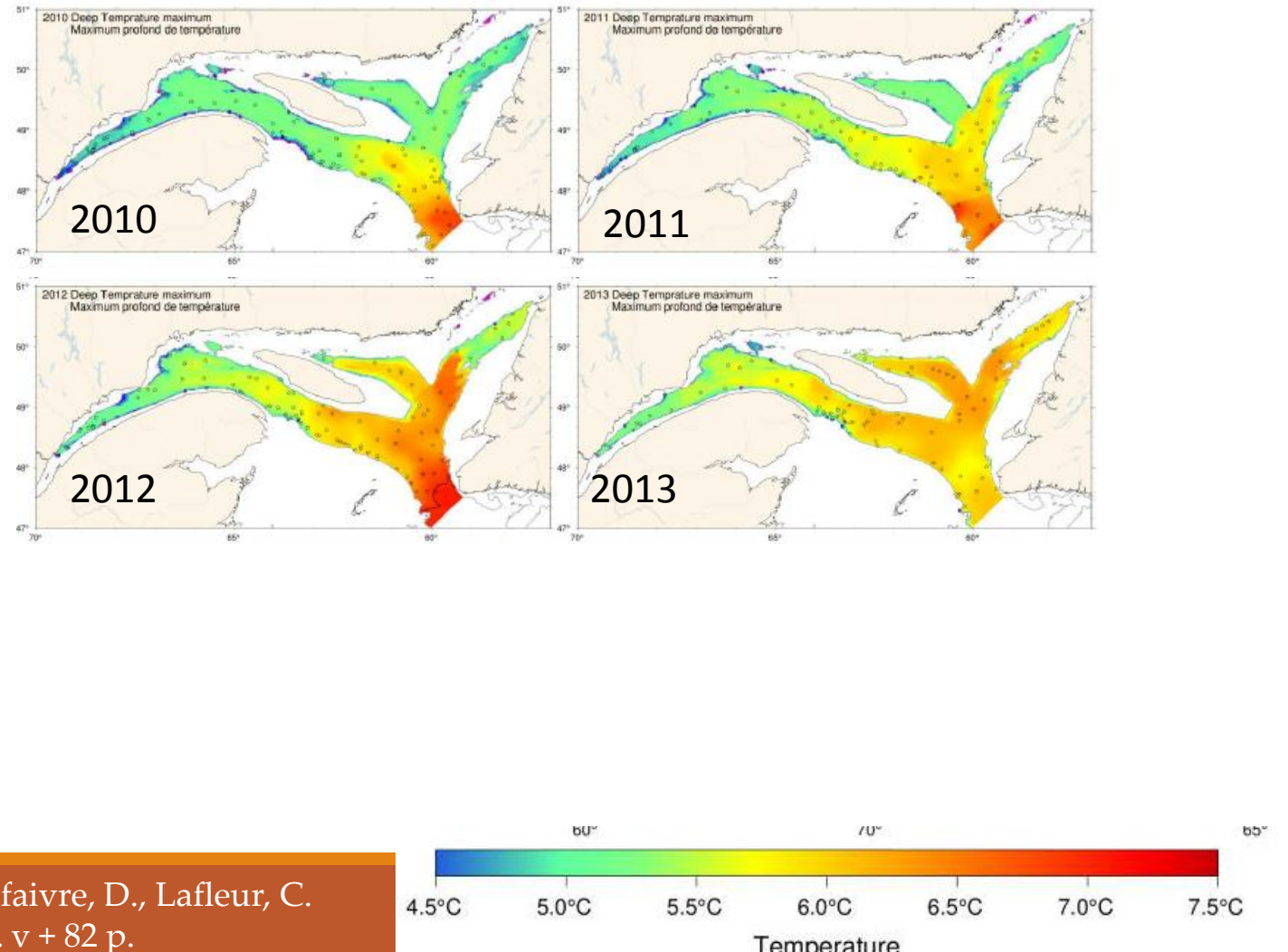
Recent evolution of deep water temperature in the EGSL

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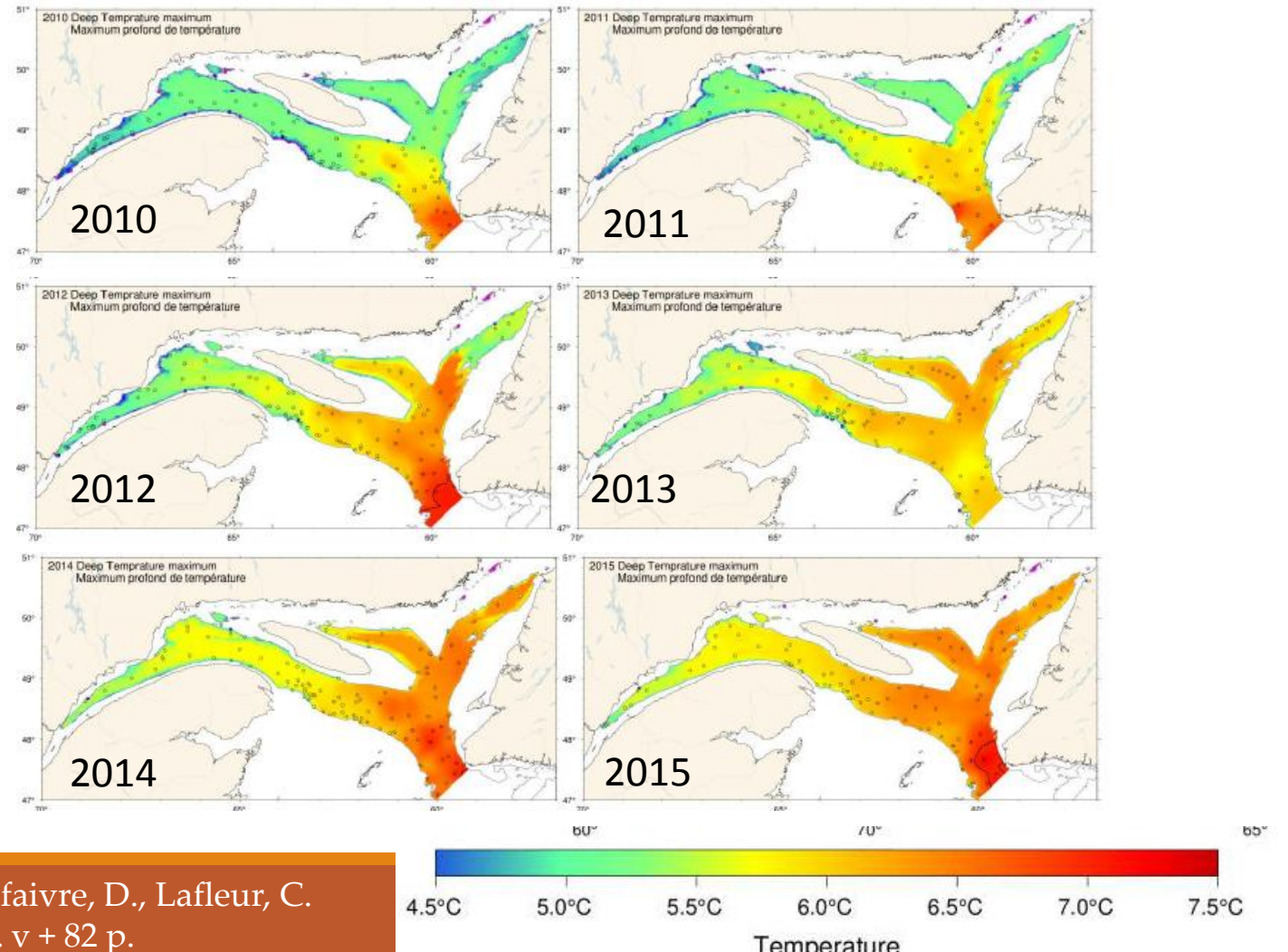
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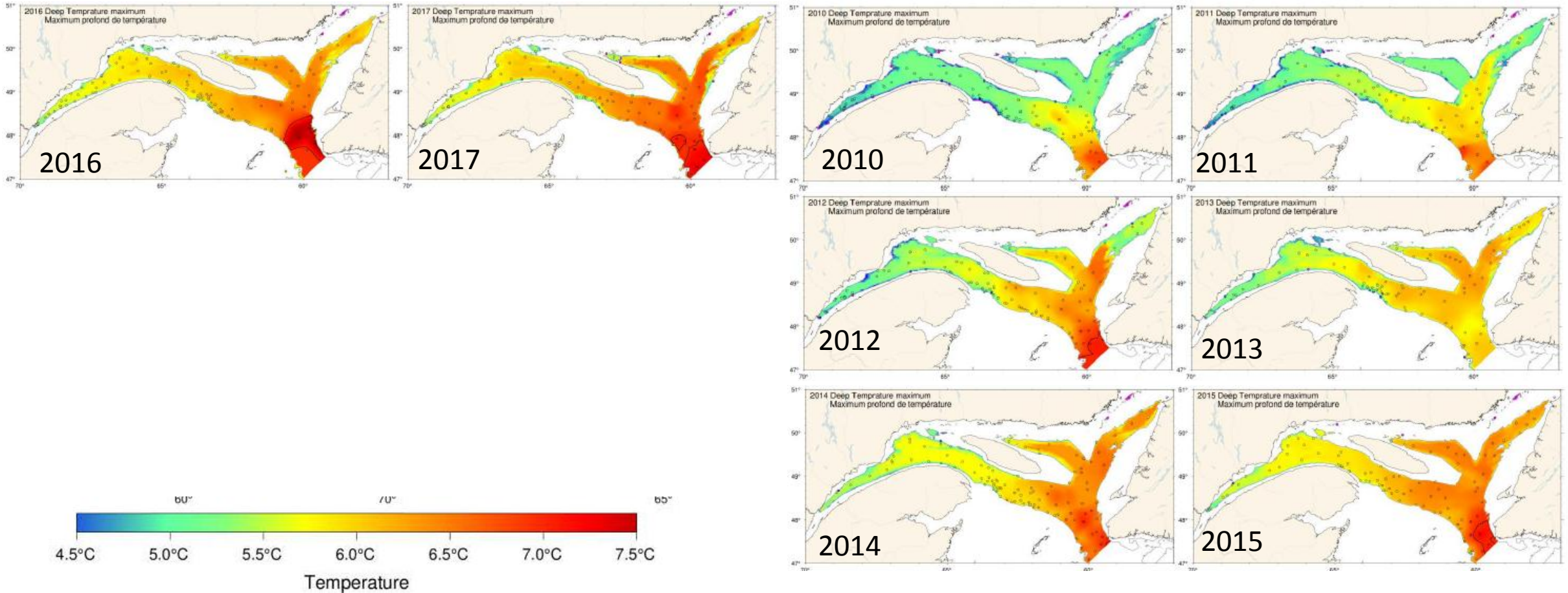


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Recent evolution of deep water temperature in the EGSL



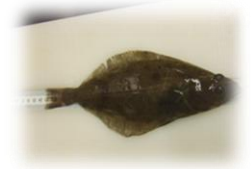
How temperature affects hypoxia tolerance in northern shrimp?



- A rise in temperature increased O_{2crit} by 44% in females and 52% in males, showing that hypoxia tolerance is lower at higher temperature.
- This could be the result of the higher metabolic activity required for homeostasis

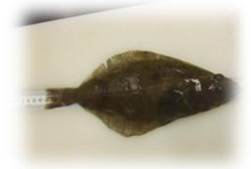
	Sex	5 °C	8 °C
N	F	8	13
	M	10	14
CT length	F	25.05 ± 0.24	25.77 ± 0.31
	M	17.47 ± 0.82	16.63 ± 0.66
Mass	F	10.19 ± 0.23	10.73 ± 0.38
	M	3.83 ± 0.49	3.14 ± 0.42
SMR	F	0.034 ± 0.002	0.045 ± 0.003
	M	0.047 ± 0.004	0.060 ± 0.004
SMR _{5g}	F	0.046 ± 0.002	0.062 ± 0.004
	M	0.040 ± 0.003	0.047 ± 0.003
O_{2crit}	F	15.5 ± 1.6	22.2 ± 1.9
	M	9.0 ± 1.7	13.8 ± 1.1
Q_{10}	F	2.65	
	M	1.71	

Work in progress



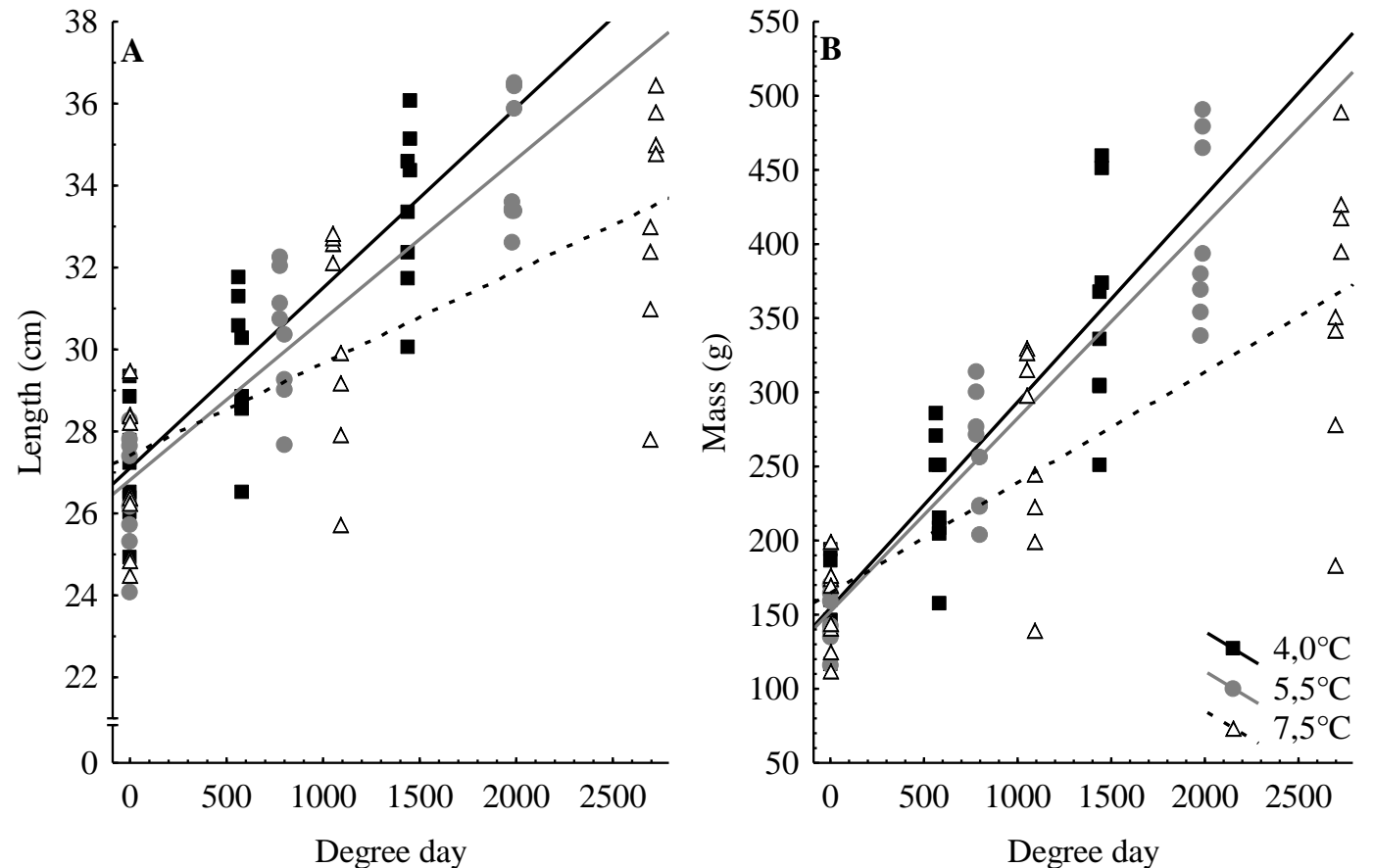
- Fish captured from the wild (St. Lawrence estuary)
- One year rearing in controlled conditions
- Natural photoperiod conditions
- Three temperatures
- Normoxia

Work in progress

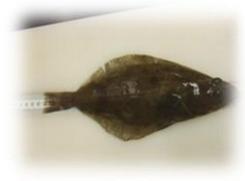


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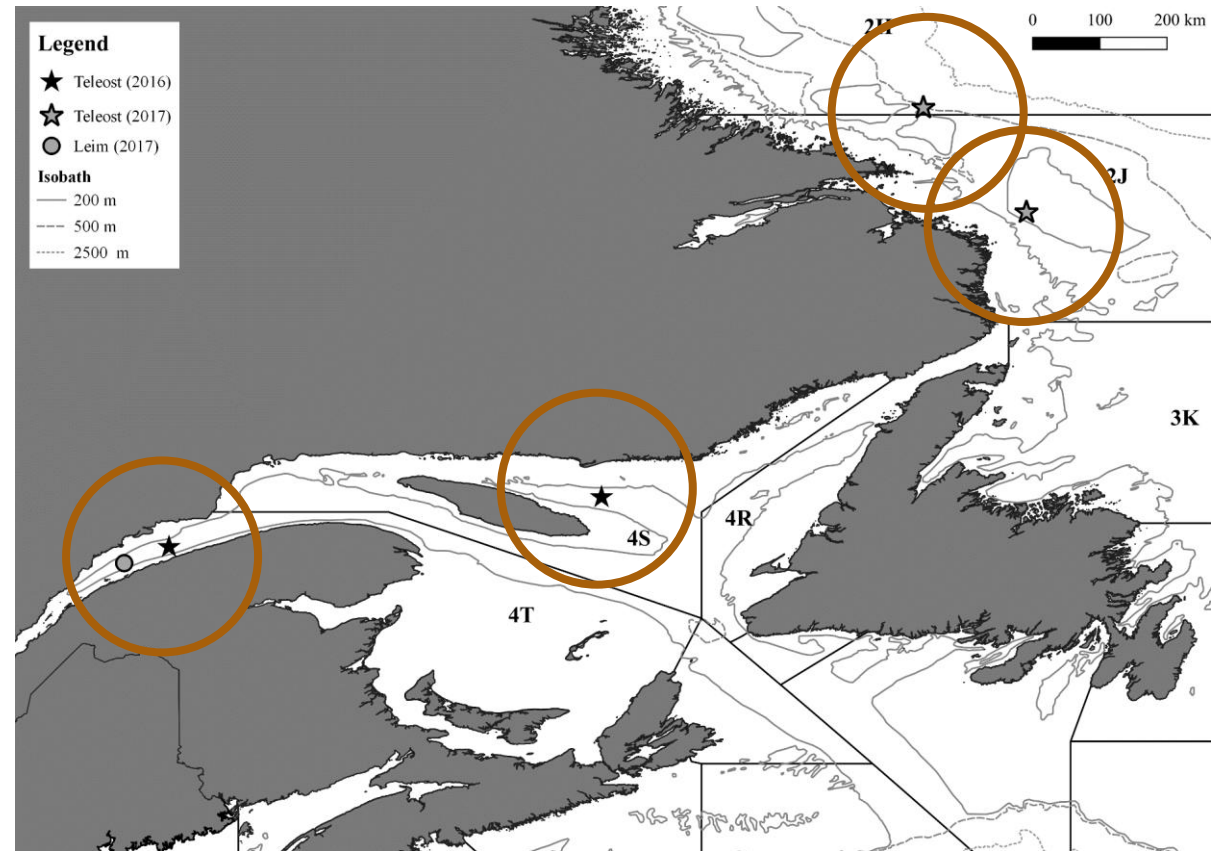
- Juvenile growth is continuous
- No sexual maturation during the course of the experiment



Work in progress



- Fish were captured during the multidisciplinary research bottom-trawl survey conducted by Fisheries and Oceans (Québec and NFL regions)
- Fish were sacrificed on board after measurement: gonads, liver, heart, muscle tissue preserved for histology, biochemistry and gene expression analysis
- We will compare metabolism, growth, anti-oxidant response indicators with juveniles maintained in the lab, at the three temperatures



Acknowledgments



Fisheries and Oceans
Canada

Pêches et Océans
Canada

Canada



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Aquatiques
Québec* | **RAQ** |

UQAR *SMER*