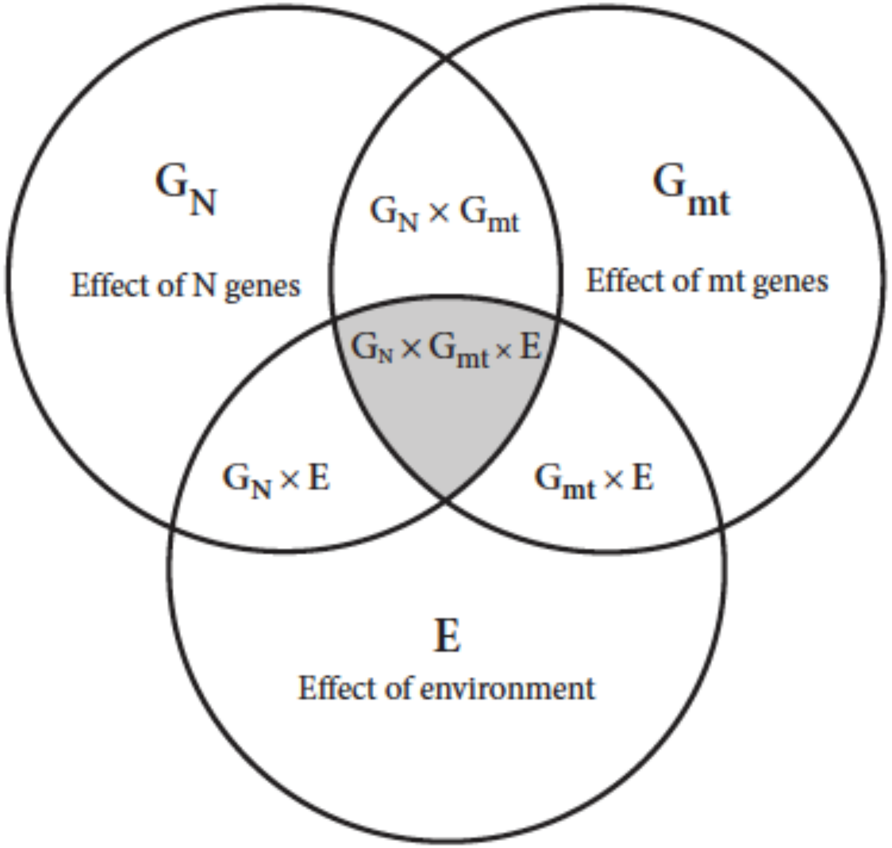
Adaptation and adaptive radiations

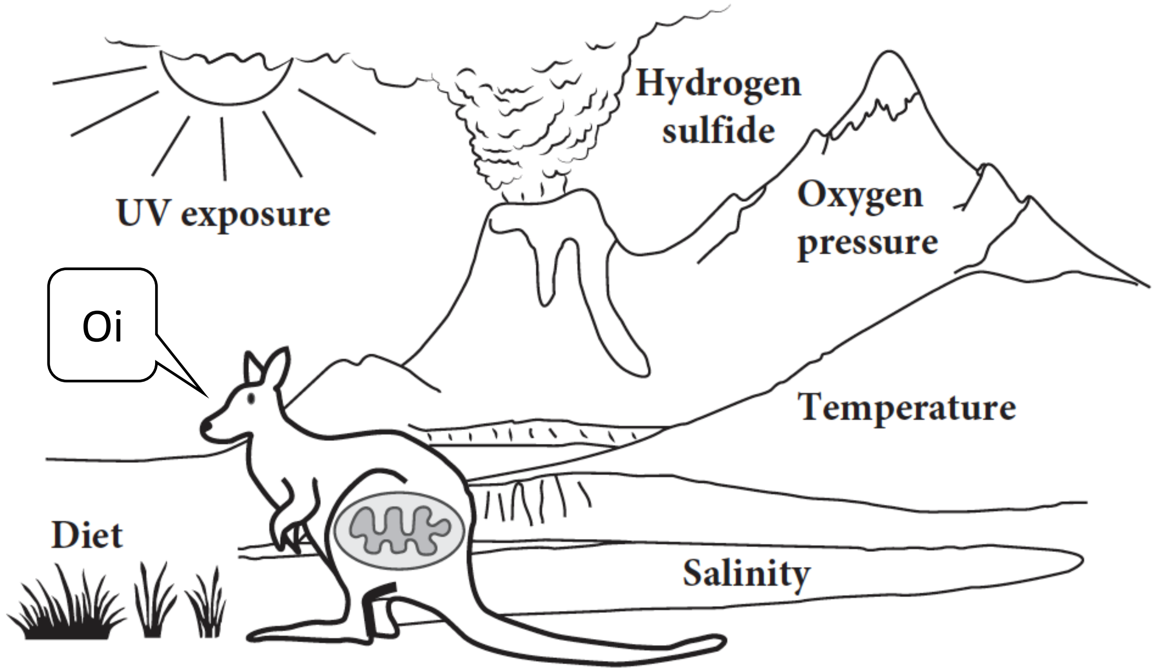
Effects of mt types in different environments

- Mitonuclear incompatibilities only exposed in stressful environments
- Relative strength of these effects
  - Biological vs. statistical importance
- Pervasive, but not predictable
- “Match” isn’t always best



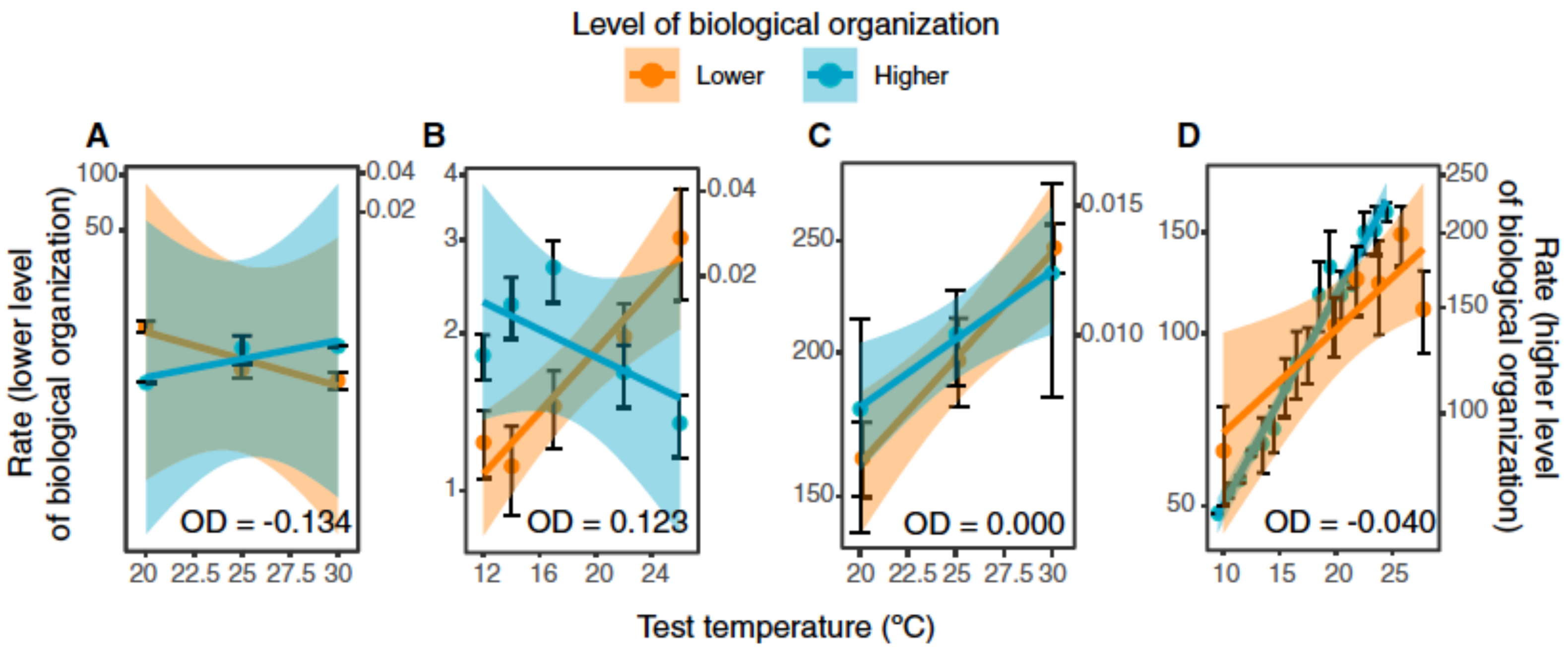
Environmental factors linked to mt function

- Temperature
- UV exposure
- O2 content
- Salinity
- H2S
- Diet
- Basically, anything where energy requirements change… so everything



Acclimation vs. adaptation

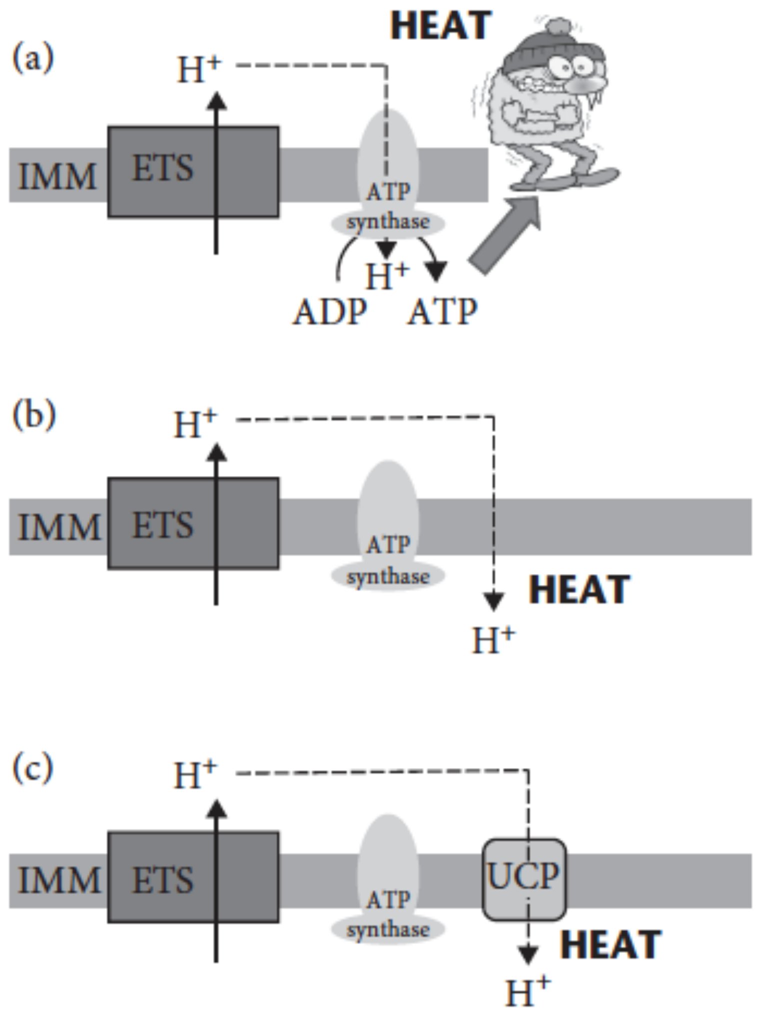
- Plasticity vs. genetic selection



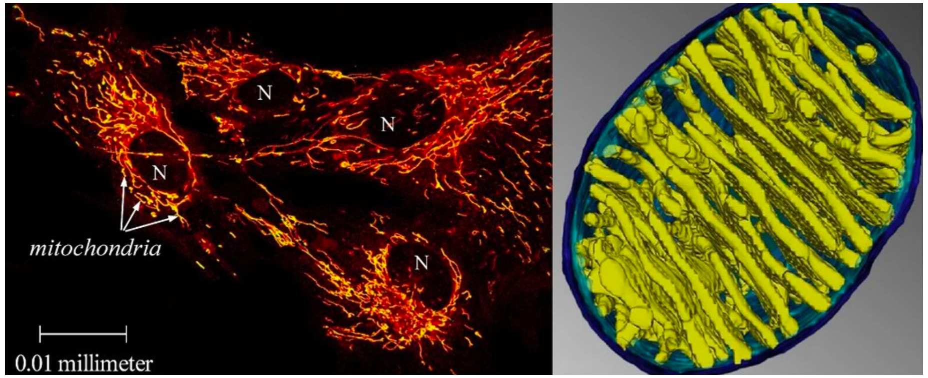
Iverson et al. 2020

Temperature

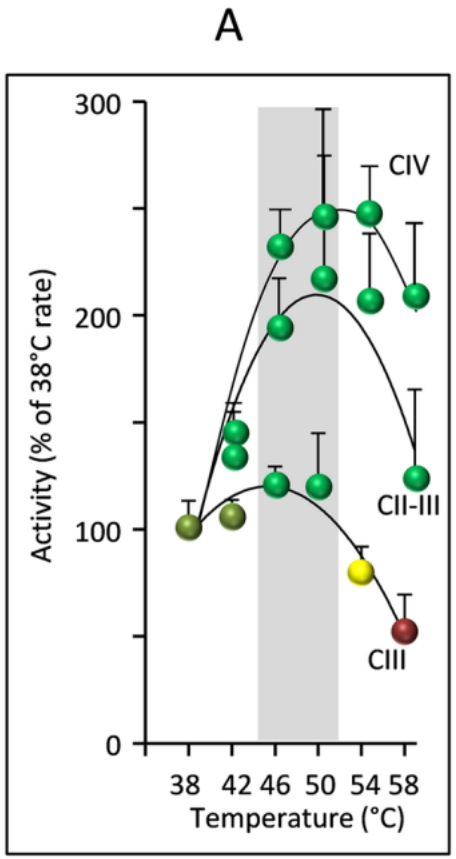
- Lots of studies on this
- Ectotherms vs. endotherms
- Mt provides ATP for thermogenesis
- Mt can also provide heat directly via uncoupling proteins and leak
- BAT



Some mitos like it hot

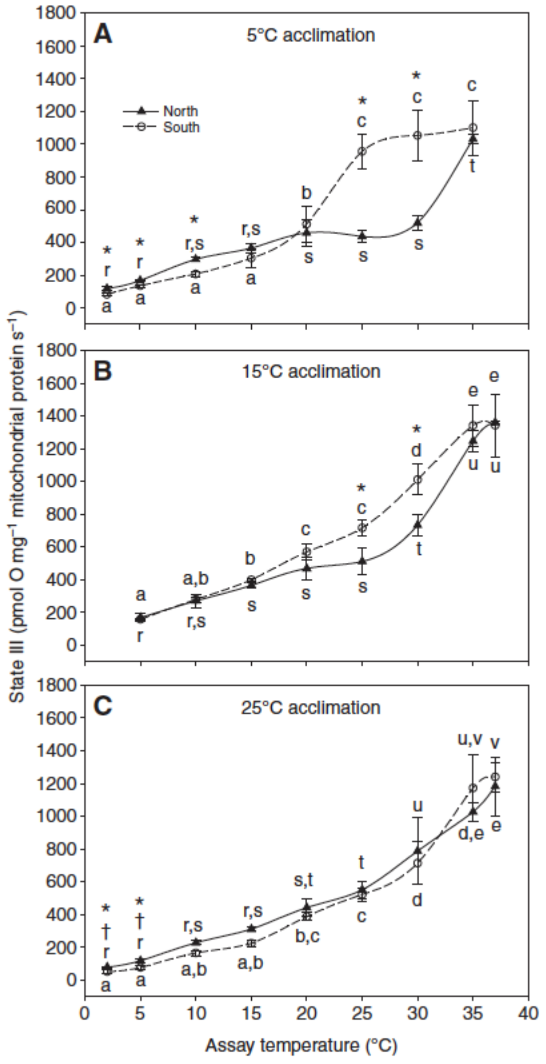


- Human mitos operate at 10C warmer than body temp.
- Respiration is most efficient at this higher temp.
- Mito. respiration often continues to increase after whole animal respiration dies at high temps.



Examples of mt thermal adaptation

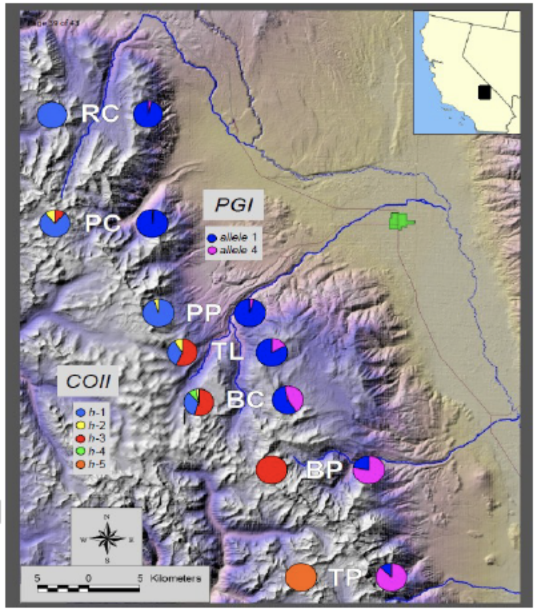
- Fishes
  - Antarctic/arctic fishes
  - Killifish across latitude
  - Commercial fishes
  - Others…
  - Often don't have controlled genetic and acclimation study designs

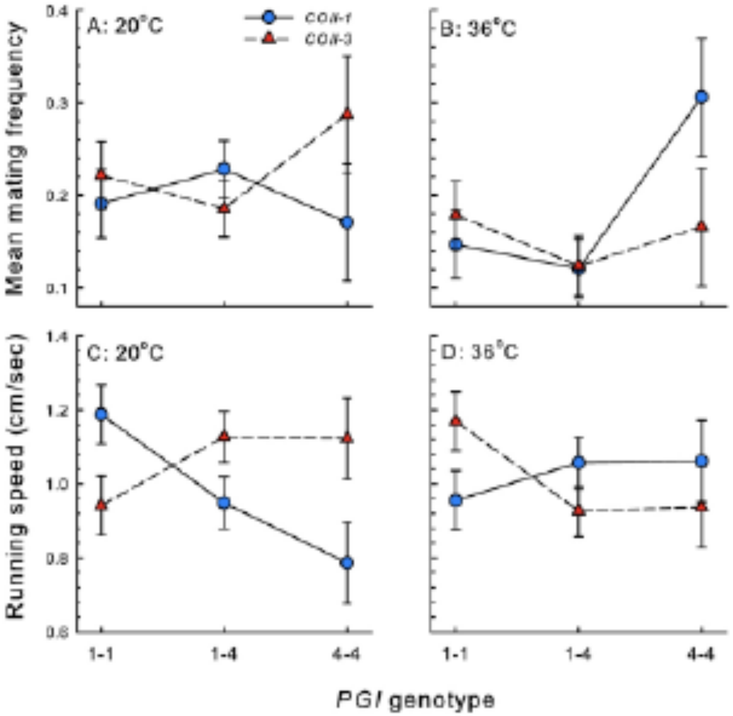


Fangue et al. 2009

Examples of mt thermal adaptation

- Arthropods
- Drosophila
- Seed beetles
  - Lots more controlled
  - Dowling work
- Tigriopus
- Natural experiments in montane leaf beetles

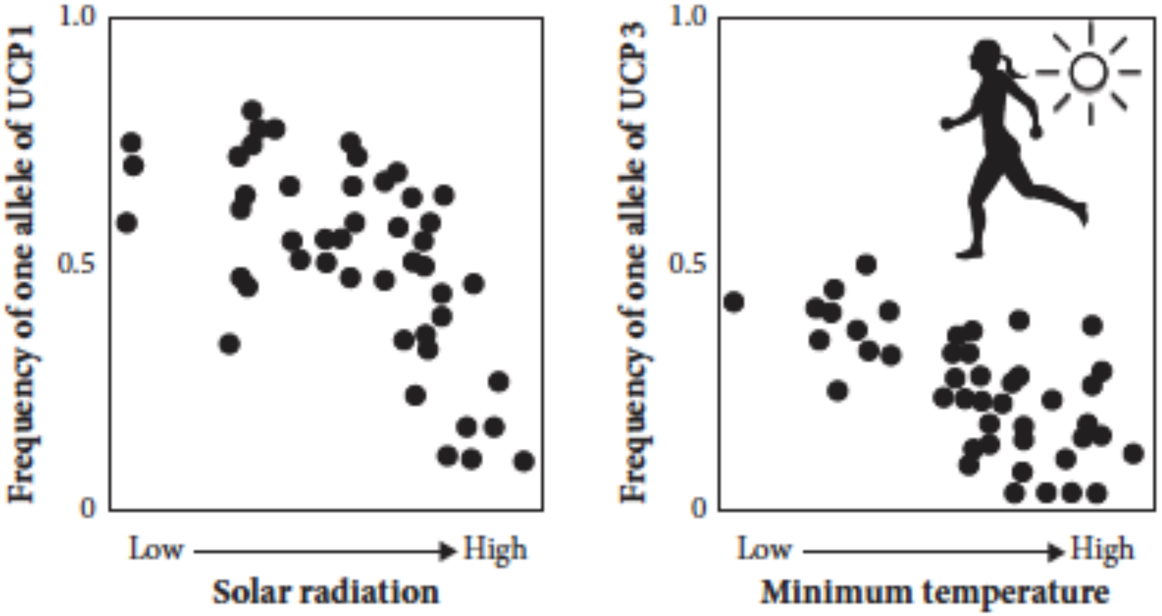


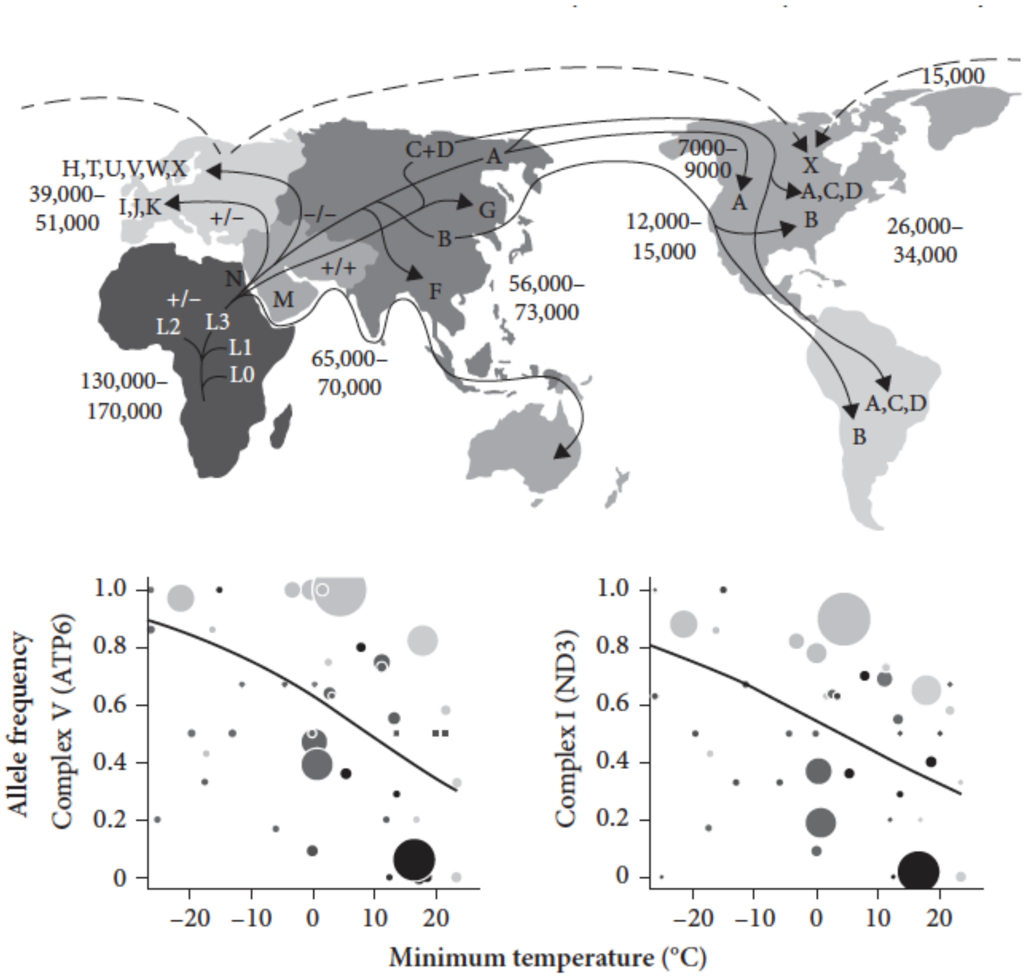


Rank et al. 2020

Examples of mt thermal adaptation

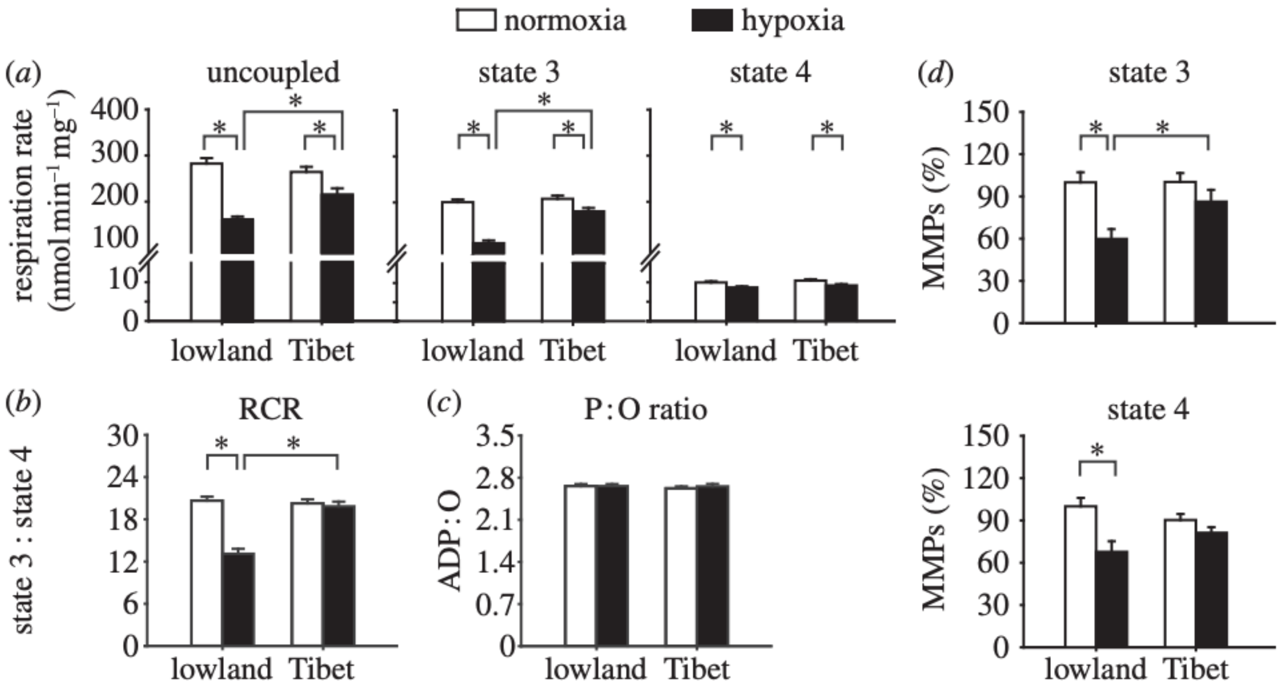
- Vertebrates
  - Birds
  - Mammals (mice)
  - Hoomans





Oxygen content

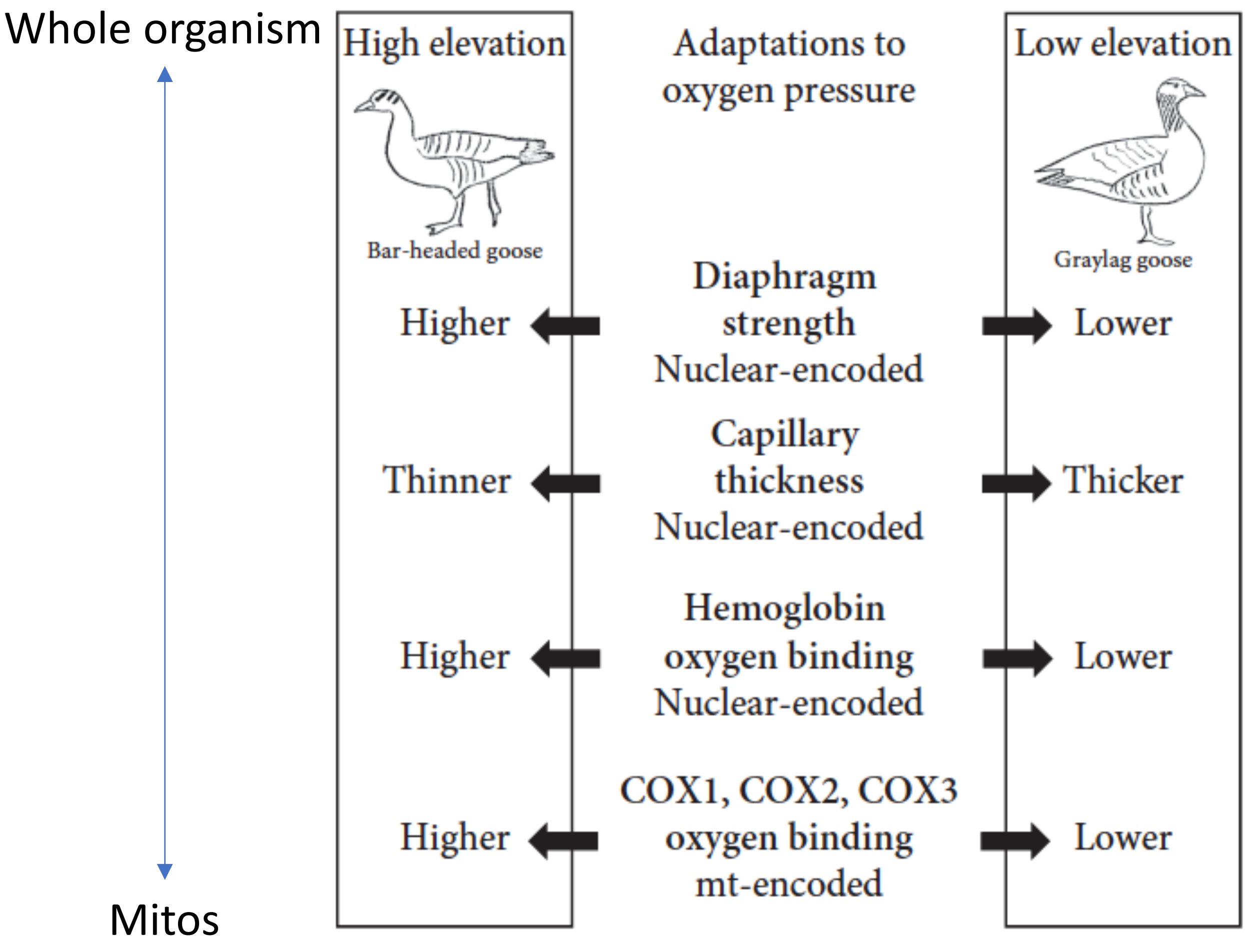
- Hypoxia
  - Altitude
  - Burrowing marine/FW organisms
- More precise biochemical pathway for selection to act on
- Often confounded with temp



Zhang et al. 2013

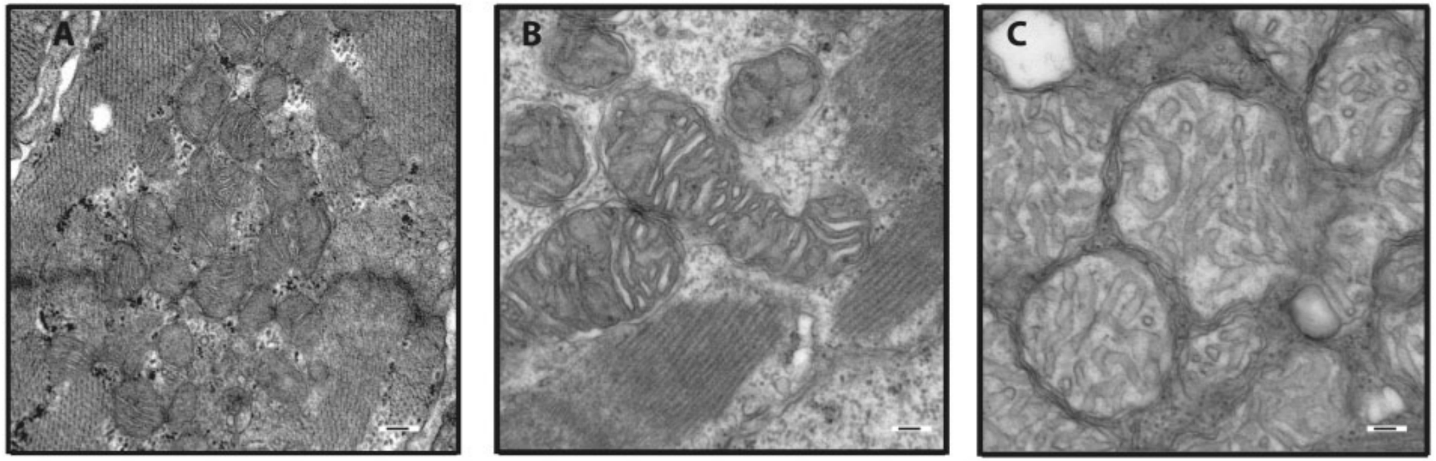
Oxygen content

- Many effects across levels of biological organization



Oxygen content

- Cool ice fishes
- Integrate across levels of organization



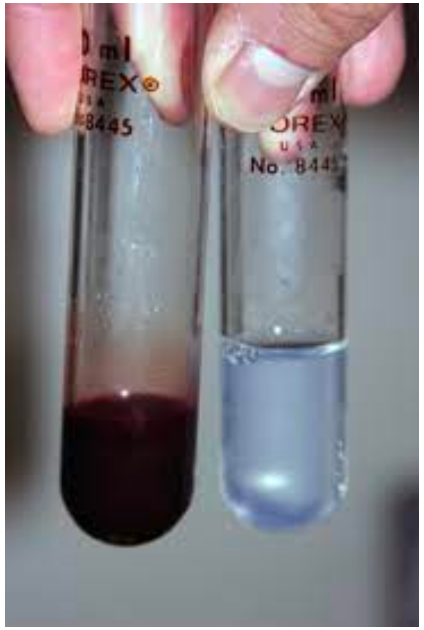


Table 2 Mitochondrial state III respiration rates of notothenioid fishes

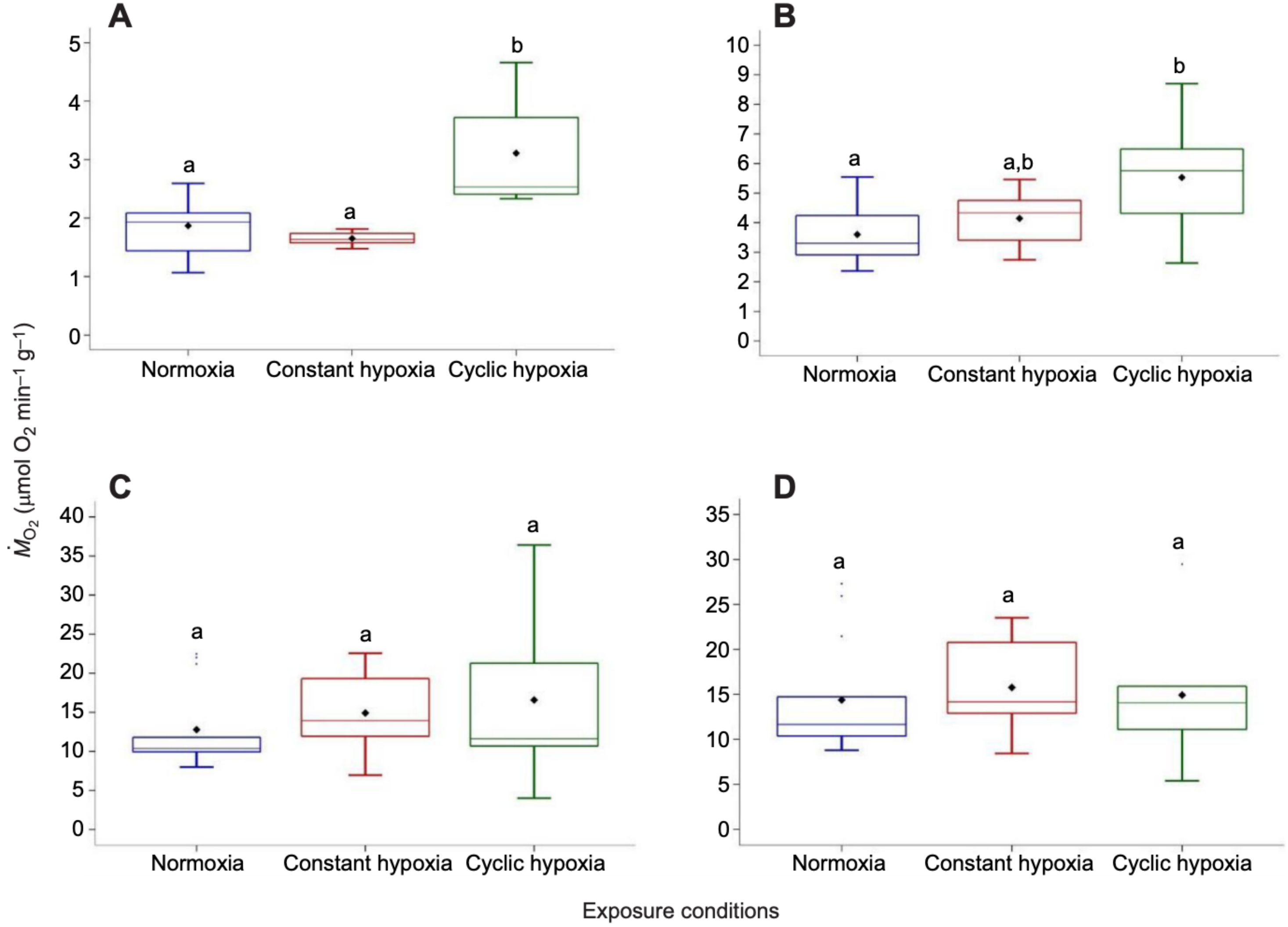
	Gobionotothen gibberifrons (+Hb/+Mb)	*Chionodraco rastrospinosus* (−Hb/+Mb)	*Chaenocephalus aceratus* (−Hb/−Mb)
State III respiration rate (nmol O_2 mg^{-1} protein min^{-1})	46.7 ± 0.9^{a}	$42.0 \pm 1.3^{a,b}$	38.5 ± 2.4^{b}

Measurements were made at 2°C in mitochondria isolated from heart ventricle by differential centrifugation. Values are presented as means ± SEM. ($N = 6$ for *G. gibberifrons* and *C. aceratus*; $N = 4$ for *C. rastrospinosus*). Letters denote significant differences among the species ($P < 0.05$). Adapted from Urschel and O'Brien (2009).

O'brien and Muller 2010

Oxygen content

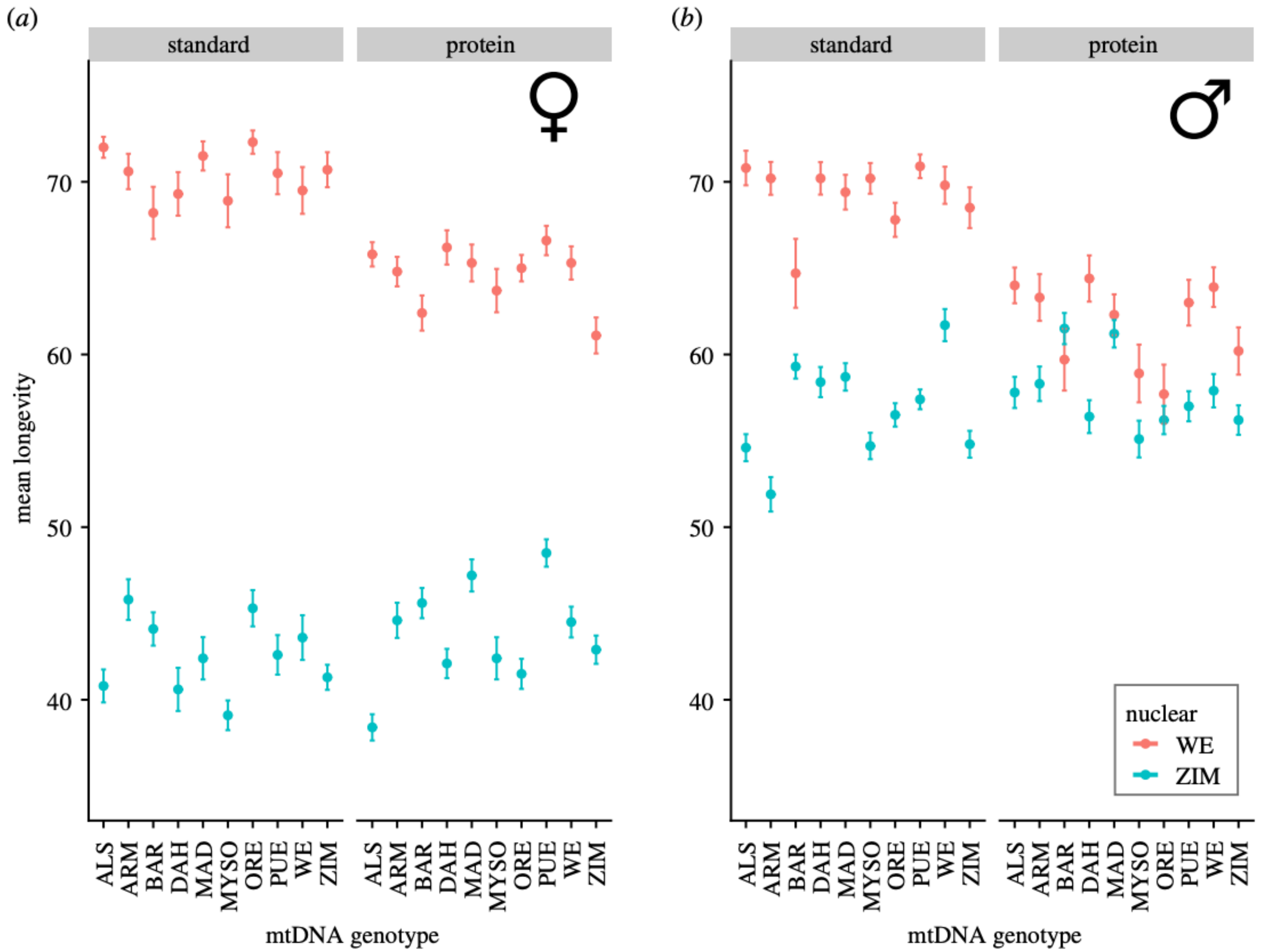
- Sokolova work



Oulion et al. 2020

Diet

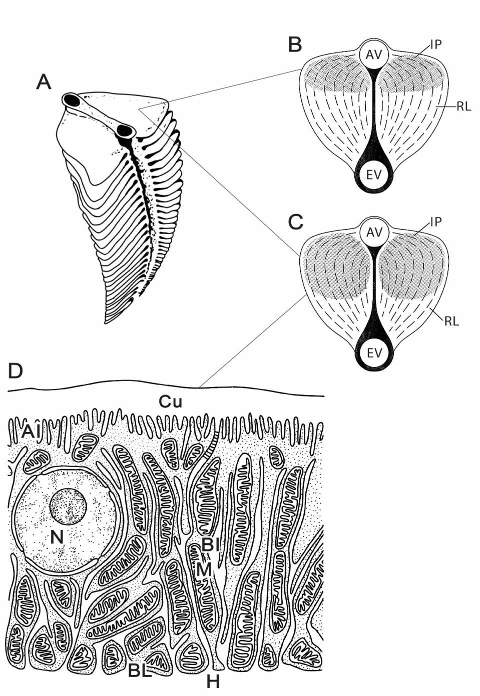
- Mitos transform food into energy
- Lots of *Drosophila* work
- Dowling, Rand work

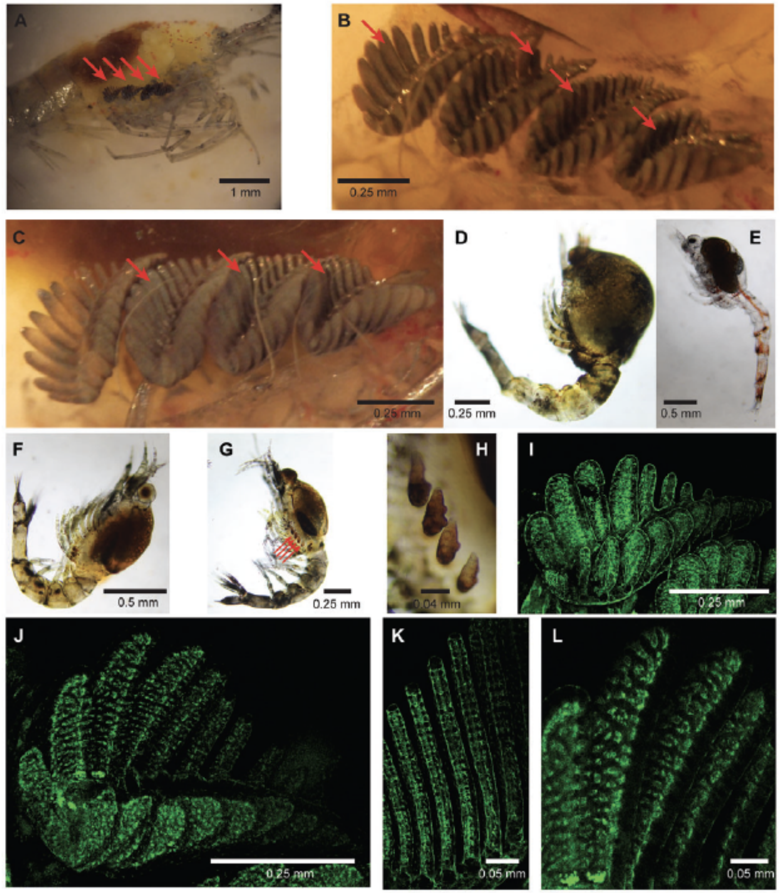


Camus et al. 2019

Salinity

- Some studies in plants looking at direct consequences of mt function (e.g., TCA cycle, transport of metabolites in mitos)
- Osmoregulation is very energetically expensive, MRCs
- Living in variable salinities may require highly efficient mitos

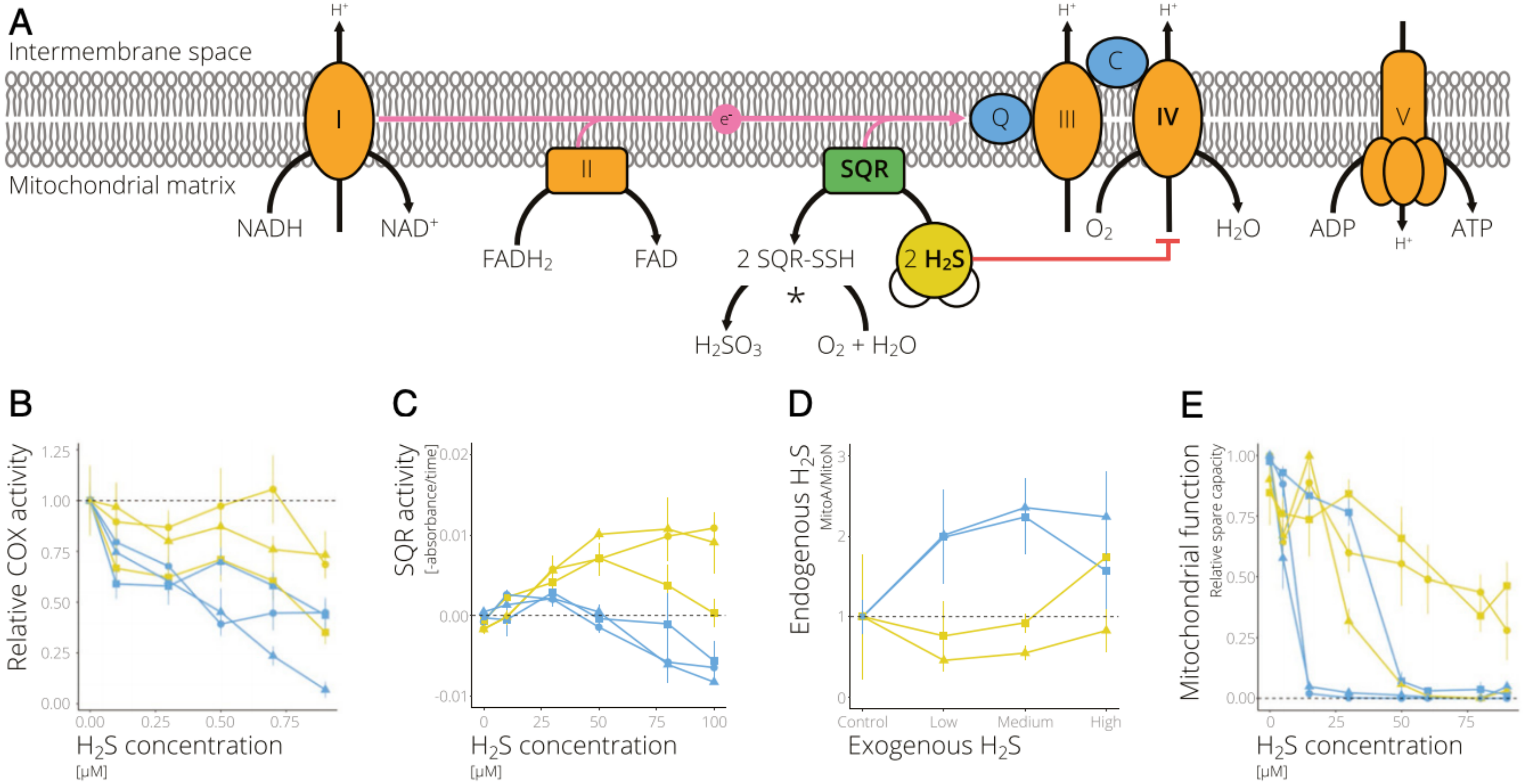




Havird et al. 2014 – yeah!

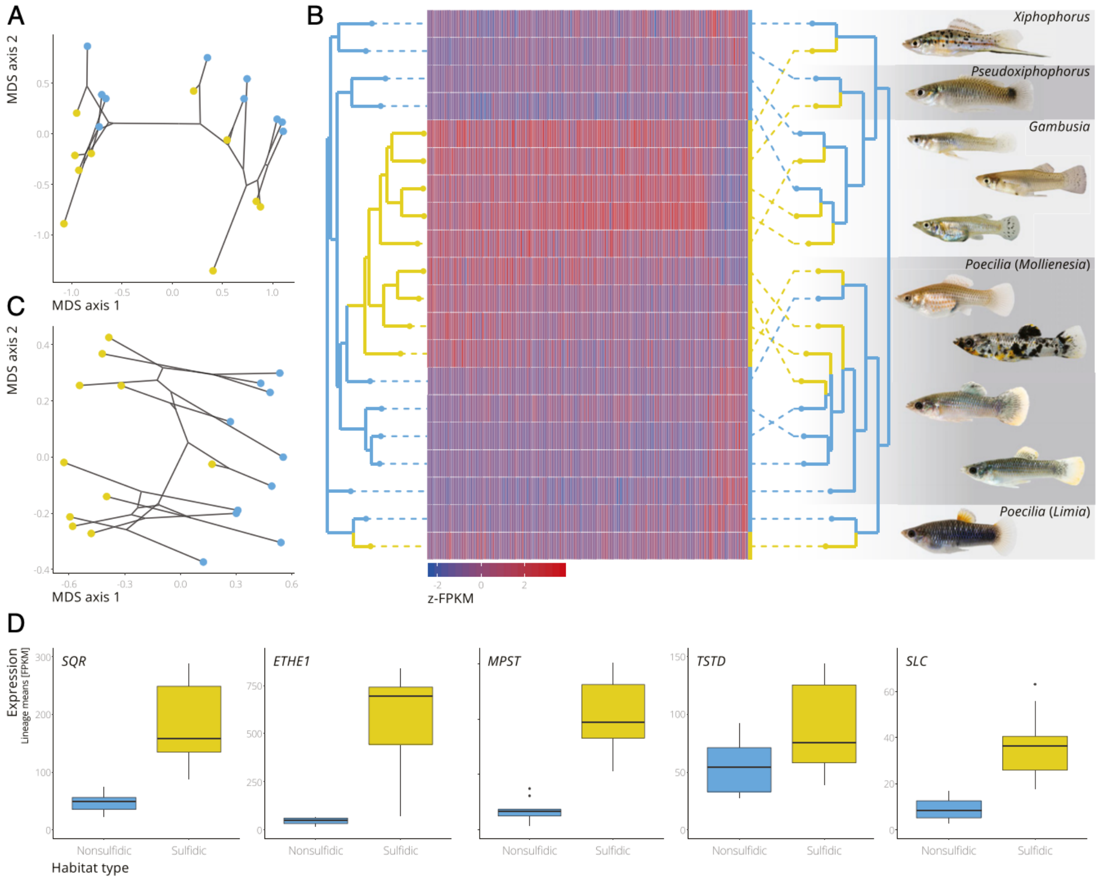
H_2S

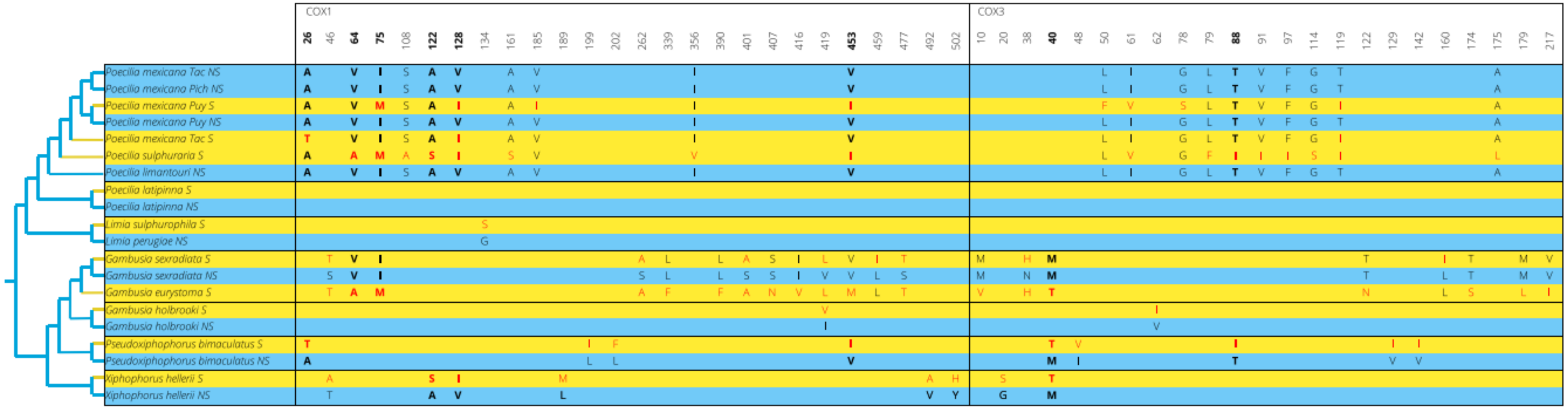
- Some organisms have adapted to H2S rich environments
- It’s a OXPHOS poison, acting on COX



Greenway et al. 2020

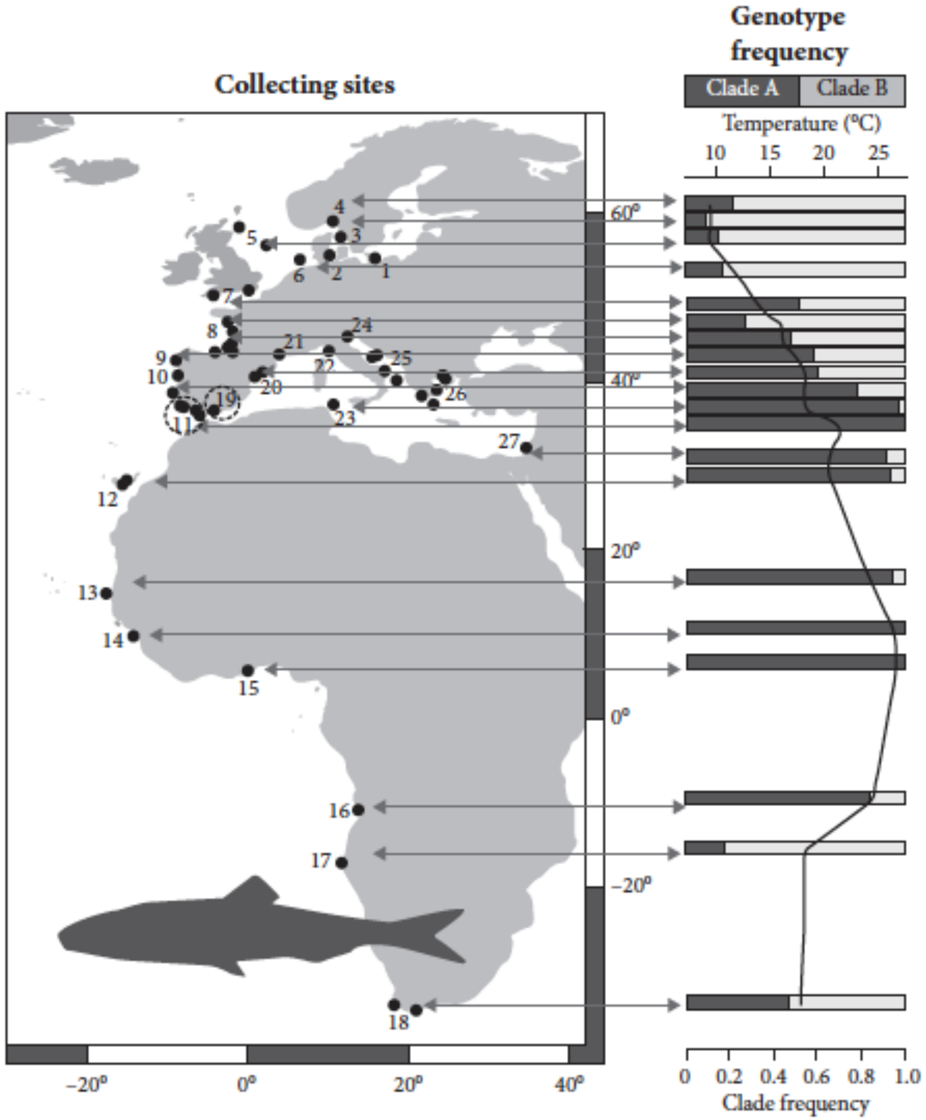
H2S


A
B
C
D
MDS axis 1
MDS axis 2
Xiphophorus
Pseudoxiphophorus
Gambusia
Poecilia (Mollienesia)
Poecilia (Limia)
z-FPKM
Expression
Lineage means [FPKM]
SQR
ETHE1
MPST
TSTD
SLC
Nonsulfidic
Sulfidic
Habitat type


COX1
COX3
Poecilia mexicana Tac NS
Poecilia mexicana Pich NS
Poecilia mexicana Puy S
Poecilia mexicana Puy NS
Poecilia mexicana Tac S
Poecilia sulphuraria S
Poecilia limantouri NS
Poecilia latipinna S
Poecilia latipinna NS
Limia sulphurophila S
Limia perugiae NS
Gambusia sexradiata S
Gambusia sexradiata NS
Gambusia eurystoma S
Gambusia holbrooki S
Gambusia holbrooki NS
Pseudoxiphophorus bimaculatus S
Pseudoxiphophorus bimaculatus NS
Xiphophorus hellerii S
Xiphophorus hellerii NS

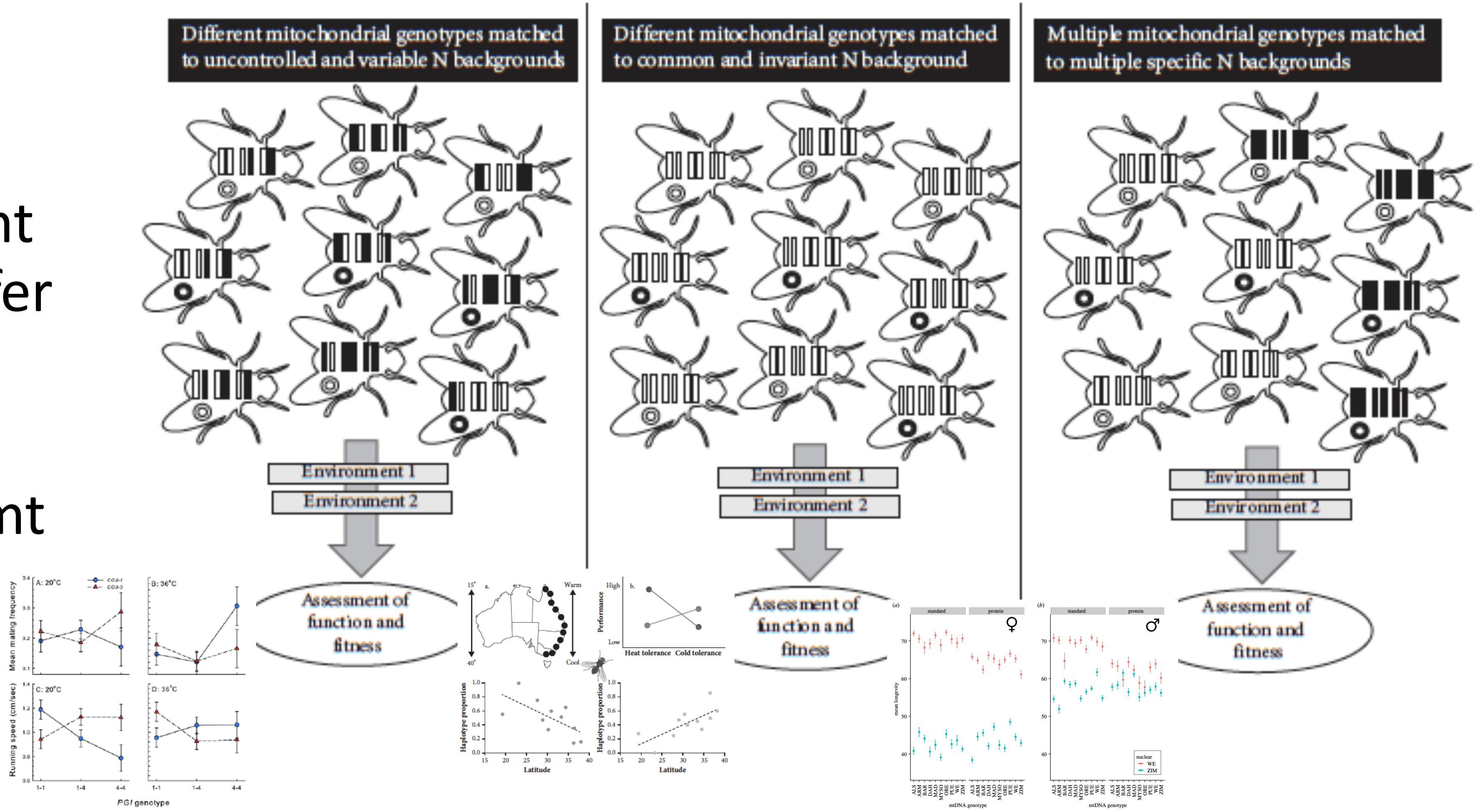
Ways to test/measure mitonuclear adaptation

- Clinal analyses of mt haplotypes



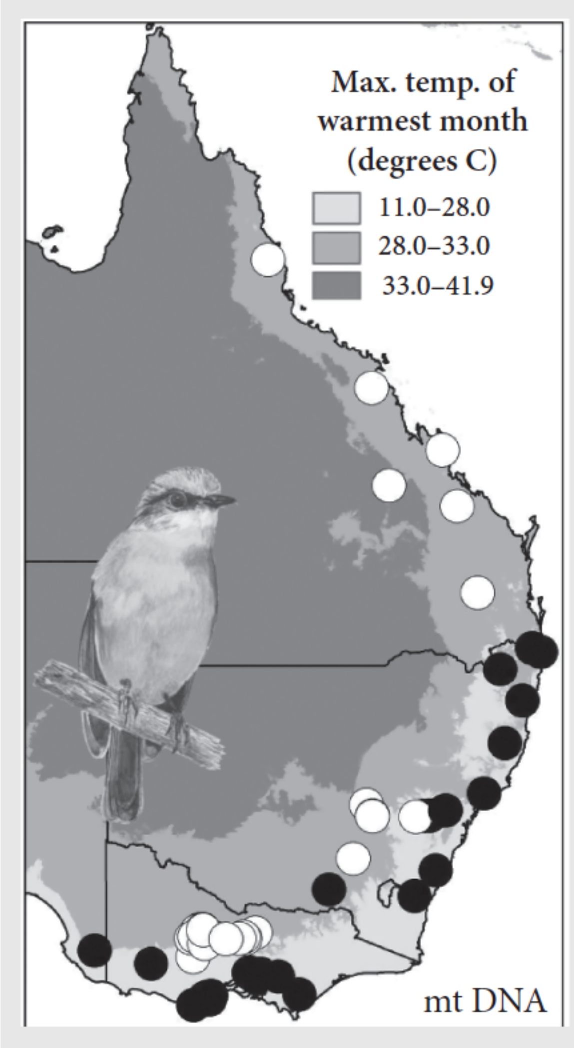
Ways to test/measure mitonuclear adaptation

- Laboratory experiments to confirm those mt haplotypes confer environmental advantage
- Controlling for mt and nuc genetic differences



Rank et al. 2020 Camus et al. 2017 Camus et al. 2019

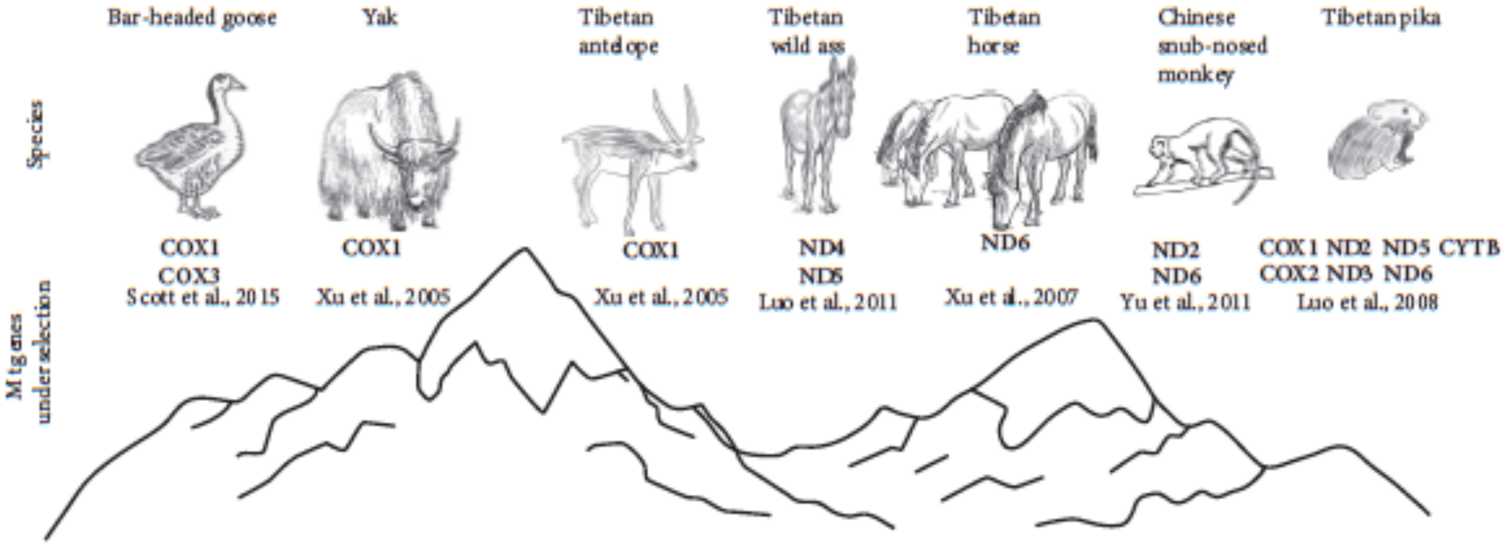
Do N-mt genes coadapt with mt genes?



Morales et al. 2017

Looking for signatures of positive selection on mt genes

- Lots of thermal/altitudinal studies invoking selection on mt genes

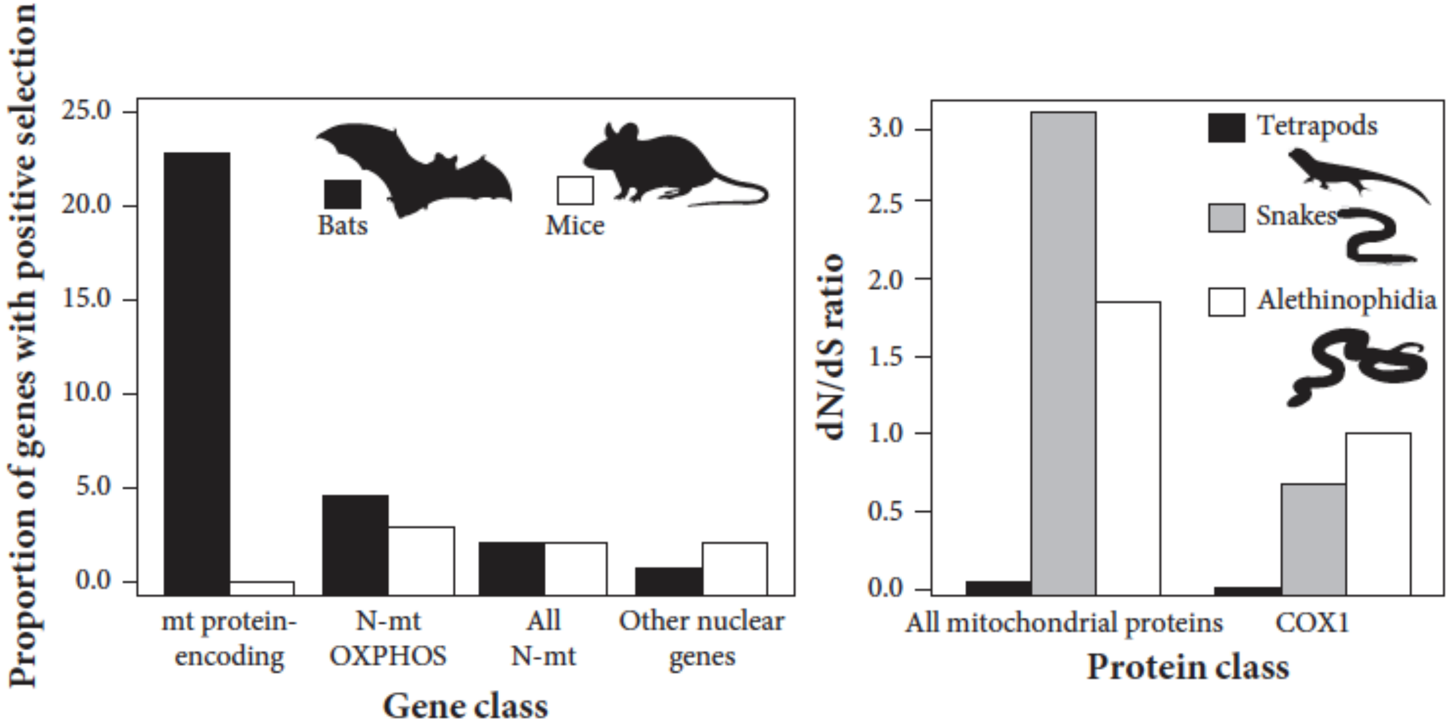


Some caveats

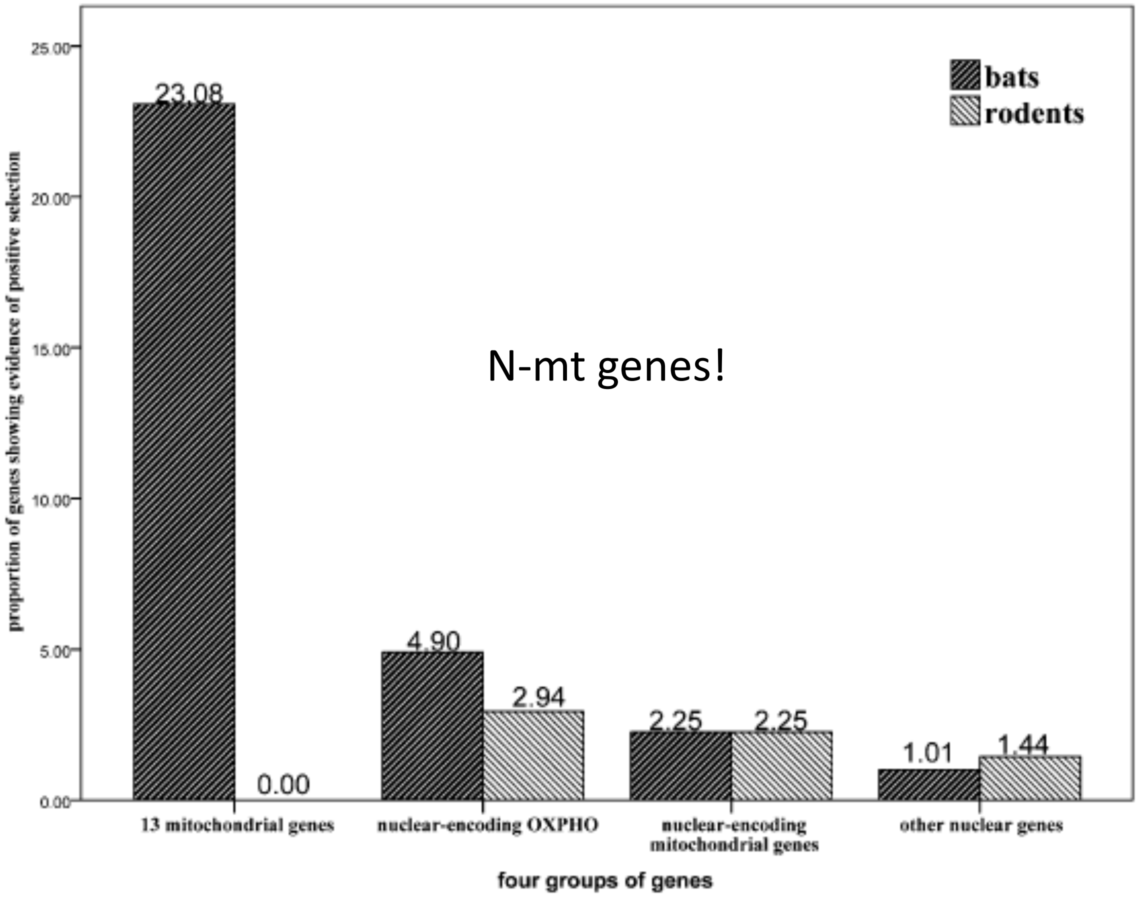
- Looking for signatures of selection on sequences is relatively easy
- Mt gene sequences are very abundant
- Easy to come up with "just so" stories
- Very few studies do any follow-up experimentation
- Most studies find signatures of selection on single sites in mt genes of target lineages (branch-site tests)
  - These are not hypothesis-driven
  - You will usually find a handful of sites given enough divergence (which is common in mt genes)
- Does not address mito*nuclear* environmental adaptation

Adaptive radiations

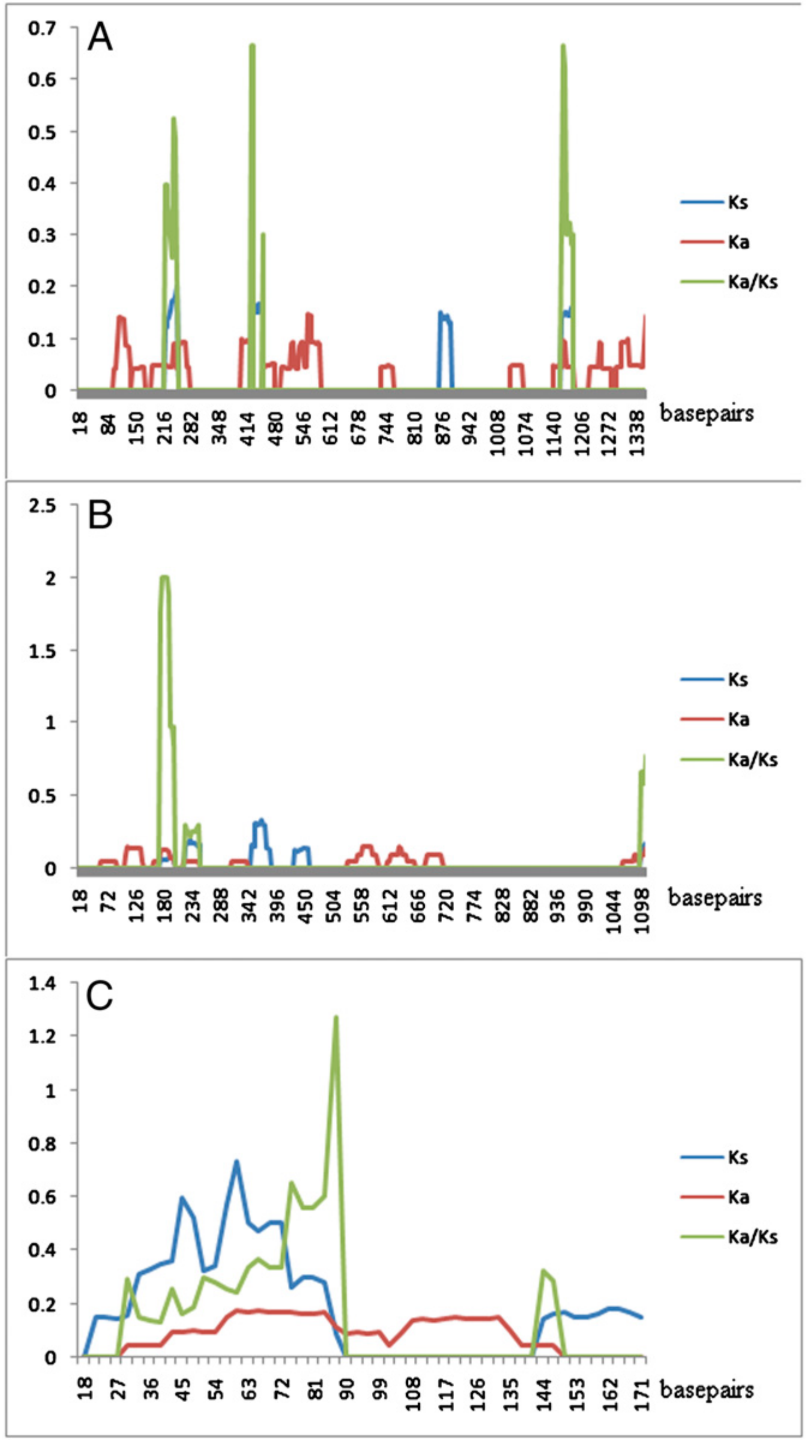
- Changes in mt genes and their N-mt counterparts may have facilitated exploitation of new niches and species radiations
- E.g., flight in bats, diet in snakes, big brains in primates (Osada and Akashii 2012)



Bats – Shen et al. 2010

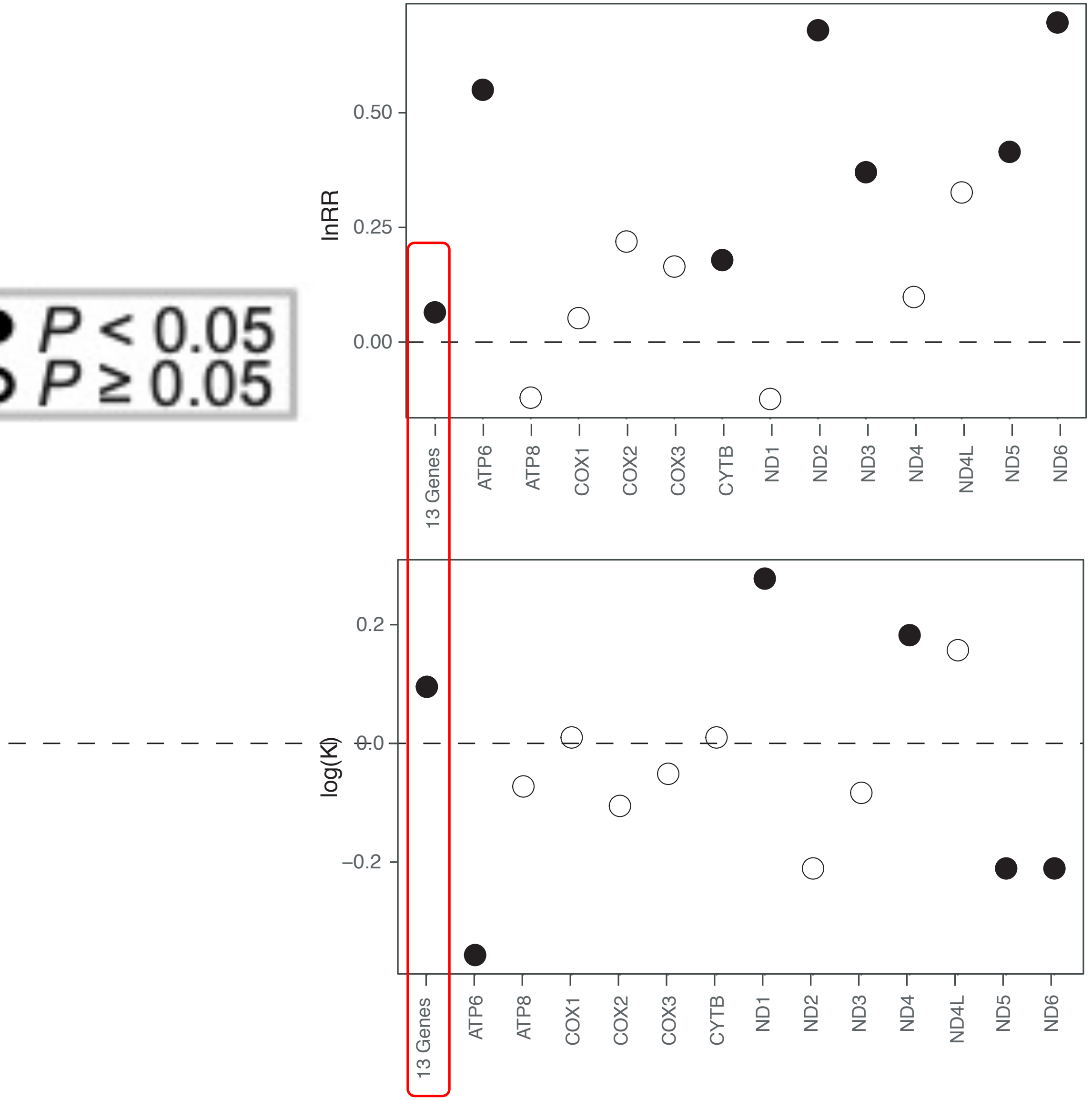


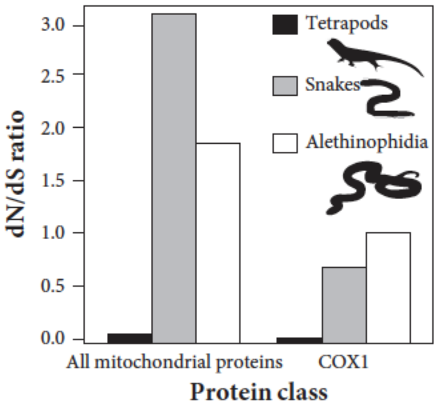
N-mt genes!

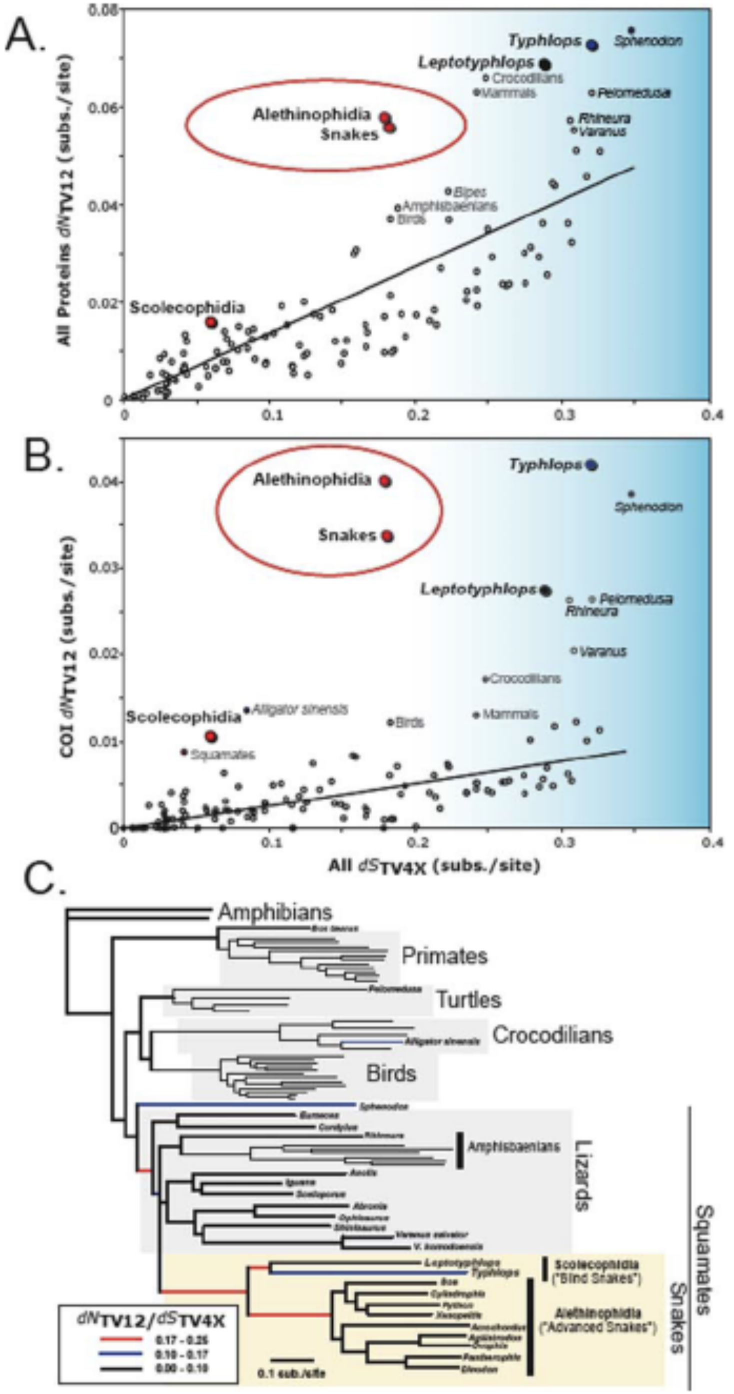


Snakes - Castoe et al. 2008

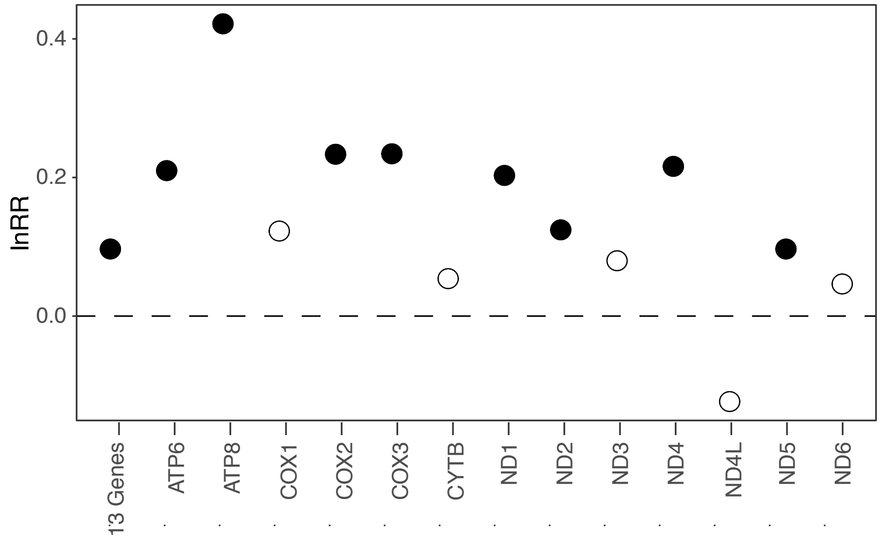
● $P < 0.05$
○ $P \geq 0.05$

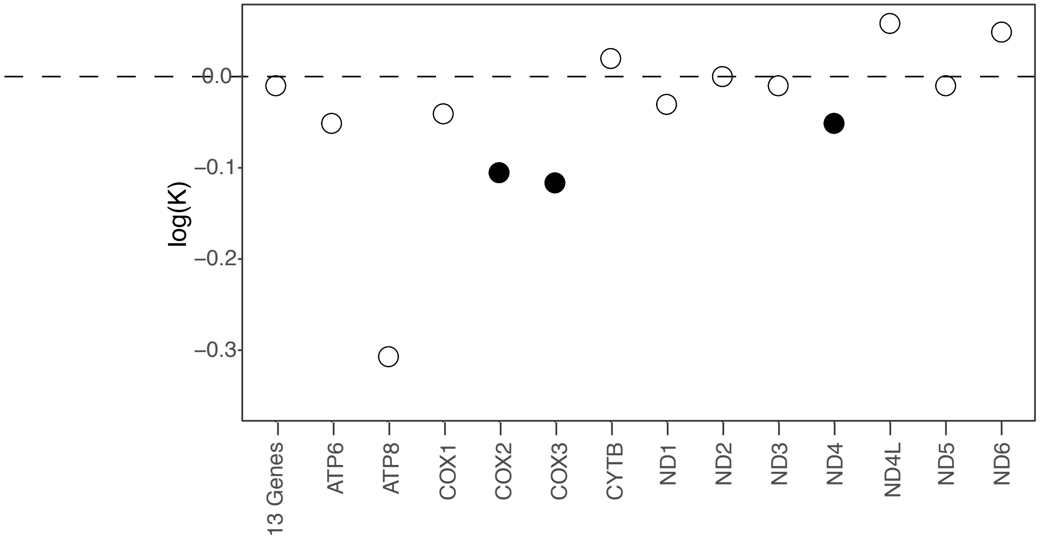


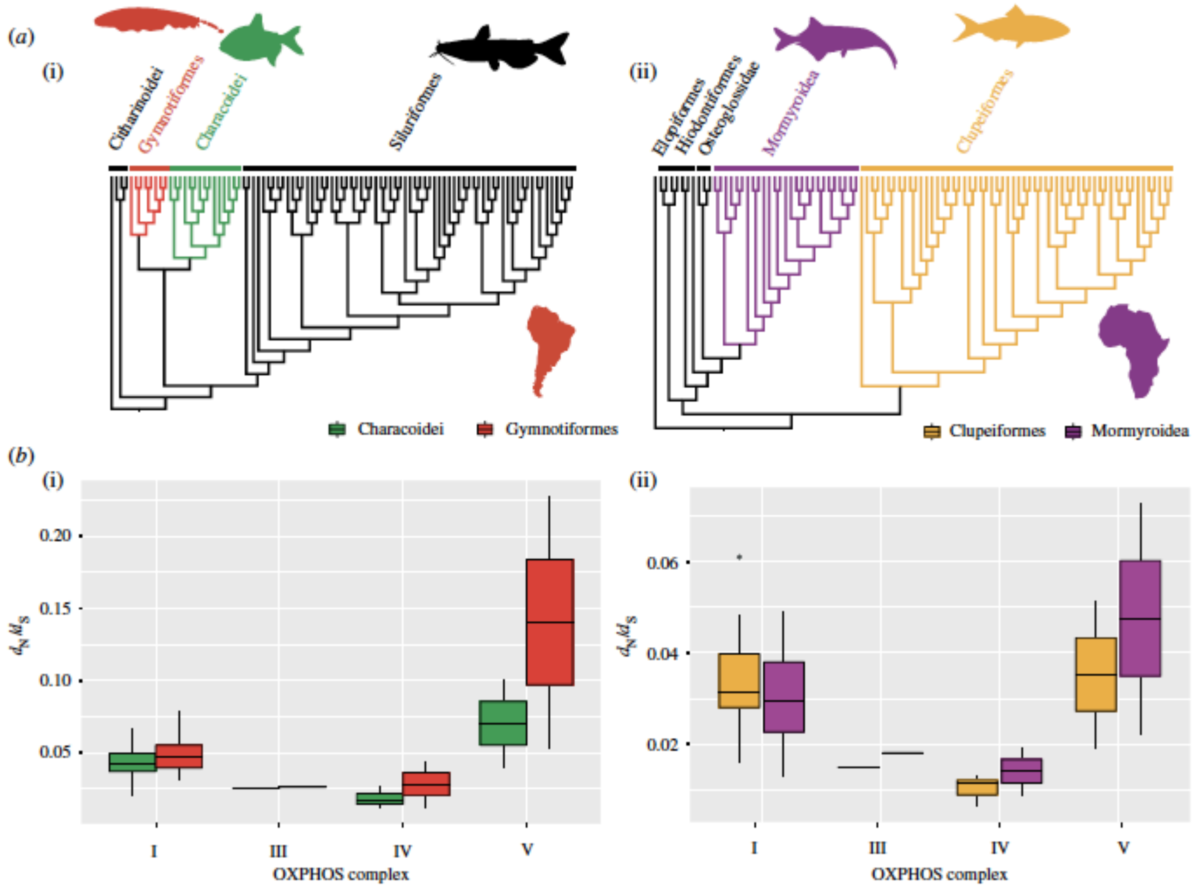




Electric fishes – Elbassiouny et al. 2019

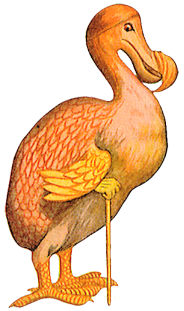


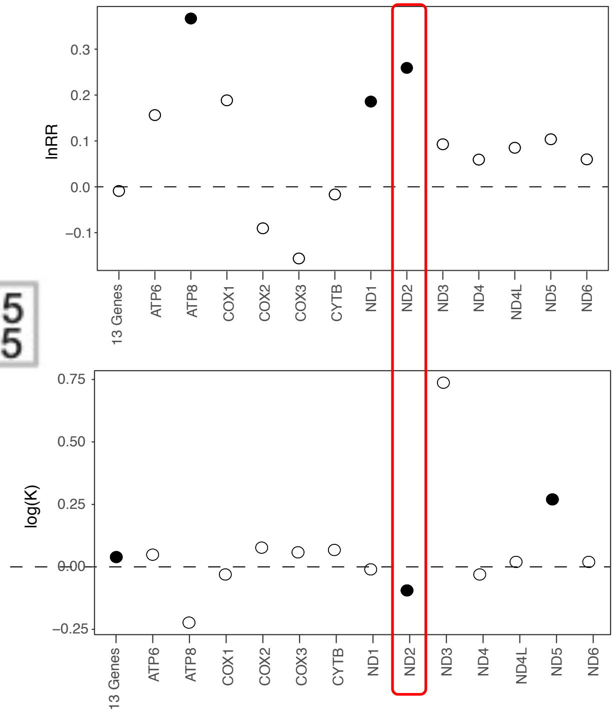


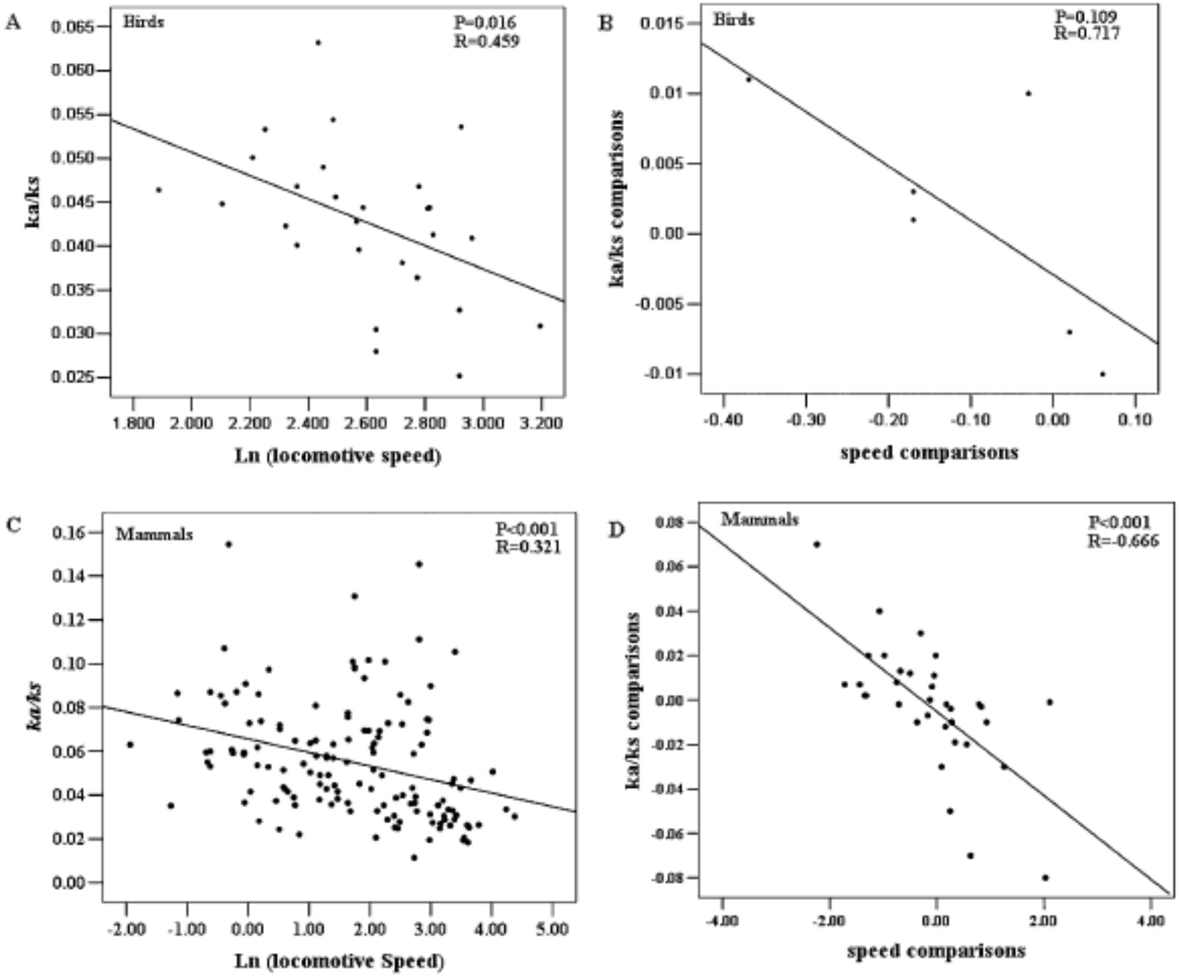


Can use to test for relaxed selection on mt function also

- Shen et al. 2009 – flight/locomotion
- Mitterboek et al. 2014 - flight







Plastid adaptation

- Light regimes? Not a lot of great work, although plenty of sites identified and “diverse environments” invoked
- Relaxed selection on pt genomes in parasitic plants is well documented