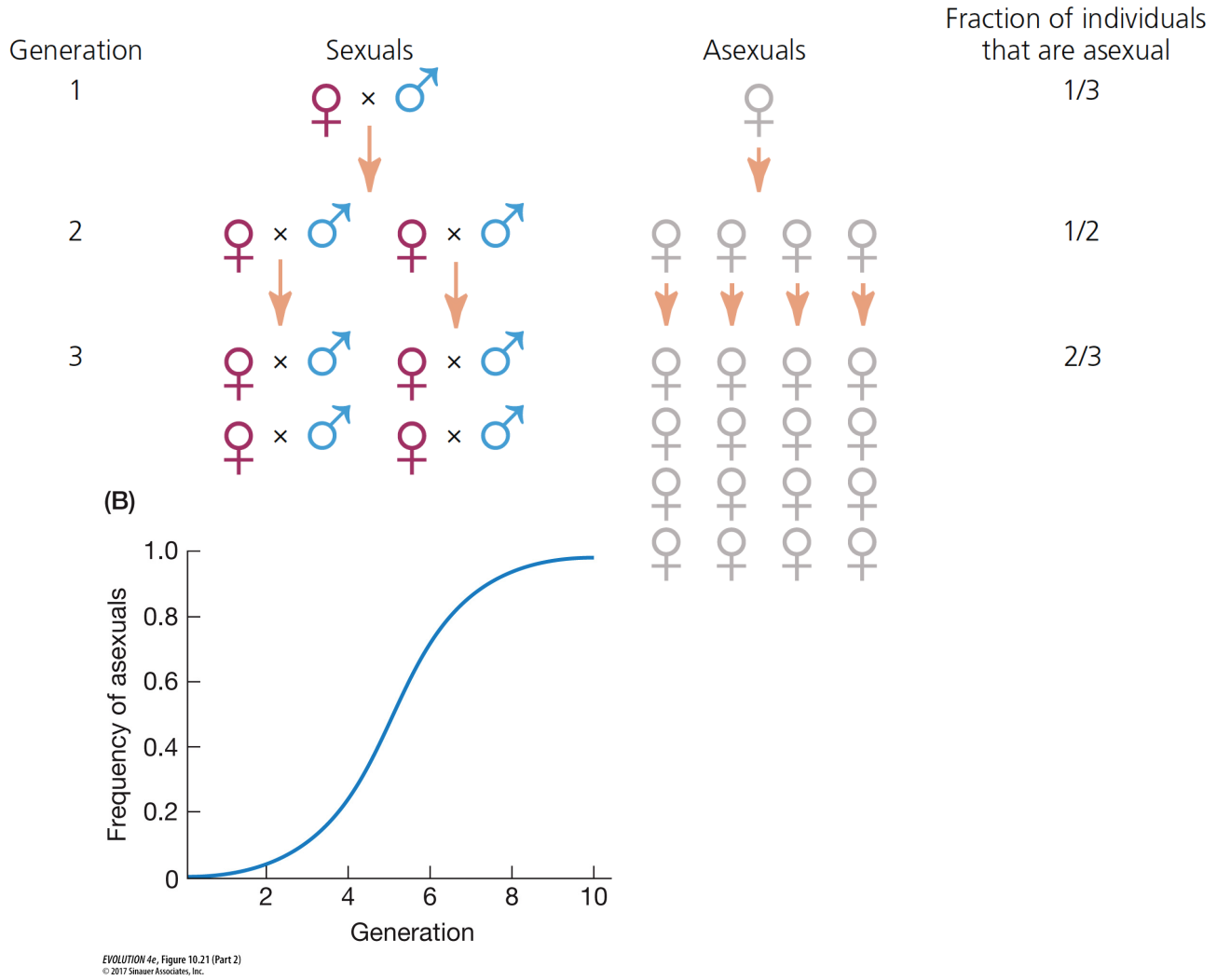
The evolution of sex and two sexes

Better to reproduce sexually or asexually?

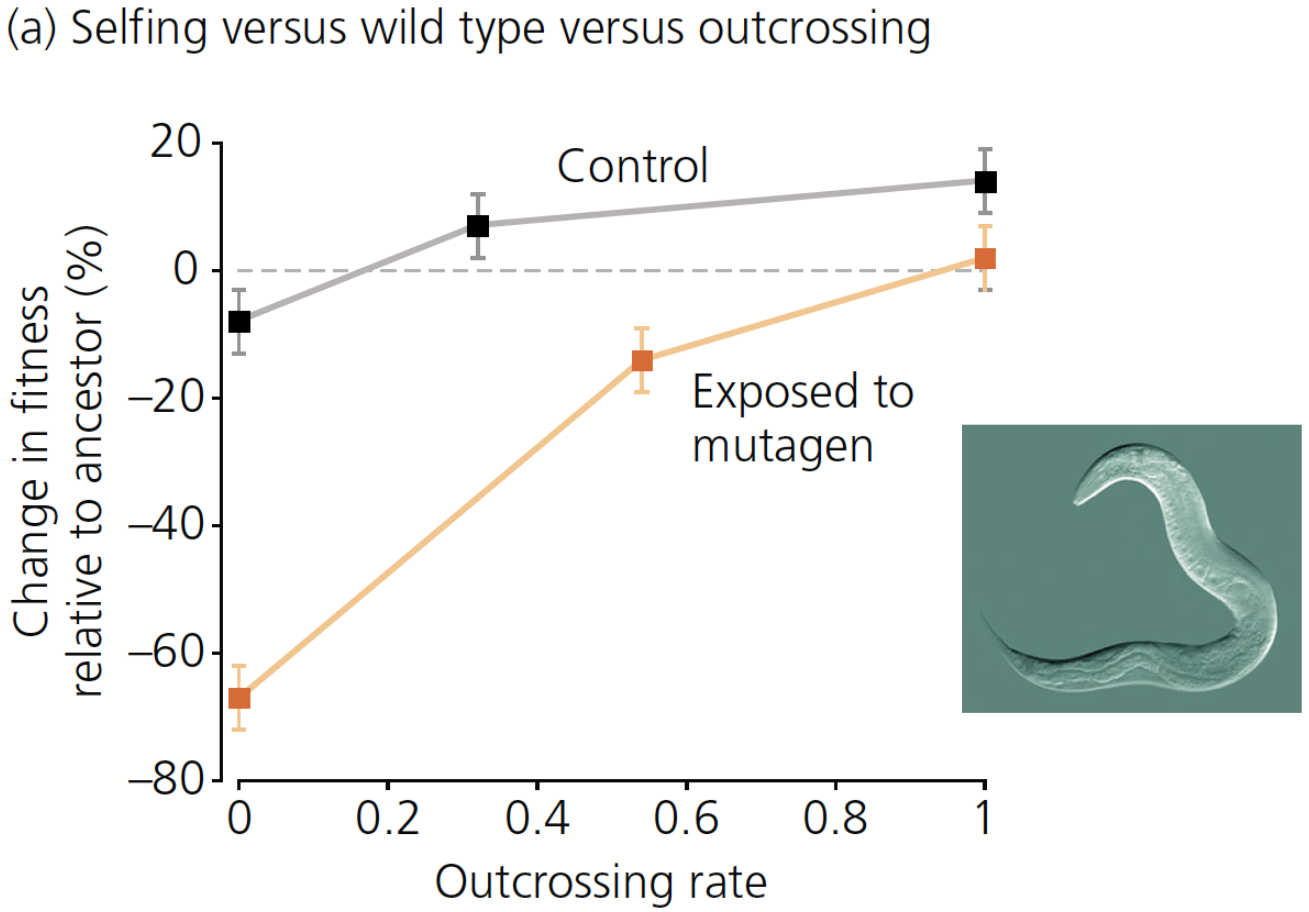
- All else being equal, asexuals produce twice as many daughters
- Cost of males
- "Two-fold" cost of sex
  1) Males
  2) Only ½ genes are passed on
- Why is sex so common then? – paradox of sex



Maynard-Smith 1978

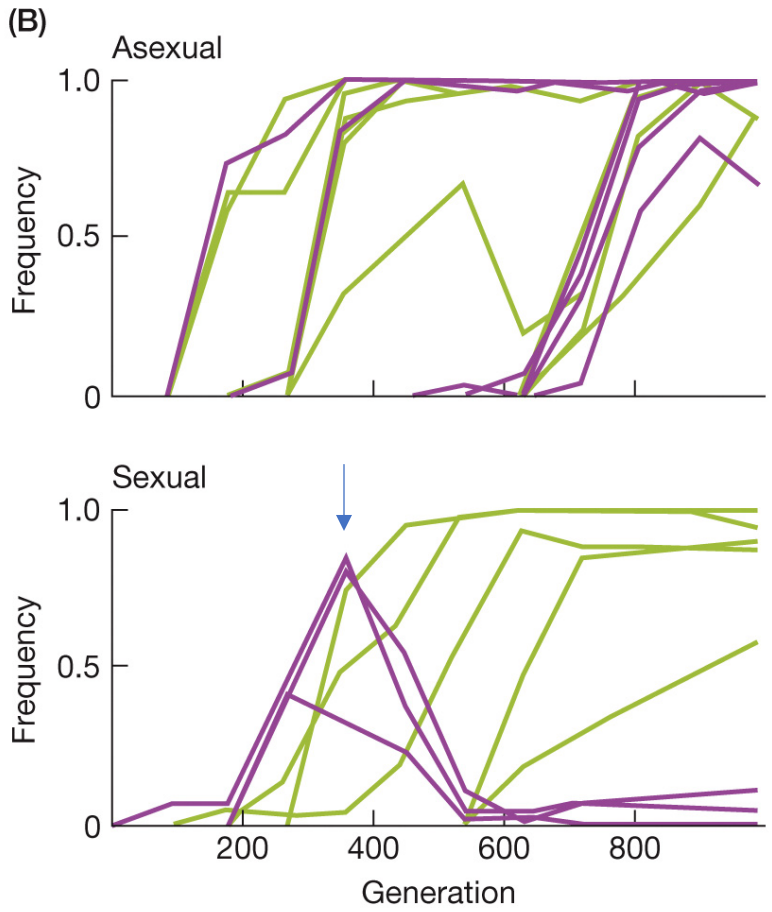
Is all else equal?

- In a harsh environment, sex resulted in a greater increase in fitness over 50 generations
- Effects were more extreme when mutation rate was increased



Morran et al. 2009

Fate of beneficial and deleterious alleles in sexual and asexual populations

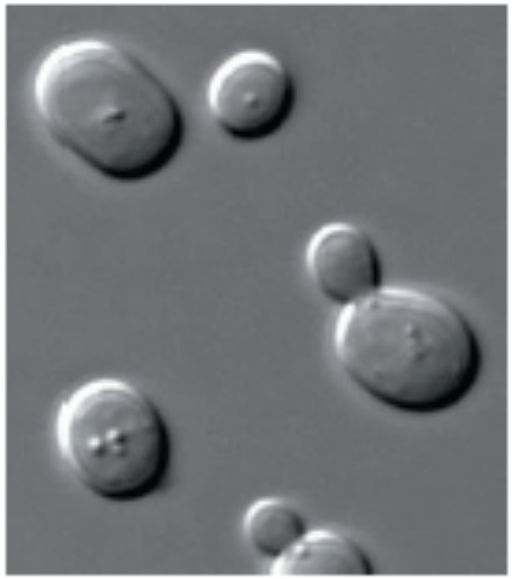


EVOLUTION 4e, Figure 10.25 (Part 2)

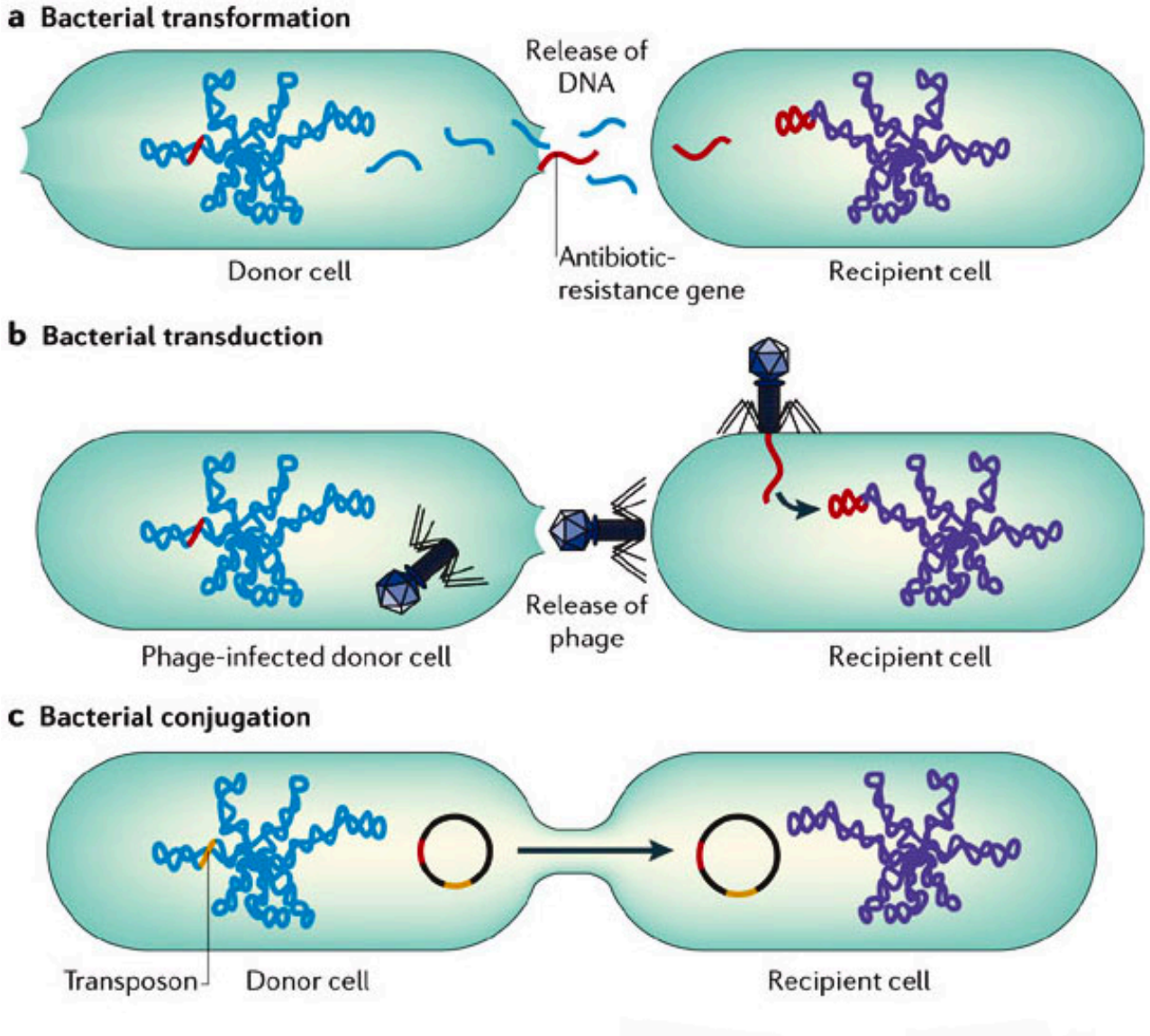
Beneficial mutations

Deleterious mutations

(b) Brewer's yeast



Gene exchange and recombination in prokaryotes



Bacteria vs. eukaryotes

- Though bacteria are predominantly asexual, the genetic information in their genomes can be expanded and modified through mechanisms that introduce DNA from outside sources. Bacterial sex differs from that of eukaryotes in that it is unidirectional and does not involve gamete fusion or reproduction. The input of DNA during bacterial sex generates diversity in two ways--through the alteration of existing genes by recombination and through the introduction of novel sequences--and each of these processes has been shown to aid in the survival and diversification of lineages – Narra and Ochman 2006
- Pan-genomes

Sex and eukaryotes

- It is ancestral
- It is nearly universal
- Exceptions are short-lived
- Sex genes/molecular signatures found

in most taxa considered asexual

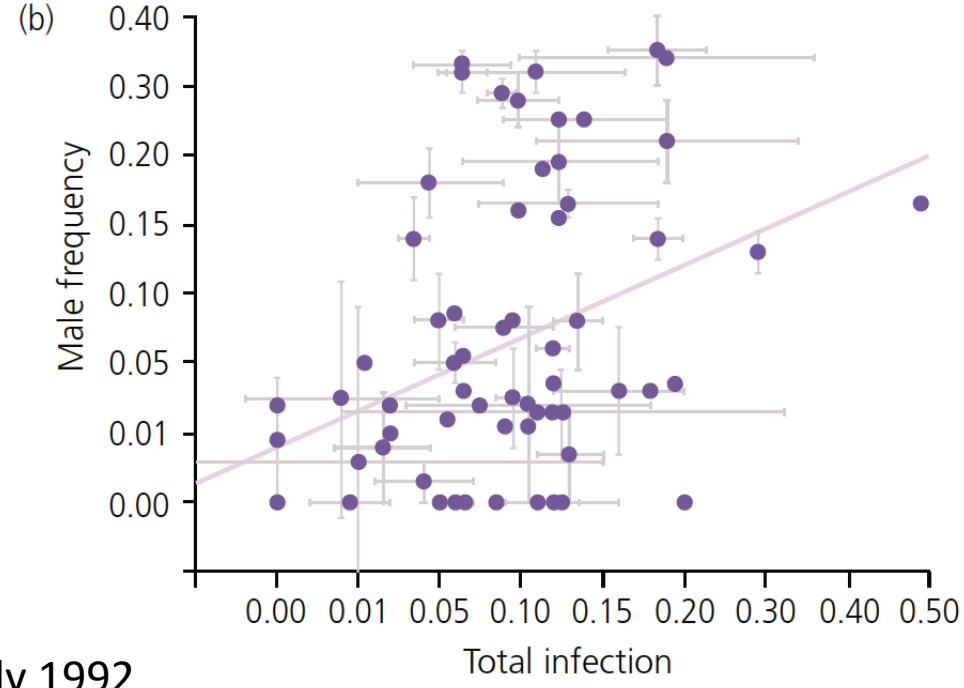
Genomic signatures of recombination in a natural population of the bdelloid rotifer *Adineta vaga* – *Vakarhushiva et al. 2020*

Sexual Reproduction in Bdelloid Rotifers – Laine et al. 2020

Why?

- Selection needs to be efficient
  - At fixing beneficial alleles – red queen
  - At removing deleterious alleles – Muller's ratchet

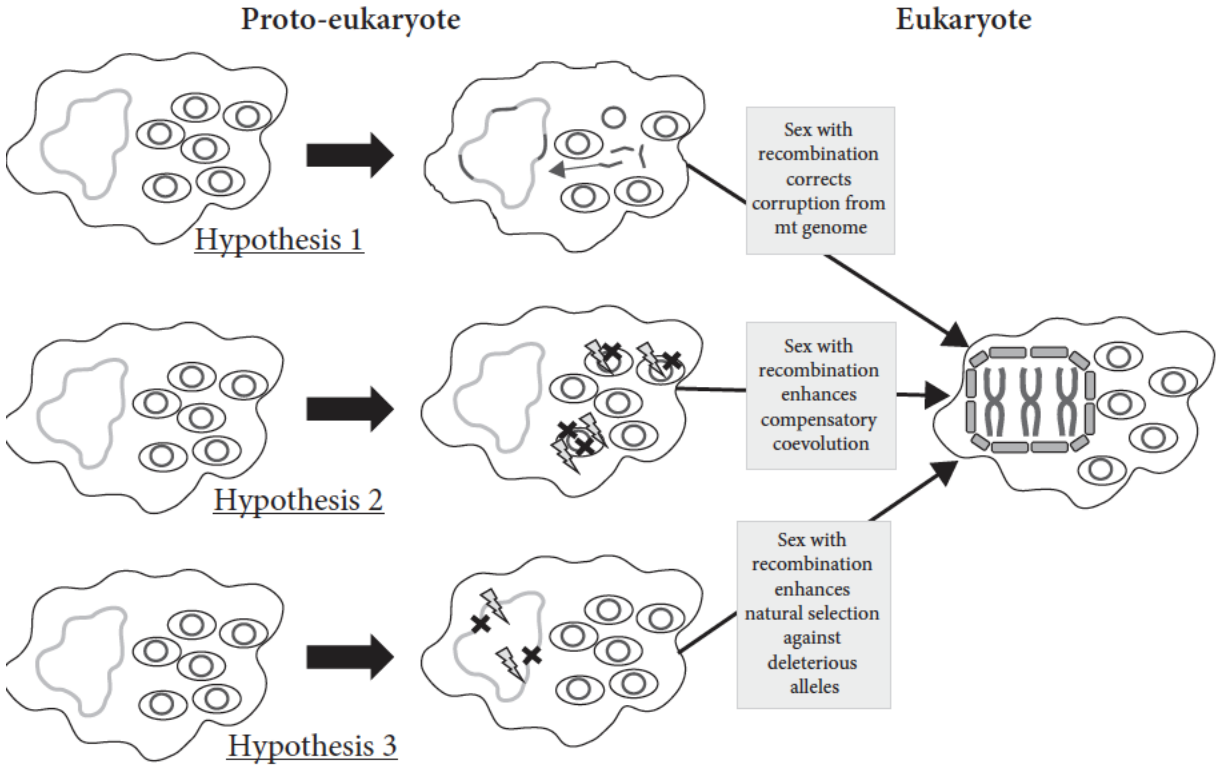
"Here, you see, it takes all the running you can do to keep in the same place."



Lively 1992

Hypotheses tying mitos with sex

- Hypothesis 1
  - Introns and spliceosome
  - Martin and Koonin 2006
- Hypothesis 2
  - Compensatory coevolution
  - “Red ratchet”
  - Havird et al. 2015
- Hypothesis 3
  - ROS in nuclear genome
  - Speijer 2016



Evidence

- Rare
- New hypotheses and models are still being published

Review Article | Open Access | Published: 15 May 2020

Oxygen, life forms, and the evolution of sexes in multicellular eukaryotes

Elvira Hörandl & Franz Hadacek

Heredity **125**, 1–14(2020) | Cite this article

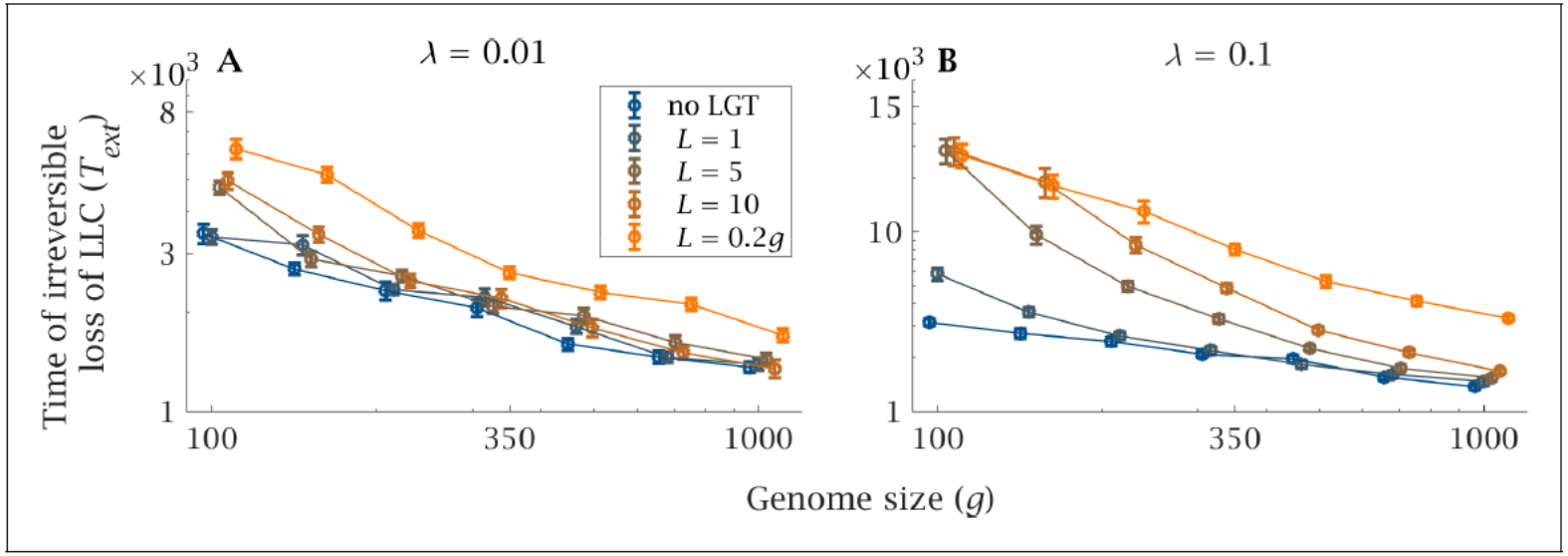
2676 Accesses | **2** Citations | **15** Altmetric | Metrics

eLife RESEARCH ARTICLE

Genome expansion in early eukaryotes drove the transition from lateral gene transfer to meiotic sex

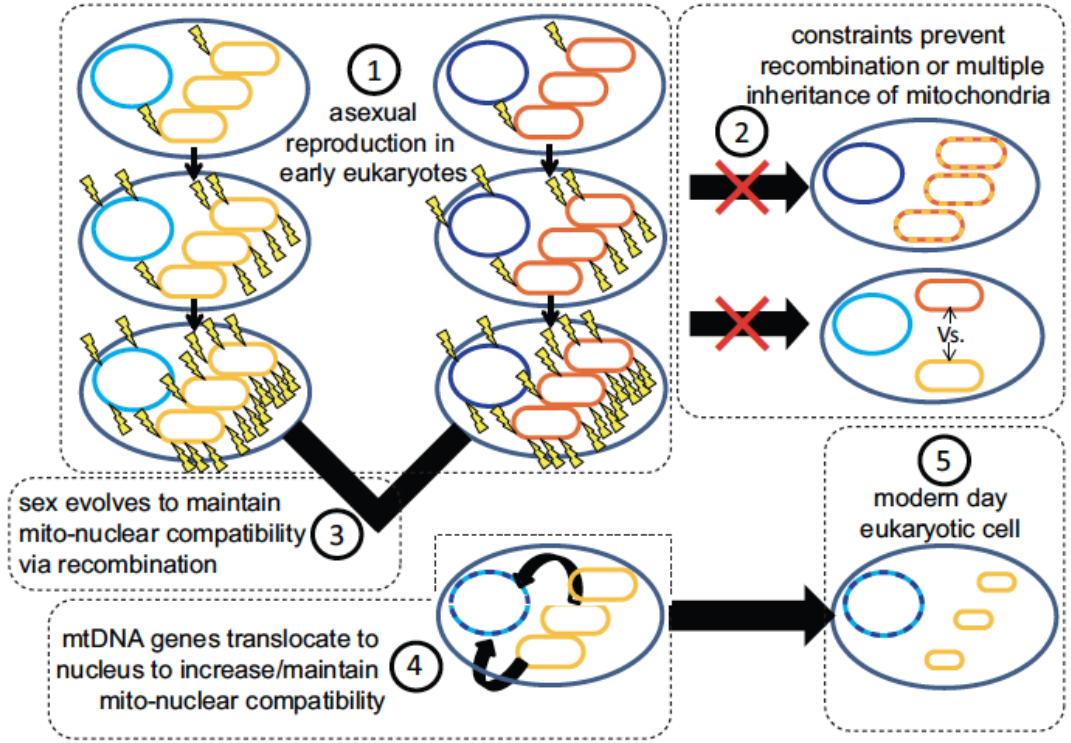
Marco Colnaghi[1,2], Nick Lane[1,2], Andrew Pomiankowski[1,2]*

[1]CoMPLEX, University College London, London, United Kingdom; [2]Department of Genetics, Evolution and Environment University College London, London, United Kingdom



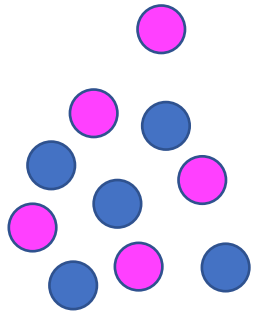
Timing the evolution of sex

- "… the evolution of eukaryotes, mitochondria, and sexual reproduction occurred simultaneously"

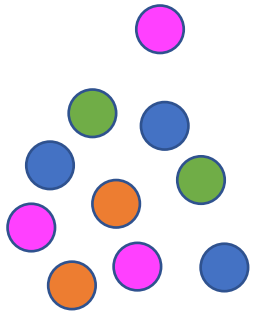


Why two sexes?

- % of population you can mate with is worst



Vs.

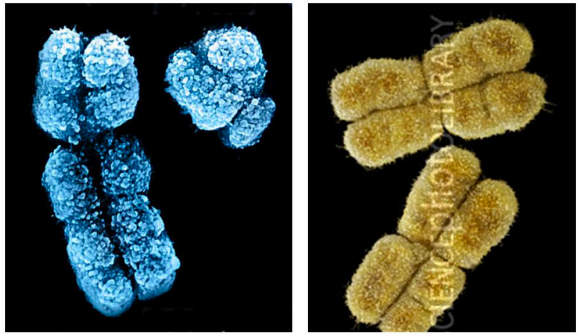


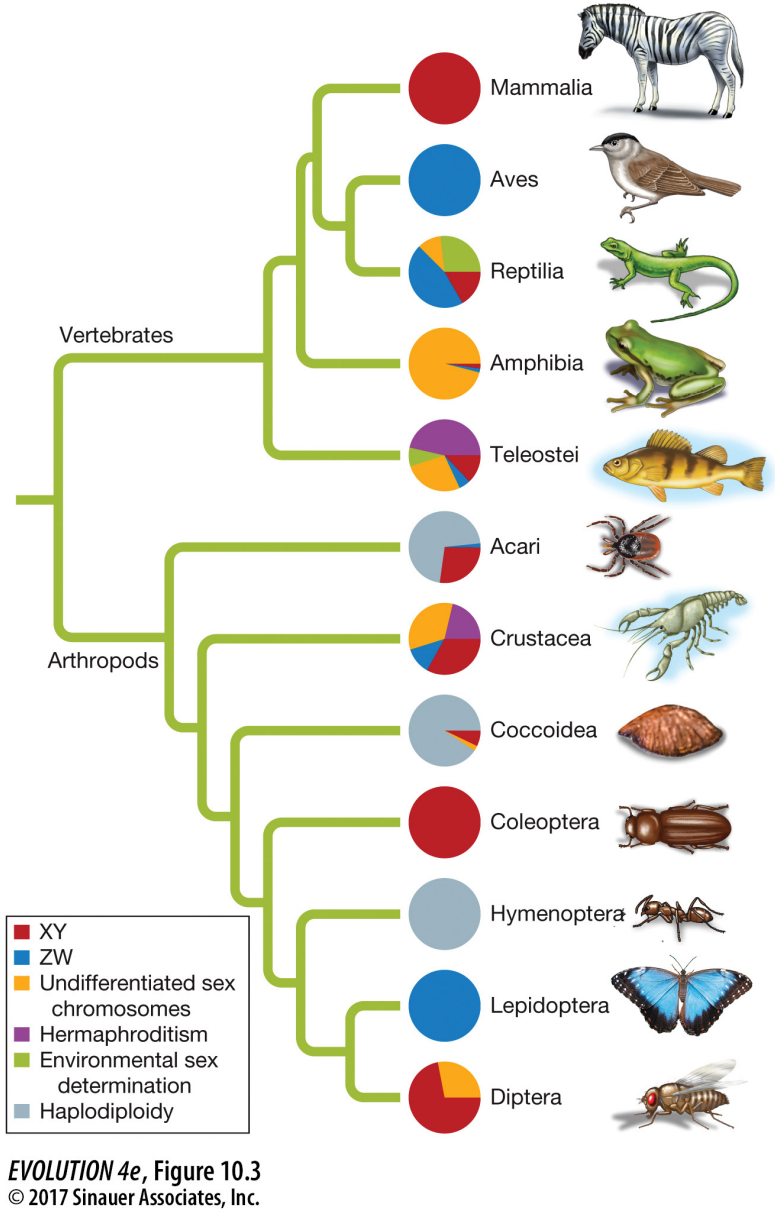
What is sex?

- How do we define males vs. females (i.e., sex)?

External genitalia?

Sex chromosomes?



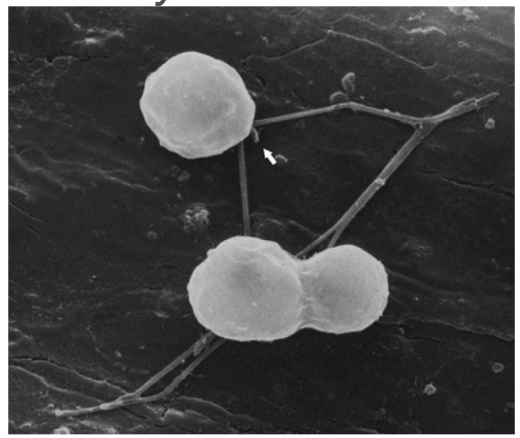


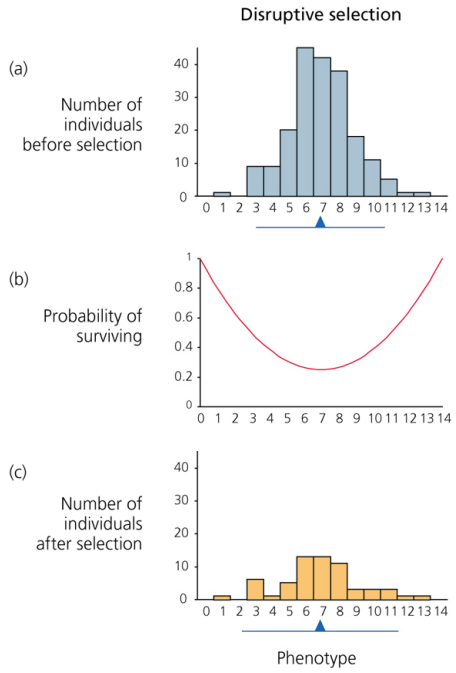
EVOLUTION 4e, Figure 10.3

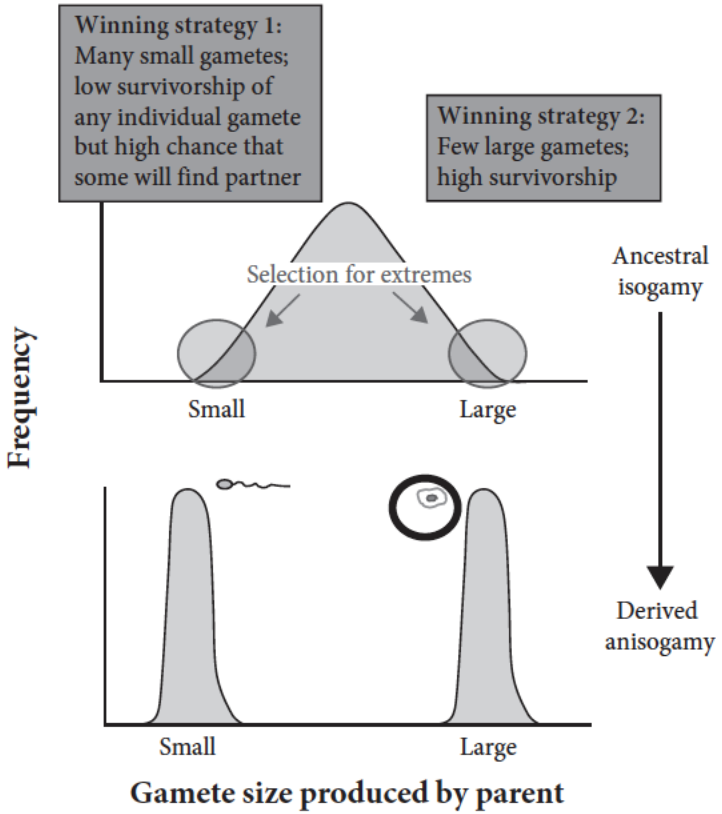
Gamete size

- females produces the larger gamete
- Not perfect – isogamy
- Why no intermediate gametes?
- Alternative, mt based definition

Chlamydomonas

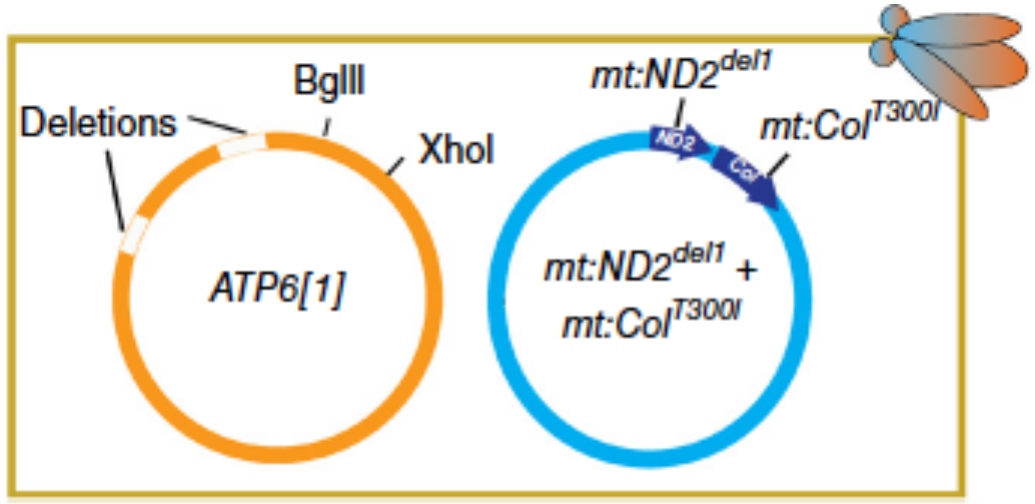


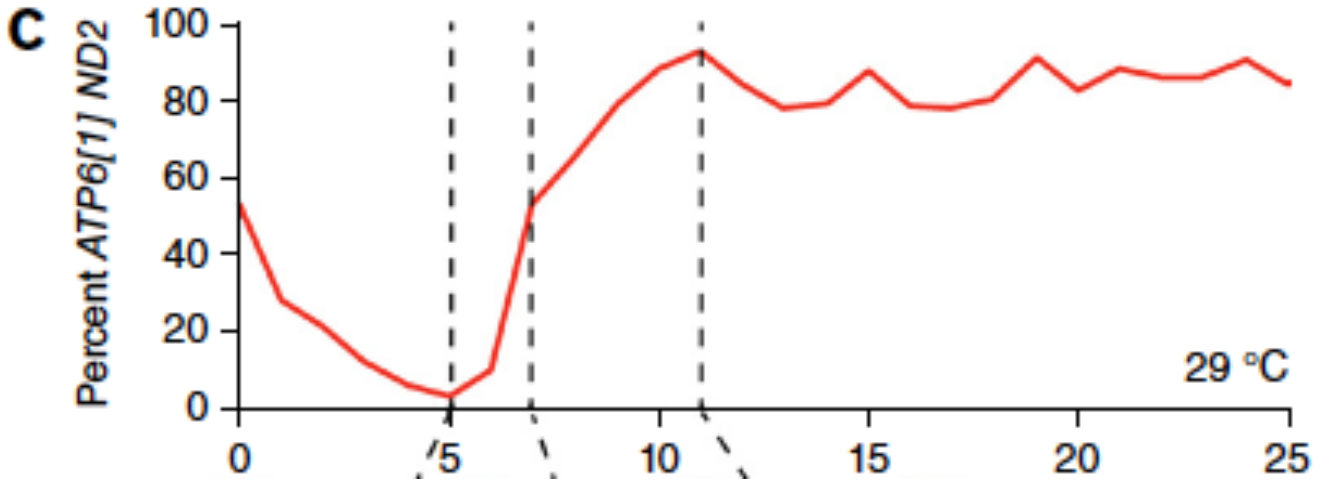




Why heteroplasmy is bad

- Selfish conflict within an individual
- Types of heteroplasmy

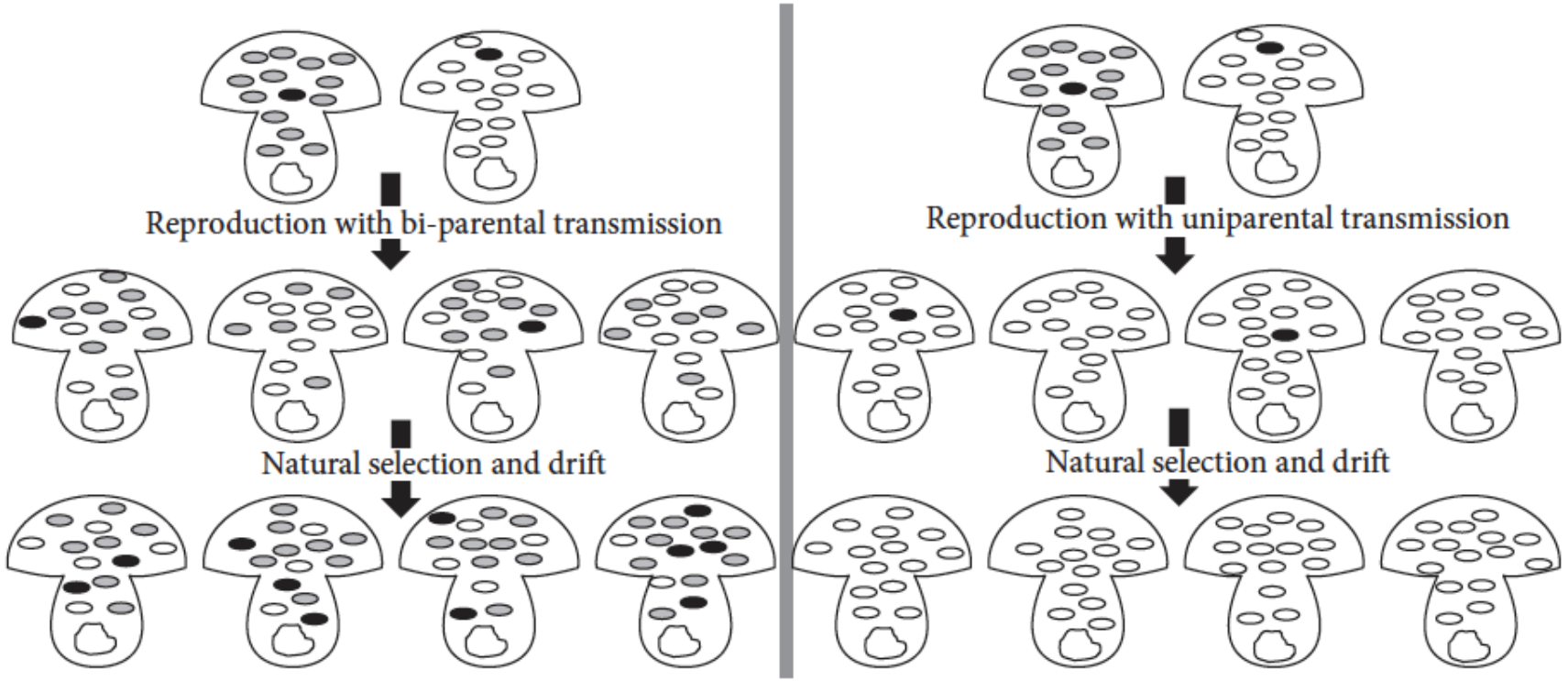




Ma and O'Farrell 2016

Uniparental inheritance and units of selection

Muller's ratchet
Assumptions



Lots of modeling work on this

- Hadjivasiliou

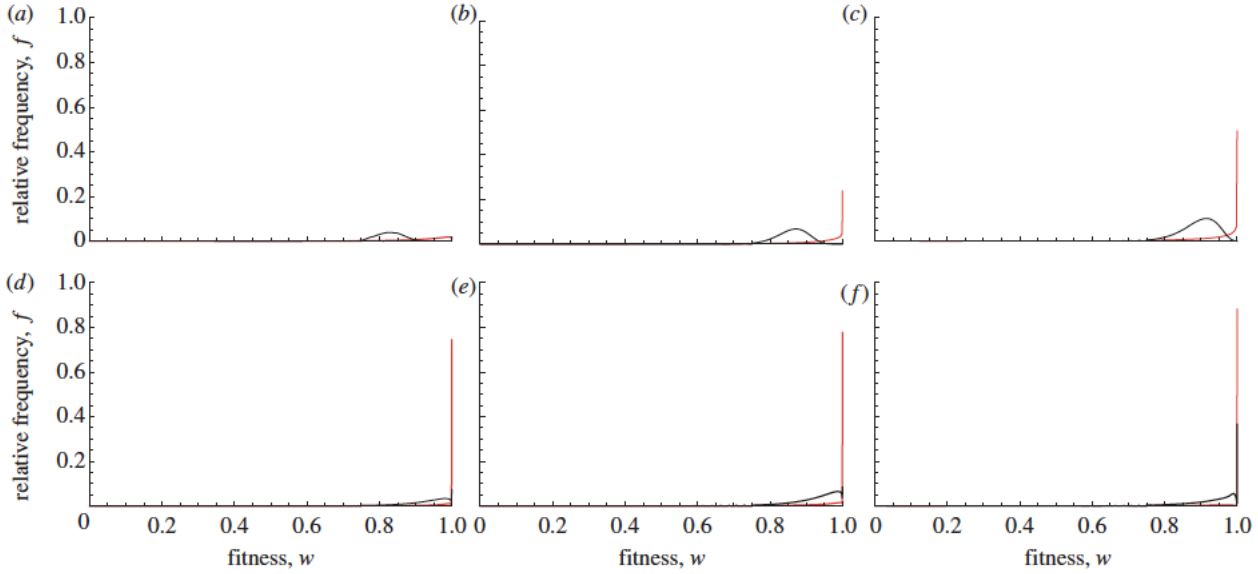
PROCEEDINGS OF THE ROYAL SOCIETY B

Proc. R. Soc. B (2012) **279**, 1865–1872
doi:10.1098/rspb.2011.1871
Published online 7 December 2011

Selection for mitonuclear co-adaptation could favour the evolution of two sexes

Zena Hadjivasiliou[1,2], Andrew Pomiankowski[1,2,*], Robert M. Seymour[1,3] and Nick Lane[1,2]

[1]CoMPLEX, [2]Department of Genetics, Evolution and Environment, and [3]Department of Mathematics, University College London, Gower Street, London W1E 6BT, UK



Lots of modeling work on this

- Christie

PLOS | GENETICS

RESEARCH ARTICLE

Selection against Heteroplasmy Explains the Evolution of Uniparental Inheritance of Mitochondria

Joshua R. Christie[1,2]*, Timothy M. Schaerf[1,2], Madeleine Beekman[1,2]

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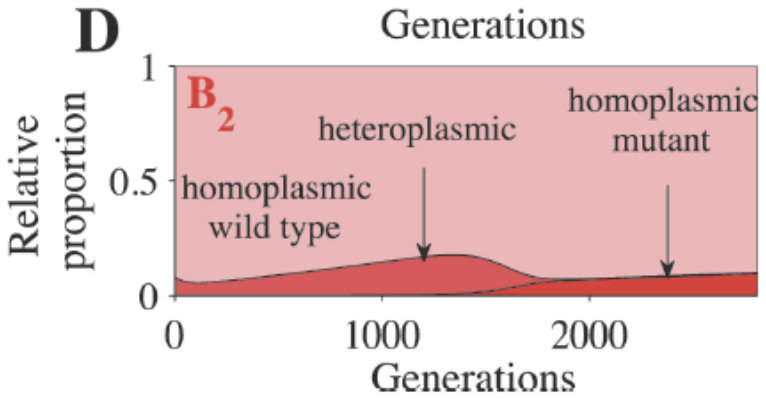

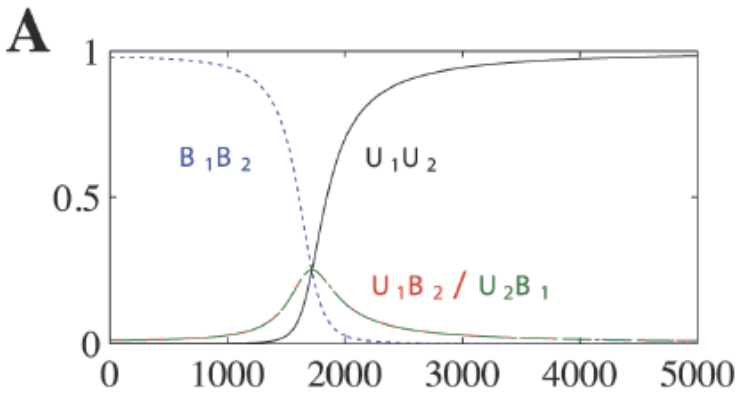

Costs vs. benefits

- Uniparental inheritance helps avoids the costs of Muller's ratchet, but also helps promote mitonuclear coevolution
- Lots of modeling work, but little empirical evidence
- Plants could be a good system to test these ideas

Christie and Beekman 2016

- Introduction
  - Briefly define the following in terms of why sexual reproduction is good:
    - Ruby in the rubbish
    - Clonal interference
    - Muller's ratchet
    - Genetic hitchhiking
  - What's the big difference between asexual cytoplasmic genomes vs. asexual free-living genomes?
- The model
  - What are the assumptions of their model? Are they valid?
  - Is there anything their model doesn't take into account?
- Results
  - Briefly summarize Fig. 2 and Fig. 8
- Everyone
  - What are the benefits/detriments of uniparental vs. biparental vs. paternal leakage vs. free-living asexual vs. free-living sexual modes of inheritance and reproduction?
  - What are the implications of this work for mitonuclear ecology?