Horizontal gene transfer can rescue prokaryotes from Muller's ratchet

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Reticulated Microbial Evolution

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Evolutionary consequences of genetic recombination

- have been extensively considered in relation to evolution of sexual reproduction in eukaryotes
- But, many prokaryotes also undergo genetic recombination → horizontal gene transfer (HGT)
  - How frequent is HGT? → HGT can be more freq. than mutations

    S. pneumoniae, N. meningitidis (Feil et al '00):

    Event ratio: HGT/mutation ≈ 5-10

    Base substitution ratio: HGT/mutation ≈ 100-50

    Other various prokaryotes (Vos & Didelot '09):

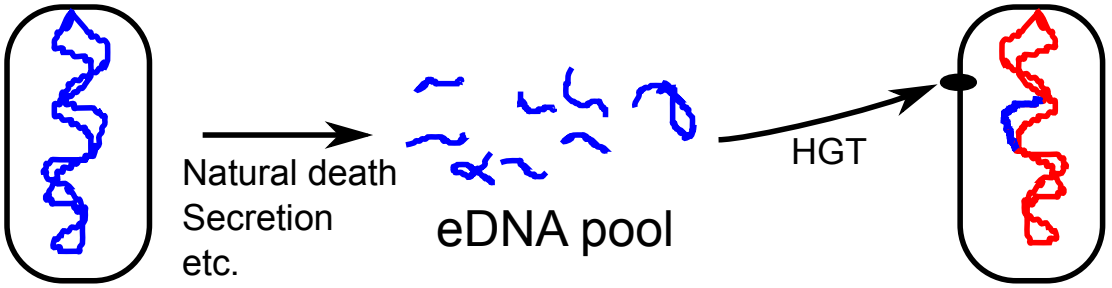
    Base substitution ratio: HGT/mutation ≈ 100-50

- Is exchange of genetic information important for life in general?

HGT is different from meiotic recombination

- Mechanisms of HGT
  - Transformation ←
  - Transduction
  - Conjugation
- Transformation

  Cells absorb DNA in environment and undergo recombination

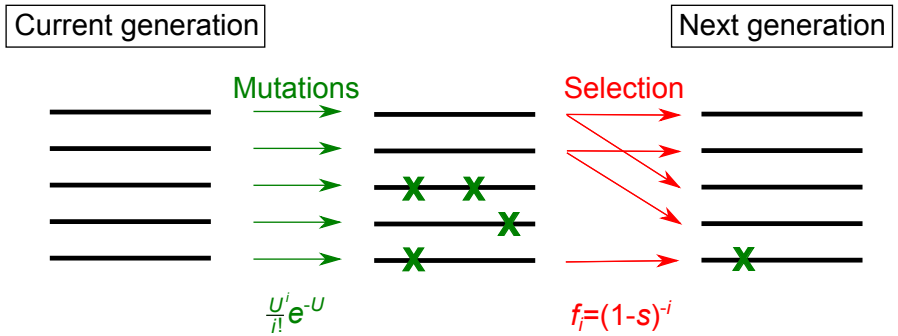


Exchange of genetic information happens indirectly via environmental DNA

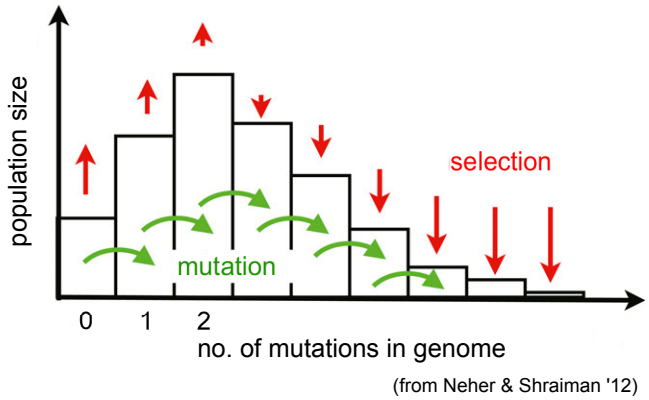
Muller's ratchet

- Assumption: Genome has undergone sufficient evolutionary adaptation

  → Mutations always decrease fitness



- Frequency distribution of mutations per genome (Haigh '78)

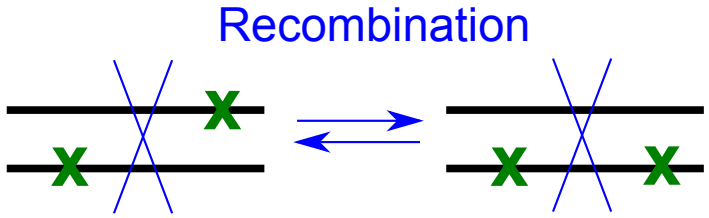


- Mutations accumulate in finite population (Muller '64; Felsenstein '74)

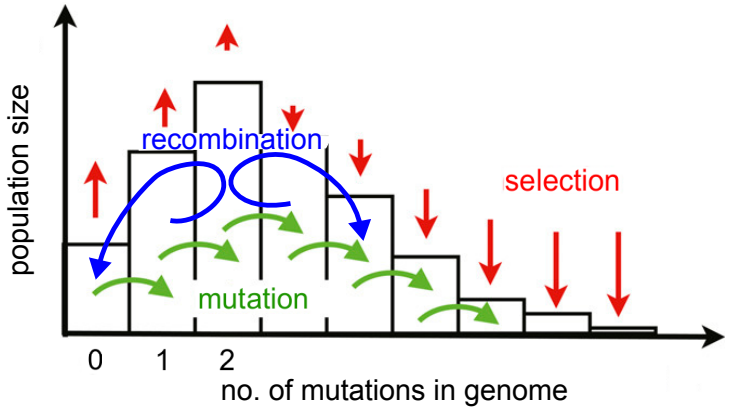
Relationship between Muller's ratchet and recombination

Case of eukaryotes (meiotic recombination)

- Recombination shuffles mutations between chromosomes



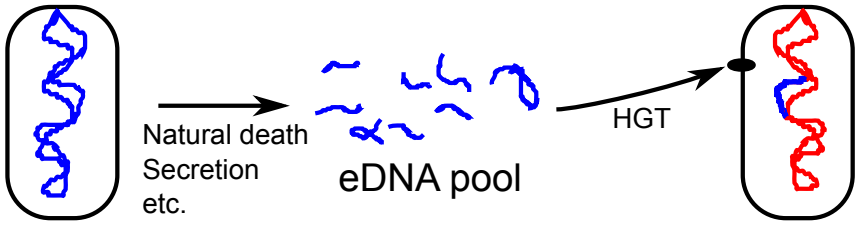
- Recombination can stop Muller's ratchet
  (Pamilo et al. '87; Charlesworth & Charlesworth '93)



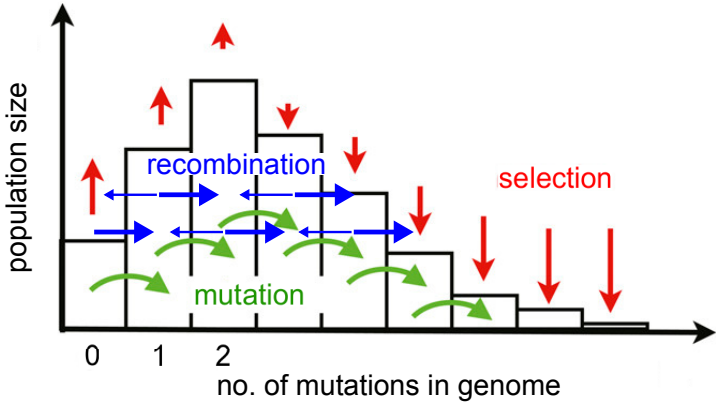
How Muller's ratchet is related to recombination

Case of prokaryotes (HGT)

- Recombination shuffles mutations via environmental DNA (eDNA)



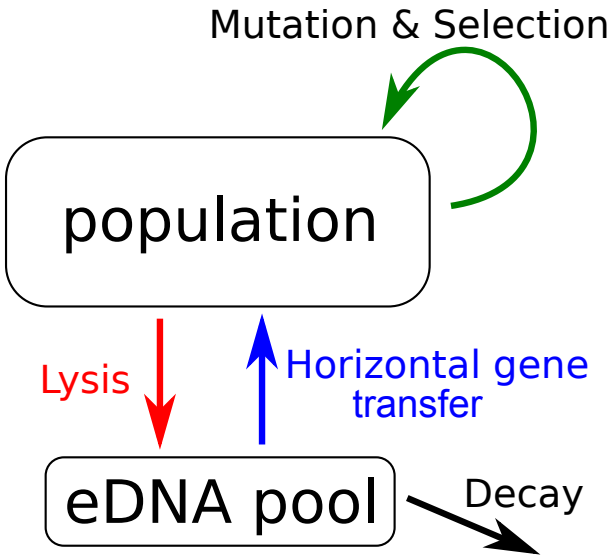
- Deleterious mutations increase mortality of cells, so eDNA on average contains more mutations than the population (Redfield '88)



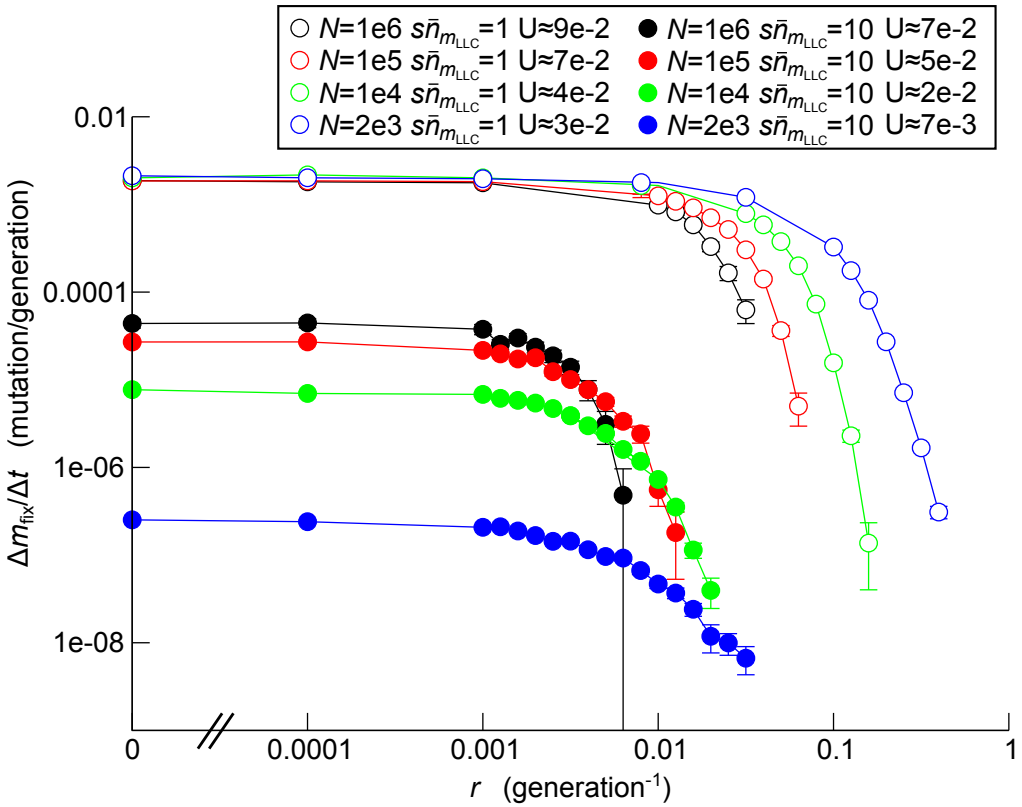
Model

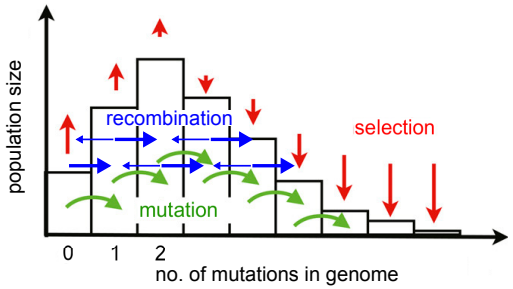
- Model = population + eDNA pool
- Population dynamics
  - Wright-Fisher process
  - mutation + eDNA uptake (HGT)
  - fitness $f_i = (1\text{-}s)^i$
- eDNA pool dynamics
  - Input from dead bacteria

    Death rate $1\text{-}f_i/f_{max}$
  - Decay



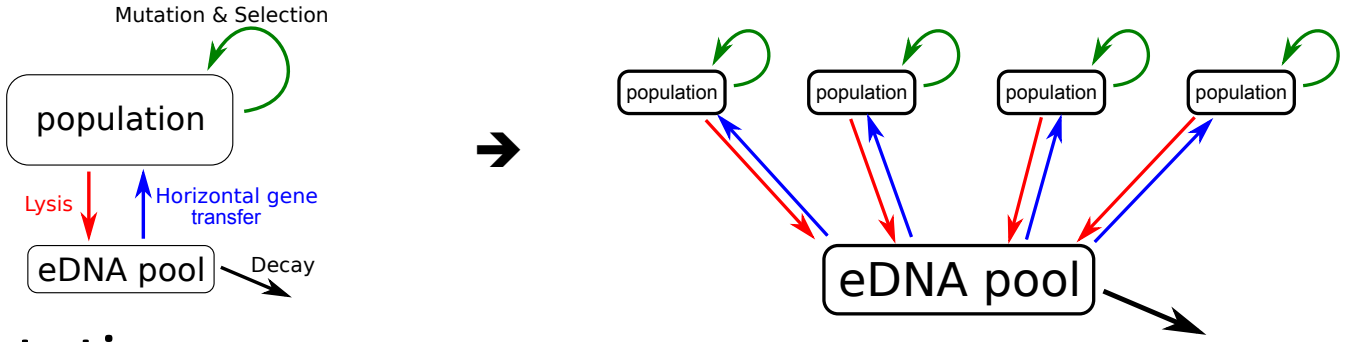
HGT can stop Muller's ratchet





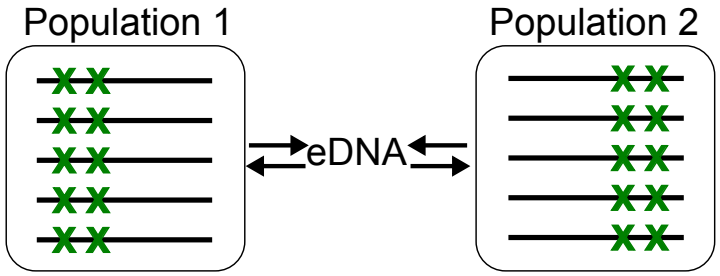
Potential benefit of indirect genetic exchange

- Incorporate population subdivision into model

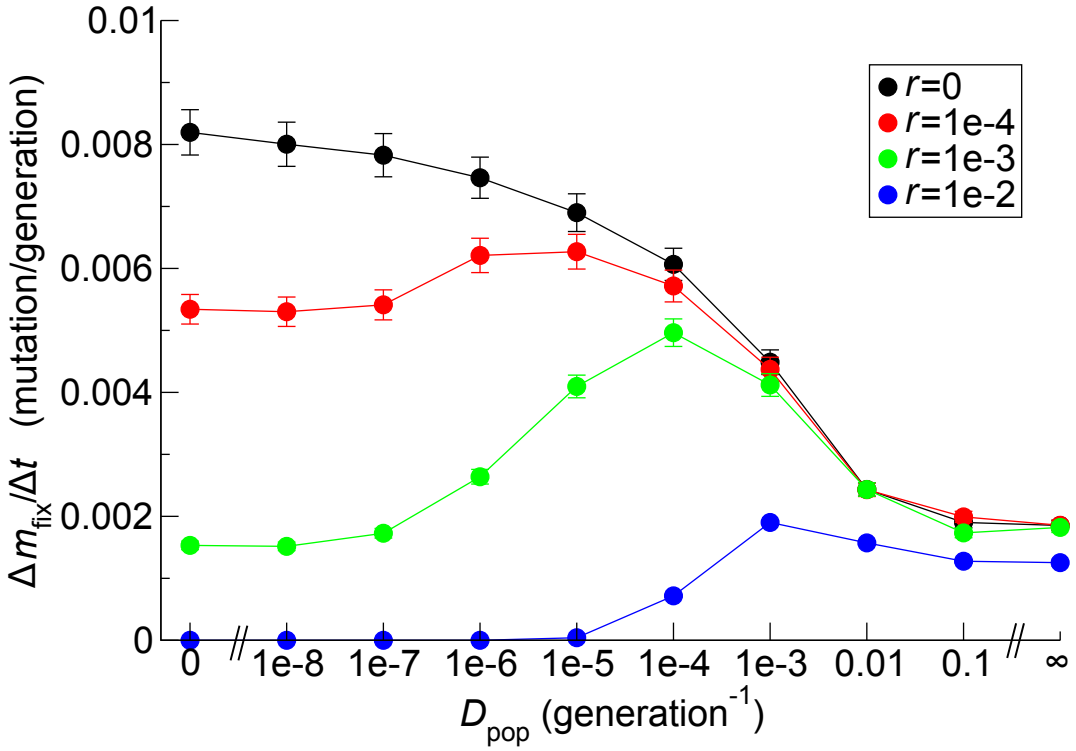


- Expectation
  - Each subpopulation is more susceptible to Muller's ratchet
  - But, ratchets operate independently

→ complementation between subpopulations



Population subdivision and “gene-sharing” help to maintain genetic information



Summary

- HGT helps the maintenance of genetic information on evolutionary timescales even if on average it introduces more deleterious mutations than it removes

- To maintain genomic information, it is more advantageous to partition individuals into multiple subpopulations and let them "cross-reference" each other's genetic information

Takeuchi et al. (2014) *G3* **4**:325

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