Cytoplasmic Genomes
mtDNA and cpDNA

- **Small relative to nuclear genome**
- **Often sex biased transmission**
- **More homogenous in sequence “type” than nuclear**
- **Homoplastic (i.e., haploid)**
- **High copy number**

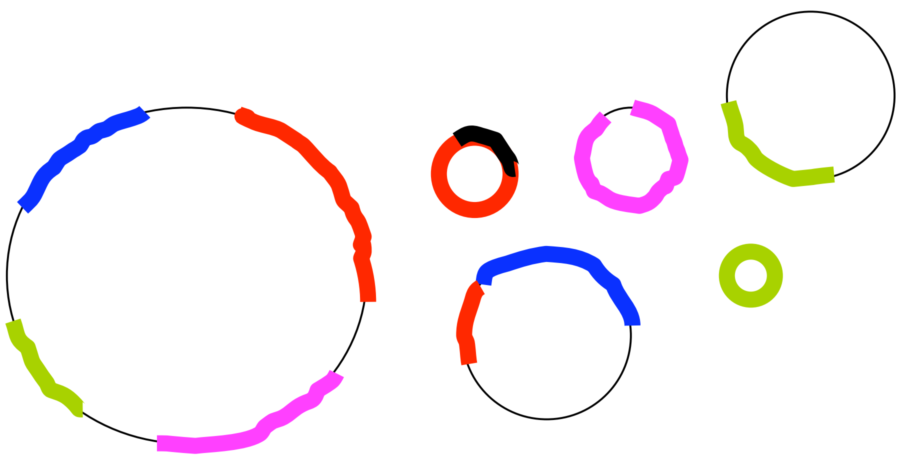
Animal mitochondrial DNA

- **Best known and most used**
- **Small number of genes**
  - **2 ribosomal genes**
  - **22 transfer RNA genes (dispersed)**
  - **13 ATP synthesis genes**
- **Small overall size (14 – 30 kbp)**
- **Mostly coding**
  - **1 region of non-coding used for replication called the control region of d-loop**
- **female transmitted**
- **homoplastic (mostly)**
- **rapid sequence evolution**
  - **may lack proof reading system**
- **generally conserved gene order within phyla but not between (and sometime not within)**

N_e is then 1/4 of nuclear so population processes happen faster. Rapid evolution = higher μ (mutation rate)

Plant mtDNA

- Very, very different
- Almost never used (not in same way)
- Much less known about sequence
- 10X larger or smaller than animal mtDNA
- Very unstable (homoplastic?)
    - Many sub-satellite genomes



- female and male transmitted (sometimes both)
- non-coding regions

Plant cpDNA

- **cpDNA to the rescue!**
- **Still larger than animal mtDNA**
  - **~10 times**
- **Some repeated DNA segments**
- **Coding and noncoding regions (introns)**
- **Slow rate of sequence evolution (and gene order) relative to animal mtDNA**
- **Female or male transmitted or both but usually female**
- **Homoplasmic**

(two out of three isn't bad!)

Uses of mtDNA and cpDNA

- **Protein stuff?**
- **They are all DNA so…**
  - **DNA-DNA hybridization**
  - **Restriction analysis**
  - **Direct DNA sequencing**
  - **Can use PCR**
    - **RFLP**
    - **DNA sequencing**

DNA Sequence Data

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Boulengero    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Serranochr    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Tylochromi    CAATTCATTAGAGG-----CTGGCTGTATAGCACAAGAGTAGGCAGG----CTGAG-CCA
Tmoorii       CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Astatoreoc    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Astatotila    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Labidochro    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Pelvicachr    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Hemichromi    AAATTCATTAGAGG-----TTGGCTGTTTAGCACAAGAGCAGGCAGG----CTGAG-CCA
Crenicichl    CAATTCATTAGAGG-----CTGGCTGTTTAGTGC--GAGTAGGCAGT----CTGAG-ACA
Astronotus    CAATTCATTAGAGG-----CCGGCTGTTTAGTAC--GAGTAGGCAGG----CTGAG-GCA
Paretroplu    CAATTCATTAGAGA-----CTGCCTGCTCAGCAGAAGAGTAGAGAGT----CTGAG-CCA
Etroplus      CATTTCATTAGAGA-----CTGGCTGCTTAGCTGG----------------TTGAG-CCA
Abudefduf     CAGTT----AGACA-----CCGCCTGTTTAGCAGGAGAGTAGGCAGG----CCGAG-CGG
D.trimacul    CAATT----AGACA-----CTGTCTGTTTAGAGGACGAGTAGGCAGG----CCGAG-CTG
D.arcuanus    CAATT----AGAAA-----CTGTCTGTTTAGAGGCCGAGTAGG--------CCGAG-CTG
Micrometru    CAACTCATTAGACA-----CTGGCTGTTTAGCAGAAGAGTGGGTAGT----TTGAG-CTG
Damalichth    CACCTCATTAGCCA-----CTGGCTGTTTAGCAGAAGAGTGGGCAGG----TTGAG-CTG
Perca         CACTTCATTAGAGGCAACACTGGCTGTTTAGCAGAAGAGTAGGTAGA----CTGAGGCGT

Boulengero    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Serranochr    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tylochromi    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tmoorii       GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Astatotila    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Labidochro    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Pelvicachr    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Hemichromi    GCCG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Crenicichl    TCTG-----------ACCACTT------AAAATAATATTTGG---TGTGTGTTTGTGCAC
Astronotus    GCTG-----------ACCACTT------AAAATAATATTTGG---CGTGTGTTTGTGCAC
Paretroplu    GCTG-----------ACCAGTT------AAAACAATATTCAC---TGTGTCTTTGTGCAC
Etroplus      GCTG-----------ACCAGTT------AAAAAAAATATTCA--GTGTGCCTTTGTGCAC
Abudefduf     GTTG-----------TCCGAAT------CAAAGAATATTTAA--GAGAGTGTTTGTGTAC
D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru    GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Damalichth    GCCG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Perca         GTTGAGTTGGTTTGGTCTAATTGACAAGGCAACAATATTCAG-------TGTTTGTGTGC

Boulengero    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Tylochromi    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tmoorii       GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Astatoreoc    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Astatotila    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Paretroplu    GCTG-----------ACCAGTT------AAAACAATATTCAC---TGTGTCTTTGTGCAC
Etroplus      GCTG-----------ACCAGTT------AAAAAAAATATTCA--GTGTGCCTTTGTGCAC
Abudefduf     GTTG-----------TCCGAAT------CAAAGAATATTTAA--GAGAGTGTTTGTGTAC
D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru    GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Damalichth    GCCG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Perca         GTTGAGTTGGTTTGGTCTAATTGACAAGGCAACAATATTCAG-------TGTTTGTGTGC
Boulengero    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
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Crenicichl    CAATTCATTAGAGG-----CTGGCTGTTTAGTGC--GAGTAGGCAGT----CTGAG-ACA
Astronotus    CAATTCATTAGAGG-----CCGGCTGTTTAGTAC--GAGTAGGCAGG----CTGAG-GCA
Paretroplu    CAATTCATTAGAGA-----CTGCCTGCTCAGCAGAAGAGTAGAGAGT----CTGAG-CCA
Etroplus      CATTTCATTAGAGA-----CTGGCTGCTTAGCTGG----------------TTGAG-CCA
Abudefduf     CAGTT----AGACA-----CCGCCTGTTTAGCAGGAGAGTAGGCAGG----CCGAG-CGG
D.trimacul    CAATT----AGACA-----CTGTCTGTTTAGAGGACGAGTAGGCAGG----CCGAG-CTG
D.arcuanus    CAATT----AGAAA-----CTGTCTGTTTAGAGGCCGAGTAGG--------CCGAG-CTG
Micrometru    CAACTCATTAGACA-----CTGGCTGTTTAGCAGAAGAGTGGGTAGT----TTGAG-CTG
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Etroplus      GCTG-----------ACCAGTT------AAAAAAAATATTCA--GTGTGCCTTTGTGCAC
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D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru    GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
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Tylochromi    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tmoorii       GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Paretroplu    GCTG-----------ACCAGTT------AAAACAATATTCAC---TGTGTCTTTGTGCAC
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D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru    GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Damalichth    GCCG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Perca         GTTGAGTTGGTTTGGTCTAATTGACAAGGCAACAATATTCAG-------TGTTTGTGTGC

Boulengero    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
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Paretroplu    CAATTCATTAGAGA-----CTGCCTGCTCAGCAGAAGAGTAGAGAGT----CTGAG-CCA
Etroplus      CATTTCATTAGAGA-----CTGGCTGCTTAGCTGG----------------TTGAG-CCA
Abudefduf     CAGTT----AGACA-----CCGCCTGTTTAGCAGGAGAGTAGGCAGG----CCGAG-CGG
D.trimacul    CAATT----AGACA-----CTGTCTGTTTAGAGGACGAGTAGGCAGG----CCGAG-CTG
D.arcuanus    CAATT----AGAAA-----CTGTCTGTTTAGAGGCCGAGTAGG--------CCGAG-CTG
Micrometru    CAACTCATTAGACA-----CTGGCTGTTTAGCAGAAGAGTGGGTAGT----TTGAG-CTG
Damalichth    CACCTCATTAGCCA-----CTGGCTGTTTAGCAGAAGAGTGGGCAGG----TTGAG-CTG
Perca         CACTTCATTAGAGGCAACACTGGCTGTTTAGCAGAAGAGTAGGTAGA----CTGAGGCGT

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Crenicichl    TCTG-----------ACCACTT------AAAATAATATTTGG---TGTGTGTTTGTGCAC
Astronotus    GCTG-----------ACCACTT------AAAATAATATTTGG---CGTGTGTTTGTGCAC
Paretroplu    GCTG-----------ACCAGTT------AAAACAATATTCAC---TGTGTCTTTGTGCAC
Etroplus      GCTG-----------ACCAGTT------AAAAAAAATATTCA--GTGTGCCTTTGTGCAC
Abudefduf     GTTG-----------TCCGAAT------CAAAGAATATTTAA--GAGAGTGTTTGTGTAC
D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru    GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Damalichth    GCCG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Perca         GTTGAGTTGGTTTGGTCTAATTGACAAGGCAACAATATTCAG-------TGTTTGTGTGC

Boulengero    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Serranochr    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tylochromi    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tmoorii       GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Astatoreoc    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Astronotus    GCTG-----------ACCACTT------AAAATAATATTTGG---CGTGTGTTTGTGCAC
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Etroplus      GCTG-----------ACCAGTT------AAAAAAAATATTCA--GTGTGCCTTTGTGCAC
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D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru    GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Damalichth    GCCG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Perca         GTTGAGTTGGTTTGGTCTAATTGACAAGGCAACAATATTCAG-------TGTTTGTGTGC

Boulengero    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Serranochr    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Tylochromi    CAATTCATTAGAGG-----CTGGCTGTATAGCACAAGAGTAGGCAGG----CTGAG-CCA
Tmoorii       CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Astatoreoc    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
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Crenicichl    CAATTCATTAGAGG-----CTGGCTGTTTAGTGC--GAGTAGGCAGT----CTGAG-ACA
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Paretroplu    CAATTCATTAGAGA-----CTGCCTGCTCAGCAGAAGAGTAGAGAGT----CTGAG-CCA
Etroplus      CATTTCATTAGAGA-----CTGGCTGCTTAGCTGG----------------TTGAG-CCA
Abudefduf     CAGTT----AGACA-----CCGCCTGTTTAGCAGGAGAGTAGGCAGG----CCGAG-CGG
D.trimacul    CAATT----AGACA-----CTGTCTGTTTAGAGGACGAGTAGGCAGG----CCGAG-CTG
D.arcuanus    CAATT----AGAAA-----CTGTCTGTTTAGAGGCCGAGTAGG--------CCGAG-CTG
Micrometru    CAACTCATTAGACA-----CTGGCTGTTTAGCAGAAGAGTGGGTAGT----TTGAG-CTG
Damalichth    CACCTCATTAGCCA-----CTGGCTGTTTAGCAGAAGAGTGGGCAGG----TTGAG-CTG
Perca         CACTTCATTAGAGGCAACACTGGCTGTTTAGCAGAAGAGTAGGTAGA----CTGAGGCGT

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Tylochromi    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tmoorii       GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Astatoreoc    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Labidochro    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Astronotus    GCTG-----------ACCACTT------AAAATAATATTTGG---CGTGTGTTTGTGCAC
Paretroplu    GCTG-----------ACCAGTT------AAAACAATATTCAC---TGTGTCTTTGTGCAC
Etroplus      GCTG-----------ACCAGTT------AAAAAAAATATTCA--GTGTGCCTTTGTGCAC
Abudefduf     GTTG-----------TCCGAAT------CAAAGAATATTTAA--GAGAGTGTTTGTGTAC
D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru    GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Damalichth    GCCG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
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Perca         GTTGAGTTGGTTTGGTCTAATTGACAAGGCAACAATATTCAG-------TGTTTGTGTGC

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Tylochromi    CAATTCATTAGAGG-----CTGGCTGTATAGCACAAGAGTAGGCAGG----CTGAG-CCA
Tmoorii       CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Astatoreoc    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Astatotila    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Labidochro    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Pelvicachr    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Hemichromi    AAATTCATTAGAGG-----TTGGCTGTTTAGCACAAGAGCAGGCAGG----CTGAG-CCA
Crenicichl    CAATTCATTAGAGG-----CTGGCTGTTTAGTGC--GAGTAGGCAGT----CTGAG-ACA
Astronotus    CAATTCATTAGAGG-----CCGGCTGTTTAGTAC--GAGTAGGCAGG----CTGAG-GCA
Paretroplu    CAATTCATTAGAGA-----CTGCCTGCTCAGCAGAAGAGTAGAGAGT----CTGAG-CCA
Etroplus      CATTTCATTAGAGA-----CTGGCTGCTTAGCTGG----------------TTGAG-CCA
Abudefduf     CAGTT----AGACA-----CCGCCTGTTTAGCAGGAGAGTAGGCAGG----CCGAG-CGG
D.trimacul    CAATT----AGACA-----CTGTCTGTTTAGAGGACGAGTAGGCAGG----CCGAG-CTG
D.arcuanus    CAATT----AGAAA-----CTGTCTGTTTAGAGGCCGAGTAGG--------CCGAG-CTG
Micrometru    CAACTCATTAGACA-----CTGGCTGTTTAGCAGAAGAGTGGGTAGT----TTGAG-CTG
Damalichth    CACCTCATTAGCCA-----CTGGCTGTTTAGCAGAAGAGTGGGCAGG----TTGAG-CTG
Perca         CACTTCATTAGAGGCAACACTGGCTGTTTAGCAGAAGAGTAGGTAGA----CTGAGGCGT

Boulengero    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Serranochr    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tylochromi    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tmoorii       GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Astatoreoc    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Pelvicachr    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Hemichromi    GCCG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Crenicichl    TCTG-----------ACCACTT------AAAATAATATTTGG---TGTGTGTTTGTGCAC
Astronotus    GCTG-----------ACCACTT------AAAATAATATTTGG---CGTGTGTTTGTGCAC
Paretroplu    GCTG-----------ACCAGTT------AAAACAATATTCAC---TGTGTCTTTGTGCAC
Etroplus      GCTG-----------ACCAGTT------AAAAAAAATATTCA--GTGTGCCTTTGTGCAC
Abudefduf     GTTG-----------TCCGAAT------CAAAGAATATTTAA--GAGAGTGTTTGTGTAC
D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru    GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Damalichth    GCCG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Perca         GTTGAGTTGGTTTGGTCTAATTGACAAGGCAACAATATTCAG-------TGTTTGTGTGC

Boulengero    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Serranochr    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Tylochromi    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Etroplus      GCTG-----------ACCAGTT------AAAAAAAATATTCA--GTGTGCCTTTGTGCAC
Abudefduf     GTTG-----------TCCGAAT------CAAAGAATATTTAA--GAGAGTGTTTGTGTAC
D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
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Tmoorii       CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
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Astatotila    CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
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Hemichromi    AAATTCATTAGAGG-----TTGGCTGTTTAGCACAAGAGCAGGCAGG----CTGAG-CCA
Crenicichl    CAATTCATTAGAGG-----CTGGCTGTTTAGTGC--GAGTAGGCAGT----CTGAG-ACA
Astronotus    CAATTCATTAGAGG-----CCGGCTGTTTAGTAC--GAGTAGGCAGG----CTGAG-GCA
Paretroplu    CAATTCATTAGAGA-----CTGCCTGCTCAGCAGAAGAGTAGAGAGT----CTGAG-CCA
Etroplus      CATTTCATTAGAGA-----CTGGCTGCTTAGCTGG----------------TTGAG-CCA
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D.arcuanus    CAATT----AGAAA-----CTGTCTGTTTAGAGGCCGAGTAGG--------CCGAG-CTG
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Paretroplu    GCTG-----------ACCAGTT------AAAACAATATTCAC---TGTGTCTTTGTGCAC
Etroplus      GCTG-----------ACCAGTT------AAAAAAAATATTCA--GTGTGCCTTTGTGCAC
Abudefduf     GTTG-----------TCCGAAT------CAAAGAATATTTAA--GAGAGTGTTTGTGTAC
D.trimacul    GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus    GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru    GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Damalichth    GCCG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Perca         GTTGAGTTGGTTTGGTCTAATTGACAAGGCAACAATATTCAG-------TGTTTGTGTGC

Boulengero    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
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Pelvicachr    GCTG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
Hemichromi    GCCG-----------ACCAGTT------AAAACAATATTTGG---TGTGTGTTTGTGCAC
```

Sequence Alignment

```
Boulengero      CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Serranochr      CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
Tylochromi      CAATTCATTAGAGG-----CTGGCTGTATAGCACAAGAGTAGGCAGG----CTGAG-CCA
Tmoorii         CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
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Astatotila      CAATTCATTAGAGG-----CTGGCTGTTTAGCACAAGAGTAGGCAGG----CTGAG-CCA
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Hemichromi      AAATTCATTAGAGG-----TTGGCTGTTTAGCACAAGAGCAGGCAGG----CTGAG-CCA
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Paretroplu      CAATTCATTAGAGA-----CTGCCTGCTCAGCAGAAGAGTAGAGAGT----CTGAG-CCA
Etroplus        CATTTCATTAGAGA-----CTGGCTGCTTAGCTGG----------------TTGAG-CCA
Abudefduf       CAGTT----AGACA-----CCGCCTGTTTAGCAGGAGAGTAGGCAGG----CCGAG-CGG
D.trimacul      CAATT----AGACA-----CTGTCTGTTTAGAGGACGAGTAGGCAGG----CCGAG-CTG
D.arcuanus      CAATT----AGAAA-----CTGTCTGTTTAGAGGCCGAGTAGG--------CCGAG-CTG
Micrometru      CAACTCATTAGACA-----CTGGCTGTTTAGCAGAAGAGTGGGTAGT----TTGAG-CTG
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D.trimacul      GGTGTCCATT-----TCAAATATTGTTGGAGACTATATTTAA--GGGTGTGTTTGTGTAC
D.arcuanus      GGTGTCCATT-----TCAAATAGCGTTG-AAACAATATTTAA--GGGTGTGTTTGTGTAC
Micrometru      GTTG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Damalichth      GCCG-----------TCCAGTTGAAACGGCAACTATACCCAG-TGTGTGTGTTTGTGTGC
Perca           GTTGAGTTGGTTTGGTCTAATTGACAAGGCAACAATATTCAG-------TGTTTGTGTGC
```

Types of Sequences

- Coding (e.g., cytochrome b)

```
3′ – TGT CTG TGG CGT CCC TGC GAG TCA – 5′
5′ – ACA GAC ACC GCA GGG ACG CTC AGT – 3′
```

↓ **Transcription**

```
– ACA GAC ACC GCA GGG AGC CUC AGU – mRNA
```

↓ **Translation**

```
– Thr-Asp-Thr-Ala-Gly-Thr-Leu-Ser –
```

ACU	GAU	GCU	GGU	CUU	AGU
ACC	GAC	GCC	GGC	CUC	AGC
ACA		GCA	GGA	CUA	UCU
ACG		GCG	GGG	CUG	UCC
				UUA	UCA
				UUG	UCG

Genes with:

Little variation – use 3° sites only (or any!)
Moderate variation – use 1° and 2° sites only
Lots of variation – use 2° sites only, AA sequence or transversions (Purine to Purine or Pyrimadine to Pyrimadine).

Transitions versus Transversions

Expect Ts:Tv ration of 1:2

Observations are variable but generally see Tv > Ts (sometimes 10-15X).

Mutation Saturation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
…	A	C	A	G	T	T	A	G	C	T	C	T	A	G	…

P(position 3 mutates) = $\frac{1}{14}$

P(position 3 does not mutate) = $\frac{13}{14}$

P(position has been previously mutated) = 0

↓ **Time**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
…	A	T	G	G	T	C	A	G	C	C	C	C	G	G	…

P(position has not been previously mutated) = $\frac{8}{14}$

P(position has been previously mutated) = $\frac{6}{14}$

P(position 3 mutates AND has been previously mutated)

$$= \frac{1}{14} \text{ X } \frac{6}{14} = 3.06\%$$

This results in multiple mutations to a site:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
…	A	T	A	G	T	C	A	G	C	C	C	C	G	G	…

A => G mutation

… A T G G T C A G C C C C G G …

= 1 difference between

Reversions – a second mutation at the same site that changes the nucleotide back to the original

G => A (reversion)

… A T A G T C A G C C C C G G …

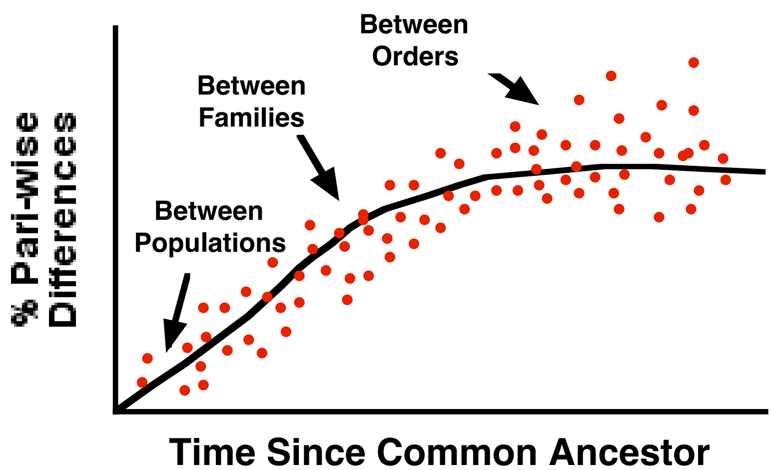
= 0 differences between

Any other mutation: **G => C**
G => T

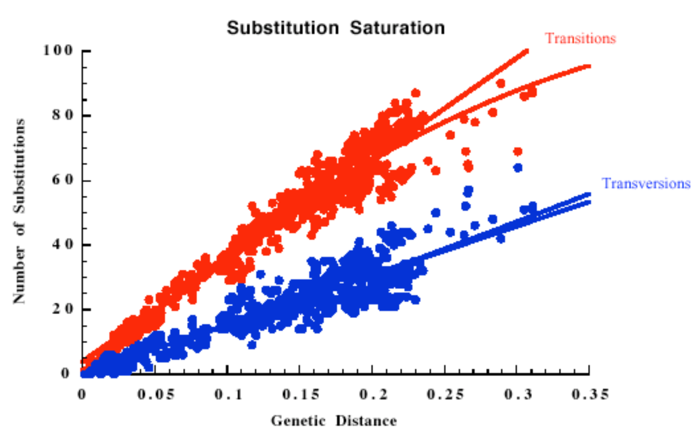
... A T C G T C A G C C C C G G ...

= 1 differences between although there has actually been two mutations to the same site

Substitution Saturation:

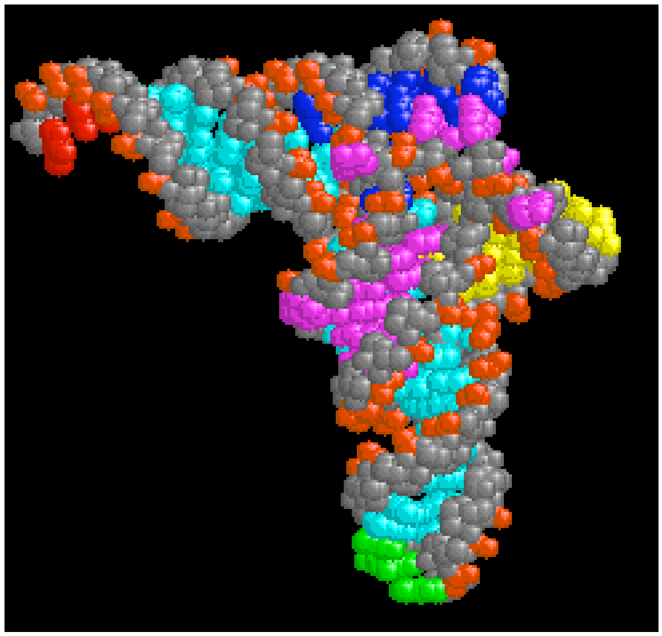


Saturation of Transitions versus Transversions



Types of Sequences – noncoding

Transfer RNAs, ribosomal RNAs, d-loop.



Aspects:

1. **Is the secondary structure known?**
2. **Is the molecular as a whole generally considered conserved or variable?**
3. **Are there known active sites and hyper-variable sites?**
4. **Will alignment to other sequences be difficult due to insertions/deletions?**
5. **Is there a known transition:transversion bias?**

MtDNA considerations

1) **fast and slow evolving genes**

2) **coding and non-coding regions**

3) **primers available**

4) **what other information is available**

5) **structural/functional information**

6) **probability of homoplasy/divergence**

Applications of Cytoplasmic DNA

Description and distribution of 13 distinct mtDNA genotypes (A-M) in sea turtles.

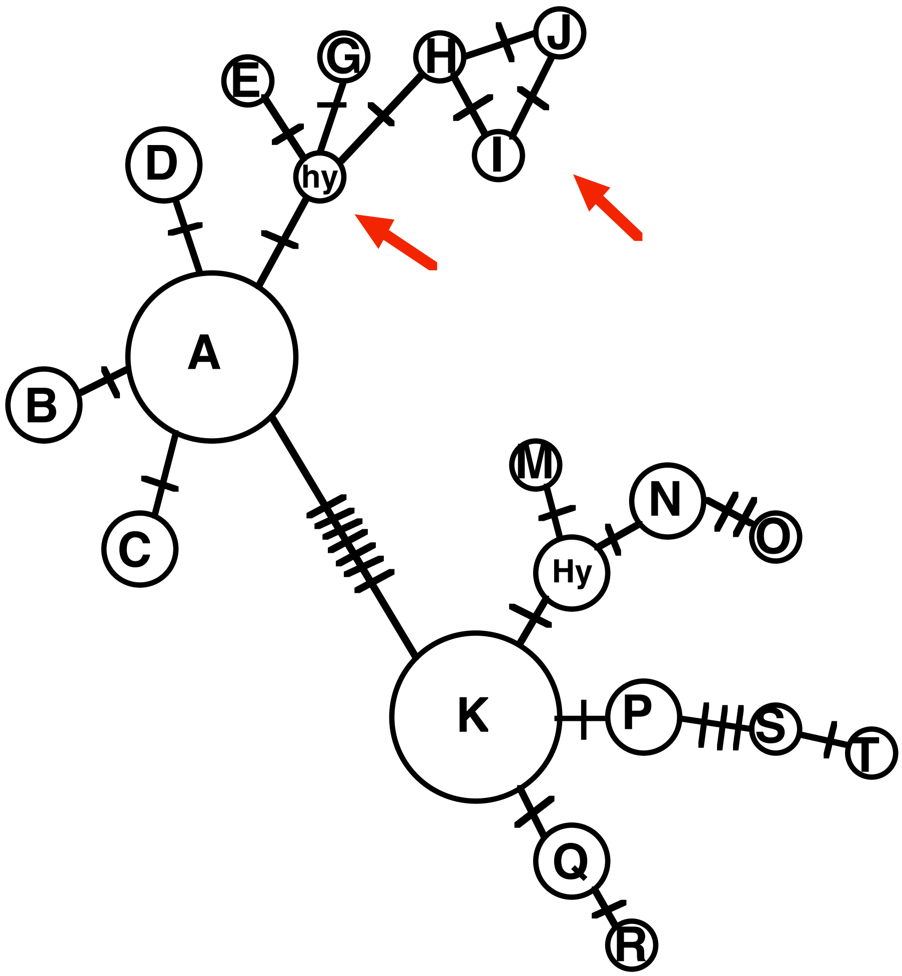
Code	MtDNA Genotype	Rookery Location	Sample Size
A	ACCCCCCCCCCCCCDCC	Florida, USA,	21
		Tortuguero, Costa Rica	154
		Aves Island, Venezuela	1
B	ACCCBCCCCCCCCCDCC	Florida, USA	3
C	ACCCCCCCBCCCCCCCC	Galibri, Surinam	15
		Aves Island, Venezuela	7
D	ACCCCCCCCCCCCCCCC	Ascension Island, UK	34
		Atol das Rocas, Brazil	15
E	ACCCCCCCCCCCCCCCD	Ascension Island, UK	1
F	BCCCCBCCCCCCCCCCC	Atol das Rocas, Brazil	1
G	ACCCCCCCCCCDCCCCC	Lara, Cyprus	10
H	CCCCCBDCCCCCDBBCD	Ras Al Hadd, Oman	15
		Galapagos, Ecuador	8
		Michoacan, Mexico	7
		Hawaii, USA	6
I	CCCCCBECCCCCDBBCD	Hawaii, USA	16
J	BCCCCBECCCCACBBCC	French Polynesia	2

Geographical Distribution of mtDNA haplotypes

Haplotype

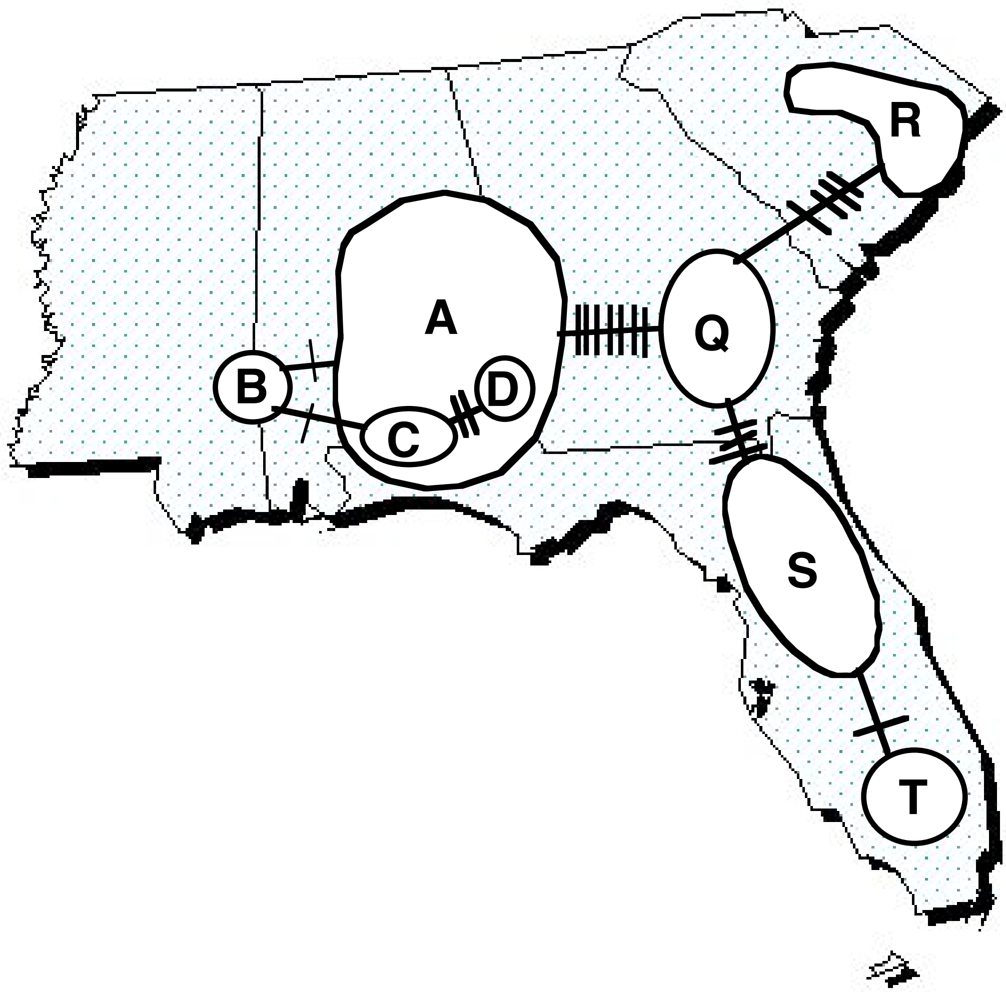
	A	B	C	D	E	F	G	H	I	J	K	L	M
Costa Rica	15	—	—	—	—	—	—	—	—	—	—	—	—
Florida	21	3	—	—	—	—	—	—	—	—	—	—	—
Venezuela	1		7	—	—	—	—	—	—	—	—	—	—
Suriname	—	—	15	—	—	—	—	—	—	—	—	—	—
Ascension	—	—	—	34	1	—	—	—	—	—	—	—	—
Brazil	—	—	—	15	—	1	—	—	—	—	—	—	—
Cyprus	—	—	—	—	—	—	10	—	—	—	—	—	—
Mexico	—	—	—	—	—	—	—	7	—	—	—	—	—
Galapagos	—	—	—	—	—	—	—	8	—	—	—	—	—
Hawaii	—	—	—	—	—	—	—	6	16	—	—	—	—
Polynesia	—	—	—	—	—	—	—	—	—	2	1	—	—
Australia	—	—	—	—	—	—	—	—	—	—	15	—	—
Japan	—	—	—	—	—	—	—	—	—	—	1	5	—
Oman	—	—	—	—	—	—	—	15	—	—	—	14	—

Ball and Stick
(AKA Minimum Spanning Network)



So? What do you get?

– ORDERED, highly polymorphic, rapidly evolving, discrete characters.



Conservation Genetics