PMB 220 - Week 11
Species concepts in microbes
Why are species important?

Geographic range and phenotype can be misleading

Intraspecific variation can be high

Methods of species recognition can influence concepts about dispersal and adaptation
Neurospora: Tropical and Subtropical

Perkins Lab - Fungal Genetics Stock Center
Jacobson et al. 2004 *Mycologia*
Neurospora discreta in western North America

Jacobson et al. 2004
Mycologia
Neurospora discreta in western North America
Outbreeding Neurospora
15 phylogenetic species

Dettman, Jacobson & Taylor
Mycologia (in revision)
Dave Jacobson’s European Trip
Fall 2003
Neurospora species distribution at European sites

- **N. crassa**
- **N. sitophila**
- **N. discreta**
- **N. tetrasperma**
Neurospora sp.
In Europe
Outbreeding Neurospora
15 phylogenetic species

N.crassa clade

N.discreta clade

Dettman, Jacobson & Taylor
Mycologia
(in revision)
Figure 3. The relationships among the eight Phylogenetic Species within the \textit{N. discreta} complex. Maximum parsimony phylogram produced from the sequences of three loci combined. Taxon labels indicate strain number and geographic source. Branch support values (bootstrap and Bayesian posterior probabilities) are displayed for major branches only. Phylogenetic species are subtended by a triangle; see Material and Methods and Dettman et al. 2003a for more detail on species recognition criteria.
Neurospora discreta clade 4b
Equator to 63° north latitude
Neurospora: Tropical and Subtropical

- N. crassa (48)
- N. intermedia (71)
- N. sitophila (7)
- N. tetrasperma (4)
- Putative hybrids (9)
- N. discreta (8)

Perkins Lab - Fungal Genetics Stock Center
Neurospora discreta clade 4b
Equator to 63° north latitude
Brubaker et al. 2005
J Biogeography
*Neurospora discreta* clade 4b
Equator to 63° north latitude
Why are species important?

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Distribution of *Coccidioides* species

Coccidioides immitis dimorphic life cycle

Diagram courtesy of Theo Kirkland, UC San Diego
Arthroconidia
**Coccidioides immitis** dimorphic life cycle

Diagram courtesy of Theo Kirkland, UC San Diego
Spherules in an Endospore

vfce.arl.arizona.edu
Two phylogenetic species in *Coccidioides*

California
- *Coccidioides immitis* Rixford and Gilchrist 1896

non-California
- *Coccidioides posadasii* Fisher et al. 2002

At least five populations of *Coccidioides*.

Phase-specific Transcription

Garry Cole and Ruth Schaller, Medical College of Ohio
Two individuals from one C. posadasii population
RNA Transcripts

*C. posadasii* C735

Hyphae
Spherules
Spherules releasing endospores

*C. posadasii* Silveira

RNA Transcripts
9 competitive hybridizations
Up to 15 competitive hybridizations
11 competitive hybridizations
Saprobic > Parasitic
Hyphae > Spherule

Johannesson et al. FGB in press
Saprobic > Parasitic
Hyphae > Spherule

173
92
182
S. cerevisiae
633 genes

Fay et al.
2004
Genome Biol.
5:R26
S. cerevisiae
633 genes

Fay et al.
2004
Genome Biol.
5:R26
Intraspecific variation in other organisms

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<tr>
<th>Publication</th>
<th>Year</th>
<th>Organism</th>
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<td>Drnevich et al.</td>
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<td>Whitehead &amp; Crawford</td>
<td>2005</td>
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<td>Stranger et al.</td>
<td>2005</td>
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*Paxillus* mycorrhiza

LeQuéré et al. 2004
Paxillus mycorrhizae
66/1075

LeQuéré et al. 2004
Male competitive reproductive success

*Drosophila*  Drneveich et al. 2004
Male competitive reproductive success

*Drosophila*  Drnevich et al. 2004

Low MCRS  up  High MCRS  up

27 genes
Three populations, three individuals each, three tissues.

*Fundulus*

192 genes

Whitehead and Crawford 2005
Three populations, three individuals each, three tissues.

*Fundulus*

192 genes

Whitehead and Crawford 2005
Why are species important?

Geographic range and phenotype can be misleading

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Methods of species recognition can influence concepts about dispersal and adaptation
Size of fungal spores

1 mm

100 µm

10 µm
Size of fungal spores

- 10 mm
- 100 μm
- 10 μm
Size of fungal spores

1 mm

100 µm

10 µm
Figure 1a

Neurospora

Dettman et al.
2003 Evolution
Figure 1b

N. crassa clade

N. discreta clade

0.005 substitutions/site

Dettman et al. 2006
Figure 2

Penn CA & Italy

Italy

Saccharomyces cerevisiae

Aa et al. 2006
Six gene phylogeny

Liti et al. 2006
Genetics 174:839-850
Evolutionary Species Concept

- Sexual Reproduction Only
  - Biological Species Recognition

- Sexual & Asexual Reproduction
  - Morphological Species Recognition
  - Phylogenetic Species Recognition

Mayden 1997
Evolutionary Species Concept

"A phyletic lineage (ancestral-descendant sequence of interbreeding populations) evolving independently of others, with its own separate and unitary evolutionary role and tendencies." - G. G. Simpson 1950

"A species is a lineage of ancestral descendant populations which maintains its identity from other such lineages and which has its own evolutionary tendencies and historical fate." - E. O. Wiley 1978
Evolutionary Species Concept

after G. G. Simpson 1950
Morphological Species Recognition
Morphological Species Recognition

"Species are the smallest groups that are consistently and persistently distinct and distinguishable by ordinary means."
- A. Cronquist 1978
Morphological Species Recognition
Biological Species Recognition
Biological Species Recognition

"Actually or potentially interbreeding natural populations which are reproductively isolated from other such groups."
- E. Mayr 1942
Phylogenetic Species Recognition
Phylogenetic Species Recognition

"... the smallest diagnosable cluster of individual organisms [forming a monophyletic group] within which there is a parental pattern of ancestry and descent."

- Cracraft 1983, McKitrick & Zink 1988
BEGINNING OF GENETIC ISOLATION

SHARED POLYMORPHISM

LOSS OF SHARED POLYMORPHISM AS THE LOCUS BECOMES FIXED IN ONE SPECIES

LOCUS BECOMES FIXED IN BOTH SPECIES
UNCERTAINLY ABOUT THE LIMITS OF SPECIES IN A SINGLE GENE GENEALOGY
CONCORDANCE

CLONAL

RECOMBINING

CONSSENSUS
Consensus of gene genealogies
Genealogical Concordance

Phylogenetic Species Concept
Coccidioides immitis

Burt et al. 1996, 1997
Koufopanou et al. 1997
Distribution of Coccidioides species

Coccidioides immitis: Polymorphisms in five protein coding genes

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<th>Locus</th>
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<th>Orotidine decarboxy.</th>
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### Nucleic acids Consensus

| Strain | A | G | T | G | C | C | G | C | T | C | A | G | C | C | A | A | G | C | C | G | A | C | A | C | T | T | C | T | C | C | G |
| S      |   | G |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| AZ1    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| AZ2    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| TX1    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| TX2    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| MX1    |   |   |   | C |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| MX2    |   |   |   | A |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| AG1-5  |   |   |   |   | G |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| CA1    | G | A | C | A | T | T | A | T | C |   | G | G | T | T | G | C | G | T | T | T |   |   |   |   | C |   |   |   |   |   |   |   |
| CA2    | G | C | A | T | T | A | T | C |   | G | G | T | T | G | C | G | T | T | T |   |   |   |   |   | C |   |   |   |   |   |   |   |
| CA3    | G | A | C | A | T | T | A | T | C | G | G | T | T | G | C | G | T | T | T |   |   |   |   |   | C |   |   |   |   |   |   |   |
| CA4    | G | C | A | T | T | A | T | C | G | G | T | T | G | C | G | T | T | T |   |   |   |   |   |   | C |   |   |   |   |   |   |   |
| CA5    | G | C | A | T | T | A | T | C | G | G | T | T | G | C | G | T | T | T |   |   |   |   |   |   | C |   |   |   |   |   |   |   |

### Amino acids Consensus

| Amino acids Consensus | G | K | L | E | D | I | K | D | N | T | I | L | A | H | Y | L | A | T | R | A | R | N | N | I | S | * | T | N | I | N | N | T |
| Substit/s             |   |   |   |   |   |   |   |   |   | S | V |   |   | P | S | S | S | S | D | V | Y | * | K | T |   |   |   |   |   |   |   |   |


Coccidioides immitis: Five gene genealogies
Phylogenetic Species in *C. immitis*

17 fixed sites

CA

CA1, CA2, CA3, CA4, CA5

nonCA

S, AZ1, AZ2, TX1, TX2, MX1, AG1-5, MX2

CA
Coccidioides immitis: Polymorphisms in five protein coding genes

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### Nucleic acids Consensus

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<td>C . . . . . .</td>
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### Amino acids Consensus

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<th>A T R A R N N I</th>
<th>S * T N I N N T</th>
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Substit/s
BEGINNING OF GENETIC ISOLATION

SHARED POLYMORPHISM

LOSS OF SHARED POLYMORPHISM AS THE LOCUS BECOMES FIXED IN ONE SPECIES

LOCUS BECOMES FIXED IN BOTH SPECIES
Aspergillus flavus

Geiser et al. 1998
Aspergillus flavus -- Dave Geiser
Wiley Schell
Aspergillus flavus

Geiser, Dorner, Horn, Taylor, 2001

Small Sclerotia
Aflatoxin B
Cyclopiazonic Acid

Large Sclerotia
Cyclopiazonic Acid

Small Sclerotia
Aflatoxin B and G
Cyclopiazonic Acid
California and non-California are phenotypically different

Five isolates from each species grown for 18 days on HIGH SALT PLATES

…California grows faster

Do the two species have differences in immunogenicity / pathogenicity?
Phylogenetic Species Recognition

Genetic isolation Uncultivated Asexual

Evolutionary Species Concept after G. G. Simpson 1950
Gevers et al. 2005
Doolittle et al. 1999
### rRNA topology

<table>
<thead>
<tr>
<th>Genome A</th>
<th>Genome B</th>
<th>Genome C</th>
<th>Genome D</th>
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<td><strong>Escherichia</strong></td>
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<td><strong>Enterobacteria</strong></td>
<td><strong>Buchnera</strong></td>
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<td>S. enterica</td>
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<td>S. aureus MW2</td>
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**Interspecies**

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Daubin et al. 2003
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<td><em>S. epidermidis</em></td>
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Daubin et al. 2003

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**Genome content approach**

- **Gains**:
  - A to B: 522 (22)
  - B to C: 259 (38)
  - A to C: 549 (54)
  - B to A: 9 (10)
  - C to B: 232 (56)
  - C to A: 214 (117)
  - C to C: 71 (4)

- **Losses**:
  - A to B: 144 (114)
  - B to C: 203 (13)
  - A to C: 601 (29)
  - B to A: 1 (11)
  - C to B: 337 (19)
  - C to A: 519 (113)
  - C to C: 128 (2)

**Complete genome content**

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### Phylogenetic approach

![Phylogenetic diagram]

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**Phylogenetic approach**

![Diagram of phylogenetic relationships](image)
Daubin et al.
2003

\[ y = 0.081x - 0.005 \quad (r^2 = 0.794) \]

Didn’t use the rest in 2006, but it could fit in the species lecture
More polymorphism?

Microsatellites or Short Tandem Repeats
Molecular markers- Microsatellites

- Dinucleotide repeats randomly dispersed through the genome

\[
\text{ctgcgtgtgacatACACACACACACACACACACACACACACACACACA} \text{ctgtatgtgatc}
\]

- Highly polymorphic and multialleleic due to polymerase slippage during strand replication

Cocci_1  \text{ctgcgtgtgacatACACACACACACACACACACACACACACACACACA}---ctgtatgtgt
Cocci_2  \text{ctgcgtgtgacatACACACACACACACACACACACACACACACACA}CA---ctgtatgtgt
Cocci_3  \text{ctgcgtgtgacatACACACACACACACACACACACACACACACACACA}CACA---ctgtatgtgt
Cocci_4  \text{ctgcgtgtgacatACACACACACACACACACACACACACACACACACACA}CACACACACACACACACACACACACACACACACACACActgtatgtgt
Microsatellites
These trees have the same topology (Kishino-Hasegawa test non-significant)

THE MICROSATELLITE MARKERS ARE GOOD

Renaming the species

California
- *Coccidioides immitis* Rixford and Gilchrist 1896

non-California
- *Coccidioides posadasii* after Alejandro Posadas
North America/Mexico C. immitis (●) and C. posadasii (○) show isolation by distance...

$r = 0.694^{**}$

$r = 0.905$
...but NOT if South American isolates (all *C. posadasii*) are included…
• S. American isolates contain 6% of the variation found in N. America
• 28% of loci are in linkage disequilibrium (7% in N. America)

• This is a bottlenecked population

...and is descended from the TEXAS population of *Coccidioides posadasii*
Genetic dating show that South American populations were founded from those in North America between 9,000 - 140,000 BP (the Pleistocene)
Migration of *Homo sapiens* into South America by 10,000 BC

Jared Diamond ‘Guns, Germs and Steel’, 1997
How did non-CA *C. immitis* arrive in South America?

**Host-pathogen dispersal:**

- 9,000 year old bones of *Bison antiquus* from Nebraska contain *C. immitis* spherules. Demonstrates potential for long-distance dispersal with a host

- Human infections are viable for more than 12 years

- Ancient Amerindian middens contain high concentrations of *C. immitis*

- Documented invasion of South America by the Amerindians 12,500 yrs bp.
Does the present distribution of *C. posadasii* reflect the co-dispersal of a host and its pathogen?
Recombining and Clonal in Coccidioides

Recombining

Clonal (C. posadasii in Latin Amer?)

Recombining