Employing Genetics To Study Whales

An Informal Introduction
Of Course Not Because...
..Or ?

Lunch break in Samana Bay, the Dominican Republic 1990
Camp in Uummannaq District, Northwest Greenland 1991
Whales Are A Resource

- Many populations and species depleted due to past commercial whaling operations.
- Subsistence hunting still ongoing in many parts of the world, as well as scientific whaling, and some unknown degree of illegal whaling.
- Whale watching a source of income in many developed as well as underdeveloped countries.
...But Because...
…And Because

- Very different system compared to “standard” terrestrial or fresh water models. Also different from many marine organisms
  - Active dispersal at all life stages
  - Wide ranges of movement in an environment with few barriers
  - Long life-span and presumably some degree of “culture” among individuals
Basic Aspects

- Advantages
  - Taxonomically closely related species-complex
  - Many truly cosmopolitan species, i.e., many different levels of evolutionary divergence
  - Mating and foraging tempo-spatially separated in many species
Basic Aspects

- **Disadvantages**
  - Difficult to observe and tag directly
  - Highly political due to very different cultural views on exploitation of whales
  - “Pop science”
Marine Mammals – Very Different Creatures Than Bugs and Plants

- Finite population sizes
- Overlapping generations
- Small litter size

- For instance:
  - Humpback whales in the north Atlantic number some 10,000 individuals. Females mature at the age of six and give birth to one calf every second year. The life expectancy is supposedly 30 years, but not known.
Interacting Levels and Processes

Molecular
Mode and rate of mutation

Organismal
Mode and rate of dispersal & gene flow

Ecosystem
Changes in abundance & structure
Biopsy Collection
.....And Into Pickle Juice
Genetic Analyses Conducted

- DNA extraction
- Sex determination
- Microsatellite genotyping
- Sequencing mtDNA
Analysis of Maternally and Biparentally Inherited Genetic Markers
The Humpback Whale
*Megaptera novaeangliae*

- Cosmopolitan species
- Weight: ~40 tonnes
- Length ~45’ or 15 meters
- Age at maturity: 6-7
- Extensively harvested in all oceans during the 19th and early-mid 20th century
- Protected in the US under the endangered species as well as the marine mammal protection act
- International trade regulated by CITES (for all cetacean species)
East-west Cline in Estimates of Genetic Diversity in the Maternally Inherited Mitochondrial Genome

[Bar chart showing genetic diversity across regions: Barents Sea, Iceland, West Greenland, Labrador, Newfoundland, Gulf of St. Lawrence, Gulf of Maine, West Indies.]
Genealogy Of Mitochondrial “Alleles”

Area % of each clade

<table>
<thead>
<tr>
<th>Area</th>
<th>Common</th>
<th>western</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barents Sea</td>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>Iceland</td>
<td>86</td>
<td>14</td>
</tr>
<tr>
<td>West Greenland</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>Labrador</td>
<td>74</td>
<td>26</td>
</tr>
<tr>
<td>Newfoundland</td>
<td>68</td>
<td>32</td>
</tr>
<tr>
<td>Gulf of St. Lawrence</td>
<td>62</td>
<td>38</td>
</tr>
<tr>
<td>Gulf of Maine</td>
<td>67</td>
<td>33</td>
</tr>
</tbody>
</table>

Antarctic alleles

Common North Atlantic alleles

western North Atlantic alleles
Western and eastern North Atlantic areas
### Divergence Estimates

<table>
<thead>
<tr>
<th>Area</th>
<th>Nuclear DNA</th>
<th></th>
<th>mtDNA</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$F_{ST}$ (mean)</td>
<td>Range</td>
<td>$H_{ST}$ (mean)</td>
<td>Range</td>
</tr>
<tr>
<td>eastern NAtl.</td>
<td>.0022</td>
<td>-</td>
<td>.009</td>
<td>-</td>
</tr>
<tr>
<td>western NAtl.</td>
<td>.0002</td>
<td>.0001 - .0005</td>
<td>.009</td>
<td>.000 - .026</td>
</tr>
<tr>
<td>Barents Sea - wNAtl.</td>
<td>.0038</td>
<td>.0009 - .0078</td>
<td>.040</td>
<td>.015 - .085</td>
</tr>
<tr>
<td>Iceland - wNAtl.</td>
<td>.0014</td>
<td>.0003 - .0027</td>
<td>.025</td>
<td>.010 - .042</td>
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</tbody>
</table>

Nuclear DNA estimates based on six loci
MtDNA divergence among feeding grounds
Calves Stay With Their Mother the 1\textsuperscript{st} Year
Identification Of Mother & Calf Relations
Maternally-directed Site-fidelity to Summer Feeding Grounds

- Individual humpback whales appear to return to the same high-latitude feeding ground every spring throughout its life.
- The feeding ground of choice is that to which the calf migrated to with its mother.
- Cultural transmission.
Two Breeding Populations
Effects of Pleistocene Glaciations On Genetic Diversity

Expected Poisson distribution

Observed distribution

@ exponential population expansion
Divergence On An Evolutionary Time Scale
Individual-based Analyses

- Insights on an ecological time scale
  - Individual identification
    - 6-15 microsatellite loci
    - Estimation of abundance and individual ranges of movement
  - Identification of close relatives
    - 20+ microsatellite loci for parent-offspring detection
    - Estimation of abundance
    - Reproductive success -> selection
    - Population structure
    - Estimation of demographic parameters
### North Atlantic Humpback Whale

<table>
<thead>
<tr>
<th>Area</th>
<th>Period</th>
<th>Samples</th>
<th>$f$ ($10^{-7}$)</th>
<th>95% CI limits ($10^{-7}$)</th>
<th>Genotypes</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barents Sea</td>
<td>1992-1993</td>
<td>36</td>
<td>8.46</td>
<td>4.9 - 38</td>
<td>35</td>
<td>13</td>
<td>22</td>
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<tr>
<td>Gulf of St. Lawrence</td>
<td>1990-1995</td>
<td>65</td>
<td>1.94</td>
<td>1.26 - 5.52</td>
<td>56</td>
<td>28</td>
<td>28</td>
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<tr>
<td>Gulf of Maine</td>
<td>1990-1995</td>
<td>292</td>
<td>1.38</td>
<td>1.02 - 2.11</td>
<td>256</td>
<td>118</td>
<td>138</td>
</tr>
<tr>
<td>Iceland/Jan Mayen</td>
<td>1991-1993</td>
<td>112</td>
<td>1.42</td>
<td>0.88 - 3.28</td>
<td>100</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Newfoundland/Labrador</td>
<td>1991-1995</td>
<td>572</td>
<td>1.34</td>
<td>1.07 - 1.86</td>
<td>464</td>
<td>237</td>
<td>227</td>
</tr>
<tr>
<td>West Greenland</td>
<td>1988-1994</td>
<td>189</td>
<td>1.23</td>
<td>0.89 - 2.10</td>
<td>148</td>
<td>75$^&amp;$</td>
<td>72$^&amp;$</td>
</tr>
<tr>
<td>West Indies</td>
<td>1989-1995</td>
<td>1,794</td>
<td>1.81</td>
<td>1.57 - 2.15</td>
<td>1,432</td>
<td>884$^&amp;$</td>
<td>548$^&amp;$</td>
</tr>
<tr>
<td>Minus inter-area recaptures</td>
<td></td>
<td>2,491</td>
<td>1.51</td>
<td>1.34 - 1.75</td>
<td>2,368</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unique genotypes only</td>
<td></td>
<td>2,368</td>
<td>1.51</td>
<td>1.32 - 1.72</td>
<td>1,331$^&amp;$</td>
<td>1,033$^&amp;$</td>
<td></td>
</tr>
</tbody>
</table>

$^\&$Probability of identical genotype across all loci calculated from all samples (including recaptures).
$^\&$Estimated from 1,000 bootstrap samples.
$^\&$No gender was obtained for a total of four samples.
Different Number of Males and Females on the Breeding Grounds

- Abundance estimates of each sex were estimated from the samples collected on the breeding ground during 1992 and 1993
  - 4,804 males (95% CI: 3,374 - 7,123)
  - 2,804 females (95% CI: 1,776 - 4,463)

- Even sex ration in calves and among feeding ground samples

- Difference in male and female abundance probably due to “temporal fidelity” in migration timing among females
Temporal Fidelity

Temporal Fidelity

Julian Day (1992)

Julian Date (1993)

Not significant (F=2.4, df = 1, 51)

y = 0.641x + 12.553

R^2 = 0.4777
Thank You