Session B4- Migration syndromes and passage “success” in diadromous fishes

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University of Idaho

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Migration Syndromes and “Success” in Migratory Fishes

Christopher Caudill
Department of Fish and Wildlife Resources
University of Idaho
Migration Syndromes and “Success” in Migratory Fishes

Christopher Caudill

Chris Peery, Ted Bjornn, Matt Keefer, Charles Boggs, Bill Daigle, Tami Clabough, Megan Heinrich, Mike Jepson, Steve Lee, George Naughton, Rudy Ringe, Ken Tolotti, Lowell Struenberg, Mary Moser, Ben Ho, Brian McIlraith, Dan Joosten, Karen Johnson, Ryan Mann, Eric Johnson, Mark Morasch, Travis Dick, Rose Poulin Brian Burke, ...
Three Parts

1) Conceptual background

2) Three concrete case examples
   - Anadromous salmonids
   - American shad
   - Pacific lamprey

3) Implications for monitoring, conservation and management
Migration Systems

• Taxa differ in migration modes and mechanisms

Dingle and Drake 2007
Migration Systems

- Taxa differ in migration modes and mechanisms
- Interplay among genes, phenotypes, behavior, environment, and population dynamics
Migration Systems

- Taxa differ in migration modes and mechanisms
- Interplay among genes, phenotypes, behavior, environment, and population dynamics
- Predicting response to perturbation requires some knowledge of migration system

Dingle and Drake 2007
Migration syndromes

• Need to ask questions at multiple scales:
  – Do adults return to natal drainage basin (homing)?
  – Do adults return to breeding site of parents within natal basin? If so, at what scale?
  – If not, what mechanisms are used to find and select spawning habitat upon return to freshwater?
Migration System

Natal Site Fidelity ← Site Infidelity
Migration System

Natal Site Fidelity  →  Site Infidelity

Site Fidelity!!!

(Apparent) random dispersal

Fidelity to region followed by site fidelity

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College of Natural Resources
Migration System

Natal Site Fidelity

- Homing to natal stream
- Repeated use of same breeding site when iteroparous
- Strong population structure
- Locally adapted
- Density-independent behavior

Site Infidelity

- Rarely return to natal stream
- No repeatability
- Genetic panmixia or weak structure
- Generalists
- Density-dependent behavior (e.g., Ideal Free Distribution)
Migration System

Natal Philopatry

• Homing to natal stream
• Repeated use of same breeding site when iteroparous
• Strong population structure
• Locally adapted
• Density-independent behavior

Site Infidelity

• Rarely return to natal stream
• No repeatability
• Genetic panmixia or weak structure
• Generalists
• Density-dependent behavior (e.g., Ideal Free Distribution)
Part II: Case examples

Natal Philopatry  Site Infidelity

Where on this continuum should we place salmonids, American shad and Pacific lamprey?

Site Fidelity!!!

( Apparently) random dispersal

Fidelity to region followed by site fidelity

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University of Idaho
College of Natural Resources
University of Idaho Fish Ecology Research Lab & Adult Passage Project

- Basic and applied research in fisheries and freshwater conservation since the early 1990s
- Provide technical research support to cooperating agencies
  - USACE, USFWS, NPS, Tribes
- Primarily anadromous fish studies, focusing on migration in the Columbia Basin
  - Identify problem areas and potential modifications
  - Evaluate structural and operational modifications
  - Address basic knowledge gaps
  - Large focus on direct and indirect effects of dams
Bonneville Dam

- First dam encountered (rkm 235)
- Complex series of fishways (9+ entrances, 4 major ladders, two exits)
- Typical maximum **daily** passage rates:
  - Chinook salmon = 25,000
  - American shad = 250,000
  - Pacific lamprey = 2,000
Fishway Modification Monitoring
Telemetry Approaches
## Radio-tagged Adult Salmon & Steelhead

<table>
<thead>
<tr>
<th>Bonneville Dam</th>
<th>Spring Chinook</th>
<th>Summer Chinook</th>
<th>Fall Chinook</th>
<th>Steelhead</th>
<th>Sockeye</th>
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<td>368</td>
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<td>964</td>
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<tr>
<td>2010</td>
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<td>312</td>
<td>325</td>
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<td>Total</td>
<td>4,588</td>
<td>1,503</td>
<td>6,091</td>
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</table>
Monitoring arrays

4 Lower Columbia dams
4 Lower Snake dams
Priest Rapids, Wanapum
Major tributaries
≥ 147 Fixed Receiver Sites + Mobile Tracking
Monitoring arrays

4 Lower Columbia dams
4 Lower Snake dams
Priest Rapids, Wanapum
Major tributaries
≥ 147 Fixed Receiver Sites + Mobile Tracking
Homing in salmonids

- Remarkably precise return to natal site using memory of olfactory cues
- Fine scale genetic structure (10-100s of m)
- Local adaptation
- Multiple Evolutionary Significant Units (ESUs)
Homing in salmonids

- Remarkably precise return to natal site using memory of olfactory cues
- Fine scale genetic structure (10-100s of m)
- Local adaptation
- Multiple Evolutionary Significant Units (ESUs)
- Dominant (and often implicit) paradigm

- Primary Model Hypothesis: adults return to natal stream
Barging and straying

A) Chinook Salmon

B) Steelhead

Keefer et al. 2008 (EA)
Migration System

Obligate Natal Philopatry

Site Fidelity!!!

Obligate Site Infidelity
American Shad

- 1871 – Introduced to Sacramento River, CA.
- Adults spawn 1-4 times in Columbia River reservoirs
Adult shad PIT tagging: Traits and Behavior

• Do American shad home to natal reservoir?
• **Hypothesis**: Iteroparous individuals should exhibit repeat migration distance if they home to natal reservoir
Repeatability and homing

Did adults spawning in two years return consistently to McNary Dam?

Preliminary results: 2005-2007 tag years

<table>
<thead>
<tr>
<th>Migrated upstream to:</th>
<th>Next Year</th>
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<tbody>
<tr>
<td>Tag Year</td>
<td>BO</td>
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<tr>
<td>BO</td>
<td>42</td>
</tr>
<tr>
<td>MN</td>
<td>13</td>
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</table>

- Conclude homing to reservoir is absent or weak
- Can’t rule out tag effects
American shad

- American shad home to natal river basin (e.g., Columbia, Umpqua, Sacramento)
- Migration distance upstream within river appears flexible and may be depend on adult condition; needs further study...

![Box plot showing muscle lipid at river entry for American shad detected at McNary Dam.](image-url)
Migration System

Obligate Natal Philopatry

Basin-scale fidelity

Obligate Site Infidelity
Pacific lamprey

- Pacific lamprey in decline; petitioned twice for listing under ESA
- Semelparous, marine parasitic
- Native species, culturally and ecologically important
- Tagging of outmigrating juveniles impractical
- Passage rates over Columbia River dams low (30-50%)
Pacific Lamprey

1939-1969 mean: ~104,700

1998-2010 mean: ~39,600

2010: ~6,200

Sources: Starke & Dalen 1995; DART
Dam passage estimates - 2009

Escapement from release below BON

- Radio only
- HD only
- Double tag

<table>
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<th>Dam</th>
<th>Percent past (%)</th>
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<tr>
<td>BON</td>
<td>45</td>
</tr>
<tr>
<td>TDA</td>
<td>10</td>
</tr>
<tr>
<td>JDA</td>
<td>0</td>
</tr>
<tr>
<td>MCN</td>
<td>0</td>
</tr>
<tr>
<td>IHR</td>
<td>0</td>
</tr>
<tr>
<td>PRD</td>
<td>0</td>
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</table>
Date and size effects

Weight @ tagging, BO Dam (g)

- Release
- Pass BO
- Pass TD
- Pass JD
- Pass MN

+5%
+7%
+14%
+19%
What is the migration system of lamprey?

- Homing predicts:
  - return to site of capture if displaced downstream
  - population genetic structure
  - use of geographically specific cues for orientation
Evidence for site fidelity and population structure in Pacific lamprey

- **Direct evidence: Mark-recapture/telemetry**
  Hatch and Whiteaker (2009)
  25 Willamette Falls; 25 Bonneville
  Radio-tagged, released 26 km below confluence

- **No evidence of return to site of capture when displaced downstream**
Evidence for site fidelity and population structure in Pacific lamprey

- Indirect evidence: population genetic structure
- 3 Studies:
  - Goodman et al. 2008 MtDNA, 1246 lamprey from 81 populations; Skeena R., BC to Ventura R., CA.
  - Lin et al. 2008 AFLP, 218 lamprey from 8 populations; Naka R., Japan to Klamath R., CA.
  - Docker et al. 2010 Microsats, 965 lamprey from 21 sites; N. BC to S. CA
- All studies found evidence of high levels of gene flow among populations
Evidence for site fidelity and population structure in Pacific lamprey

- **Indirect evidence: Breeding site selection**
  - Pacific lamprey are sensitive to Lamprey Bile Acids (Robinson et al. 2009)
  - May be used to locate stream reaches with high larval densities

- **Chemically simple pheromones are unlikely to be geographically specific homing cues**
Selective, but little evidence of natal site fidelity
- within rivers
- among river systems
Selective, but little evidence of natal site fidelity
  - within rivers
  - among river systems
Selective, but little evidence of natal site fidelity
- within rivers
- among river systems
Why it Matters: Migration system and “success”

Site Fidelity

Obstruction

Natal Stream

15% Unsuccessful

85% Successful
Migration system and “success”

Site fidelity:

- Natal Stream: 85% Successful
- 15% Unsuccessful

Site infidelity:

- Natal Stream: 85% Successful
- 15% Successful
Migration system and “success”: Site infidelity

Unaltered migration corridor: 15% Unsuccessful

Obstruction

85% Successful

Spawning Stream
Migration system and “success”

Altered migration corridor: Obstruction

15% Successful

85% Successful

Altered migration corridor: Obstruction

Reduction in total population size & Need to assess lifetime fitness

“Successful”?
Recommendation and Opportunities

• Critical to consider underlying migration system if scientifically rigorous conclusions about passage “success” are desired, but...
Recommendation and Opportunities

• Critical to consider underlying migration system if scientifically rigorous conclusions about passage “success” are desired, but...

• Improved passage conditions are improved passage conditions
  – improved hydraulic conditions
  – heterogeneity in velocity, etc.
Recommendation and Opportunities

• Conceptual model(s) provides a framework for making **predictions**

• Use available data to make **inferences and generate hypotheses** about migration behavior and motivation in understudied taxa
Questions?

http://www.cnr.uidaho.edu/UIFERL or Google “UI FERL”
Adult shad studies:

• PIT Tagging of adults
  – Tagging: 2004-2007 @ Bonneville.
  – Monitor migration at BO, McN, IH, and LGr
Muscle lipid and migration distance

- Individual lipid levels varied by an order of magnitude
- Adults observed at McNary had higher initial lipids

![Box plot showing muscle lipid at river entry](image)

- Similar, though more complex pattern, observed for growth rate

\[ P_{fat} = 0.0234 \]
Annual shad counts at Bonneville

![Graph showing annual shad counts at Bonneville Dam from 1950 to 2010. The graph indicates a significant peak in shad numbers around the year 2000.](graph.png)
Longitudinal distribution in Columbia & Snake rivers

![Graph showing the longitudinal distribution of Columbia and Snake rivers with river kilometers and proportion of run over dam(i) (+/-1 SE) on the axes.](#)
Fishway Modification Monitoring
Repeatability and homing

Did adults spawning in two years return consistently to McNary Dam?

**Predictions:**

**Strong Homing**

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<tr>
<th>Tag Year</th>
<th>Migrated upstream to:</th>
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<tbody>
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**No Homing**

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</table>
Repeatability and homing

Did adults spawning in two years return consistently to McNary Dam?

Preliminary results: 2005-2007 tag years

| Migrated upstream to: | Next Year |  |
|-----------------------|-----------|
| **Tag Year**          | **BO**    | **MN** |
| BO                    | 42        | 19     |
| MN                    | 13        | 9      |
Summary

• Underlying migration system affects measures of success and the biological response of populations to anthropogenic change
Summary

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• In particular, site fidelity (e.g., homing) has strong effects on “motivation” during migration and on population structure.
Summary

• Underlying migration system affects measures of success and the biological response of populations to anthropogenic change.

• In particular, site fidelity (e.g., homing) has strong effects on “motivation” during migration and on population structure.

• Critical to define population and align different concepts before demographic or genetic effects can be evaluated.
Summary

• Underlying migration system affects measures of success and the biological response of populations to anthropogenic change.

• In particular, site fidelity (e.g., homing) has strong effects on “motivation” during migration and on population structure.

• Critical to define population and align different concepts before demographic or genetic effects can be evaluated.

• Fish passage improvements still critical.
Migration system and “success”

 Philopatry:

 Obstruction

 Natal Stream

 85% Successful

 15% Unsuccessful

 Selection for traits to pass obstruction?

 Site infidelity:

 Obstruction

 85% Successful: selection for plasticity and/or passage?

 15% Successful
Recommendation and Opportunities

• Can we compare metrics among dams?
• What is passage success?
  -answer depends on population structure and migration system
Recommendation and Opportunities

- Can we compare metrics among dams?
- What is passage success?
  - answer depends on population structure and migration system
- Should we reframe the question(s)?
  - continue to focus on minimizing passage obstacles
  - how does adult vs. juvenile migration success affect lifetime fitness?
Evidence for site fidelity and population structure in Pacific lamprey

- Indirect evidence: Comparative data from sea lamprey
  - Mark recapture revealed lack of homing in Lake Huron (Bergstedt and Seelye 1995)
  - Strong sensitivity and orientation to larval pheromones (e.g., Johnson et al. 2009)
  - mtDNA revealed no population genetic structure among North American anadromous populations (Waldman et al 2008)
Migration Systems

- Taxa differ in migration modes and mechanisms
- Interplay among genes, phenotypes, behavior, environment, and population dynamics
- Predicting response to perturbation requires some knowledge of migration system

Dingle and Drake 2007