Determining potential functional connectivity of fish species with various life history traits

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Intro

Stream Fragmentation
Migratory Fish

Diadromous species require both freshwater and marine habitat to complete lifecycle

Cool-water habitat

Headwaters

Estuary

(e.g., Atlantic salmon)

watershed

Photos: Gary Tyson; BBC
Non-Migratory Fish

Non-diadromous species remain in freshwater

Cool-water habitat

(e.g., Ninespine Stickleback)

Headwaters

Estuary

watershed

Photos: Gary Tyson; BBC
Stream Fragmentation and Connectivity

Functional Connectivity: species ability to disperse through the landscape

- Cool-water habitat
- Headwaters
- Estuary

Passability Levels:
- Low passability
- Moderate passability
- Complete passability

Photos: Andrew Chin
Question
Do culverts differently affect the potential functional connectivity of diadromous and non-diadromous species?
Weak swimming diadromous species are most adversely affected by stream fragmentation.
Fisheries and Oceans Canada
Located culverts upstream from mouth of estuaries (2006-2008)

Culverts surveyed
- Length
- Diameter
- Slope
- Drop height
- Material

25 species in 3 watersheds
Study Area

Fisheries and Oceans Canada
Located culverts upstream from mouth of estuaries (2006-2008)

Culverts surveyed
• Length
• Diameter
• Slope
• Drop height
• Material

25 species in 3 watersheds
Richibucto estuary
Study Area: Richibucto

Richibucto (119 culverts)
198 km²

143 road crossings
= 83.2% culverts
Study Area: Shediac

Shediac (30 culverts)
221 km²

107 road crossings
= 28.0% culverts
Study Area: Scoudouc

Scoudouc (10 culverts)
144 km²

71 road crossings
= 14.1% culverts
Morphometrics

Use morphological traits to imply the swimming strength

Adult fish length

Total length

Photo: Andrew Chin
## Methods

### Swimming Strength

<table>
<thead>
<tr>
<th>Stronger Swimmer = Higher Connectivity</th>
<th>Weaker Swimmer = Lower Connectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainbow Smelt*</td>
<td>Fourspine Stickleback</td>
</tr>
<tr>
<td>Atlantic Tomcod</td>
<td>Northern Redbelly Dace</td>
</tr>
<tr>
<td>Alewife*</td>
<td>Ninespine Stickleback*</td>
</tr>
<tr>
<td>Striped Bass*</td>
<td>Fathead Minnow</td>
</tr>
<tr>
<td>American Shad*</td>
<td>Finescale Dace</td>
</tr>
<tr>
<td>Brook Trout*</td>
<td>Threespine Stickleback*</td>
</tr>
<tr>
<td>Atlantic Salmon*</td>
<td>Slimy Sculpin</td>
</tr>
<tr>
<td>White Perch</td>
<td>Blacknose Dace</td>
</tr>
</tbody>
</table>

*diadromous
Focal Species

NON-DIADROMOUS

Ninespine Stickleback
(Pungitius pungitius)

Fourspine Stickleback
(Apeltes quadracus)

Alewife
(Alosa pseudoharengus)

American Shad
(Alosa sapidissima)
For each culvert, it is impassable if half the total length of the species is less than the drop height.
Methods

Connectivity Index

Each particular obstacle (e.g., road culvert, bridge, etc.) will have a different probability of passage.

- **American Shad** (strong swimmer):
  - 1. Bridge: 100% passage
  - 2. Culvert: 70% passage
  - 3. Dam: 0% passage

- **Stickleback** (weak swimmer):
  - 1. Bridge: 100% passage
  - 2. Culvert: 50% passage
  - 3. Dam: 0% passage

- **Dendritic Connectivity Index (DCI)** (Cote et al. 2009)
Potential Connectivity Index

Diagram showing the connectivity between headwaters, culvert, and estuary.
Methods

Potential Connectivity Index

Diadromous \( DCI_D \)
HEADWATERS

Non-diadromous \( DCI_p \)
HEADWATERS

CULVERT

ESTUARY

ESTUARY
High fragmentation

Richibucto ($n = 119$ culverts)

**Alewife** $DCI_D = 69.69$

**American Shad** $DCI_D = 74.28$
Results

High fragmentation

Richibucto \((n = 119 \text{ culverts})\)

Ninespine Stickleback \(\text{DCI}_P = 45.45\)

Fourspine Stickleback \(\text{DCI}_D = 65.62\)
Results

Moderate fragmentation

Shediac ($n = 30$ culverts)

Alewife  $\text{DCI}_D = 69.69$

American Shad  $\text{DCI}_D = 75.18$

Upstream
Results

Moderate fragmentation

Shediac ($n = 30$ culverts)

Ninespine Stickleback \[ \text{DCI}_p = 47.00 \]

Fourspine Stickleback \[ \text{DCI}_D = 66.54 \]

Upstream
Results

Low fragmentation

**Scoudouc** (n = 10 culverts)

**Alewife**  \( DCI_D = 92.70 \)

**American Shad**  \( DCI_D = 93.22 \)
Results

Low fragmentation

**Shediac** ($n = 10$ culverts)

**Ninespine Stickleback**  \( DCI_P = 85.37 \)

**Fourspine Stickleback**  \( DCI_D = 92.17 \)
Results

Connectivity within streams

**Richibucto**
(n = 119 culverts)

**Shediac**
(n = 30 culverts)

**Scoudouc**
(n = 10 culverts)
Varying cost values for obstacles
(Rayfield et al., 2010)

Sensitivity analysis of fish passage:
• species traits
• culvert features

American Shad
(strong swimmer)
1. Bridge
2. Culvert
3. Culvert

Stickleback
(weak swimmer)

Estuary
Headwater
Significance

- Morphological trait-based analysis is a surrogate for functional connectivity

- Species-based approach is necessary to consider for functional connectivity and species persistence in stream networks

- Sensitivity analysis of passage will provide insights on which combination of species traits and culvert features affect potential functional connectivity

- Findings will inform policy and management
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Methods

Potential Connectivity Index

\[ c_{ij} = \prod_{m=1}^{M} p_m^u p_m^d \]

- \( c_{ij} \): connectivity
- \( M \): number of barriers
- \( p_m^u \): upstream passability
- \( p_m^d \): downstream passability
Methods

Potential Connectivity Index

$$DCl_D = \sum_{i=1}^{n} c_{ij} \frac{l_i}{L} \times 100$$

$$DCl_p = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} \frac{l_i l_j}{L^2} \times 100$$

$C_{ij}$: connectivity between segment $i$ and $j$

$L$: total length of all segments

$l$: length of segment between $i$ and