Shoreline armoring disrupts marine-terrestrial connectivity in the Salish Sea, with consequences for invertebrates, fish, and birds

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Motivation: What are the ecological effects of shoreline armoring in the Salish Sea?
1. Ecological framework:
   a) Ecotones and spatial subsidies
   b) Beach wrack
2. Results: Beach surveys
   a) Physical characteristics
   b) Beach wrack and logs
3. Results: Primary consumers (beach invertebrates)
4. Results: Secondary consumers:
   a) Terrestrial birds
   b) Juvenile salmon
5. Conclusions
   a) Ecological context of shoreline armoring
   b) Restoration and conservation implications
Well-studied aquatic-terrestrial ecotones: sandy coasts, forested streams

SPATIAL SUBSIDY: INCREASED
+ primary productivity
+ consumer density
Beach wrack

Romanuk & Levings 2010 – terrestrially derived carbon in chum salmon in Howe Sound

Ecological framework
How does armoring affect:
- Aquatic-terrestrial connectivity?
- Permeability of boundary?
- Fluxes of material and organisms?
- Subsidies for primary consumers?
Physical parameters

Armored differences (N = 29 pairs):

- Lower maximum elevation (*paired t-test, p < 0.01*)
- Narrower beach width (*paired t-test, p < 0.01*)

ARMORING = REDUCED SIZE OF ECOTONE, LOWER ELEVATION OF AQUATIC-TERRESTRIAL INTERFACE
Logs and wrack

Spring N = 24 pairs
Fall N = 27 pairs

Armored differences:
- Significantly fewer logs (paired t-test, \( p < 0.01 \))
- Width of log line significantly smaller (paired t-test, \( p < 0.01 \))

**ARMORING = REMOVAL OF LOG ZONE HABITAT**
Beach wrack

Spring N = 24 pairs
Fall N = 27 pairs
• Less wrack in spring than in fall (ANOVA, $p < 0.01$)

Armored differences:
• Less wrack (paired t-test, $p < 0.01$)
• Lower proportion of terrestrial material in wrack (paired t-test, $p < 0.01$)

ARMORING = REDUCED TERRESTRIAL-AQUATIC FLUX OF ORGANIC MATERIALS
Wrack invertebrates

Including some insect taxa that have been found in juvenile salmon diets (e.g. Toft et al. 2007; Romanuk & Levings 2010)

ARMORING = FEWER INVERTEBRATES AND DIFFERENT TAXA
Wrack invertebrates

- Overall invertebrate assemblage significantly different between armored and unarmored
- Differences explained by combination of physical predictor variables
- Unarmored assemblage correlated with talitrid amphipods, flies, and beetles
- Armored assemblage correlated with aquatic isopods and bivalves
Secondary consumers: birds

Abundance and species composition

- Fewer birds overall at armored beaches
  - Armored beaches: crows most common, no shorebirds
  - Unarmored beaches: sparrows most common, no seagulls

**FEWER BIRDS AND DIFFERENT TAXA AT ARMORED BEACHES**
Secondary consumers: birds

Behavior (terrestrial birds)

- DIFFERENCES IN HABITAT USE BETWEEN ARMORED AND UNARMORED BEACHES
- FEWER PREY? OR REDUCED FORAGING OPPORTUNITY?

Ecological framework/Beach survey results/Primary consumers/Secondary consumers
Secondary consumers: juvenile salmon

- More observations at unarmored beaches
- Juvenile salmon in deeper water along armored shorelines

- DIFFERENCES IN DISTRIBUTION BETWEEN ARMORED AND UNARMORED BEACHES
- FEEDING RATES CONSISTENT
- FEWER PREY?
Conclusions

- Aquatic-terrestrial connectivity is important for Salish Sea ecosystem health
- Armoring disrupts connectivity – landward and seaward impacts
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Restoration and conservation considerations

- Aquatic-terrestrial
- Physical-biological

Restoring connectivity can restore ecological functions
- Can be stable/self-maintaining over time
Restoration and conservation considerations

- Aquatic-terrestrial
- Physical-biological

- Full restoration of aquatic-terrestrial connectivity sometimes not possible
- Connectivity can be restored for some components or processes within urban constraints
Shoreline armoring – previous research

- Loss of terrestrial vegetation
  - Romanuk & Levings 2003

- Lower density and diversity of insects
  - Rice 2006; Morley et al. 2012

- Greater microclimate variability
  - Rice 2006; Morley et al. 2012

- Altered fish distribution
  - Toft et al. 2007; Bilkovic & Roggero 2008

- No sediment source
  - Pilkey & Wright 1988; Griggs 2005

- Wave reflection

- Suspended sediment

- Lower density and diversity of invertebrates on bottom substrates
  - Chapman 2003

- Encroachment on upper beach

- Armoring structure

- Hypothetical unarmored profile

- Water

- Beach
AMOUNT AND COMPOSITION OF WRACK SIGNIFICANTLY DIFFERENT

(LESS WRACK)

(MORE WRACK)

Eelgrass

Terrestrial

Amount of algae, eelgrass, and terrestrial wrack

(Type)

Armored

Unarmored

2D Stress: 0.12

Wrack assemblage significantly different by type

(paired PERMANOVA, fall, p = 0.001; spring, p = 0.002)
Results: wrack “assemblage”

- MORE WRACK CORRELATED WITH WIDTH OF LOG LINE AND MAX ELEVATION/BEACH WIDTH
- SIZE OF ECOTONE IMPORTANT

Amount of algae, eelgrass, and terrestrial wrack

(paired PERMANOVA, fall, \( p = 0.001 \); spring, \( p = 0.002 \))
Wrack invertebrates

- Density of invertebrates (how many?)
- Taxonomic composition (what kind?)

Variation between points explained by physical variables (6 out of 12 possible)
Secondary consumers: juvenile salmon

- PRIMARY BEHAVIOR: FORAGING AT SURFACE
- INSECTS?

Straightness index: Net/Total = 0.57

Total distance: 87 m

Net distance: 50 m
• FEEDING RATES, MOVEMENT RATES, STRAIGHTNESS INDEX CONSISTENT BETWEEN ARMORED-UNARMORED
• DIFFERENCES IN DEPTH DISTRIBUTION

Total distance: 87 m
Net distance: 50 m
Straightness index: Net/Total = 0.57
Secondary consumers: juvenile salmon

FEEDING BEHAVIOR AFFECTS MOVEMENT PATHS

ST:
Net/Total
= 0.57

Total distance: 87 m

Net distance: 50 m

Intro/Hypotheses, Approach, Methods/Beach survey results/Conceptual model/Primary consumers/Secondary consumers
Conceptual model: Unarmored nearshore

Marine riparian – trees and shrubs

Riparian insects

Beach wrack

Eelgrass

Algae

Marine/estuarine water

Shallow water

Juvenile salmon

Wrack invertebrates

Birds

Leaf litter

Riparian insects

Fallen trees

Logs

Driftwood

Ecotone: upper intertidal
Marine riparian – trees and shrubs

Eelgrass

Marine/estuarine water

Wrack invertebrates

Beach wrack

Birds

Terrestrial

Zone of armoring

Estuarine

Eelgrass

Algae

Juvenile salmon

Marine/estuarine water

Conceptual model: Armored nearshore

Ecotone: upper intertidal

Intro/Hypotheses, Approach, Methods/Beach survey results/Conceptual model/Primary consumers/Secondary consumers/Conclusions