A breakdown of habitat isolation among coastal fish by an artificial habitat modification

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Hybridization

Hexagrammos agrammus

Hexagrammos octogrammus

Hexagrammos otakii

Photo by T. Abe
Habitat alteration by human activities:

- Deforestation
- Soil contamination
- Fragmentation
- Eutrophication
- Water pollution
- Desertification

Images depicting various forms of habitat alteration caused by human activities.
Coastal area is not an exception…
Artificial modification of coast line are very common in Japan.

Transition of coastal line of each category in Japan

(Ministry of the Environment of Japan, Nature Conservation Bureau)
Artificialization of coast line cause serious influence on marine ecosystems.

Decrement of seaweed bed

Artificialization
- shore protection
- reclamation
- artificial construction
- ...etc.

Today’s topic

Construction of breakwater

suitable habitat for growing, feeding, shelter, and reproduction

Extinction of local population

Artificialization of coast line

Breakdown of habitat isolation

Hybridization between naturally isolated species
Habitat Isolation

a reproductive isolating mechanism that prevents gene exchange among species in different habitats

● maggot fly *Phagoletis pompnella* (Forbes & Feder, 2006)

  apple-infesting host race
  V.S.
  hawthorn-infesting host race

→ distinguish each host plat by olfactory and visual fruit cues

● *Heliconius* butterflies (Estrand & Jiggins, 2002)

  *H. melpemene* inhabit open secondary forest
  V.S.
  *H. cydno* inhabit closed-canopy forest

→ difference of microhabitat contribute to pre-mating isolation
Such human-caused hybridization sometimes lead to extinctions of local population. Well known example is species introduction.

- Endemic Cutthroat Trout
- Introduced Rainbow Trout
- Endemic grey duck
- Introduced mallard ducks
greenling (*Hexagrammos* generic species)

Coastal benthic fish

Commons species in North Pacific

Males establish breeding territories during breeding season.

Females visit males’ territories and spawn egg masses on substrates.

Egg masses deposited by multiple females are cared for by territorial males until hatching.
Hybridization among three *Hexagrammos* species

- **H. octogrammus**
- **H. otakii**
- **H. agrammus**

A boreal species (*H. octogrammus*) and two temperate species (*H. otakii* & *H. agrammus*) secondary came into contact after glacial age. Down arrow indicating hybrid zone.
Hybridization among three *Hexagrammos* species

Habitat use of three *Hexagrammos* species

- **H. agrammus**
- **H. octogrammus**
- **H. otakii**

**Difference of Habitat** = Habitat Isolation

- Shallow seaweed bed
- Deep reef or sandy floor

**H. agrammus** × **H. octogrammus**
( has been reported since 1970’s )

**H. otakii** × **H. octogrammus**
( first reported in 2001 )

Why ! ?
Hybridization among three *Hexagrammos* species

Habitat use of three *Hexagrammos* species

- **H. octogrammus**
- **H. agrammus**
- **H. otakii**

**Difference of Habitat = Habitat Isolation**

- **Shallow seaweed bed**
- **Deep reef or sandy floor**

We hypothesized...

Man-made construction such as breakwater would approximate shallow and deep environment owing to its steep slopes, allowing naturally isolated shallow and deep species to breed in same area.
We researched their distribution with SCUBA...

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**Question:**
1. **What is the factor that make their natural distribution segregated?**
   (What cause habitat isolation?)
2. **Why all three species co-occurred in Breakwater area?**
   (What is the breakdown mechanism?)
Research about distribution patterns and habitat use

- **Habitat characteristic**
  - **depth**
  - **bottom materials** (rock, sand, boulder, fishing banks, tetrapods, net)
  - **vegetation** (small algae, macroalgae, surfgrass, bryozoans, net knot, bare)

- **Distribution of Hexagrammos fish**
  (non-territorial and territorial)

- **Spawning substrates**

- **Sandy Area**
  (with fishing banks)
  depth: 19-21m, 30 × 50m

- **Natural Reef 1**
  depth: 0-9m, 20 × 70m

- **Natural Reef 2**
  depth: 0-5m, 20 × 70m

- **Breakwater Area**
  depth: 0-11m, 25 × 70m
1. What is the factor that make their natural distribution segregated?

Which environmental factor most influence the distribution patterns of *Hexagrammos* species?

A series of Maltinomial log-liner models

**A. non-territorial individuals**

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<tr>
<th>Model</th>
<th>independent variables</th>
<th>AIC</th>
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<td>Model 7</td>
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**B. territories**

<table>
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<td>Model 6</td>
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<tr>
<td>Model 7</td>
<td>$\beta_0$ + $\beta_1$ (vegetation)</td>
<td>95</td>
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</table>

The distributions of non-territorial individuals might NOT be determined by any particular factors.

The distributions of territories were well explained by *vegetation*. 
1. What is the factor that make their natural distribution segregated?

What vegetation does each *Hexagrammos* species prefer?

Selectivity for vegetation
( Gabriel’s selectivity index $Li$ )

- Each species showed different preference for vegetation.
- Selectivity for preferred vegetation of territory were higher than that of non-territorial individuals.
1. What is the factor that make their natural distribution separated?

Why the selectivity for vegetation were higher as to territory?

(No. of egg masses)
- Red: H. agrammus (N=428)
- Blue: H. octogrammus (N=261)
- Yellow: H. otakii (N=362)

Distribution of territories might be influenced by the distribution of spawning substrates!?
1. What is the factor that make their natural distribution segregated?

Why spawning substrates are different among three species?

- **Gelidium elegans**
  - wrapped up with seaweed branches, shaping into globular masses

- **H. agrammus**
  - very viscous egg masses
    - pressed over rugged materials, shaping into platy masses

- **H. octogrammus**
  - less viscous egg masses

- **H. otakii**
  - less viscous egg masses

Males might select suitable substrates according to the property of egg masses.
The distribution of territories were well explained by vegetation.

co-occurrence of three *Hexagrammos* species

= co-occurrence of different vegetation

**Natural reef**

- *H. agrammus*
- *H. octogrammus*
- thick seaweed

**Breakwater area**

- *H. otakii*
- thin seaweed but abundant bryozoans

2. **Why all three species co-occurred in Breakwater area?**

How is the environment of Breakwater area like?
2. Why all three species co-occurred in Breakwater area?

How is the environment of Breakwater area like?

The distribution of territories were well explained by vegetation.

co-occurrence of three Hexagrammos species

= co-occurrence of different vegetation

Natural reef

- *H. agrammus*
- *H. octogrammus*
- *H. otakii*

- Thick seaweed
- Thin seaweed but abundant bryozoans

egg masses spawned on seaweed

egg masses spawned on bryozoans
The distribution of territories were well explained by vegetation.

How is the environment of Breakwater area like?

2. Why all three species co-occurred in Breakwater area?

Steep slope and complex structure of tetrapods create heterogeneous environment in which shallow and deep environment coexist.

egg masses spawned on net knod
Hybridization occurred in Breakwater area

Male’s breeding territories of three species were observed in Breakwater area.

We estimated mother species of cared egg masses with mtDNA.

Egg masses in the territories of... mtDNA (estimated female)

The territories of *H. agrammus* and *H. otakii* contained many egg masses probably spawned by *H. octogrammus* females.

Unidirectional hybridization occurred in artificial habitat.

*H. octogrammus* and *H. otakii* are at a risk of human-caused hybridization by the breakdown of habitat isolation.
Mechanisms of breakdown of habitat isolation through habitat modification by human activity

- **Hybridization of Habitat**
  - *Iris fulva* in habitat A
  - *Iris hexagona* in habitat B
  - New intermediate habitat

- **Habitat loss**
  - *Phoxinus tennesseensis* in habitat A
  - *Semotilus atromaculatus* in habitat B
New breakdown mechanism “Habitat coexistence”

Natural

approximate heterogeneous environment

Habitat fragmentation

Human activity

Reduction of effective population size

Artificial

mosaic habitat

Habitat coexistence

Human activity

Hybridization
Influences of human-caused hybridization

- hybridize
- genetic introgression
- species replacement
- hybrid swarm

...etc.
To quantify the influence of breakdown of habitat isolation by artificial habitat modifications…

We need to simulate the dynamics of genetic population structure within hybrid zone.

Further study requires …

- Frequency of annual hybridization
- Survival rate of hybrid offspring
- Proportion of genetic introgression
- Relation between a degree of habitat modification and a rate of hybridization
Thank you for your attention!

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