

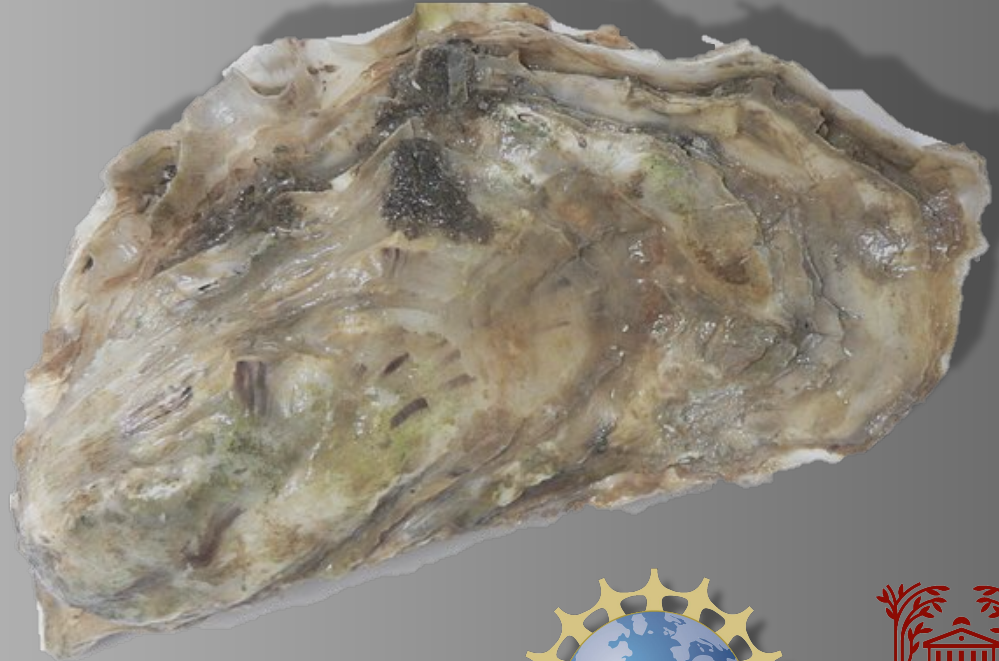
The genetic legacy of a global marine invader

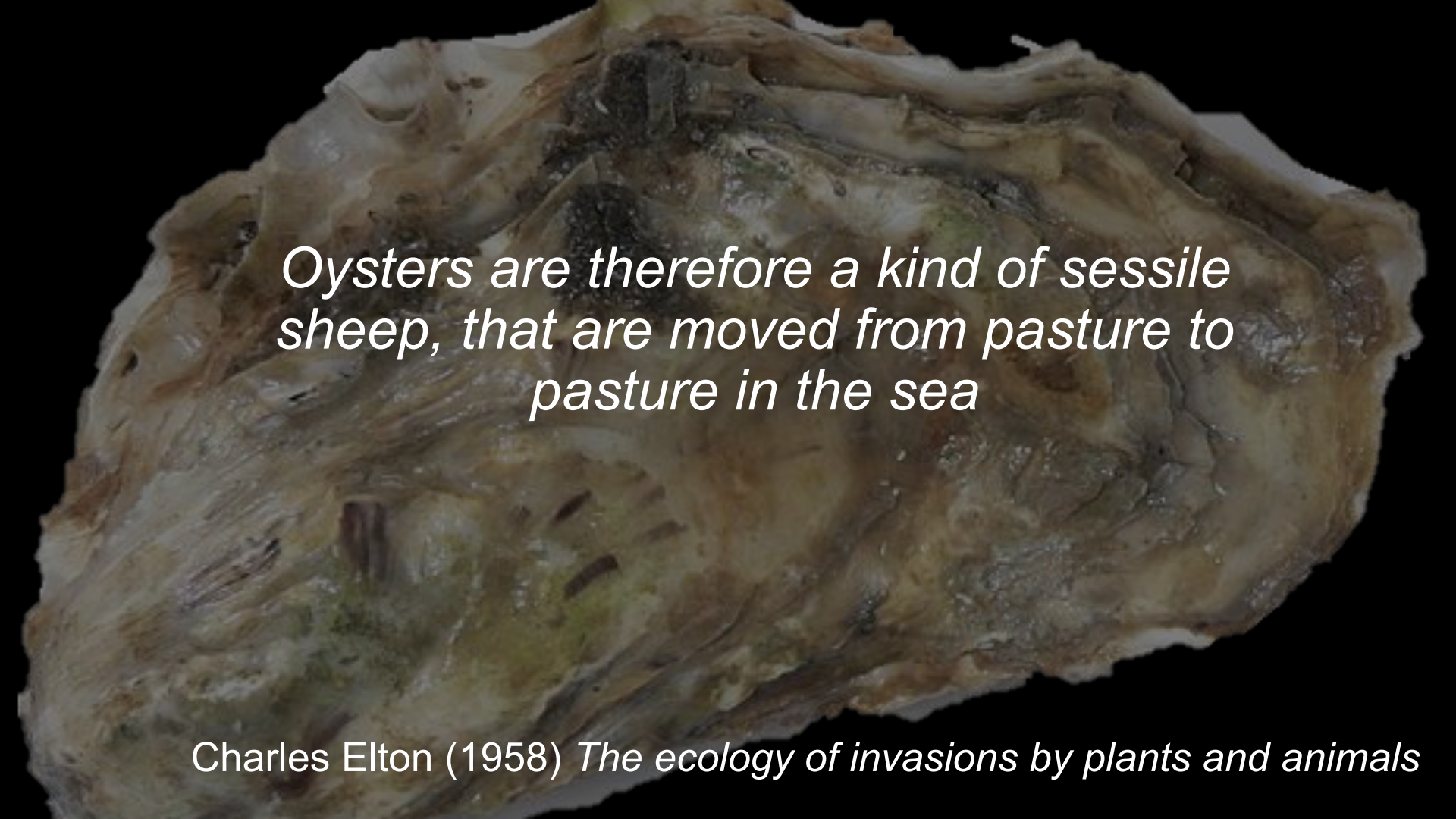
Erik Sotka*

Allan Strand

Ryan Carnegie, Jim Carlton, Lucia Couceiro, Jeff Crooks, Hikaru Endo, Hilary Heyford, Masakazu Hori, Mits Kamiya, Gen Kanaya, Judith Kochmann, Kun-Seop Lee, Lauren Lees, Hannah Miller, Massa Nakaoka, Eric Pante, Jennifer Ruesink, Evangelina Schwindt, Åsa Strand, Richard Taylor, Ryuta Terada, Martin Thiel, Takefumi Yorisue, Danielle Zacherl

* SotkaE@cofc.edu





Oysters are therefore a kind of sessile sheep, that are moved from pasture to pasture in the sea

Charles Elton (1958) *The ecology of invasions by plants and animals*

Crassostrea (Magallana) gigas Pacific cupped oyster

- Among the most important aquacultural shellfish worldwide



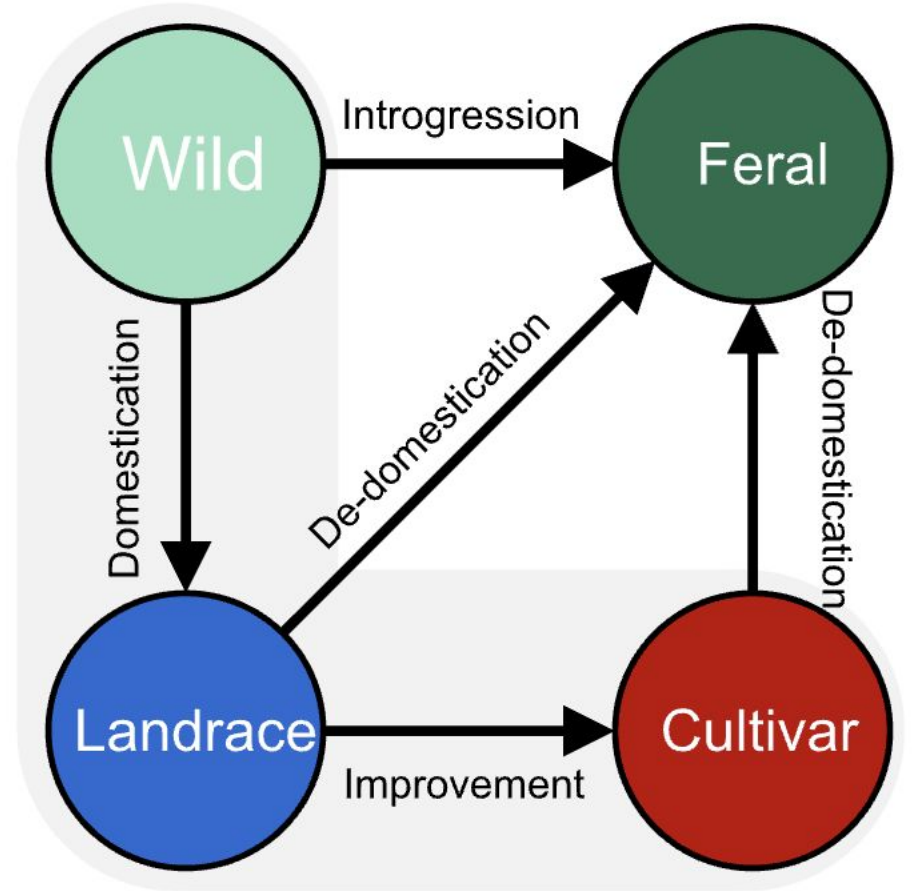
C. gigas aquaculture
- \$1.2 Billion per year
- 644,000 tons per year

Eric Pante

Magallana (Crassostrea) gigas
occurrences (GBIF)



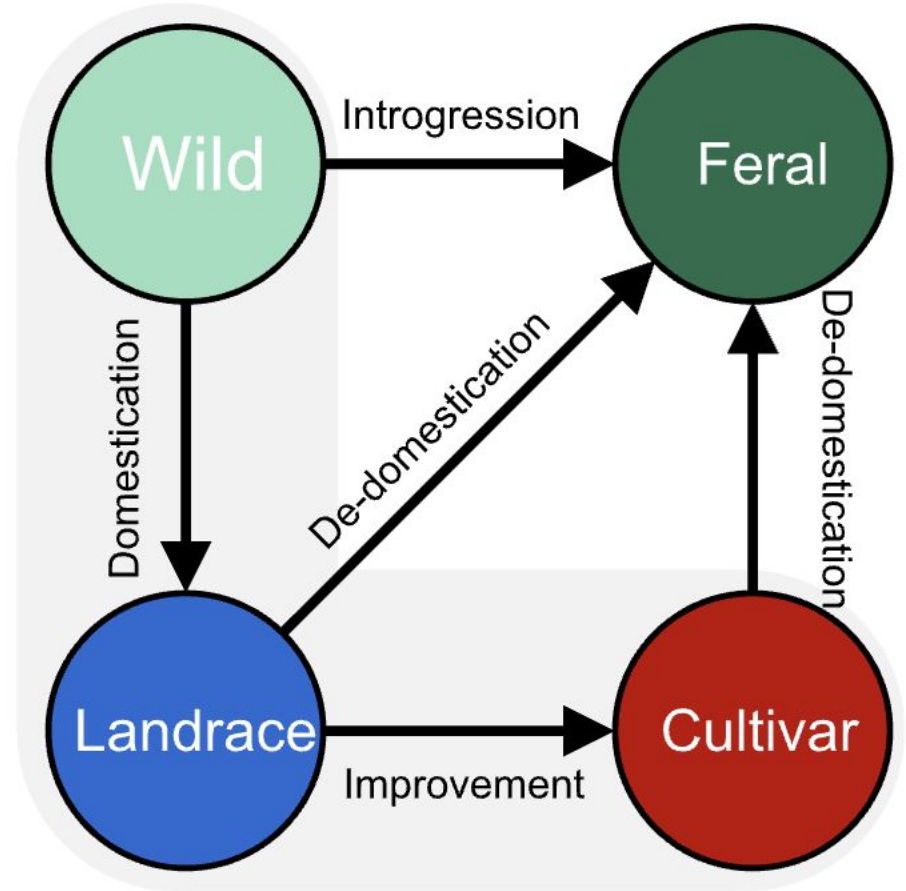
The introduction histories of most domesticated species remain vexing



The introduction histories of most domesticated species remain vexing

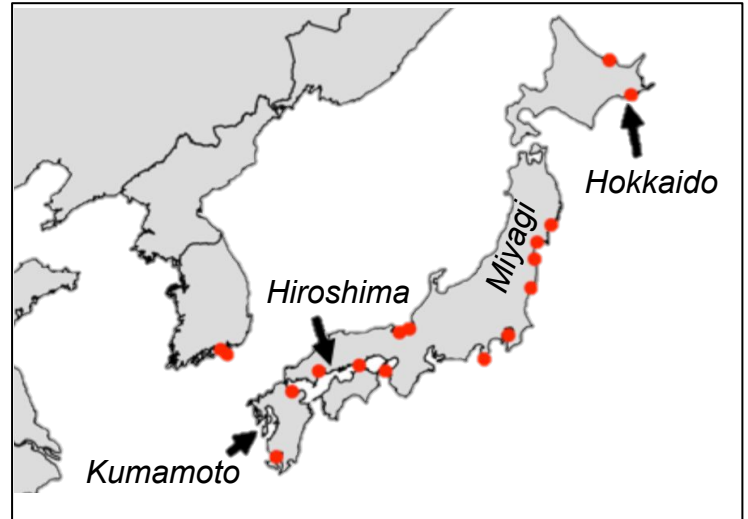
Introduction histories help....

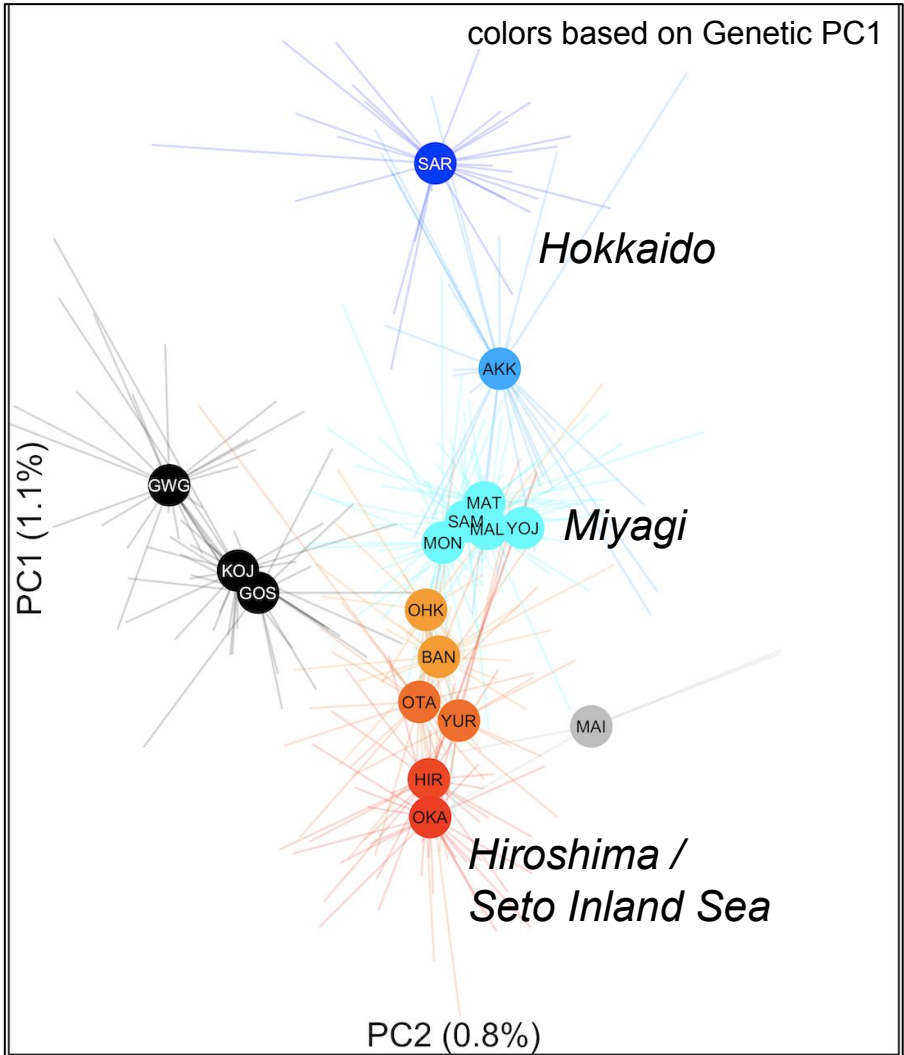
- 1) maintain crop diversity
- 2) Explain adaptation, de-domestication and ferality
- 3) Describe capacity to adapt to future environmental conditions



Sampling design

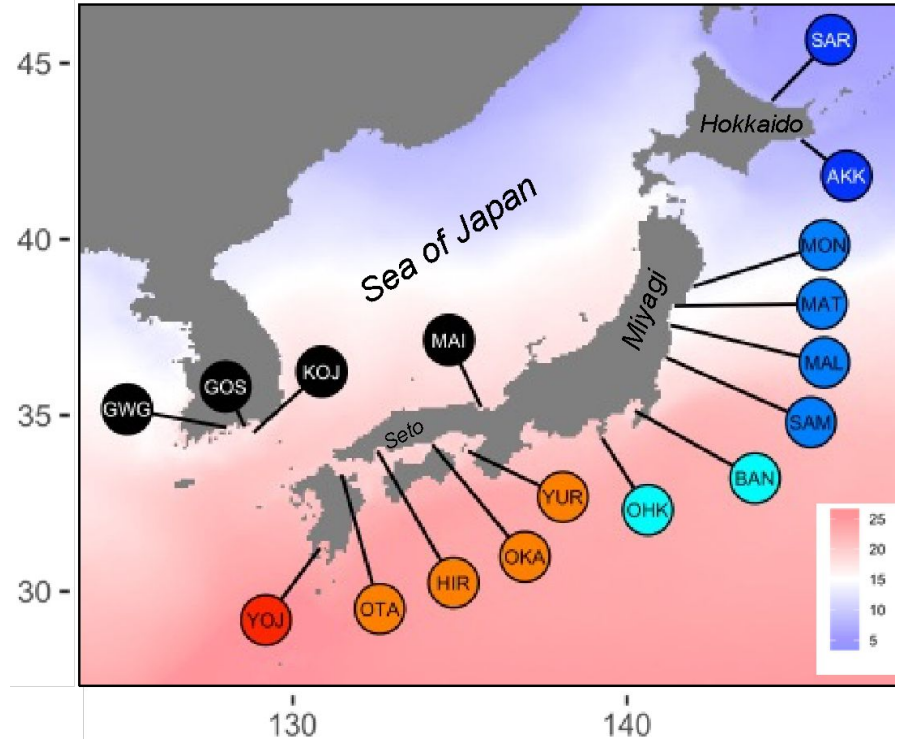
- 41 populations (n ~ 20)
 - 20 native (Korea, Japan)
 - 21 non-native (Europe, Western US, Chile, Argentina, NZ)
- Feral populations (on rocks, jetties, reefs, etc..)
- Genotype-by-sequencing
- Dataset: 726 individuals and 7046 SNPs (no missing data and at HWE)



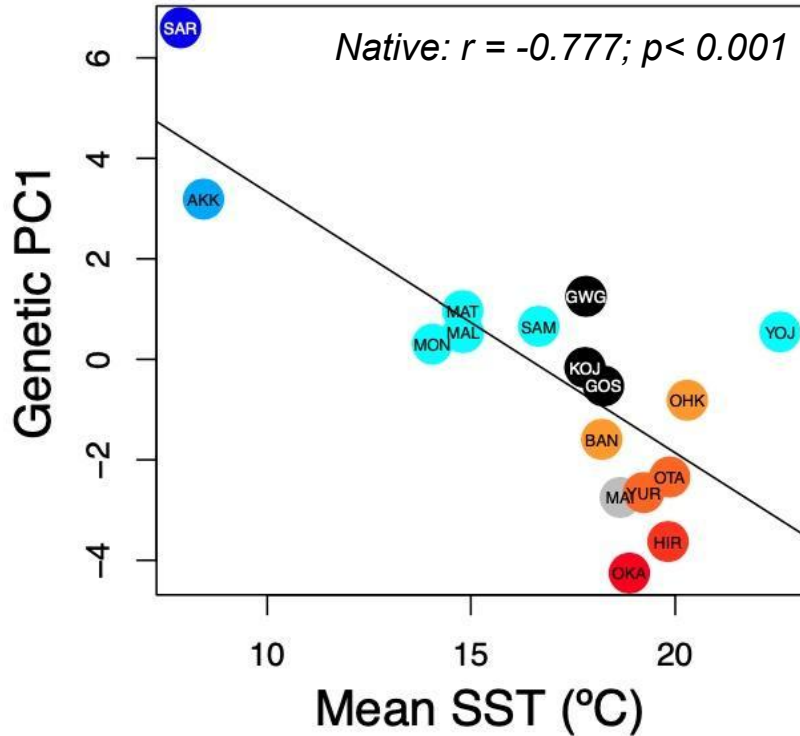


Genetic differentiation mirrors a geographical map

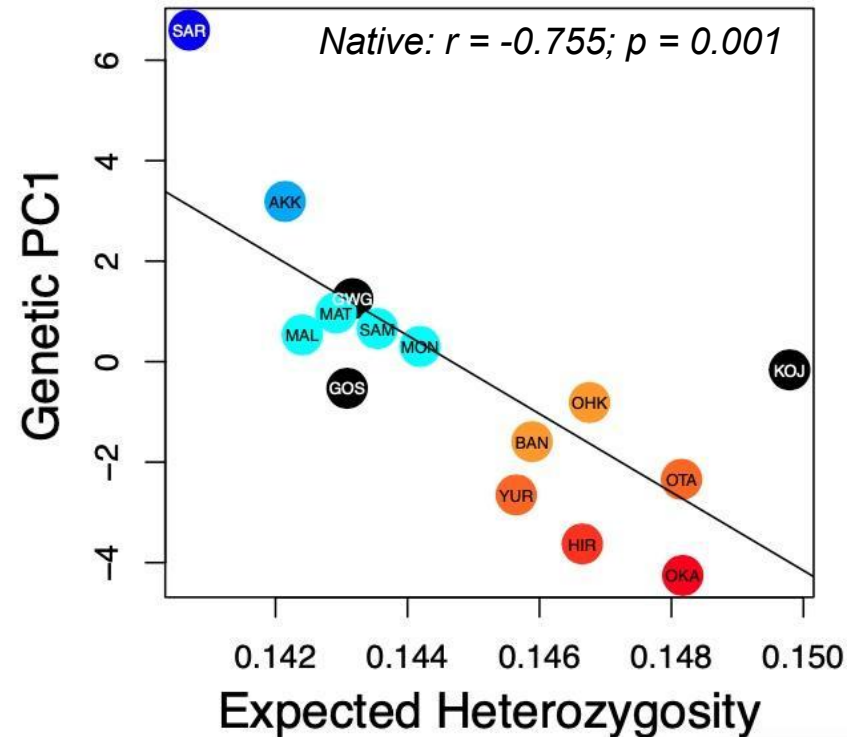
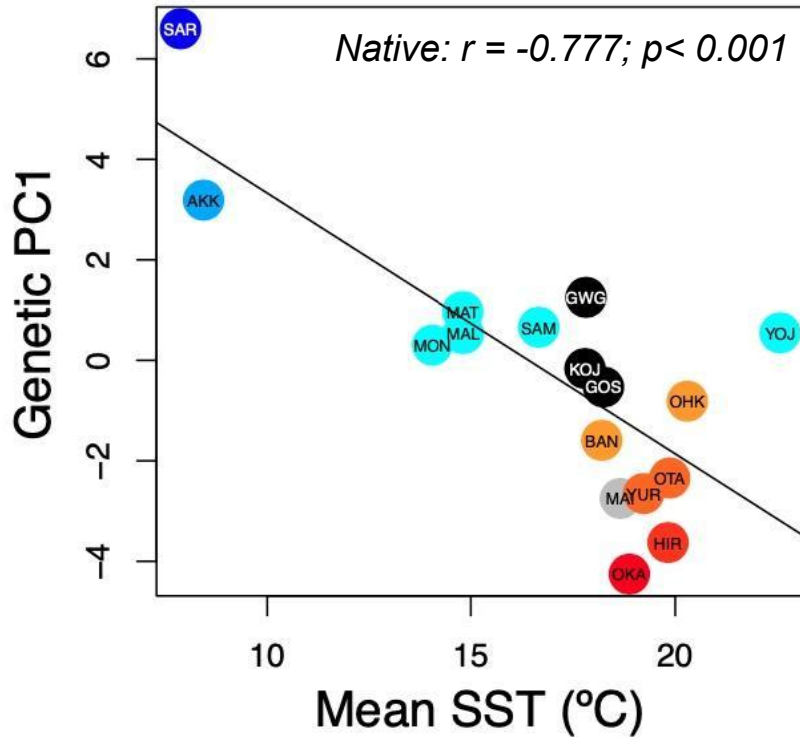
Fst= 0 to 0.011



Genetic PC1 correlates with sea surface temperature (SST)



Genetic PC1 correlates with sea surface temperature (SST) and heterozygosity



Three principal regions of industrial farming of Pacific oysters in Japan

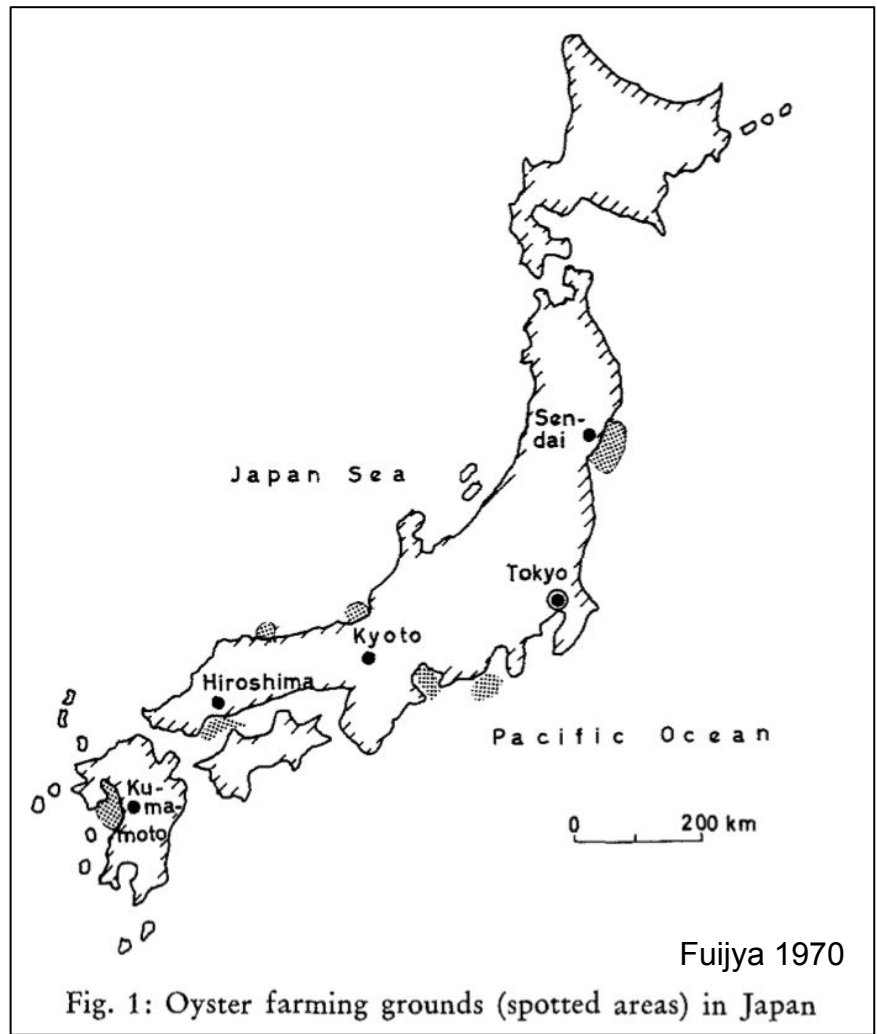


Fig. 1: Oyster farming grounds (spotted areas) in Japan

Three principal regions of industrial farming of Pacific oysters in Japan

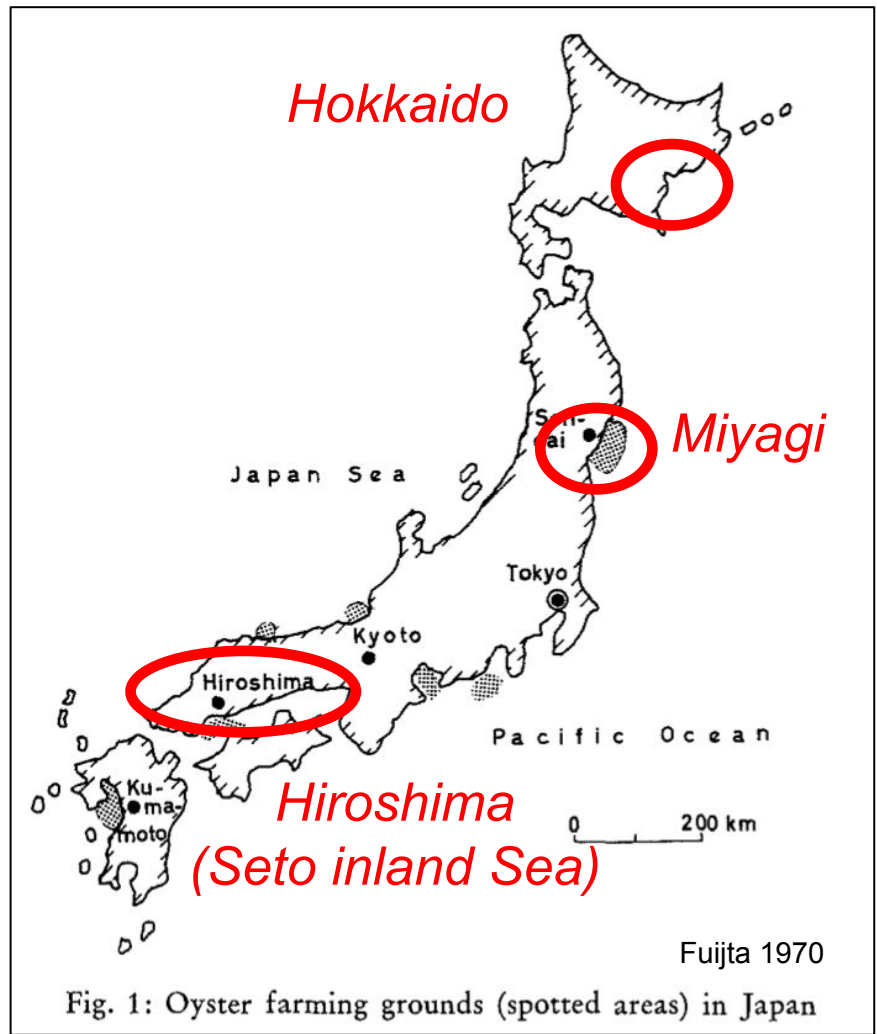


Fig. 1: Oyster farming grounds (spotted areas) in Japan

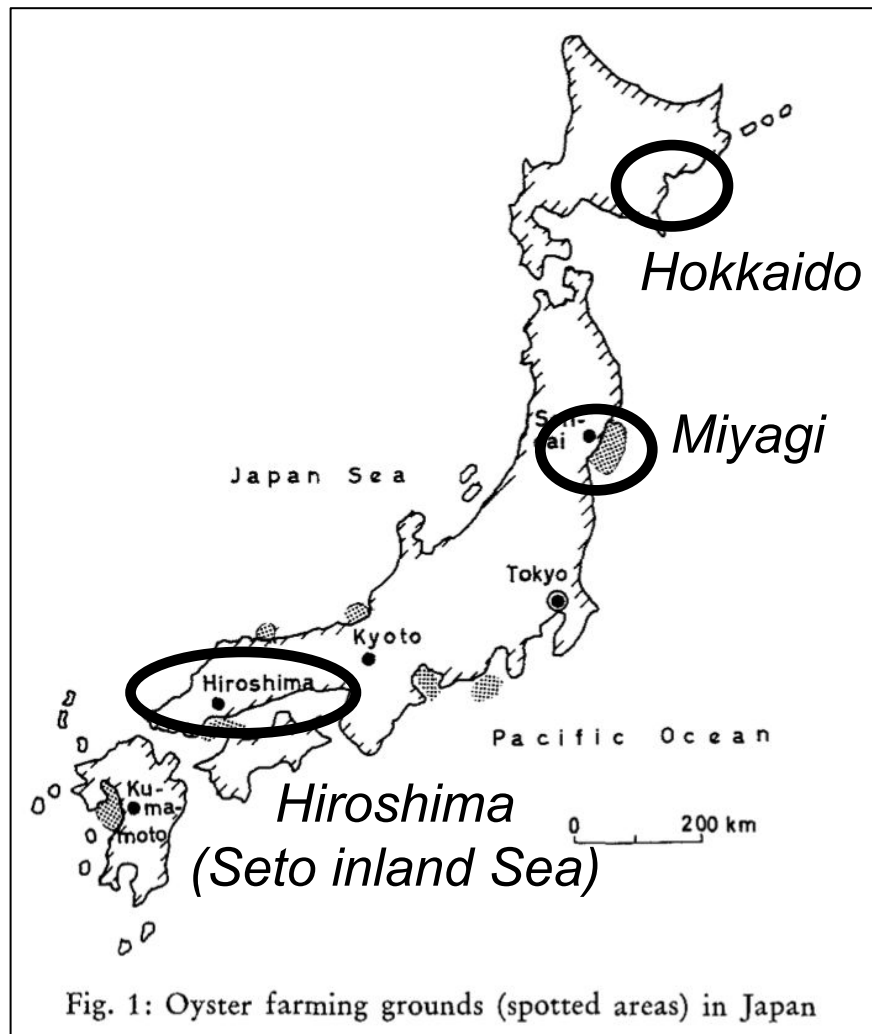


Fig. 1: Oyster farming grounds (spotted areas) in Japan

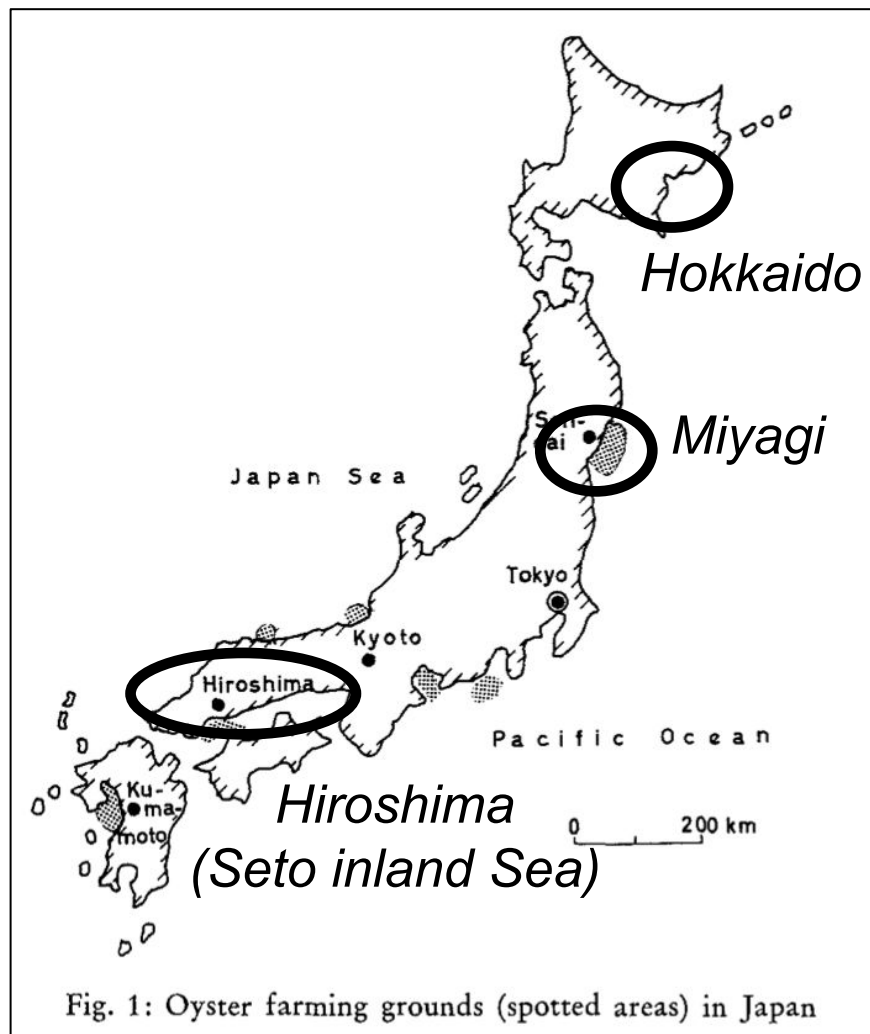
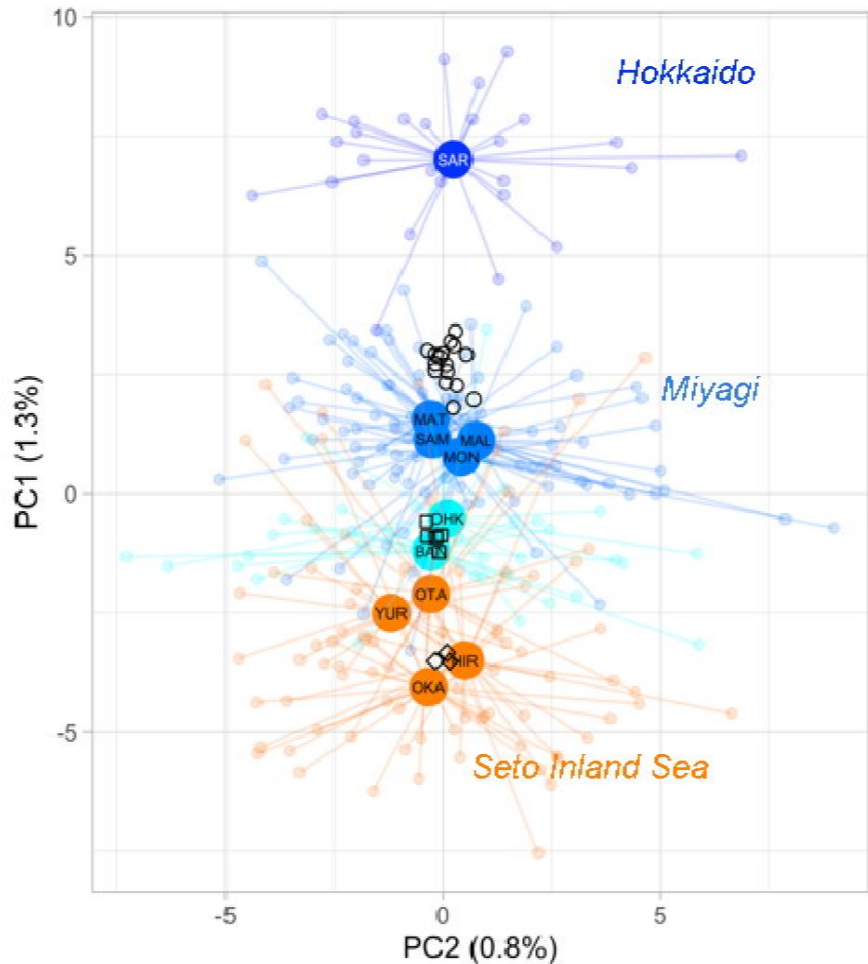


Fig. 1: Oyster farming grounds (spotted areas) in Japan

Pacific oysters are from
Seto Inland Sea and
Miyagi

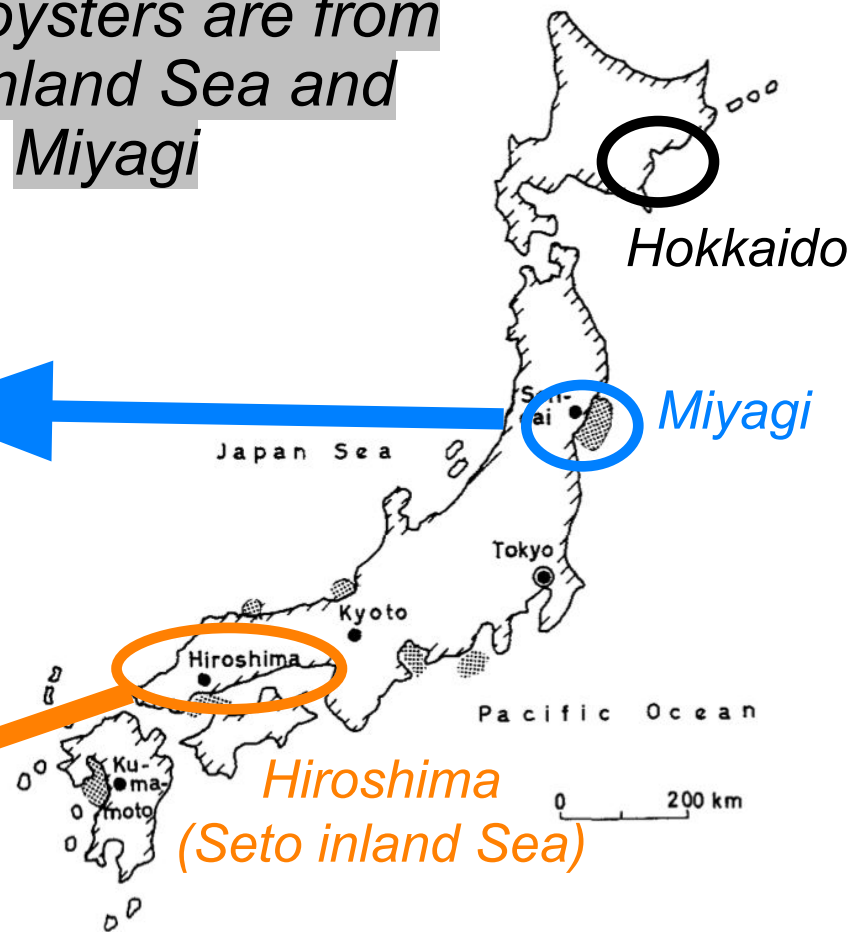
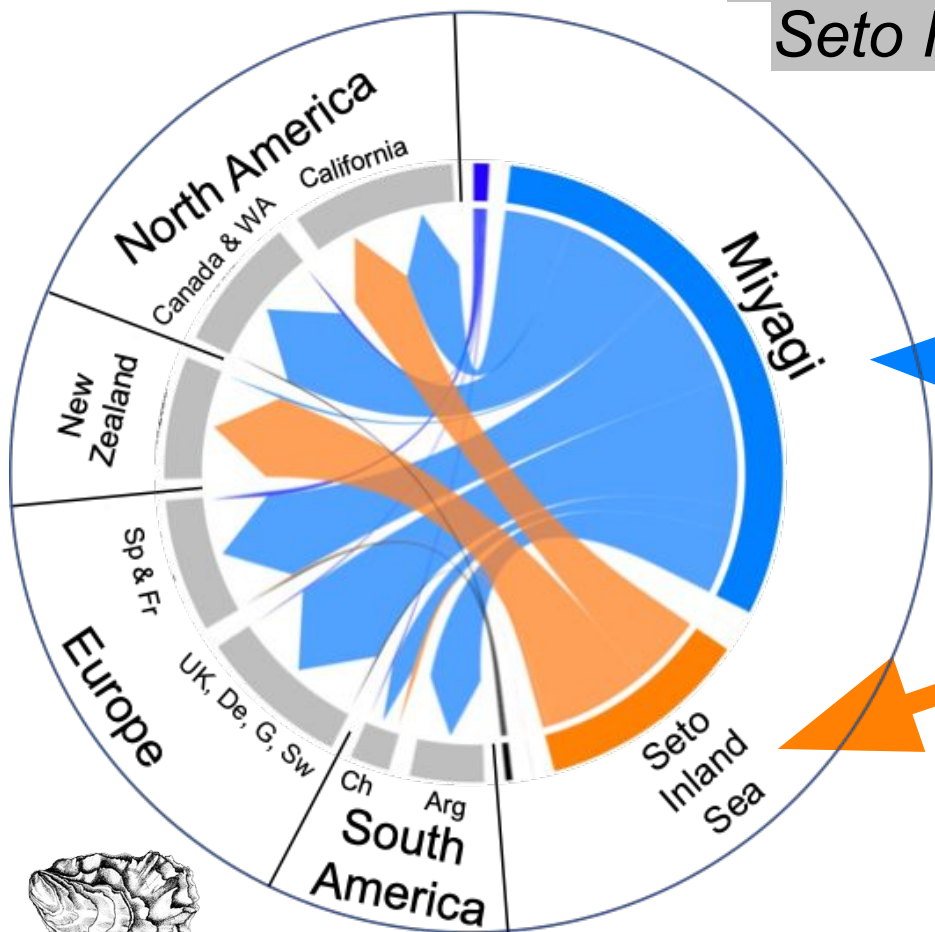


Fig. 1: Oyster farming grounds (spotted areas) in Japan



Miyagi □ Canada and WA state
Miyagi + Seto □ California

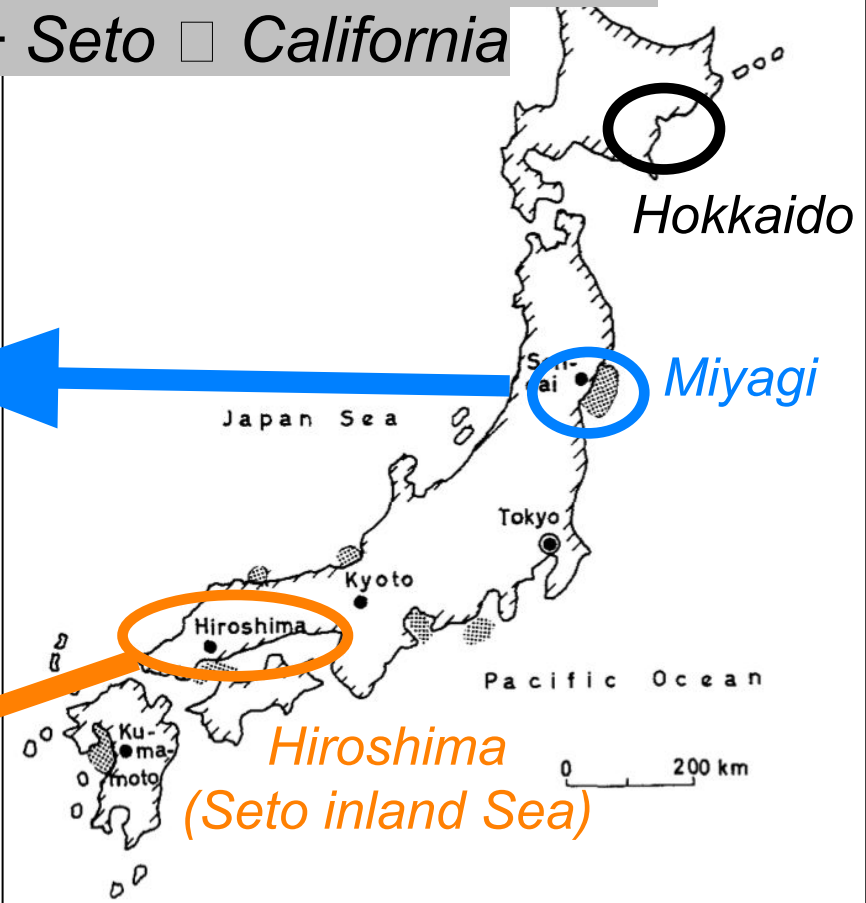
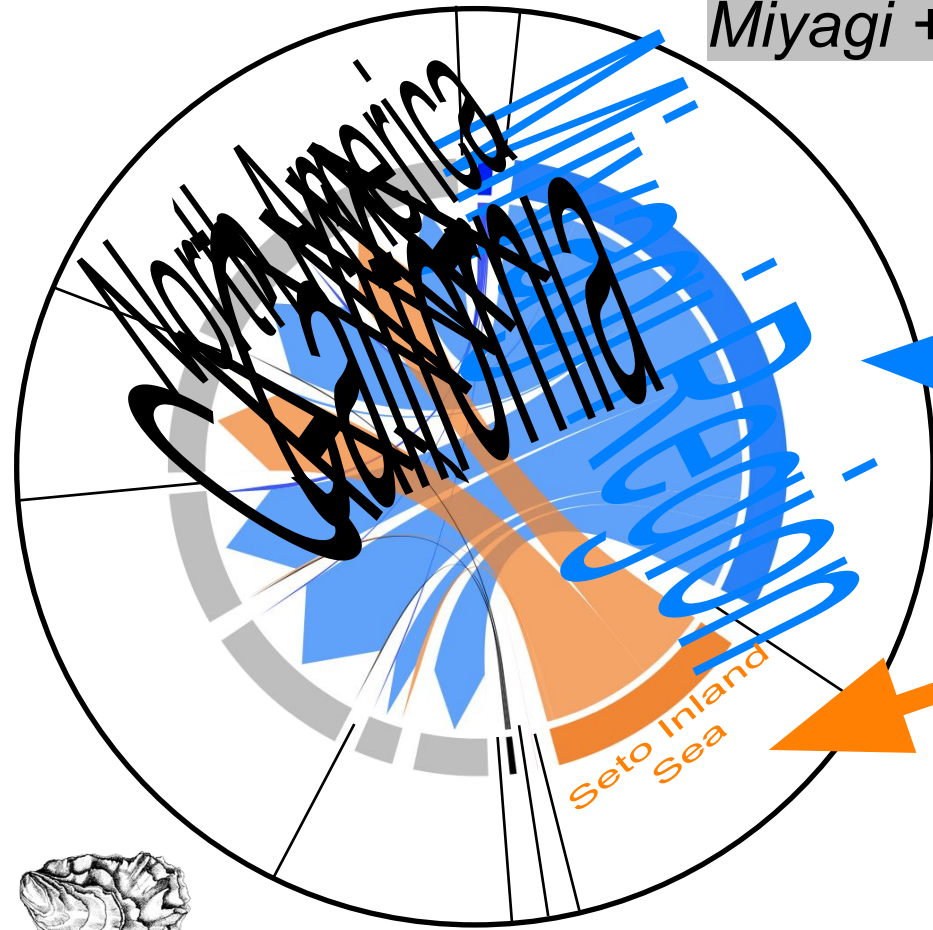


Fig. 1: Oyster farming grounds (spotted areas) in Japan

Seto □ New Zealand

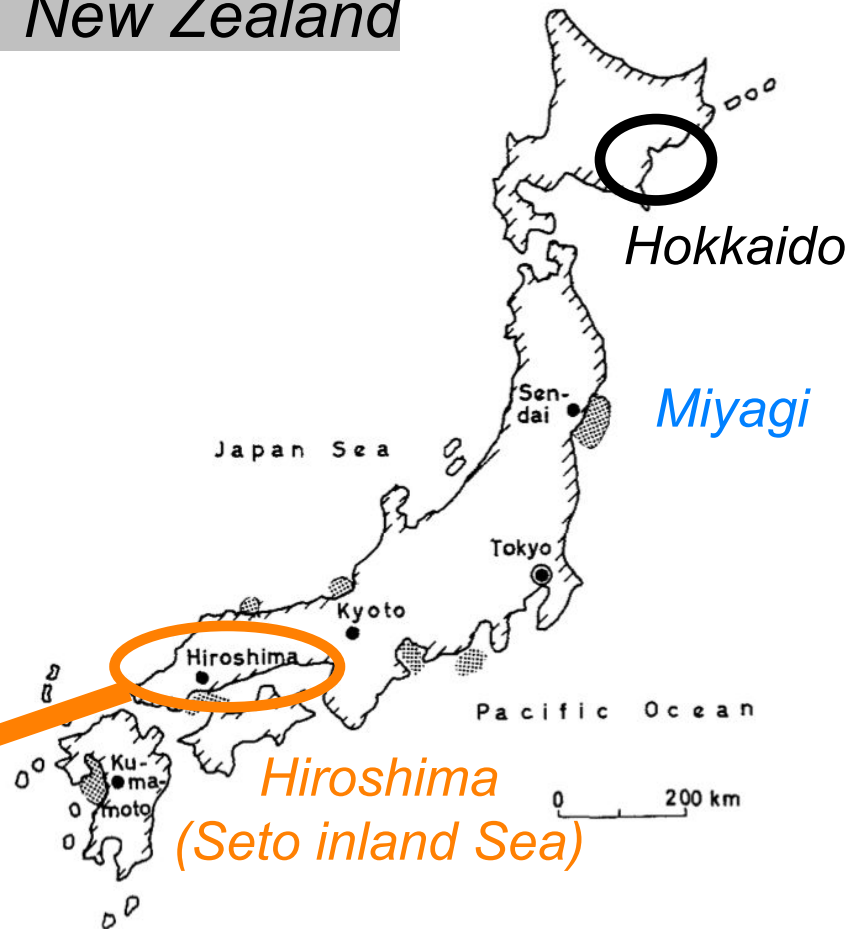
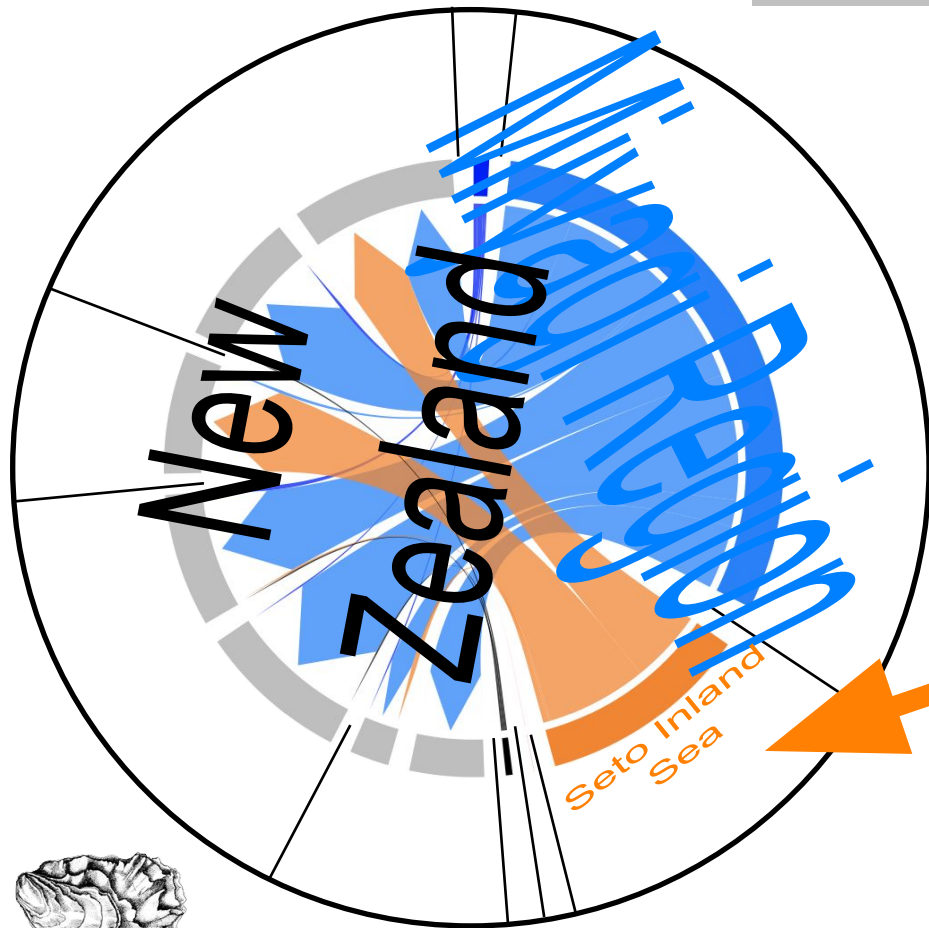


Fig. 1: Oyster farming grounds (spotted areas) in Japan

Miyagi □ Europe (2 invasions)

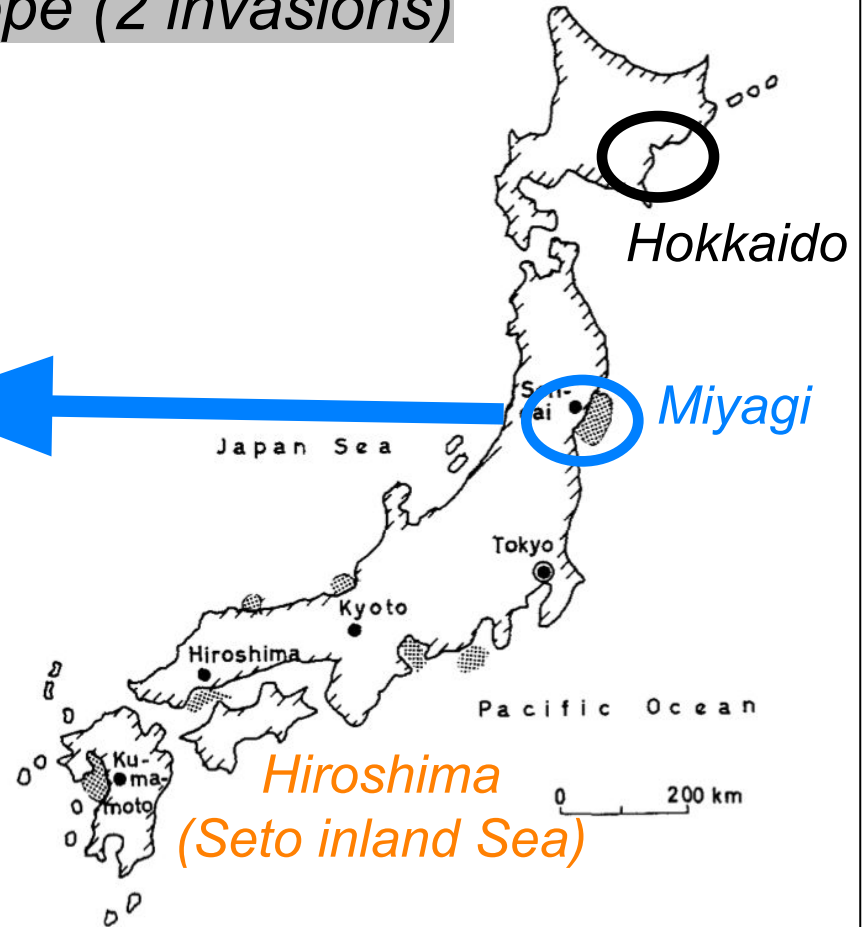
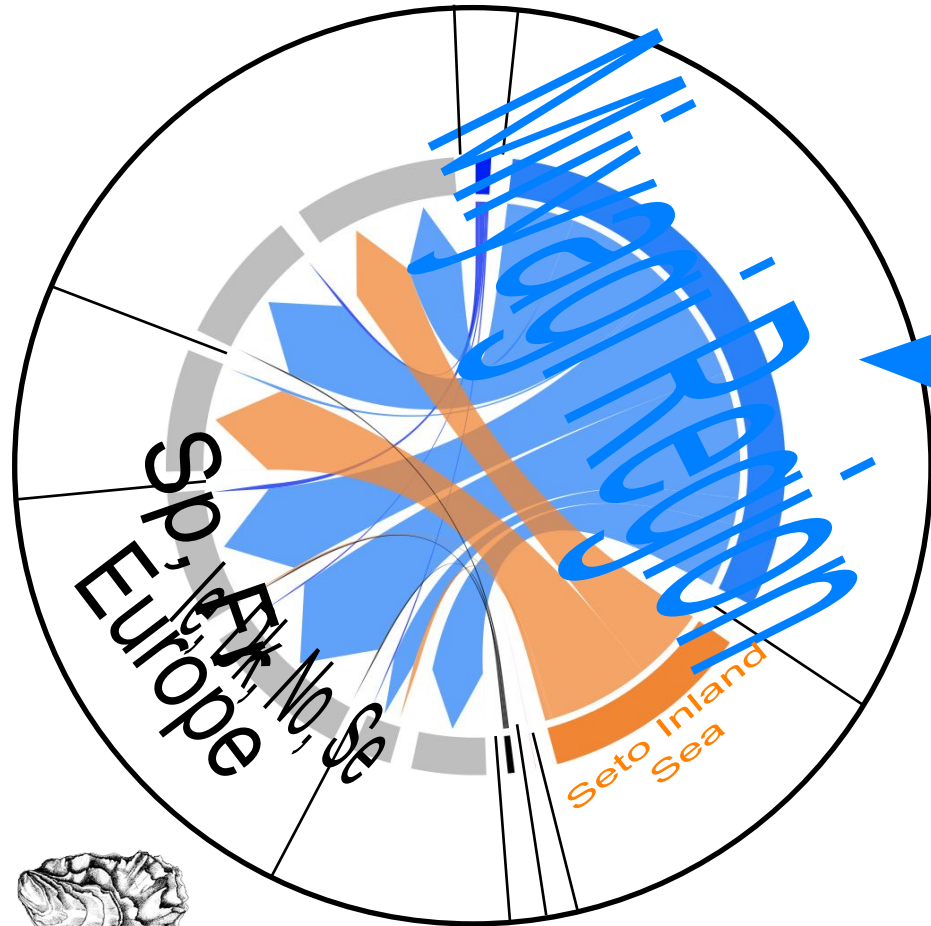
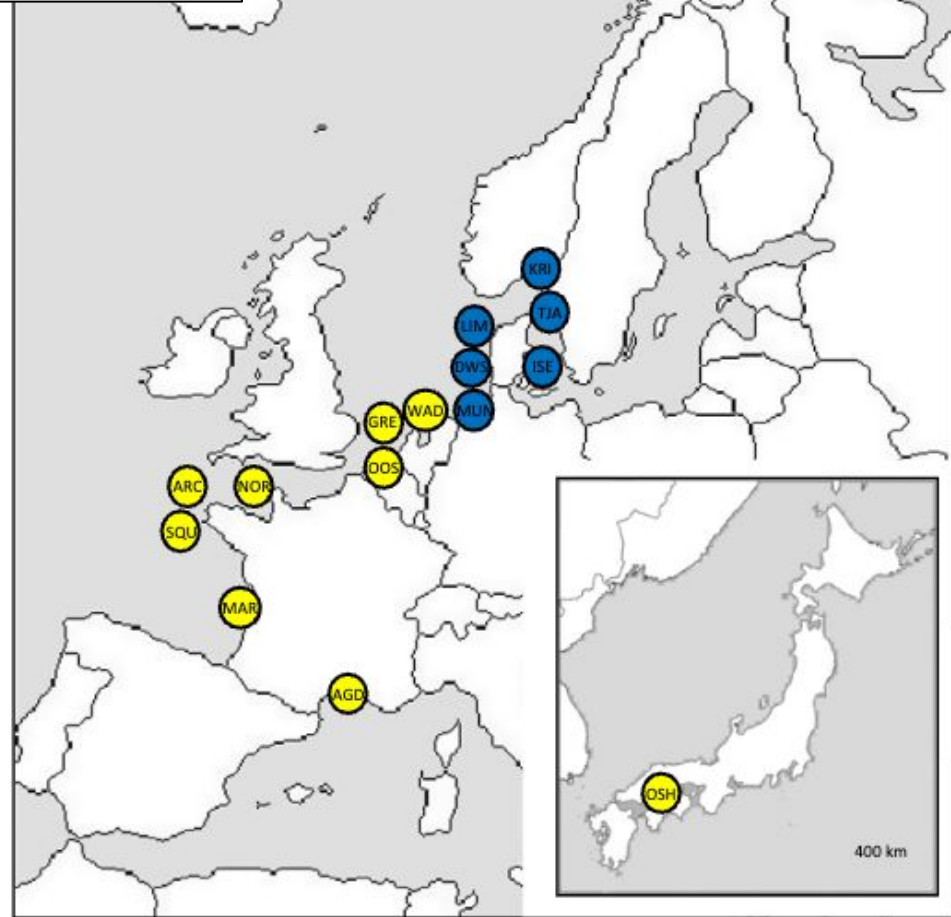


Fig. 1: Oyster farming grounds (spotted areas) in Japan



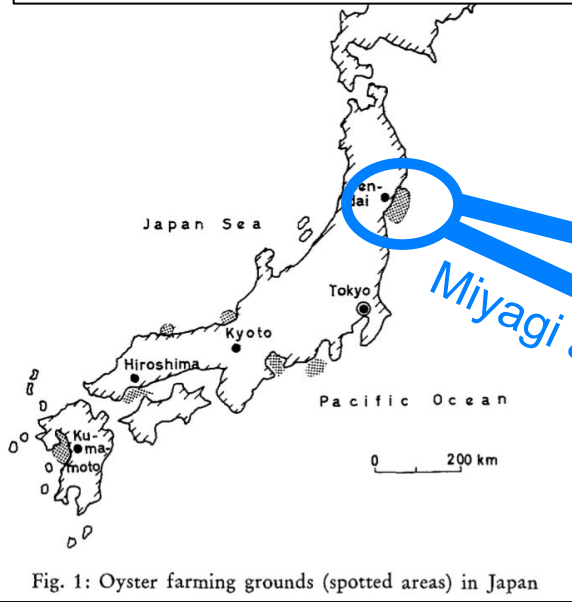
Two invasion histories in Europe

Rohfritsch (2013) *Evol Appl*

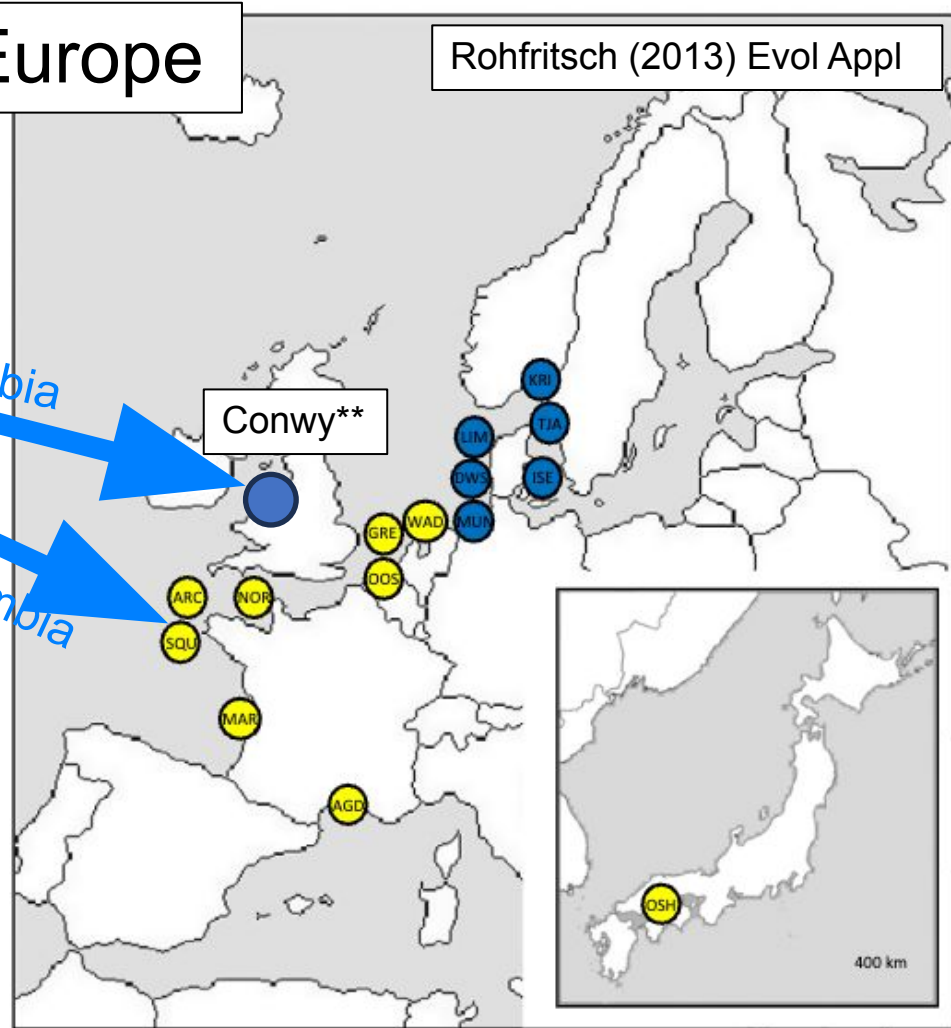


Two invasion histories in Europe

Rohfritsch (2013) Evol Appl



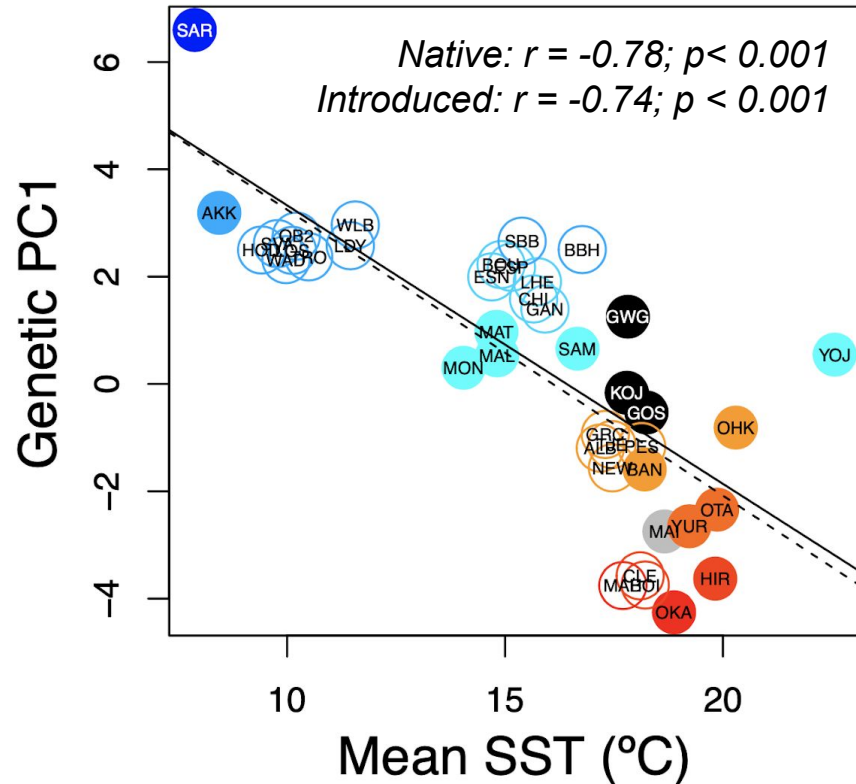
British Columbia
Miyagi and British Columbia



*** *“Adults of the Miyagi strain”* were imported from hatcheries in British Columbia to a facility in Conwy, United Kingdom, bred, and then deliberately introduced to UK estuaries (Walne and Helm 1978)

Genetic legacy of Pacific oysters

1) 'deliberate' environmental fitting

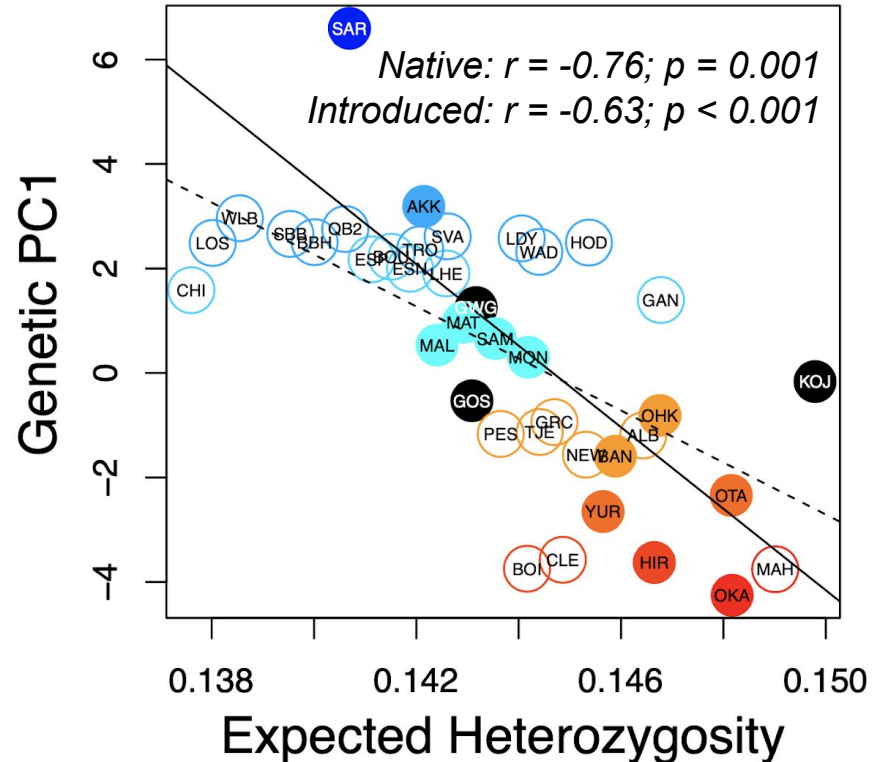


Ecological fitting reflects deliberate decisions by smart oyster biologists of appropriate genetic sources

Genetic legacy of Pacific oysters

2) Heterozygosity

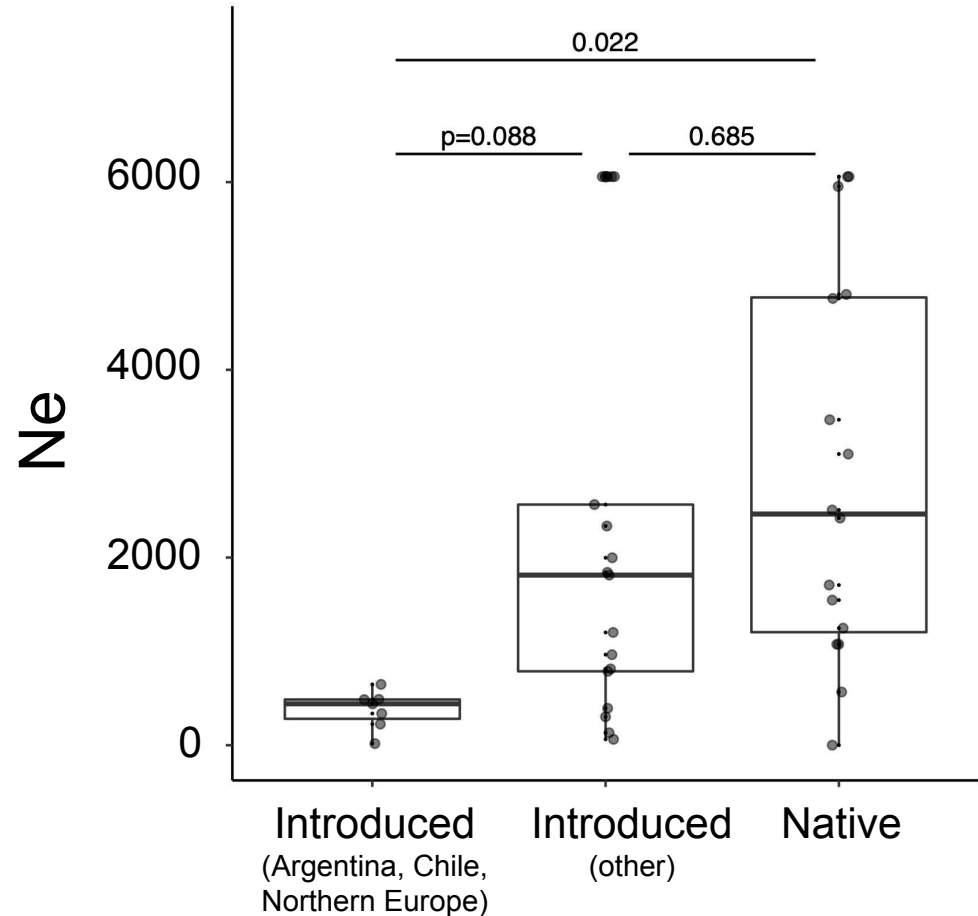
Introduced populations maintain similar heterozygosity as their genetic source



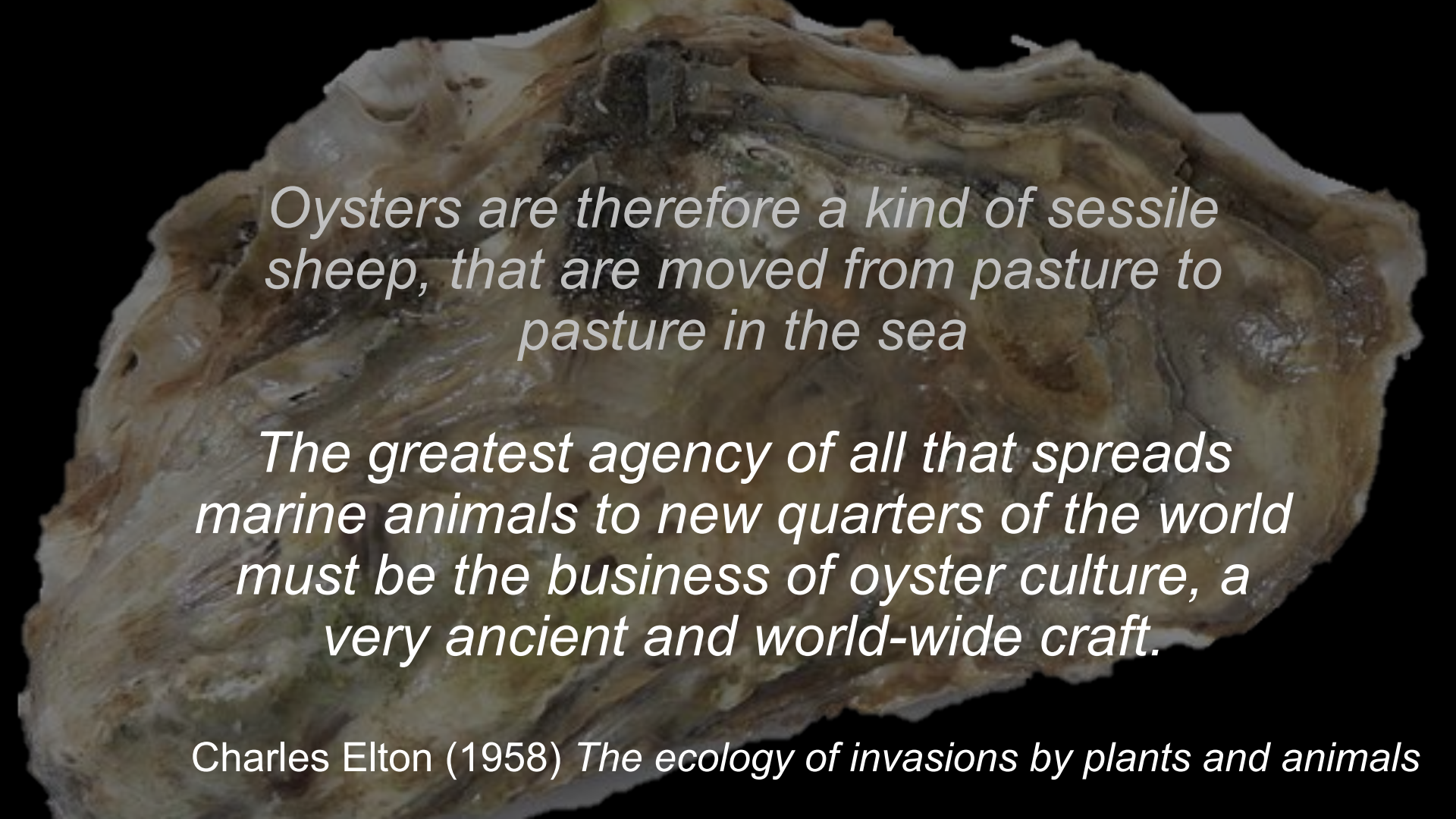
Genetic legacy of Pacific oysters

3) genetic bottlenecks

Populations with an aquacultural history (e.g., Northern Europe, Argentina) have lower effective population sizes (N_e)



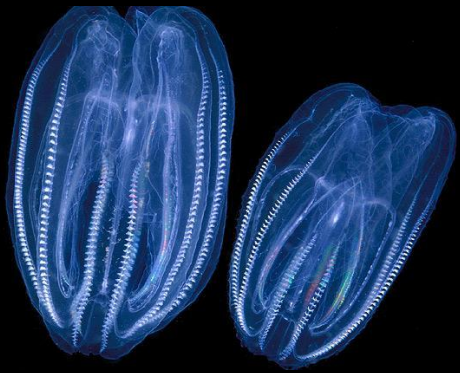
N_e estimated from linkage disequilibrium



Oysters are therefore a kind of sessile sheep, that are moved from pasture to pasture in the sea

The greatest agency of all that spreads marine animals to new quarters of the world must be the business of oyster culture, a very ancient and world-wide craft.

*Charles Elton (1958) *The ecology of invasions by plants and animals**



THE NAUTILUS

Vol. XLIX.

July, 1935

No. 1

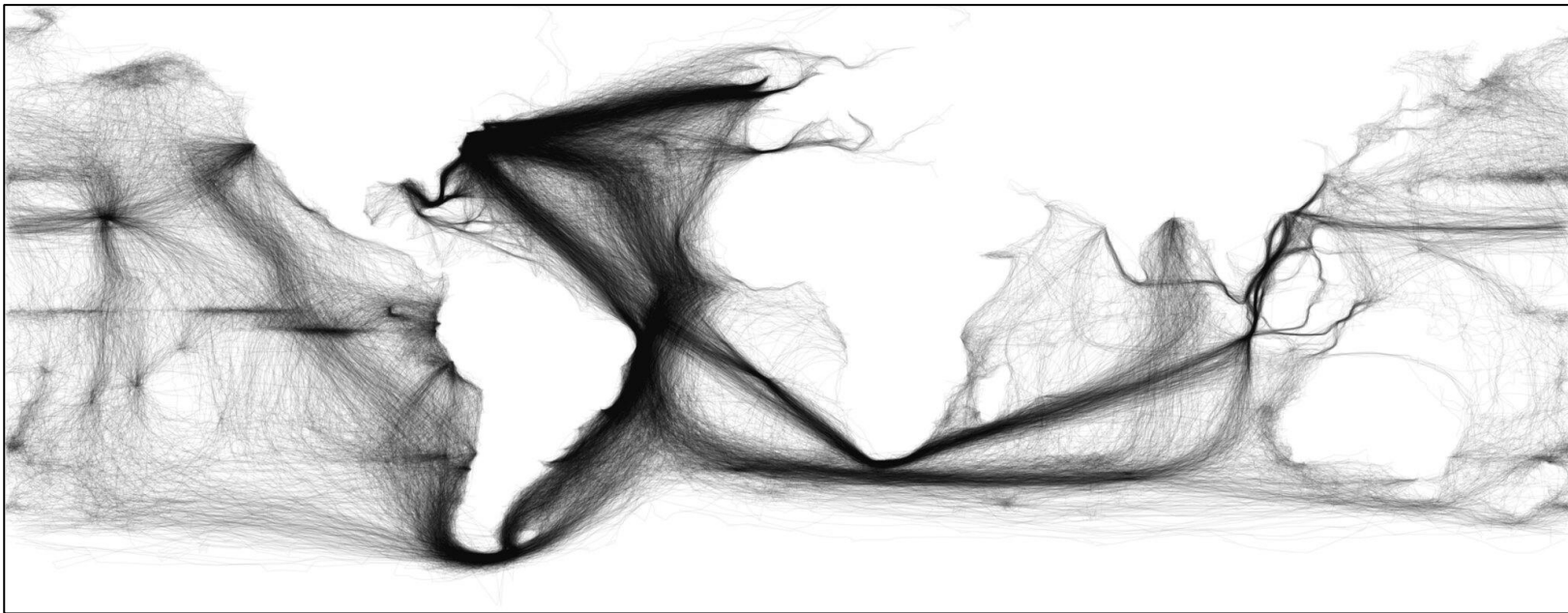
A RECENT INTRODUCTION OF EXOTIC SPECIES OF MOLLUSCS INTO CALIFORNIA WATERS FROM JAPAN

BY PAUL BONNOT

During the last few years, interest in the culture of oysters in California waters has brought about the introduction of seed oysters (*Ostrea gigas*) from Japan. The California oyster business has been confined for many years to San Francisco and Tomales Bays which were used as holding grounds for the eastern oyster (*O. virginica*). Several pests were brought in and planted with them. None of the other bays in California were

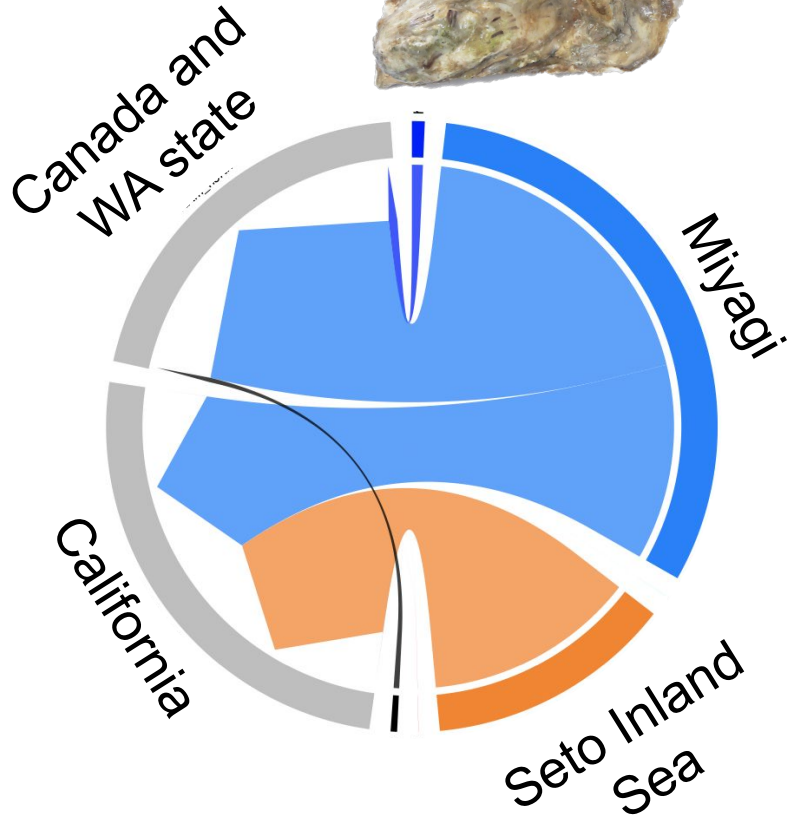
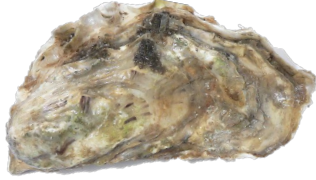
Bonnot 1935:
direct
observation of
molluscan
invaders in
oyster
shipments

One alternative hypothesis = shipping
(via fouling or ballast water)

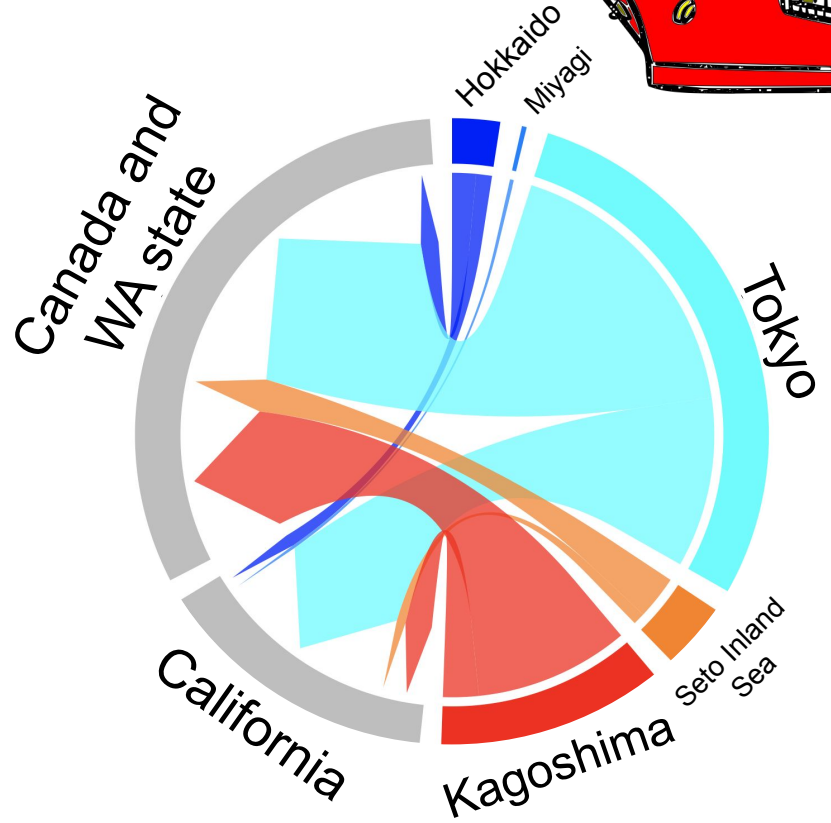
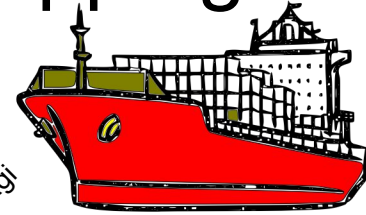


ICOADS ship log data - <https://icoads.noaa.gov>
1950-2010

Vector = Oysters



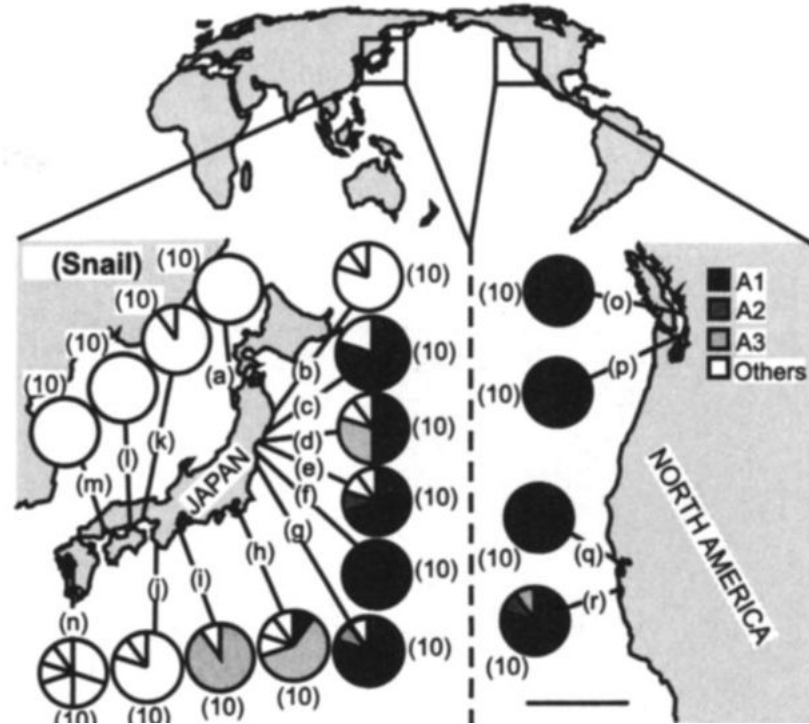
Vector = Shipping



Approximate Bayesian Computation (ABC) evaluates alternative invasion hypotheses

*Battillaria
atramentaria*

Miura et al. 2005 *PNAS*





Haminoea japonica



Hemigrapsus sanguineus



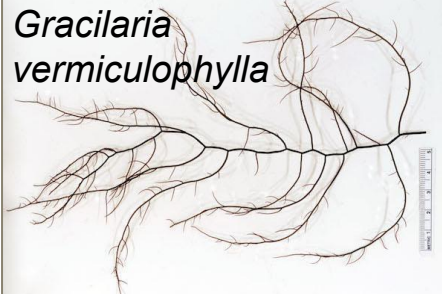
Hemigrapsus takanoi

Criteria for inclusion

- Genetic data are publicly available
- 2+ regions in Japan
- Western NA, Europe or both



Battillaria attramentaria



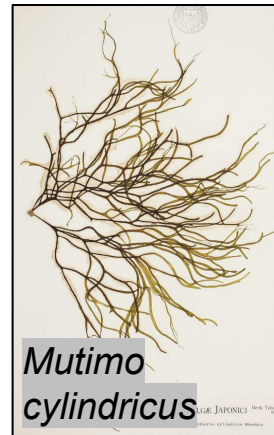
Gracilaria vermiculophylla



Ulva pertusa



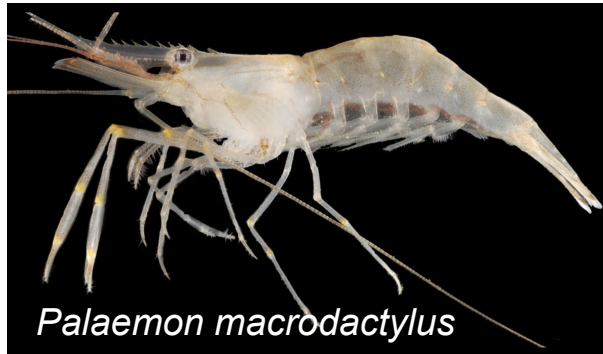
Undaria pinnatifida



Mutimo cylindricus

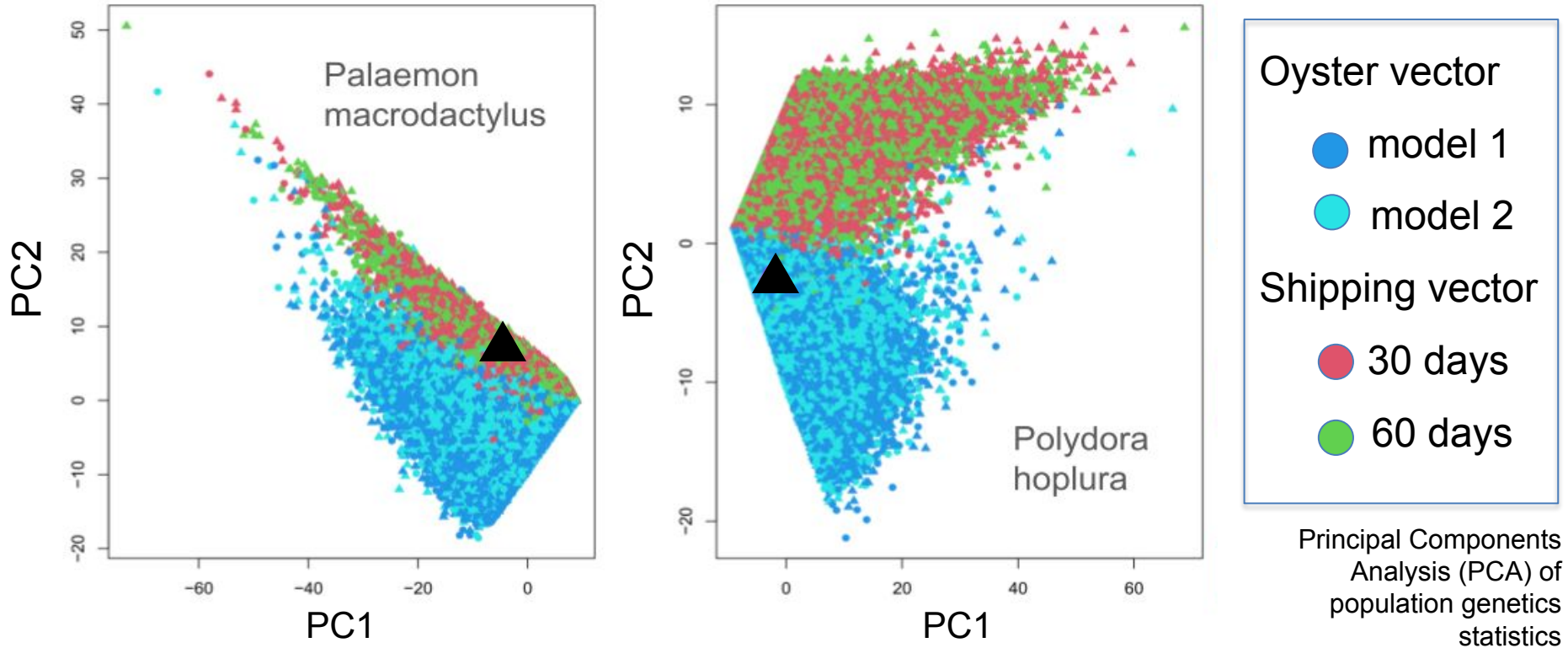


Didemnum vexillum

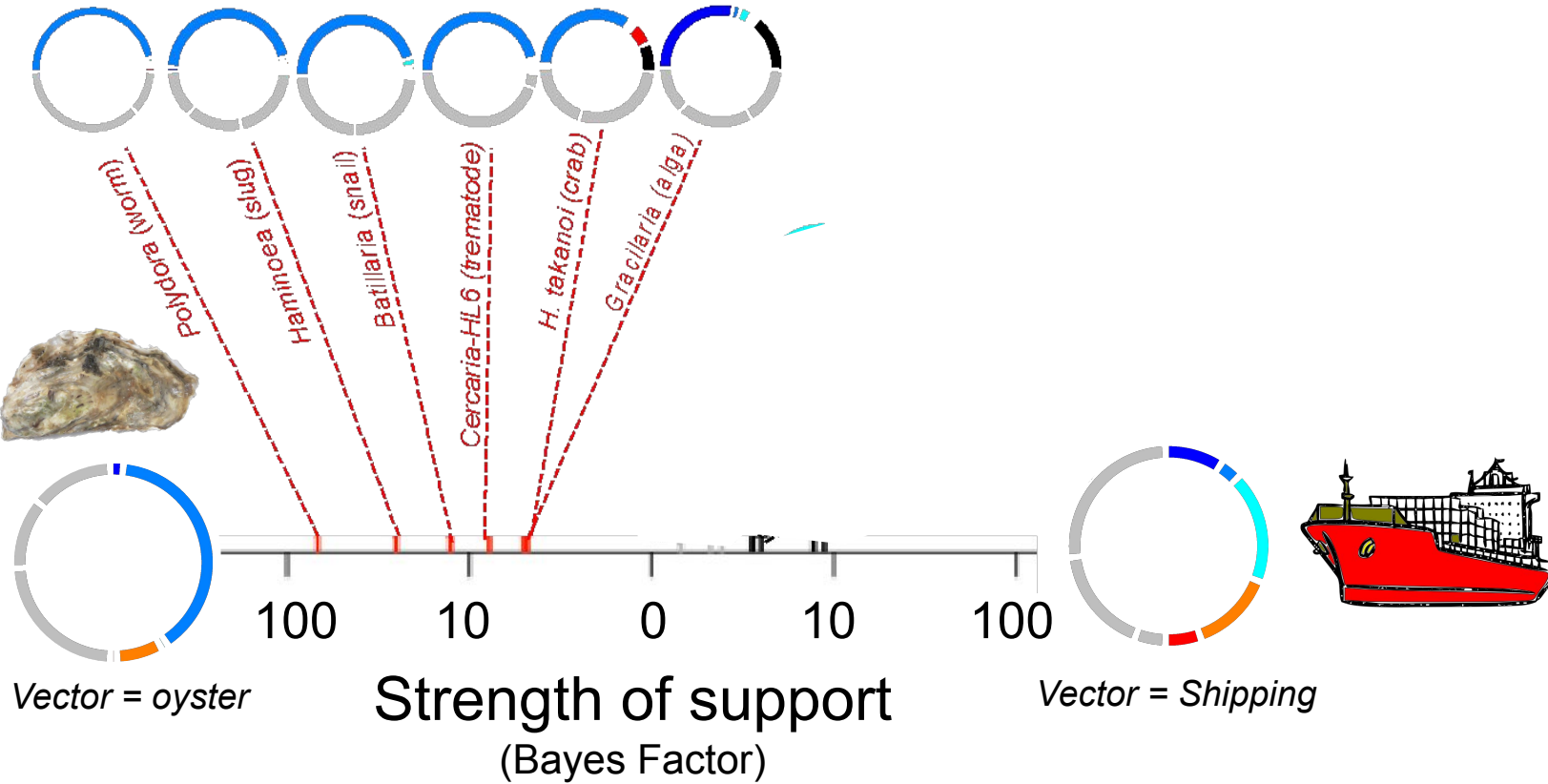


Palaemon macrodactylus

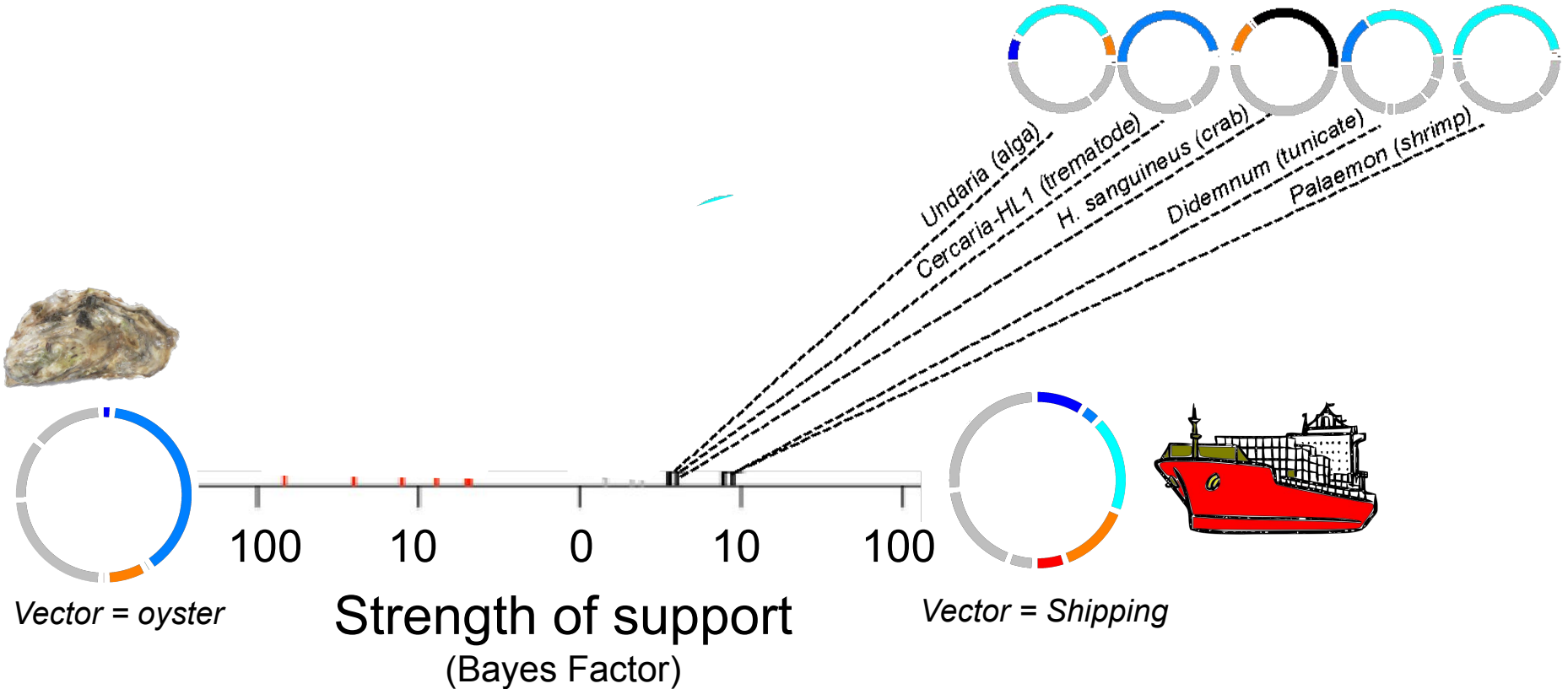
Approximate Bayesian Computation (ABC) evaluates alternative invasion hypotheses



Pacific oyster was 4 to 68-fold more likely to be a vector for six species



Shipping activity was 3 to 9-fold more likely for five species

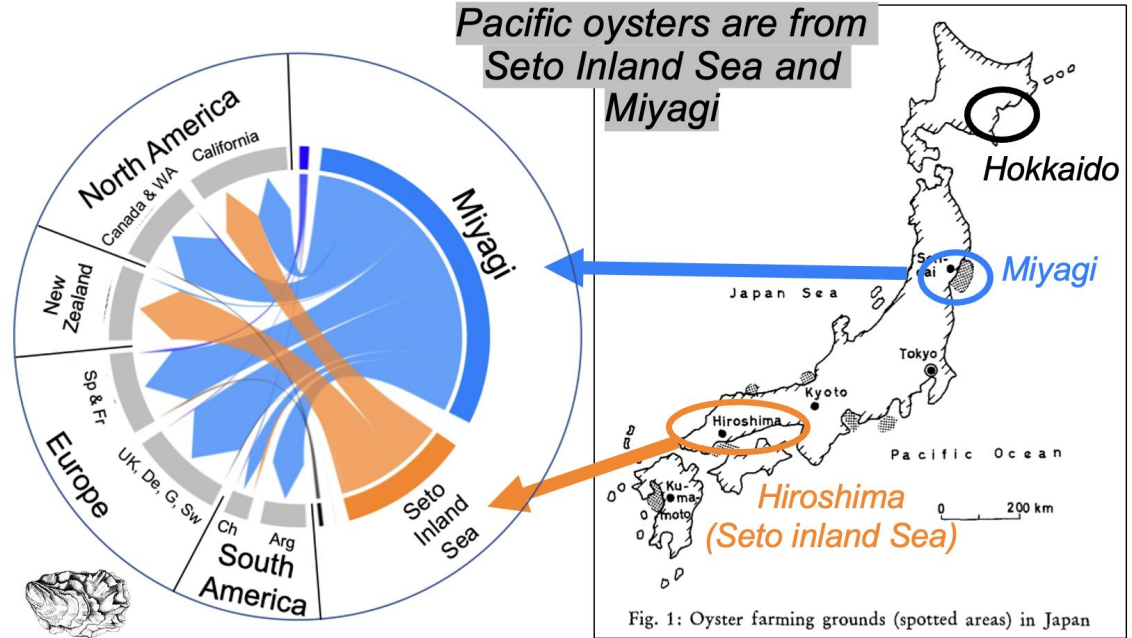


Vector inference based on historical evidence is very good – but not perfect

Species	Taxonomy	HistoricalPrior	Inference
<i>Polydora hoplura</i>	Polychaeta	Shipping	Oyster
<i>Haminoea japonica</i>	Mollusc	Oyster	Oyster
<i>Batillaria attramentaria</i>	Mollusc	Oyster	Oyster
<i>Cercaria batillaria (HL6)</i>	Trematode	Oyster	Oyster
<i>Hemigrapsus takanoi</i>	Mollusc	Shipping	Oyster
<i>Gracilaria vermiculophylla</i>	Alga	Mixed or Unknown	Oyster
<i>Ulva pertusa</i>	Alga	Mixed or Unknown	Unknown
<i>Acanthogobius flavimanus</i>	Chordate	Shipping	Unknown
<i>Mutimo cylindricus</i>	Alga	Shipping	Unknown
<i>Undaria pinnatifida</i>	Alga	Mixed or Unknown	Shipping
<i>Cercaria batillaria (HL1)</i>	Trematode	Mixed or Unknown	Shipping
<i>Hemigrapsus sanguineus</i>	Crustacea	Shipping	Shipping
<i>Didemnum vexillum</i>	Ascidian	Shipping	Shipping
<i>Palaemon macrodactylus</i>	Crustacea	Shipping	Shipping

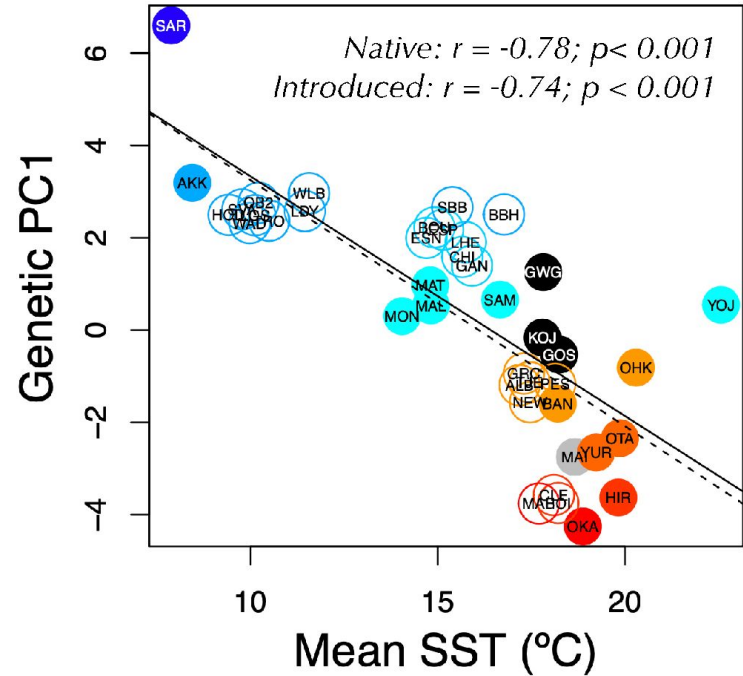
Genetic legacy of Pacific oyster introductions

- Most oysters were sourced from northeastern Japan



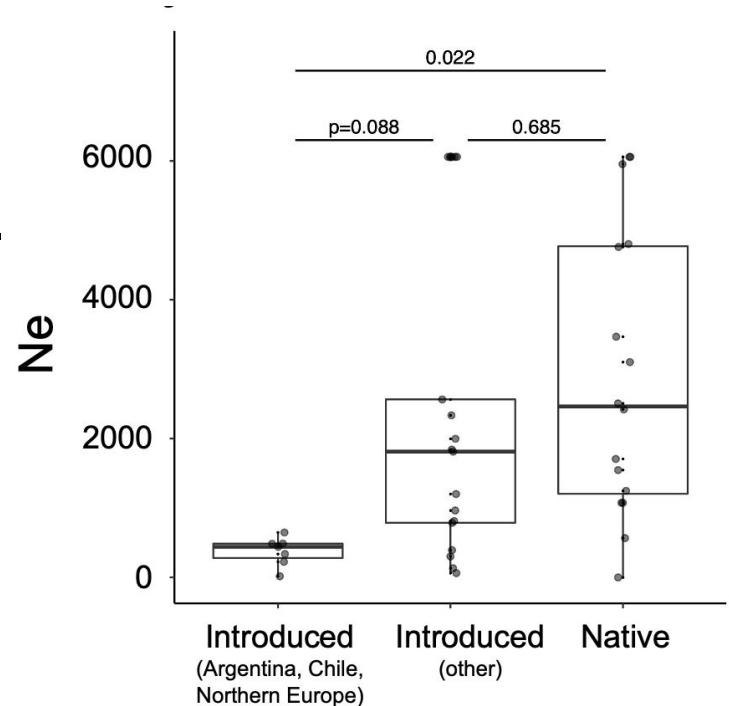
Genetic legacy of Pacific oyster introductions

- Most oysters were sourced from northeastern Japan
- Transport of locally-adapted oysters yielded “deliberate” ecological fitting.



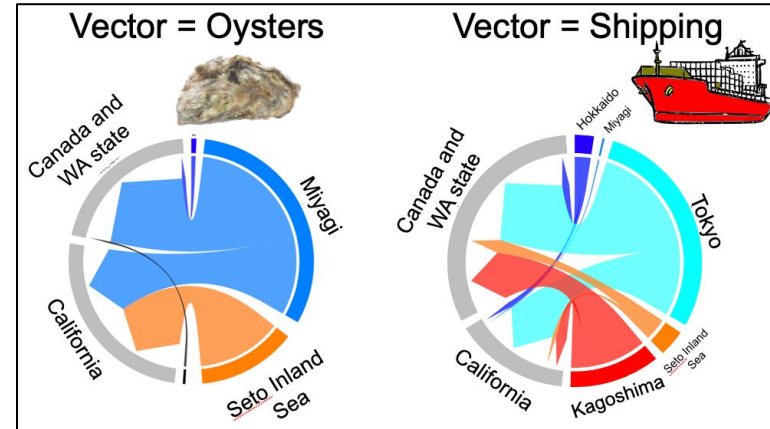
Genetic legacy of Pacific oyster introductions

- Most oysters were sourced from northeastern Japan
- Transport of locally-adapted oysters yielded “deliberate” ecological fitting.
- Non-native feral populations have bottlenecks and genetic diversity that reflect their invasion history



Genetic legacy of Pacific oyster introductions

- Most oysters were sourced from northeastern Japan
- Transport of locally-adapted oysters yielded “deliberate” ecological fitting.
- Non-native feral populations have bottlenecks and genetic diversity that reflect their invasion history
- We now have a mechanism to delineate oyster vs other vectors.



Acknowledgements



OCE-1924599



COLLEGE *of*
CHARLESTON

Also Lauren Lees, Hannah Rothkopf,
Hannah Miller, Dallas Crowder, Ryan
Carnegie, Osamu Miura

Argentina	Evangelina Schwindt
Chile	Martin Thiel, Jim Carlton
Denmark	Asä Strand
France	Eric Pante
Ireland	Asä Strand, Judith Kochmann
Japan	Takefumi Yorisue, Masahiro Nakaoka, Mits Kanaya, Masahiro Hori, Gen Kanaya, Ryuta Terada, Hikaru Endo
Korea	Kun-Seop Lee
New Zealand	Richard Taylor
Norway	Asä Strand
USA	Jennifer Ruesink, Hilary Heyford, Danielle Zacherl, Jeff Crooks
Spain	Lucia Couceiro
Sweden	Asa Strand, Judith Kochmann

Identifying vectors and the native sources of introduced species

Rius et al. 2014 *Biol. Inv.*

- Prevent future invasions
- Understand why a species succeeds or fails
- Understand its future threat (adaptive capacity)

