Northwest Atlantic population structure and gene flow in the Green Crab: current understanding of a dynamic invasion front, population admixture, & continued anthropogenic expansion

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Research comes from:

•Roman, J. (2006). "Diluting the founder effect: cryptic invasions expand a marine invader's range"

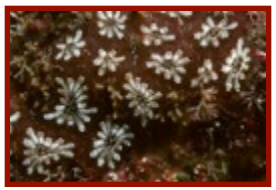
•Pringle, J.P., Blakeslee, A.M.H., Byers, J.E., Roman, J. (2011). "Asymmetric dispersal allows an upstream region to control population structure throughout a species' range."

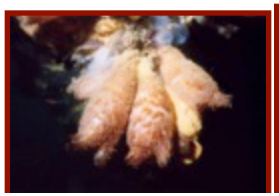
•Blakeslee, A.M.H., McKenzie, C.H., Darling, J.A., Byers, J.E., Pringle, J.P., Roman, J. (2010). "A hitchhiker's guide to the Maritimes: anthropogenic transport facilitates long-distance dispersal of an invasive marine crab to Newfoundland."

•Darling, J.A., Tsai, E.Y.H., Blakeslee, A.M.H., Roman, J. (in prep). Biased introgression of mitochondrial genomes beyond an established range limit in a dynamic admixture zone

Marine Invasions & Genetics

- **Part of human-induced global change**
- **Some introduced species may have unclear invasion histories -- multiple lines of evidence may be required**
- **Genetic data is a useful tool to understand a species' invasive biogeographic tracks, including:**
  - **Revealing source populations**
  - **Timing of introduction**
  - **Likely vector(s)**
  - **Determining gene flow**





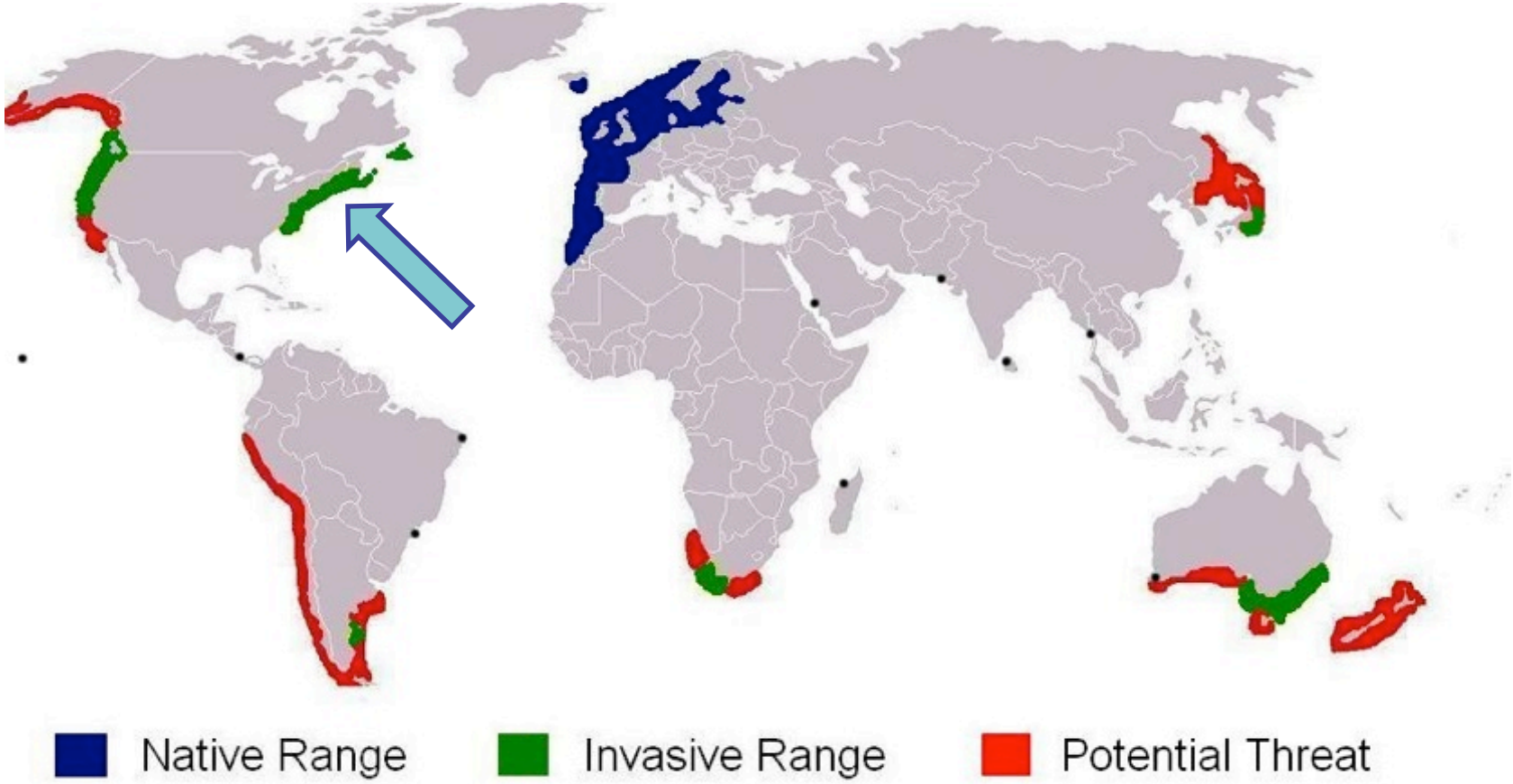
Carcinus maenas (European green crab)

- **Native to Europe and invasive globally**
- **Listed as one of the top 100 worst invasive species**
- **Shown to have major impacts on natural species and ecosystems**
  - **Competitive and predatory impacts on natives**
  - **Commercial species**

Among others…

EPA
United States
Environmental Protection
Agency

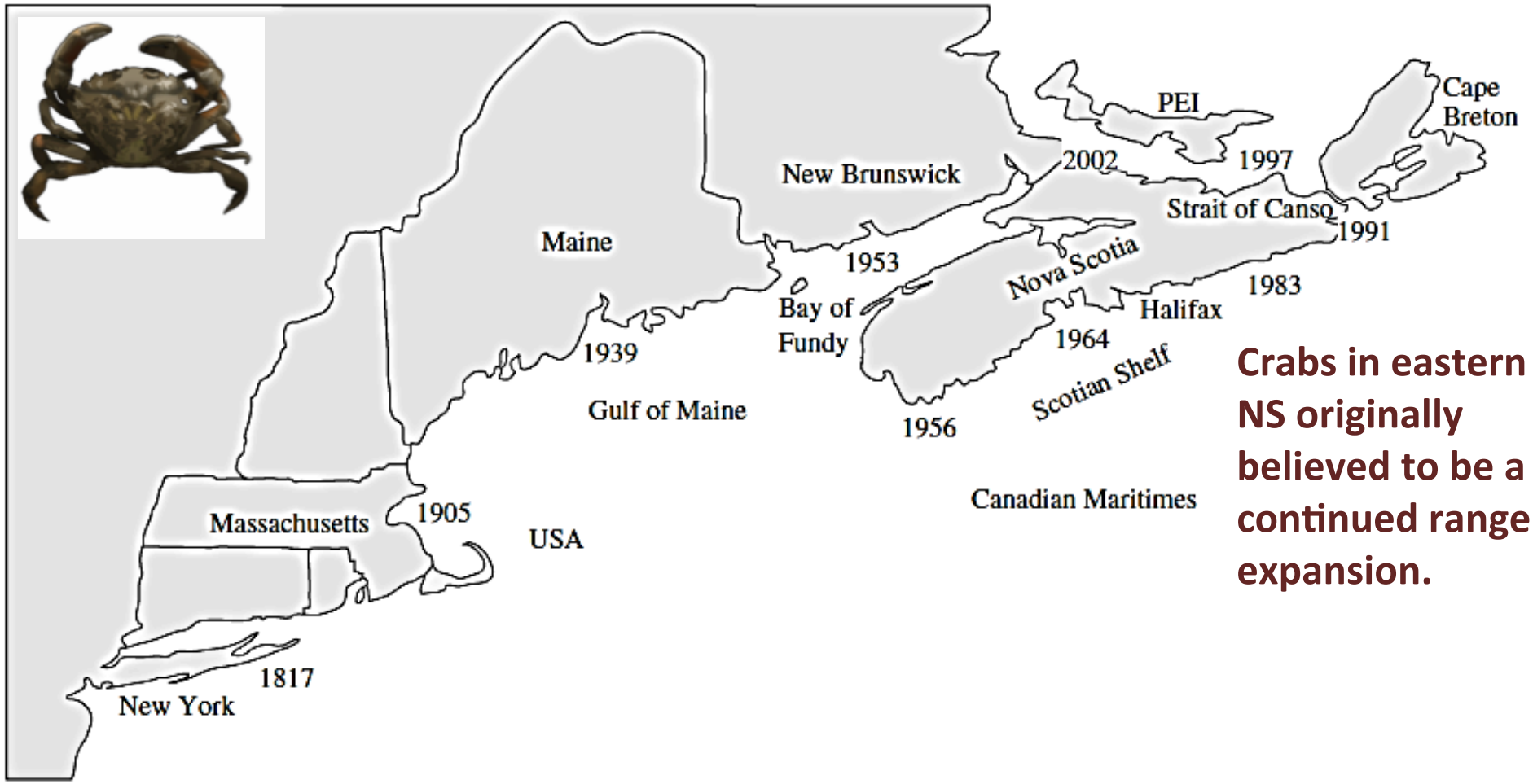
Global Distribution of *Carcinus maenas*



Slide courtesy of J. Darling

Slide courtesy of J. Darling

Northwest Atlantic Distribution & Spread of *C. maenas*

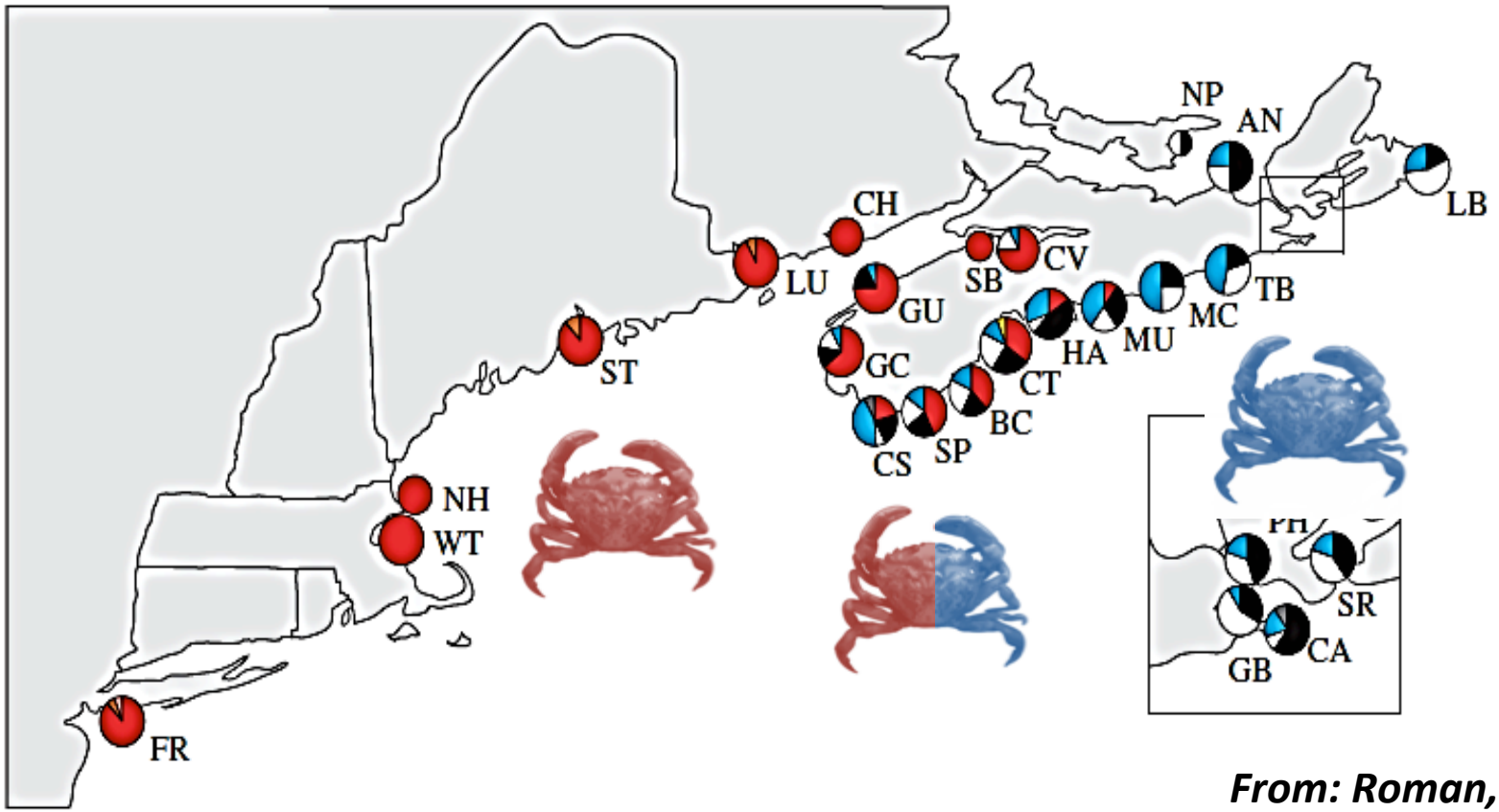


Crabs in eastern NS originally believed to be a continued range expansion.

Figure 1. Northern range of the green crab, *Carcinus maenas*, on the east coast of North America. Dates indicate the first confirmed sighting of the species (adapted from Audet *et al.* 2003).

From: Roman, 2006

Green crab population genetics: 1999-2000



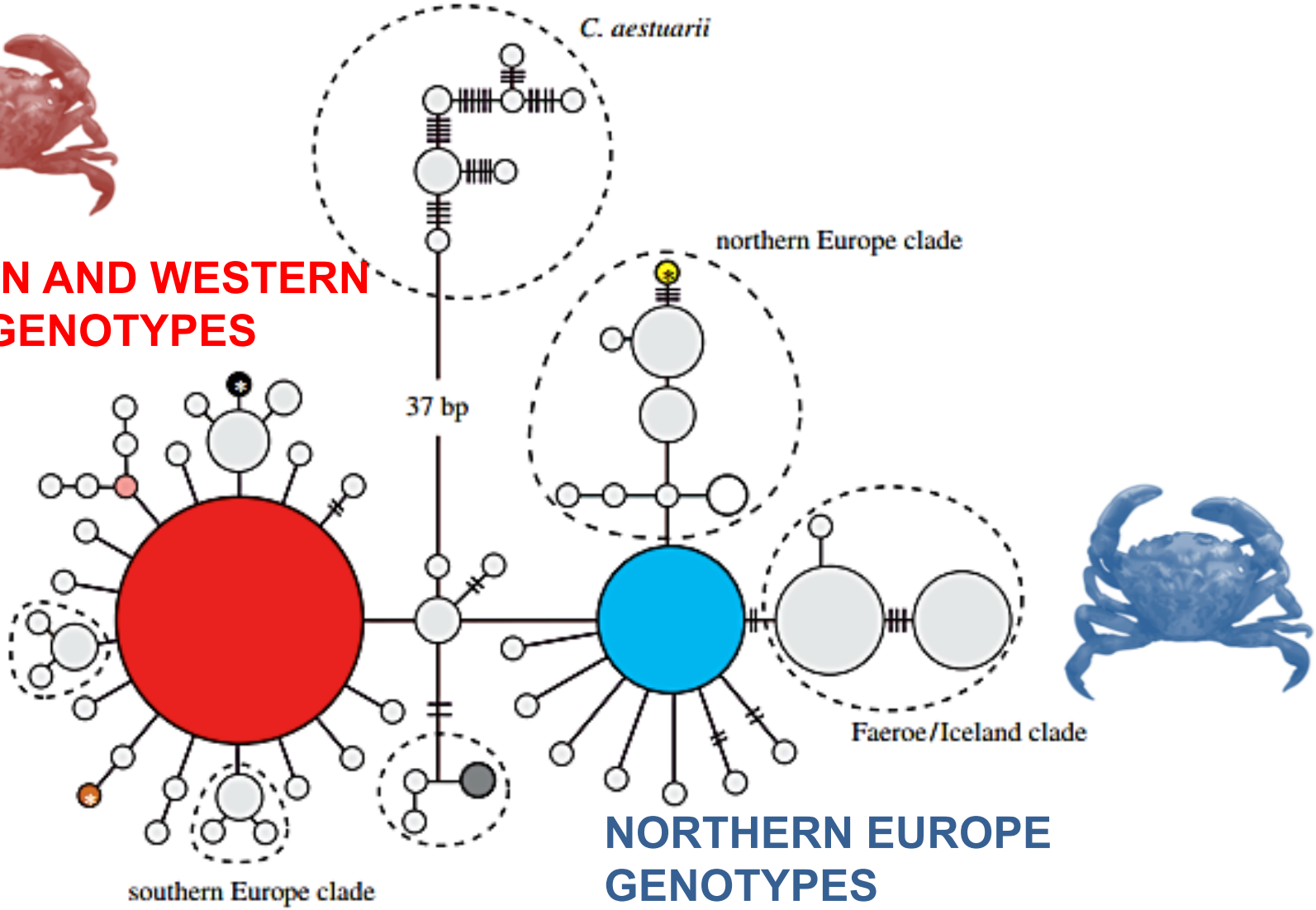
From: Roman, 2006

Figure 2. Relative frequencies of green crab haplotypes from 25 locations in North America sampled in 1996–2001. The size of each circle is approximately proportional to the sample size. Inset presents collection locales along the Strait of Canso.

Two "genotypes" detected, one in southern regions (red) nearby the crab's original introduction, and another (blue) in eastern Nova Scotia; with population mixing in western Nova Scotia

From Roman, 2006

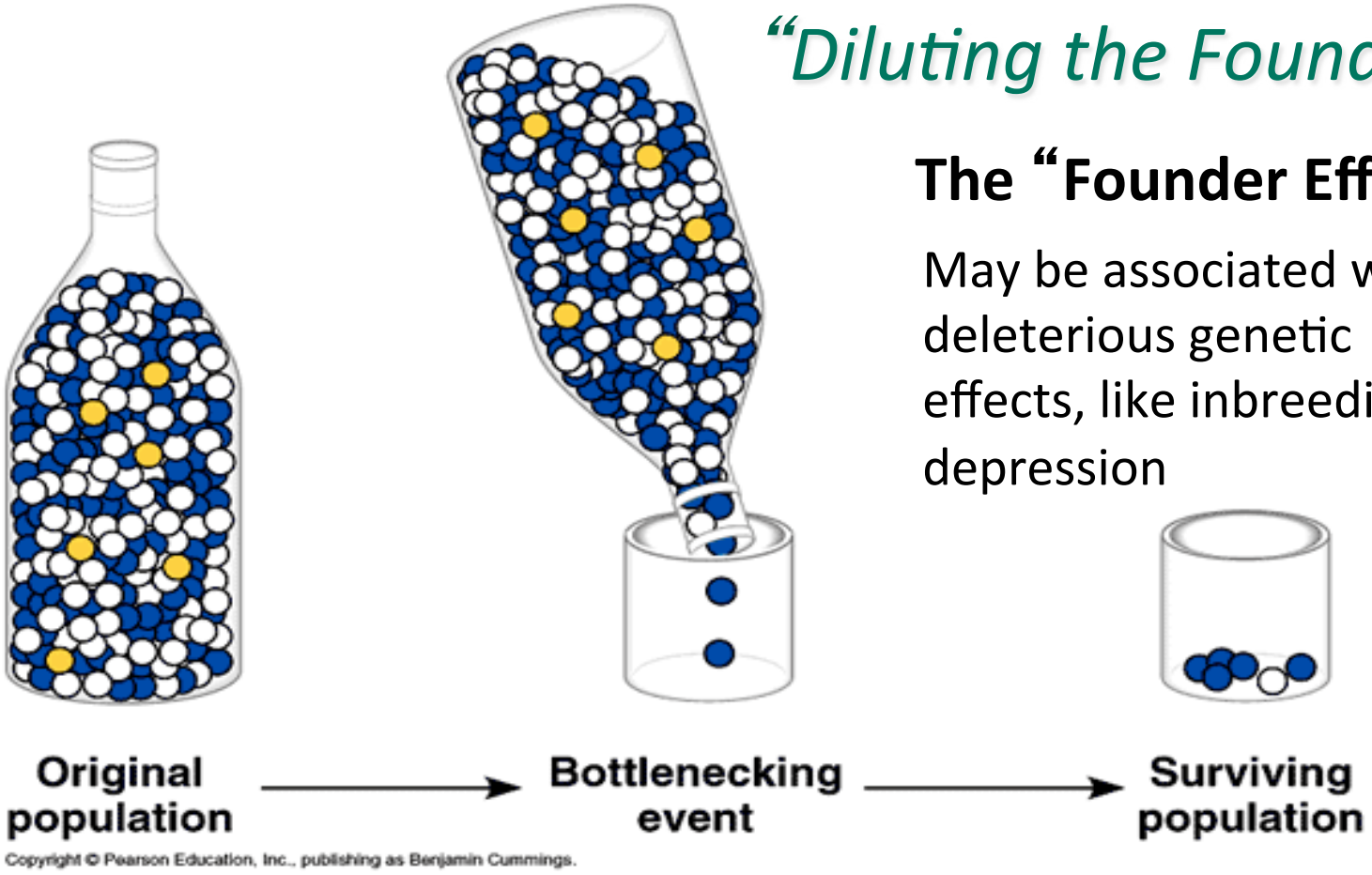
SOUTHERN AND WESTERN EUROPE GENOTYPES



NORTHERN EUROPE GENOTYPES

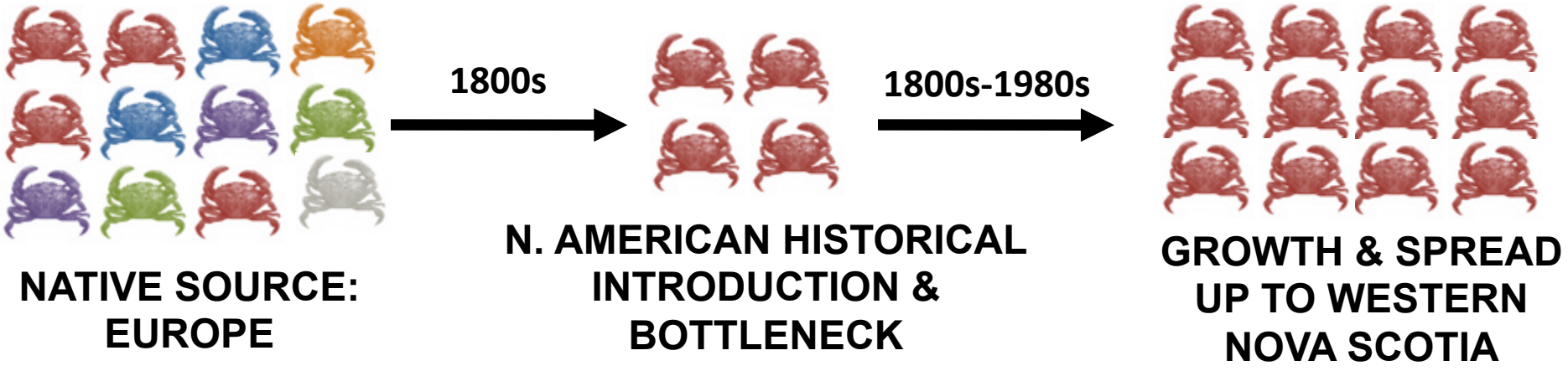
Figure 3. Parsimony network for mtDNA haplotypes of *Carcinus maenas* and *Carcinus aestuarii*. Genotypes marked with an asterisk were recovered in eastern North America but not in Europe. European haplotypes not represented in North America are in light grey. The size of the circles represents haplotype frequencies in Europe. Clades encircled by dashed lines have 100% majority-rule consensus support.

"Diluting the Founder Effect…"

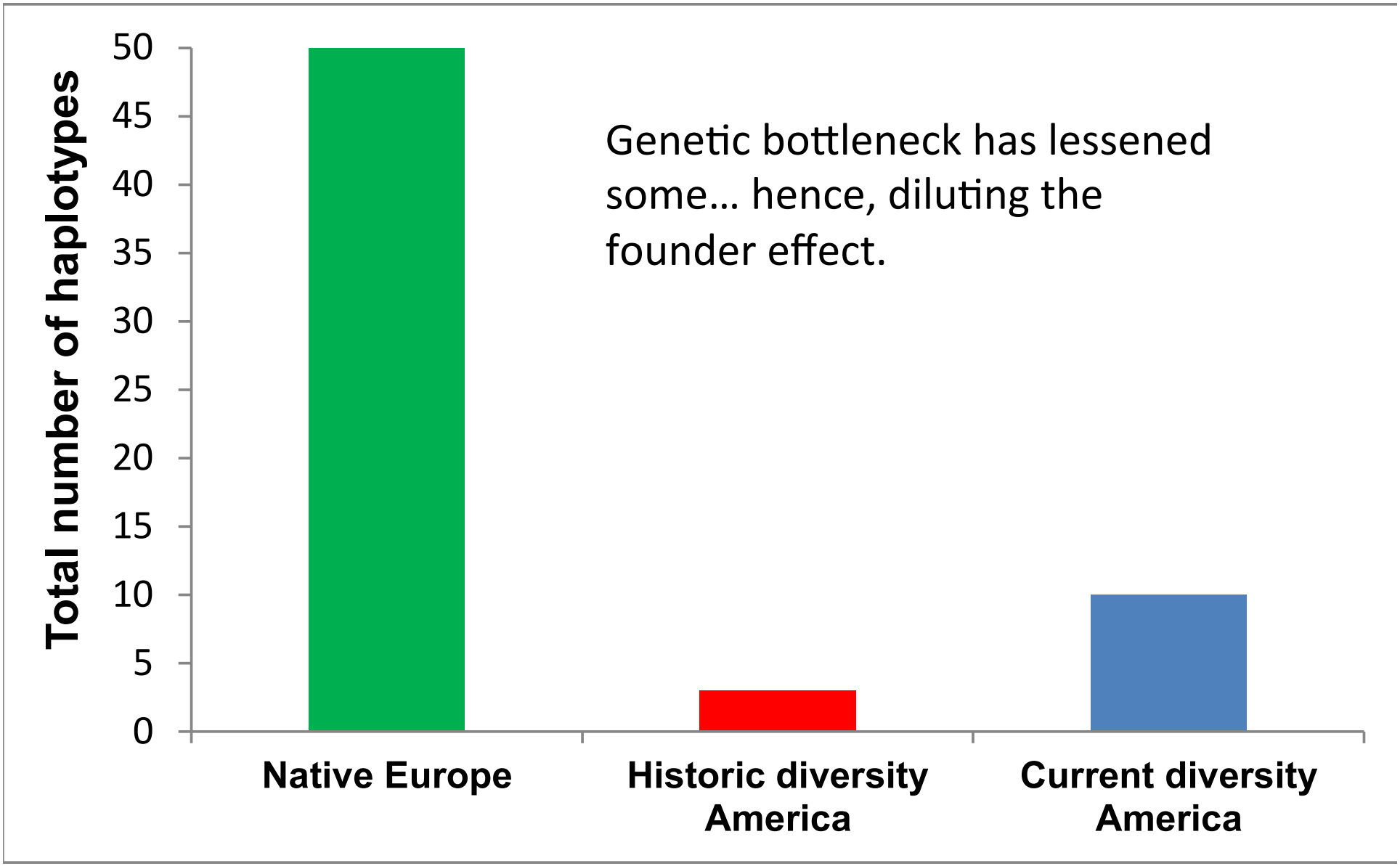


The "Founder Effect:"

May be associated with deleterious genetic effects, like inbreeding depression



"Diluting the Founder Effect…"



Tying it all together: Western Atlantic introduction was the result of two major introduction events from Europe (Roman, 2006)

2nd Introduction (1990s):

- Ballast water
- Cryptic introduction to Nova Scotia
- Introduced novel northern European genotypes
- Expanded through Canadian Maritimes and southwards

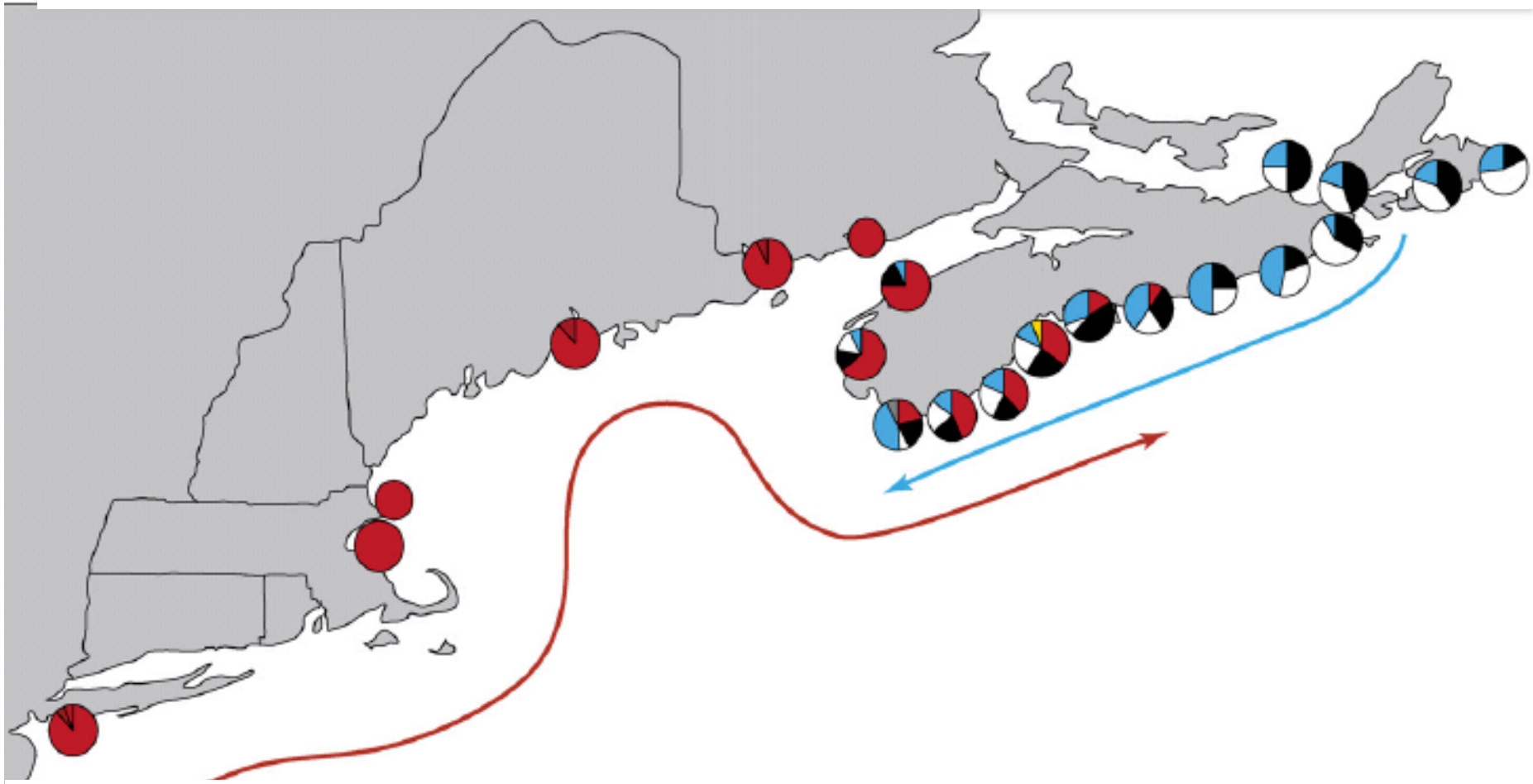
Europe

North America

1st Introduction (Early 1800s):

- Rock ballast
- First noted in MA & NY
- Expanded northwards as far as Canadian border
- Introduced south / western European genotypes

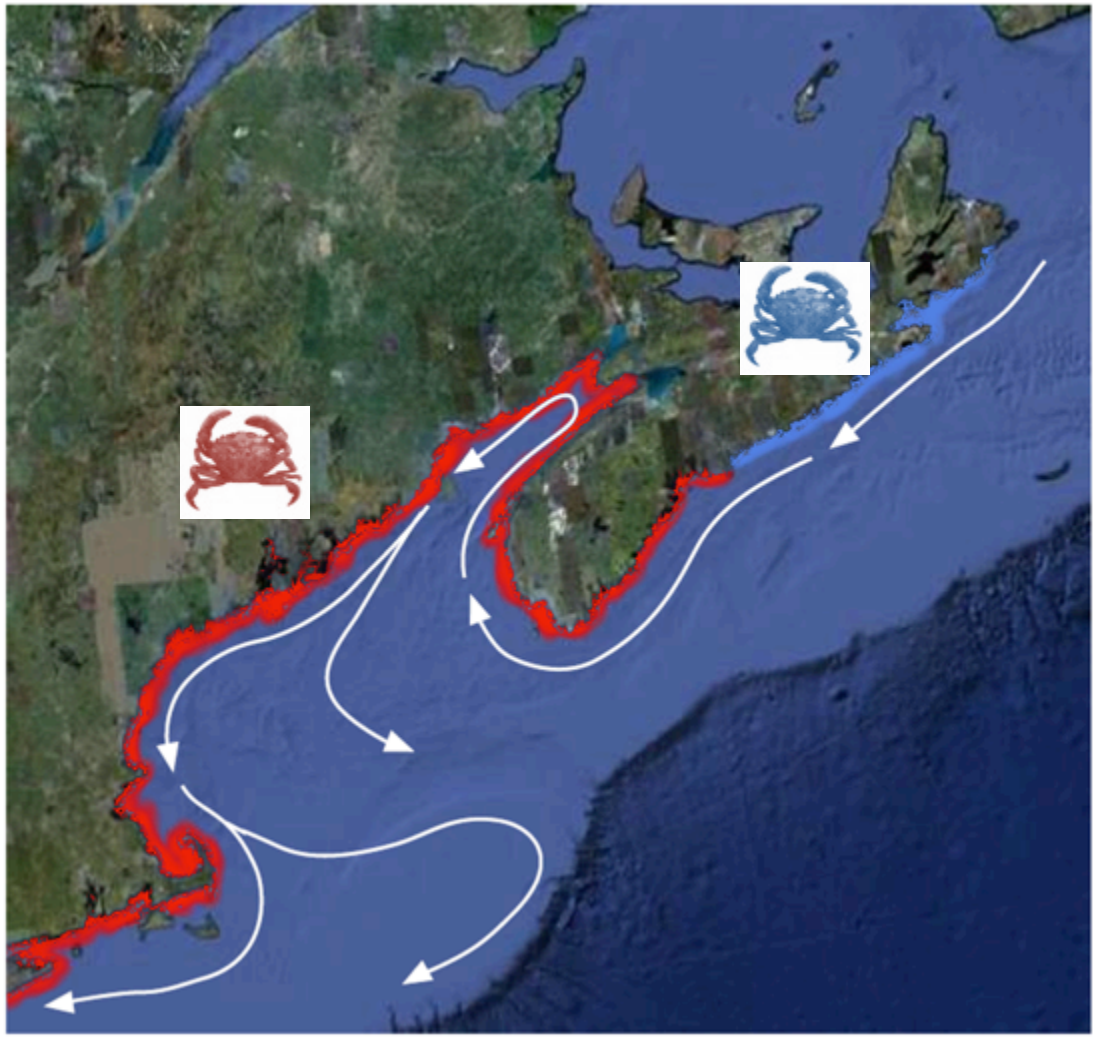
C. maenas in the northwest Atlantic: 1999-2000



Snapshot of the population genetics in 1999-2000, but this is a dynamic system – what happens with time?

Slide courtesy of J. Darling

Prediction: Advection of larvae along prevailing currents would result in a fairly quick spread of new genotypes in a southwesterly direction



Slide courtesy of J. Darling

Asymmetric dispersal allows an upstream region to control population structure throughout a species' range

James M. Pringle[a,1], April M. H. Blakeslee[b,2], James E. Byers[c], and Joe Roman[d]

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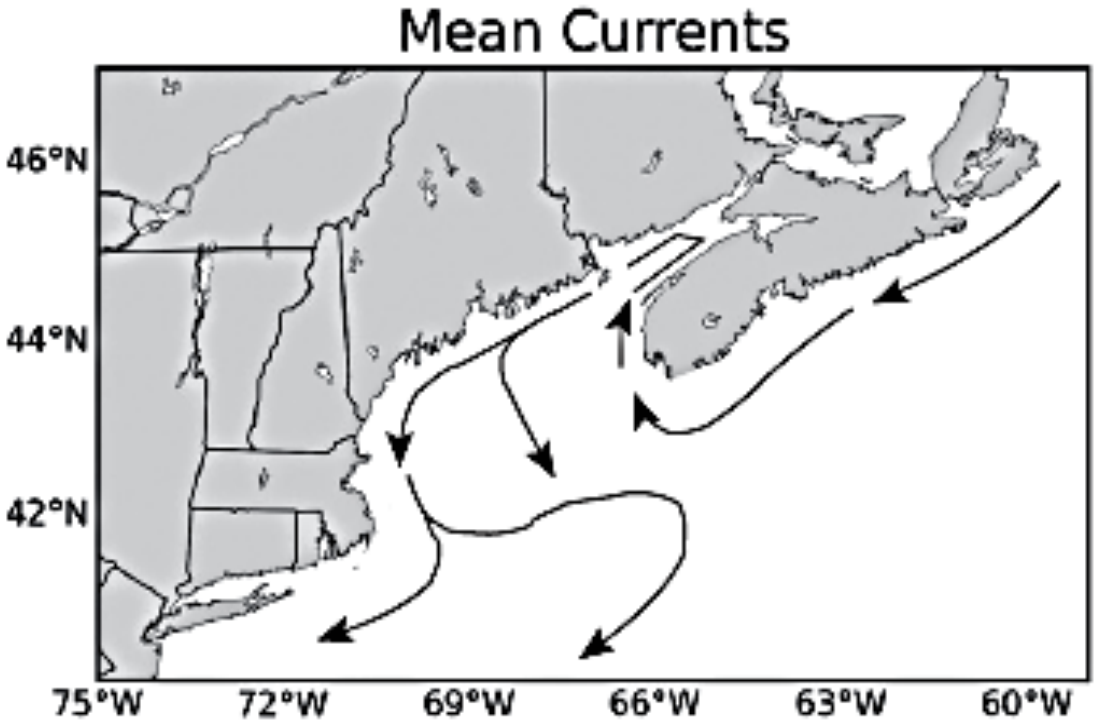
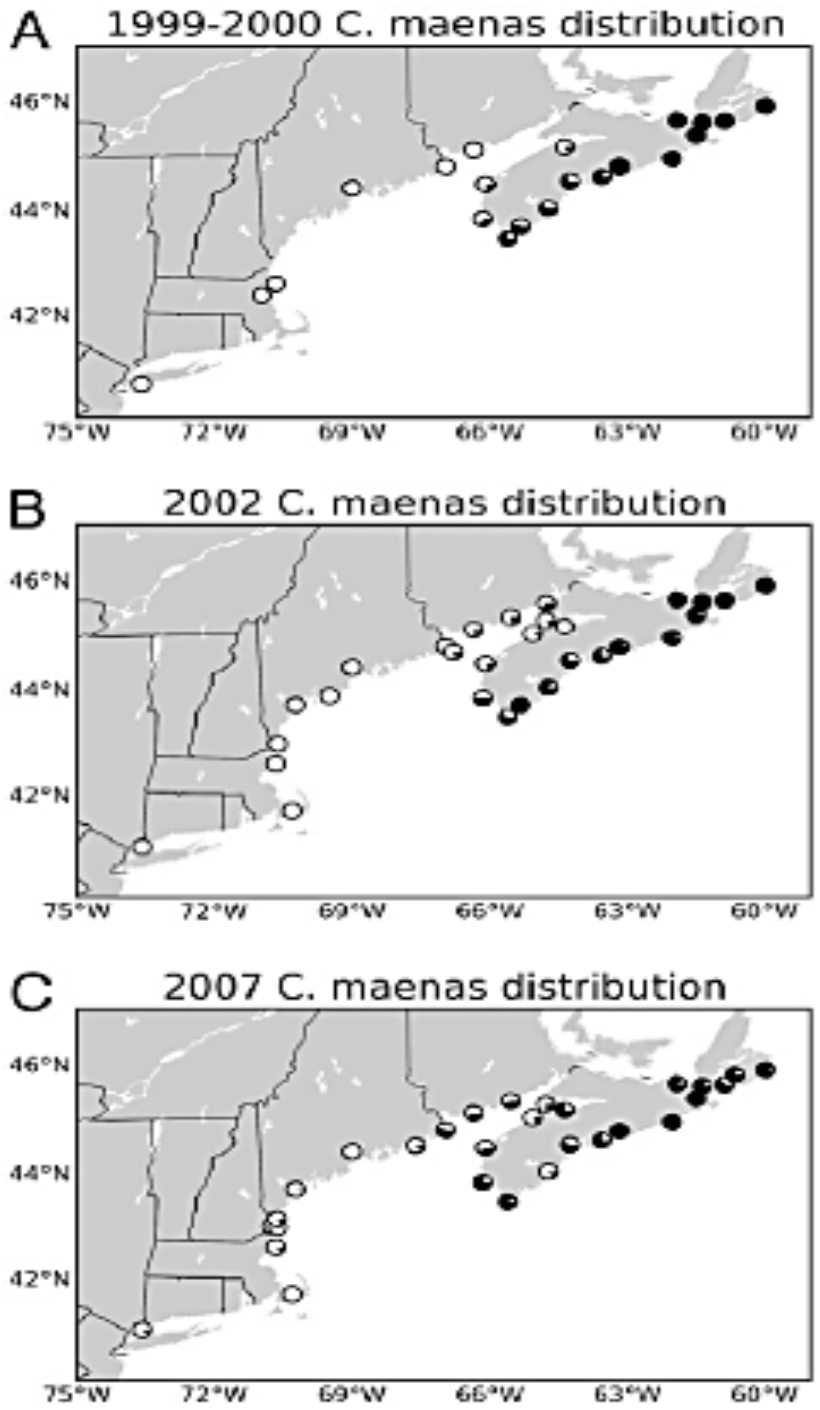
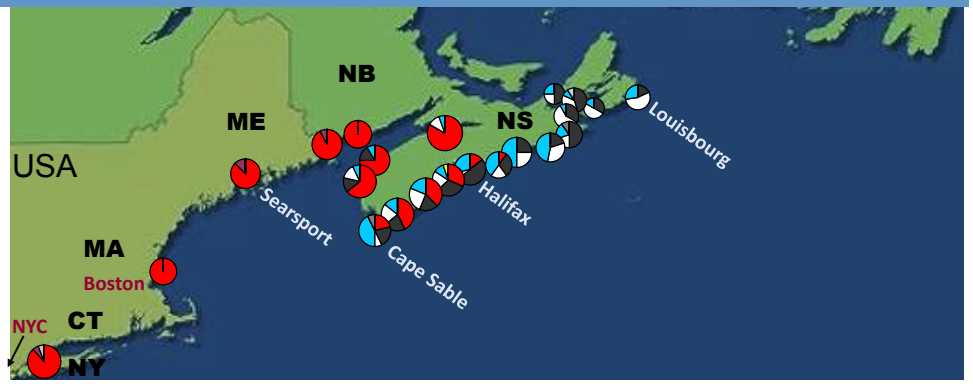


Fig. 1. Map of the New England and Canadian Maritime coastline with locations mentioned in the text. (*Upper*) The dates are the years that *C. maenas* was first observed at various locations along the coast. (*Lower*) Arrows mark the mean currents in this region (data from refs. 25, 26, and 35).

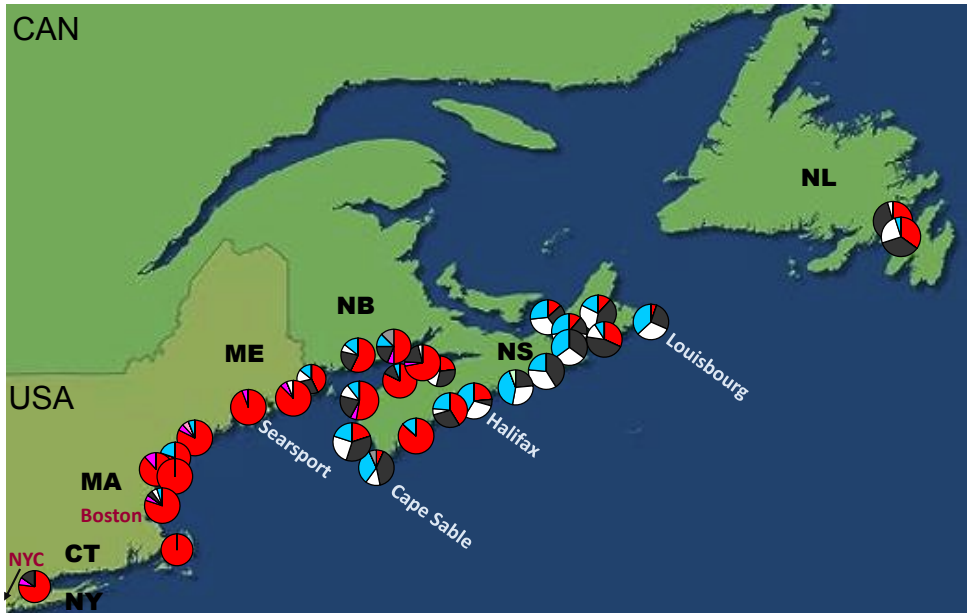


Progression of new (blue) genotypes in the SW direction & movement of original genotype (red) NE direction.



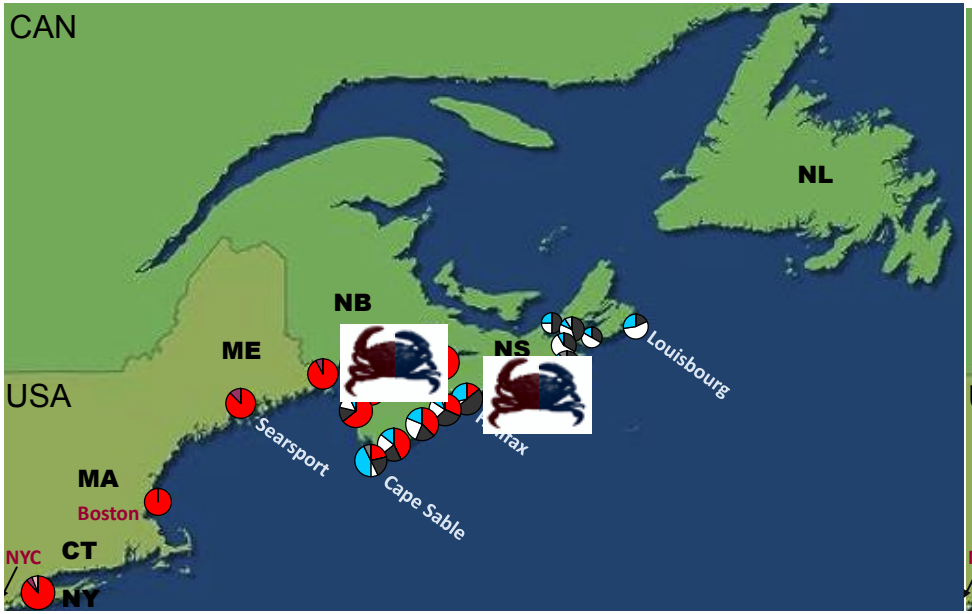
1999-2000 Haplotype Data

(originally from Roman, 2006; also used in Blakeslee et al., 2010 and Pringle et al., 2011)



2007 Haplotype Data

(used in Blakeslee et al., 2010 and Pringle et al., 2011 & unpublished data)



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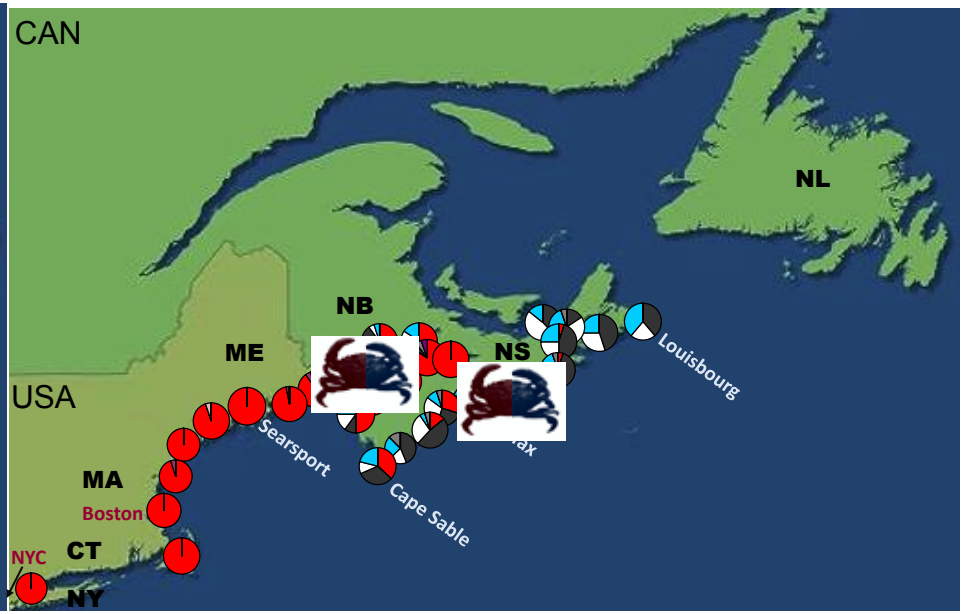
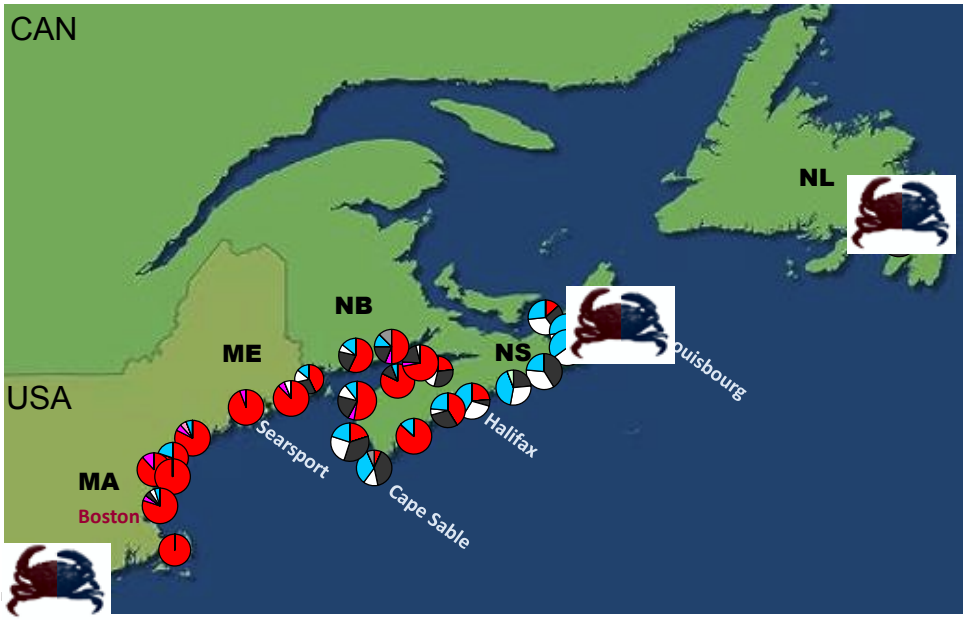


2002 Haplotype Data

(originally from Roman, 2006; also used in Blakeslee et al., 2010 and Pringle et al., 2011)

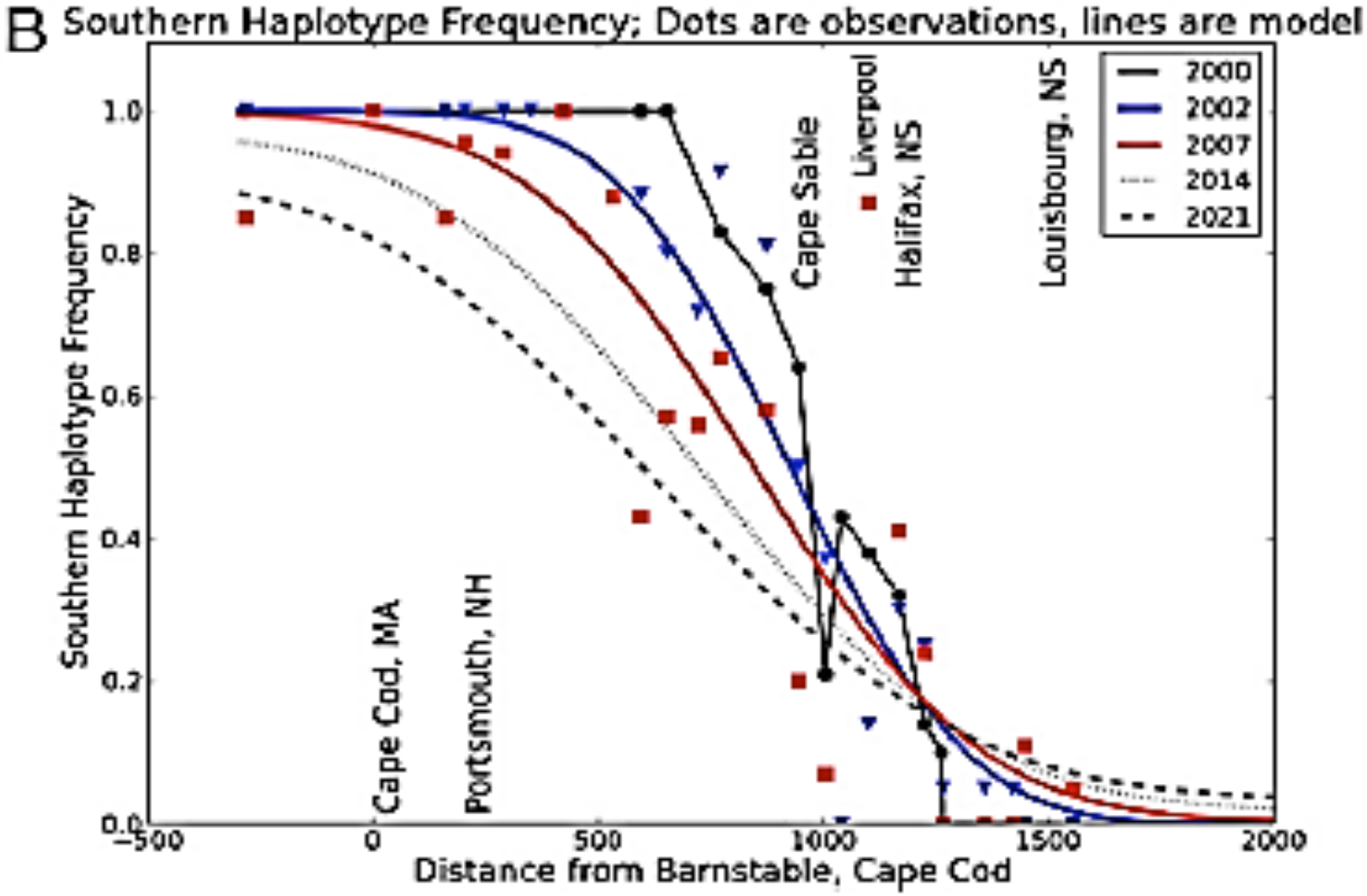
Mixture zone has shifted with time both in the southwards and northwards directions



2007 Haplotype Data

(used in Blakeslee et al., 2010 and Pringle et al., 2011 & unpublished data)

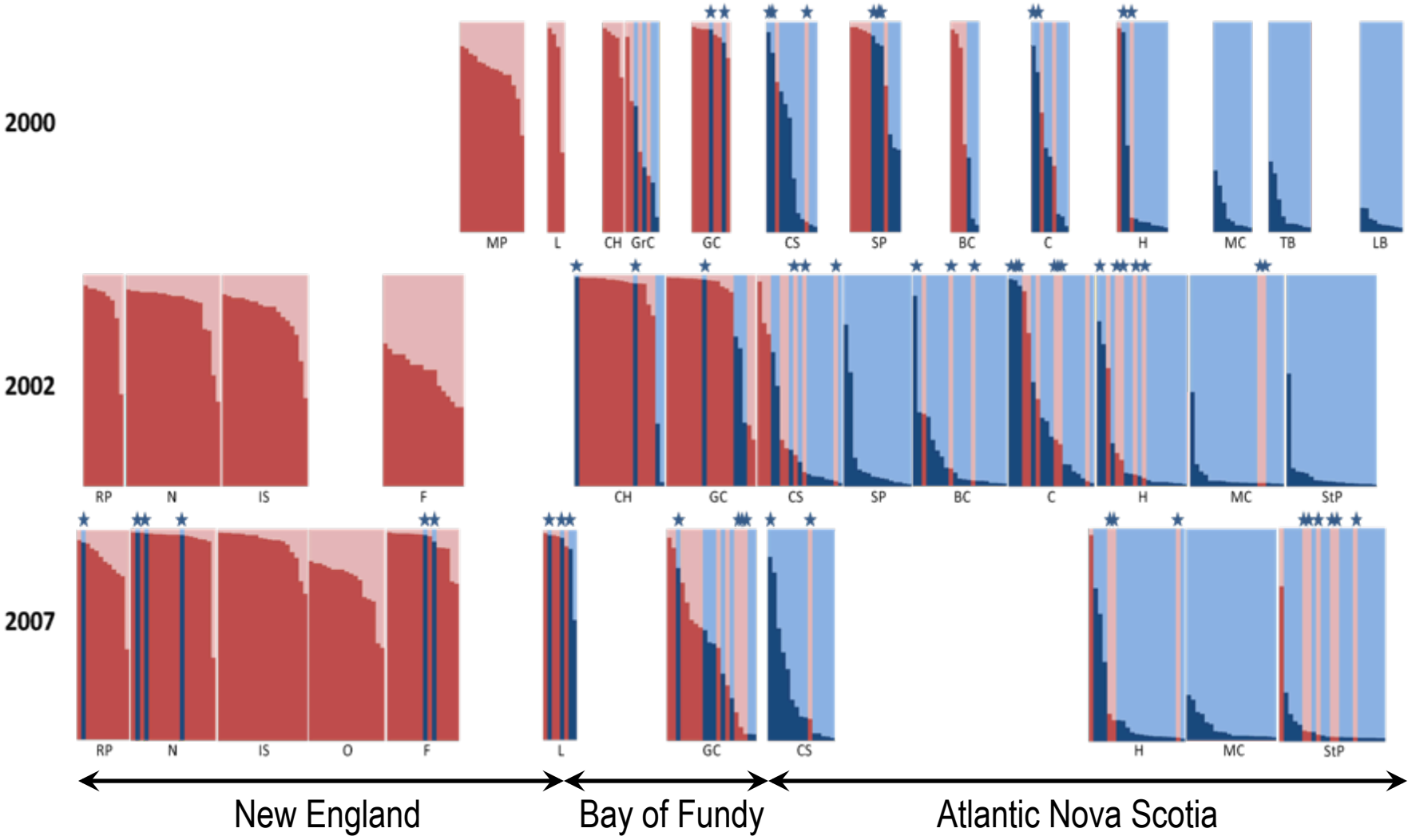
At the mtDNA marker, the frequency of the southern genotype lessens as you move northwards, and it also lessens with time



From Pringle et al., 2011

A dynamic admixture zone: microsatellites

United States Environmental Protection Agency

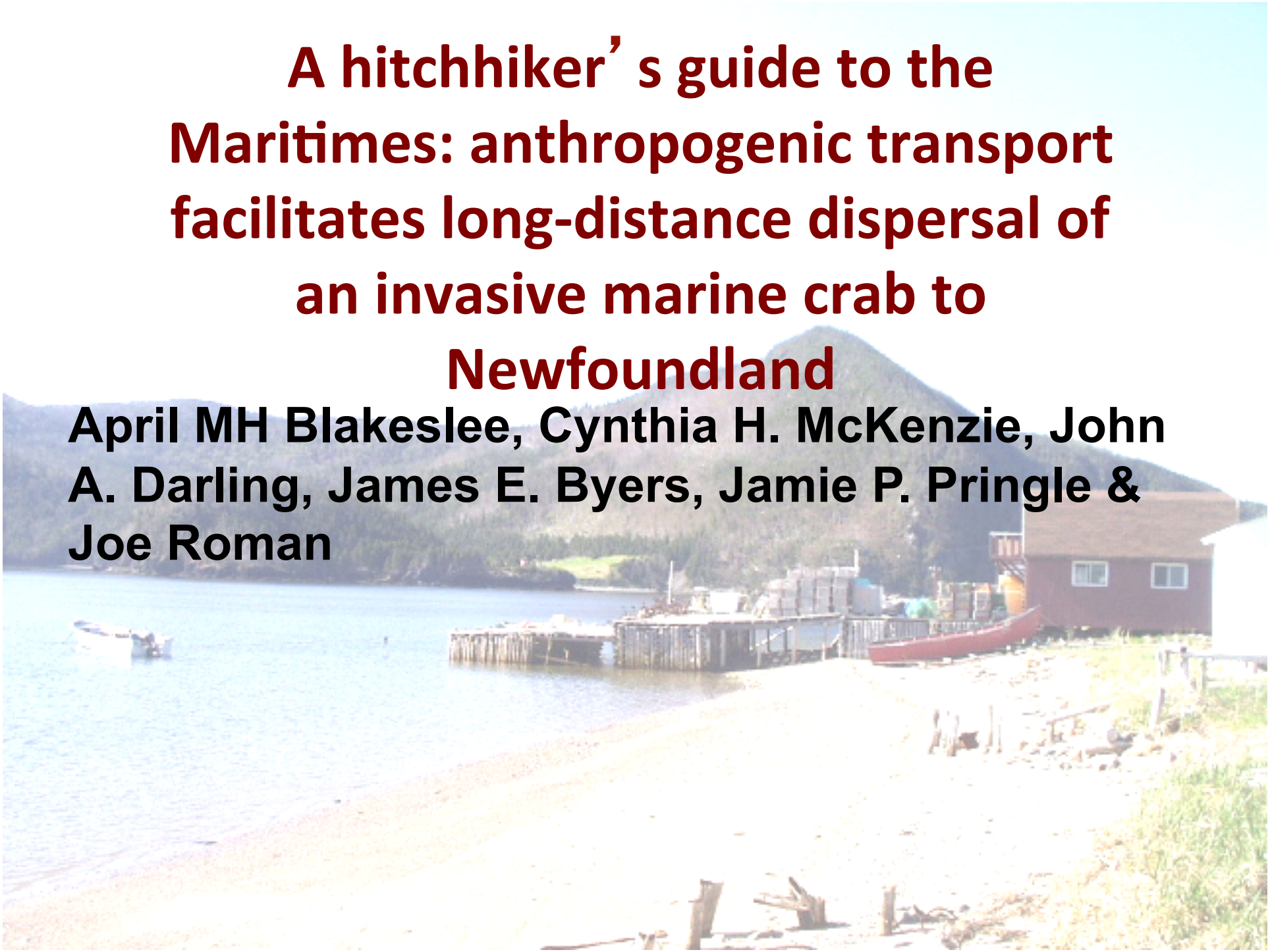


From: Darling et al., in prep

Slide courtesy of J. Darling

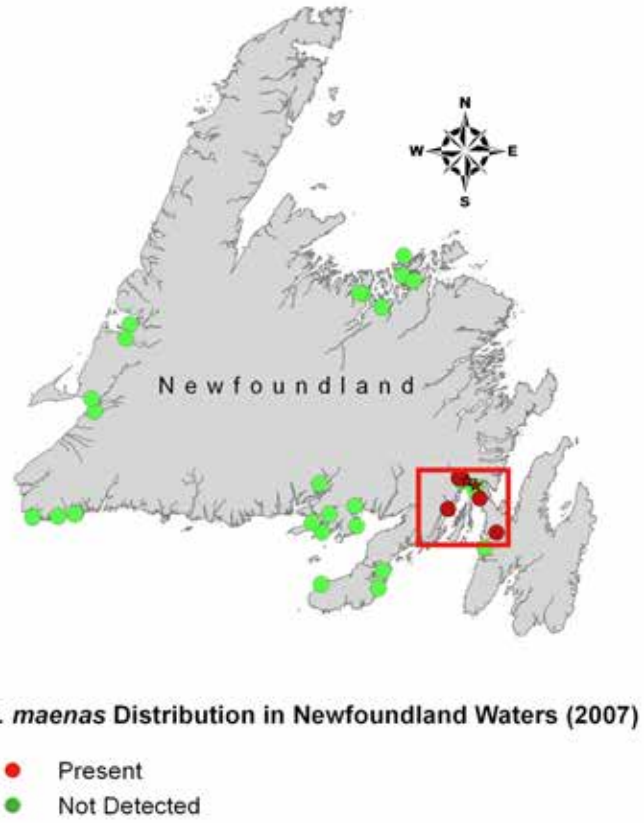
A hitchhiker's guide to the Maritimes: anthropogenic transport facilitates long-distance dispersal of an invasive marine crab to Newfoundland

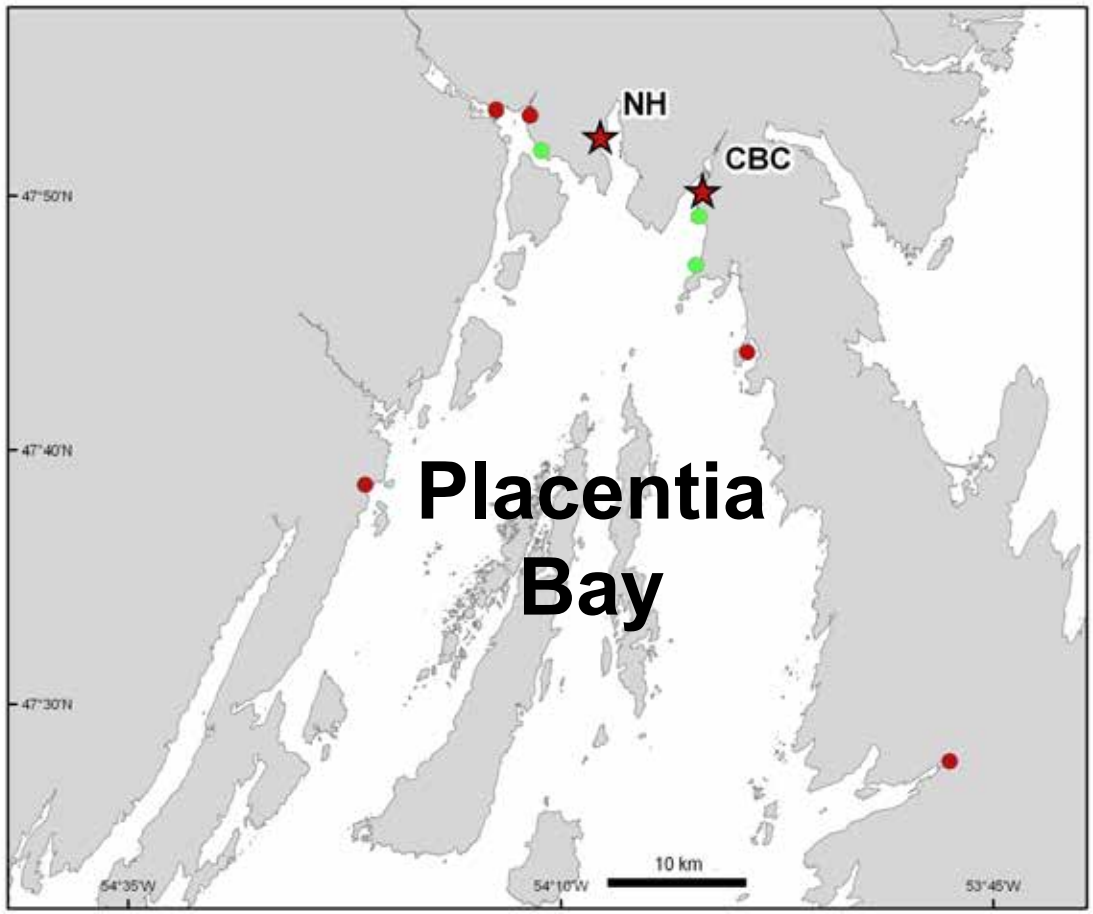
April MH Blakeslee, Cynthia H. McKenzie, John A. Darling, James E. Byers, Jamie P. Pringle & Joe Roman



Presence/absence of *C. maenas* in Newfoundland: 2007

(McKenzie – Fisheries & Oceans Canada)

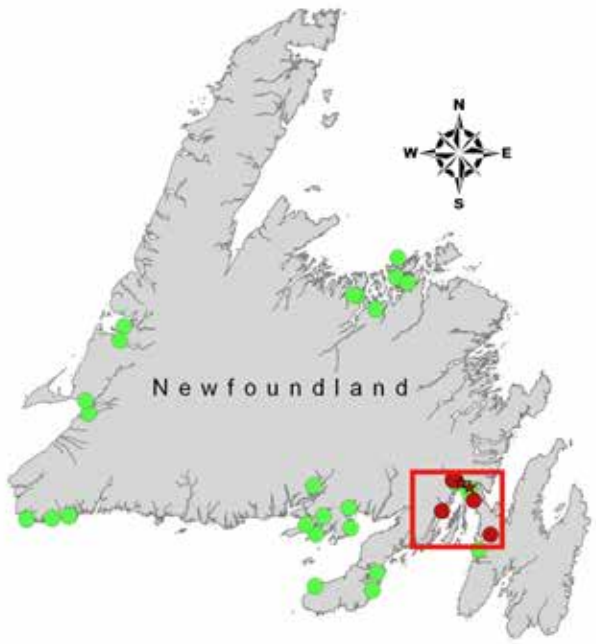


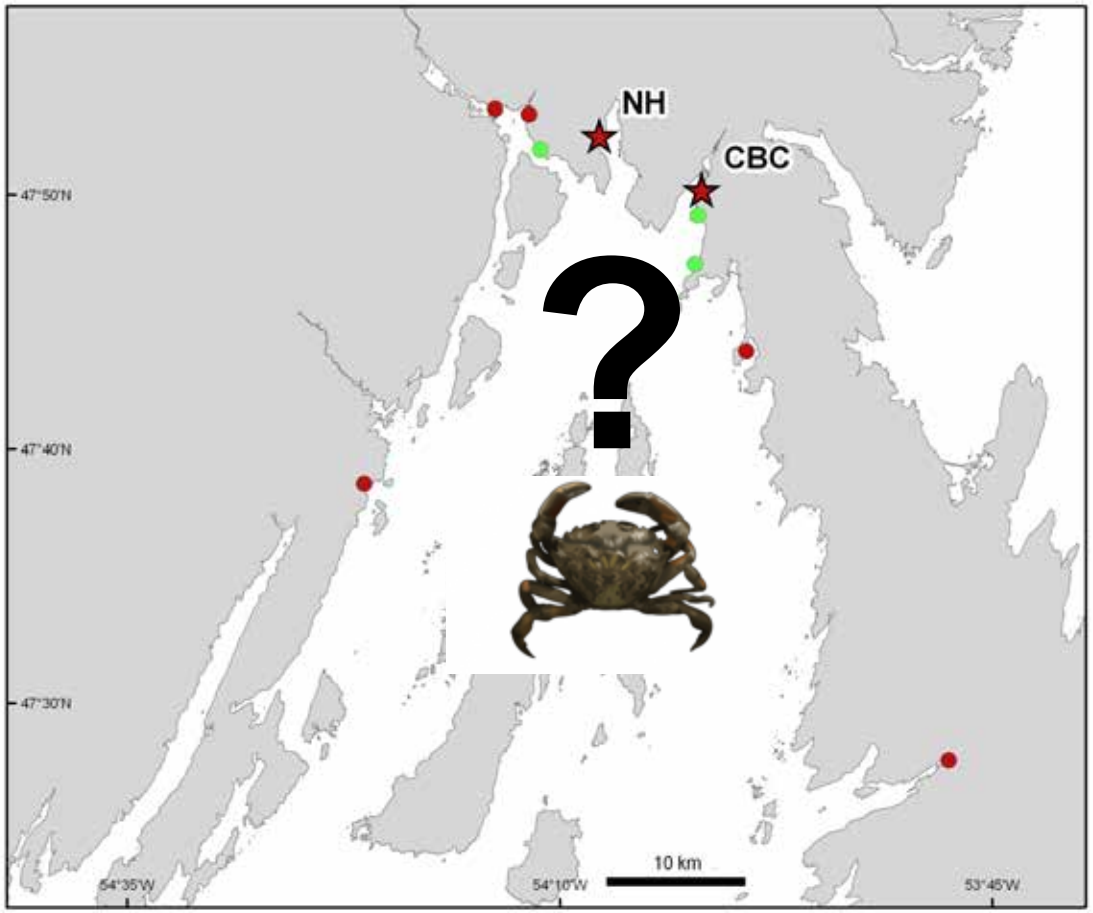


NH = North Harbour, NFLD

CBC = Come by Chance, NFLD

From: Blakeslee et al. 2010, Div. & Distrib.





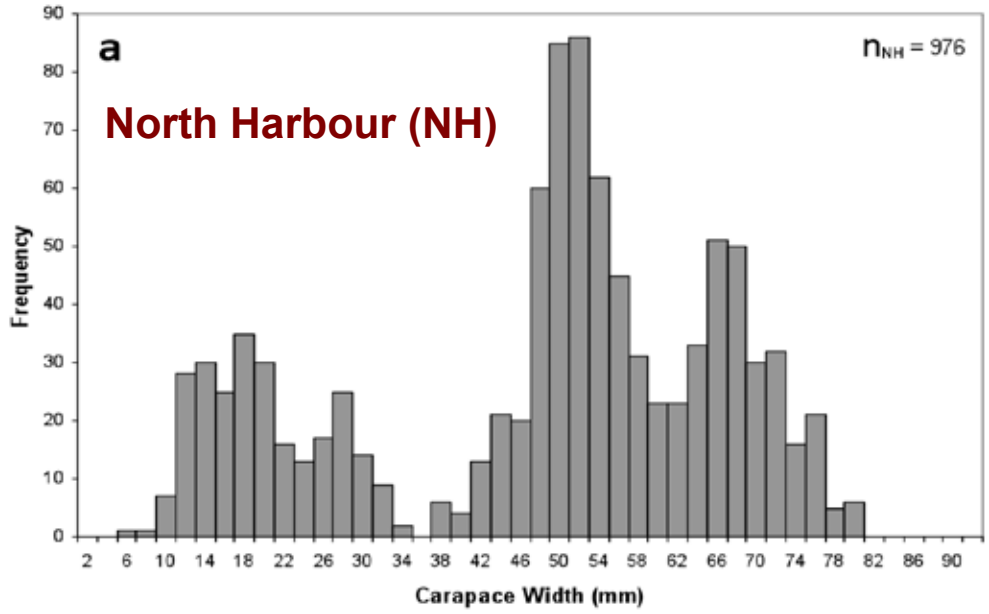
Questions about NL introduction:

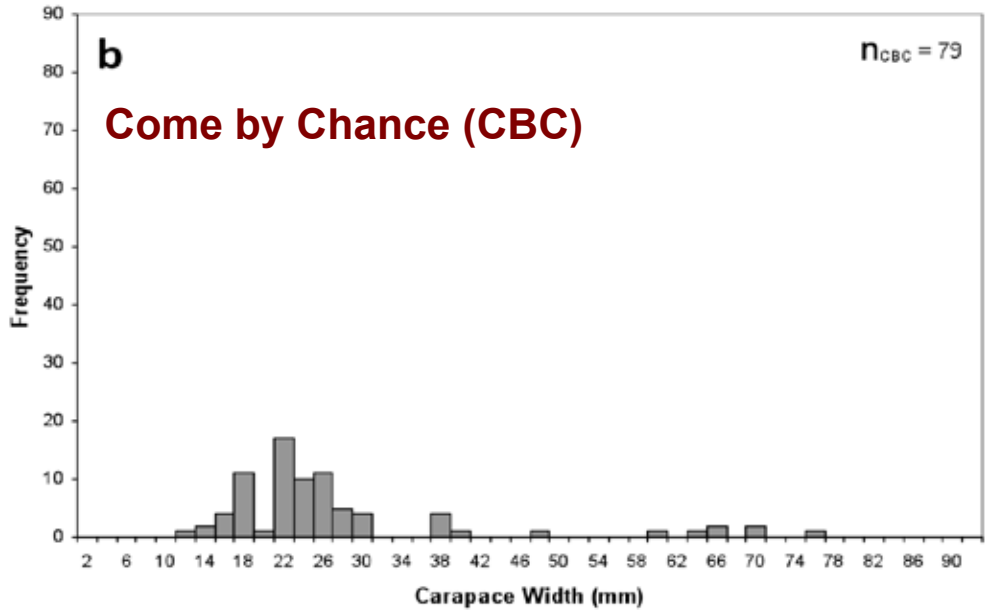
- **Source of Introduction (Europe / North America)?**
- **Vector (ballast water, fishing gear, bait)?**
- **Timing of Introduction (~2002-2007)?**

Collaborative Data Collection

- **Demographic data – NFLD surveys (C. McKenzie, Fisheries & Oceans Canada)**
- **Mitochondrial (COI) haplotype data from 2007 NFLD samples and 1999-2002 (Roman 2003, 2006) European, Canadian, and US data (A. Blakeslee; J. Roman, UVA)**
- **Microsatellite data (8 markers) to compare with mtDNA (J. Darling, EPA)**
- **National and international shipping data to NFLD (C. McKenzie)**

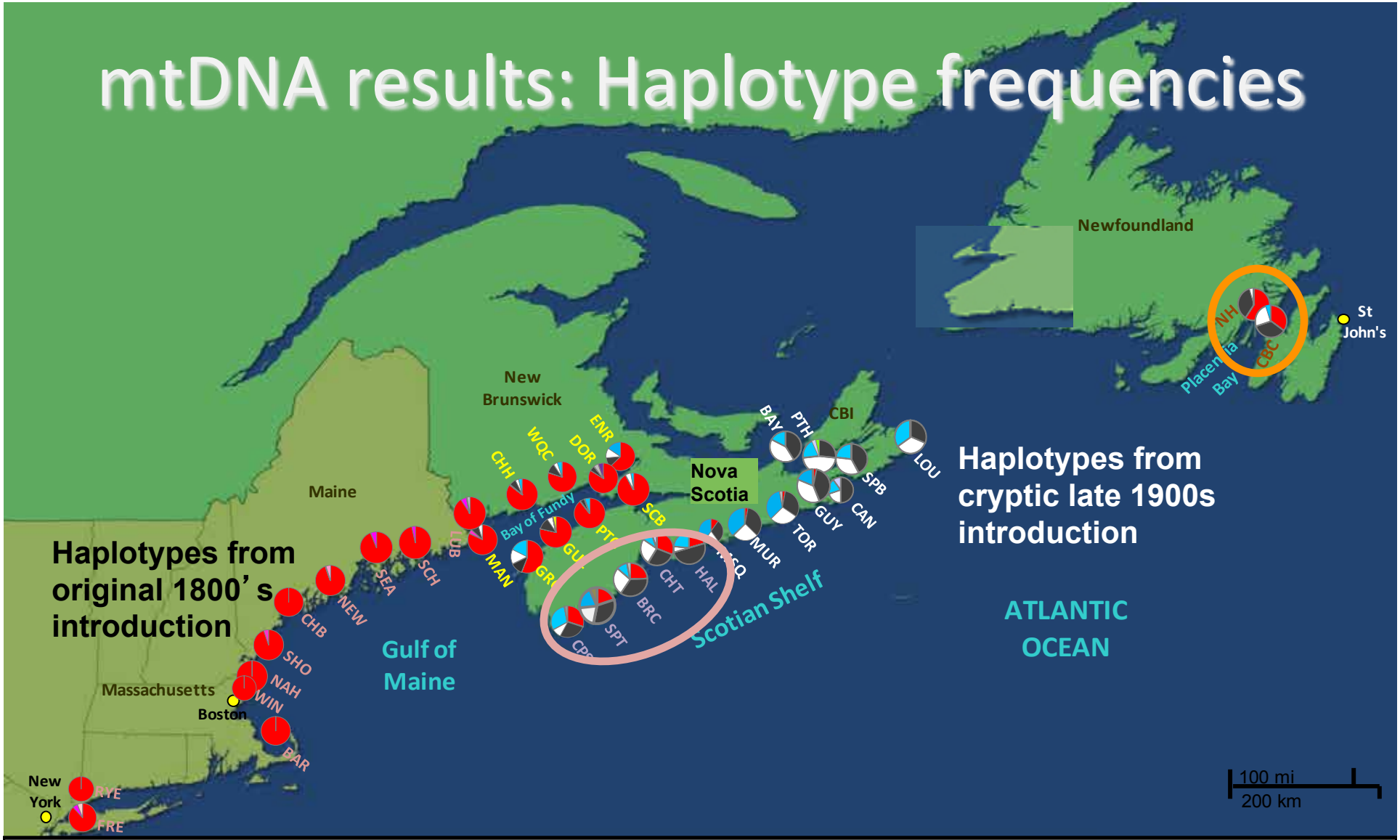
Size-Frequency of *C. maenas* in NFLD





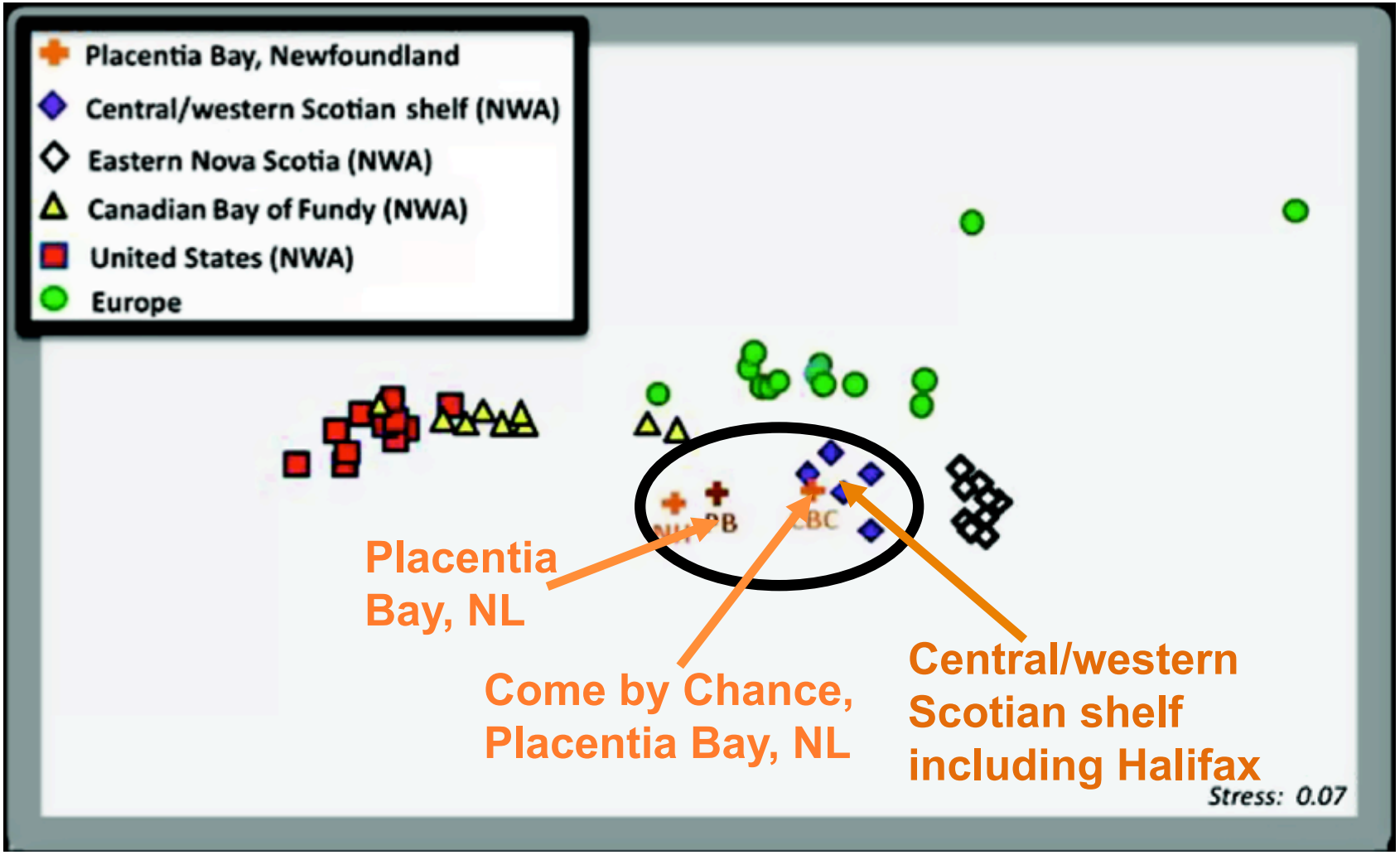
- **Crabs collected using multiple methods, including pots, seines, hand collections**
- **NH: appears to be an older, more established population than CBC.**
- **Largest individuals suggest that *C. maenas* has been in system for several years**

mtDNA results: Haplotype frequencies



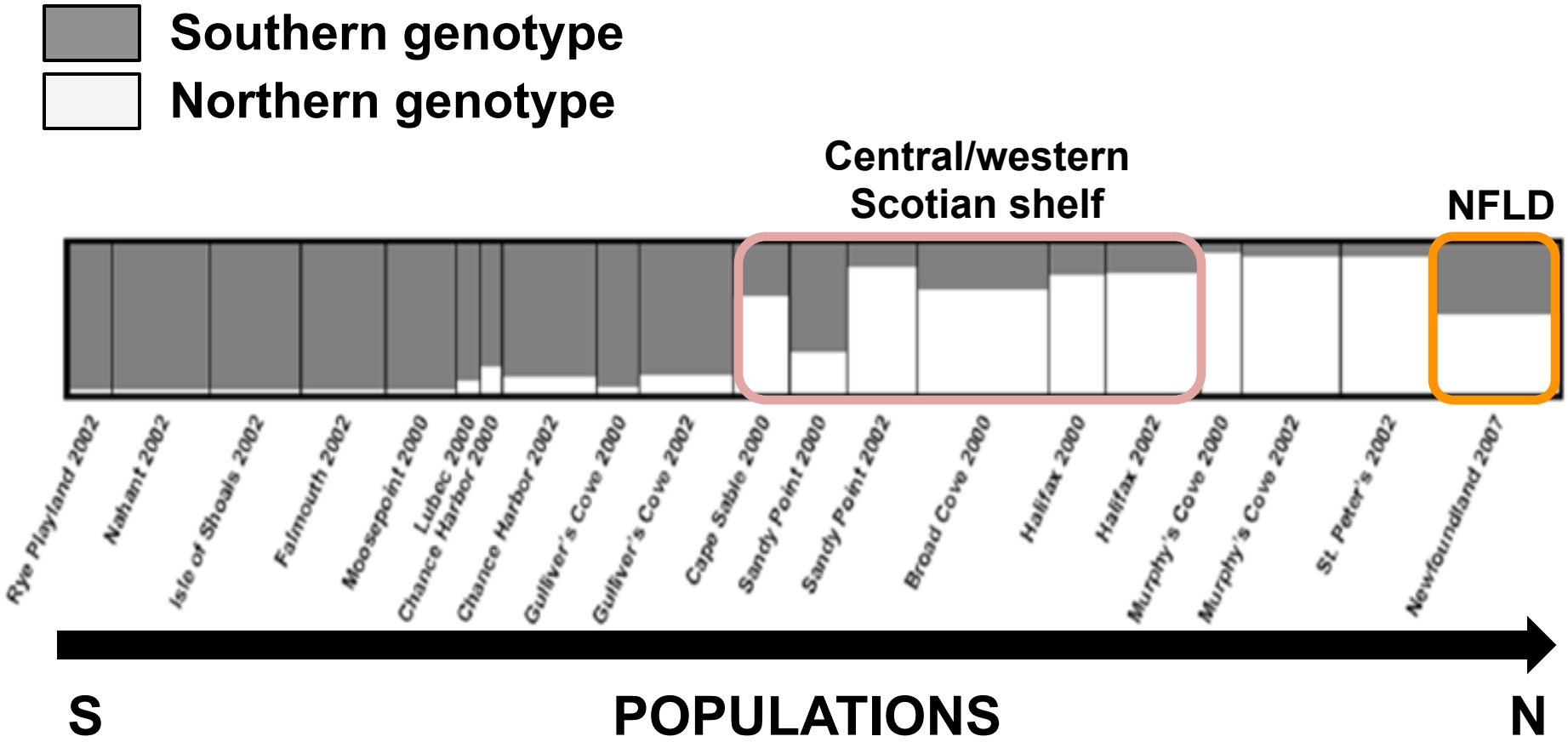
Placentia Bay populations show most similar haplotype frequencies to those populations in central/western Scotian shelf (nearby Halifax)

mtDNA results: MDS plot of pairwise Fst data



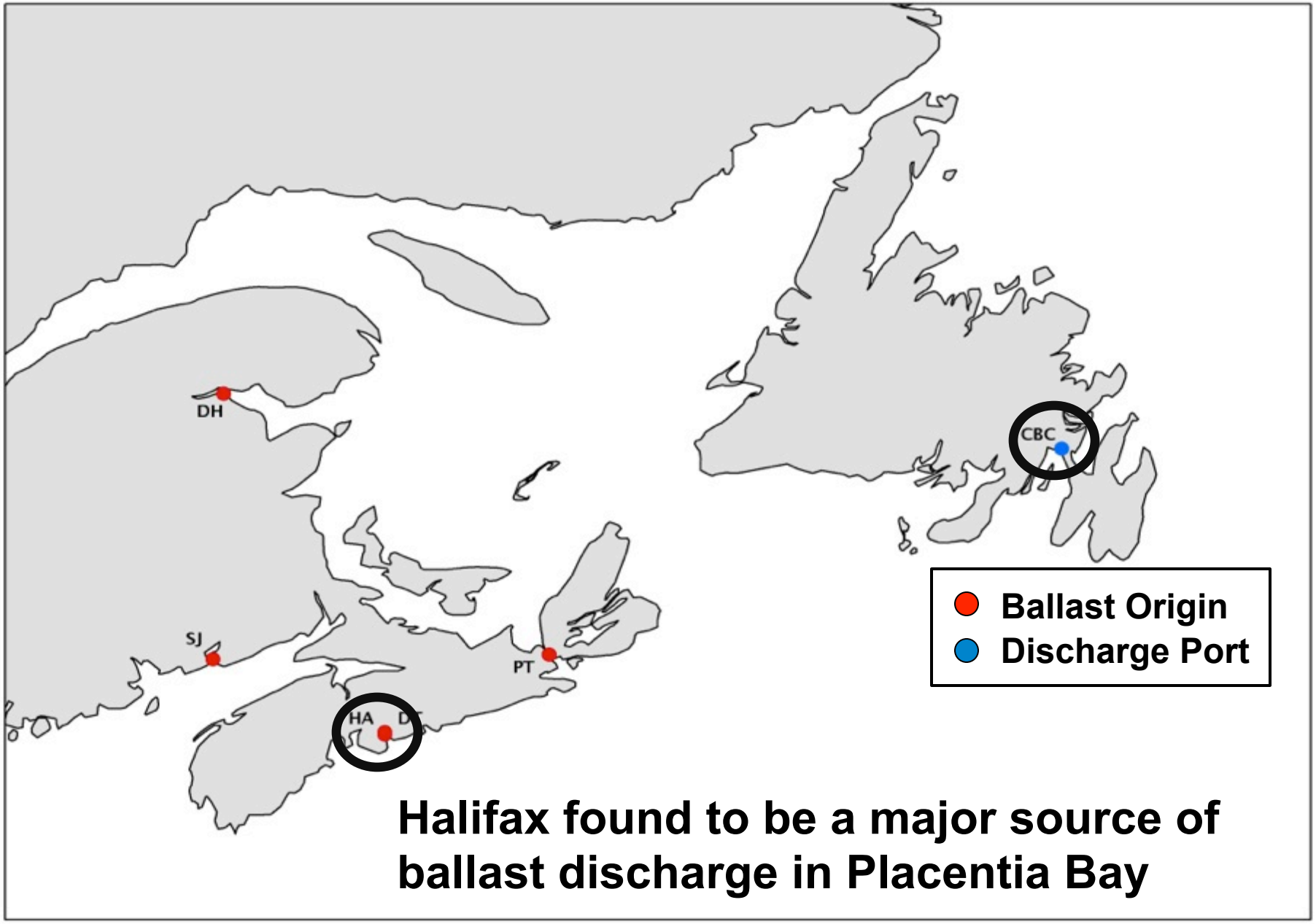
Placentia Bay populations (especially CBC) are spatially most closely related to populations in the central/western Scotian shelf (e.g., Halifax)

Microsatellite data results



Shows admixture of two major genotypes (southern & northern) in Newfoundland *Carcinus* populations; most similar to central/western Scotian shelf

Shipping data



Conclusions

Using molecular, demographic, and shipping data, we determined:

- **Vector: ballast-carrying ships --** clear evidence linking Nova Scotia, e.g. Halifax, to Come by Chance, Placentia Bay
- **Source: central/western Scotian shelf --** admixture of southern & northern genotypes in NS and also in NFLD allowed fairly precise pinpointing of source region)
- **Timing: ~2002 --** via demographic and molecular data

Significance

- *Carcinus* overcame considerable natural barriers to invade Newfoundland via anthropogenic transport.

- Non-native populations can be important secondary sources of introduction especially when aided by human transport.

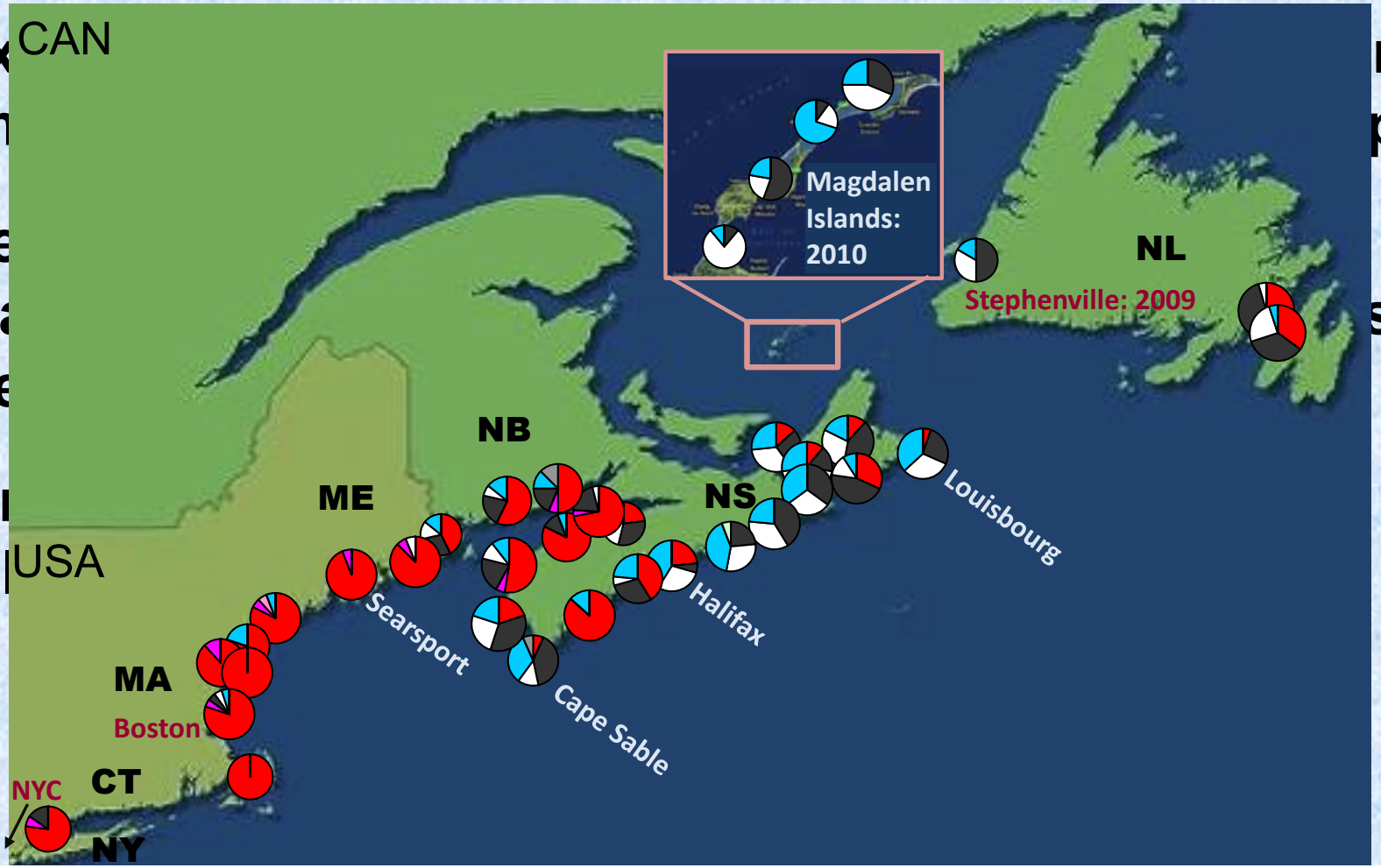
- Eradication in Placentia Bay may be difficult (2008: ~350,000 individuals harvested): risk to other NFLD populations → prevention of the vector is key.

Overall Conclusions

- Green crab had two major introduction events to the western Atlantic: (1) historical introduction (early 1800s) to mid-Atlantic USA and (2) a recent (~1990), cryptic introduction to eastern Nova Scotia
- The new introduction carried over several new genotypes – these may be more cold tolerant?
- The dynamic nature of the system has resulted in admixture zone shifting both southwestwards (along prevailing currents) and northeastwards (via new crabs in eastern Nova Scotia)
- Secondary introduction to Newfoundland as a result of shipping movements and ballast water.

Future Directions

- Continue to track the spread of the new genotypes throughout the western Atlantic. Recently collected new samples this past summer (2013).
- Ex rs (m p
- Re – ma s we
- Fi to




THANK YOU!