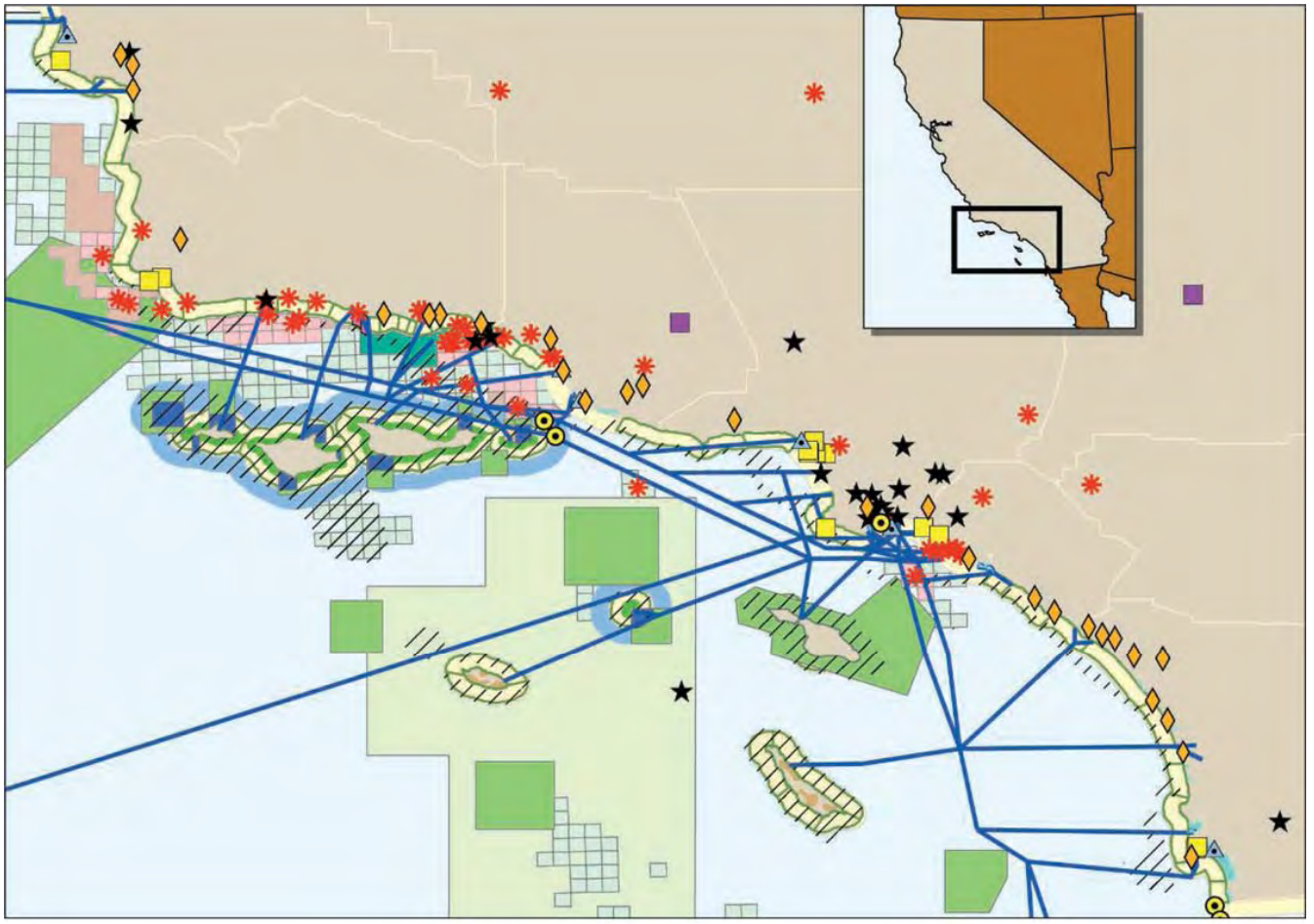
“Fragmentation of management for human uses of marine areas”

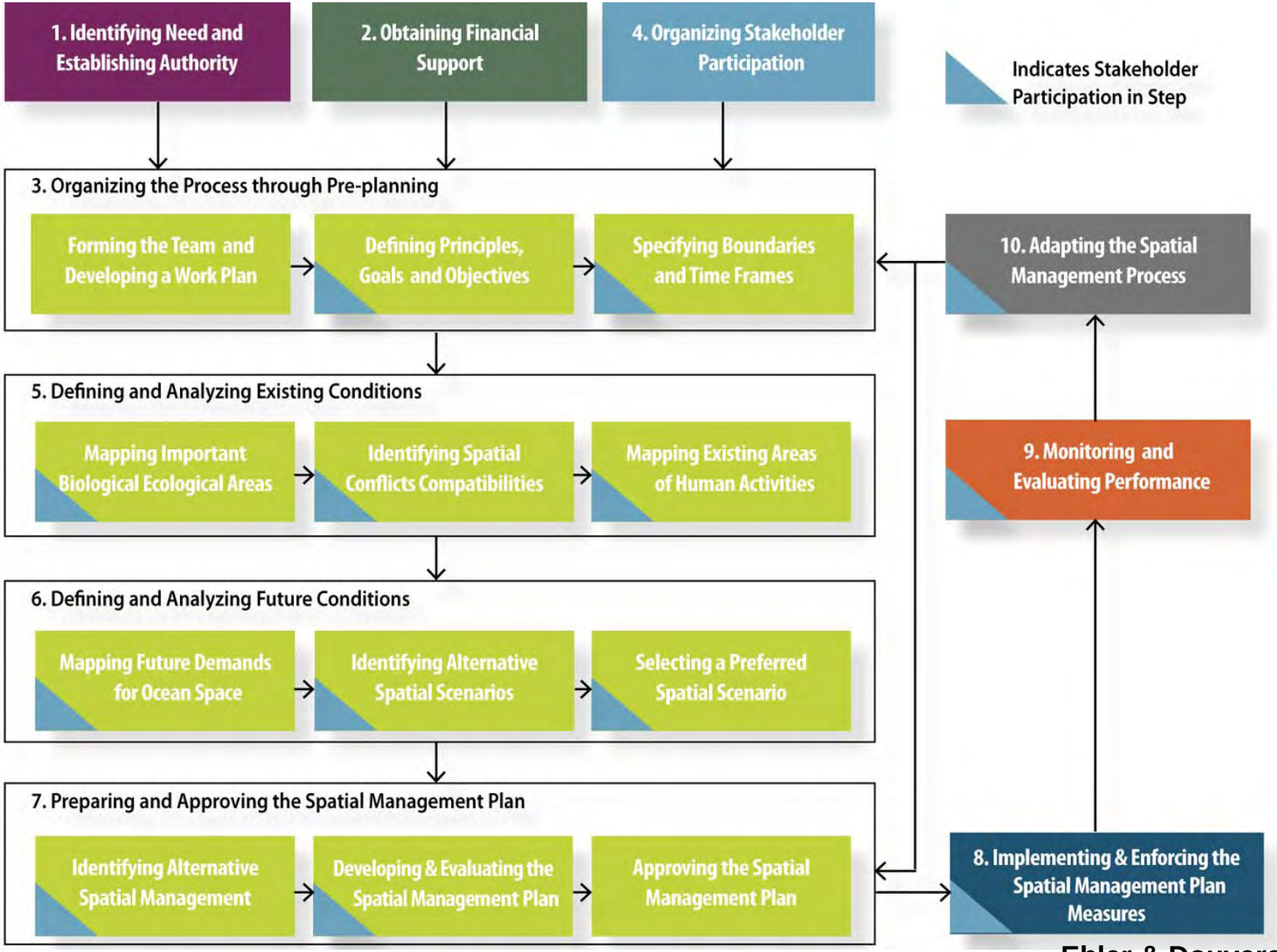



**Crowder et al. 2006**

# Marine Spatial Planning (MSP) and Non-Indigenous Species (NIS)

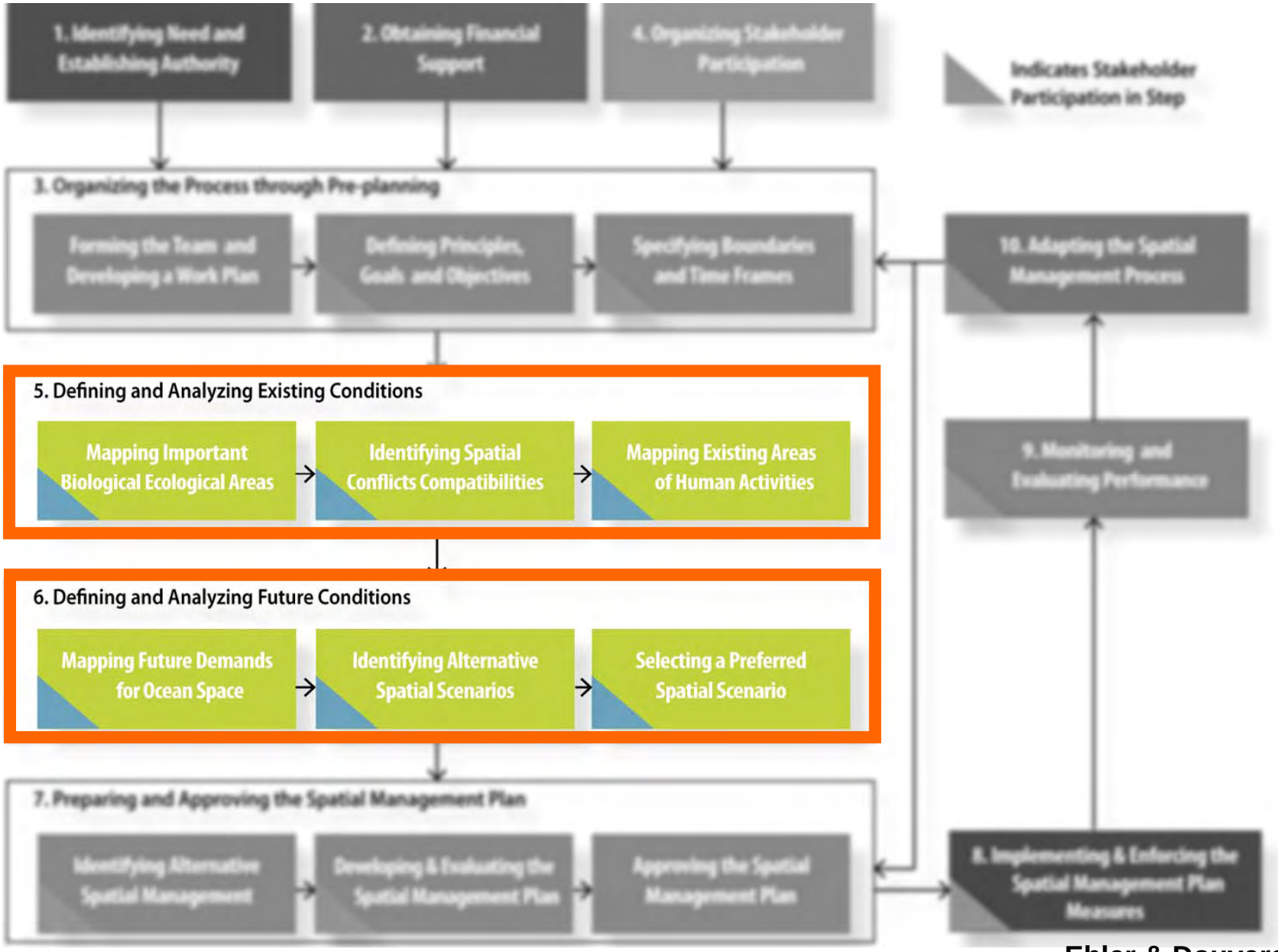
- Not a lot of marine spatial planning papers
- A handful mention NIS as a factor contributing to coastal and estuarine decline (e.g., Crowder et al. 2006; Halpern et al. 2008)
- None mention how to integrate NIS in MSP

# A Step-by-Step Approach to Marine Spatial Planning




Ehler & Douvere 2009

# A Step-by-Step Approach to Marine Spatial Planning




Ehler & Douvere 2009

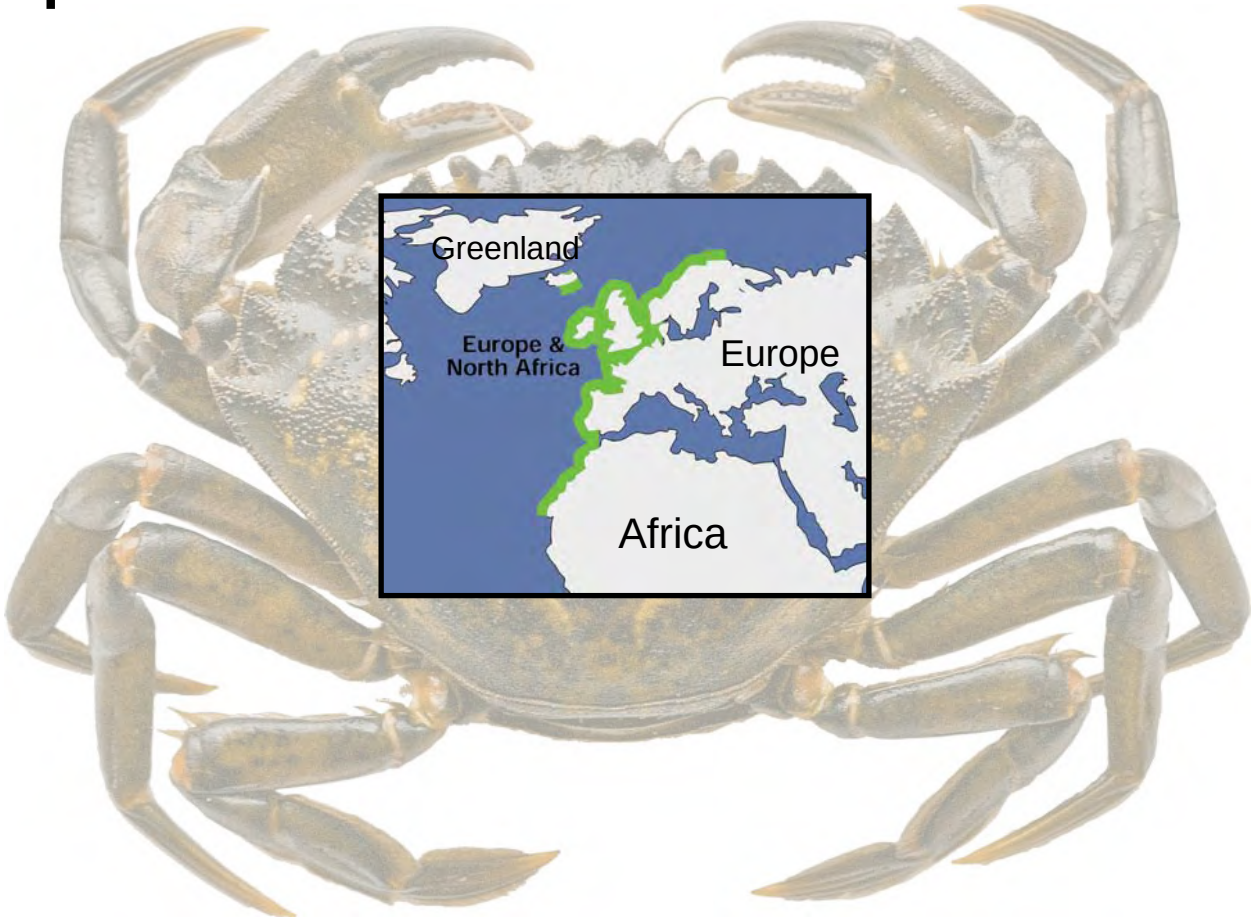
# Predicting the northward range expansion of non-indigenous European green crab (*Carcinus maenas*) along the west coast of North America: implications for marine spatial planning

Blake E. Feist[1], Carolina Parada[2], Kevin See[3], & Jennifer Ruesink[3]

[1]National Oceanic & Atmospheric Administration
National Marine Fisheries Service
NW Fisheries Science Center, Seattle, WA, USA
[2]University of Washington, School of Aquatic and Fishery Sciences, Seattle, WA, USA
[1]University of Washington, Department of Biology, Seattle, WA, USA

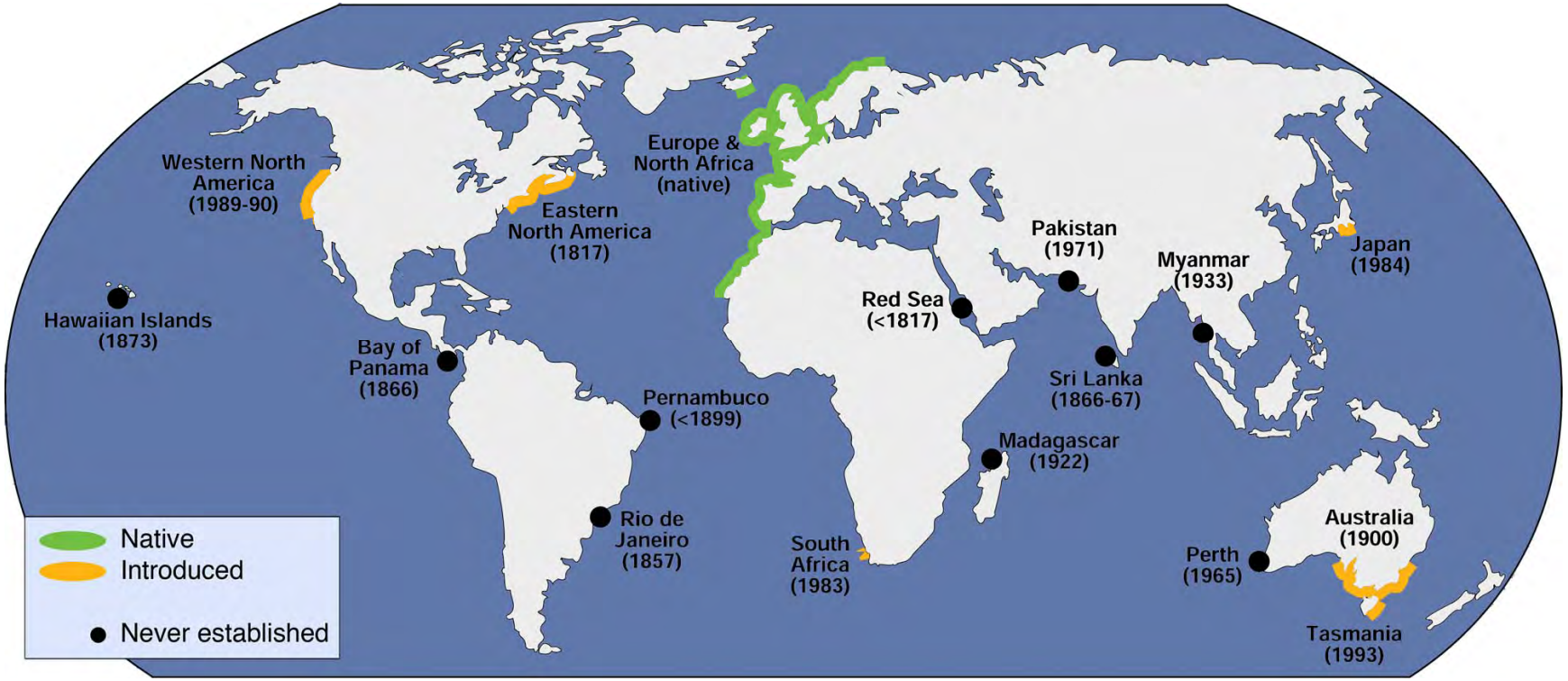
# European Green Crab

## European Green Crab Native Range




*Carcinus maenas* (Linnaeus, 1758)

# European Green Crab Invasion




Carlton & Cohen 2003

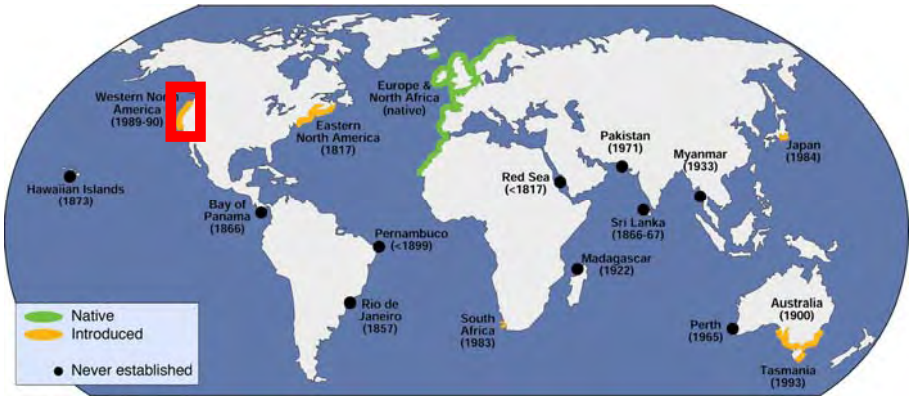
# Who Cares?

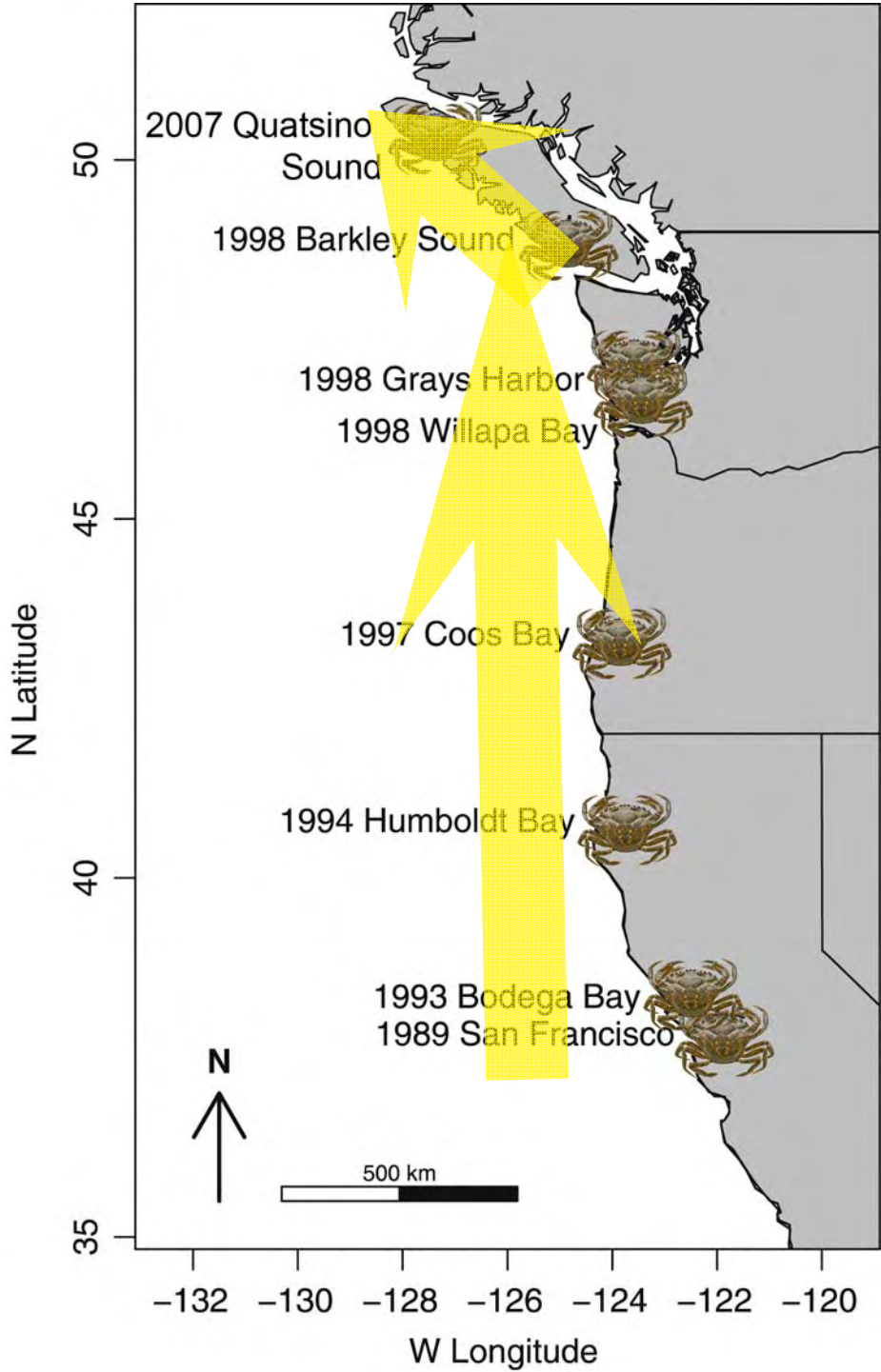
- Coastal Northwest Atlantic
  - Decline of the soft-shell clam (*Mya arenaria*, Glude 1955)
  - Negatively impact scallops, quahogs and other bivalves (Grosholz and Ruiz 2002)
  - Native rock crab, *Cancer irroratus* (Miron et al. 2005)

# Who Cares?

- Coastal Northeast Pacific
  - Native bivalves and native crabs
  - Enormous declines in abundance
    - native clams (*Nutricola tantilla* and *N. confusa*)
    - native shore crab (*Hemigrapsus oregonensis*, Grosholz et al. 2000)
  - Olympia oyster (*Ostrea conchaphila*, (Palacios and Ferraro 2003)

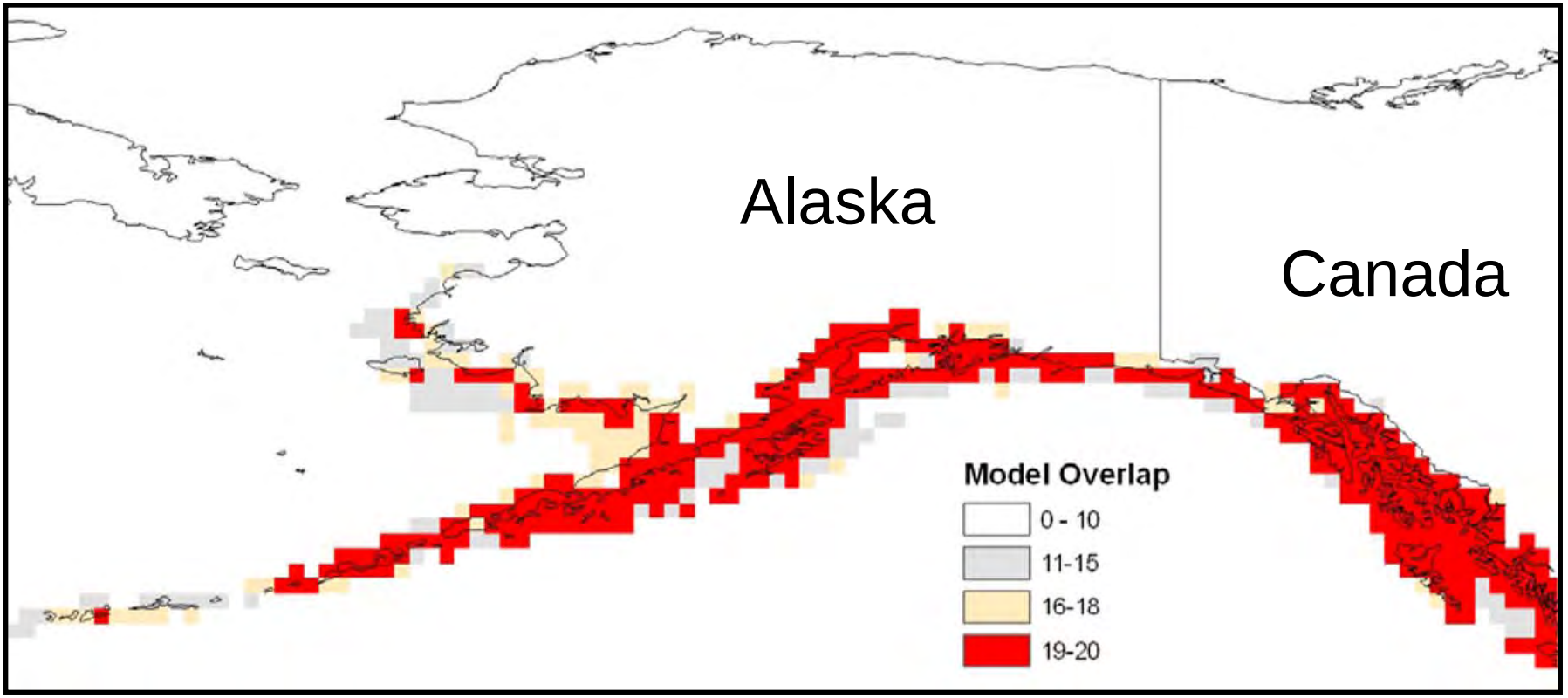
# Northward Advance along West Coast of the USA & Canada




**Gillespie et al. 2008; See & Feist 2009**

# Ecological Niche Modeling Forecasts using GARP




- **Ambient air temperature**
- **Sea surface temperature**
- **Basin runoff**
- **Water depth**
- **Salinity**
- **Chlorophyll-a**
- **Tidal amplitude**

**de Rivera et al. 2007**

# Ecological Niche Modeling

"can provide a powerful tool to assess the likelihood of nonindigenous species establishing in an area, **once it has been transported** to a region via anthropogenic or natural dispersal (Peterson & Vieglais 2001, Peterson 2003)"

**de Rivera et al. 2007**

# Objectives

- Explore the dynamics of larval dispersal in coastal waters of the northeast Pacific
- Predict future range expansion

# Questions

- How does time and location of release affect larval settlement patterns?
- How far do larvae disperse, what direction do they travel, and how large of an area do they disperse to?
- Are areas north of Vancouver Island at risk of experiencing larvae?
- Can this modeling approach be applied to MSP?

# Approach

- Develop an individual based model (IBM) of larval green crab life history
- Couple IBM to existing ocean circulation models to predict larval dispersal and incorporate the effects of temperature on larval development


13 Release Sites
1994 - 2004
Canada
Gulf of Alaska
Riou
Surge
Three Entrance
Fish Egg Is
Nehenta
P Simpson
Matheson
Pruth
San Josef
Cypress
Willapa
Humboldt
San Francisco
United
1207 km
© 2009 Europa Technologies
© 2009 Google
© 2009 Tele Atlas
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
©2009 Google


Canada
Riou
Gulf of Alaska
Surge
Three Entrance
Fish Egg Is
Nehenta
P Simpson
Matheson
Pruth
San Josef
Cypress
Willapa
Humboldt
San Francisco
Site Selection:
Existing
© 2009 Europa Technologies
© 2009 Google
© 2009 Tele Atlas
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
1207 km
©2009 Google


# Site Selection: Potential

- Protected & semi-protected wave exposures
- Mud or sand flats
- Eelgrass beds
- Fringing coastal salt marsh vegetation

ShoreZone

Harney 2007

# Regional Ocean Modeling System (ROMS)

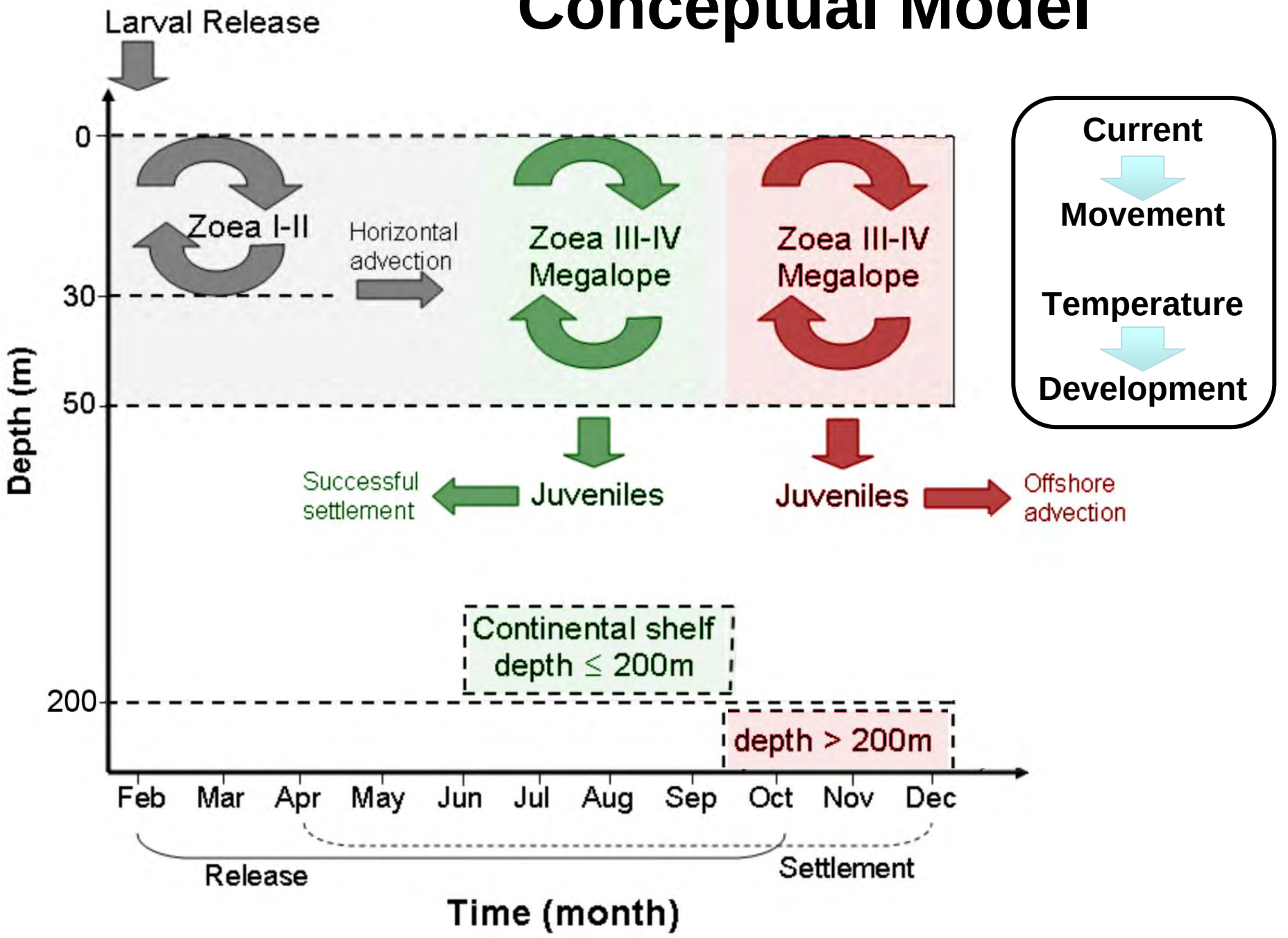
## Physical Oceanography

- Haidvogel et al. 2000
- Marchesiello et al. 2003
- Shchepetkin & McWilliams 2003
- Moore et al. 2004
- Shchepetkin & McWilliams 2005
- Warner et al. 2005
- Blaas et al. 2007
- Di Lorenzo et al. 2007
- Vikebo et al. 2007
- Centurioni et al. 2008
- Haidvogel et al. 2008

## Larval Modeling

- Mullon et al. 2003
- Kone et al. 2005
- Svendsen et al. 2007
- Vikebo et al. 2007
- Brochier et al. 2008
- Parada et al. 2008
- Marta-Almeida et al. 2008
- Lett et al. 2008

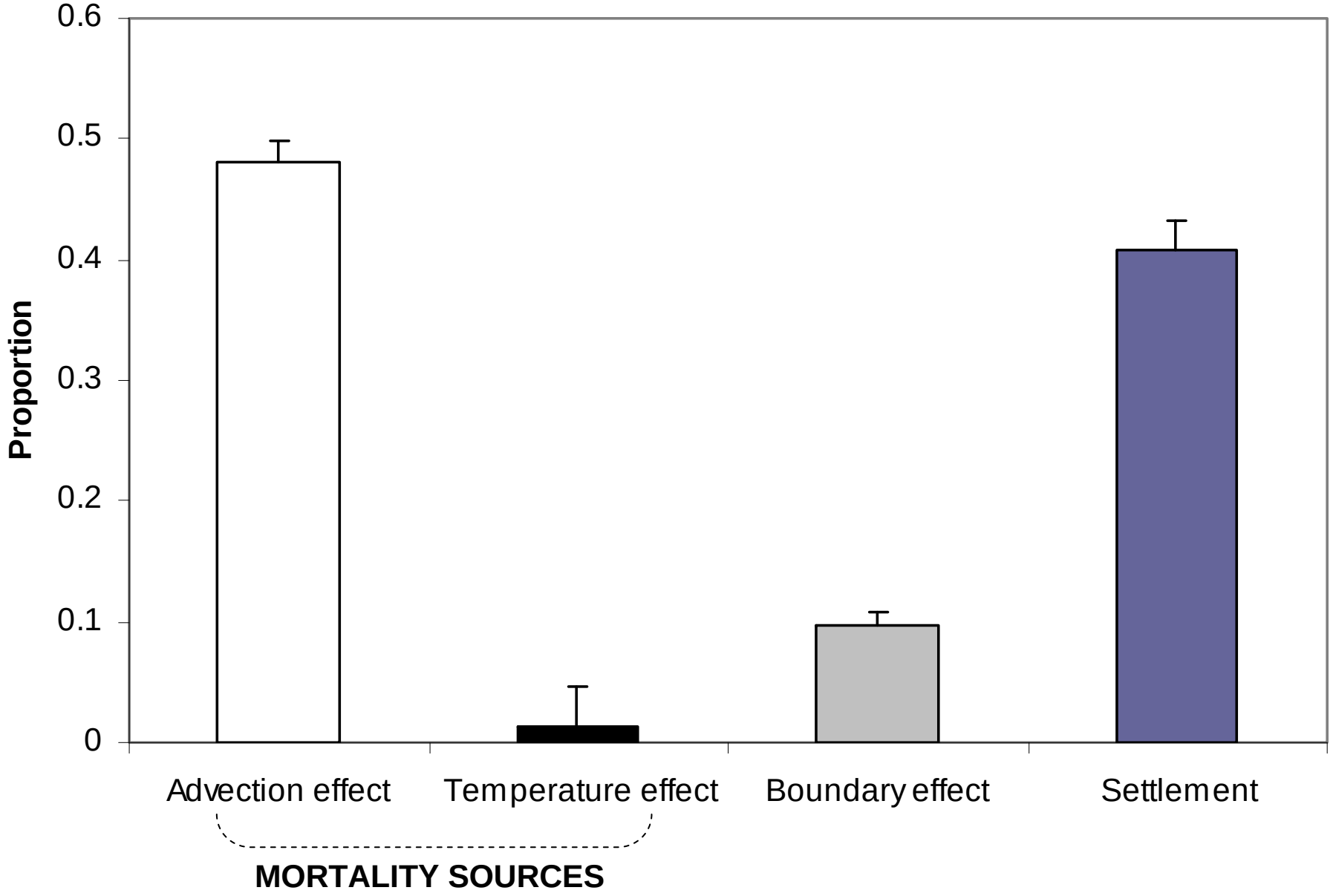
# Conceptual Model



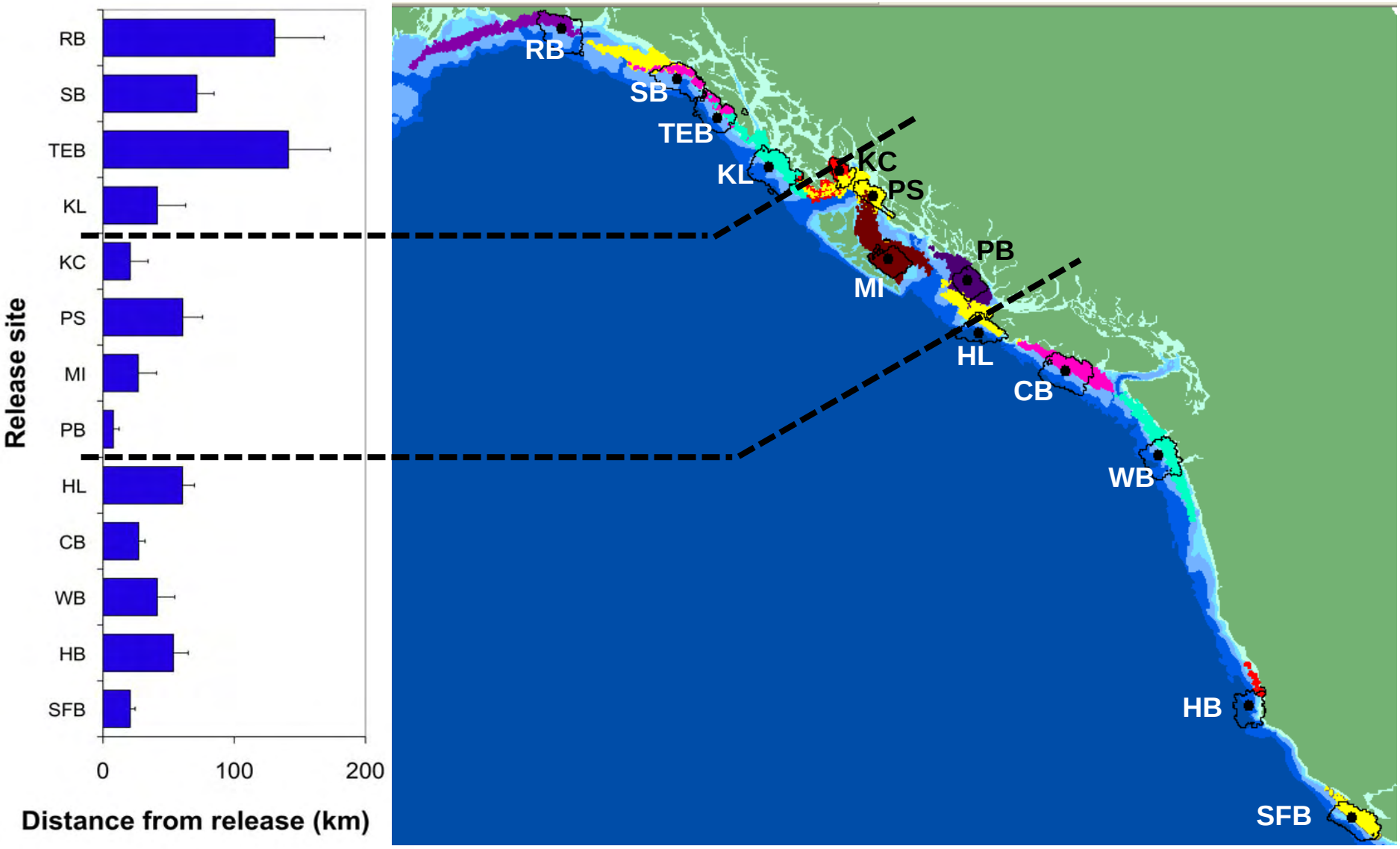
# Fate Categories

- **Advection effect**: >200 m water depth
- **Temperature effect**: exposed to low temperature for too long
- **Boundary effect**: come into contact with boundary (“coast”)
- **Settlement**: $\leq$ 200m water depth (continental shelf)

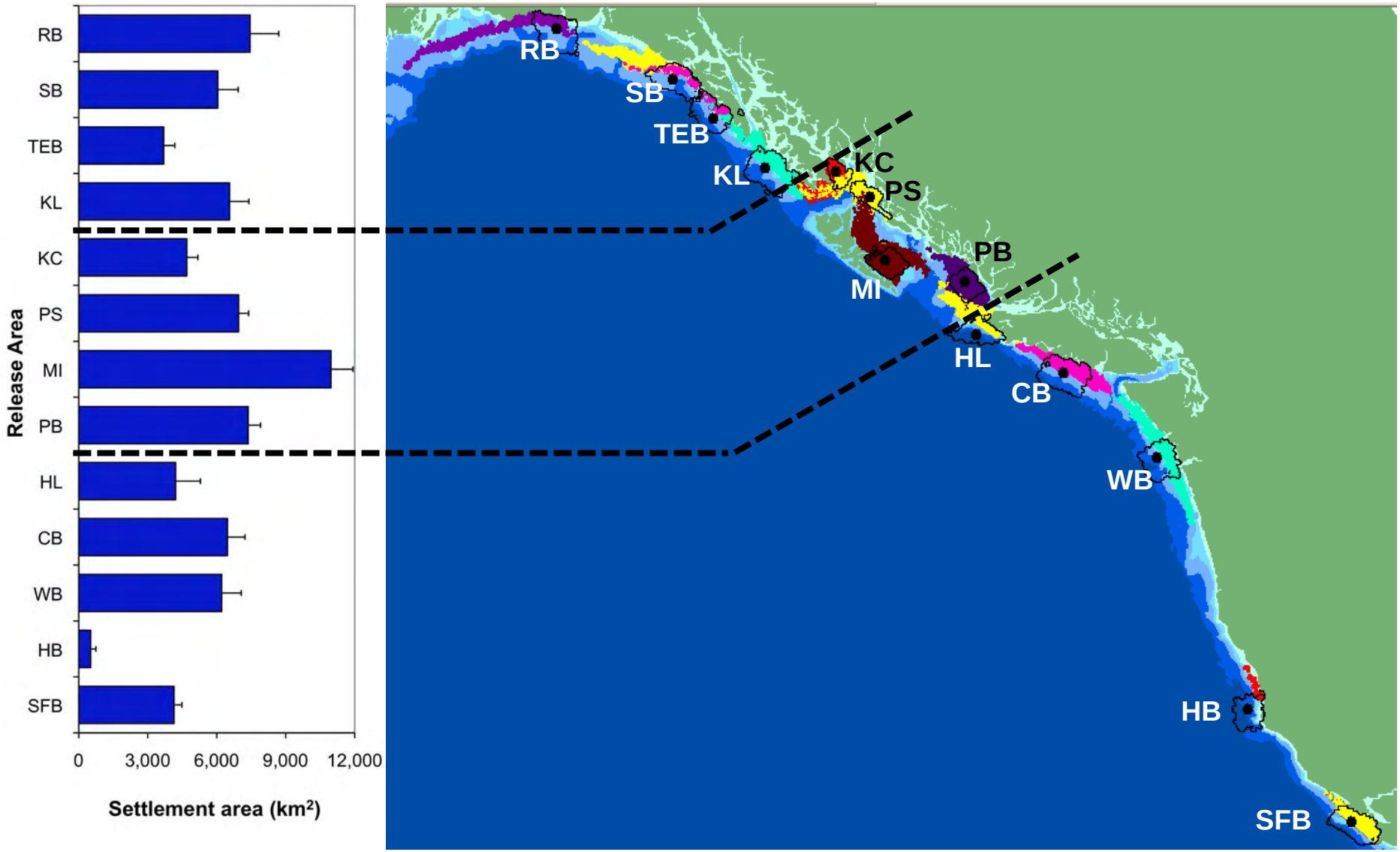
# Overall Patterns

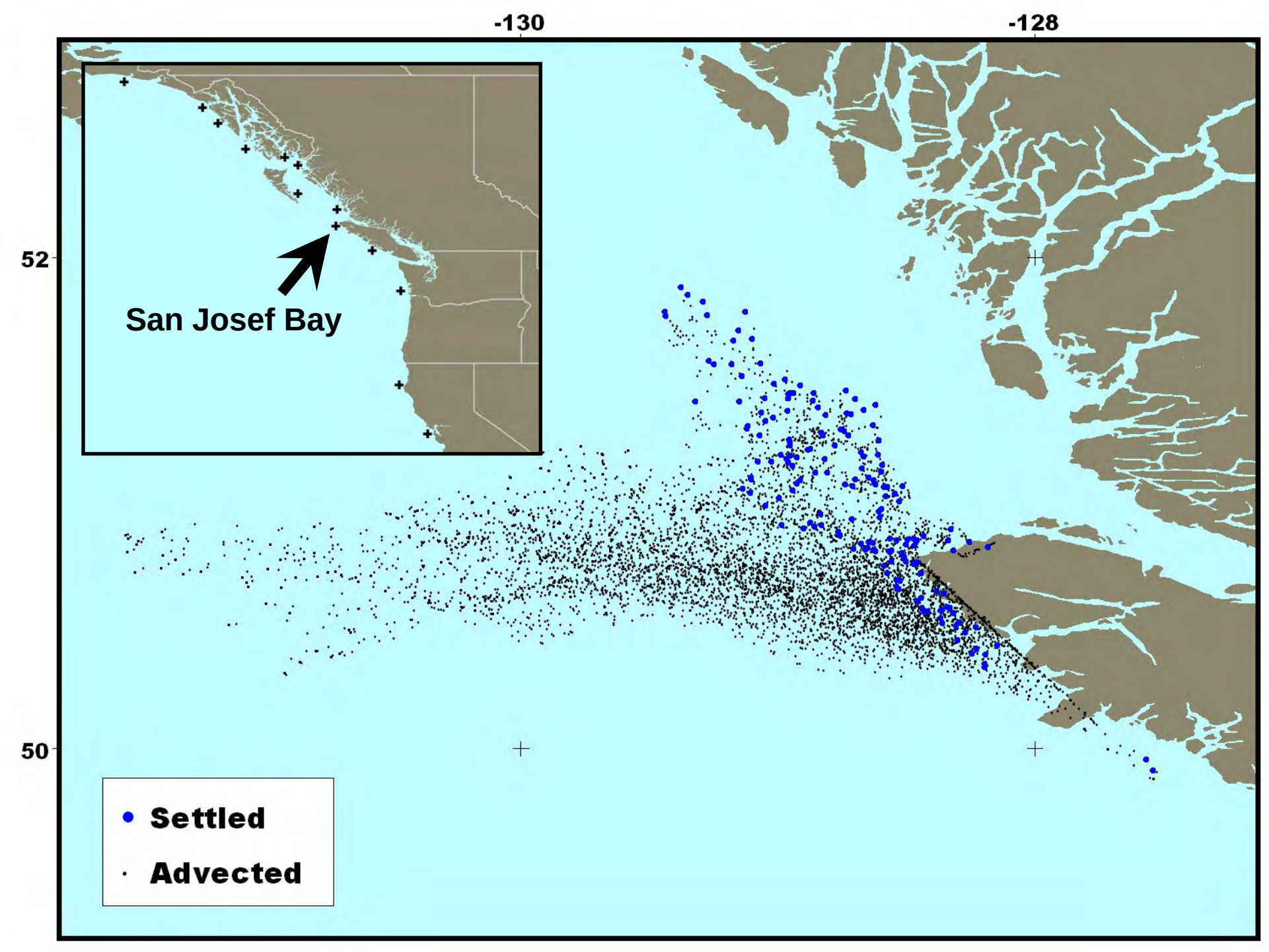


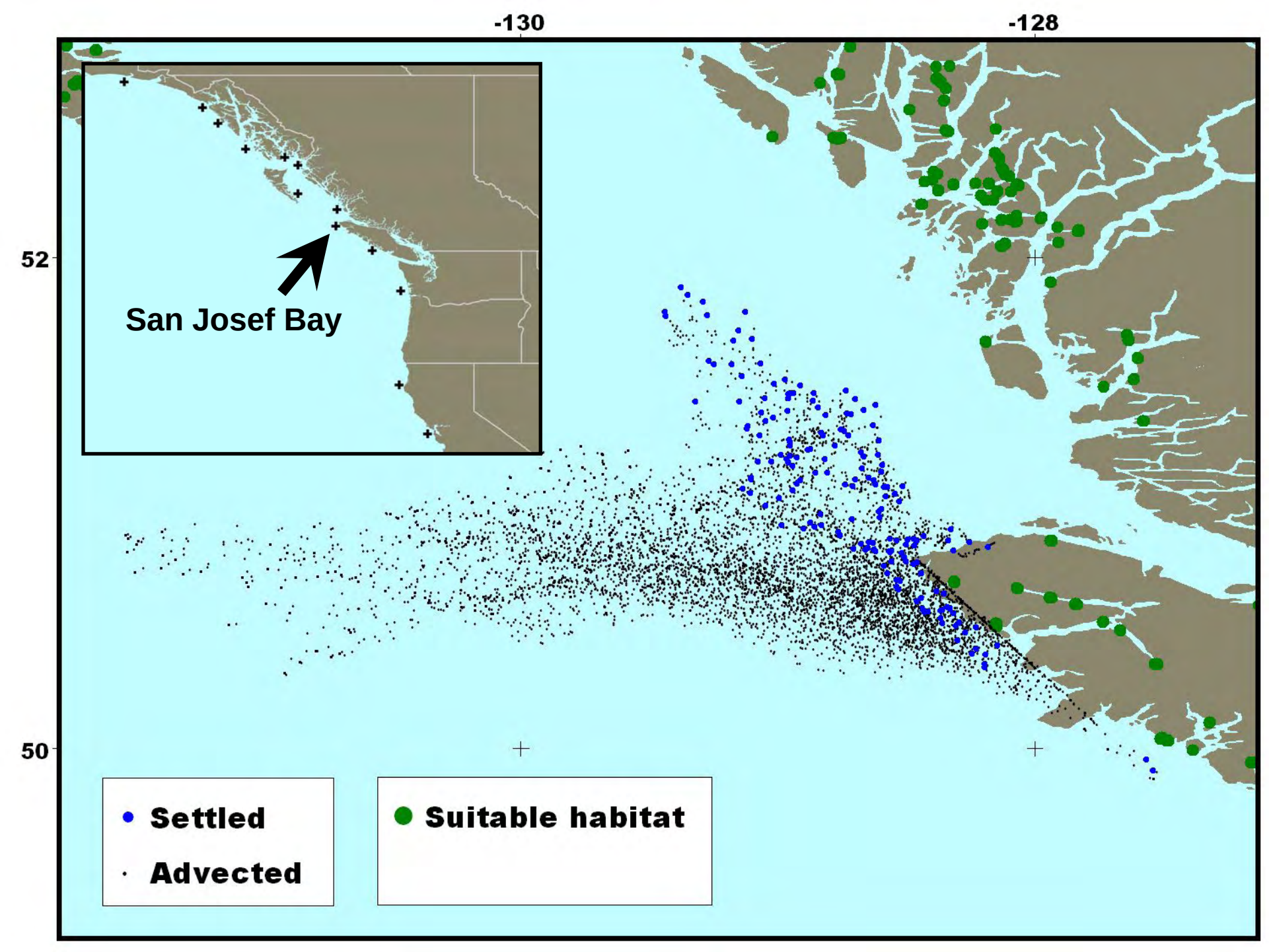
# Distance Transported

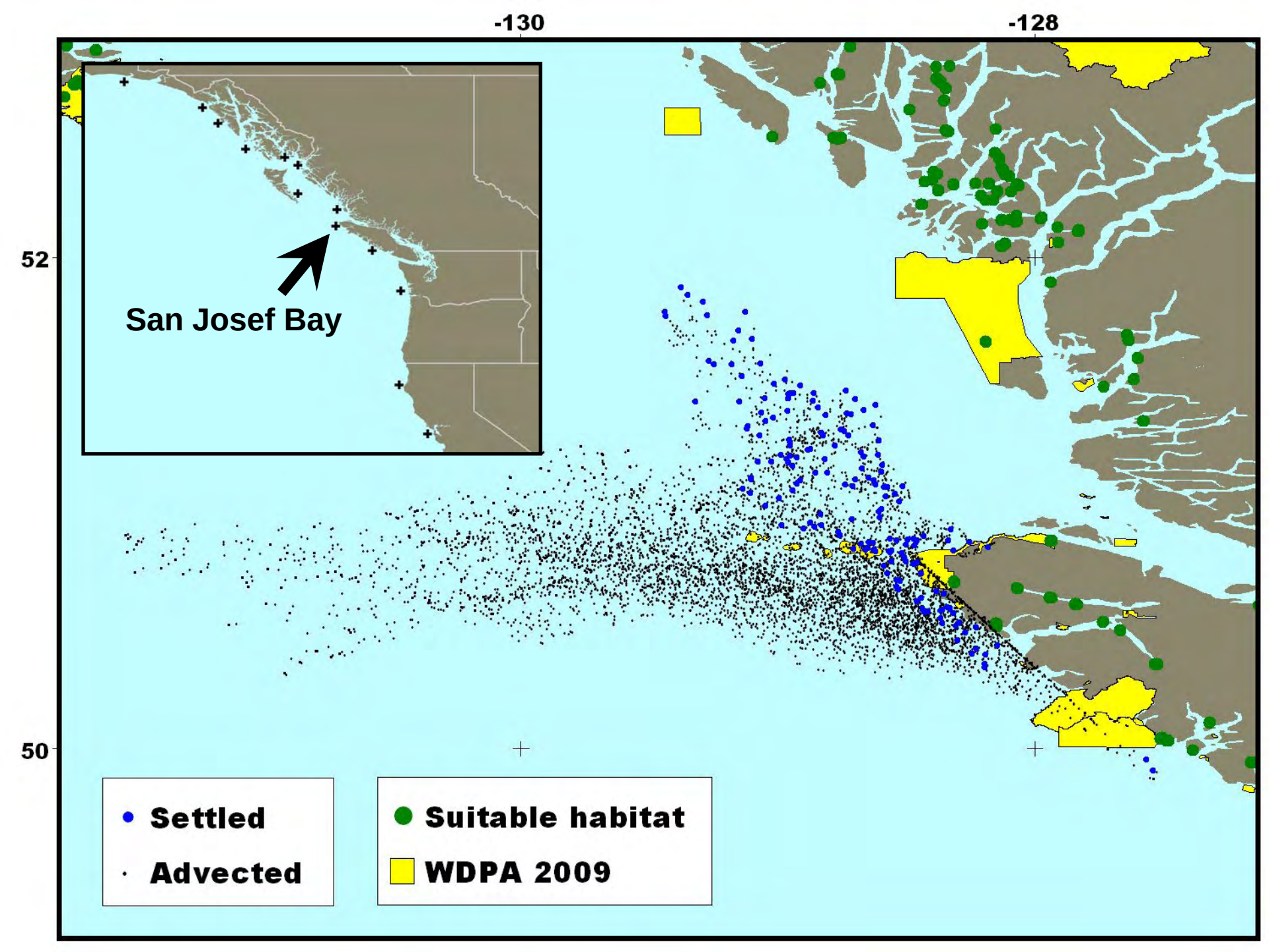


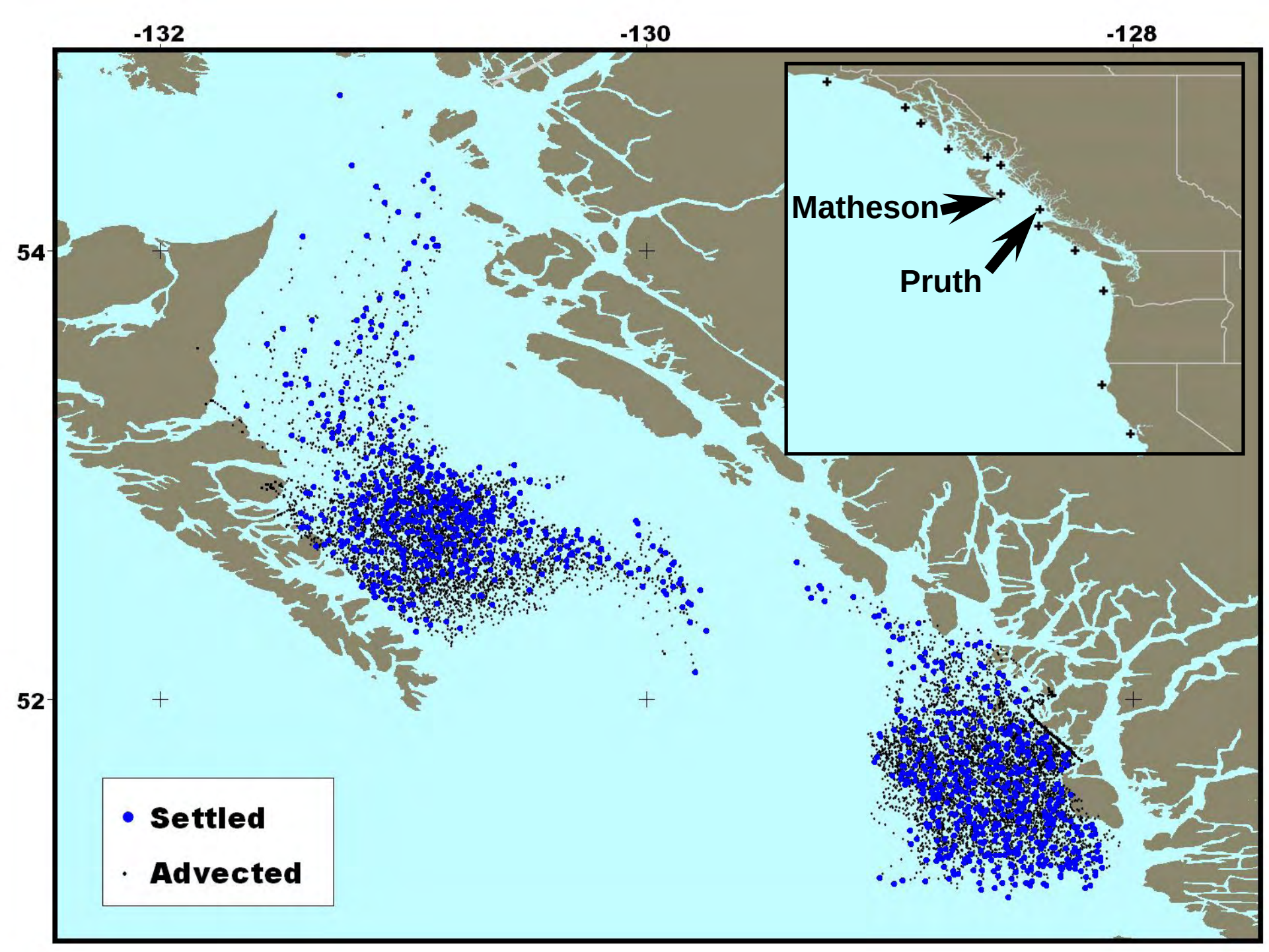
# Settlement Area Size

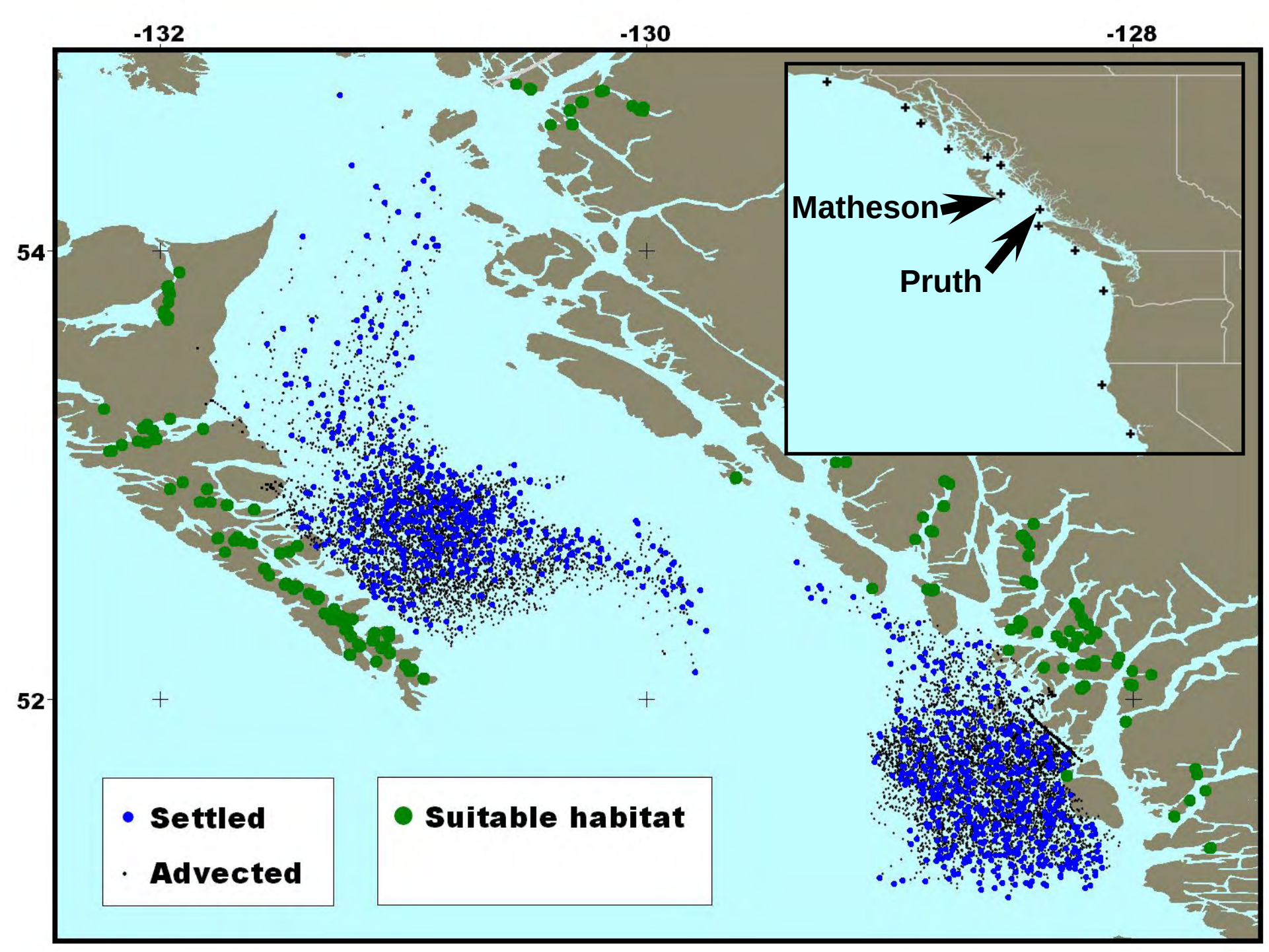


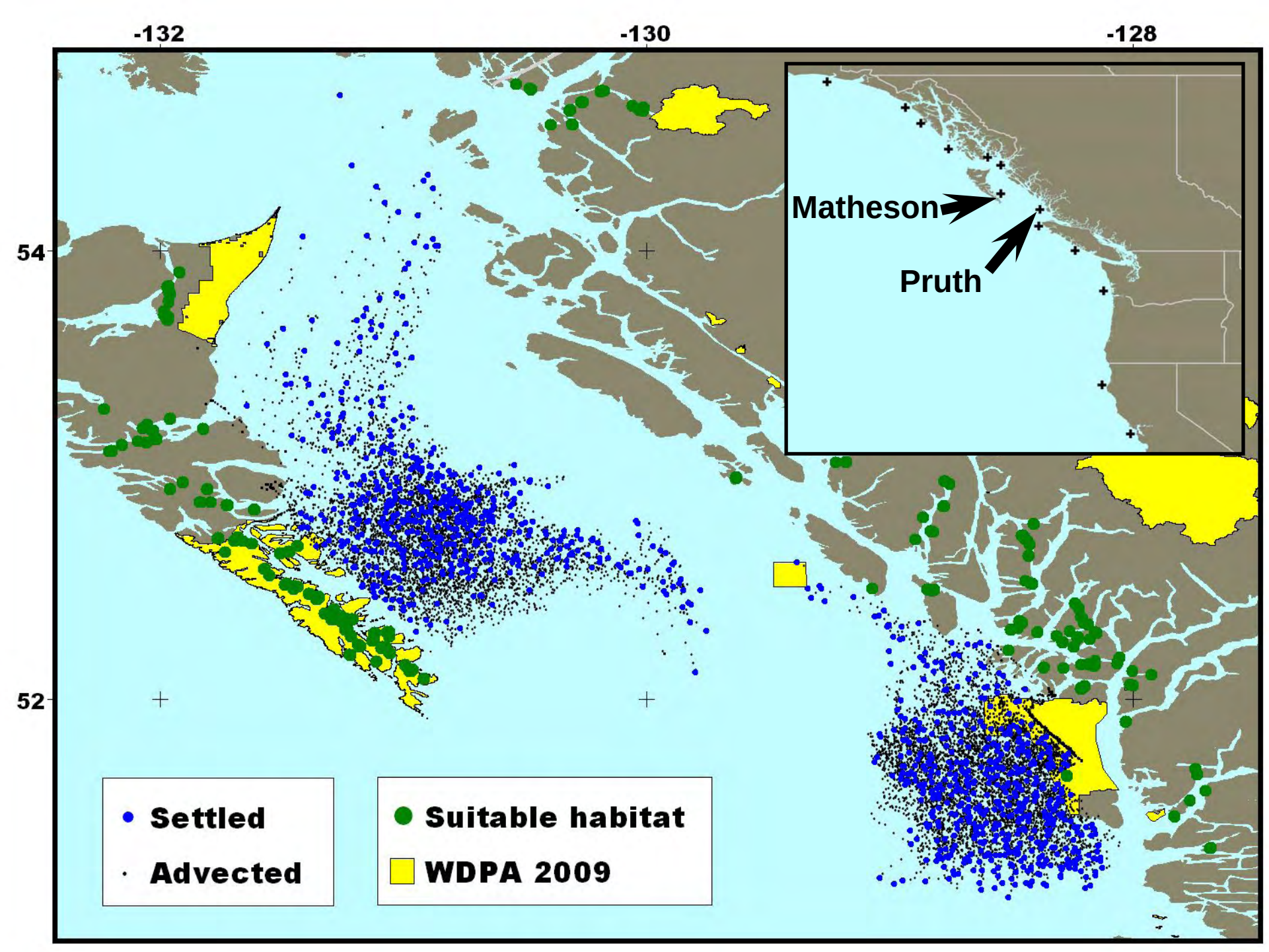

-130
-128
52
50
San Josef Bay
Settled
Advected


-130
-128
52
50
San Josef Bay
Settled
Advected
Suitable habitat


-130
-128
52
50
San Josef Bay
Settled
Advected
Suitable habitat
WDPA 2009


-132
-130
-128
54
52
Matheson
Pruth
Settled
Advected


-132
-130
-128
54
52
Matheson
Pruth
Settled
Advected
Suitable habitat


-132
-130
-128
54
52
Matheson
Pruth
Settled
Advected
Suitable habitat
WDPA 2009

# Summary

- Strong effect of advection in the system for all years, which is dependent on the **spatial structure of the reproductive population** (i.e., release area matters)
- Temperature effect (on mortality) is **very low**
- Considerable variability between sites with respect to:
  - **Net transport distance**
  - **Size of area**

# Conclusions

- Areas north of Vancouver Island, along the coast of British Columbia and Southeast Alaska, are likely to experience green crab larvae in the future
- Predictions can be used to prioritize monitoring sites
- Application of technique is useful for MSP

# Acknowledgments


- Funding
  - NOAA Aquatic Invasive Species Program
  - Mathematical Biology Program, NWFSC
- Collaborators
  - P. Sean McDonald (University of Washington)
  - Jodi Harney (Coastal and Ocean Resources, Inc.)
  - Linda Shaw (NOAA/NMFS Alaska Region)
  - Graham Gillespie (DFO Canada)
  - Al Hermann (NOAA - PMEL)
  - Sarah Hinckley (NOAA – PMEL)
  - David Armstrong (University of Washington)

# Future Work

- Summarize output at a finer grain
- Alter settlement rules
- Sensitivity analysis on model scenarios
- Couple with existing habitat suitability mapping projects (ShoreZone and GARP) to assist with early detection and monitoring