D. Griffay

INTERNATIONAL PACIFIC HALIBUT COMMISSION

Migration and population genetics research at IPHC

(T. Loher, L. Sadorus, J. Planas)

Agenda item 8.3
IPHC-2019-SRB014-09

SRB request

36. The SRB **NOTED** that the IPHC Secretariat is following up on the SRB suggestion to hire a life history modeller and that this action is subject to broader IPHC budgetary considerations.

7.1 Biological research updates

37. The SRB **NOTED** paper IPHC-2018-SRB013-07 which provided an update on the progress of the Biological and Ecosystem Science research program.

38. The SRB **AGREED** that the primary biological research activities at the IPHC should continue to follow Commission objectives, and are identified and described in the 5-Year Research Plan for the period 2017-21, including focusing on studies of migration, reproduction, growth, discard mortality and genetics.

39. The SRB **NOTED** that the biological research activities should help to define hypotheses associated with processes that affect plausible states of nature for the assessment and MSE process (e.g. climate effects on growth and recruitment).

40. The SRB **NOTED** that the IPHC Secretariat has been responsive in focusing research outcomes to management objectives required for stock assessment and MSE work, and that this work is leading to peer-reviewed journal publications.

41. The SRB **REQUESTED** that specific research topics, analysis and results be addressed in depth at subsequent SRB meetings, and that at SRB014, a presentation focused on population genetics and migration as they relate to the stock assessment and MSE work be provided. For example, how does this work identify alternative hypotheses for movement and population structure that can be considered in the MSE process and the stock assessment.

Outline

1) **Structure and Frameworks for recent connectivity research**
2) **Summary of major Findings from that work**
3) **A Model for project selection**
   - Identification of products and deliverables
   - Quantification of research plans
4) **Some Topics of current interest**
5) **Incorporation of genetics into migration-related research**

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- Ontogenic

C) Fine-scale = intrannual / individual-based

- Diurnal, sub-diurnal, seasonal

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1) **Applied Fisheries Science**

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2) **Theoretical Ecology**

   - Producing parameters leading to the **better understanding** of population function in general terms

Framework #1: Applied Science

Scale-dependent Processes and Management Actions

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Scale-dependent Processes and Management Actions

A) Large-scale: intergenerational / population-level

- How is the stock structurally organized, from a population-level perspective?
- Vaguely: Does this match our underlying management design?
- Specifically: Would we need additional Regulatory Areas to accurately encompass all functional population components?

For example, if Area 4B is composed of two genetically-distinct subpopulations, should we create a new Reg Area west of Amchitka?

Framework #1: Applied Science

Scale-dependent Processes and Management Actions

B) Meso-scale: intragenerational / cohort-level

- Spatial recruitment patterns: where do “our” fish come from?
- Vaguely: To what degree does fishing mortality in one Area affect other(s)?
- Specifically: How “wrong” is it to apply a region’s U32 trawl-bycatch mortality to its directed longline yield, when we “know” that those fish would not have stayed in that region?

That is, where is that lost yield truly being felt?

Framework #1: Applied Science

Scale-dependent Processes and Management Actions

C) Fine-scale: intrannual / individual-based

- How does individual fish behavior interact with harvest strategy?
- Vaguely: Does seasonal migration redistribute fish in ways in which we do not understand?
- Specifically: To what extent does the distribution of fish as surveyed during summer (i.e., that which we simply call "stock distribution") reflect regional mean abundance integrated over nine- (or twelve-) month fishing seasons?

  That is, if we're looking to achieve a relatively constant SPR among all regulatory areas within a Biological Region, how far from our target(s) might we be (by Area) "knowing" that the fish are unlikely to be where we surveyed them if they're harvested prior to May or after September?

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- Often referred to as “metapopulation modeling”
  - except, not really … because extinction-recolonization dynamics are not the focus

- More appropriately: a form of “landscape ecology modelling”

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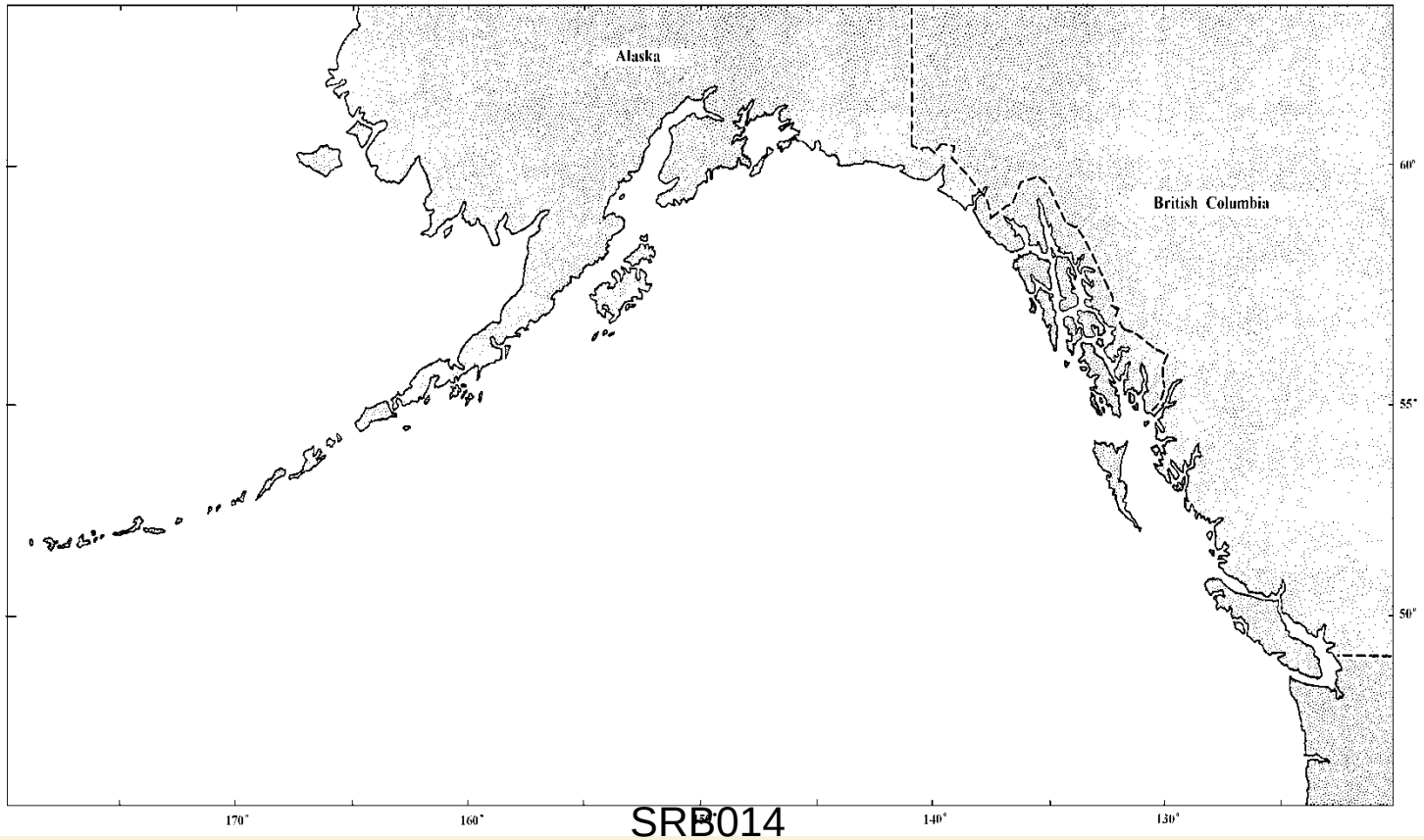

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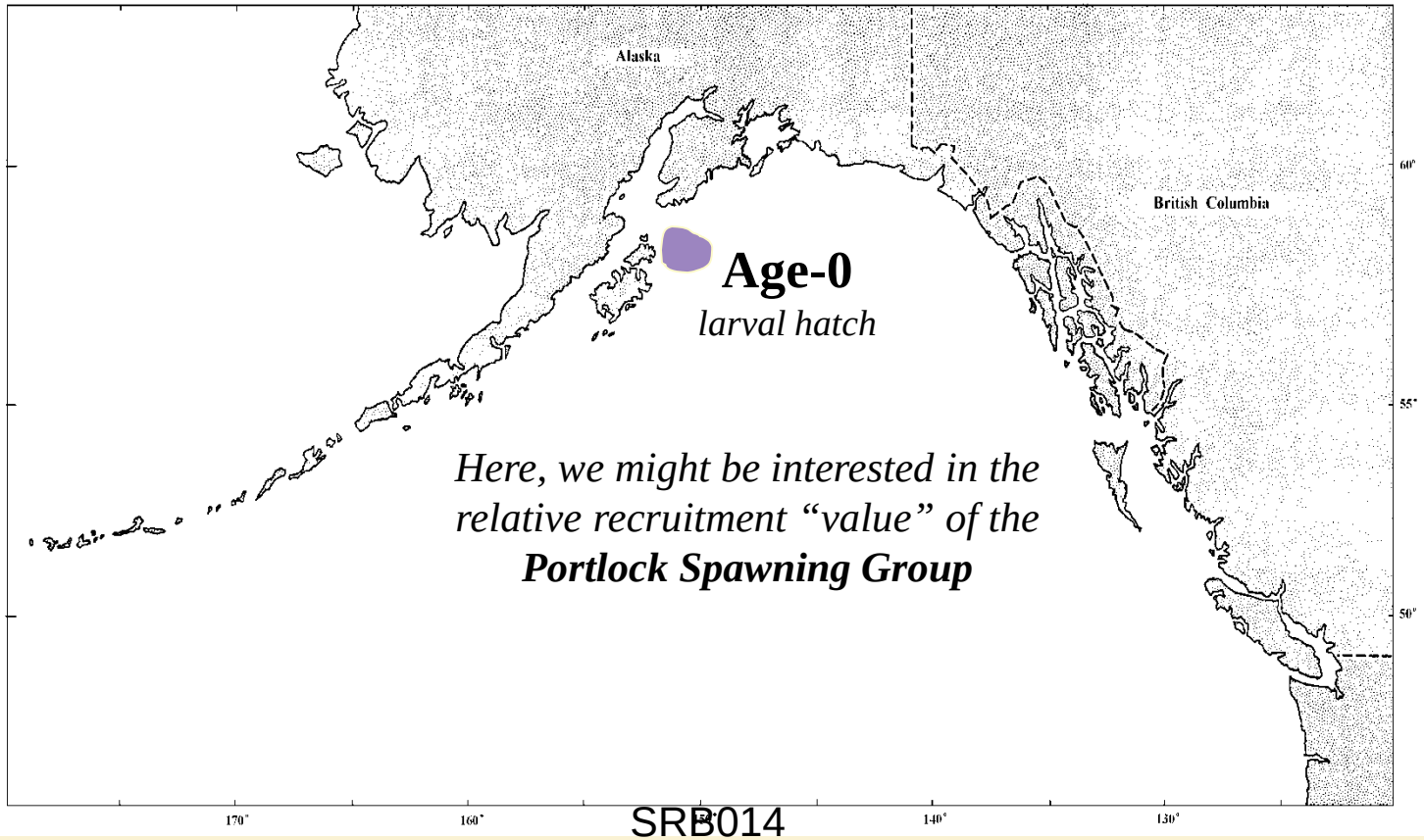

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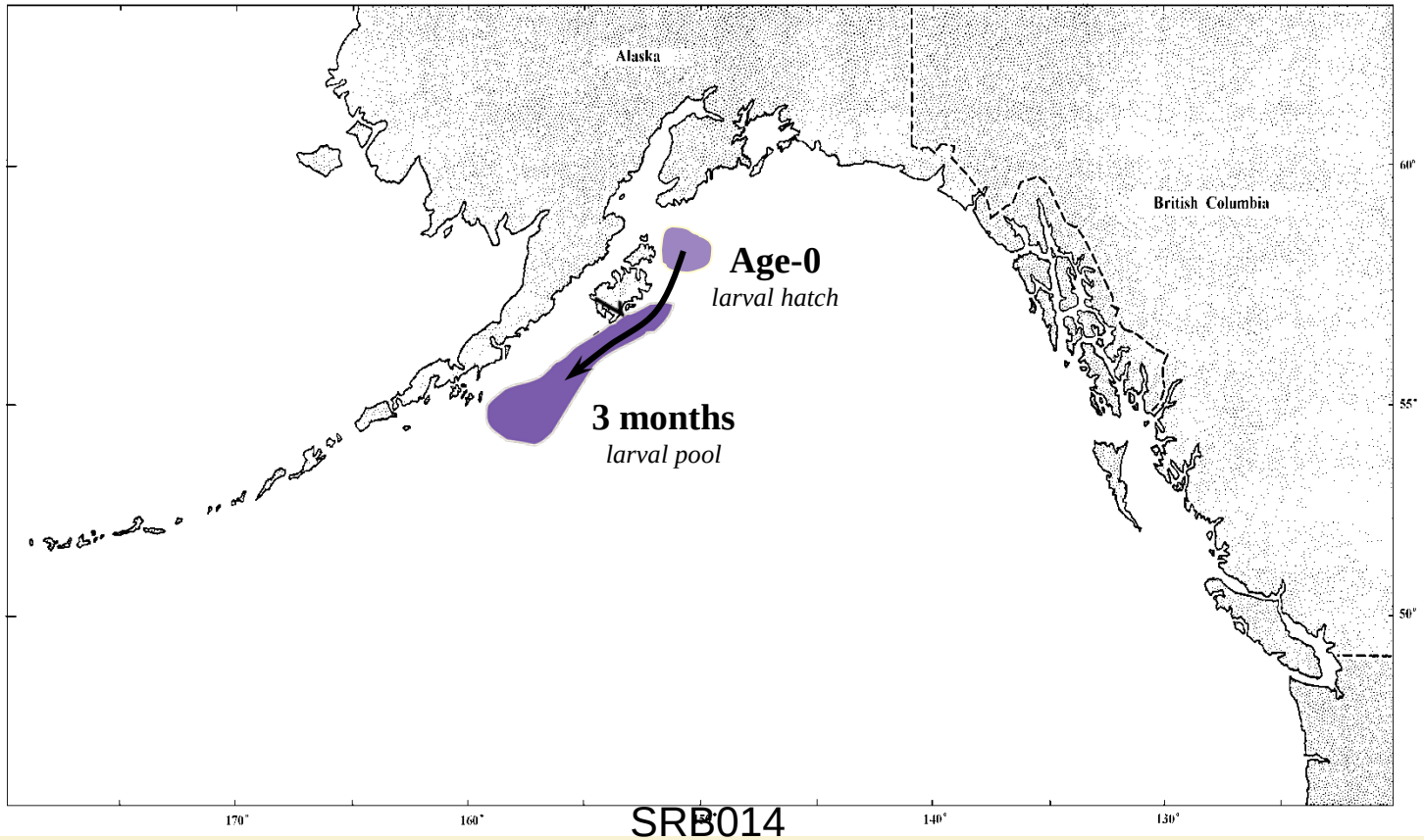

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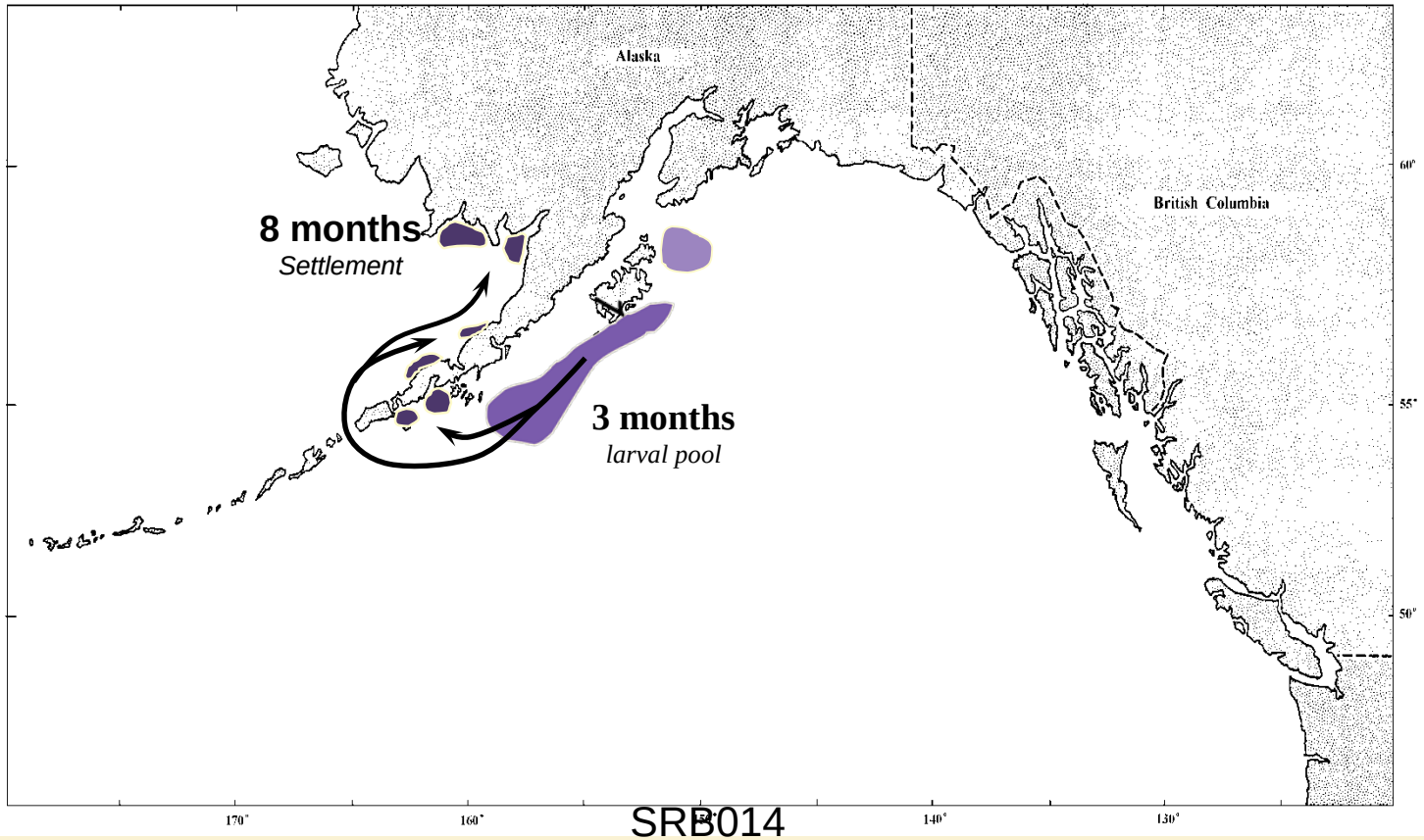

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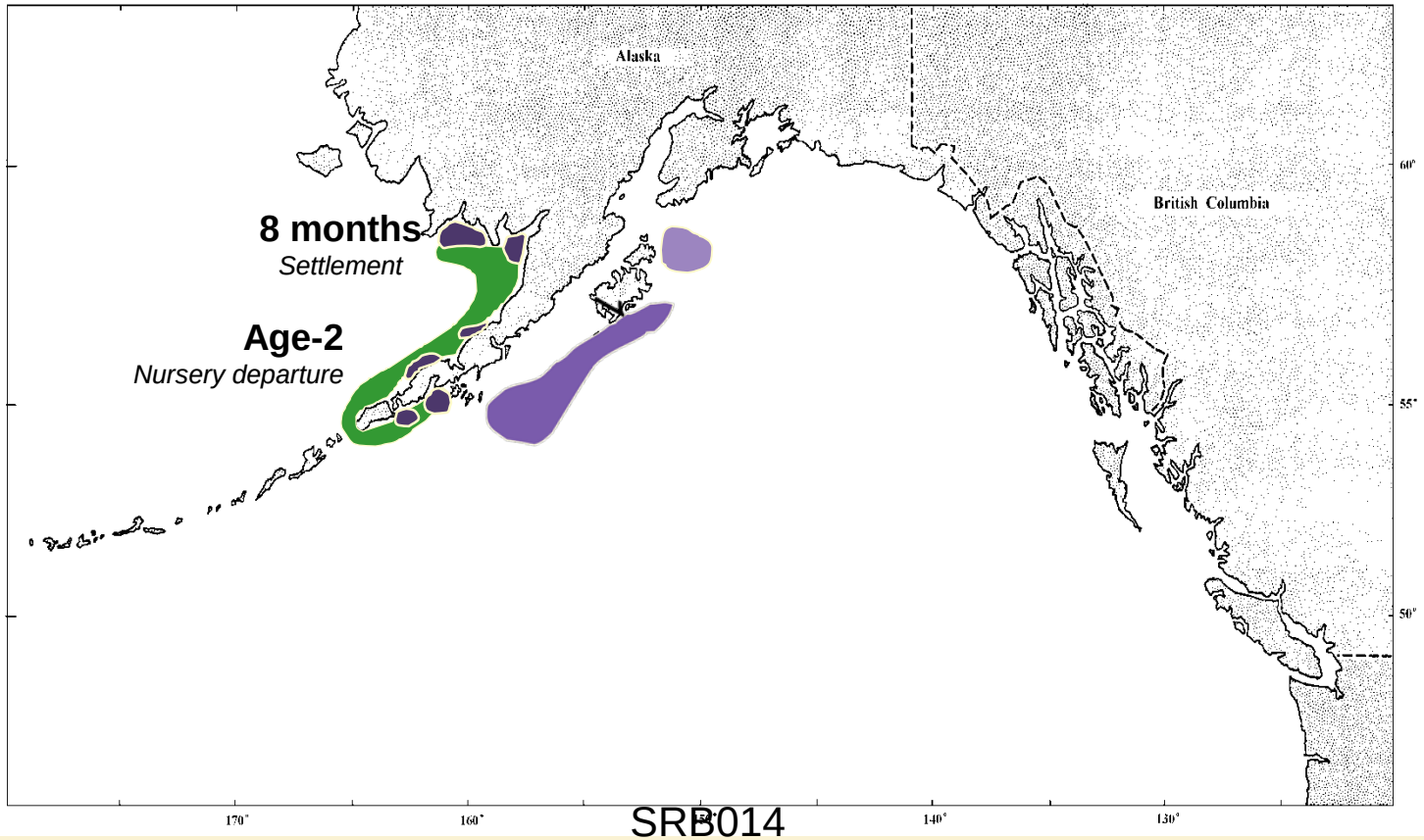

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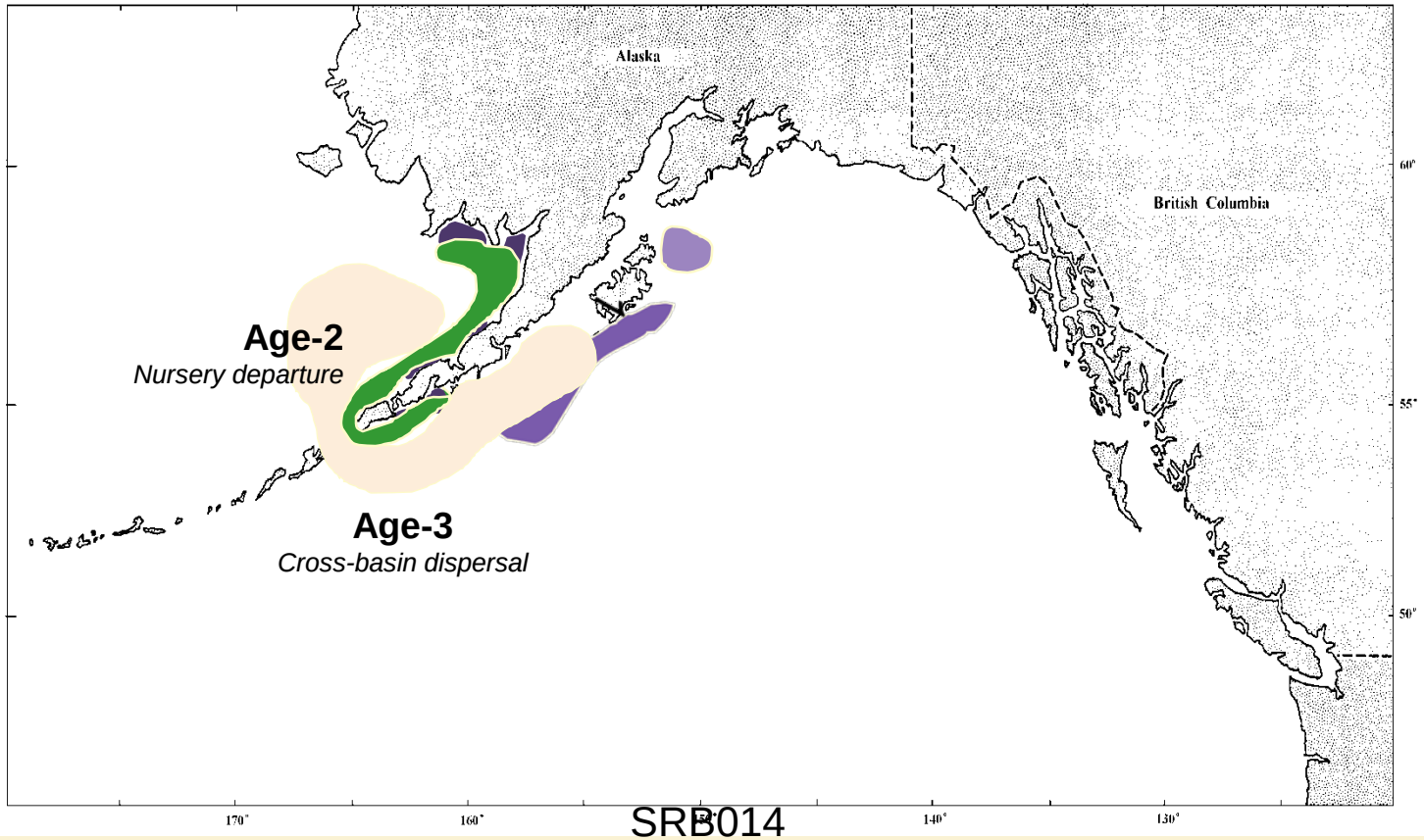

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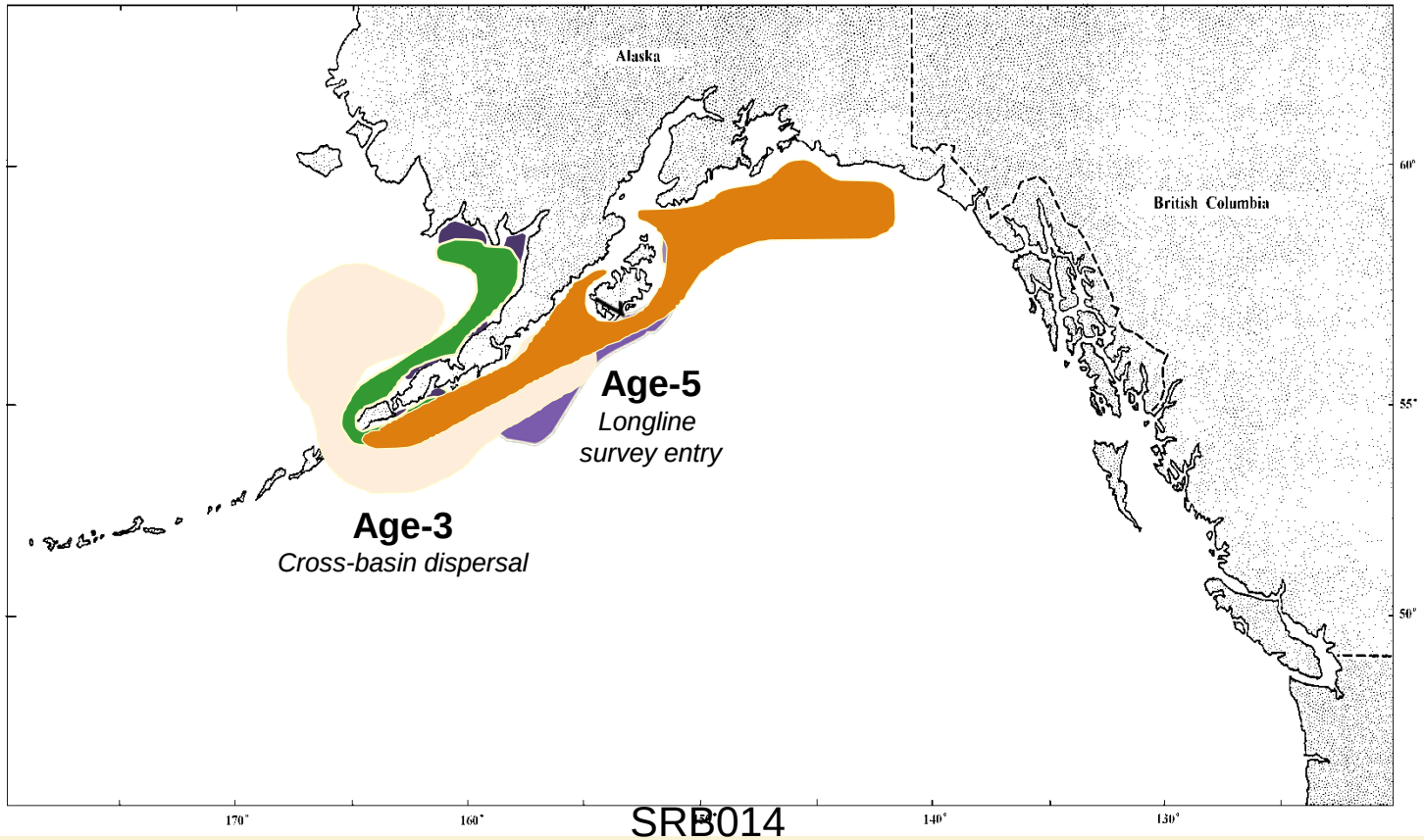

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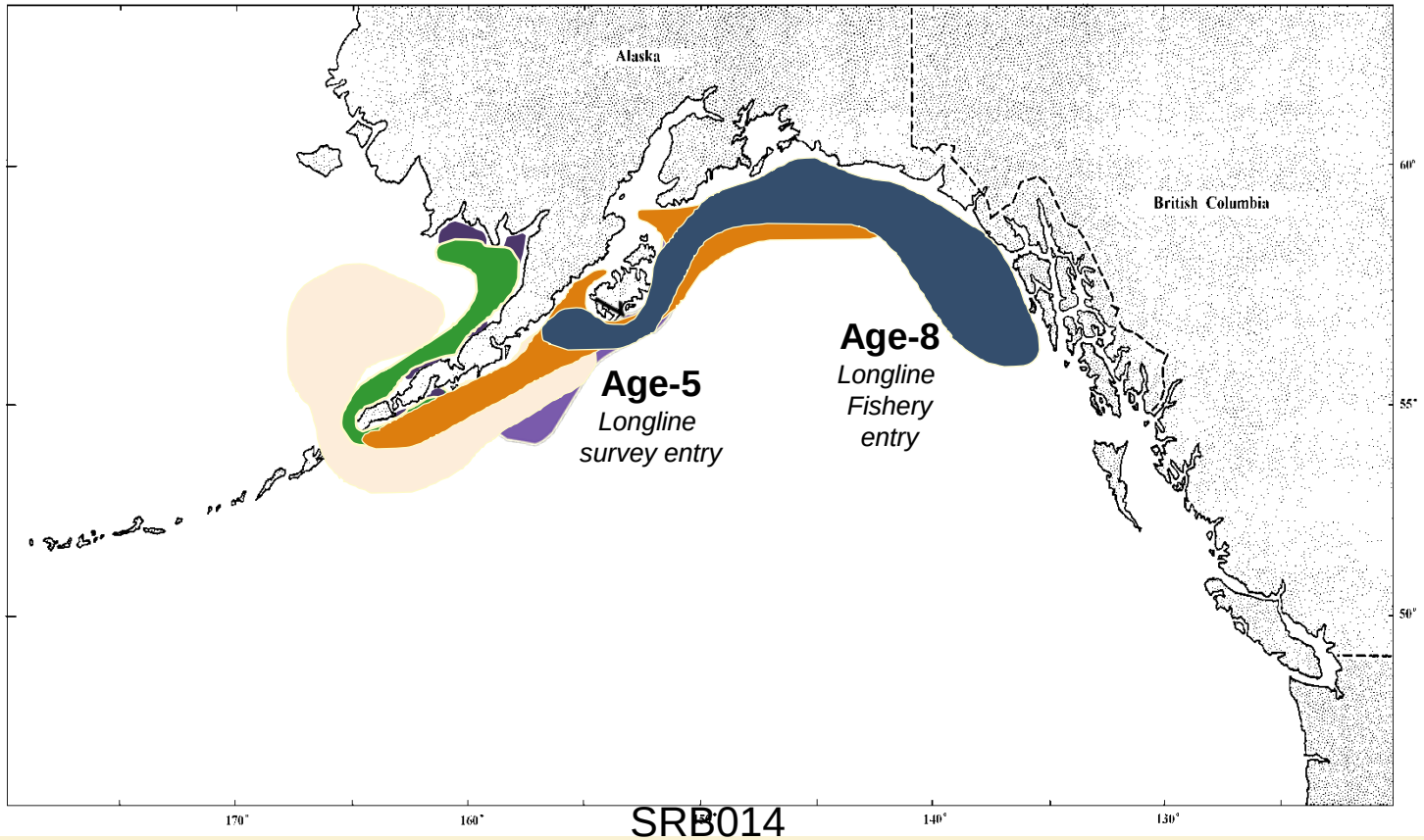

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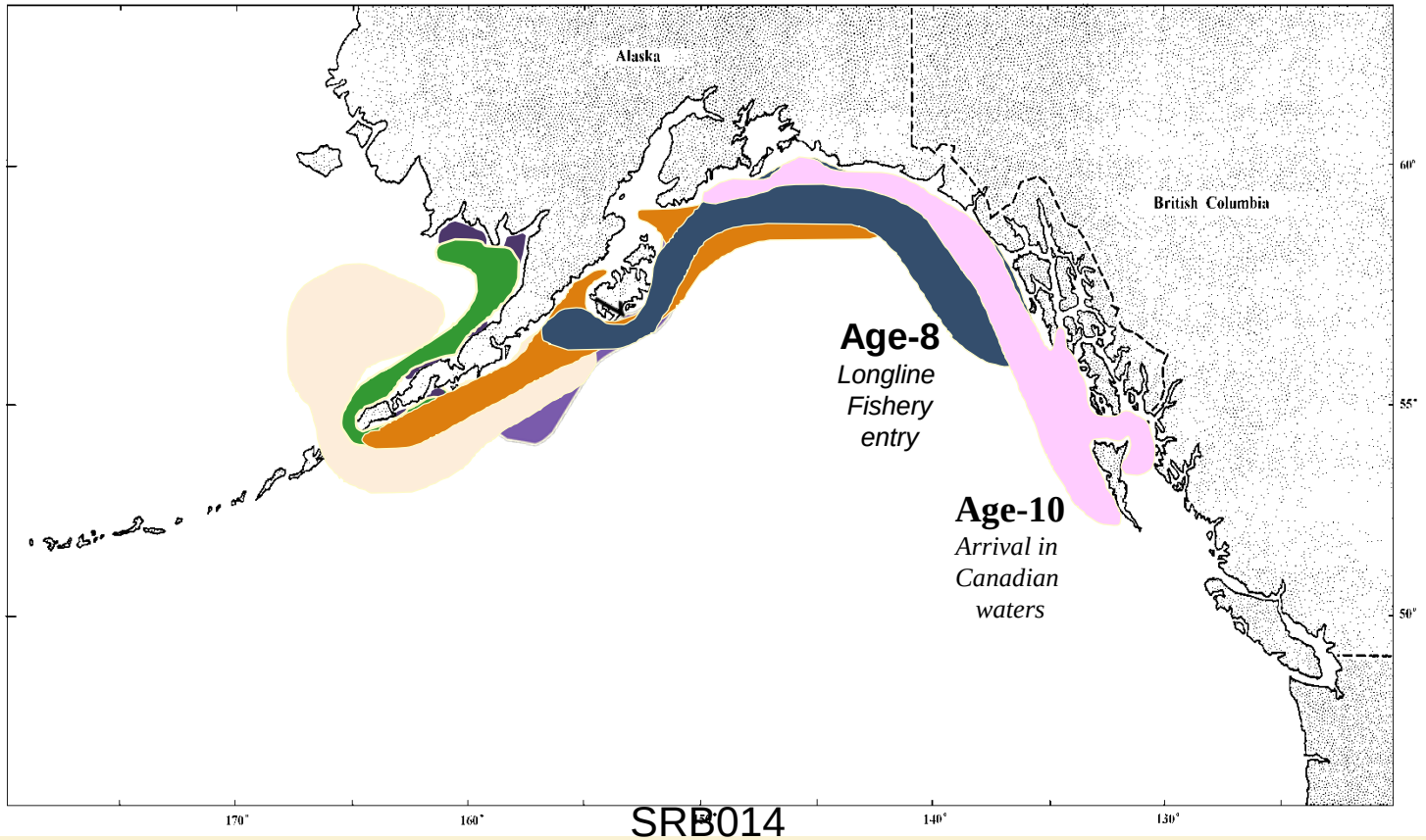

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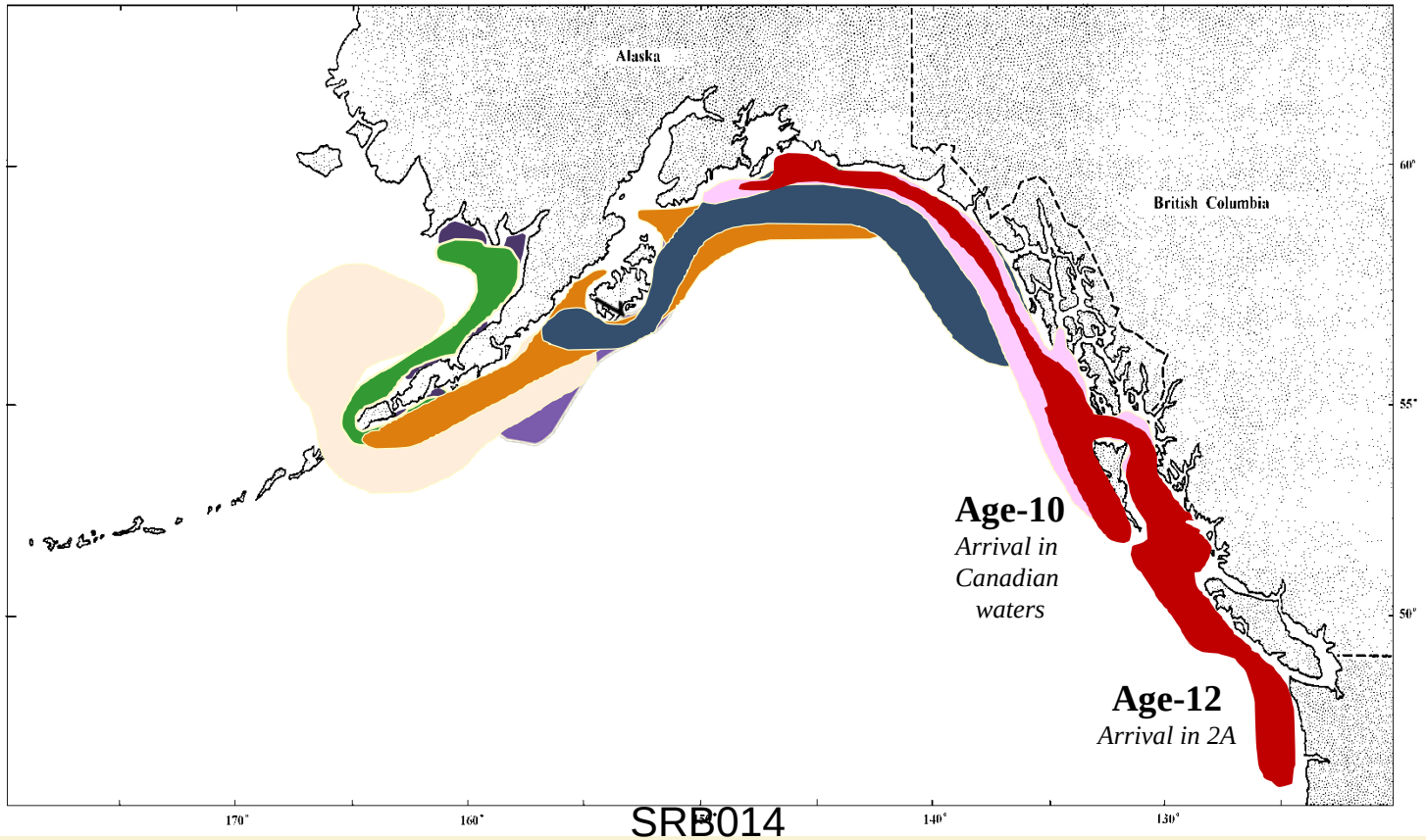

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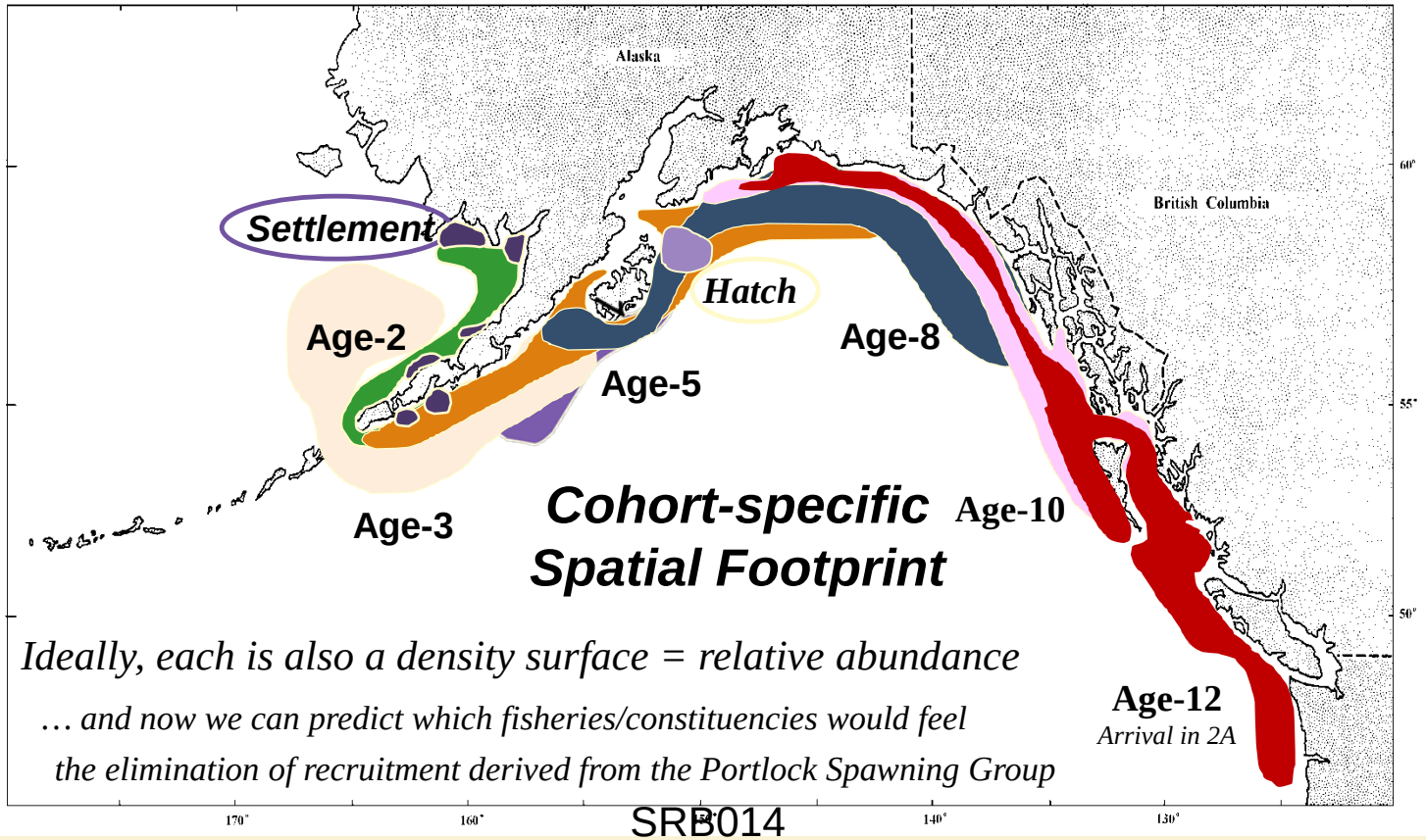
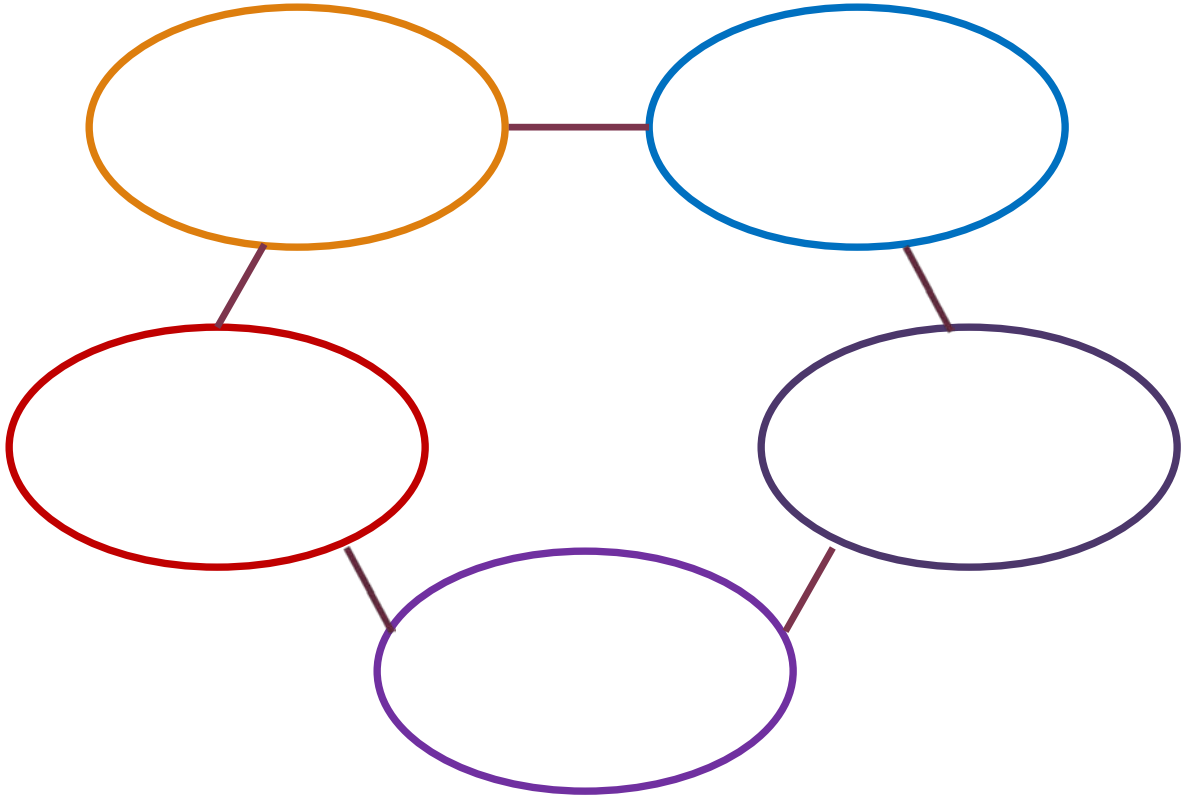


Ideally, each is also a density surface = relative abundance

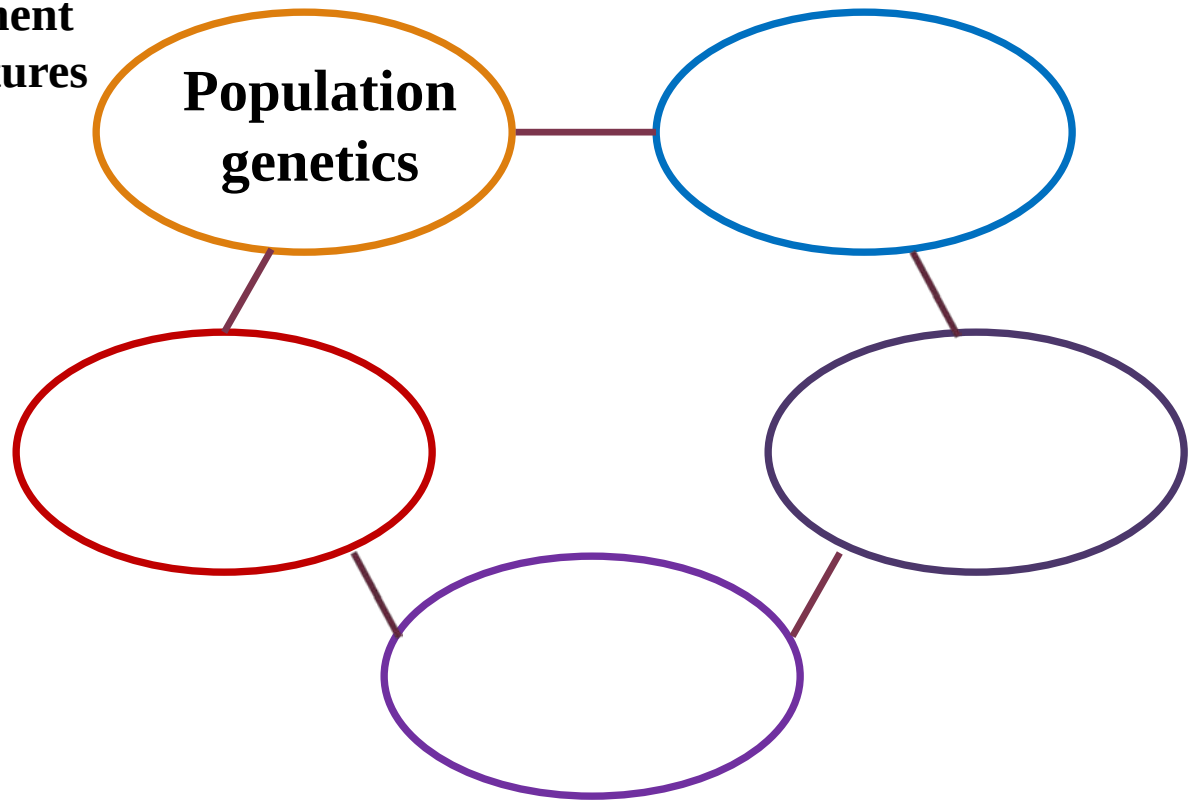
… and now we can predict which fisheries/constituencies would feel the elimination of recruitment derived from the Portlock Spawning Group

The Integrated Research Design



The Integrated Research Design

Regulatory Area and Assessment Model structures



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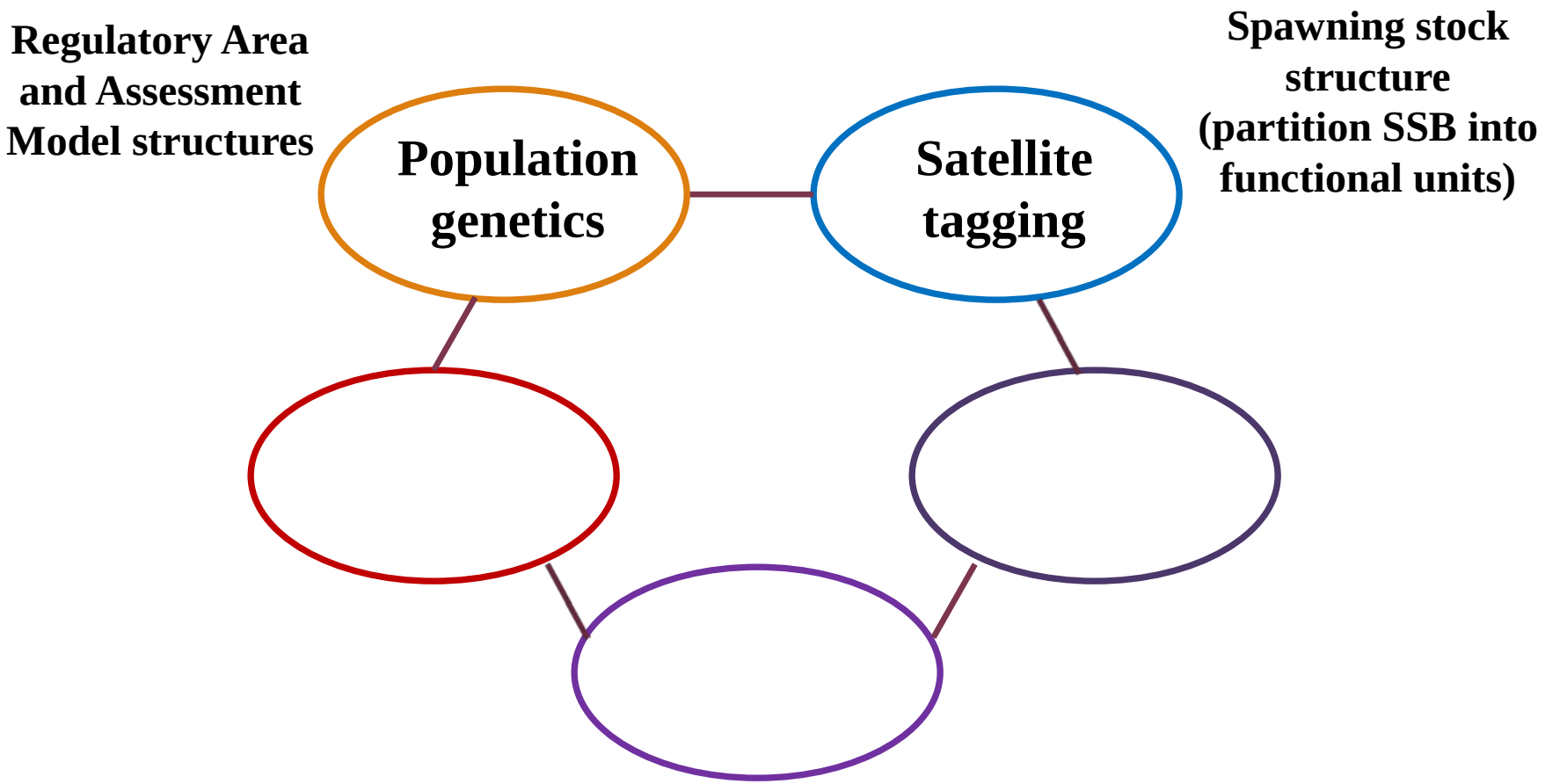

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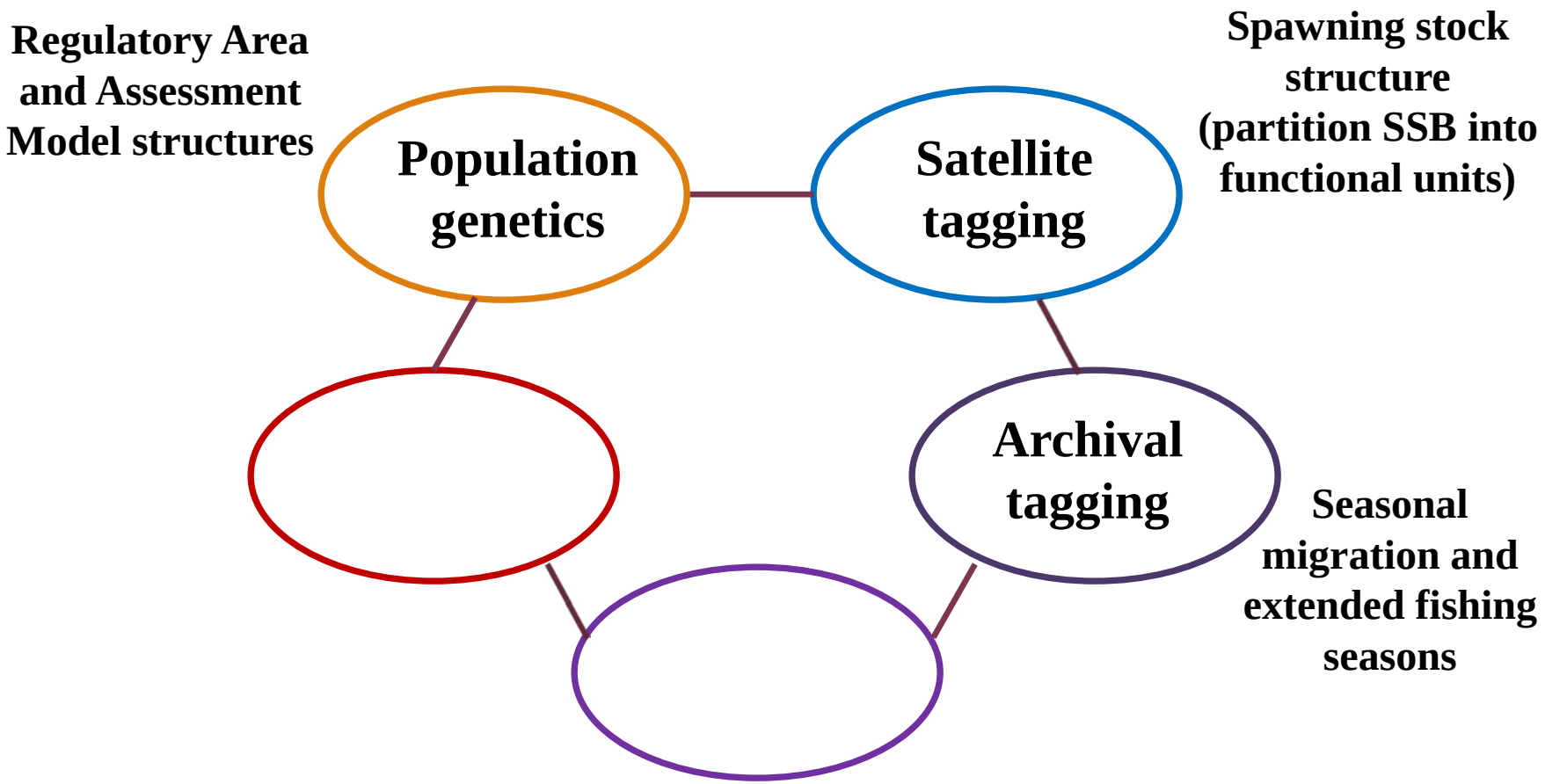

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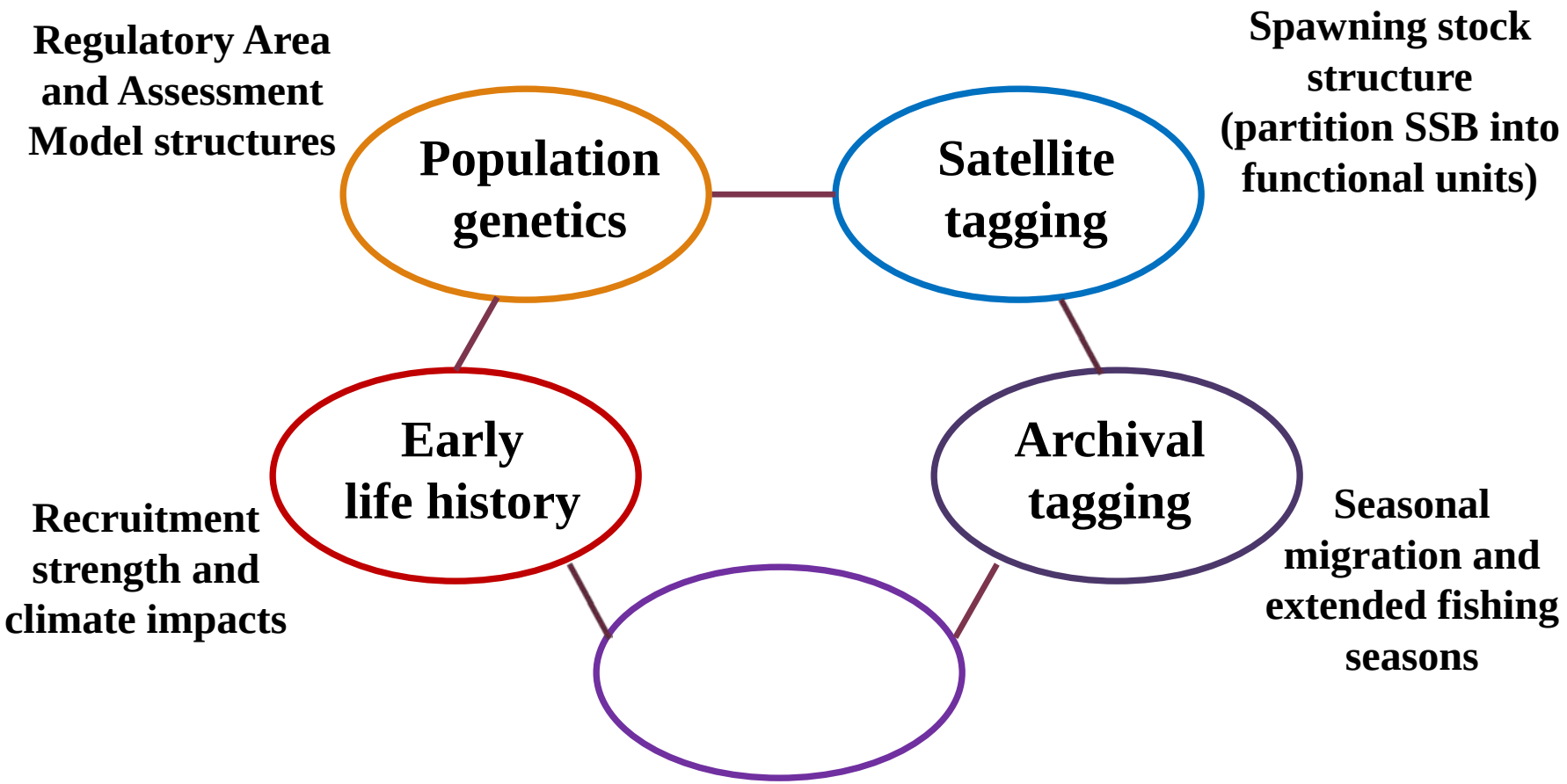

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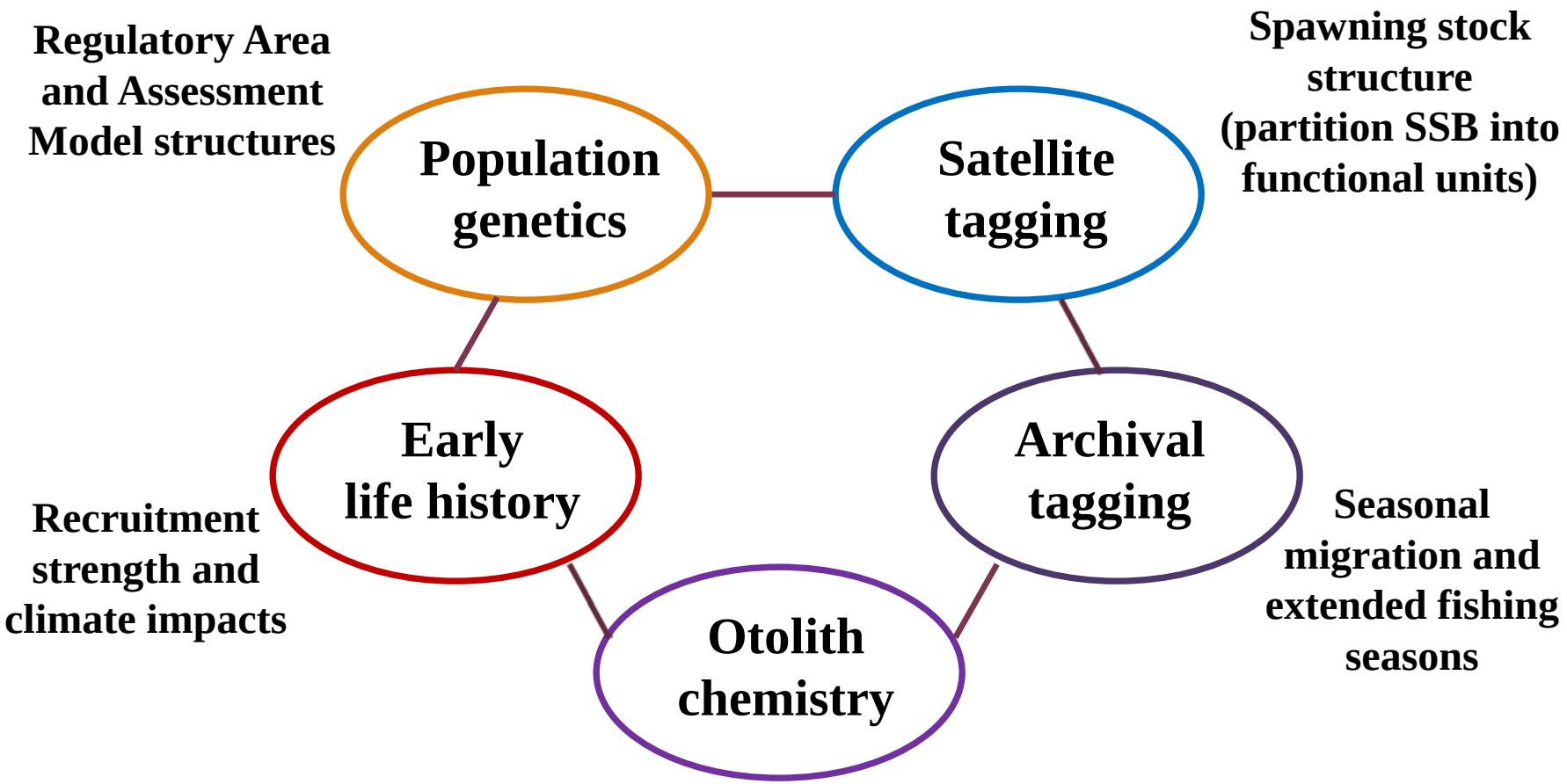

Some major findings

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From coastwide deployment of 67,436 PIT tags (2001-2009)

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Pre-dated the Integrate Design and was not intended for this context

- Preparations began in 2000, but had nothing to do with connectivity: rather, designed for mortality (F, M) and abundance estimation

  - Unexpectedly low tag-recovery rates in some areas led to questionable estimates of fishing mortality

- However, the resultant data were highly amenable to migration analysis

Some major findings

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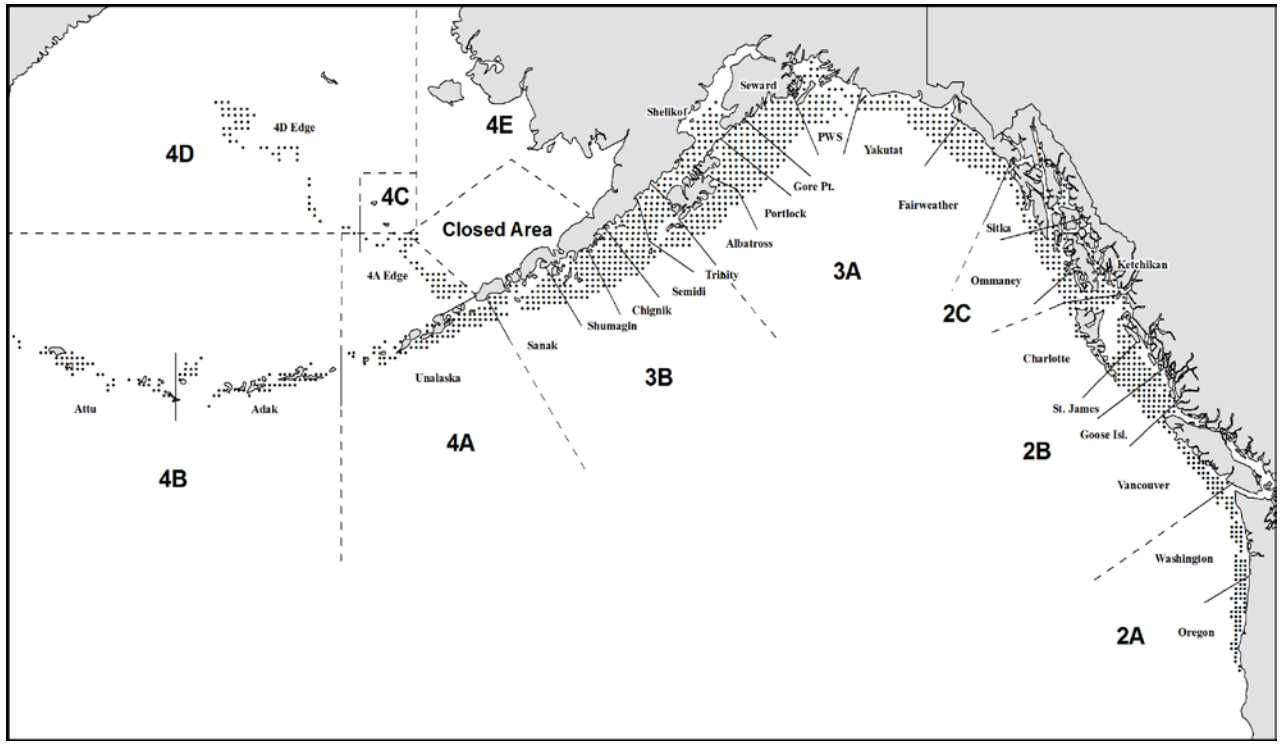

Recovered via an extensive portside commercial-harvest recovery program

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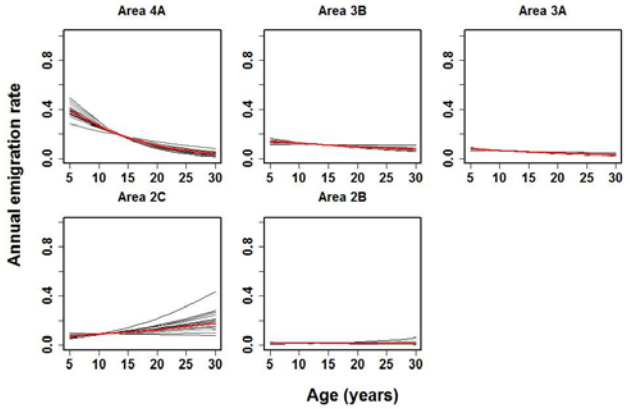
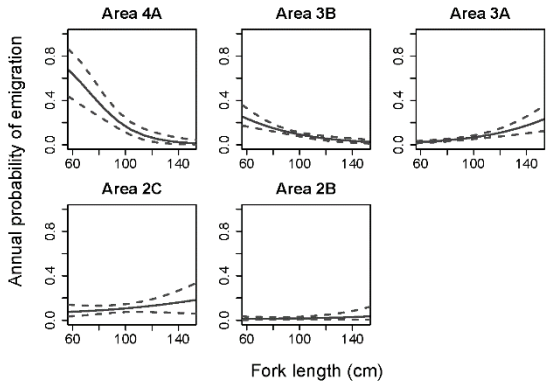
Movement rates of 032 fish modelled as functions of length and age …





… and tabulated Area-to-Area

Estimated annual migration rates for 100 cm fish from PIT tags 2003-2009 (Webster *et al*. 2013).

Area in yr i	Area in yr i+1 4A	3B	3A	2C	2B
4A	**0.833**	0.041	0.093	0.013	0.019
3B	0.002	**0.907**	0.084	0.004	0.003
3A	0.000	0.059	**0.934**	0.003	0.004
2C	0.000	0.000	0.025	**0.895**	0.080
2B	0.006	0.000	0.002	0.008	**0.984**

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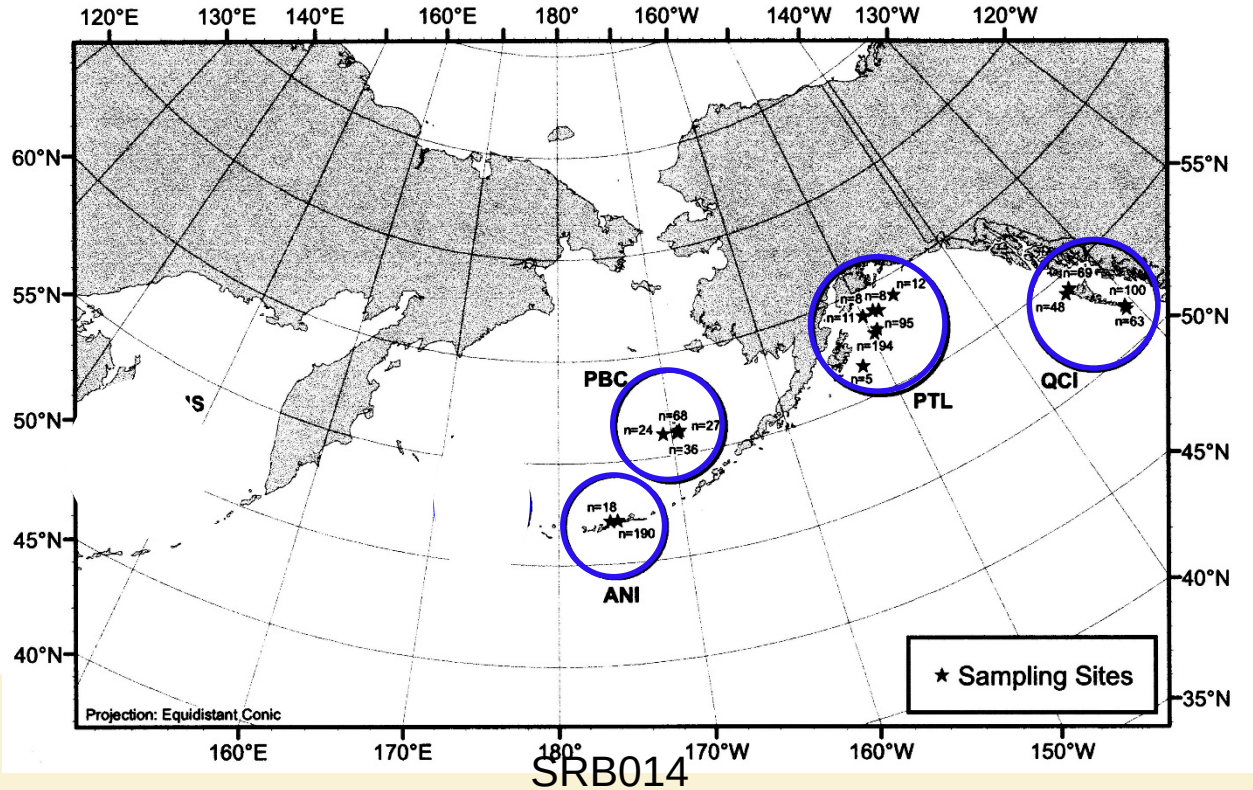
- (968) mature fish sampled at **winter** spawning grounds from British Columbia to the eastern Aleutian Islands



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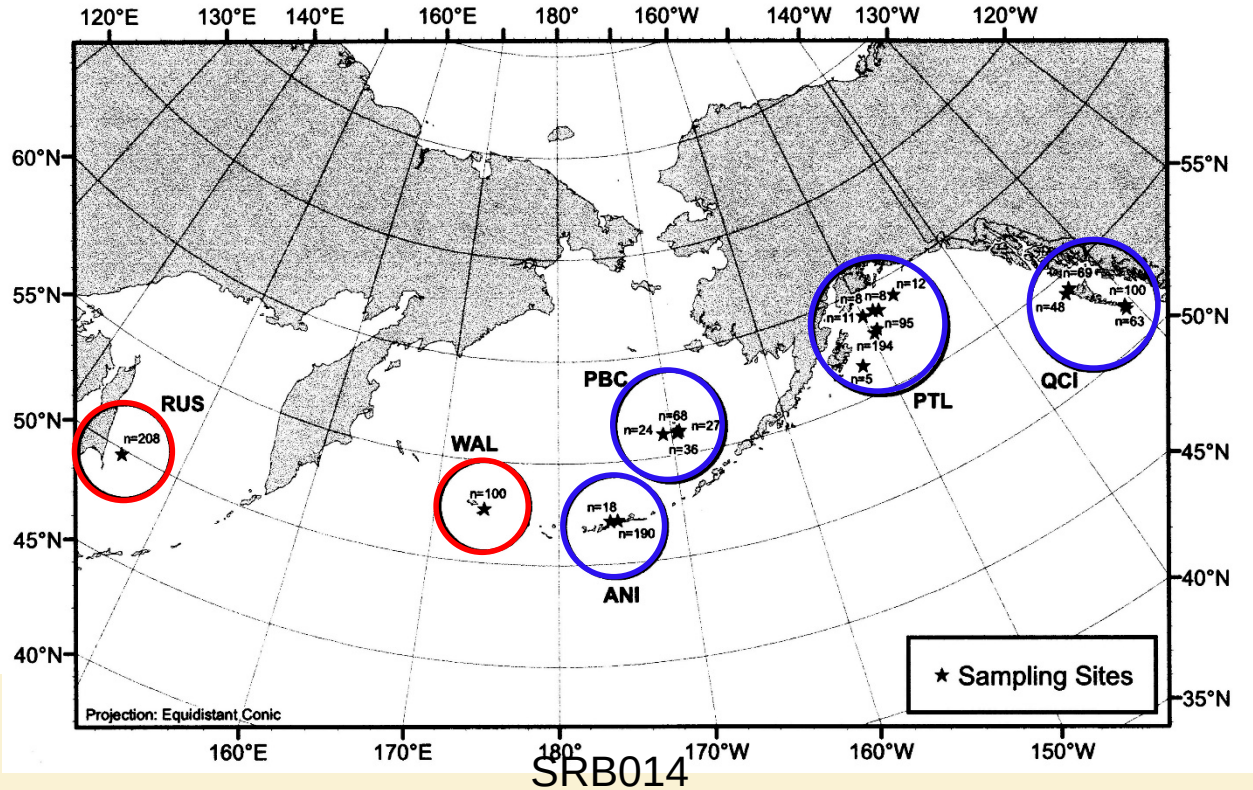

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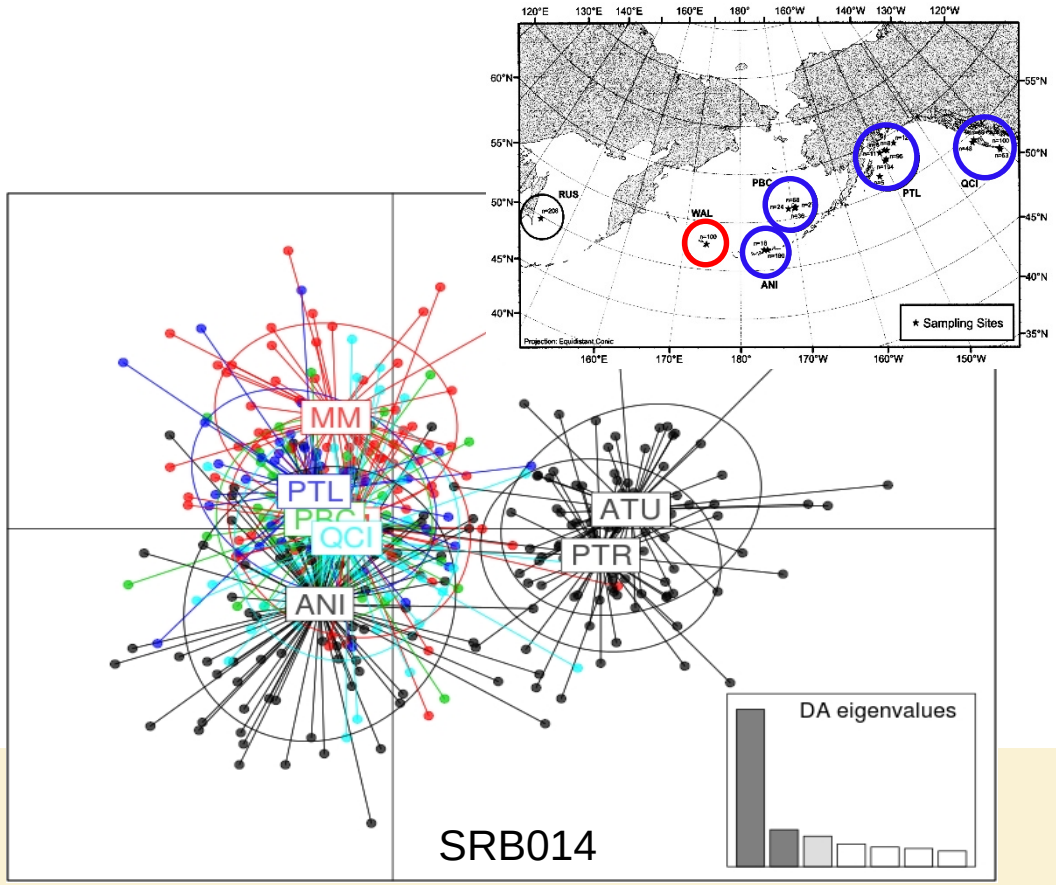
- Analyses based on 61 microsatellite loci
  - 23 anonymous loci and 38 Expressed Sequence Tags (ESTs)



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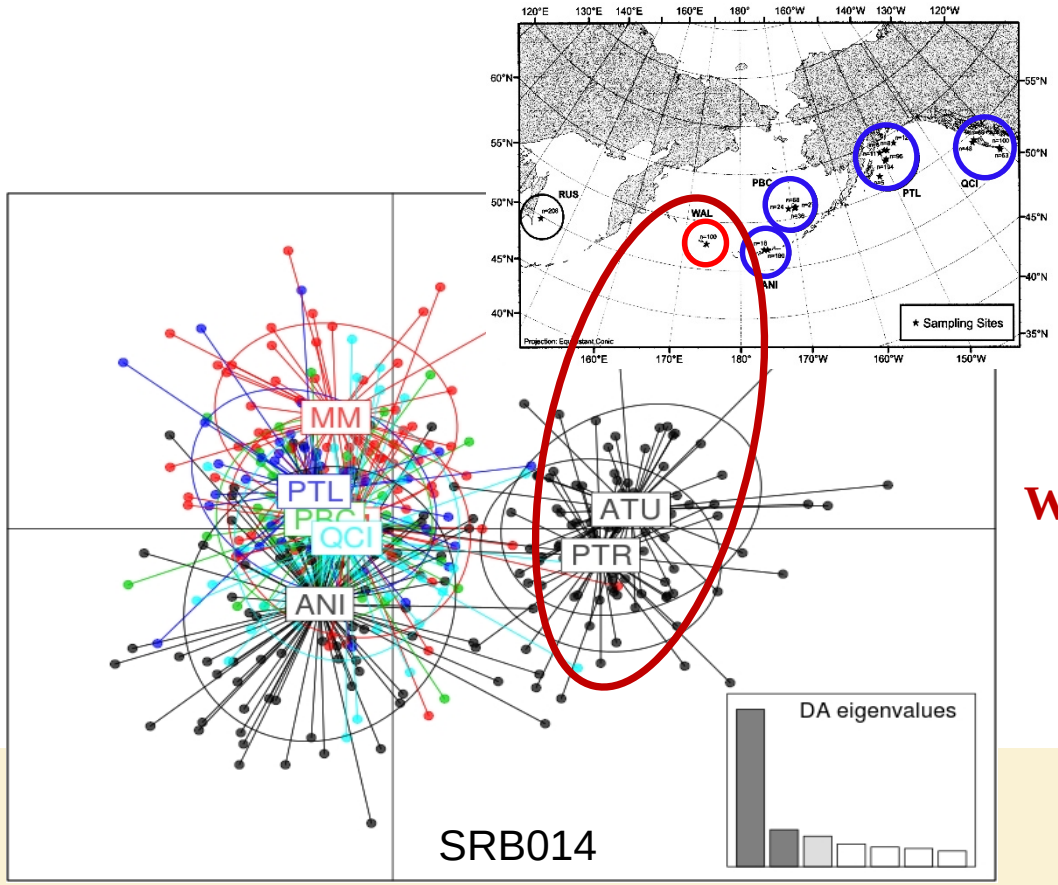

Evidence of Western Aleutian isolation

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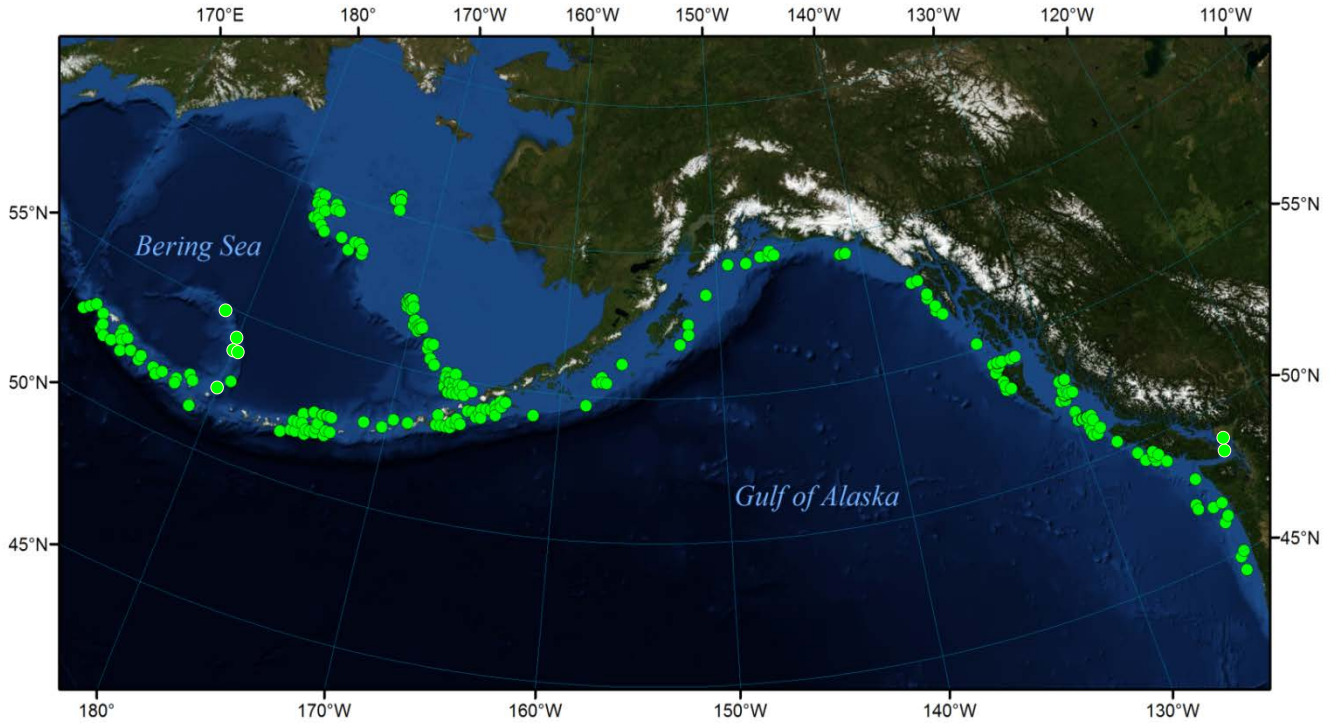
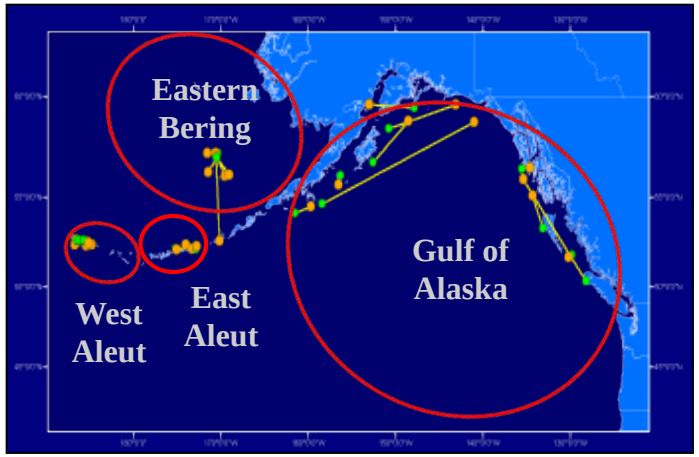


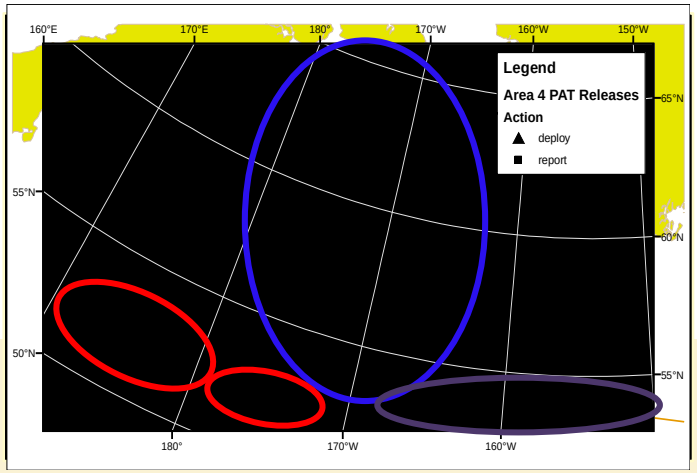
Programmed as a mixture of winter-reporting for spawning locations …
… and summer-reporting of site fidelity and regional mixing

Some major findings

From 401 summer-deployed PAT tags (2002-2017)

Indication of basin-scale spawning stock structure with West Aleutian isolation…





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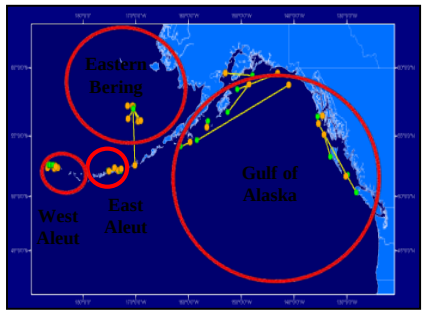

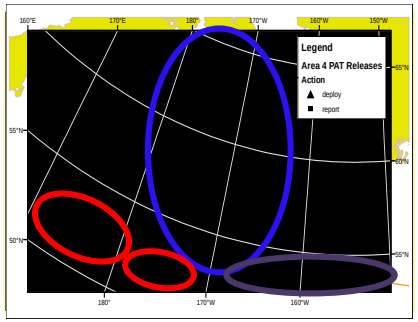

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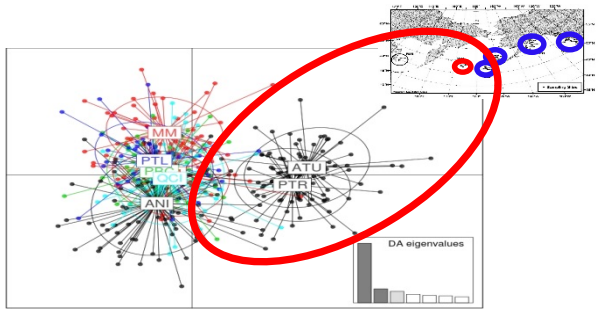

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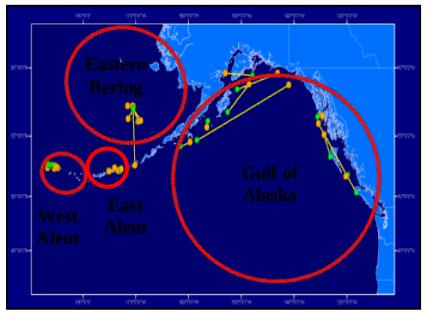

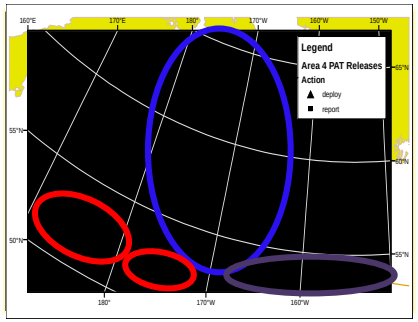

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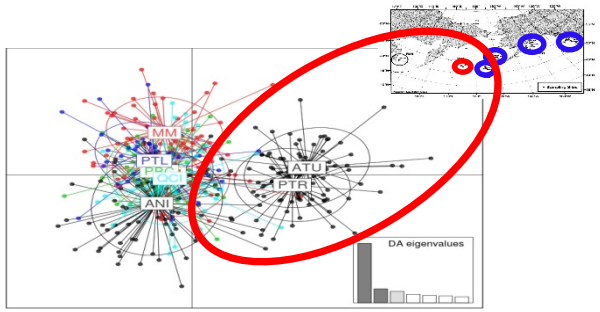
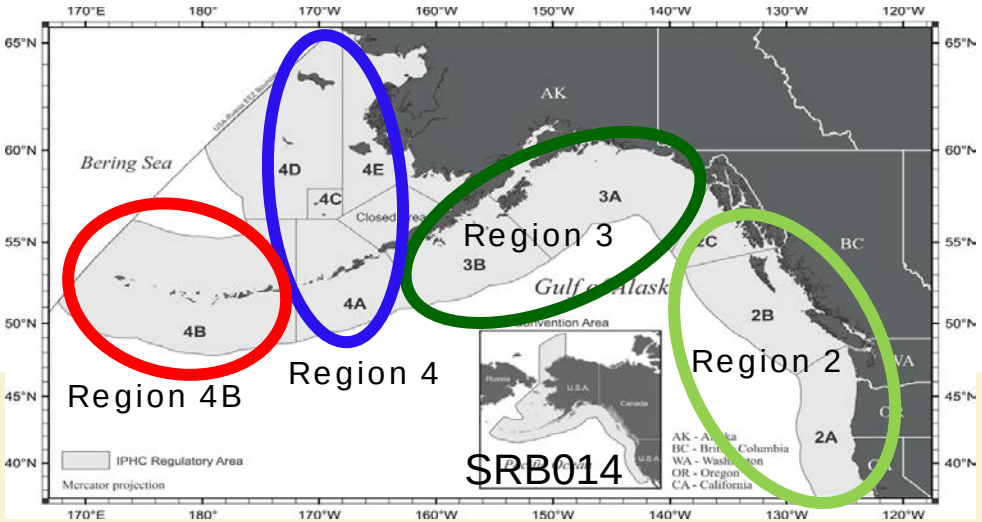


Supporting our move towards metrics within **Biological Regions**



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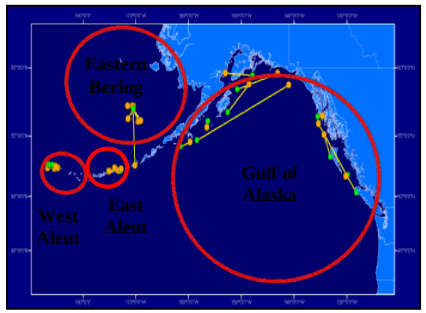

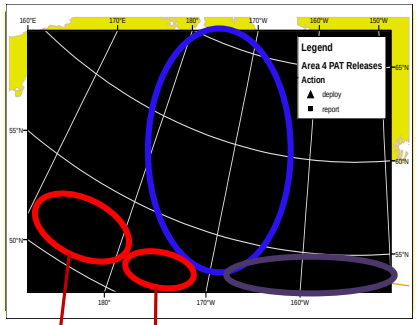

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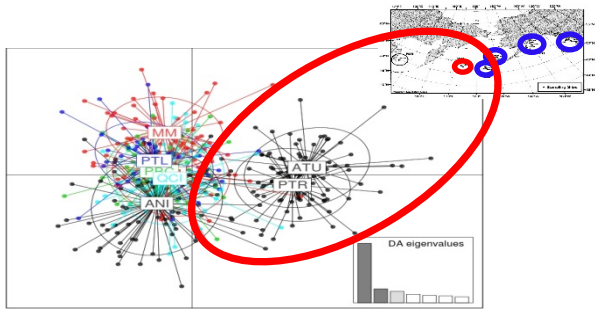
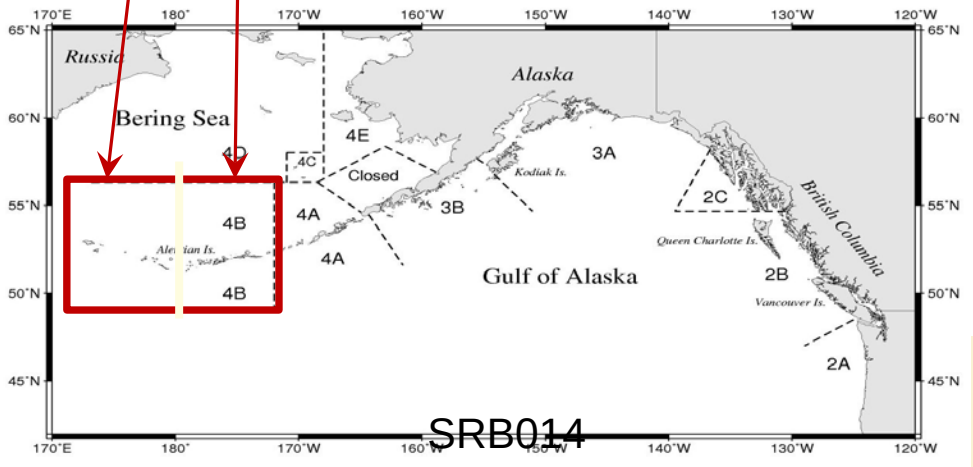


But, suggesting that Area 4B represents two discrete population components



Some major findings

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- Using archival tag data to quantify group-level seasonal migration

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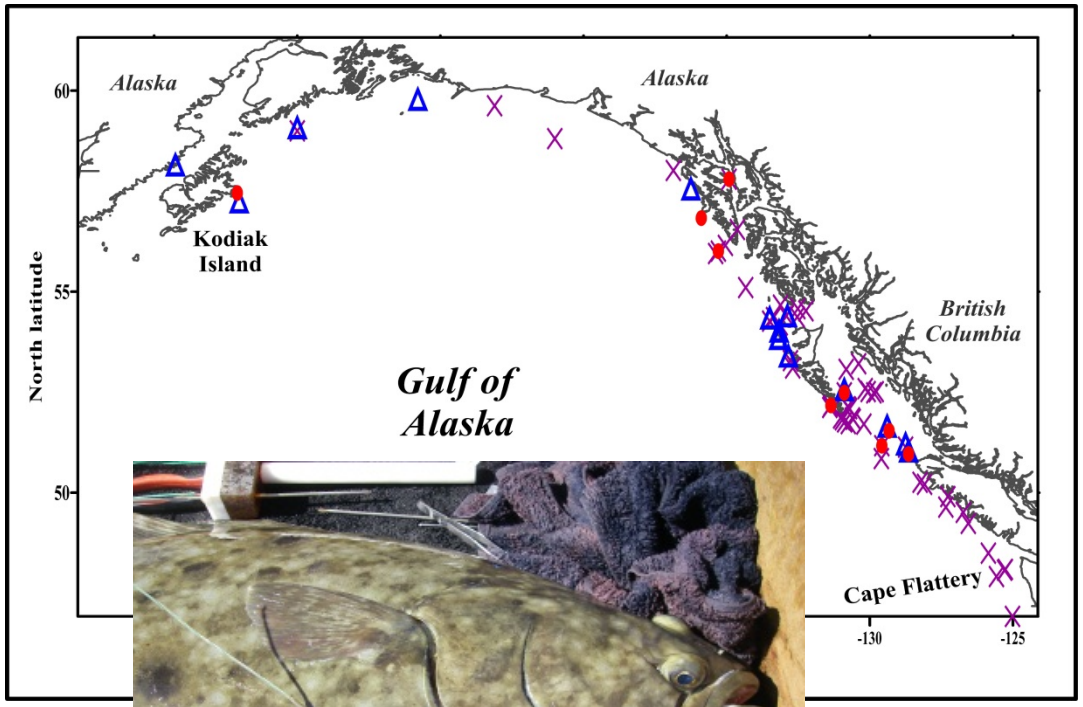

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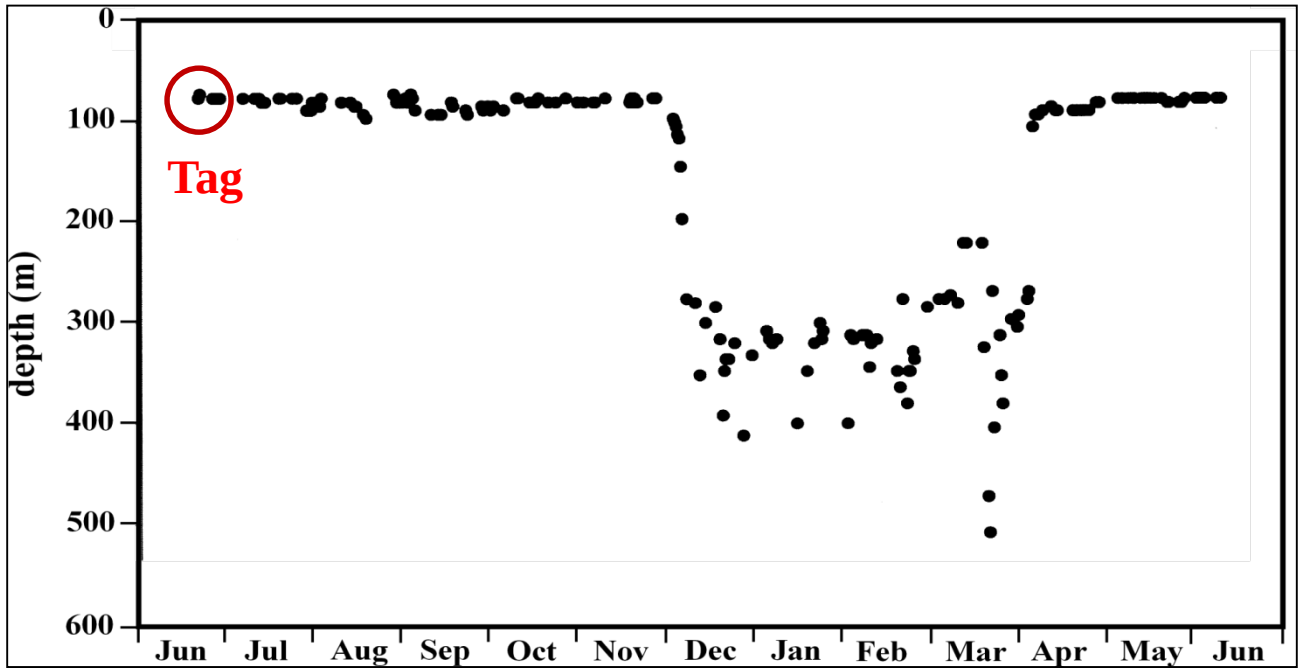

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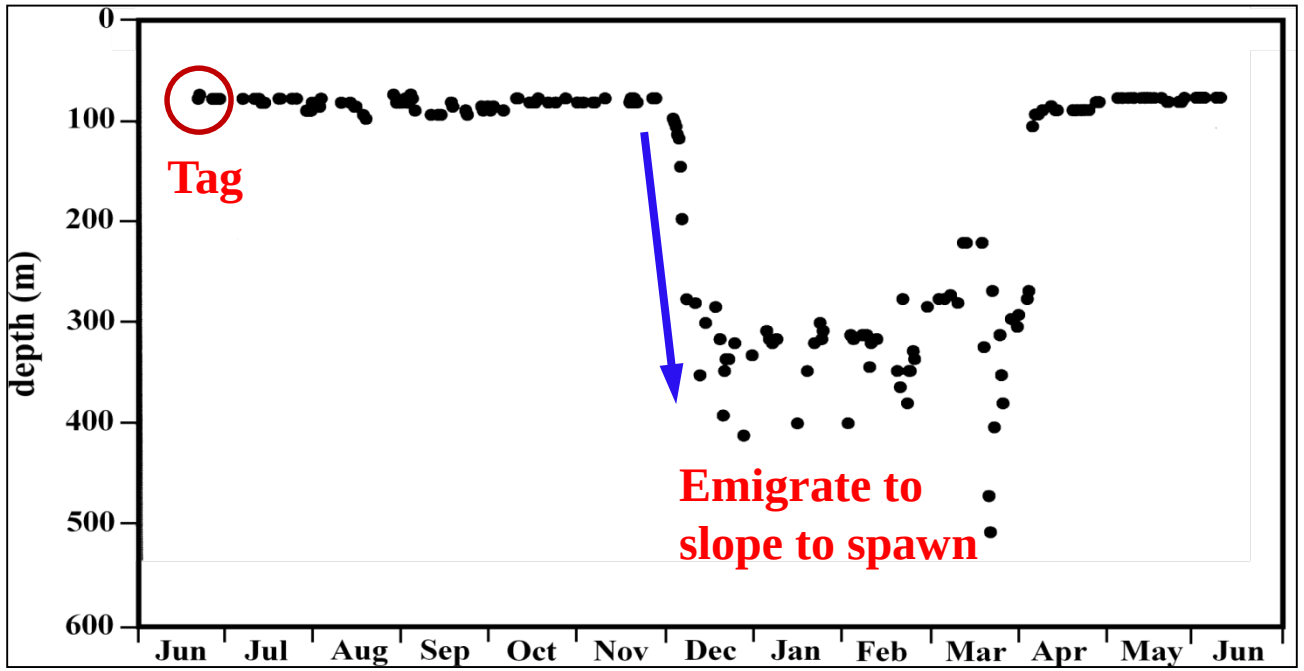

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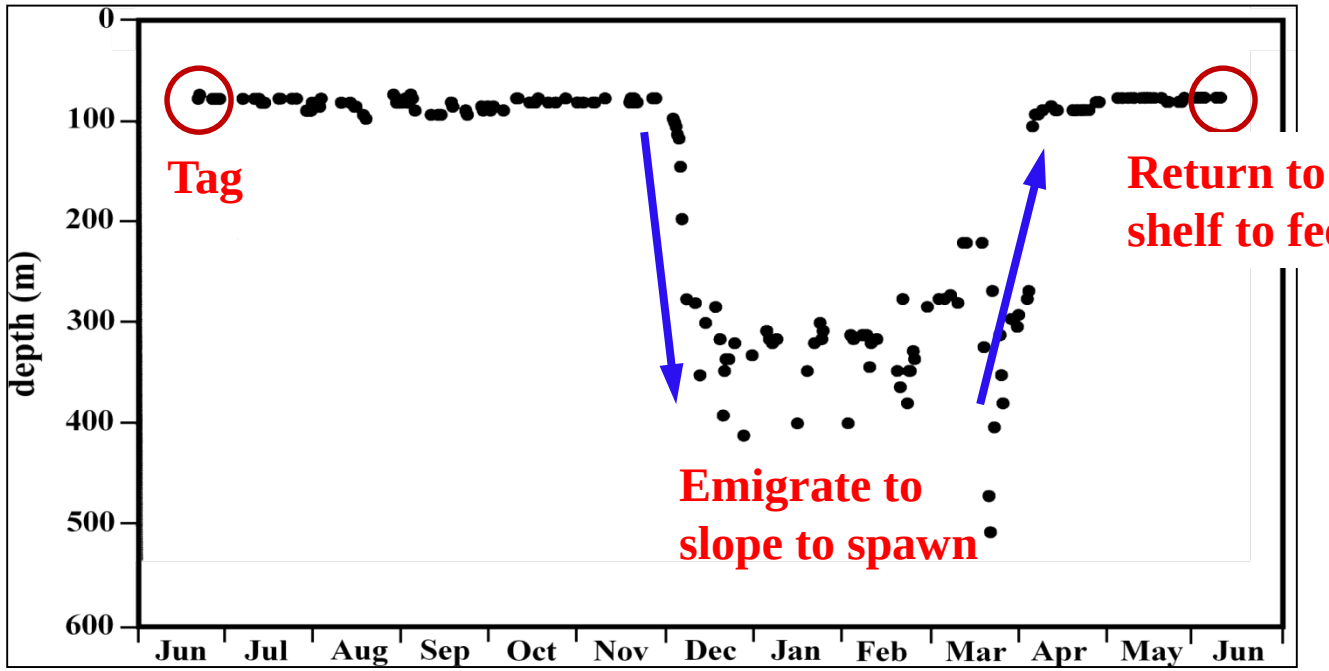

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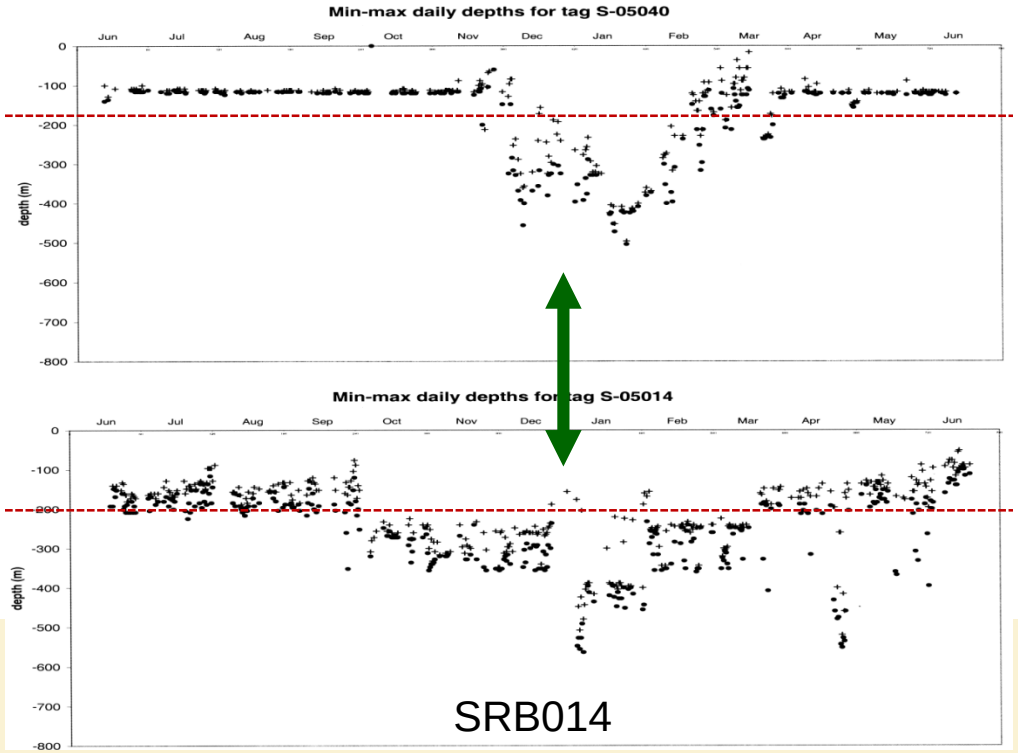
Aggregate data to characterize average annual habitat use:



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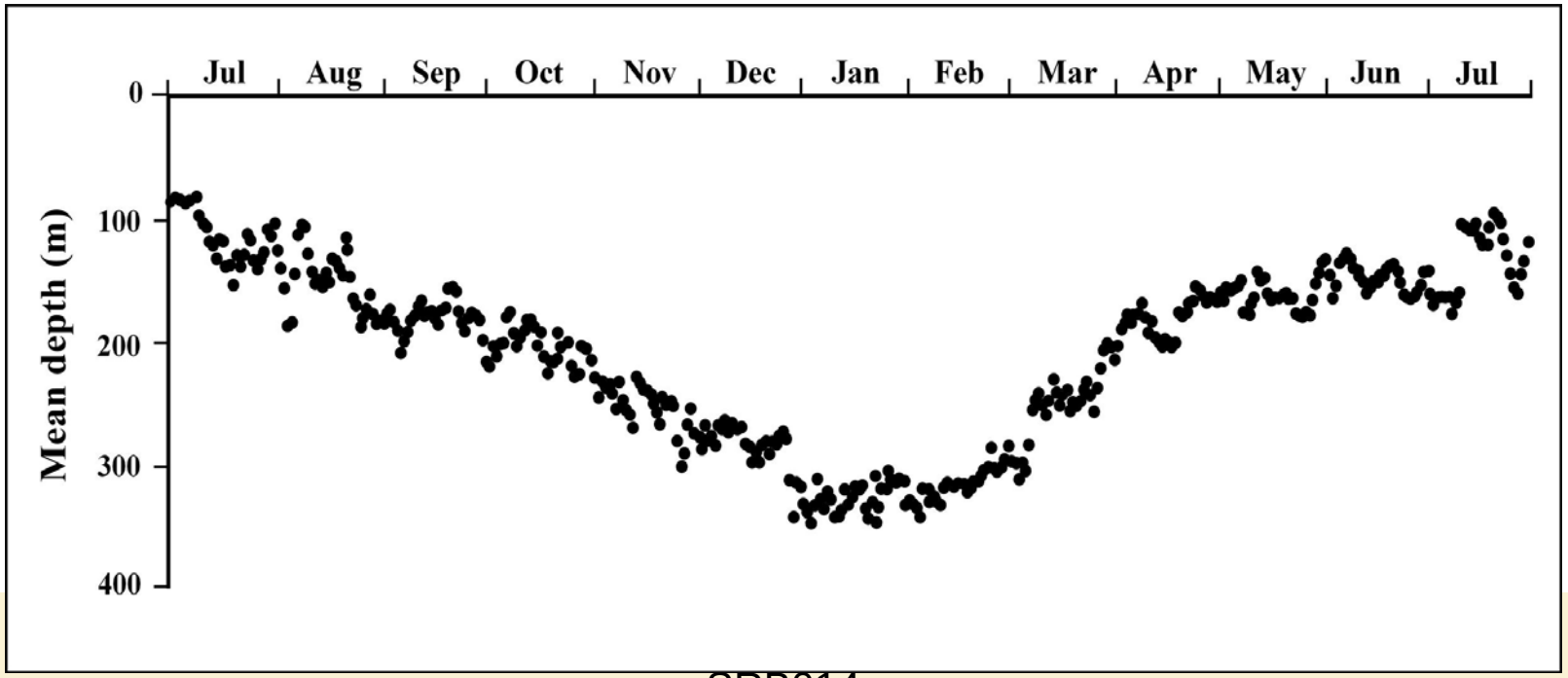

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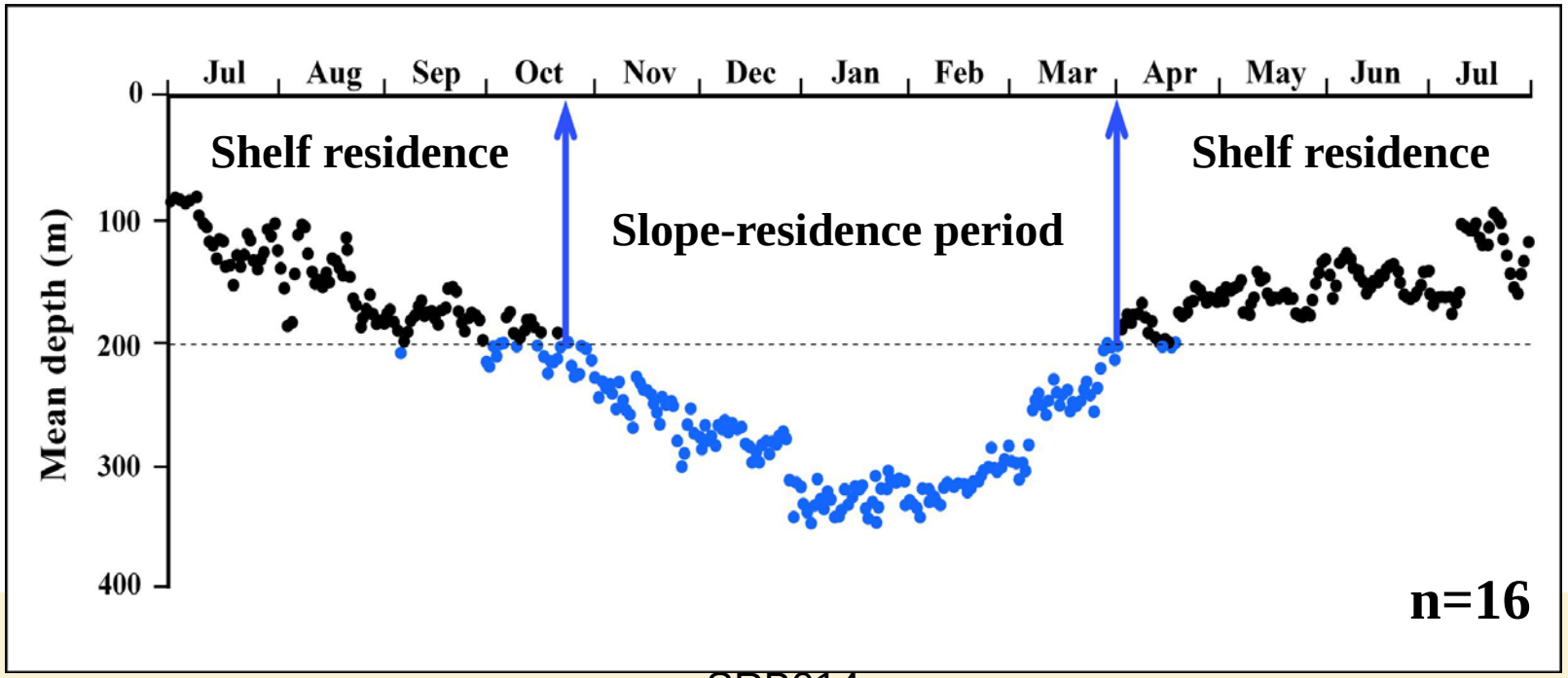

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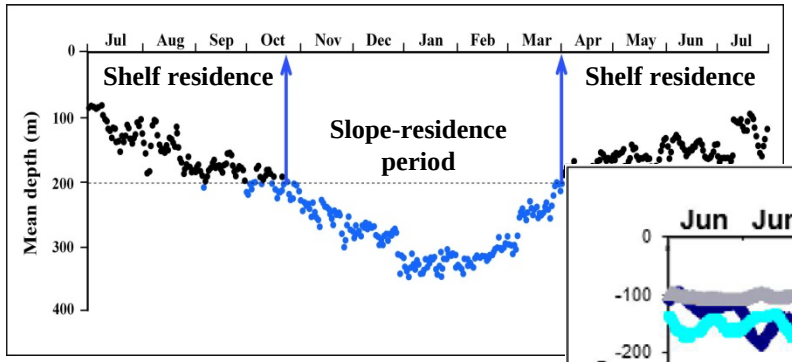

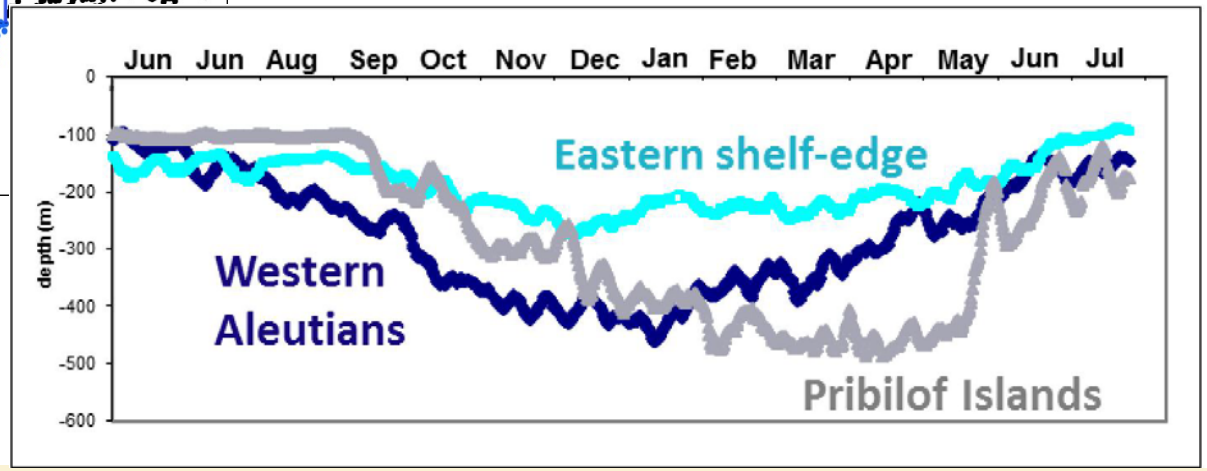

Noting evidence of regional variance …

SRB014

INTERNATIONAL PACIFIC HALIBUT COMMISSION

Some major findings

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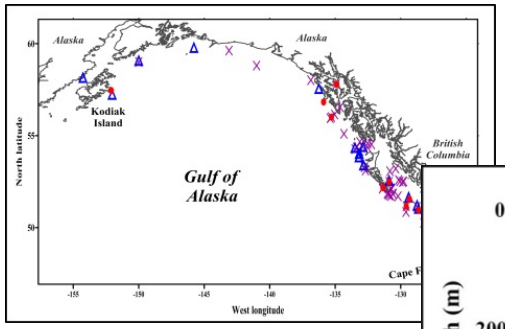
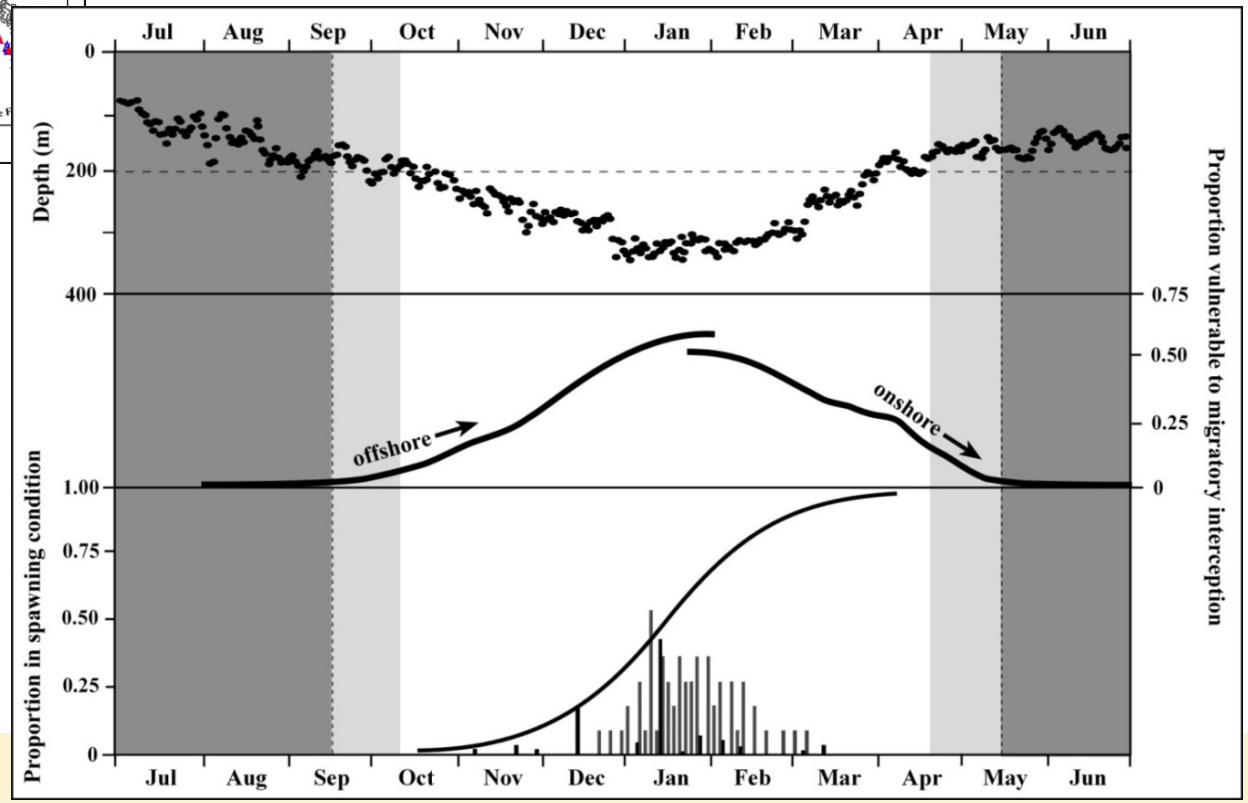


Integrated into metrics to describe habitat use
and **spatial redistribution**



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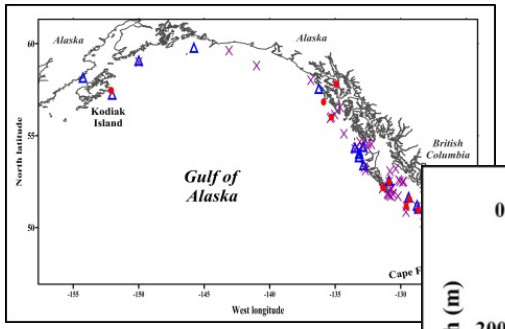

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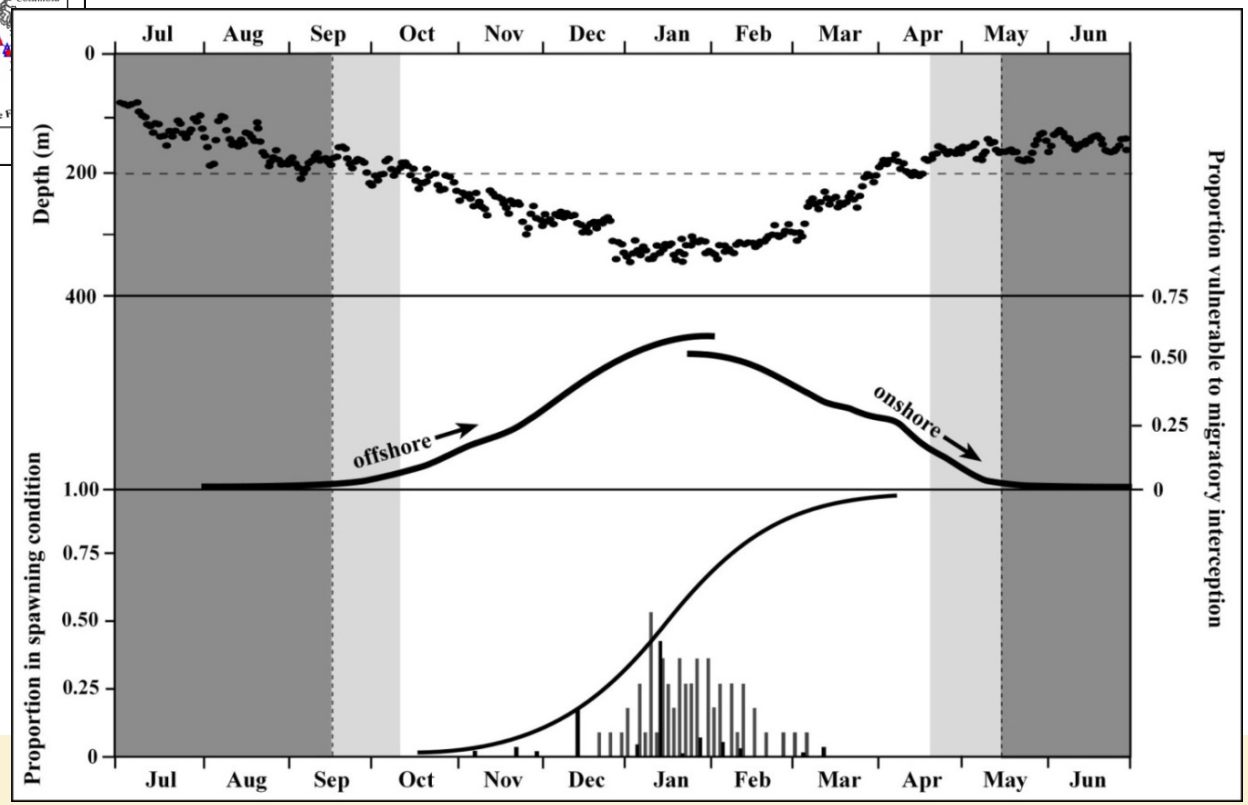

Contemporary winter closure periods have been insufficient to prevent *"interceptions of migrating fish* "*

* *Sensu* Leaman et al. (2001), IPHC Report of Assessment and Research Activities

Some major findings

From analyses of otolith microchemistry (2002-2007)

- Looking for ***spatially-trended*** patterns allowing for source identifications not prone to assigning fish from unsampled locations to those sampled

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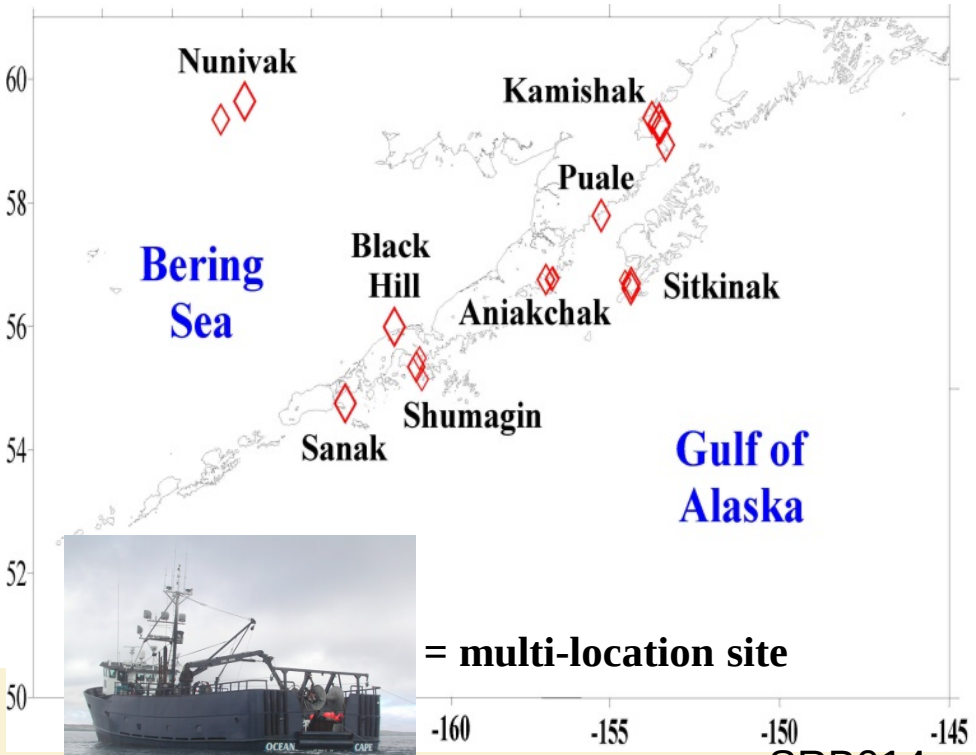
Relied on fish from NMFS trawl surveys



= multi-location site

- **From 16 locations representing 8 sites, from west-central GOA to the southeast Bering Sea**
- **Spatial coverage of ~2300 km of coastline**

Some major findings

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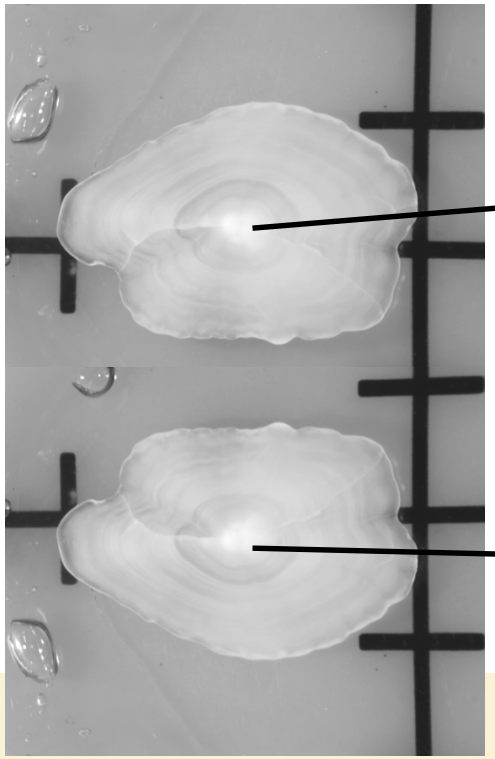
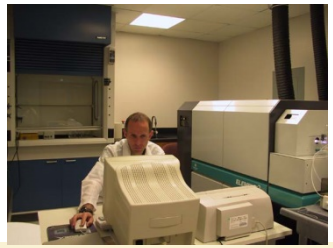
- Looking for ***spatially-trended*** patterns allowing for source identifications not prone to assigning fish from unsampled locations to those sampled



Right otolith: stable isotope ratios

Ratio Mass Spectrometry



Inductively-Coupled Plasma Mass Spectrometry (IC-PMS)

Left otolith: trace metals

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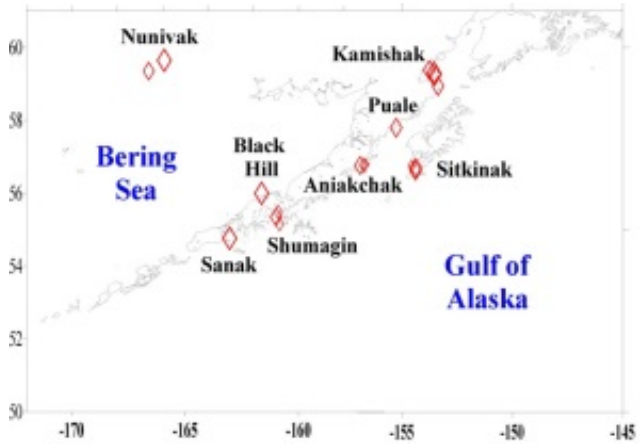

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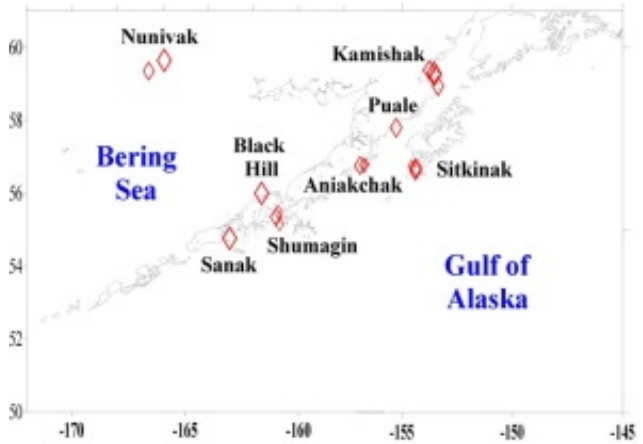

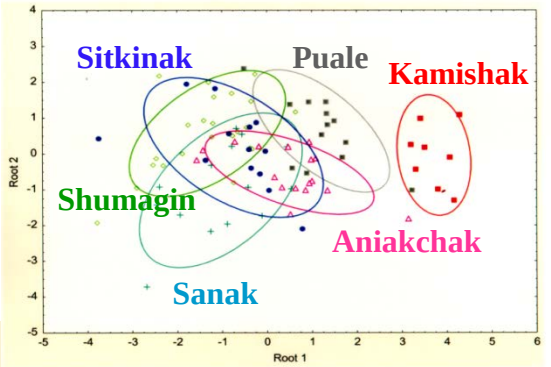

Local = muddled

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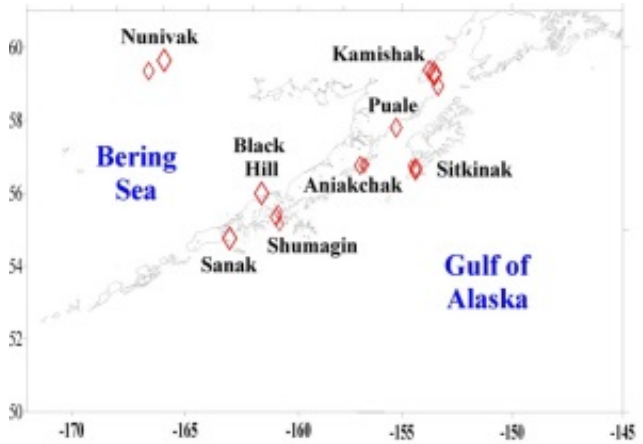

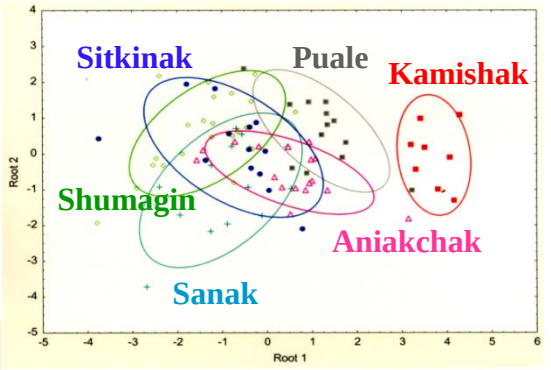

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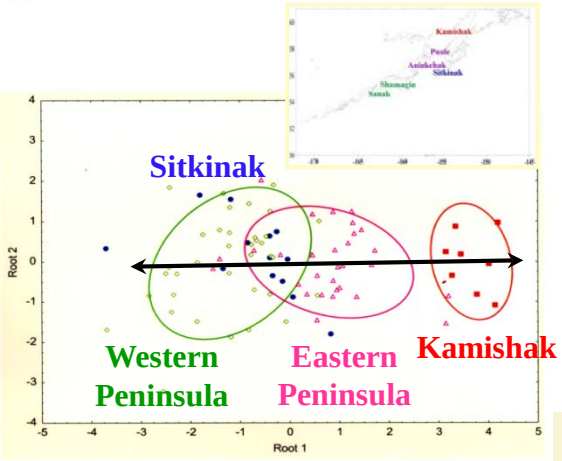

GOA Regional = E-W trend

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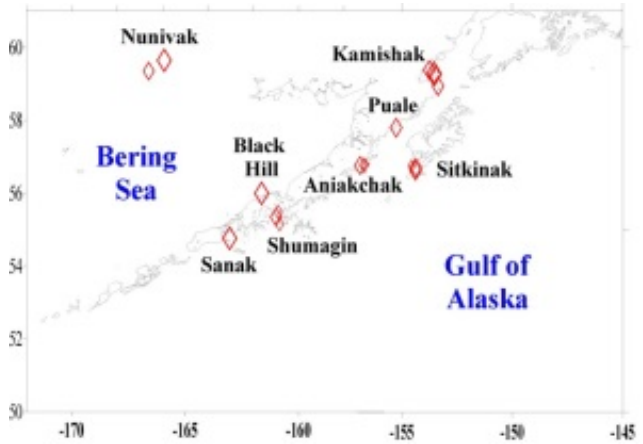

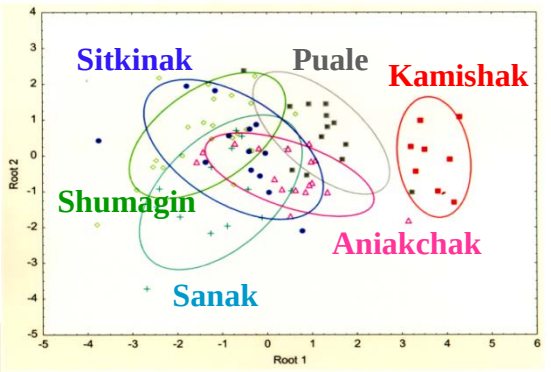

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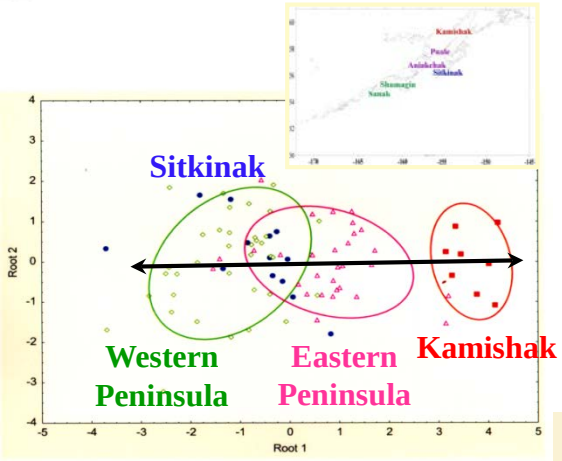

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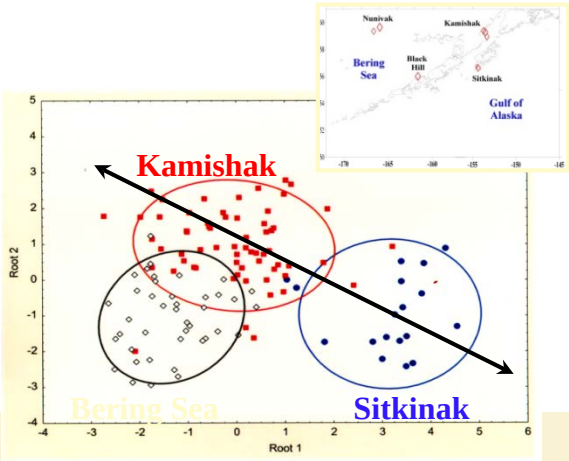

Basin-scale = Bering offset

Some major findings

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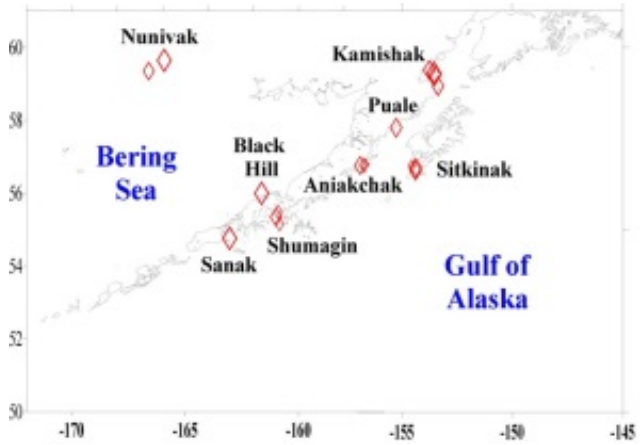
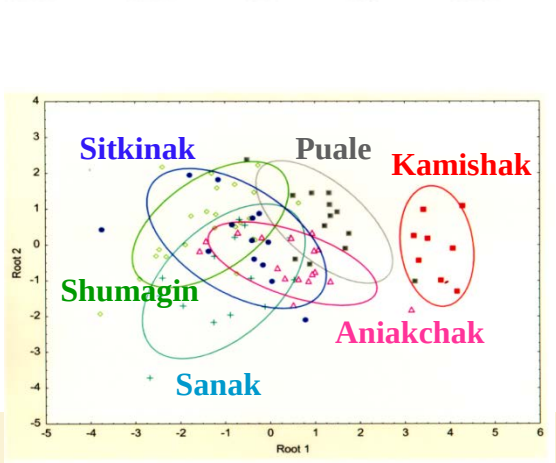


Suggesting that regional origin of individual fish *might* be distinguishable and robust



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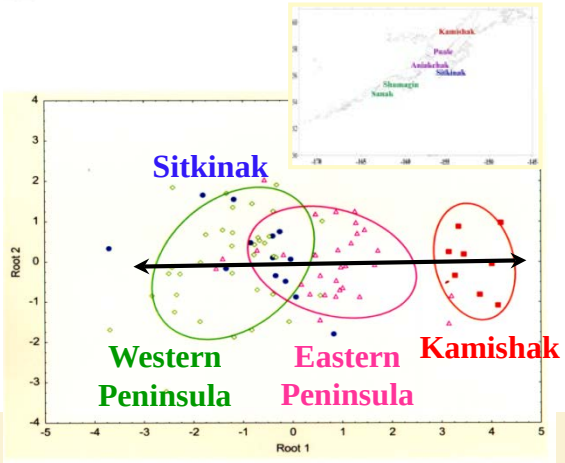

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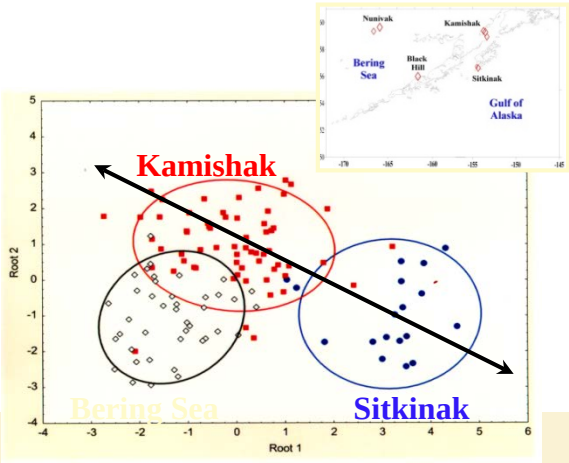

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Some major findings

From larval dispersal modelling (2015-2019)

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From larval dispersal modelling (2015-2019)

- IPHC and NOAA EcoFOCI cooperative project

INTERNATIONAL PACIFIC HALIBUT COMMISSION

EcoFOCI
Ecosystems & Fisheries-Oceanography Coordinated Investigations

In prep:

Early life connectivity of Pacific halibut (*Hippoglossus stenolepis*) within and between the Bering Sea and Gulf of Alaska

Lauri L. Sadorus[1], Esther Goldstein[2], Raymond Webster[1], Josep V. Planas[1], and Janet Duffy-Anderson[2]

[1] International Pacific Halibut Commission, Seattle, WA, USA

[2] National Oceanic and Atmospheric Administration, Seattle, WA, USA

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INTERNATIONAL PACIFIC HALIBUT COMMISSION

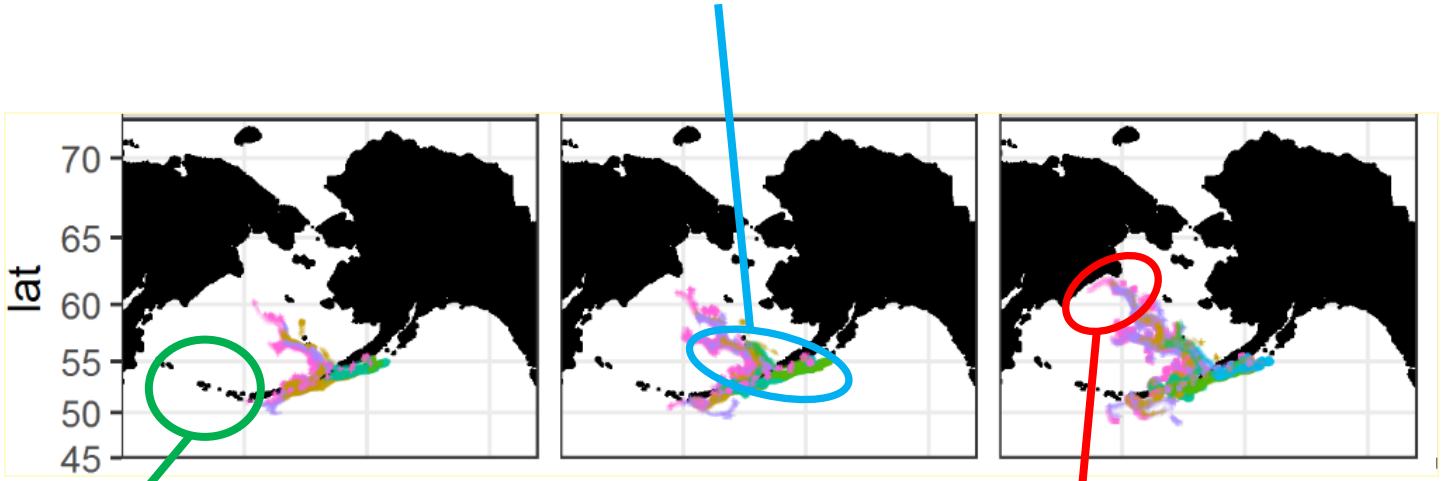
EcoFOCI
Ecosystems & Fisheries-Oceanography Coordinated Investigations

Key questions

- To what degree is the Pacific halibut population connected through larval dispersal and migration?
- Are there environmentally driven differences in dispersal?

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

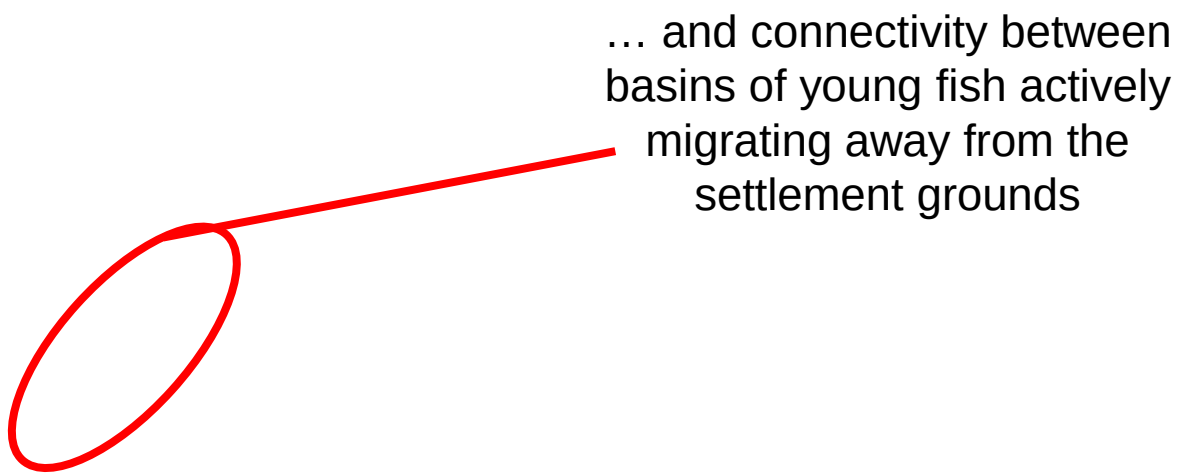
Cross-basin larval delivery that connects the Gulf of Alaska and eastern Bering Sea …



…western Aleutian isolation

… a mechanism for connectivity between north American spawning stock and Russian coastal nurseries

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

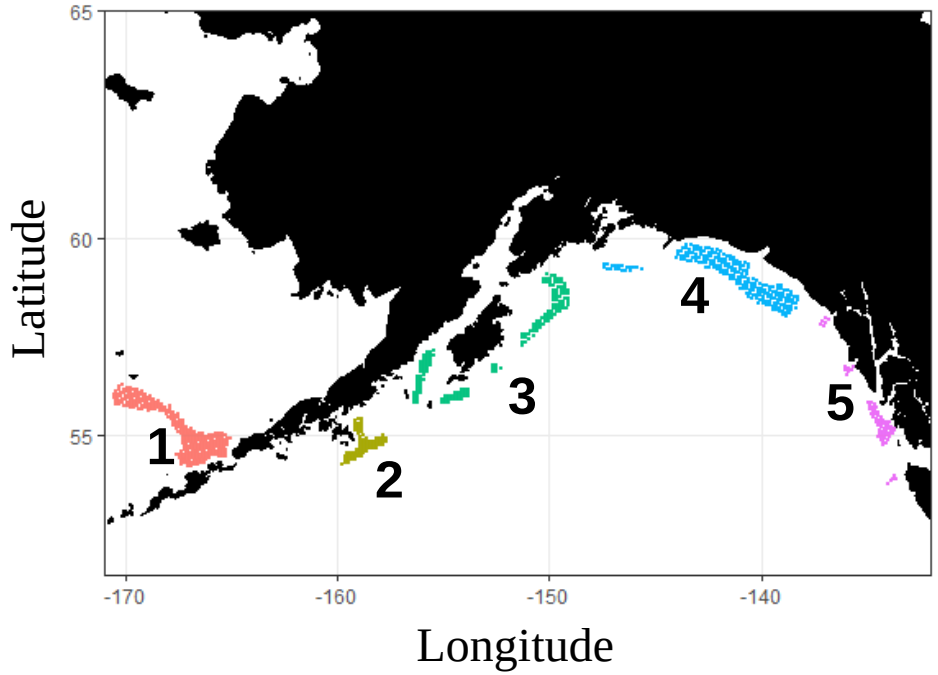


Pacific halibut connectivity: Gulf of Alaska & Bering Sea

Larval dispersal modelling

EcoFOCI
Ecosystems & Fisheries-Oceanography Coordinated Investigations

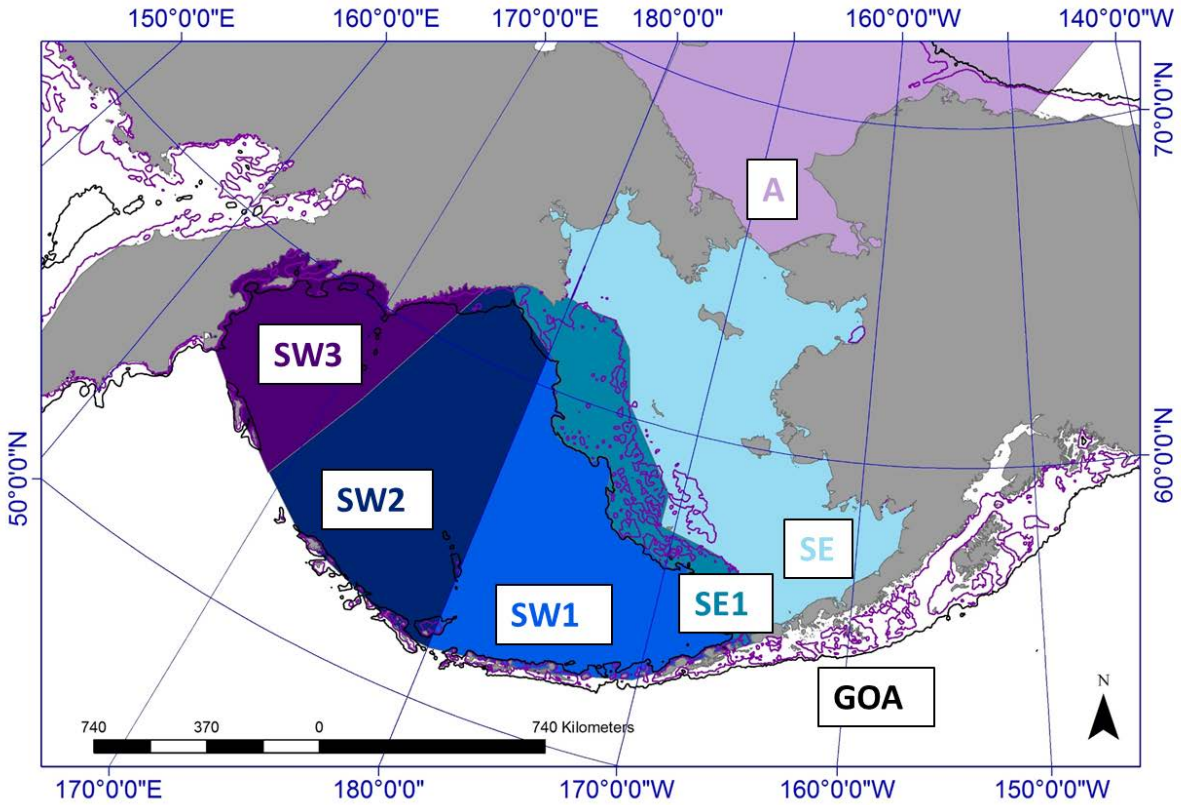
Individual-based Biophysical Model +
Oceanographic model (ROMS NEP6) + Pacific halibut larval traits



Warm years – stronger year classes
2003
2004
2005

Cold years – weaker year classes
2009
2010
2011

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

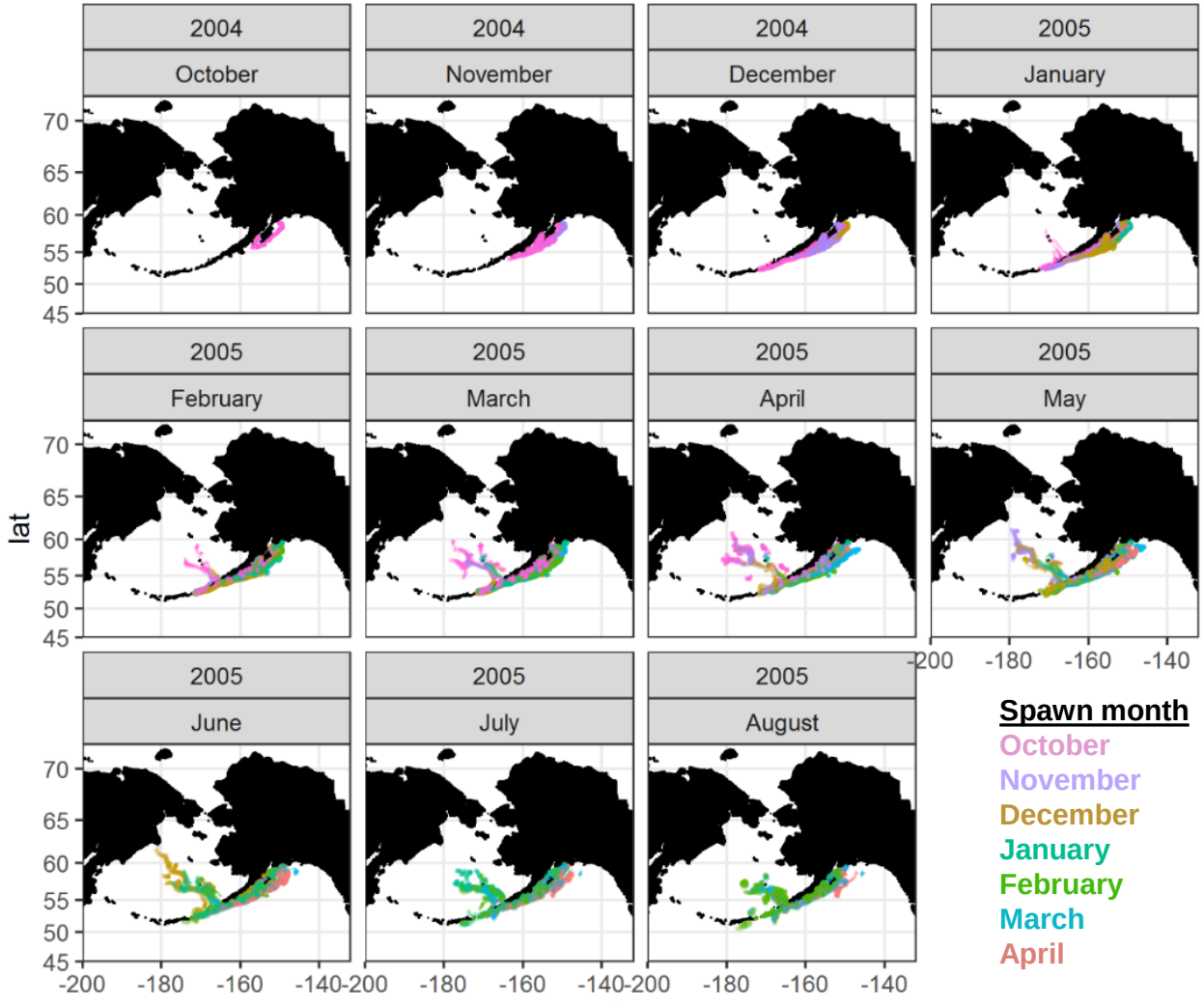


Divided the model domain into 7 regions:

GOA
SE
SE1
SW1
SW2
SW3
A

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

Example output from larval migration model: Spawning region 3



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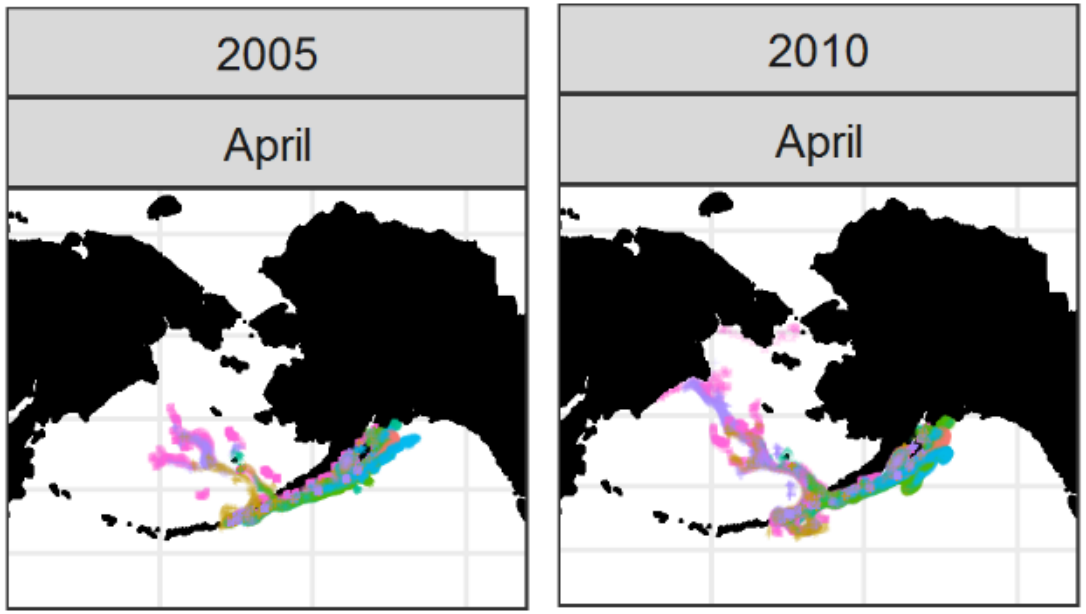
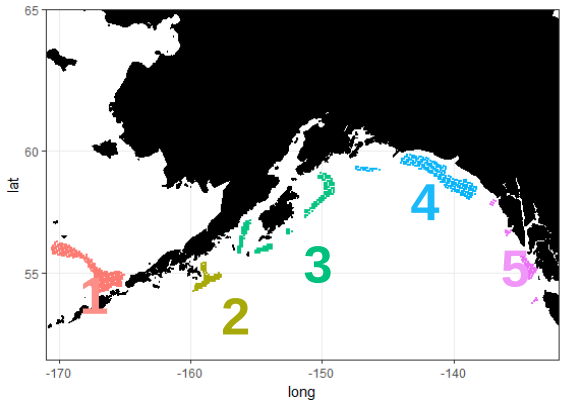
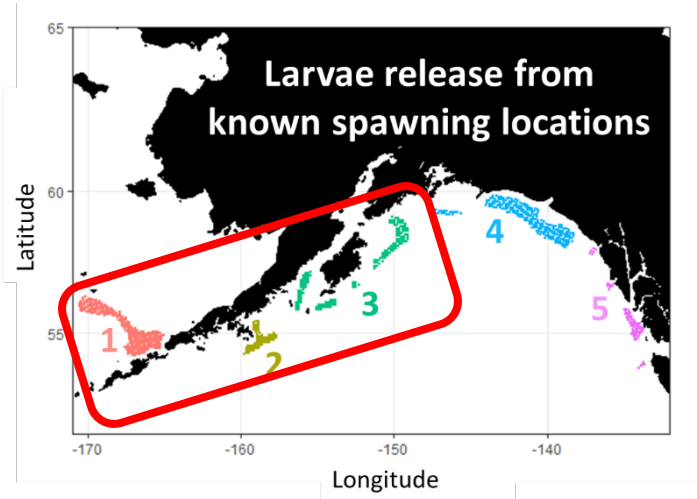
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

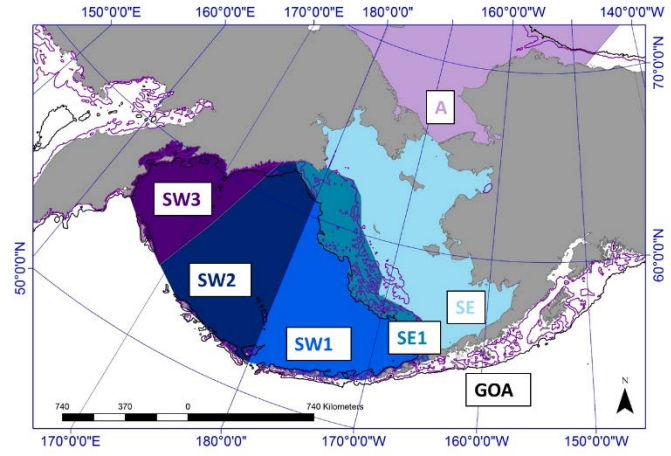
- Modeling shows inter-annual differences in northward transport

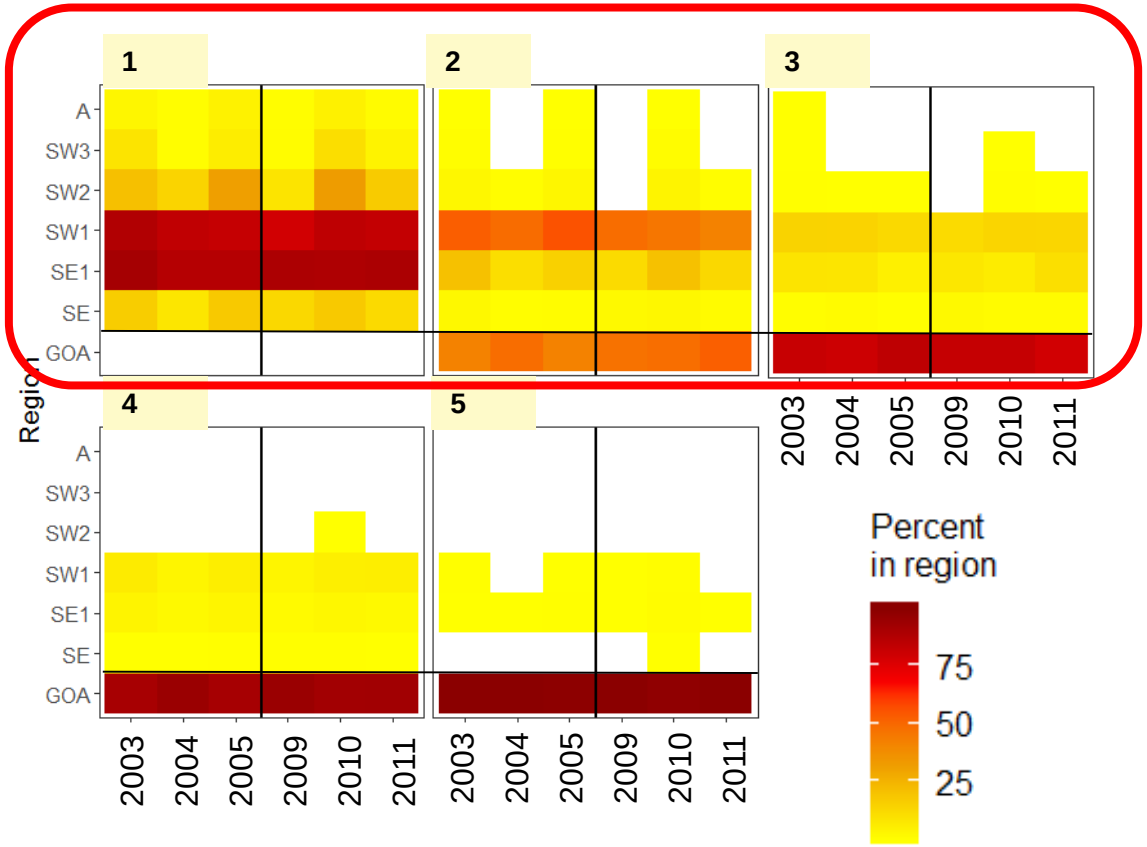




Pacific halibut connectivity: Gulf of Alaska & Bering Sea

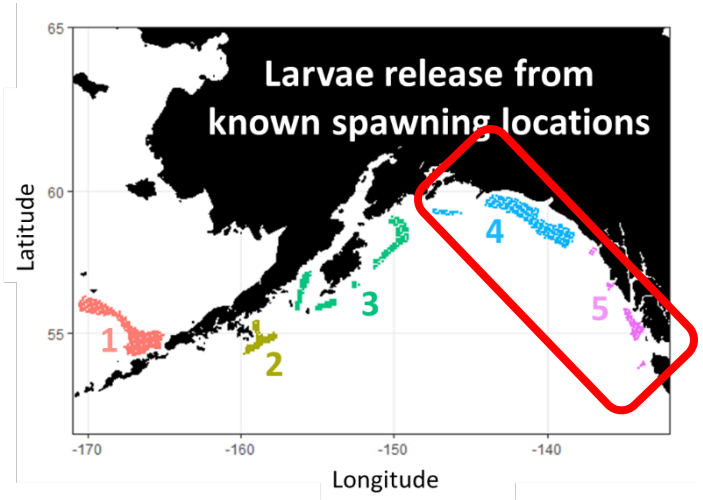


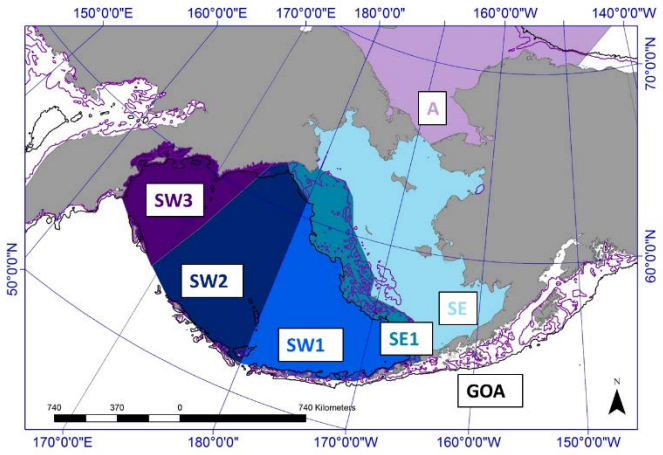


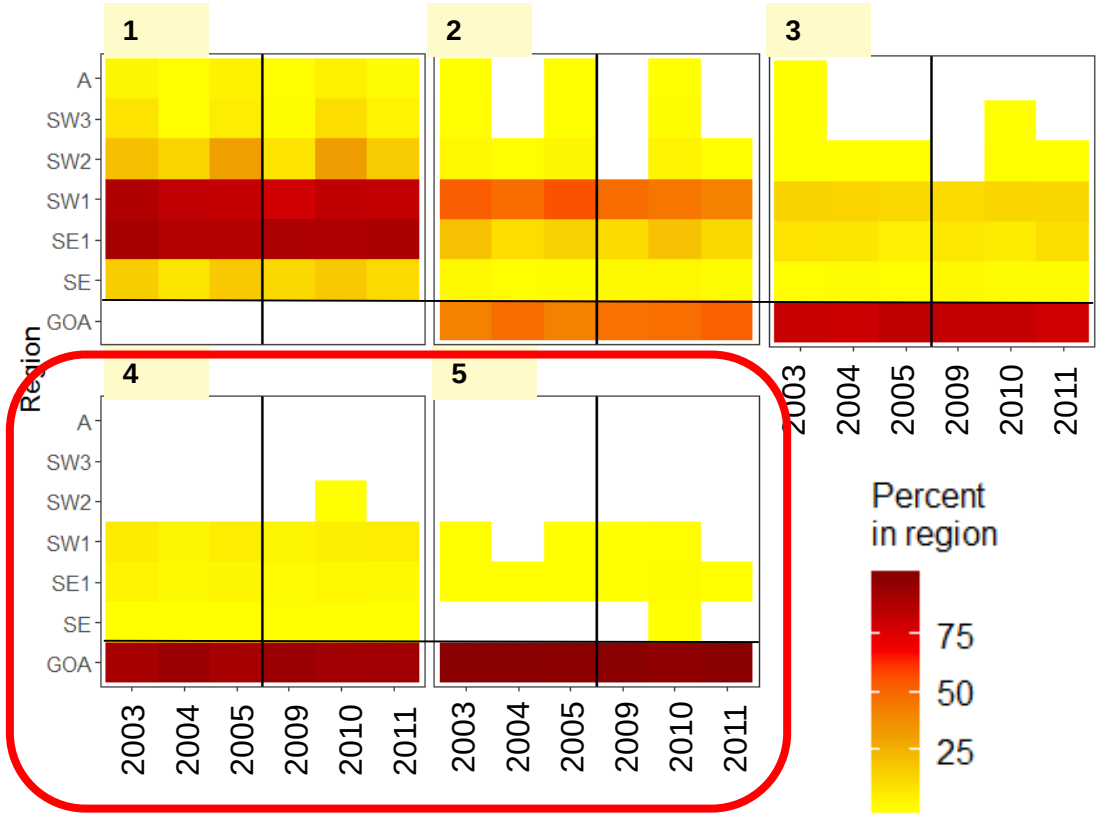


Spawn regions 1, 2, and 3 contribute to Bering Sea settlement population

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

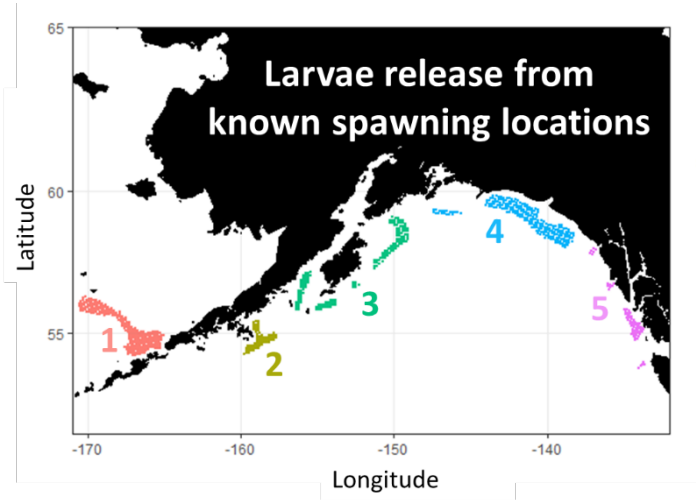


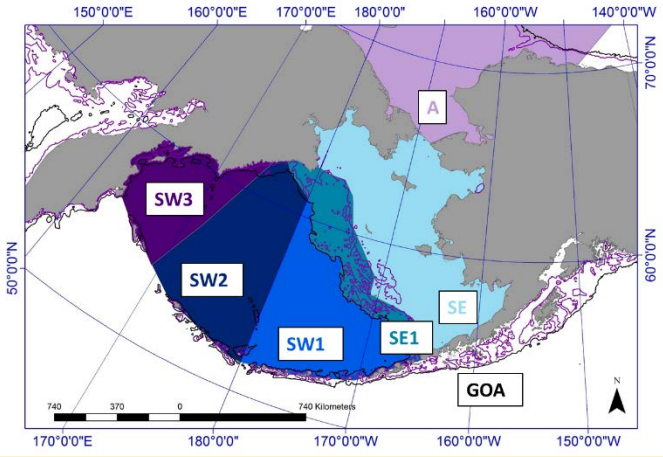


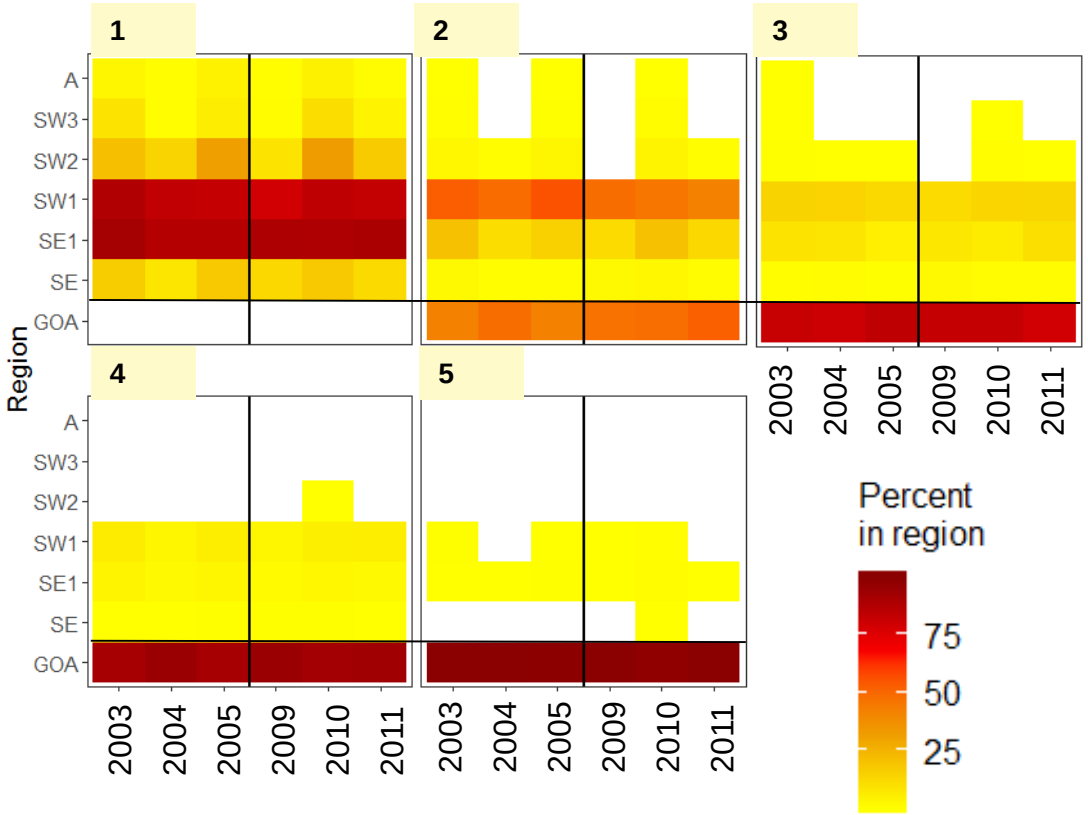


Spawn regions 4 and 5 contribute primarily to the Gulf of Alaska settlement population

Pacific halibut connectivity: Gulf of Alaska & Bering Sea





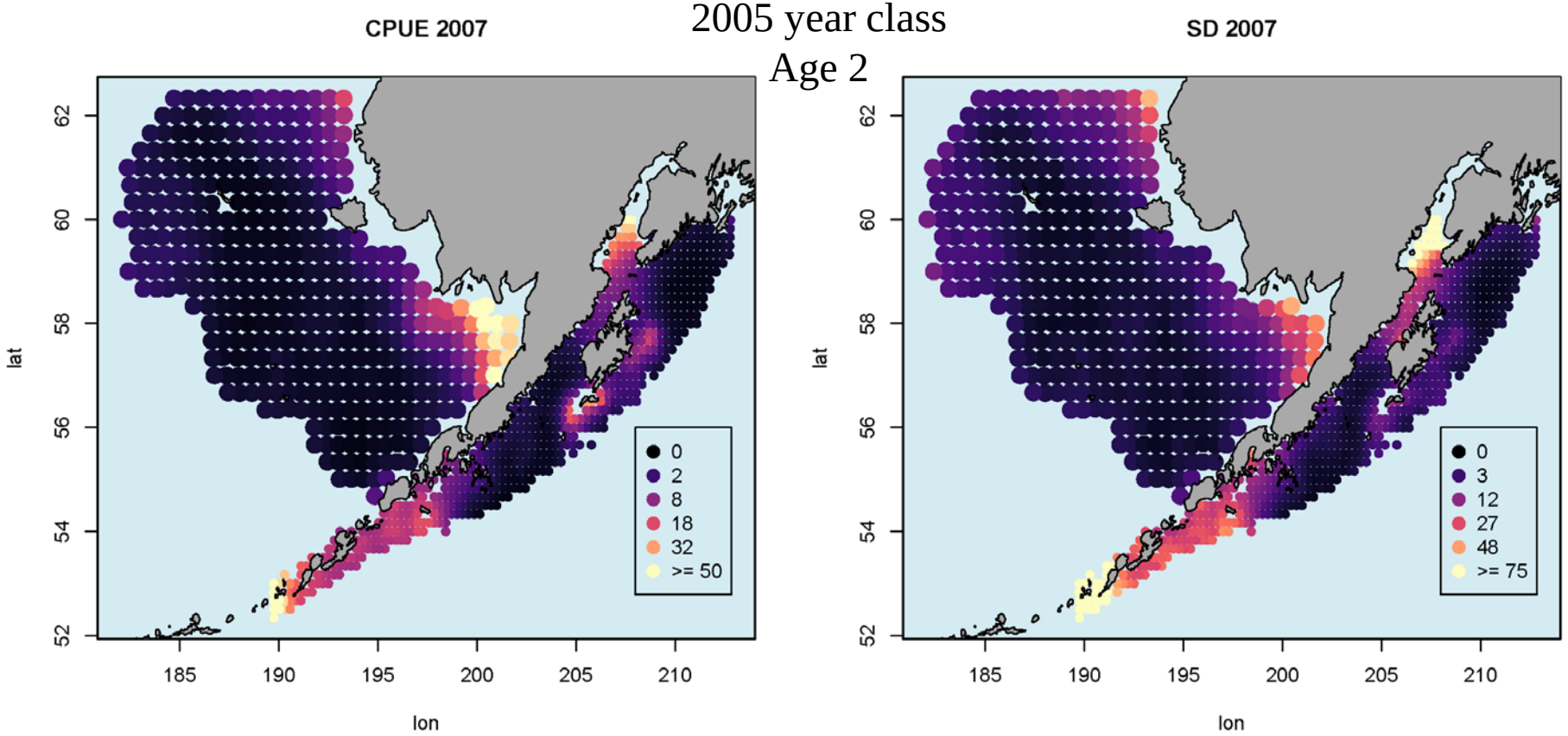


Although there are inter-annual dispersal differences, there are no obvious differences between warm and cold regimes

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

And the story continues…

2005 year class
Age 2

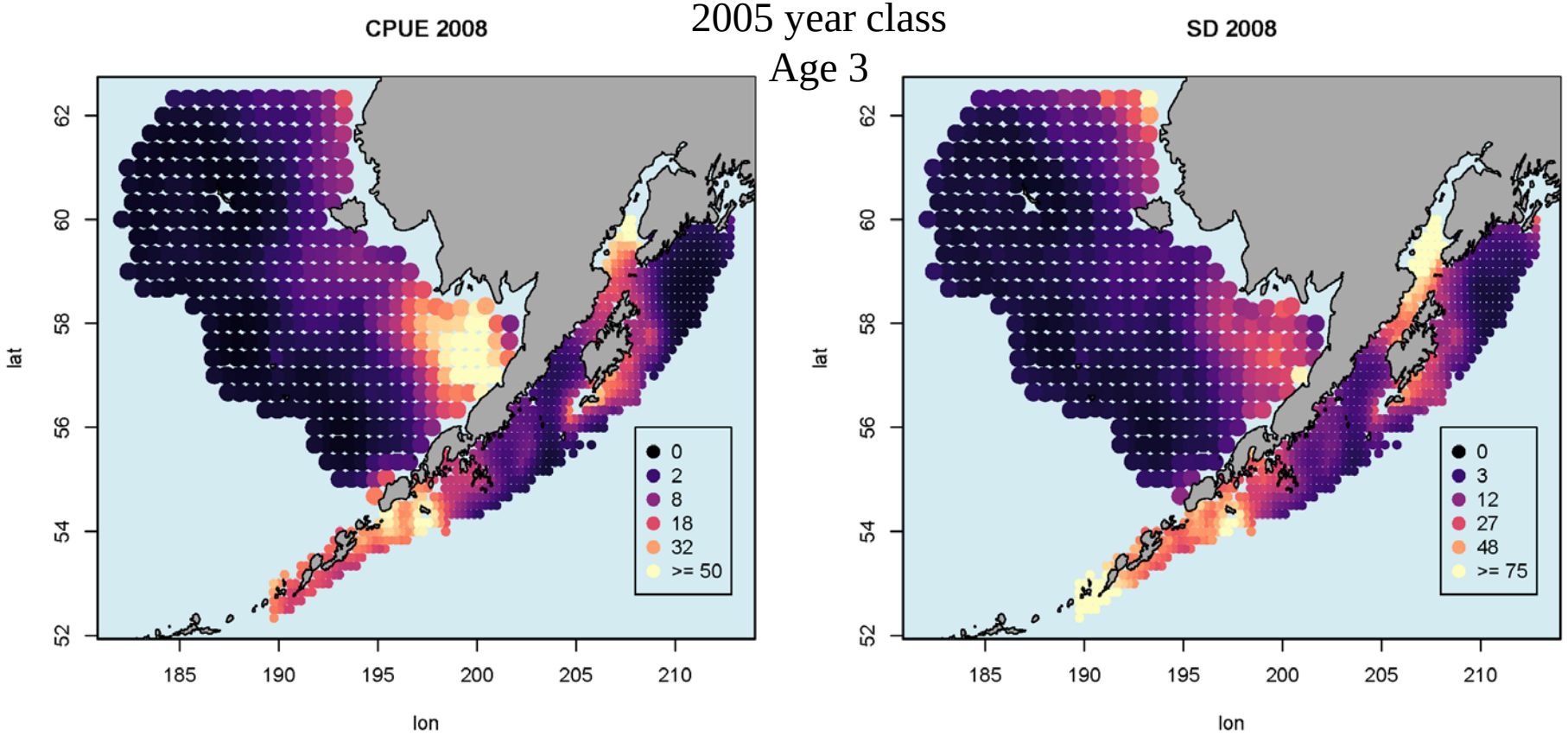


Using the IPHC Spatial Model to map the distribution of a cohort
Example output from the 2005 year class

SRB 114

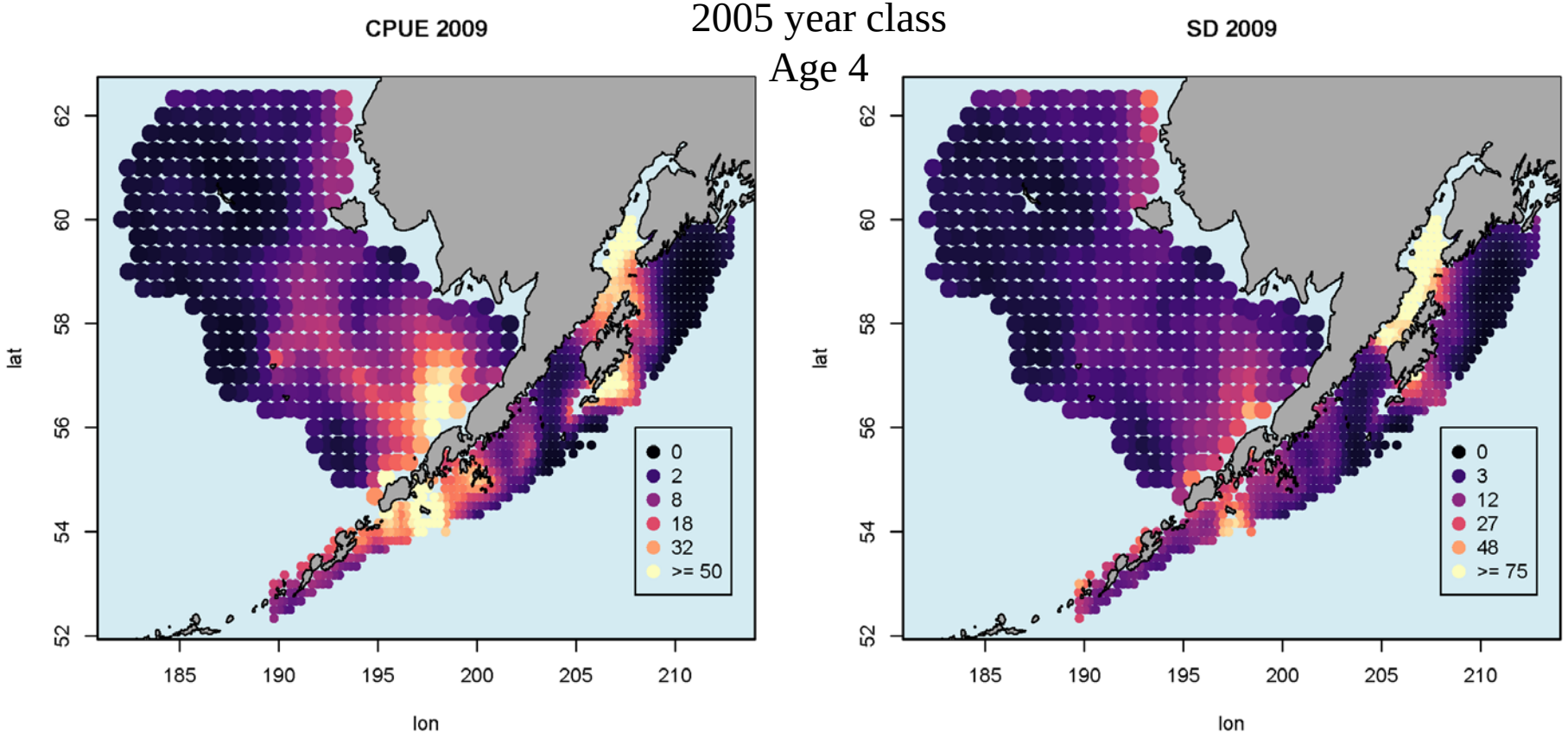
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

2005 year class
Age 3



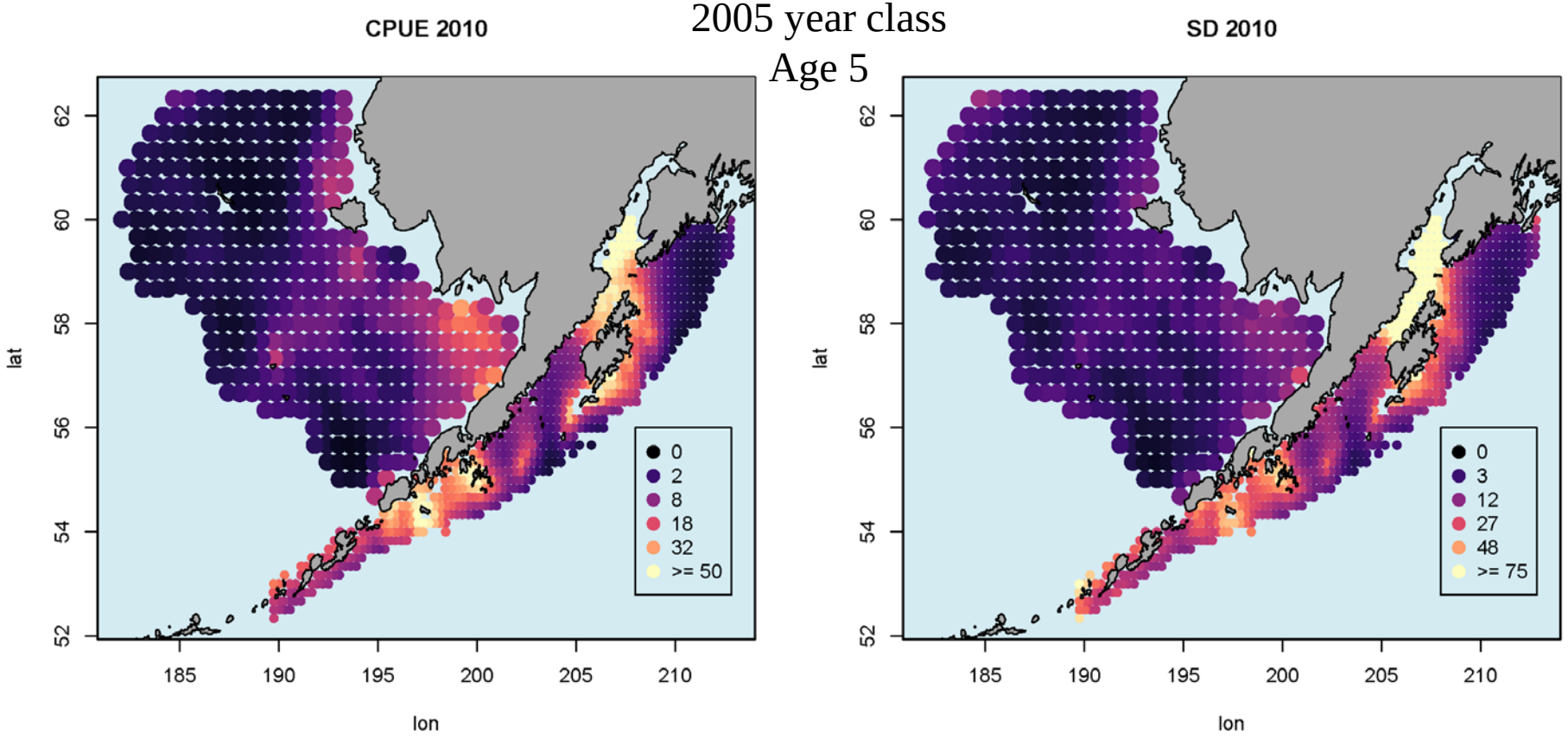
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

2005 year class
Age 4



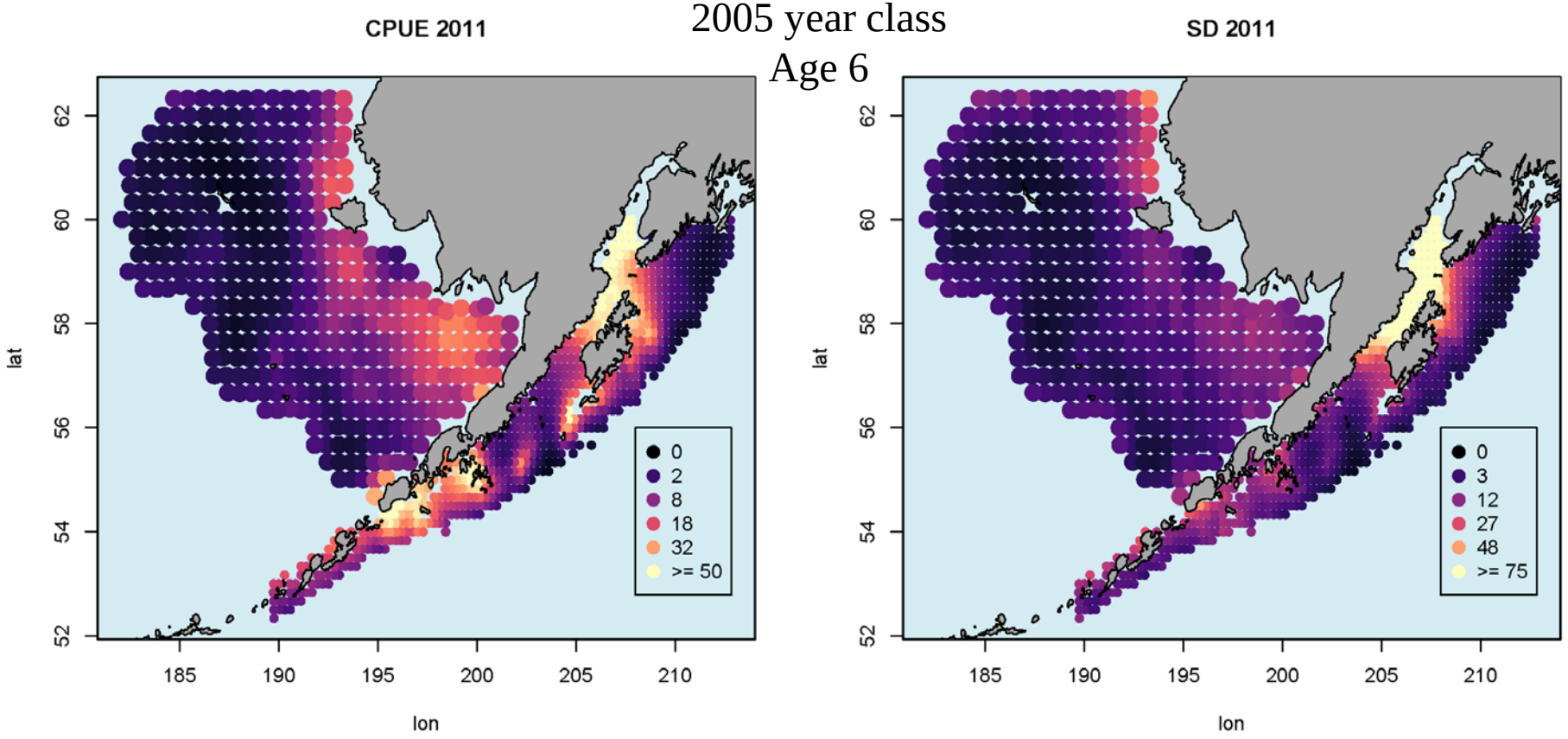
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

2005 year class
Age 5



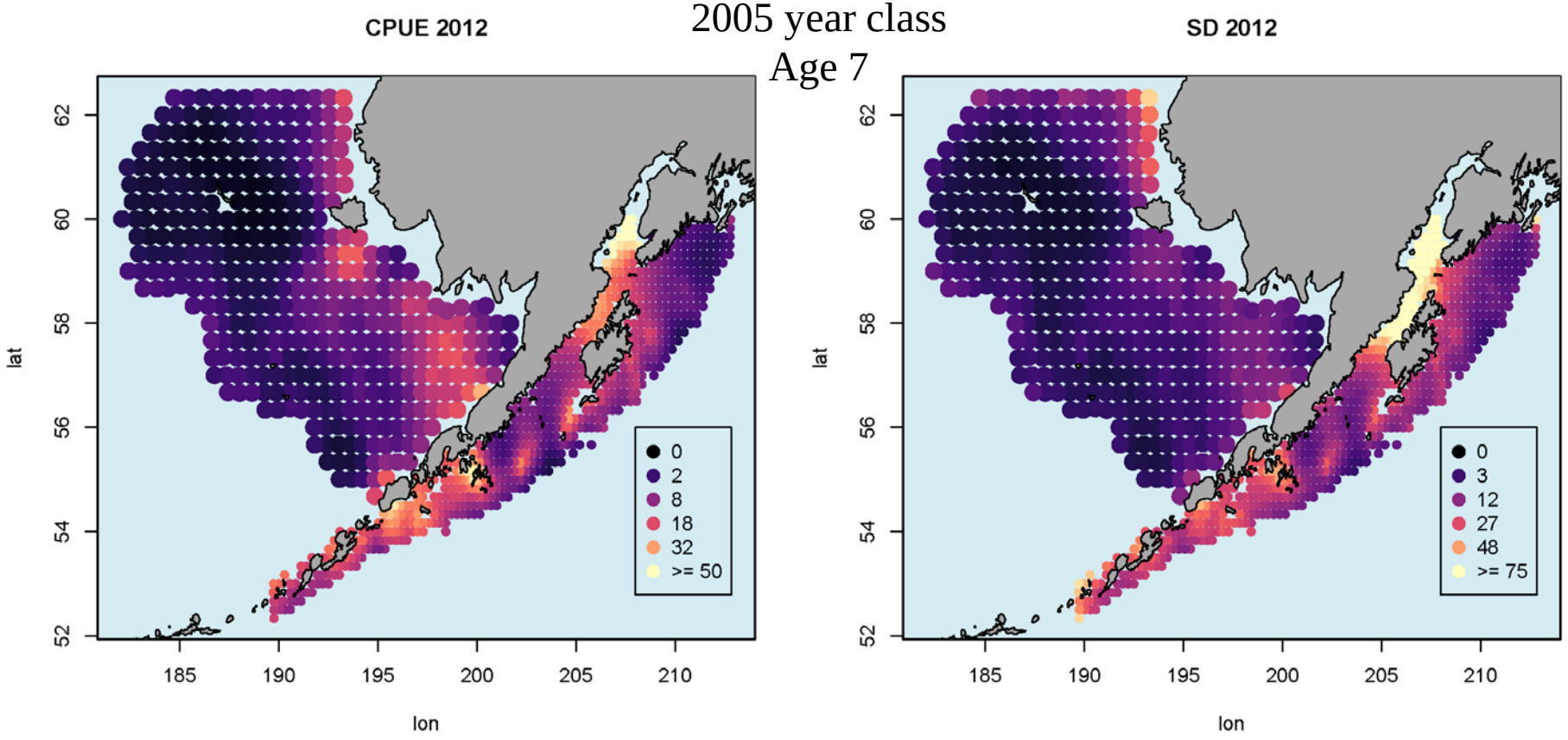
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

2005 year class
Age 6



Pacific halibut connectivity: Gulf of Alaska & Bering Sea

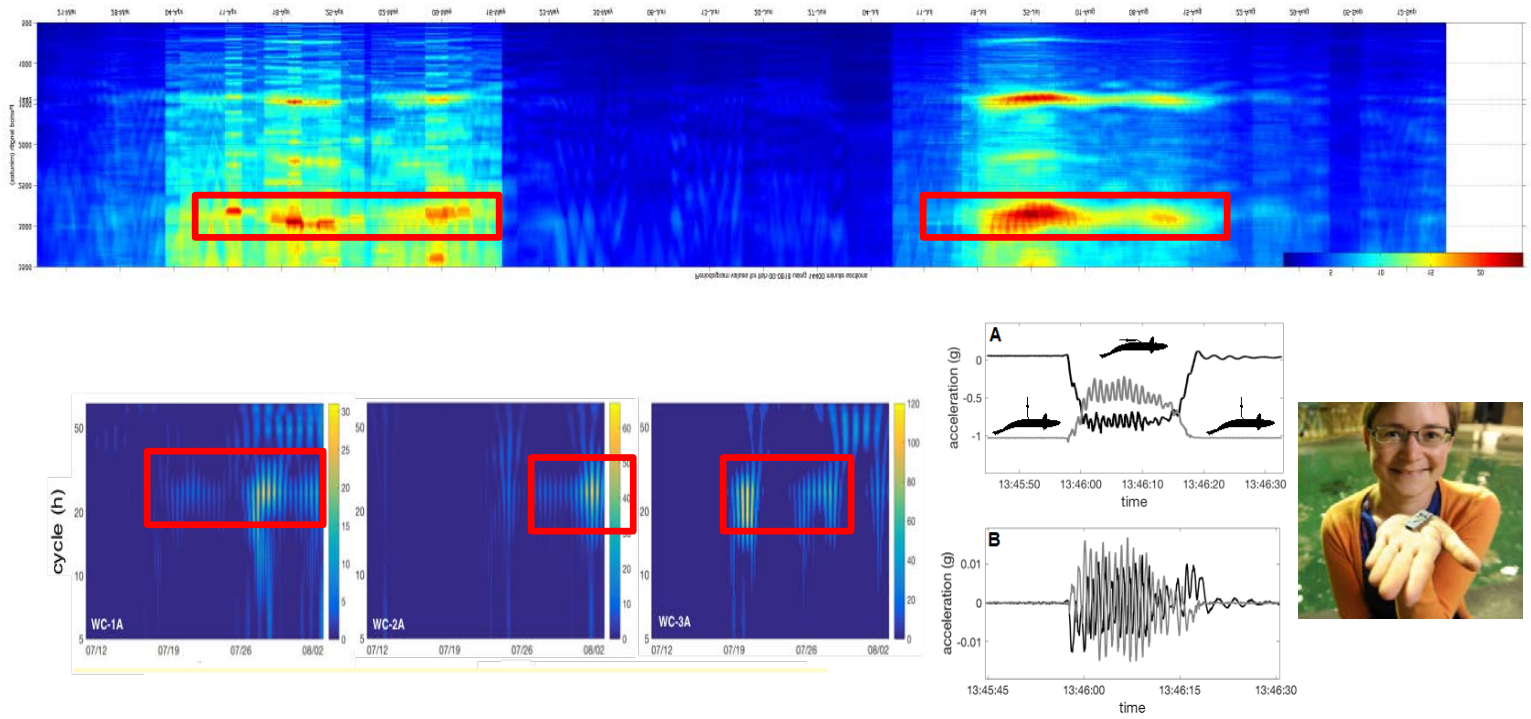
2005 year class
Age 7



Results suggest active migration of young fish from the Bering Sea to the Gulf of Alaska counter to larval dispersal

Additional insights

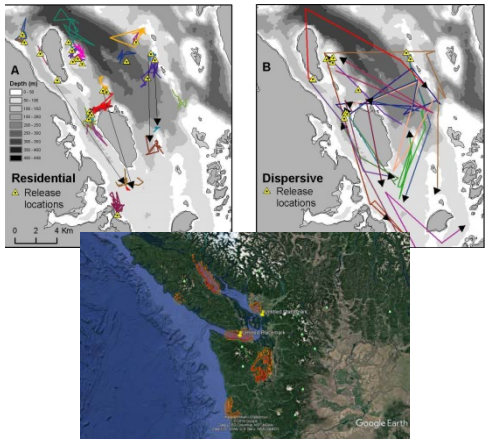
From fine-scale analysis of depth and accelerometry (2012-2015)

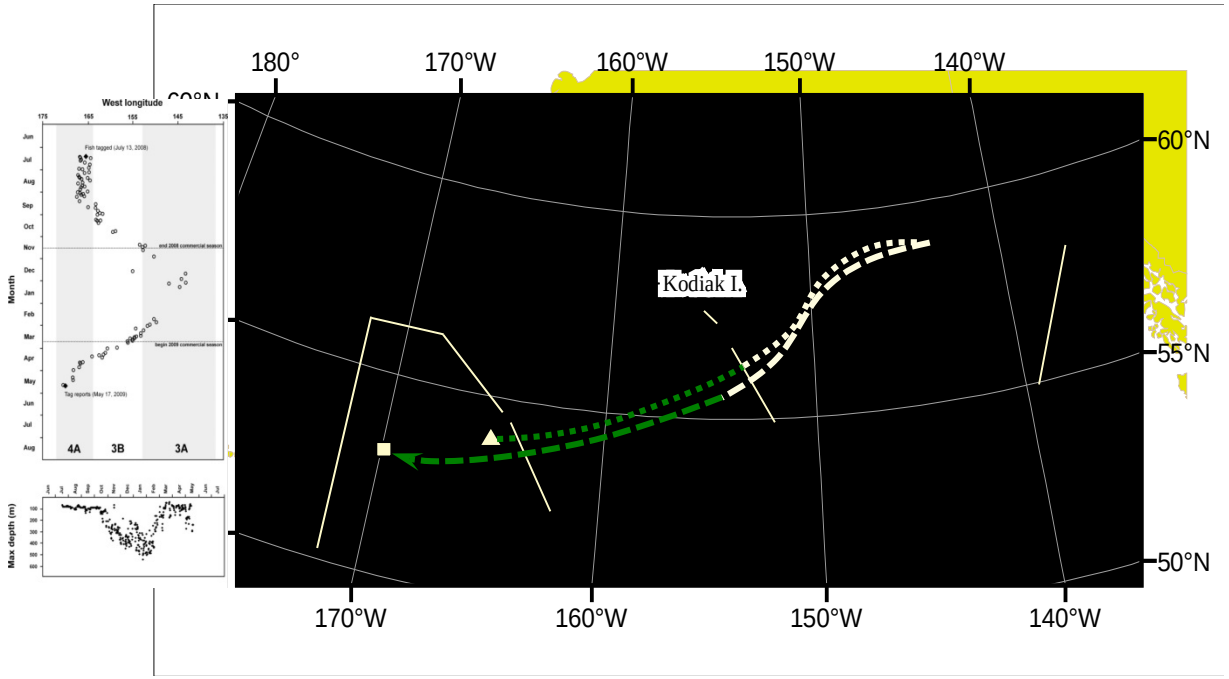


Quantification of diurnal and tidal activity, swimming speed, and *in situ* growth rates

Additional insights

From refinements of Hidden Markov Modelling (2014-2019)





A statistically-based method for tracking movements and modelling distributions

So, where do we go from here?

Philosophies of research planning

Ultimately, research planning and project selection can be viewed to exist along a continuum of planning horizons

- Using historical IPHC connectivity projects as an example:

Multi-decadal scale

Far-reaching institutional objectives

Identify recruitment sources for all harvest sectors, quantify downstream mortality impacts, and resolve between long-term changes in migration versus spatial recruitment dynamics

Juvenile otolith microchemistry (Proj. 620)

Most of what we do falls somewhere in the middle

Annual scale

Immediate Constituency concerns

2A Tribes question whether the Southern Salish should be a separate Regulatory Area

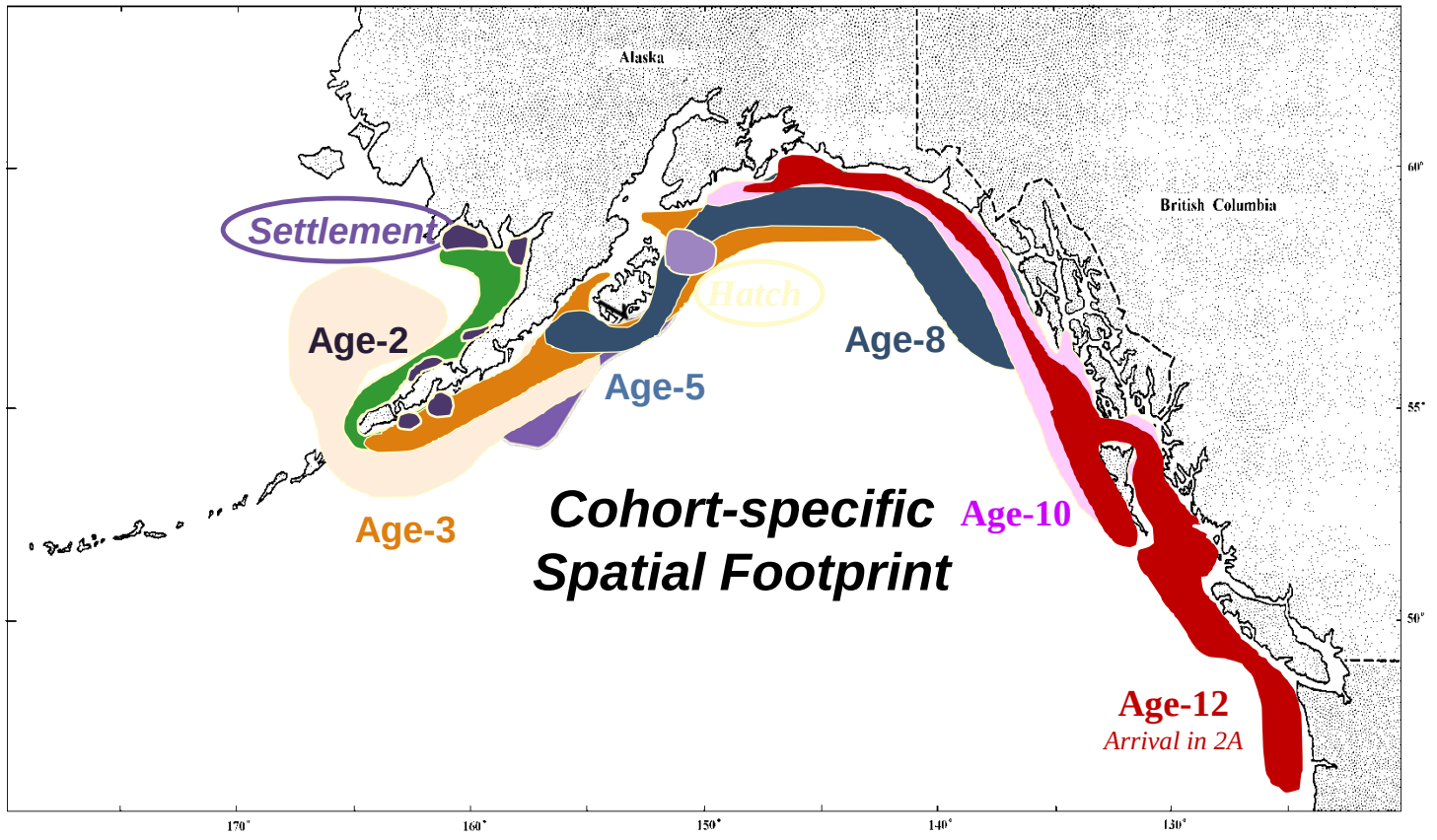
Salish Sea PAT-tagging (Proj. 646.13)

In this Planning Model I'll tend toward the left side; i.e., essentially decadal-scale

An operational question

What information/data would we need to model each step in the process?

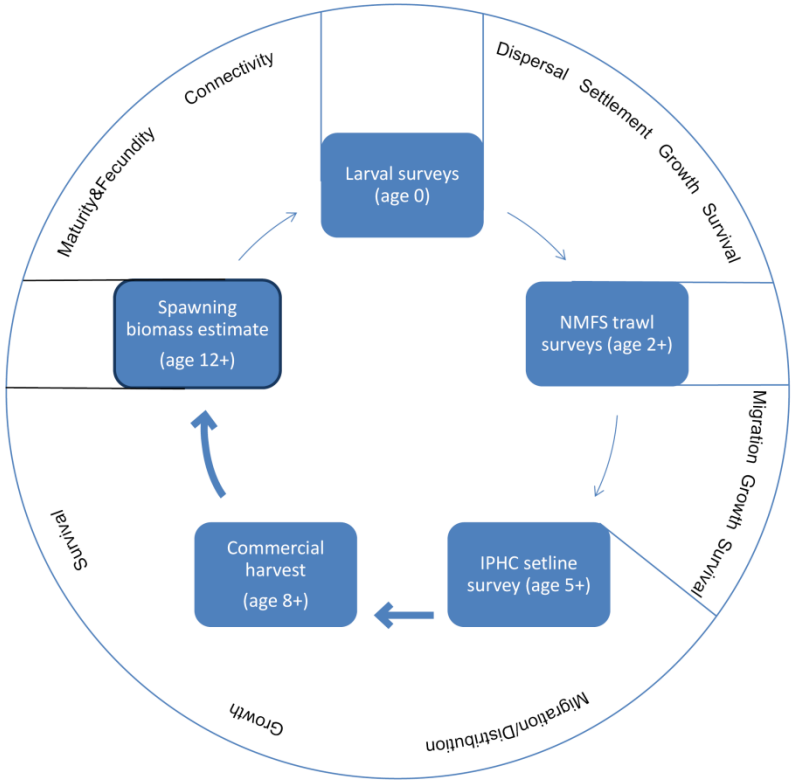
- Example: spatial progression of a distinct source population



A conceptual approach

What information/data would we need to model each step in the process?

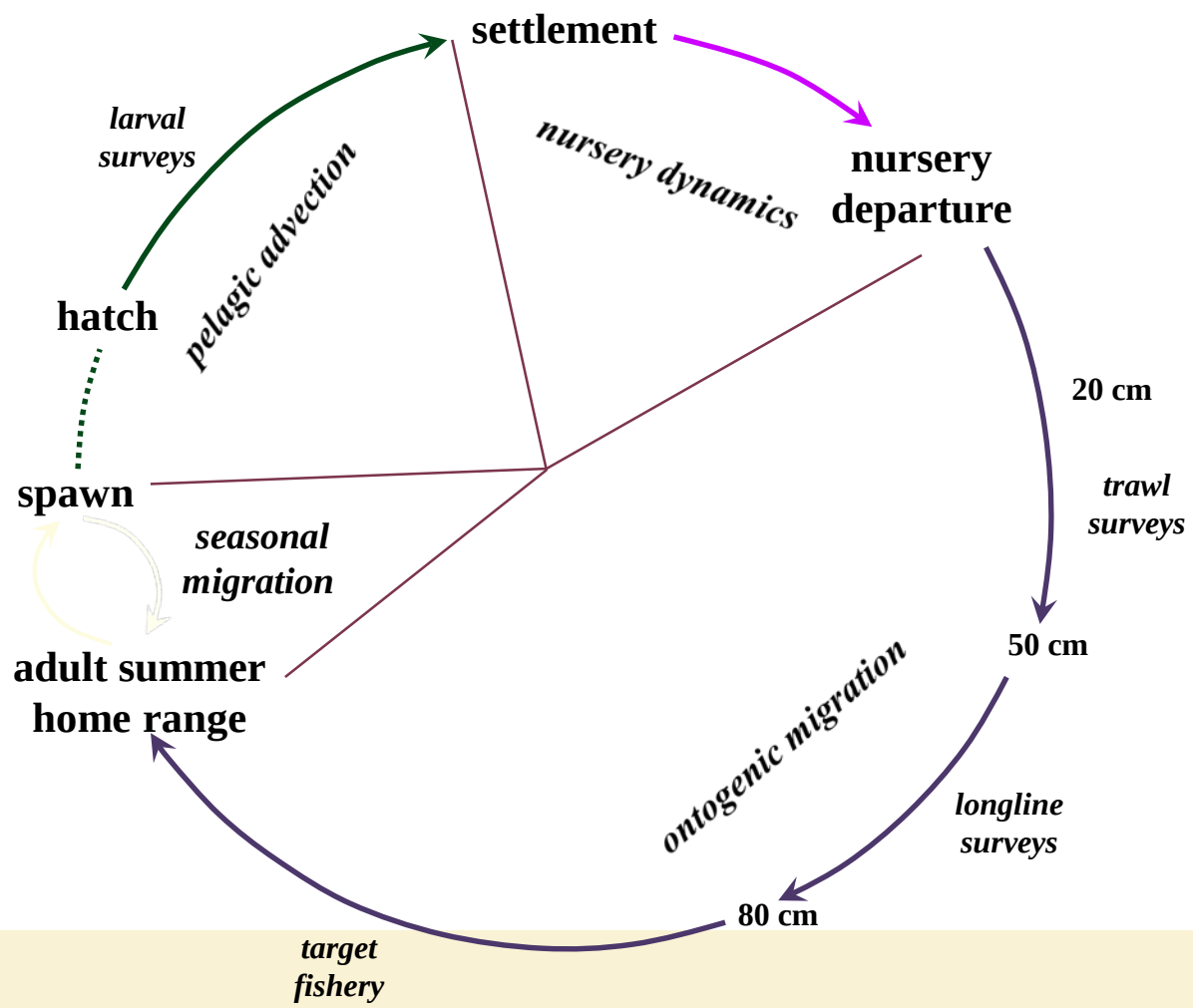
- *A conceptual life-history model* allows us to identify elements



"Elements" will translate directly into individual research projects (= budgetary plans)

A connectivity-based life-history circle

… and follow individuals through time



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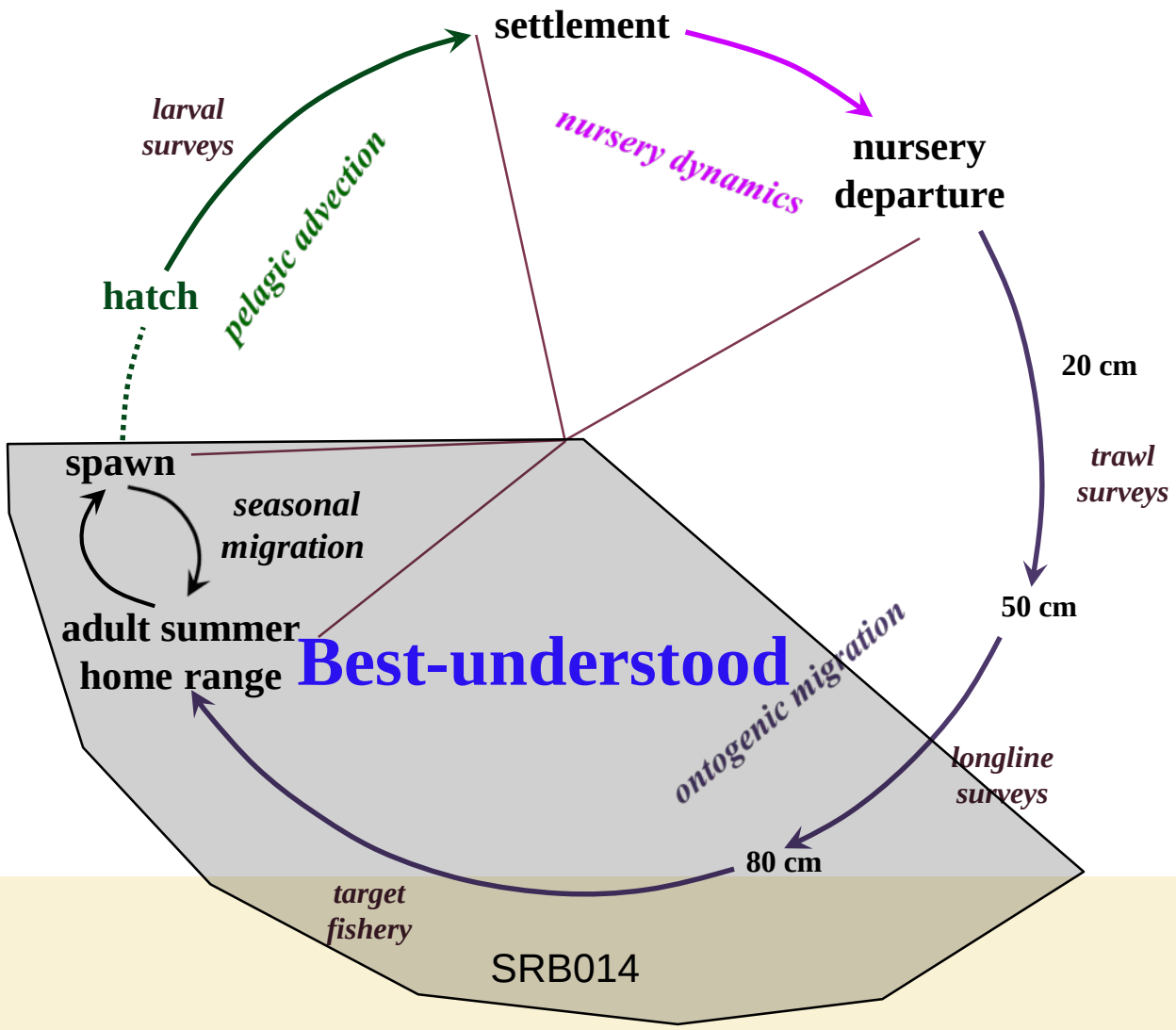

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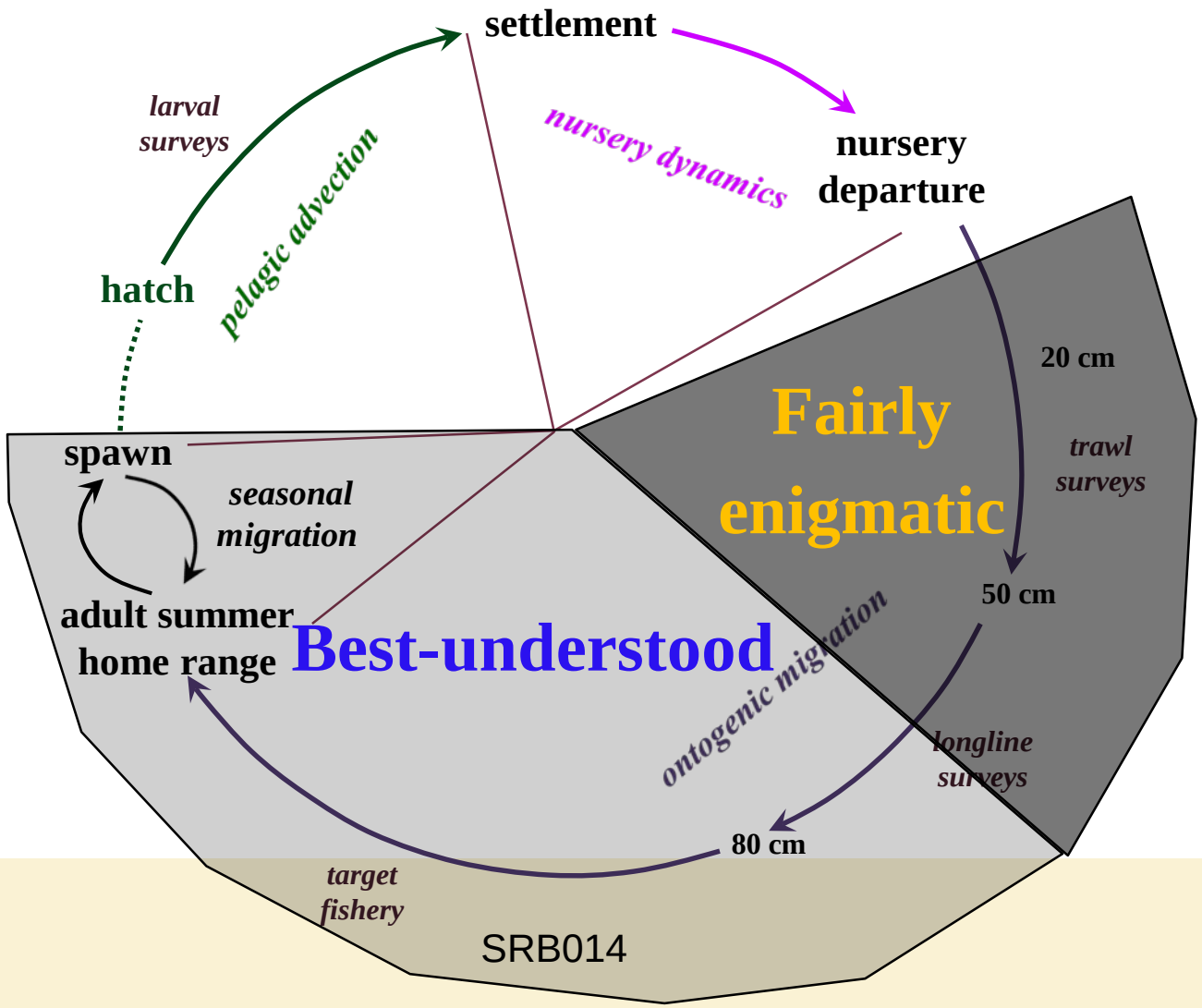

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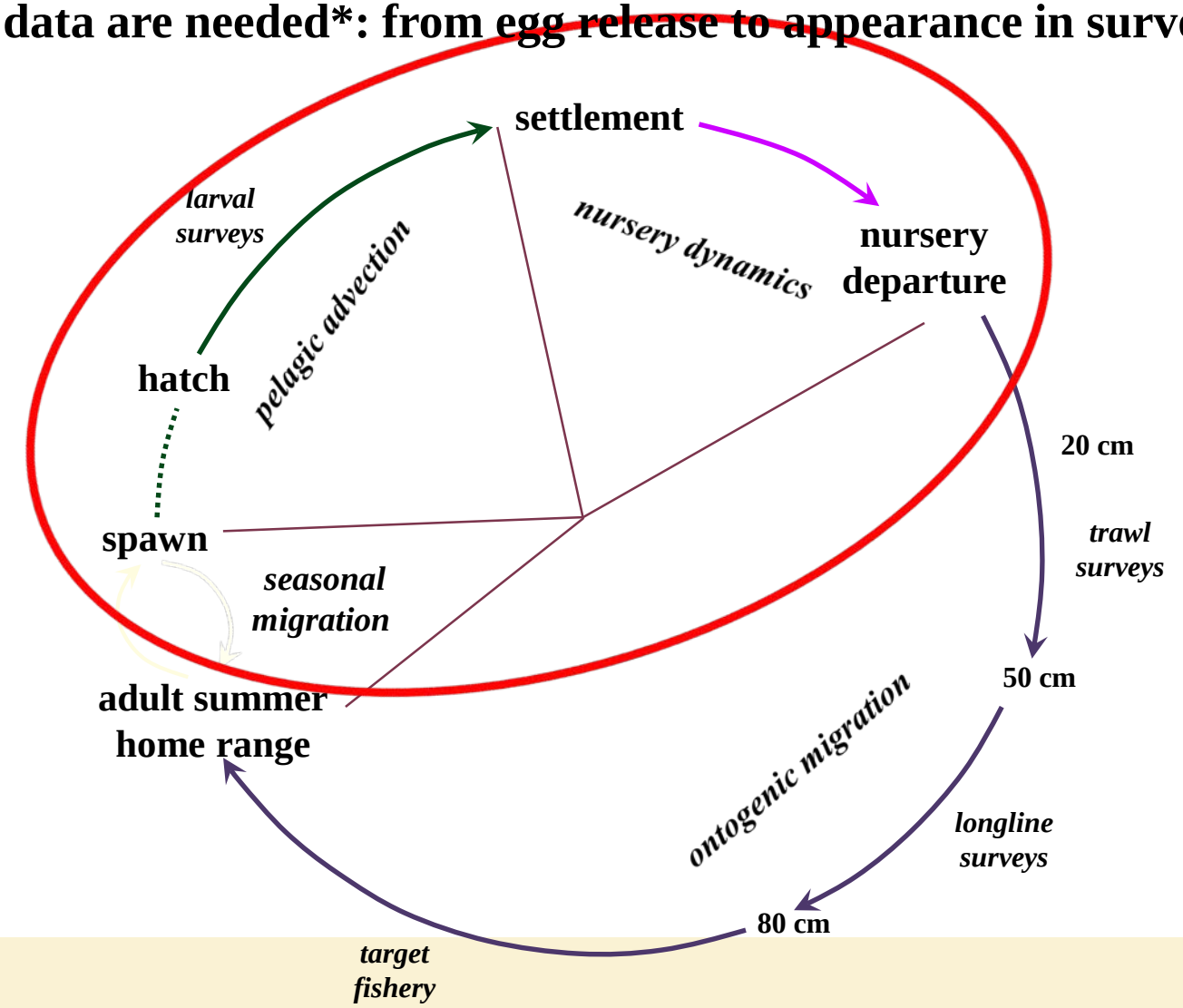
What data are needed*: from egg release to appearance in surveys?



* to parameterize a spatially-explicit landscape ecology model

From life-history model to research planning

What data are needed*: from egg release to appearance in surveys?

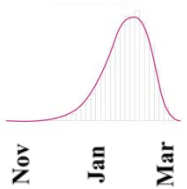
Step 1: Release (spawn) eggs

Locations

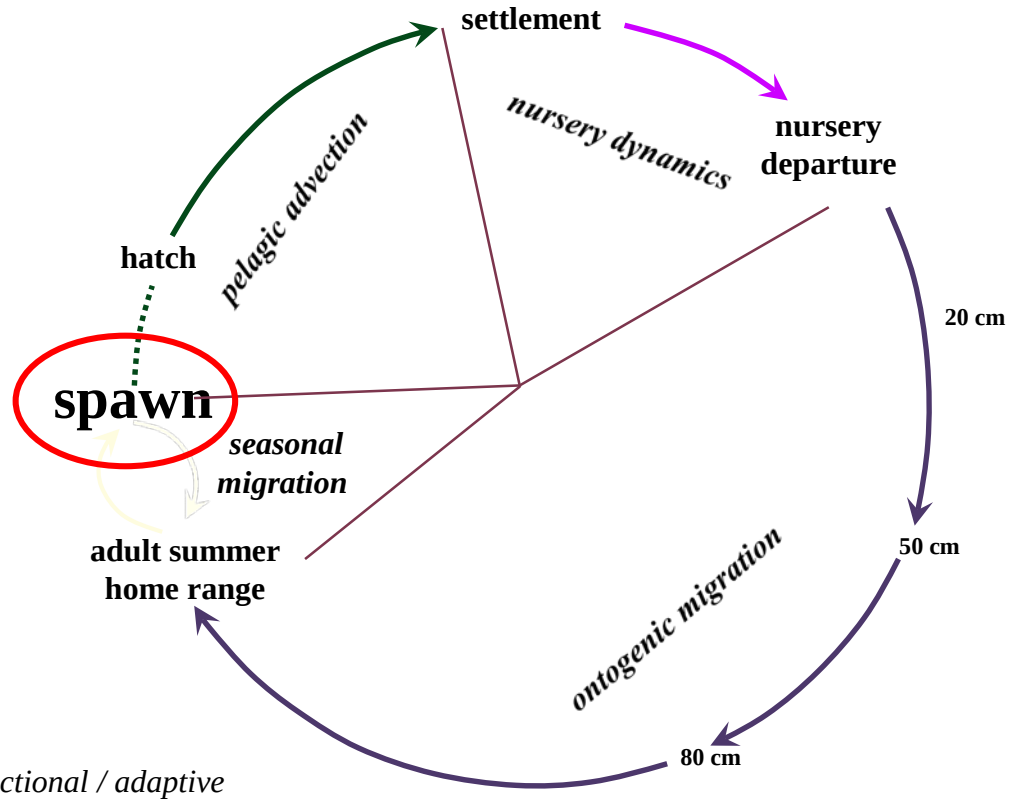
- latitude / longitude
- spatial extent (= initial larval-pool coverage)
- depth strata

Timing

- single-location, group-level distributions



- spatial variance (e.g., latitudinal trend?)
- temporal variance (e.g., climate change?)
  - *site fidelity vs. straying; random straying vs. directional / adaptive*



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From life-history model to research planning

What data are needed*: from egg release to appearance in surveys?

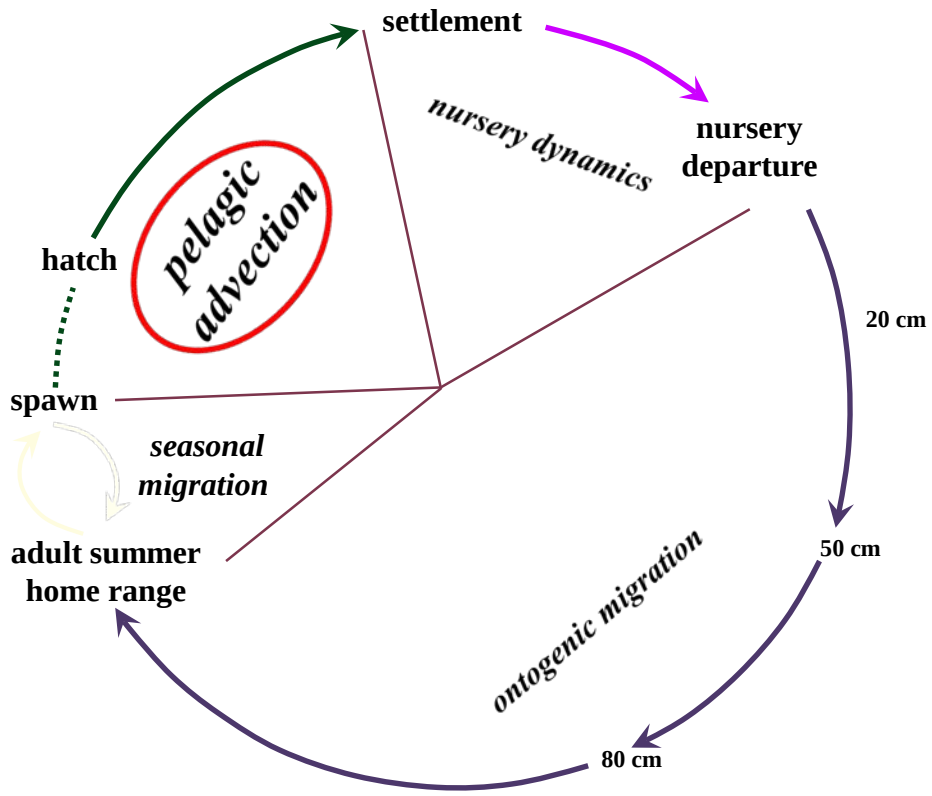
Step 2: Advect larvae

Physical-oceanographic forcing model

- collaborator with appropriate skills

Larval IBM

- developmental model: rates (e.g., degree-day formula); critical feeding periods; temperature / salinity tolerance; mean vertical position by stage
- vertical migration (DVM vs RDVM) & taxis
- swimming speeds / cues (e.g., auditory coastal orientation *sensu* reef fish)



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From life-history model to research planning

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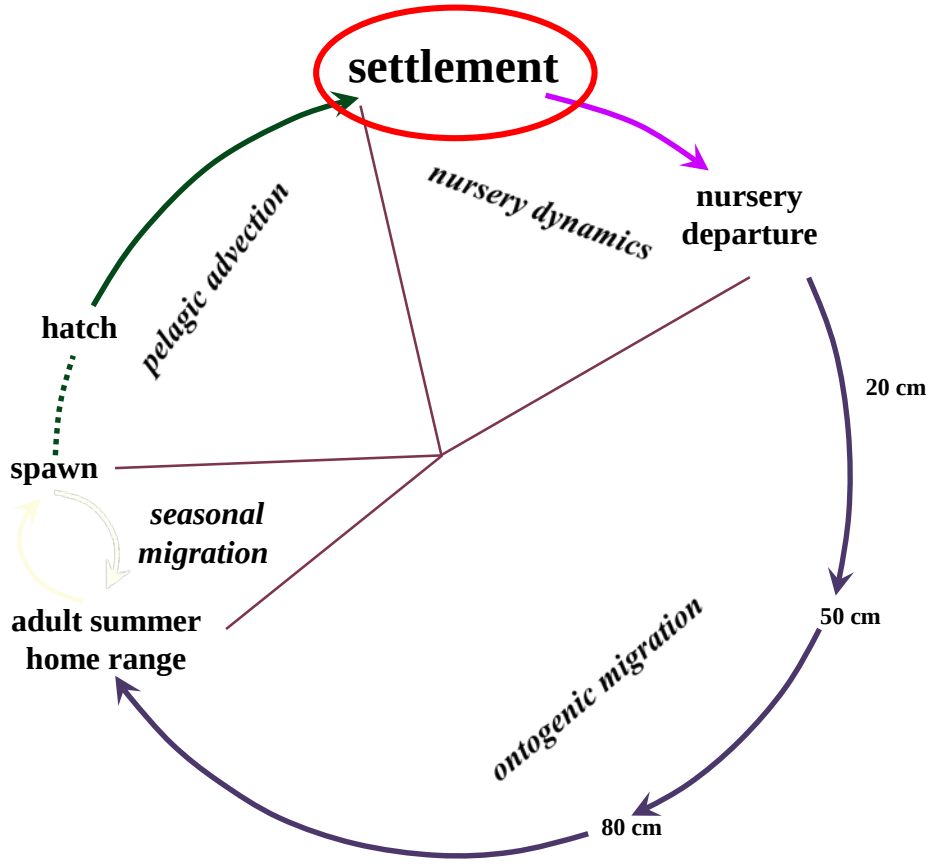
Step 3: Settle larvae

Larval IBM

- settlement preferences (habitat type)
- plastic larval duration (delayed settlement?)

Spatial benthic model

- habitat distribution



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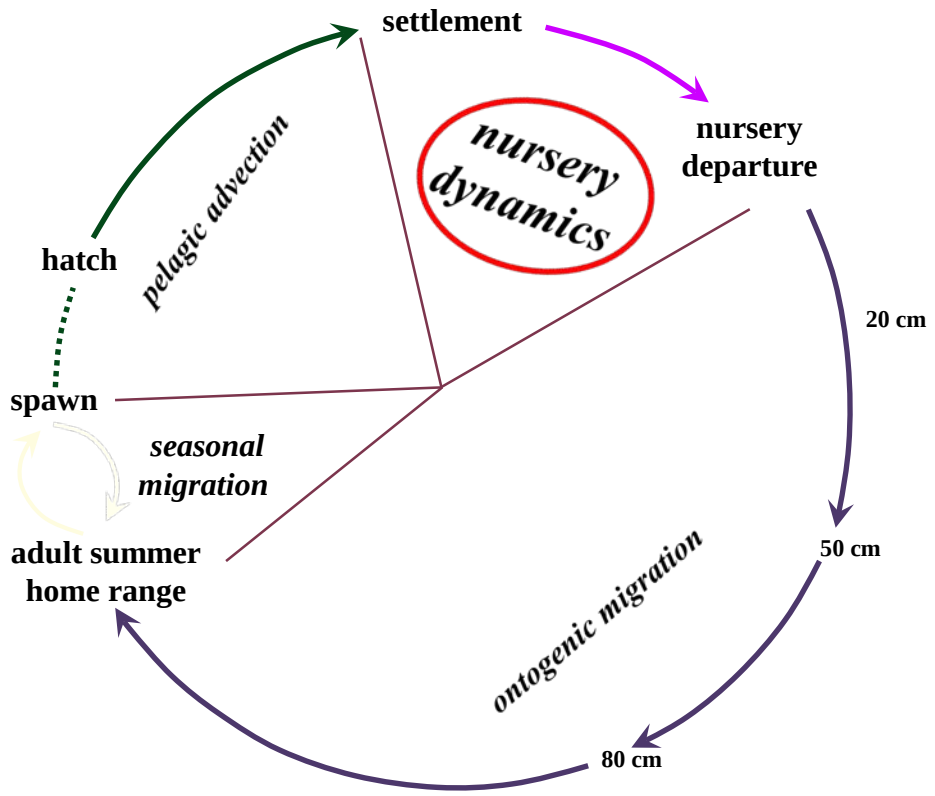
From life-history model to research planning

What data are needed*: from egg release to appearance in surveys?

Step 4: Distribute settlers

Spatial nursery-dynamic model

- early benthic dispersal kernels (magnitudes and forms; random vs. directed; density dependence)
- spatial attrition (mortality)
- emigration cues (developmental, environmental)



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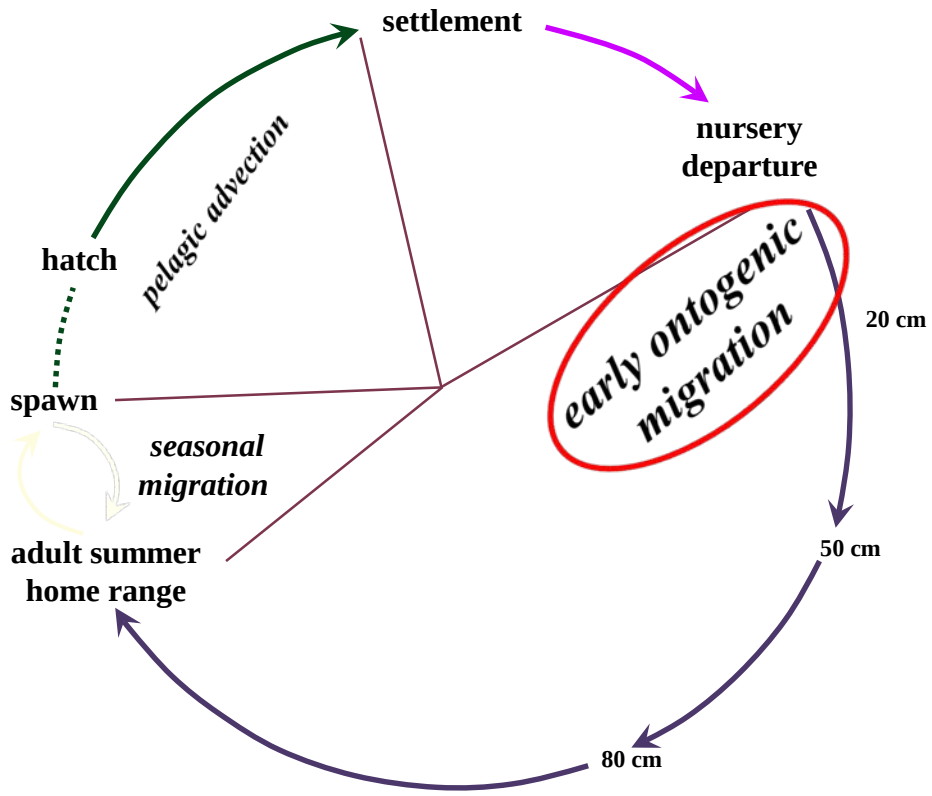
From life-history model to research planning

What data are needed*: from egg release to appearance in surveys?

Step 5: Grow and migrate emigrants

Early ontogenic movement

- dispersal kernels ~ages 2-4 (magnitudes and forms; random vs. directed; sex-specific?)



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Translate data needs into discrete projects

For example:

ELEMENT I - Spawning dynamics

A) Summer-to-winter PAT tagging ***(continues Project #s 622, 622.11.84, 622.12, 621.15, 650.21)***

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Work Summary*:

Deploy tags in Northern California; GOA Inside Waters; northeastern Bering Sea coastal waters and Navarin Canyon System

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Management Application(s)*:**

- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds

**** Amenable to conversion into formal research proposals***

***** Can be expressed as Metadata summaries describing the variables to be quantified***

****** Noting that this category would ideally be populated by the Quantitative Sciences Branch***

Translate data needs into discrete projects

For example:

ELEMENT I - Spawning dynamics

B) Coastwide long-term archival tagging of spawning stock *(NEW)*

Work Summary:

Deploy fishery-recovery archival tags at strategic locations coastwide on mature stock

Primary Data Product(s):

Refined data on spawn timing; especially individual, latitudinal, and temporal variance in mean spawn timing and duration of the spawning season

Translate data needs into discrete projects

For example:

ELEMENT II – Larval ecology

A) Larval development *(NEW)*

Work Summary:

Conduct larval rearing experiments investigating effects on development of temperature, salinity, and ration

Translate data needs into discrete projects

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ELEMENT III – Early-benthic dynamics

Theoretical habitat mapping

Field mapping and sample collection

Intrinsic dispersal and density-dependent processes

Otolith microchemistry

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ELEMENT IV – Early dispersive-phase

Early dispersal

Alternative: select projects *a la carte*

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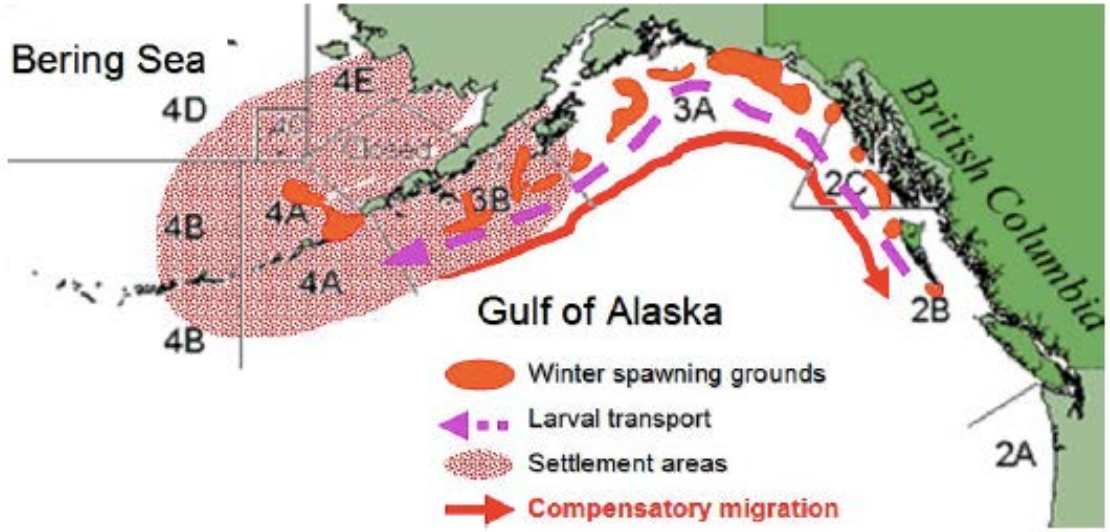
4) **Short-term migratory responses to hypoxic conditions**
   - Has bearing on the relationship between survey CPUE and underlying abundance
   - Might be investigated with acoustic tracking, displacement studies, and targeted collection of environmental data

Incorporation of genetics into migration-related research

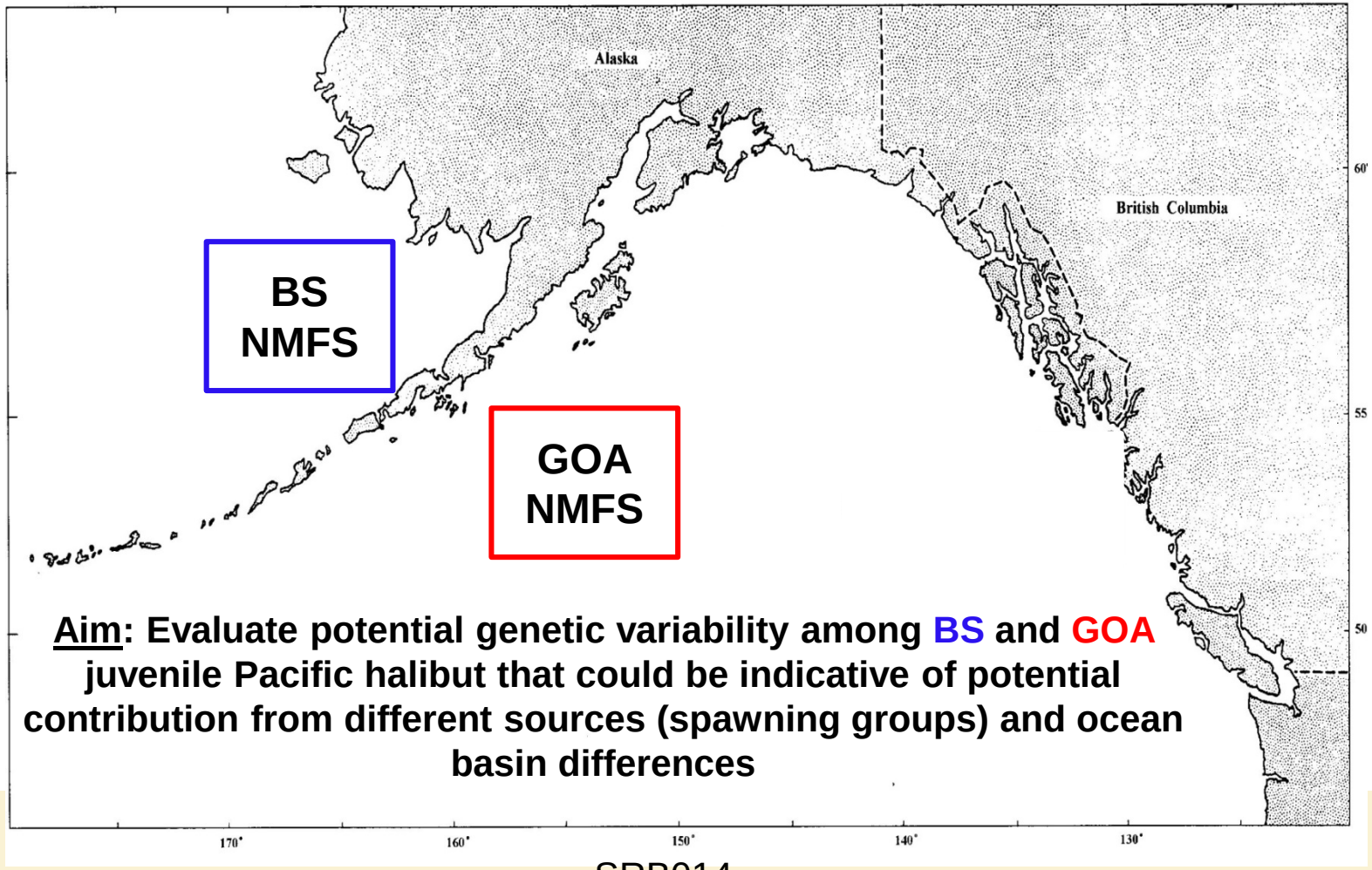


Future projects:

- **Genetic variability among juvenile Pacific halibut in the Bering Sea and Gulf of Alaska**
- **Identification of potential genetic signatures of origin (spawning groups)**
- **Genetic structure of the Pacific halibut population**

Incorporation of genetics into migration-related research

- **Genetic variability among juvenile Pacific halibut in the Bering Sea and Gulf of Alaska**

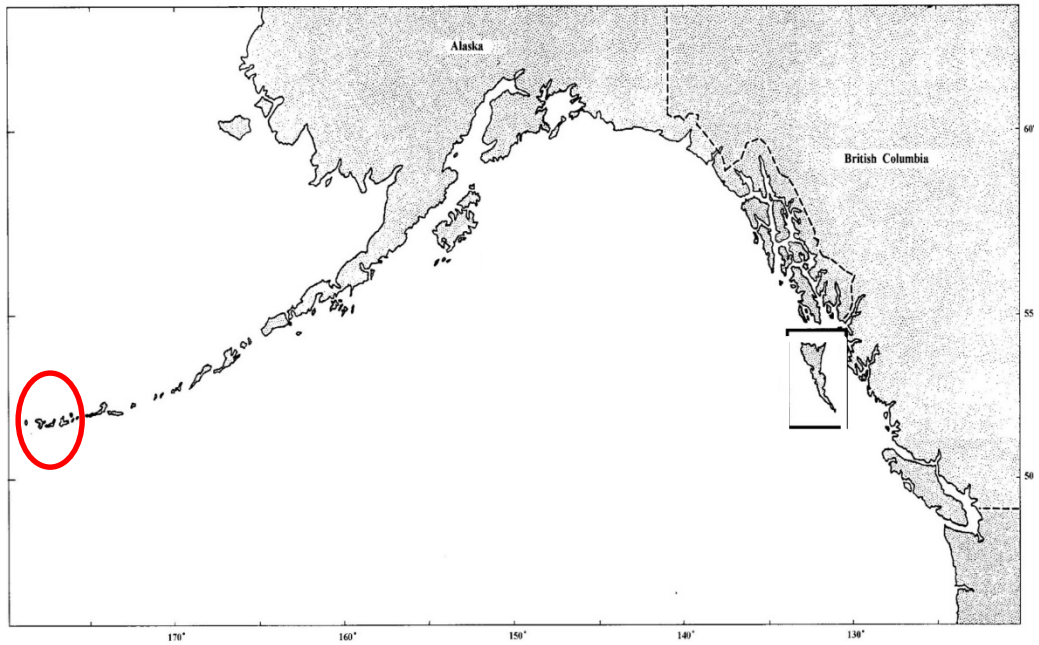


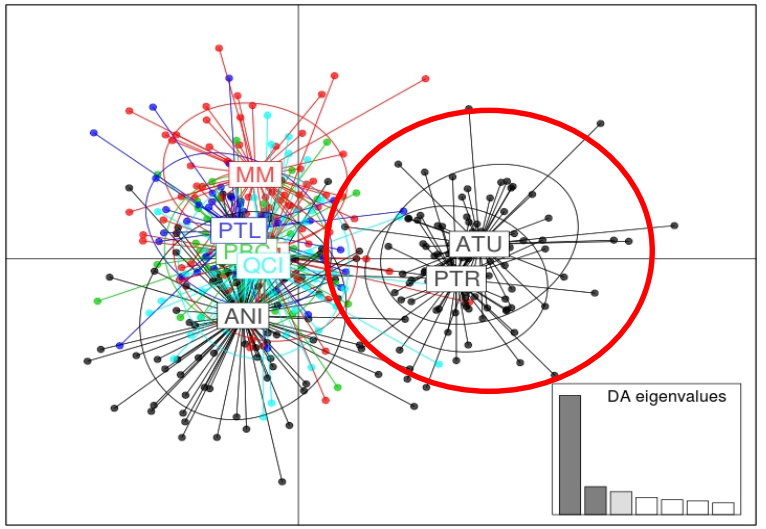
<u>Aim</u>: Evaluate potential genetic variability among BS and GOA juvenile Pacific halibut that could be indicative of potential contribution from different sources (spawning groups) and ocean basin differences

Incorporation of genetics into migration-related research

- **Genetic structure of the Pacific halibut population: Part 1 – East vs West Aleutian Is.**

Drinan et al., 2016. *J. Fish Biol.* (microsatellites)





Subtle genetic differences in fish from the Western Aleutian Islands (Reg. Area 4B)

Caviat: Summer samples compared to winter (spawning) samples

Incorporation of genetics into migration-related research

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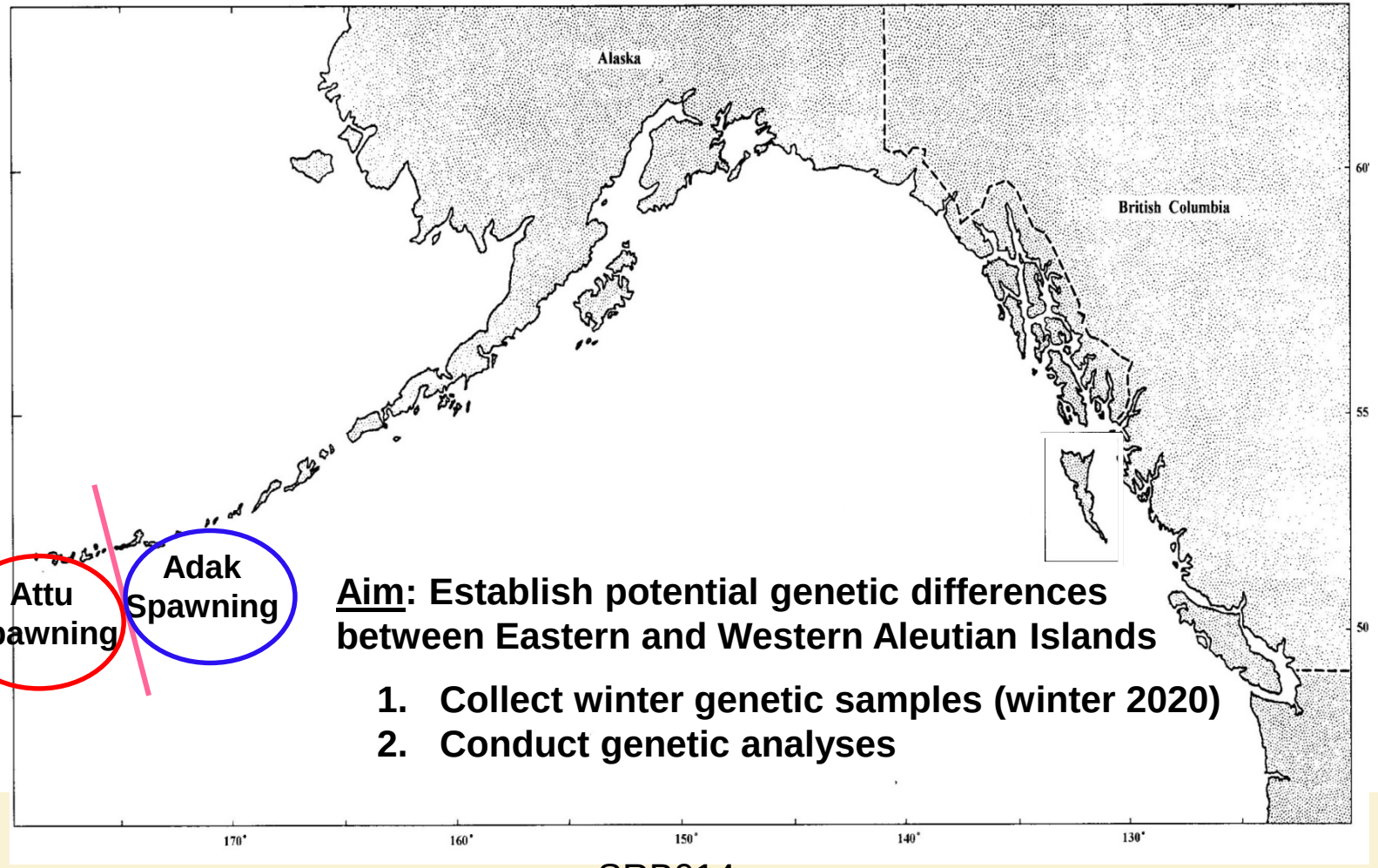
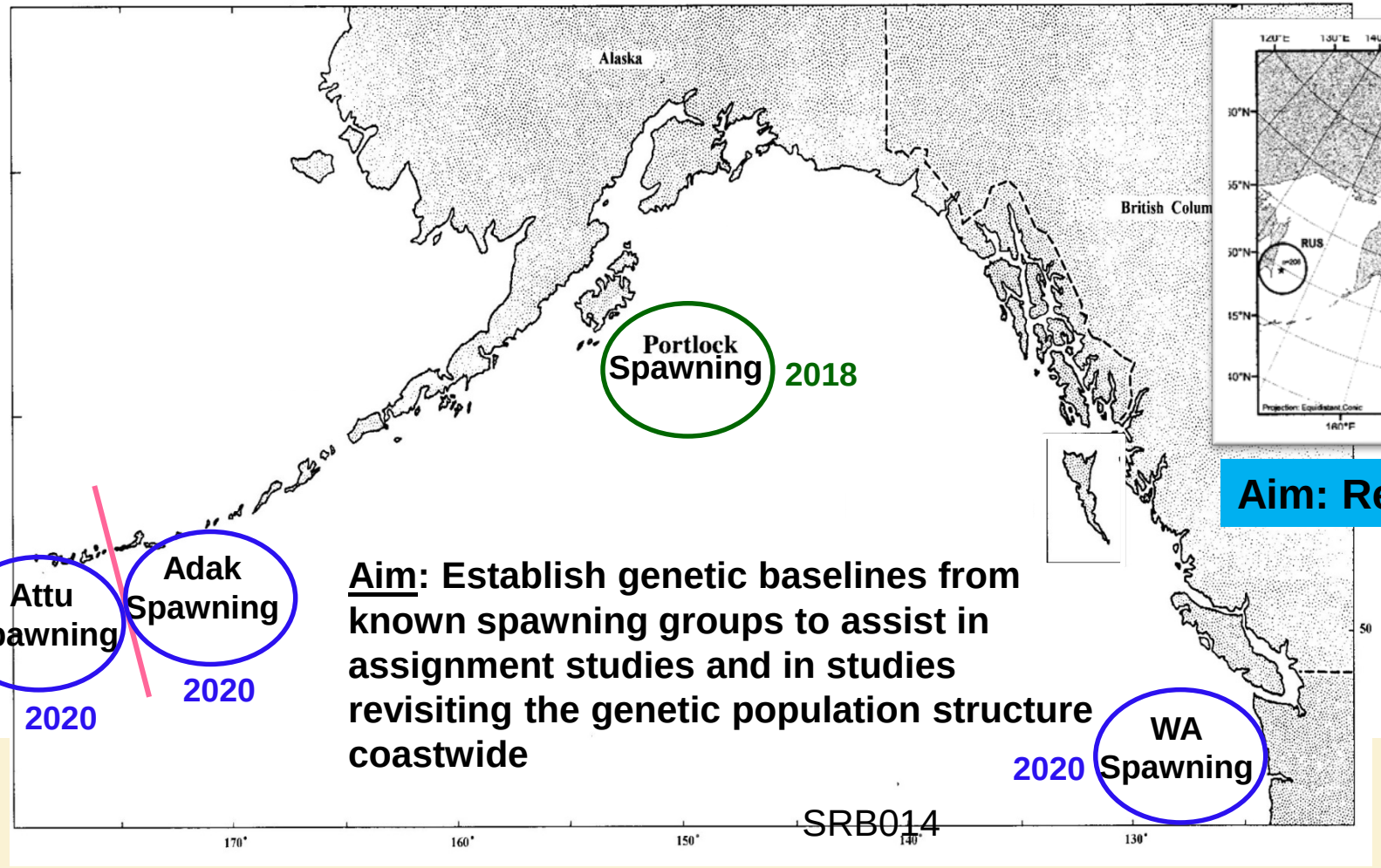


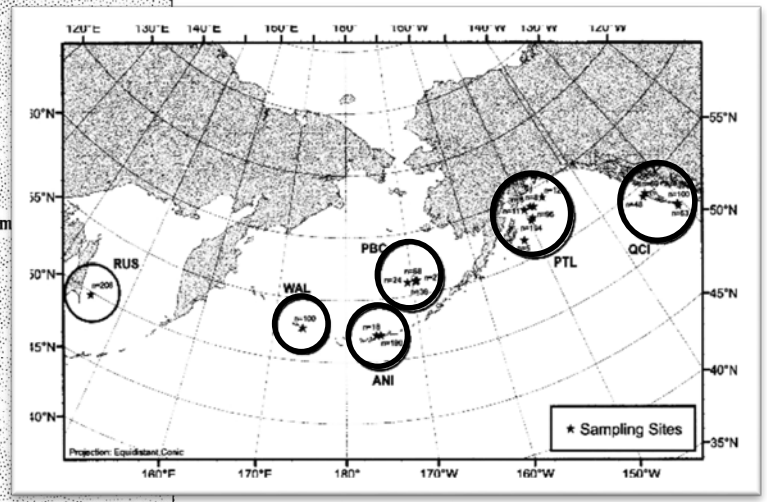
<u>Aim</u>: Establish potential genetic differences between Eastern and Western Aleutian Islands

1. **Collect winter genetic samples (winter 2020)**
2. **Conduct genetic analyses**

Incorporation of genetics into migration-related research

- **Genetic structure of the Pacific halibut population: Part 2 – Identification of potential genetic signatures of origin (baseline signals): new spawning groups)**





Aim: Revised population structure

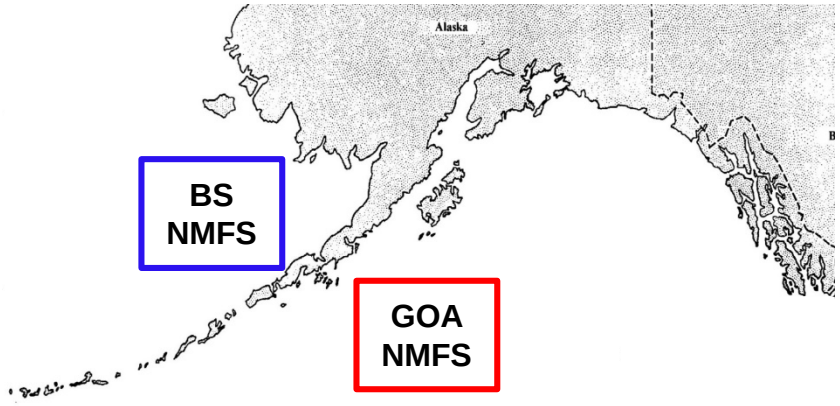
Genetic analyses using:

New samples (**2018**, **2020**)

Old samples (early 2000s)

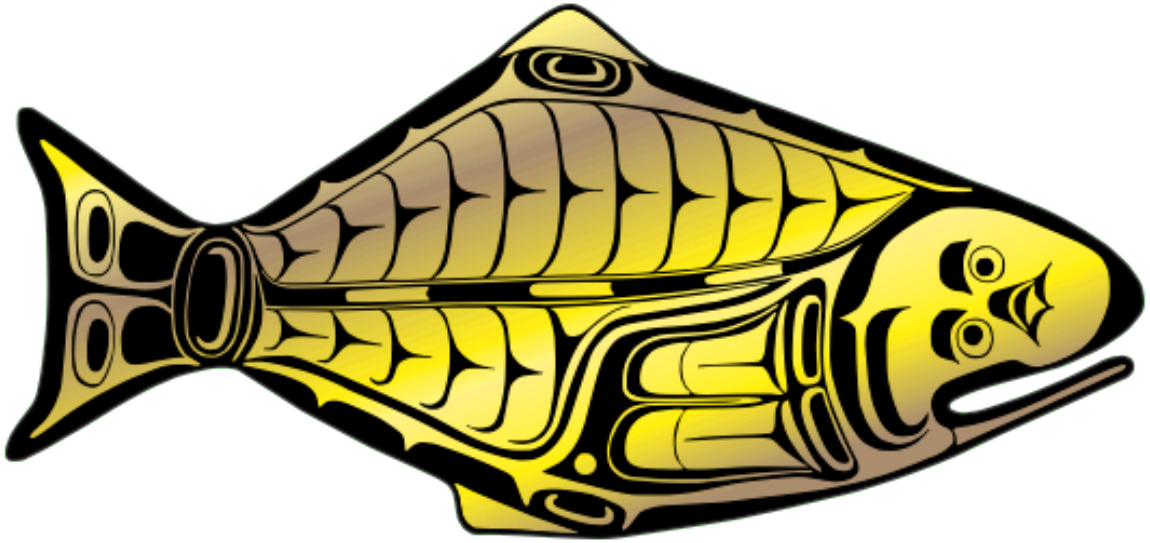
Incorporation of genetics into migration-related research

	2018	2019	2020	2021	2022
Genetic variability basin-wide			Data analysis	Paper	



Research biologist (Genetics) hired to conduct this proposed genetics work: starting date 26 Aug. 2019

INTERNATIONAL PACIFIC



HALIBUT COMMISSION