Oh crab, where art thou? Predicting mature female BBRKC spring habitat distribution to support dynamic spatial management

CPT Research Update
May 15, 2026

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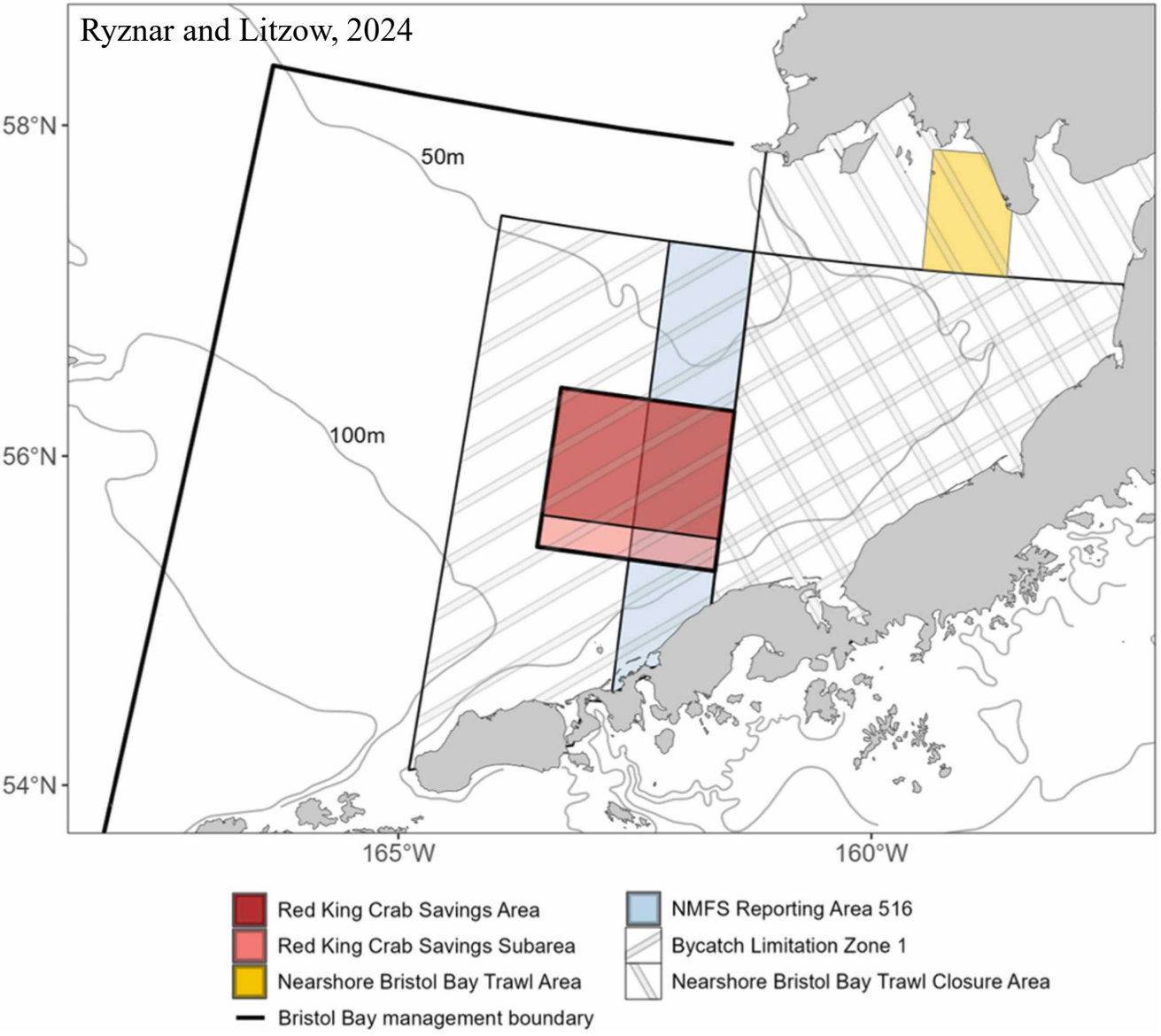
Research Associate

Understanding crab-gear interactions requires knowledge of crab seasonal distribution



Several static trawl closure areas currently in place to mitigate fishery impacts on BBRKC (bycatch, unobserved fishing mortality)

Seasonal BBRKC migrations could increase risk of interactions between trawl gear bottom contacts and crab

Understanding/mitigating crab-gear interactions is key management issue that engages diverse industry and stakeholder groups

- Given low BBRKC recruitment, particularly important for interactions between trawl gear and BBRKC broodstock

Mature female BBRKC migrations and seasonal distributions are poorly understood

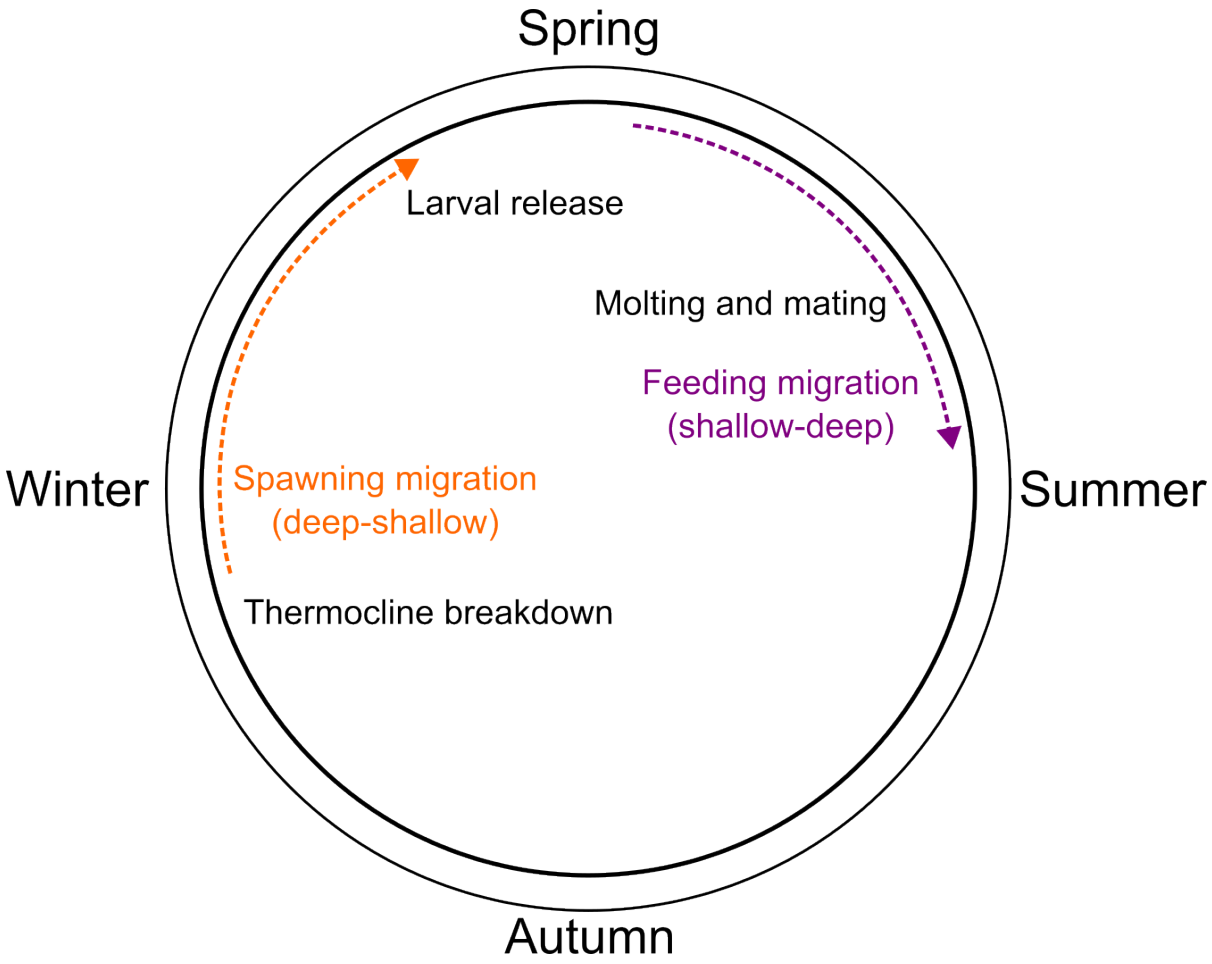
Small-scale tagging studies in coastal bays/fjords (Stone et al., 1992, Aune et al., 2022)

"Spawning migration" during winter/spring involving movement from deep to shallow habitat

- Along the way, larvae are released in intermediate depths (late Jan.-June)
- Molting and mating occur in shallow habitat

"Feeding migration" during spring/summer

- Movement back to deeper habitat where crab become available to the NMFS survey



Mature female BBRKC migrations and seasonal distributions are poorly understood

Sea ice conditions in Bristol Bay, March 2024 (credit: Cory Lescher)

Predicting female BBRKC habitat distribution in data-poor seasons

Over 300 pop-up satellite archival tags (PSATs) have been deployed on mature female BBRKC since Nov 2021

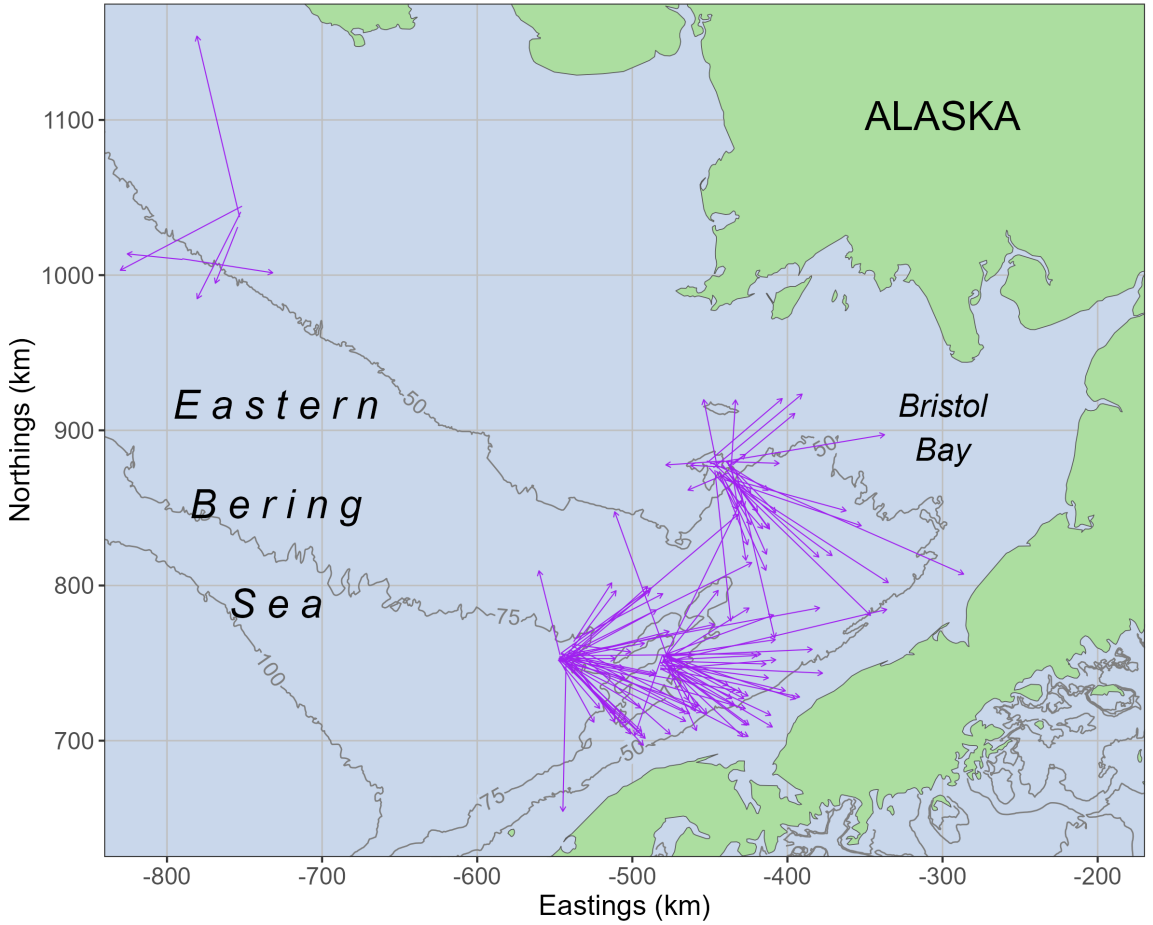
Largest single deployment of tags occurred in November 2021 with pop-up in late April/early May 2022 (N = 116 tags)

- Deployment aligned with thermocline breakdown (warm bottom temps)

We fit an **advection-diffusion model** to this group of tags ("the movement model")

Objectives:

1. Understand how environmental covariates influence movement
2. Develop maps of winter/spring habitat distribution
3. Relate habitat distribution maps to existing closure areas



Female BBRKC tag deployment and pop-up locations between November 2021- April/May 2022

Breaking down the advection-diffusion model

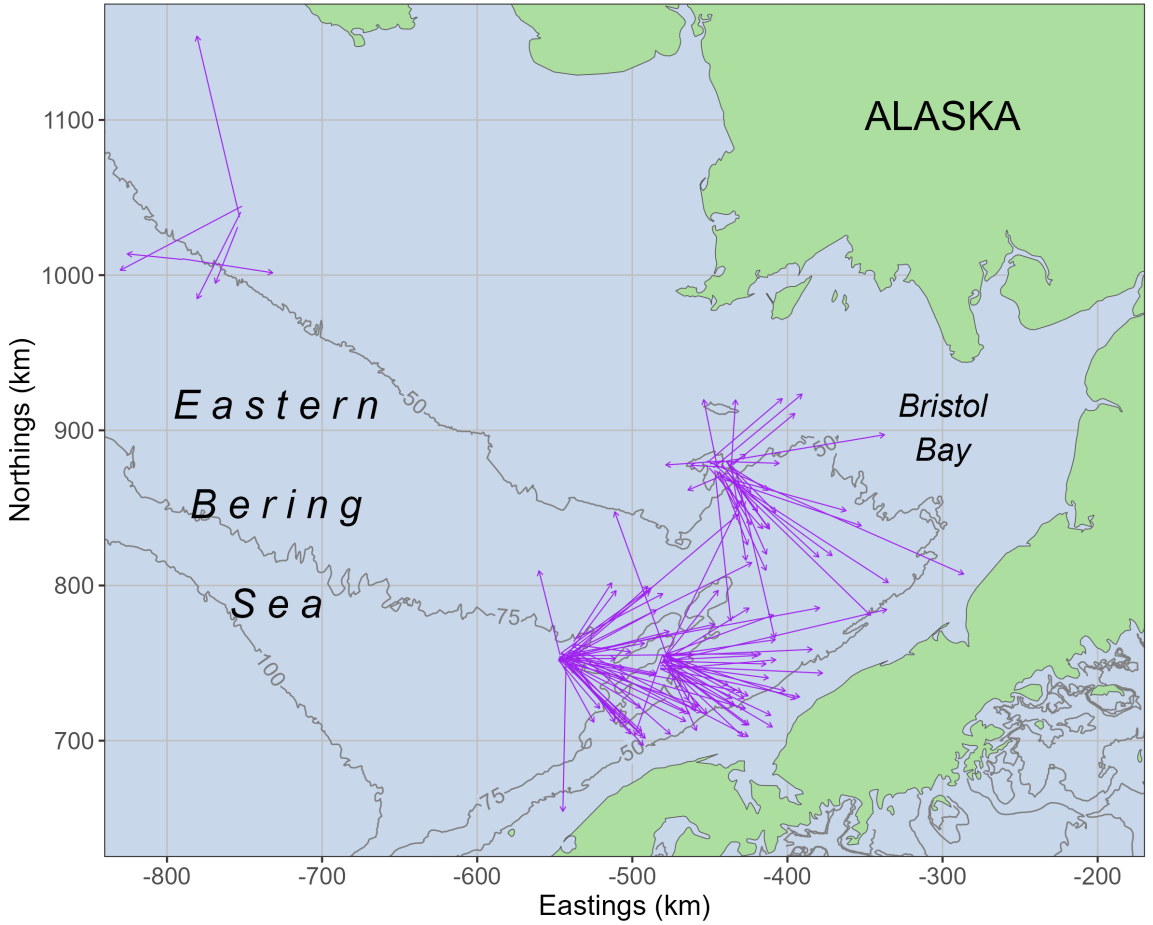
Movement is displacement over time

Movement occurs due to **taxis** and **diffusion**

- **Taxis** is directed movement towards *preferred habitats*
- **Diffusion** is residual movement not captured by the taxis term

Movement model predicts movement probabilities (**M**) over a time interval:

- If I drop a crab in any particular location, what's the probability that the crab moves to any other location given a tagging interval?
- Calculating **M** required estimating an instantaneous movement rate matrix $\dot{\mathbf{M}}$



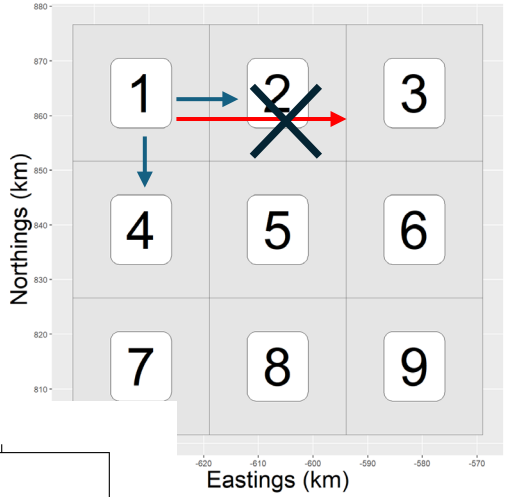
Female BBRKC tag deployment and pop-up locations between November 2021- April/May 2022

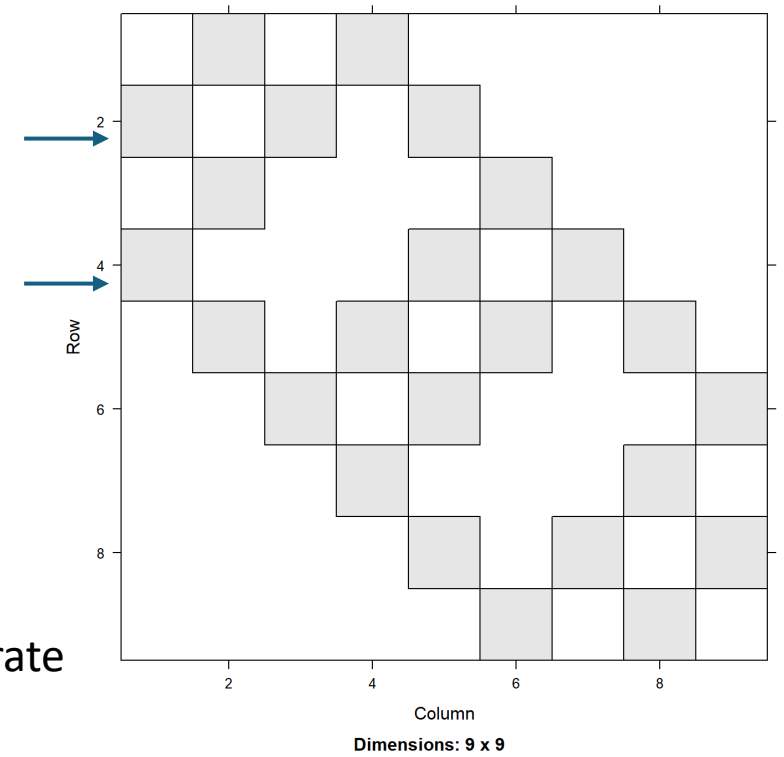
Breaking down the advection-diffusion model

$\dot{\mathbf{M}}$ is structured as adjacency matrix representing movement paths through the gridded spatial domain

- Crab can move in N/W/E/S directions

Arbitrary spatial grid (right) and its adjacency structure (below)





The elements of $\dot{\mathbf{M}}$ are instantaneous movement rates between cells ($\dot{m}_{g_1 g_2}$)

Diffusion parameter

$$\dot{d}_{g_1 g_2} = \frac{D}{\Delta_s^2}, \qquad \mathrm{D} = \exp(2\delta)$$

} Diffusion

Habitat preference

$$\dot{t}_{g_1 g_2} = \exp\left(\frac{h_{g_2} - h_{g_1}}{\Delta_s}\right)$$

} Taxis

$$\dot{m}_{g_1 g_2} = \begin{cases} a_{g_1 g_2} \dot{d}_{g_1 g_2} \dot{t}_{g_1 g_2}, & \text{if } g_1 \neq g_2 \\ -\sum_{g \neq g_1} \dot{m}_{g_1 g}, & \text{if } g_1 = g_2 \end{cases}$$

} Overall movement rate

Thorson and Kristensen, 2024; Thorson et al., 2021

Breaking down the advection-diffusion model

$\dot{\mathbf{M}}$ is the instantaneous movement rate matrix

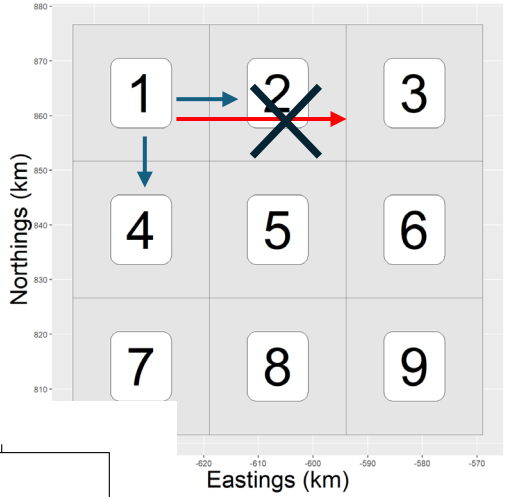
We integrate this matrix over the tag deployment interval to get the movement probability matrix $\mathbf{M}$

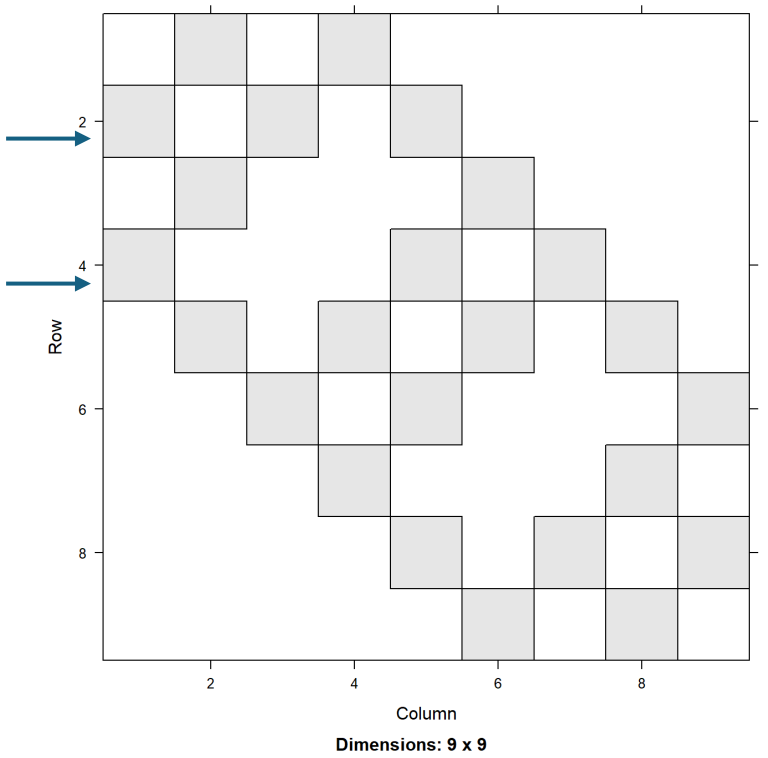
$$\mathbf{M} = e^{\Delta t \dot{\mathbf{M}}}$$

To fit model, we maximize the joint likelihood of observed tag movements given diffusion and habitat preference parameters (RTMB, Kristensen, 2024)

What is "habitat preference"?

Arbitrary spatial grid (right) and its adjacency structure (below)





Thorson and Kristensen, 2024; Thorson et al., 2021

Breaking down the advection-diffusion model: habitat preference

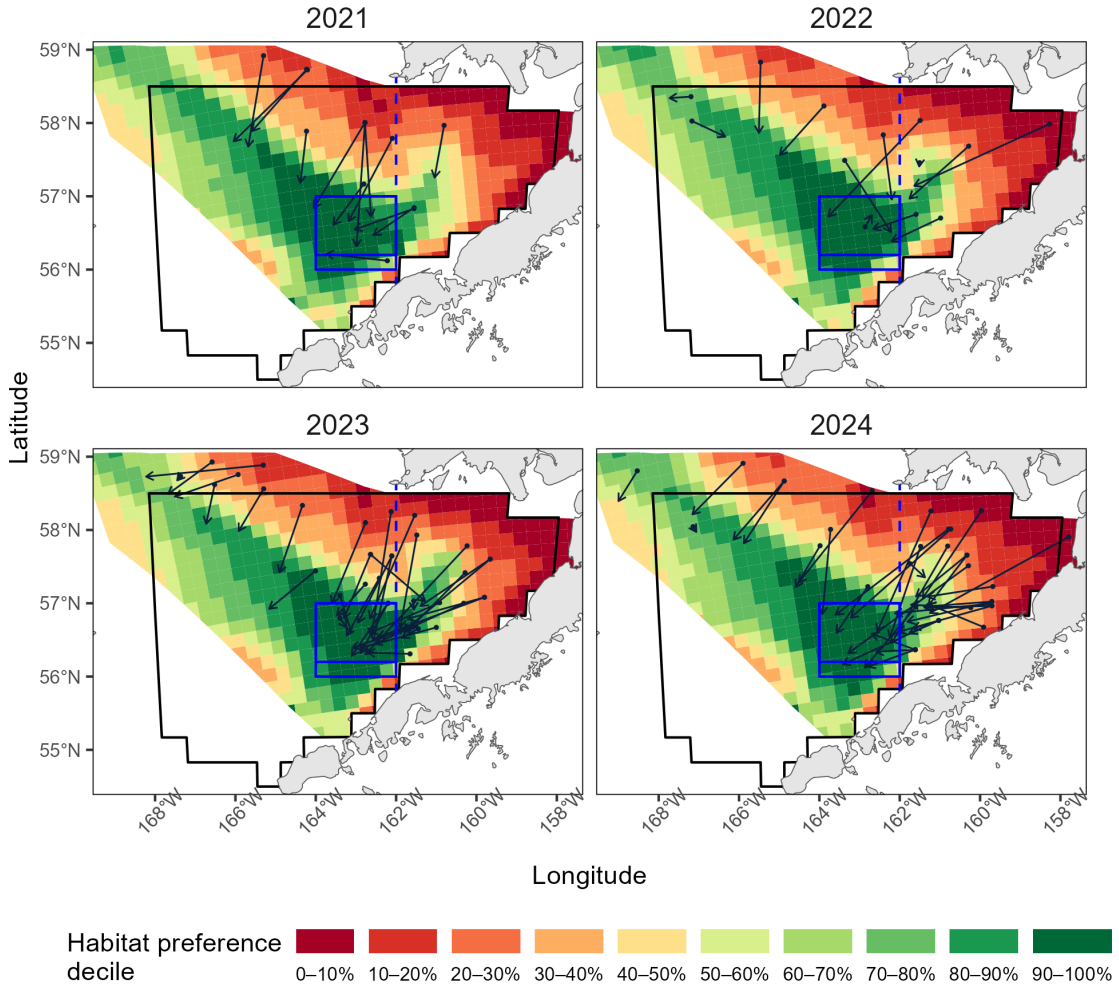
What is “habitat preference”?

- “Attractiveness” of habitat given local environmental dynamics and observed movement

Modeled using a GAM relating observed movement (deployment, pop-up only) to environmental covariates

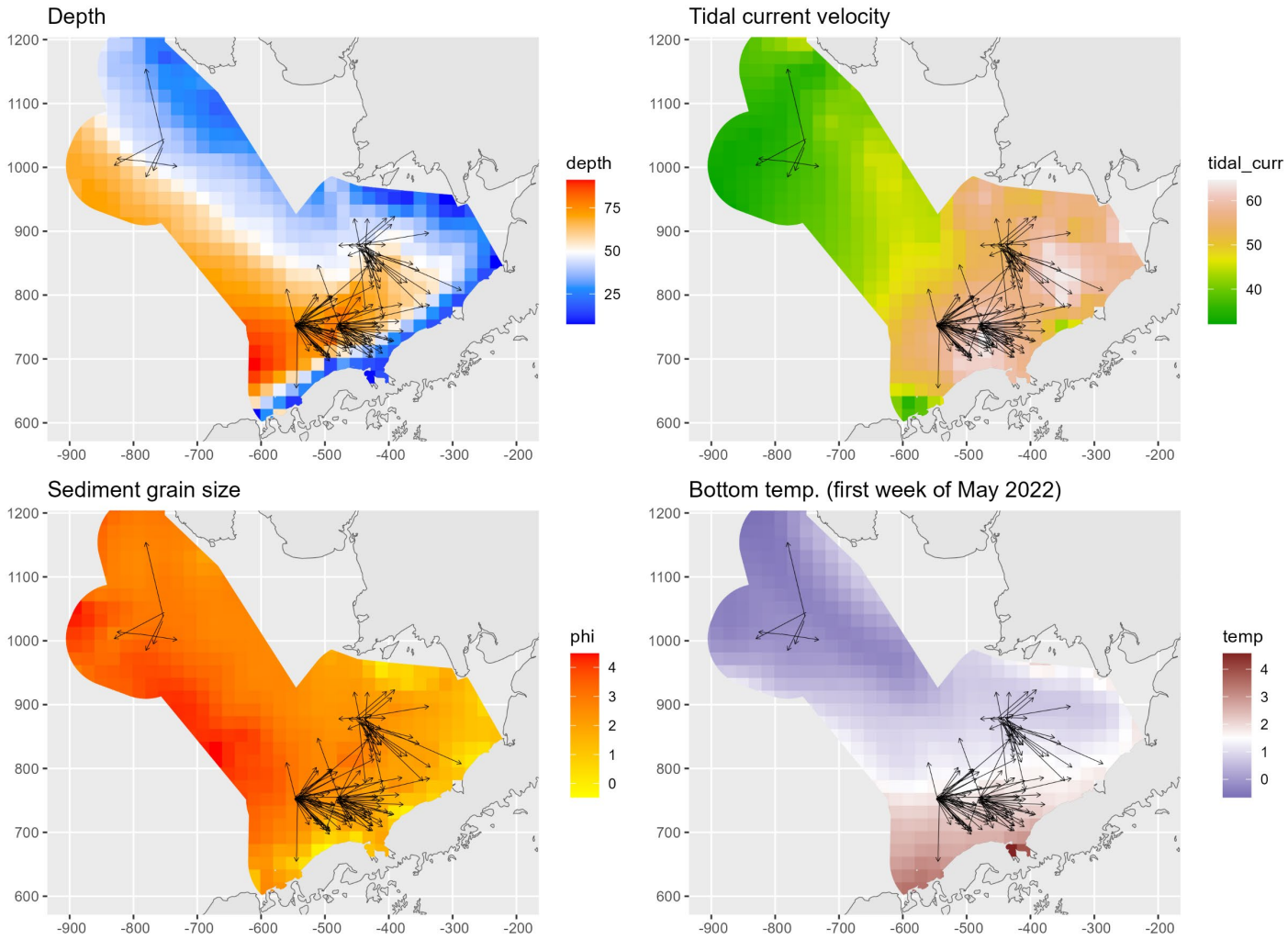
- This is the habitat preference function

Parameters of the habitat preference function must be estimated to calculate **M**



Predicted habitat preferences shown with tag vectors used to fit advection-diffusion model (Hardison et al., *in review*)

Environmental covariates used to estimate the habitat preference function



All covariates averaged to 400 sq. km spatial scale

Bottom temperature data are daily hindcasts from MOM6-NEP oceanographic model (Drenkard et al. 2025)

- Averaged to weekly temporal resolution

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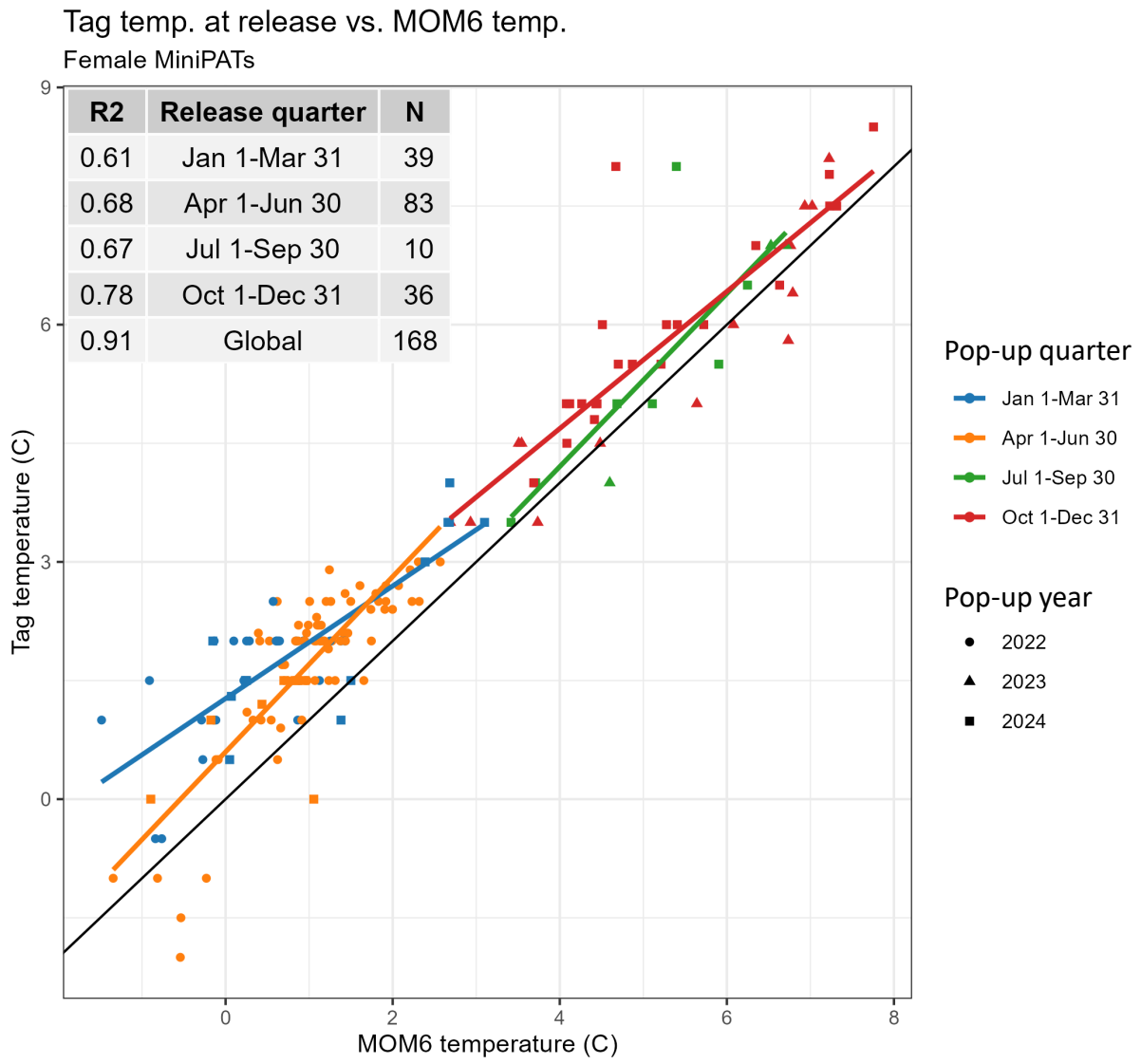

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- Averaged to weekly temporal resolution
- MOM6 predictions are well correlated (slight bias low) with average tag temps in day before pop-up

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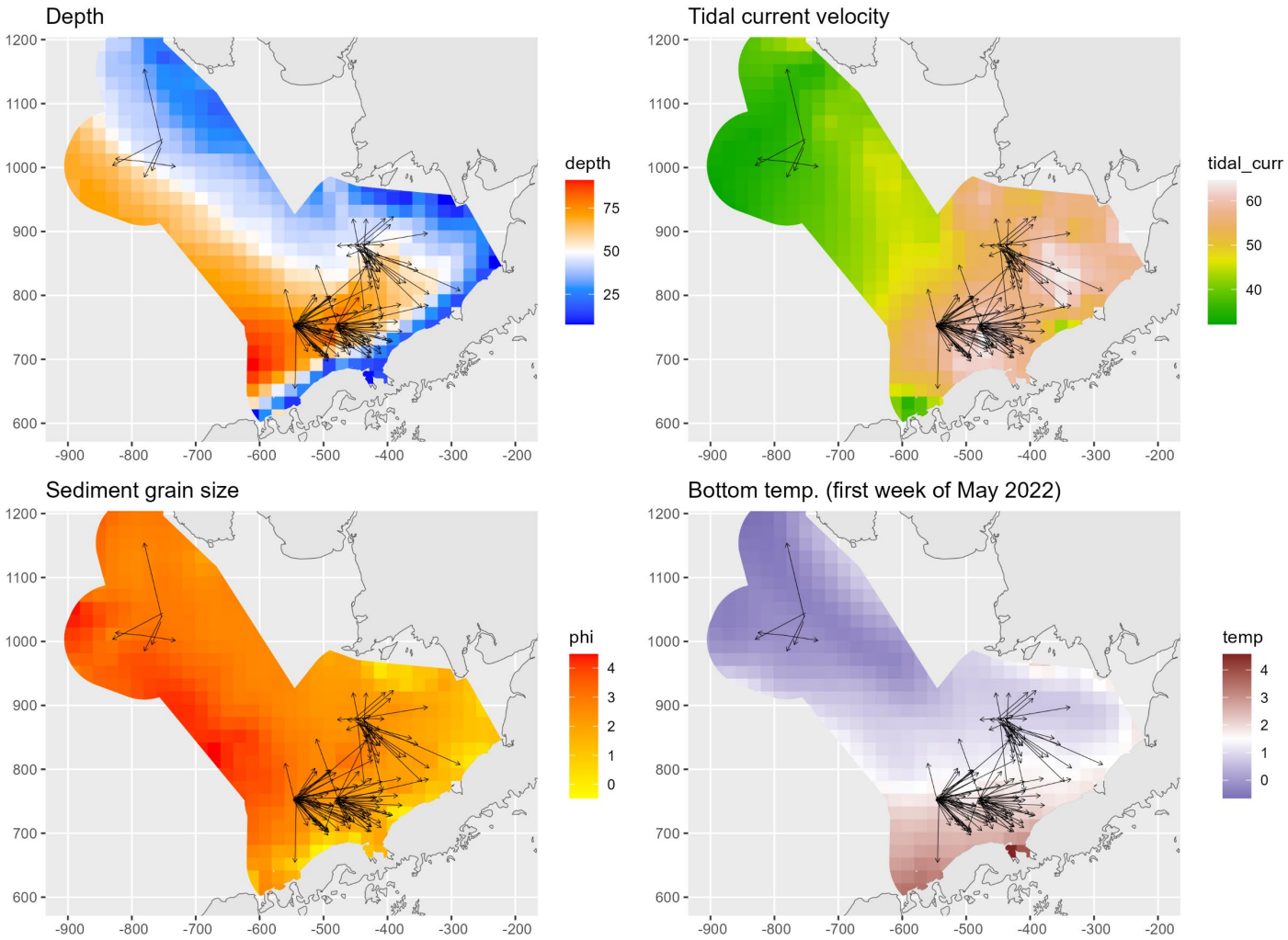

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Habitat preference model selection

- AIC
- Comparisons between preference predictions and available crab data for similar models

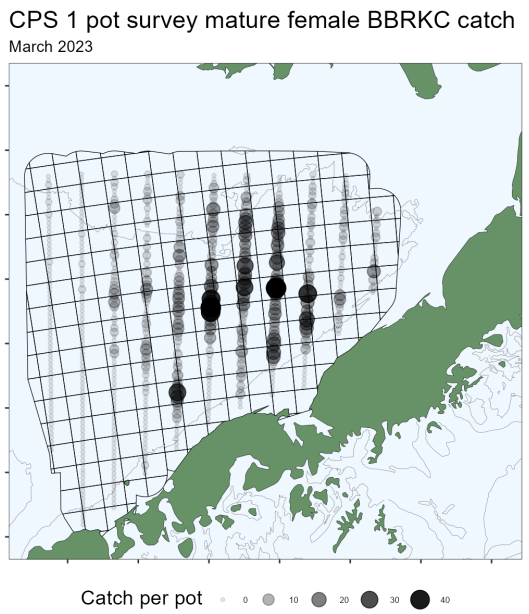
Model selection: AIC and out-of-sample comparisons

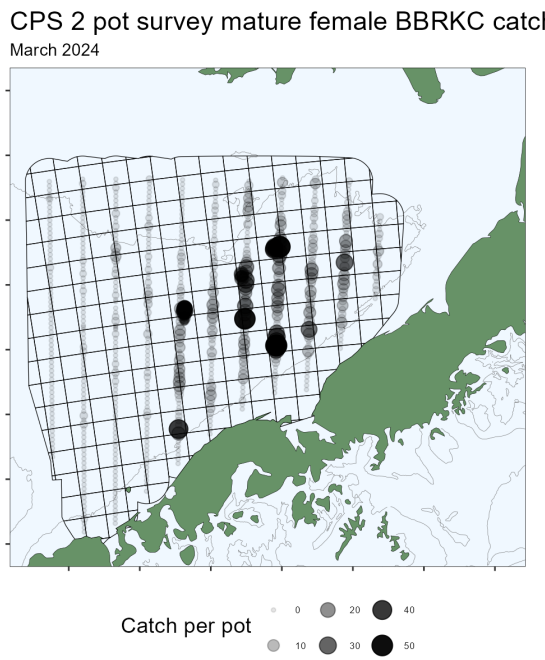
Habitat preference formula	N pars.	AIC	ΔAIC
te(depth, phi, k = 3) + s(temp, k = 4)	12	990.7947	0.000000
te(depth, temp, k = 3) + s(phi, k = 4)	12	992.5559	1.761211
te(depth, temp, k = 3) + s(velocity, k = 4) + s(phi, k = 4)	15	993.1706	2.375918
s(velocity, k = 4) + s(temp, k = 4) + s(phi, k = 4) + s(depth, k = 4)	13	998.5737	7.778997
te(depth, velocity, k = 3) + s(temp, k = 4) + s(phi, k = 4)	15	1004.7759	13.981242
te(velocity, temp, k = 3) + s(depth, k = 4) + s(phi, k = 4)	15	1004.9036	14.108988
te(depth, temp, k = 3) + s(velocity, k = 4)	12	1022.7109	31.916223
velocity + temp + depth + phi	5	1093.1671	102.372481
diffusion only	1	1116.0493	125.254621

Top two movement models by AIC considered for further evaluation

- Best fitting movement model produced habitat preferences that were not predictive of out of sample data
- Second best fitting model passed all out-of-sample prediction tests

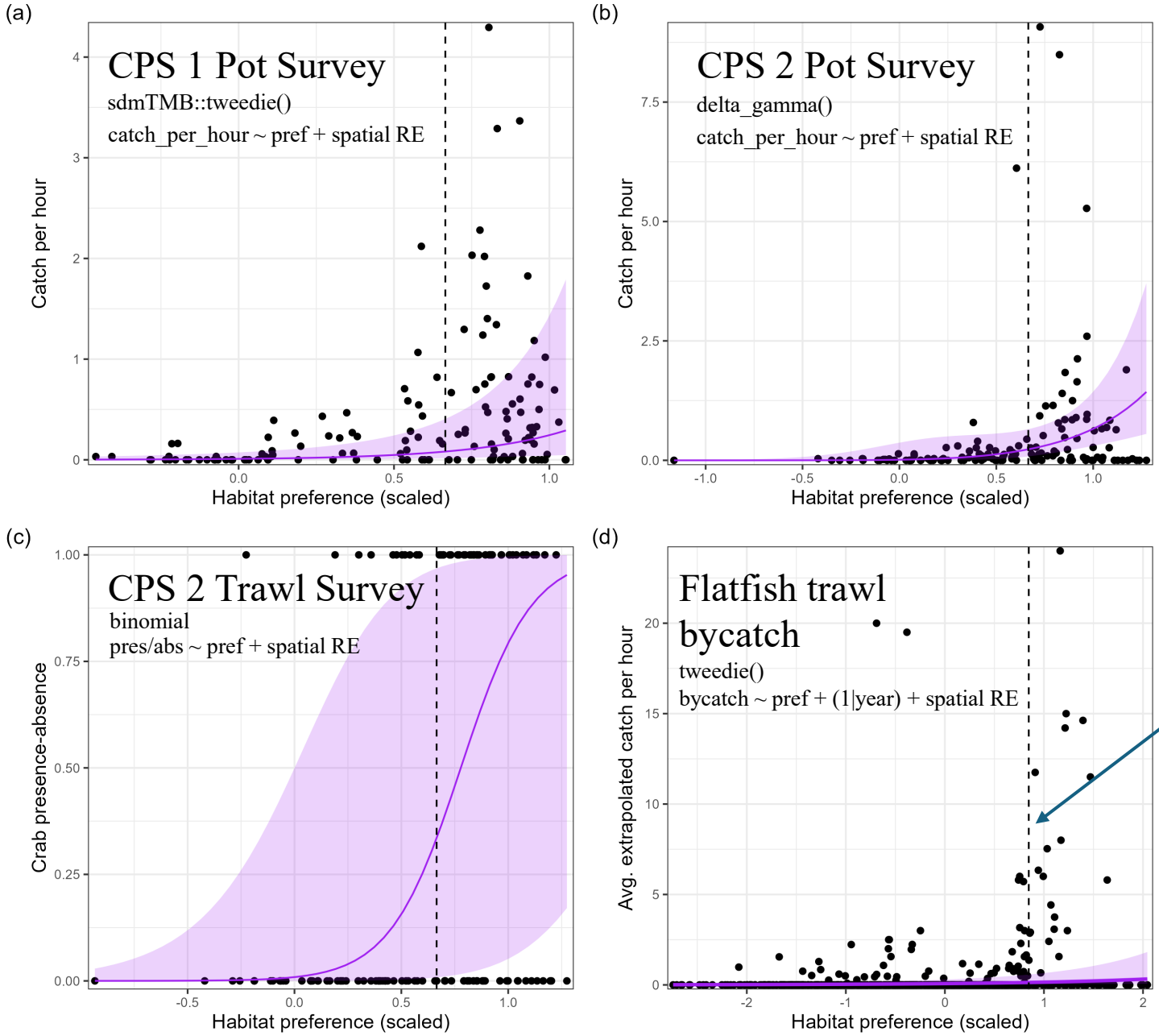
Model selection: AIC and out-of-sample comparisons





- CPS and flatfish bycatch observations aggregated to prediction grid
- Predicted preference during CPS sampling window (mid-late March 2023/2024)
- Preference during first week of May for relation with April/May bycatch

Model selection: AIC and out-of-sample comparisons



Main effects > 0 in all cases

> dashed line is upper quartile of habitat preference

Results: mature female BBRKC early May habitat preferences

Crab prefer medium-fine grain sand sediments during this period (1 < phi < 3)

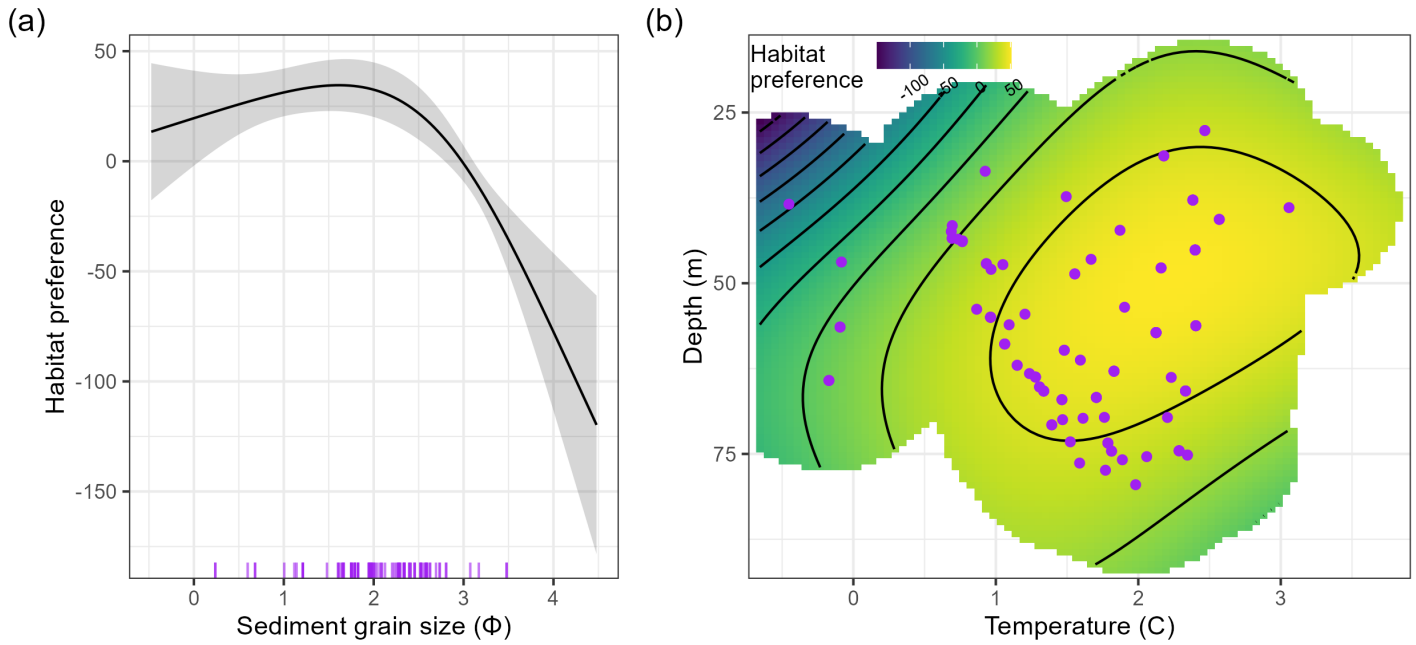
- En route to nearshore molting/mating grounds where sediment is coarser?

Preference for areas that range between ~25-75 m depth **and** ~1-3 C

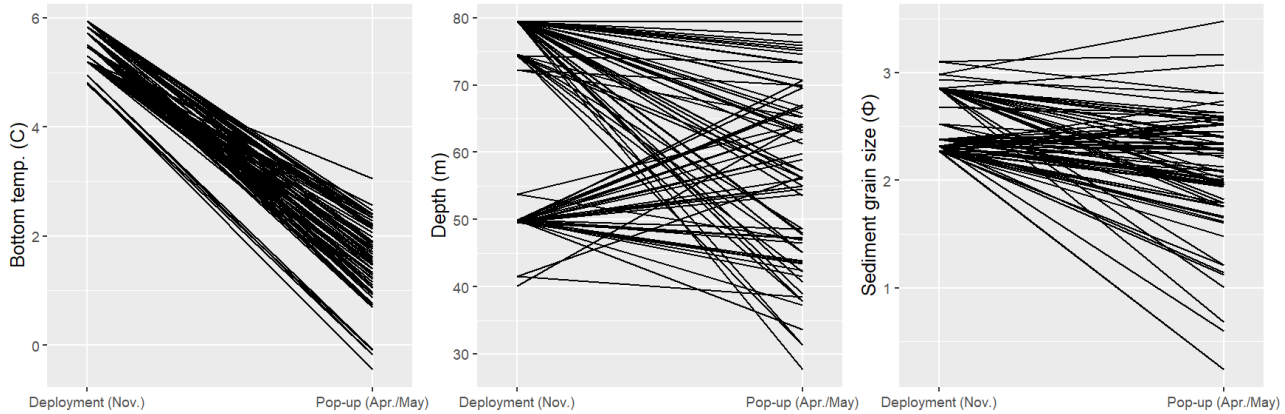
- Not as straightforward as "deep-shallow migration"

Preference for intermediate depths and sediment grain sizes visible in environmental data at tag pop-up

- Bottom temp. preference harder to parse given dynamics

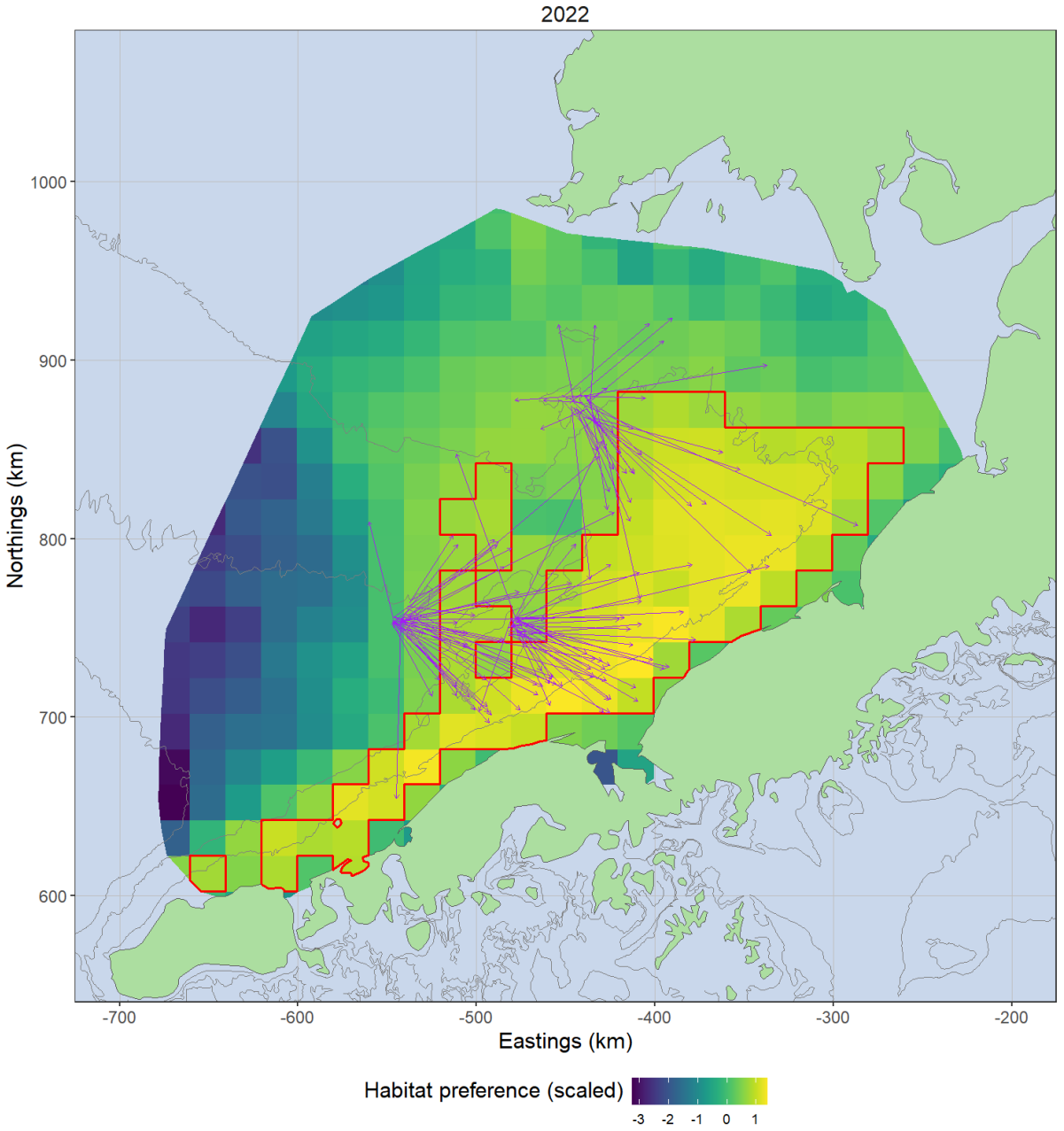


Marginal habitat preference smooths



Observations for environmental covariates at tag deployment and pop-up locations and times

Results: habitat preference distribution at time of tag pop-up



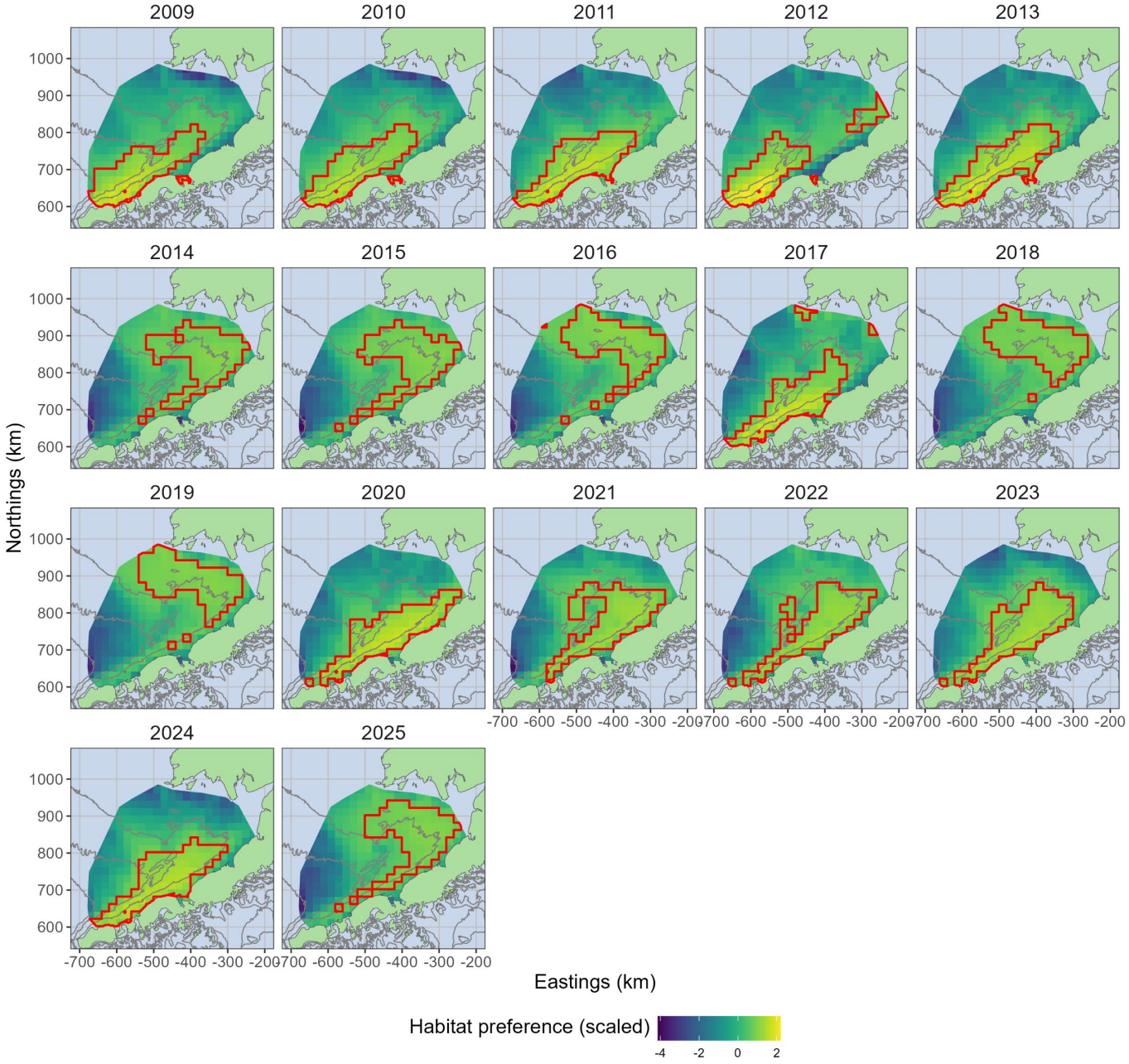
Predictions limited to 75 km from tag pop-up locations

- Excluding sparse tags deployed in NW Bristol Bay

Red polygons are upper quartile of habitat preference (top 25%)

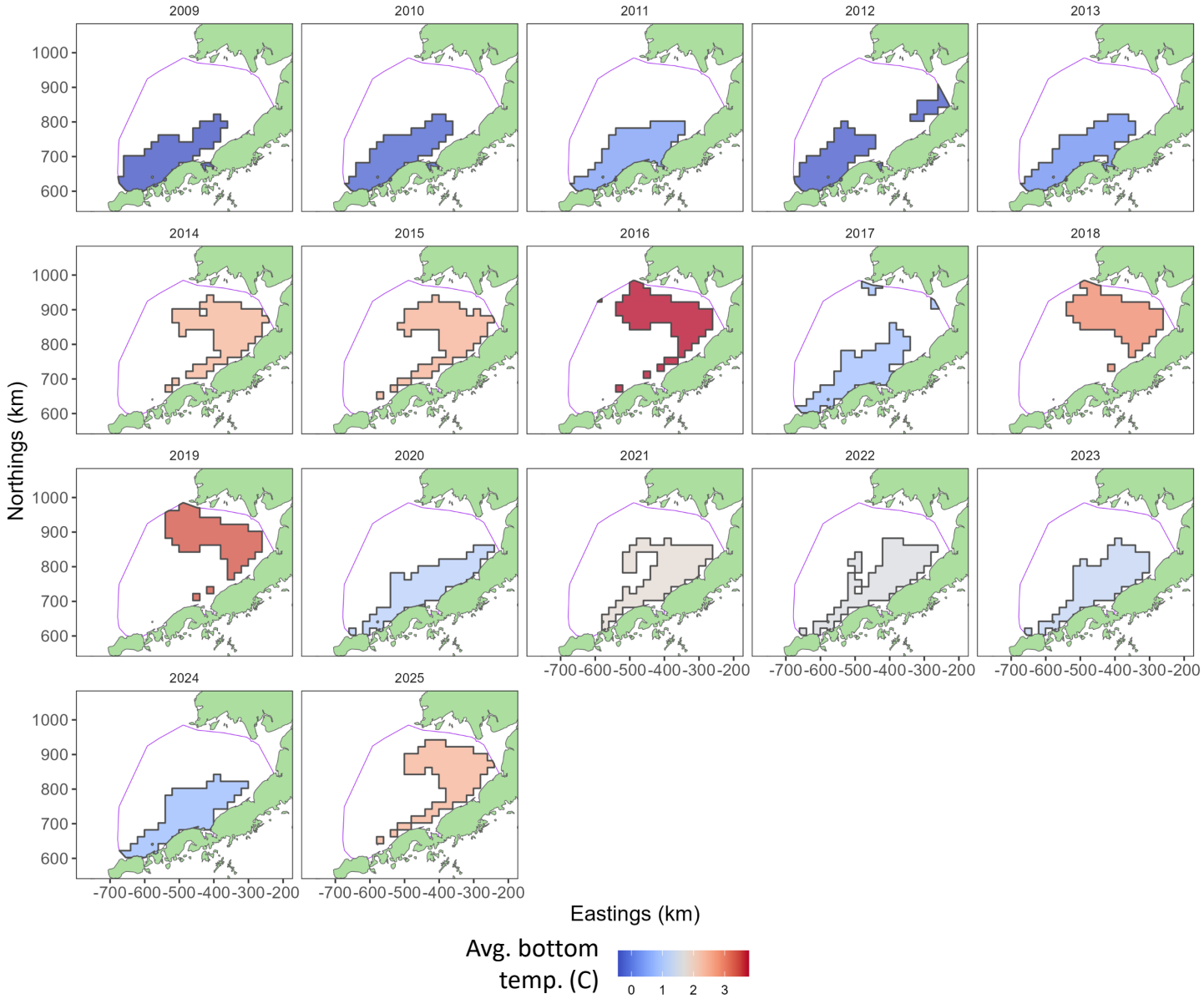
“Good habitat” is intermediate between tag deployment locations and Alaska peninsula

Results: May preference responses to bottom temperature variability



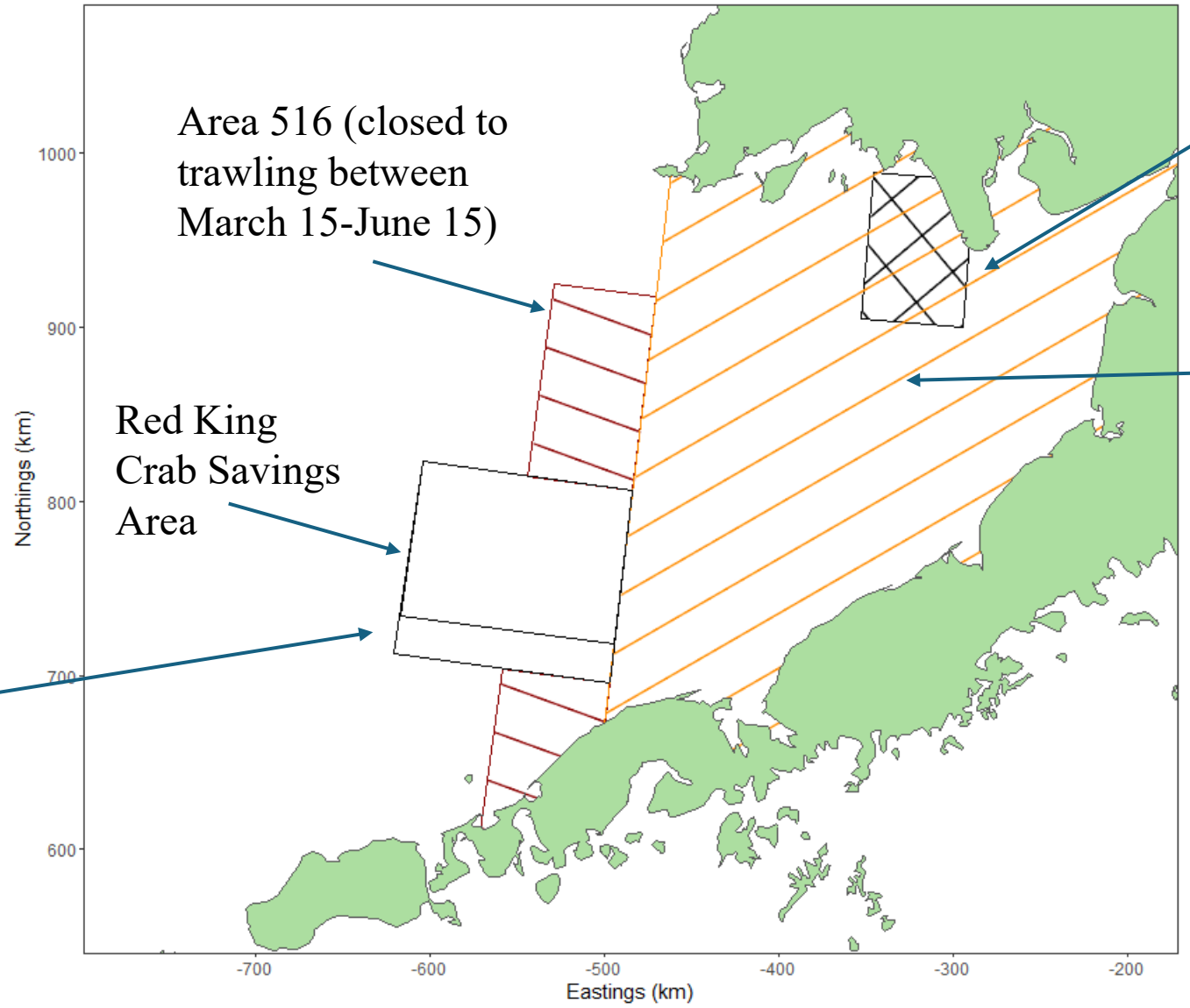
We expect that the distribution of "good habitat" in Bristol Bay is sensitive to bottom temperature regime

Results: May preference responses to bottom temperature variability

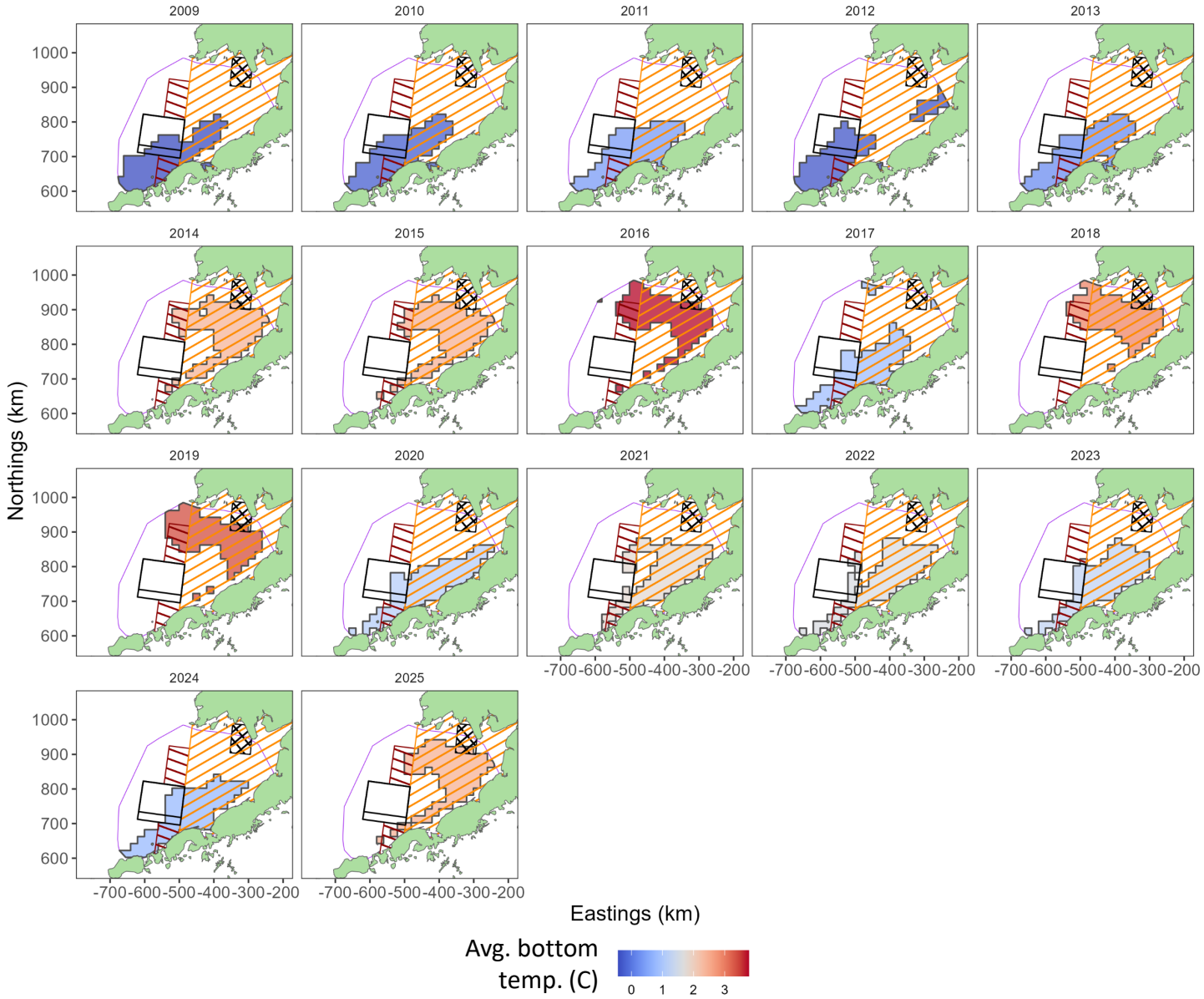


We expect that the distribution of "good habitat" in Bristol Bay is sensitive to bottom temperature regime

Conditional on stationary habitat preferences given one set of tags


Area 516 (closed to trawling between March 15-June 15)
Nearshore Bristol Bay Trawl Area (NBBTA; open between April 1-June 15)
Nearshore Bristol Bay Trawl Closure Area
Red King Crab Savings Area
Red King Crab Savings Sub-Area (open when RKC fishery occurred in previous fall)
Northings (km)
1000
900
800
700
600
-700
-600
-500
-400
-300
-200
Eastings (km)

Results: May preference distributions relative to closure areas



Warmer years (2014-2016, 2018-2019, 2025):

- Preferred habitat occurs further north in Bristol Bay
- Preferred May habitat overlaps with open NBBTA (black hatching)
- Can extend NW outside of trawl closure areas

Cooler years (2009-2013, 2020-24):

- Preferred habitat largely found north of Alaska peninsula
- Can extend SW out of closure areas to Unimak Island

Summary

- Mature female BBRKC movement patterns between November-April/May are sensitive to bottom temperature, depth, and grain size
- Habitat preferences predict crab abundance/presence in CPS surveys and flatfish bycatch
- Predicted “good habitat” during late April/early May 2022 concentrated north of Alaska Peninsula
- Preference predictions in other years suggest that habitat distributions shift with bottom temperature regime - not constrained by static closure areas

To-do

- Leave-one out cross validation for movement model
- “Utilization distribution” for prediction
- Process flatfish trawl bycatch to higher temporal resolution

Next Steps and discussion

Short to medium-term

Present overview of this work to Council in June

- Intend to share how movement models can be used for projecting preference forward in support of dynamic closure area discussions

Fit a single model to all tag deployments

- In progress, currently blows up laptop

Integrate movement model predictions with survey data to project density through time

- Attempted this by linking multiple movement model predictions over time
  - Worse than habitat preference for predicting out-of-sample data
- May be achievable via the ATM R package (Thorson et al., 2021)

Long-term

- Geolocate crab tags *during deployment* using hidden Markov Model (Nielsen and Tribuzio, 2023), use resulting likelihood surfaces as input into ATM or similar (Thorson and Kristensen, 2024)

What would you like to see prior to this model being used in a management context?

Thank you!

Leah Zacher
Erin Fedewa
Madi Heller-Shipley
Jim Thorson
Mike Litzow
Franz Mueter
Kelly Kearney
Scott Goodman
Emily Ryznar
Andrew Nault
Ben Daly
Tim Loher
Gordon Kruse
Vicki Vanek