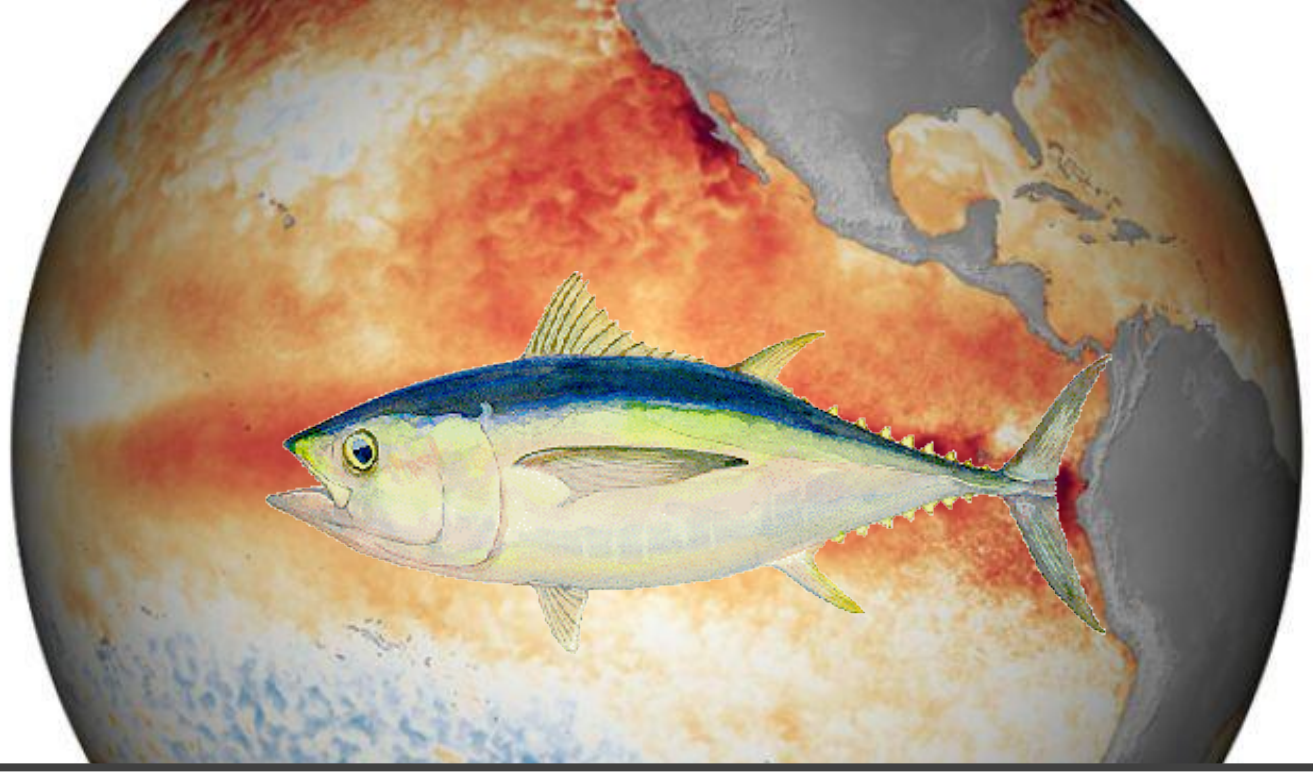

Estimating the movement rate of bigeye tuna in the eastern Pacific Ocean

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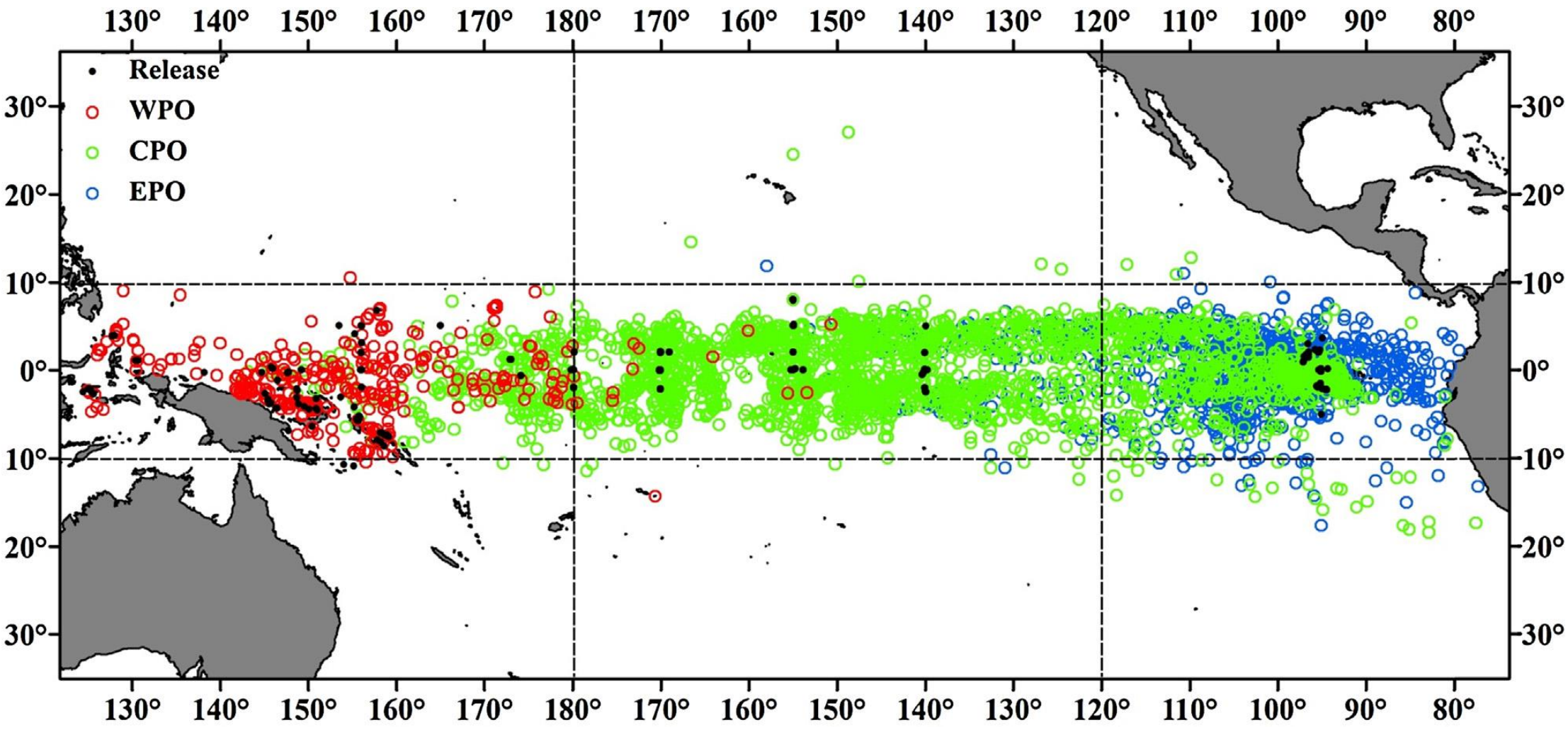
Inter-American Tropical Tuna Commission

CAPAM Spatial Assessment Models Workshop
Oct. 02, 2018, La Jolla, CA

Outline

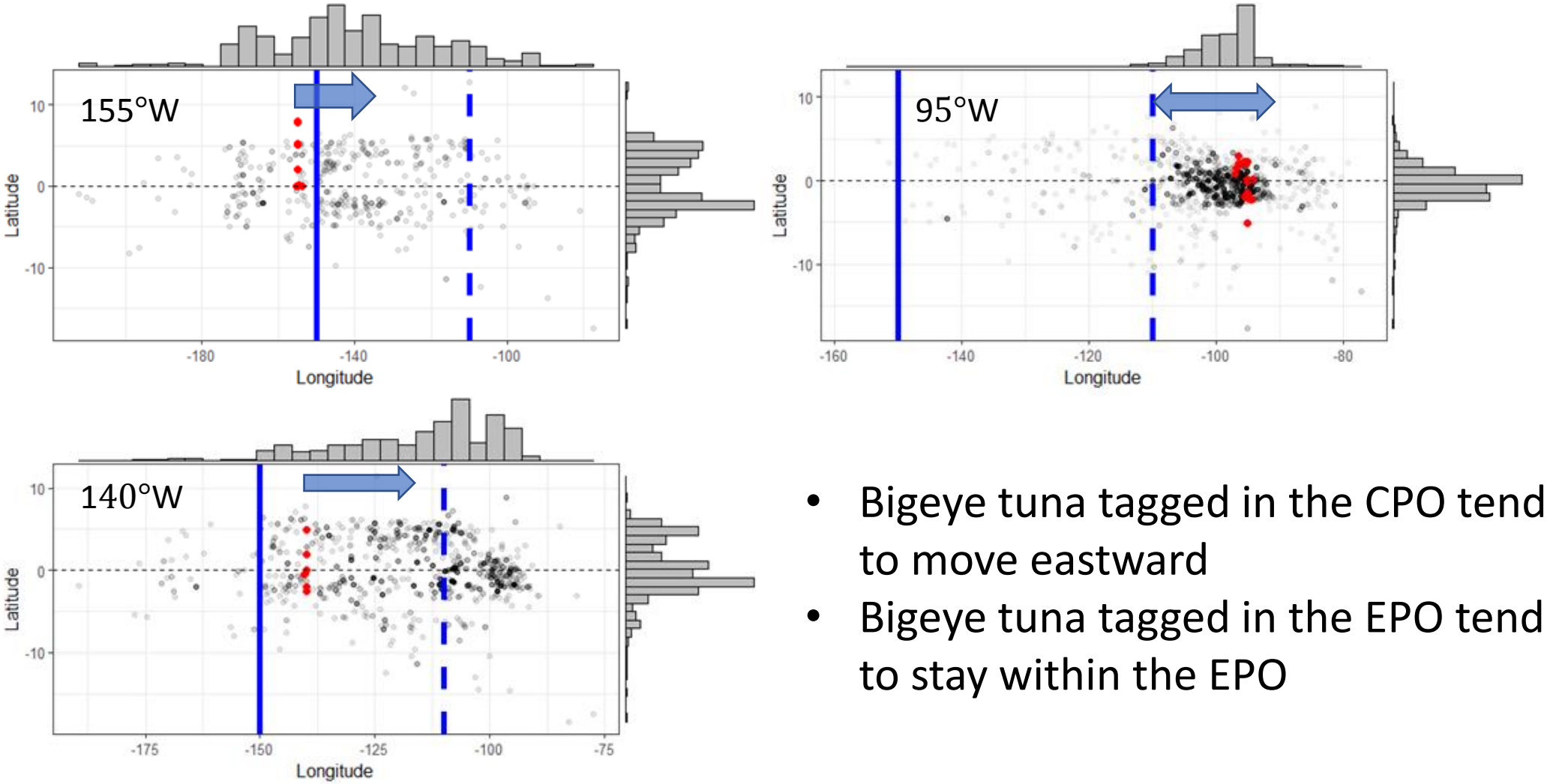
- Available tagging data
- Mark-recapture model
- Estimates of Movement rate
- Conceptual movement pattern

Conventional tagging data



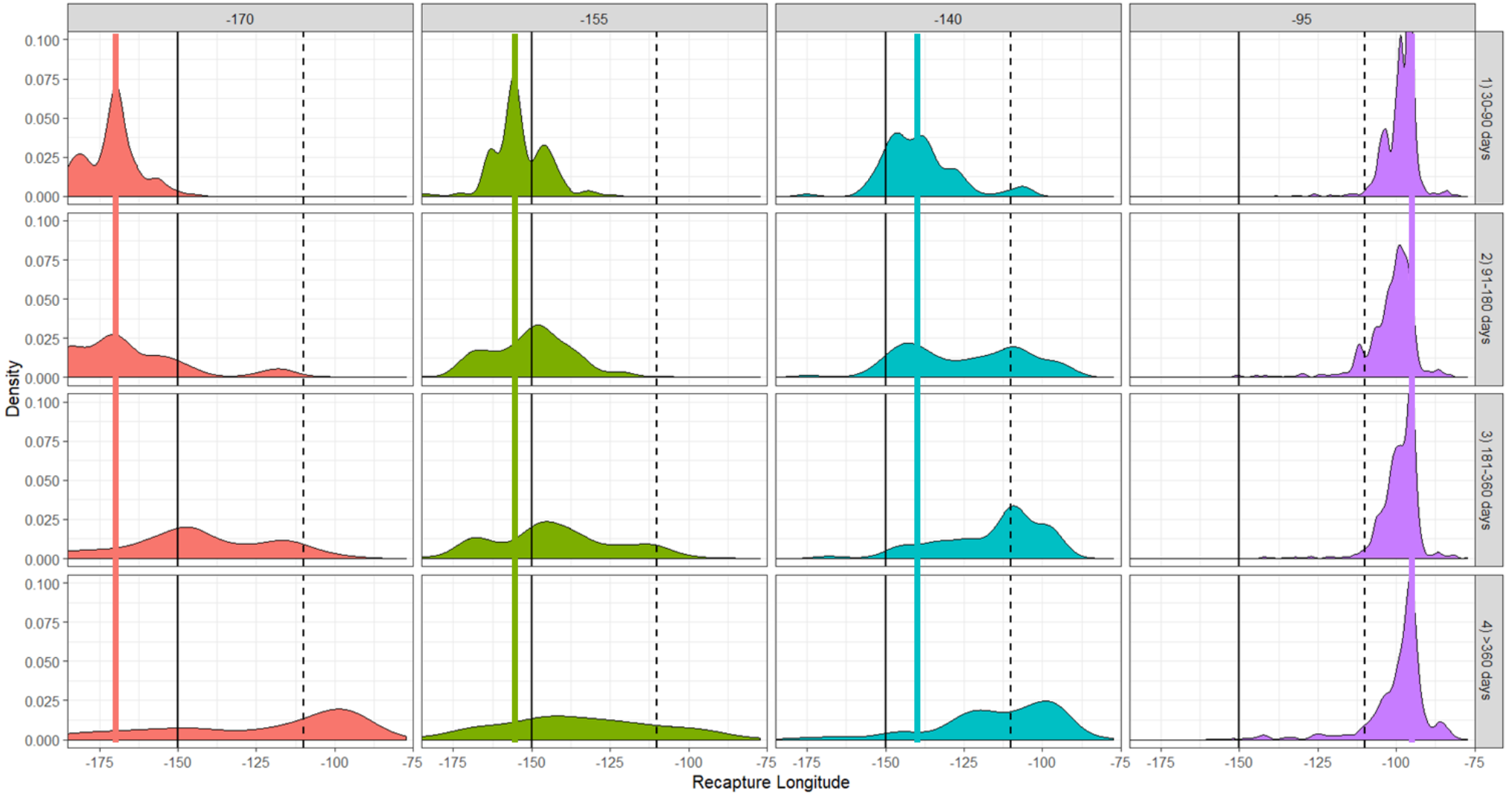
Schaefer et al. 2015

Histogram of recapture latitude and longitude by release location



- Bigeye tuna tagged in the CPO tend to move eastward
- Bigeye tuna tagged in the EPO tend to stay within the EPO

Density of recapture longitude by time at liberty



1-3 months

4-6 months

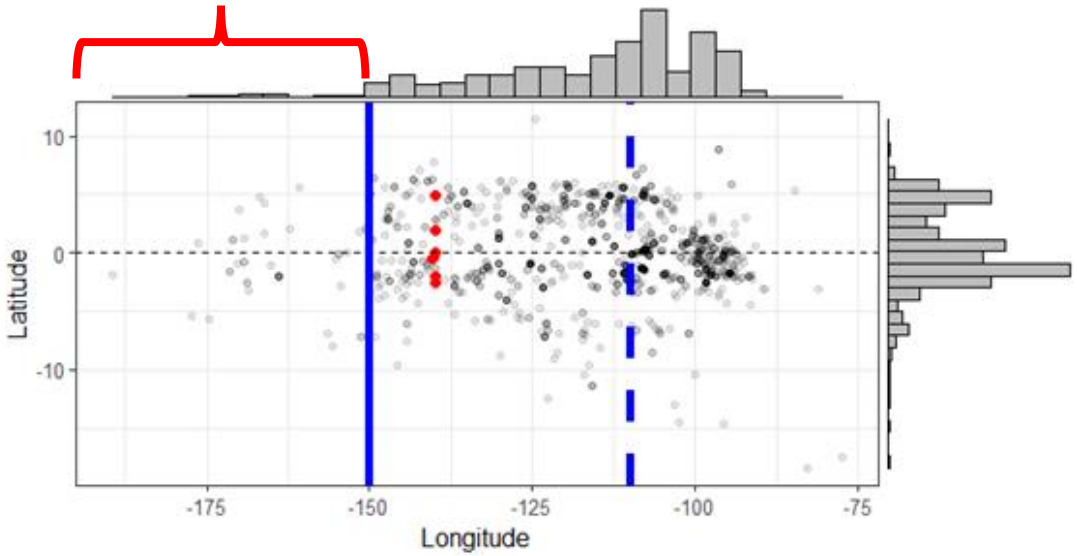
7-12 months

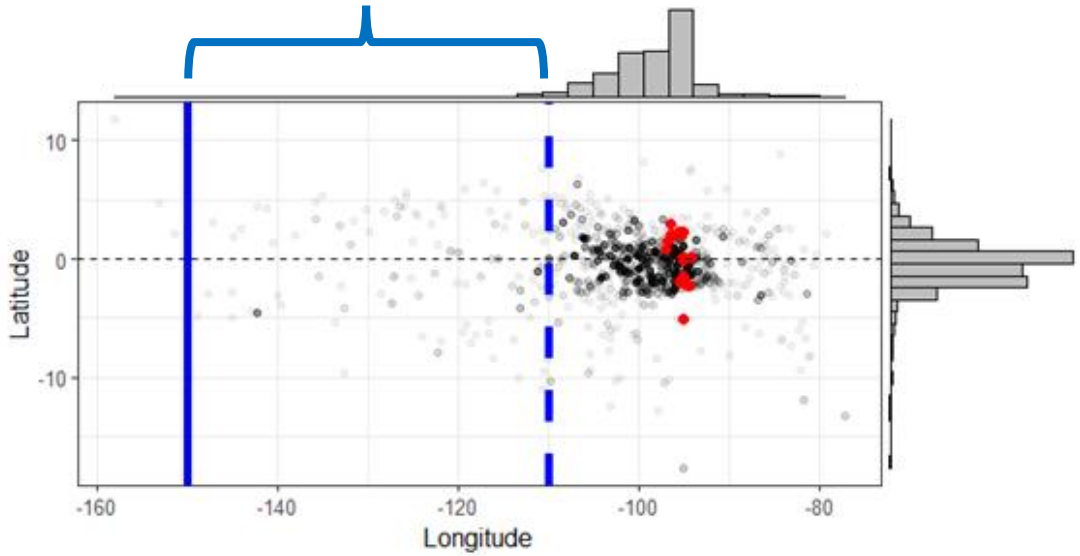
>12 months

Estimating movement rate

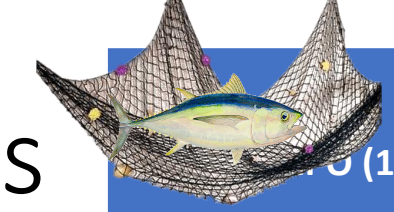
WEPO (150°W-110°W)	EEPO (East of 110°W)

- A mark-recapture model is built to estimate the movement rate from the WEPO to the EEPO
- The fish recaptured with a time at liberty <3 months are excluded
- Key assumptions we made to simplify the model:
  1. The movement rate westward across 110°W is zero
  2. The movement rate westward across 150°W is zero





Likelihood functions



…O (150°W-110°W)	EEPO (East of 110°W)

The likelihood for a fish both released and recaptured west of 110°W:

$$L_i(q, x|D_{W\to W}) = P(\text{movement}) \times P(\text{survival}) \times P(\text{recapture})$$
$$= (1-x)^{n_i} \times (1-qe_1)^{n_i-1}(1-M)^{n_i-1} \times qe_1$$

always in the WEPO

x: quarterly movement rate eastward across 110°W

n_i: quarters at liberty

M: natural mortality rate

e_1: the average density of floating-object sets in the WEPO

q: transforms fishing intensity (e_1) into recapture probability (qe_1)

Likelihood functions

The likelihood for a fish released west of 110°W and recaptured east of 110°W:

$$L_j(q, x|D_{W\to E}) = P(\text{movement}) \times P(\text{survival}) \times P(\text{recapture})$$

$$= \sum_{n_m=1}^{n_j-1} \left(x(1-x)^{n_m-1} \times (1-qe_1)^{n_m-0.5}(1-qe_2)^{n_j-1-(n_m-0.5)}(1-M)^{n_j-1} \times qe_2 \right)$$

Movement is assumed to occur in the middle of quarter n_m

x: quarterly movement rate

n_j: quarters at liberty

M: natural mortality rate

e_2: the average density of floating-object sets in the EEPO $\approx 4e_1$

q: transforms fishing intensity (e_2) into recapture probability (qe_2)

n_m: the quarter when sample j moved from the WEPO to the EEPO (unknown)

Maximum Likelihood Estimation

Recapture scaler (q) and movement rate (x) are estimated using maximum likelihood

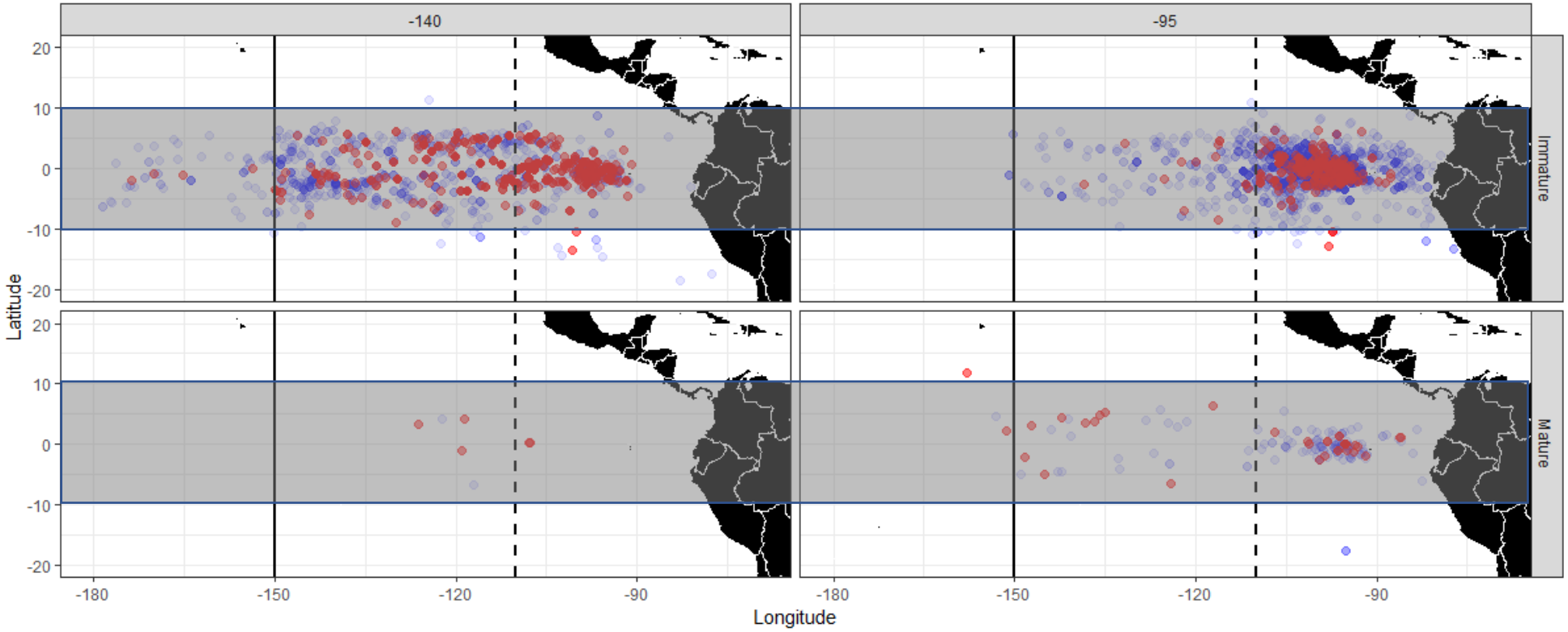
$$\mathrm{LL}(q, x|D_{W\rightarrow}) = \sum_i \log(L_i(q, x|D_{W\rightarrow W})) + \sum_j \log\big(L_j(q, x|D_{W\rightarrow E})\big)$$

$\hat{x} \approx 0.16$: 16% of BET move eastward across 110°W in each quarter

*** It should be applied to immature BET

Distribution of recapture location by release longitude and length at recapture

Red and blue dots represent samples with measured and estimated length at recapture, respectively

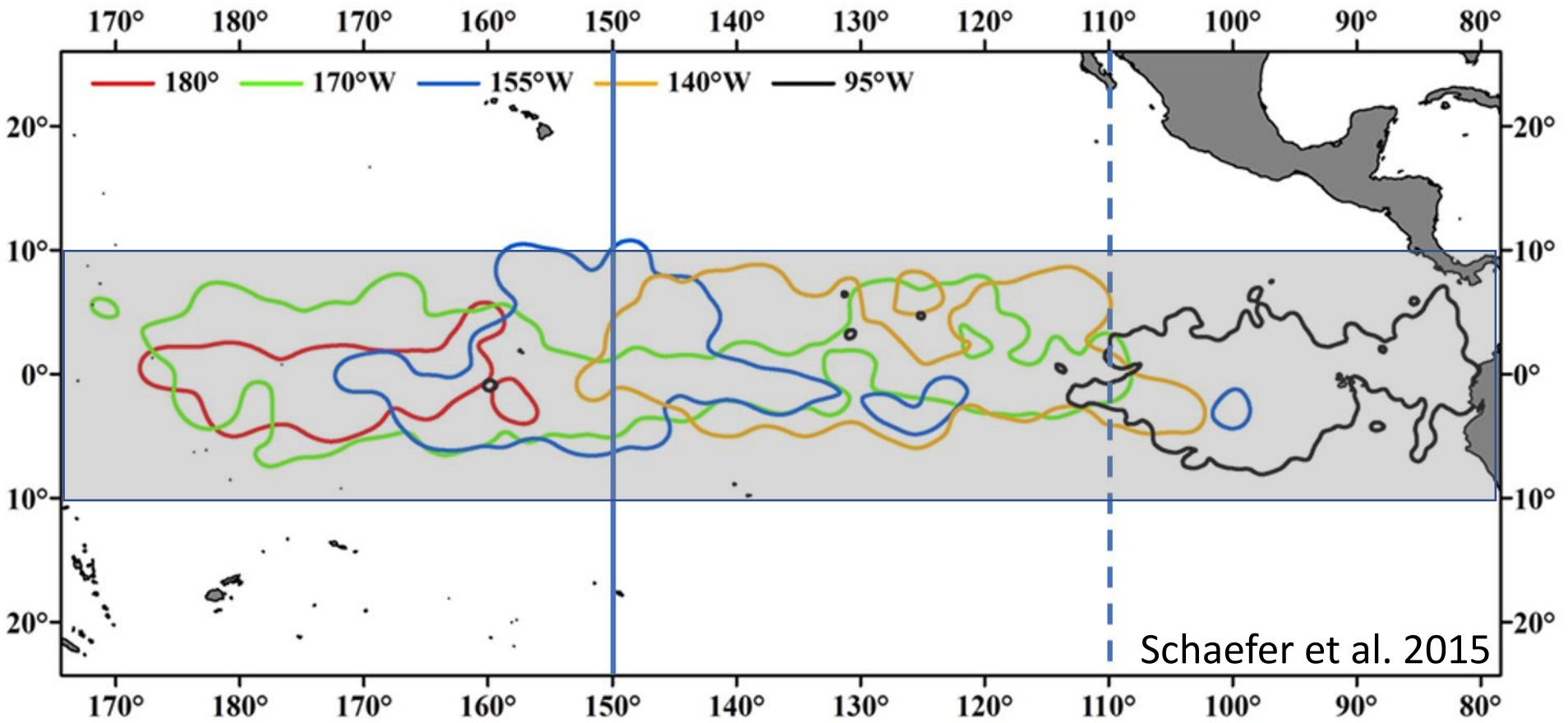


length at recapture < 135cm

length at recapture > 135cm

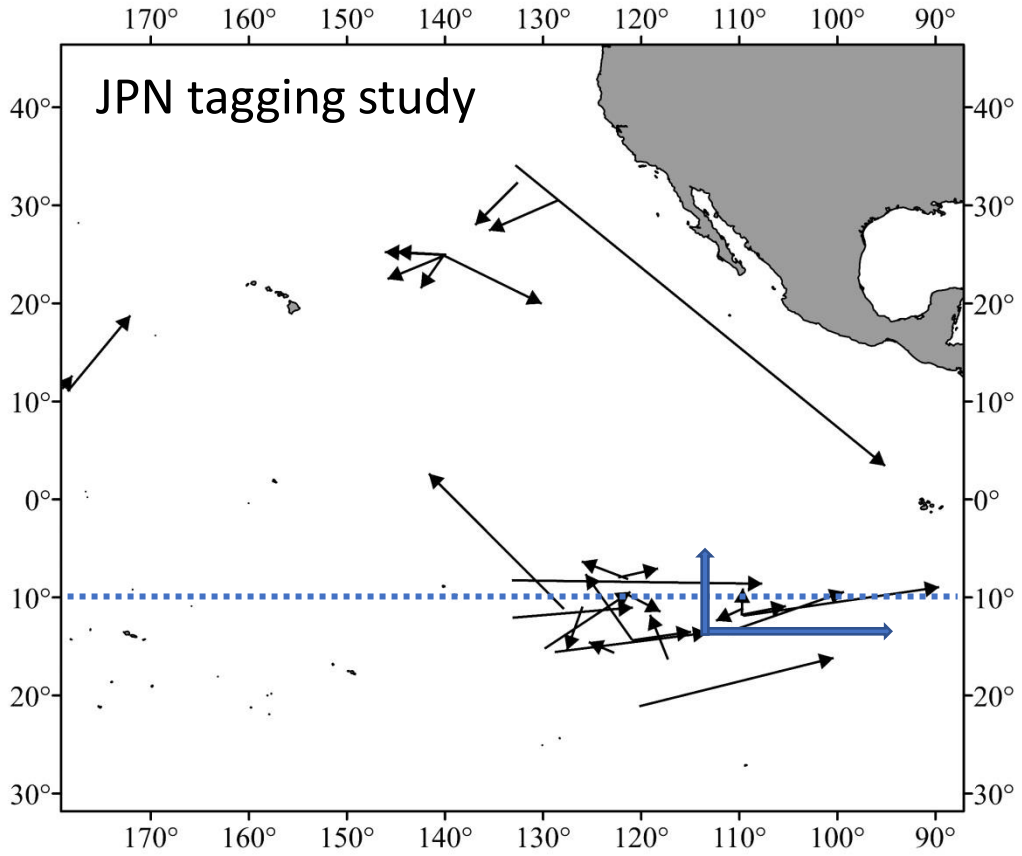
Archival tagging data are in accordance with conventional tagging data

- BET in the CPO tend to move eastward
- BET in the EPO seldomly move westward beyond 110W
- BET in the equatorial region (10S-10N) seldomly move to higher latitudes

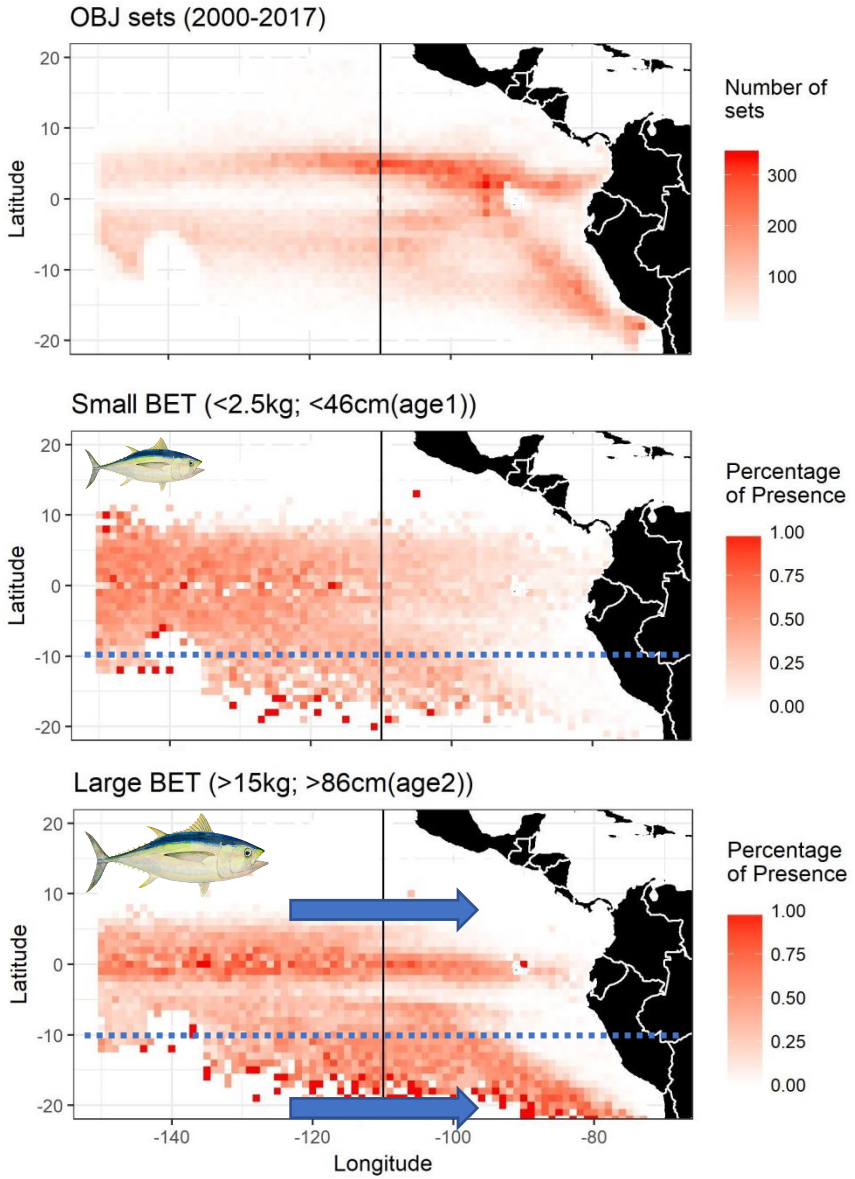


How about south of 10S?

BET tagged south of 10S tend to move eastward and a noticeable proportion move northward across 10S (low confidence due to the small sample size)



Presence/absence in the FAD fishery



Proposed movement scenarios of BET

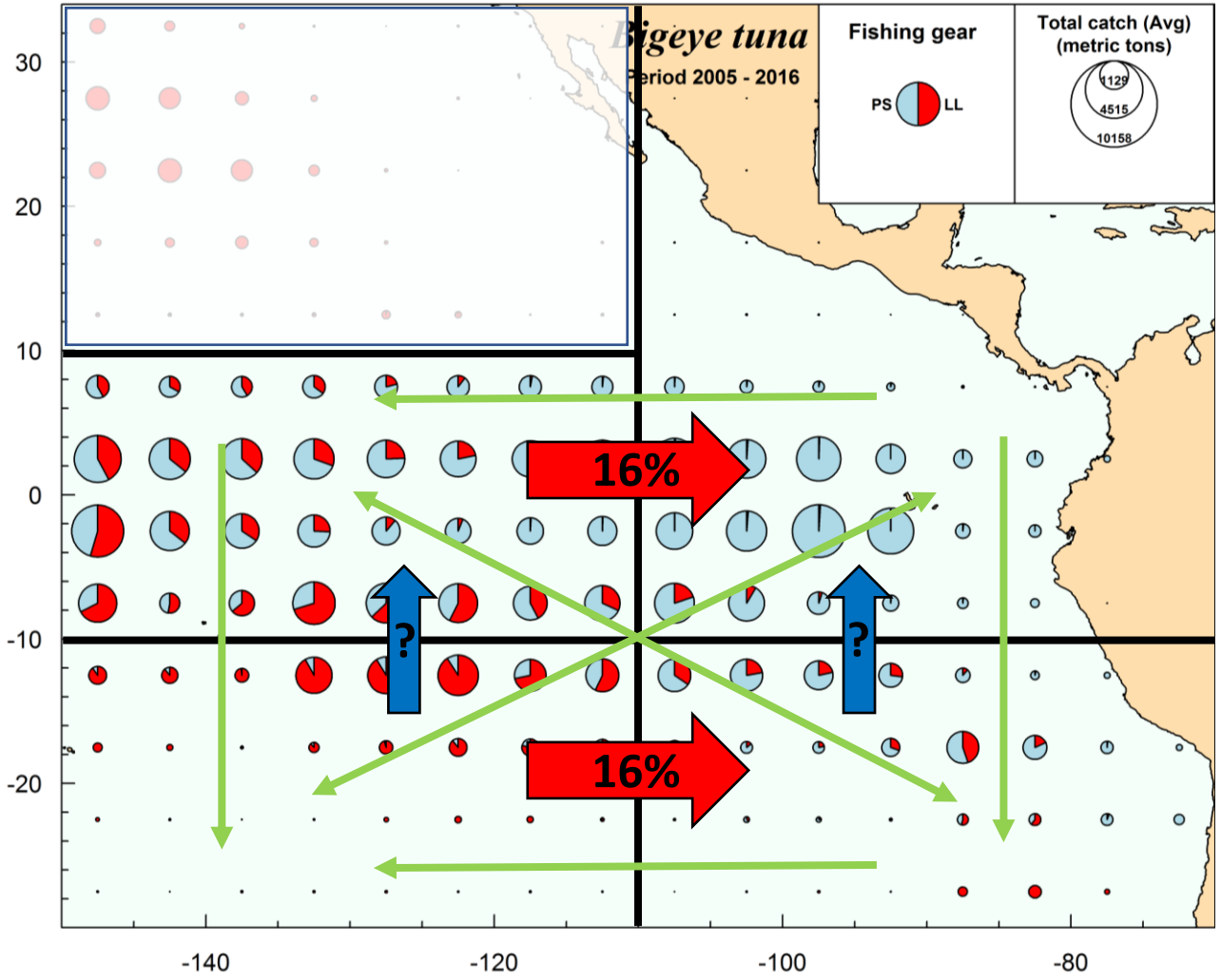
General movement rate configurations in the spatial model:

- Two age groups: juvenile (3-8 quarters) and adult (>14 quarters)
- No movement prior to age 3 (quarters)
- Linear interpolated movement rates between the two age groups
- Time-invariant

Number of movement rate scenarios

- One scenario for juvenile BET
- Three scenarios for adult BET

Conceptual movement scenario for **juvenile BET**

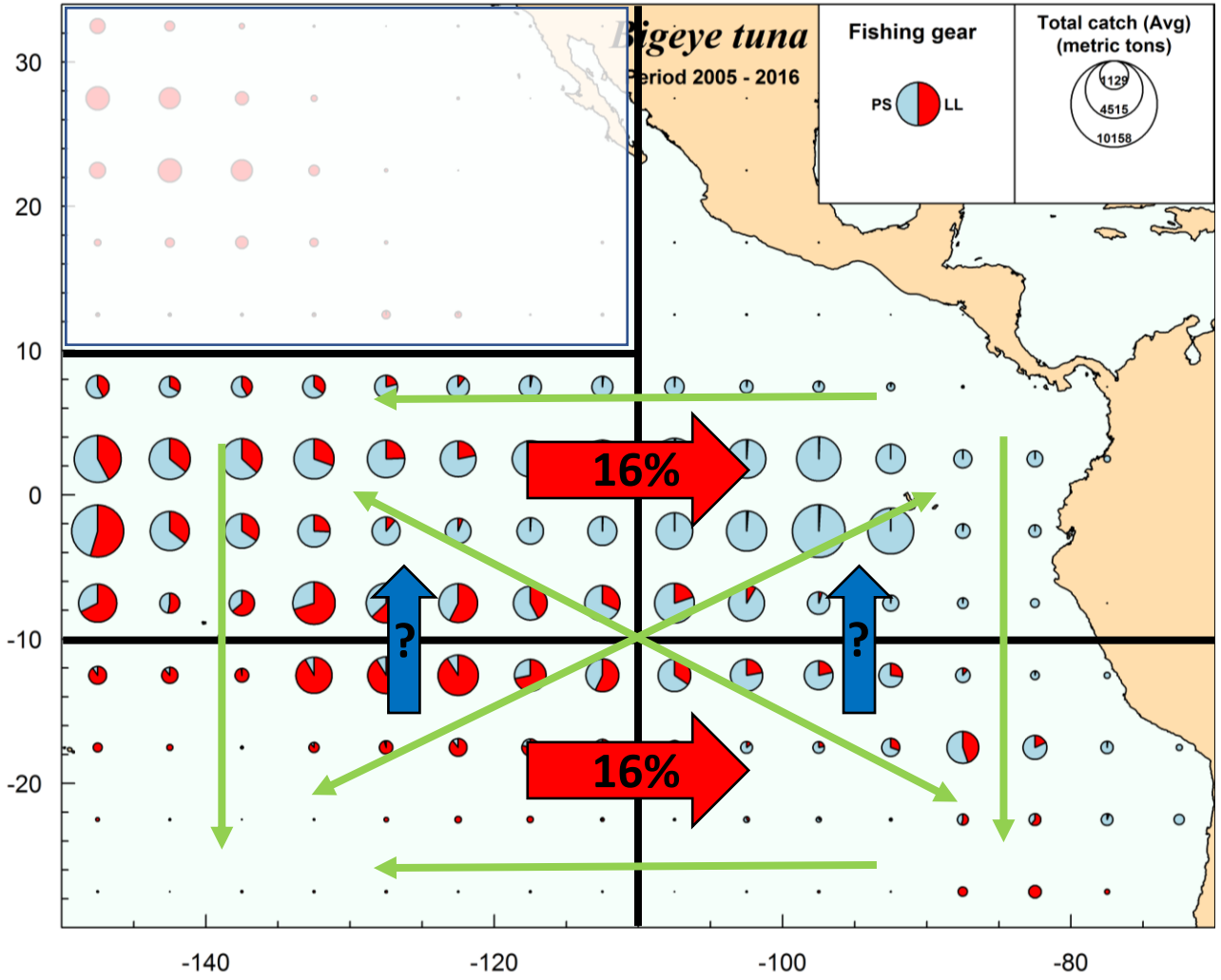


Four areas correspond to twelve between-area movements, within which:

- The two movements eastward across 110W are most pronounced
- The two movements northward across 10S are noticeable but less pronounced and credible
- The other eight movements are relatively minor

Conceptual movement scenarios for **adult BET**

Scenario1: same as that for **juvenile BET**

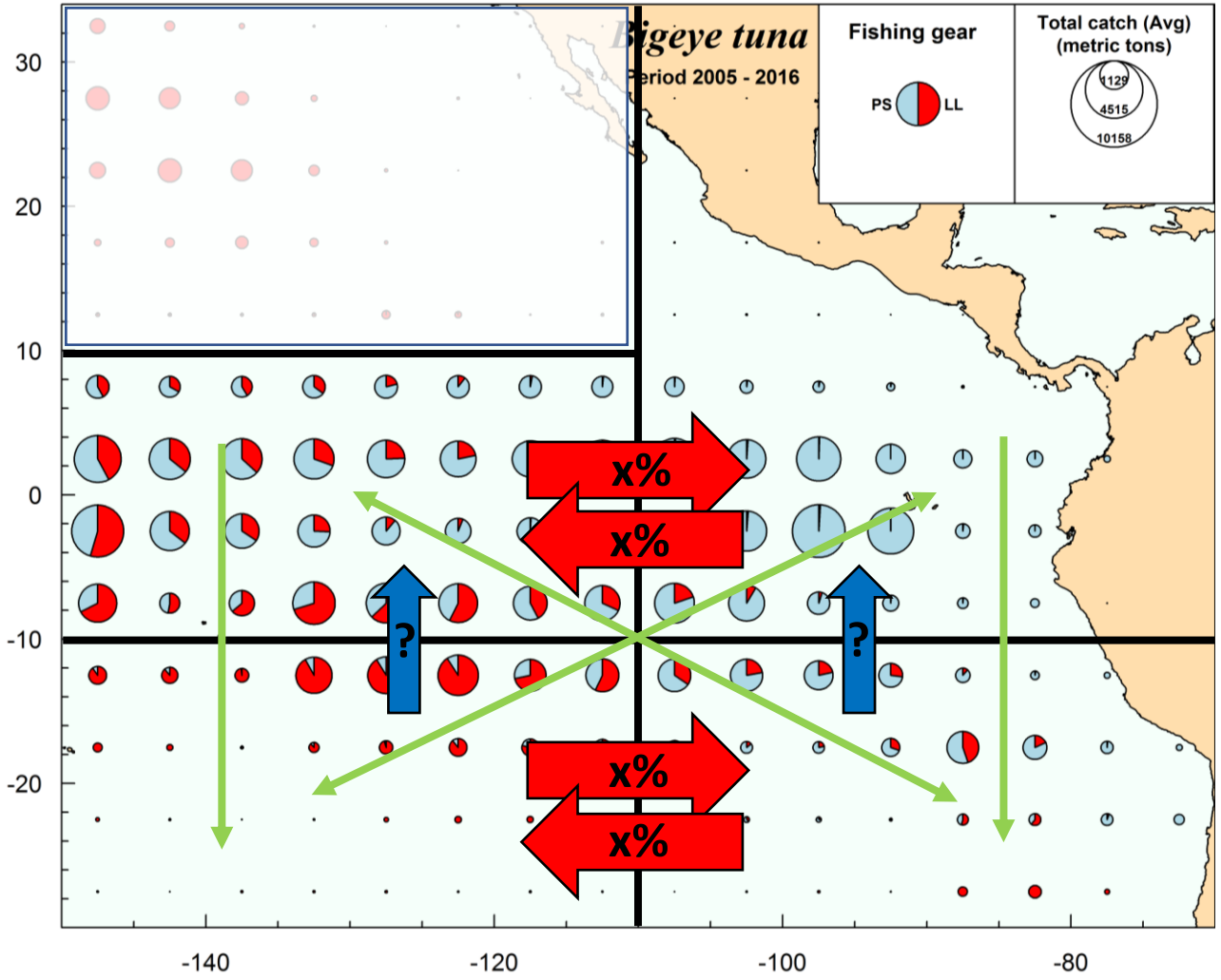


Four areas correspond to twelve between-area movements, within which:

- The two movements eastward across 110W are most pronounced
- The two movements northward across 10S are noticeable but less pronounced and credible
- The other eight movements are relatively minor

Conceptual movement scenarios for **adult BET**

Scenario2: east-west diffusion

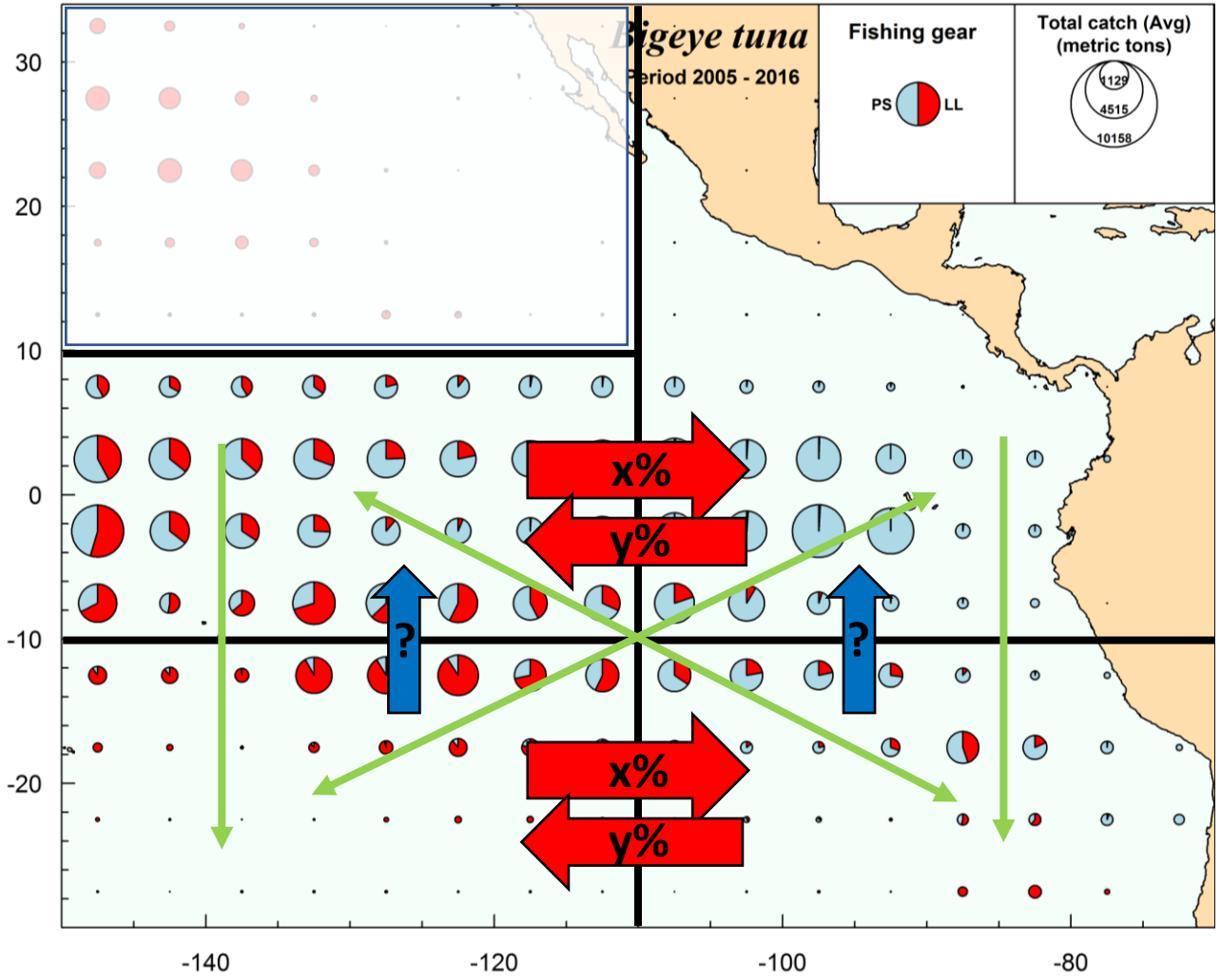


Four areas correspond to twelve between-area movements, within which:

- **The four movements across 110W are most pronounced and have the same rate (x = 4, 8, 12, etc.)**
- The two movements northward across 10S are noticeable but less pronounced and credible
- The other six movements are relatively minor

Conceptual movement scenarios for **adult BET**

Scenario3: east-west diffusion and advection



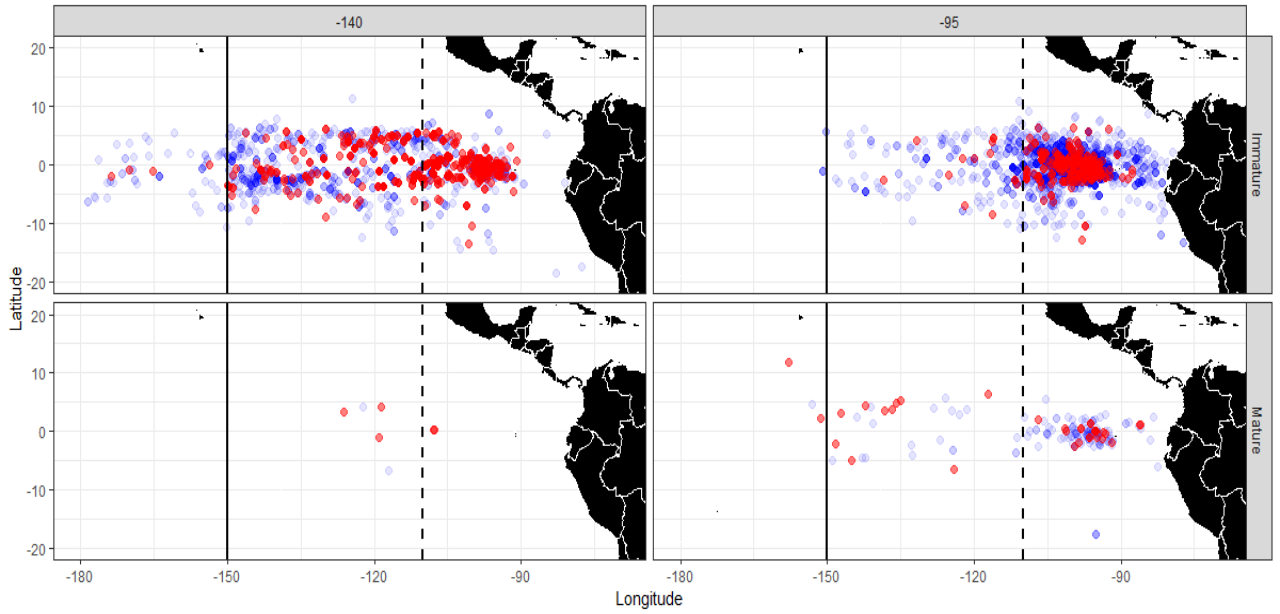
Four areas correspond to twelve between-area movements, within which:

- **The four movements across 110W are most pronounced and have different rates (x>y or x<y)**
- The two movements northward across 10S are noticeable but less pronounced and credible
- The other six movements are relatively minor

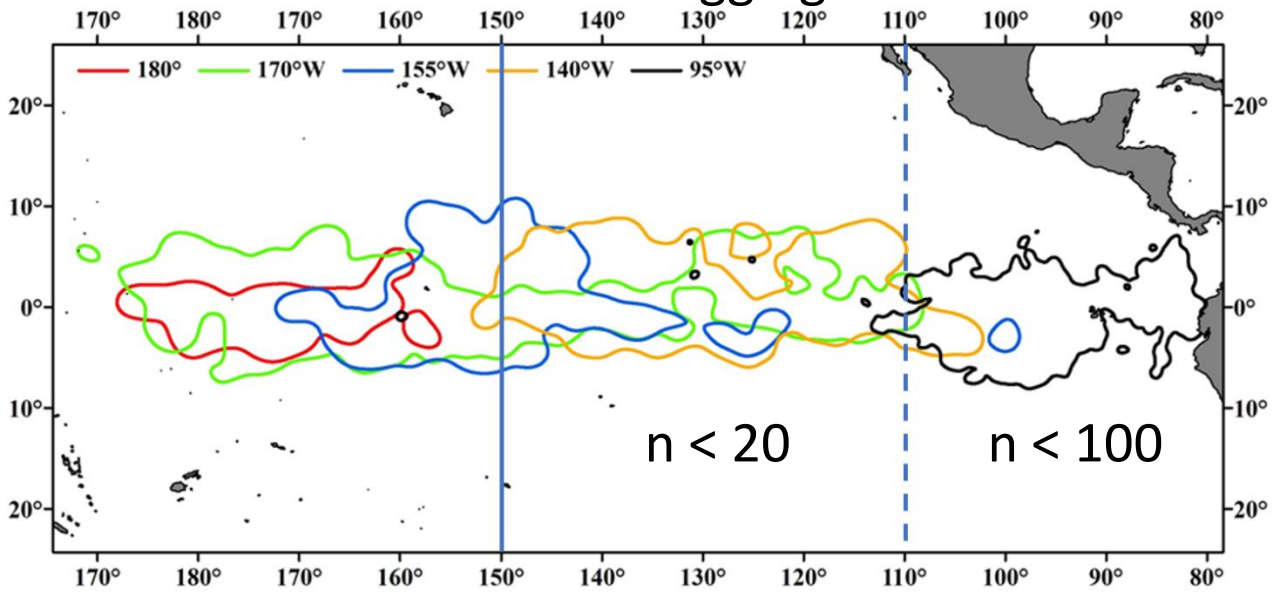
Available tagging data are limited in several aspects

- Latitudinally: 10S-10N
- Longitudinally: 140W and 95W
- Life history: immature (age 1-3yrs)
- Sample size: archival tagging data
- Tag shedding and reporting rates are both unknown

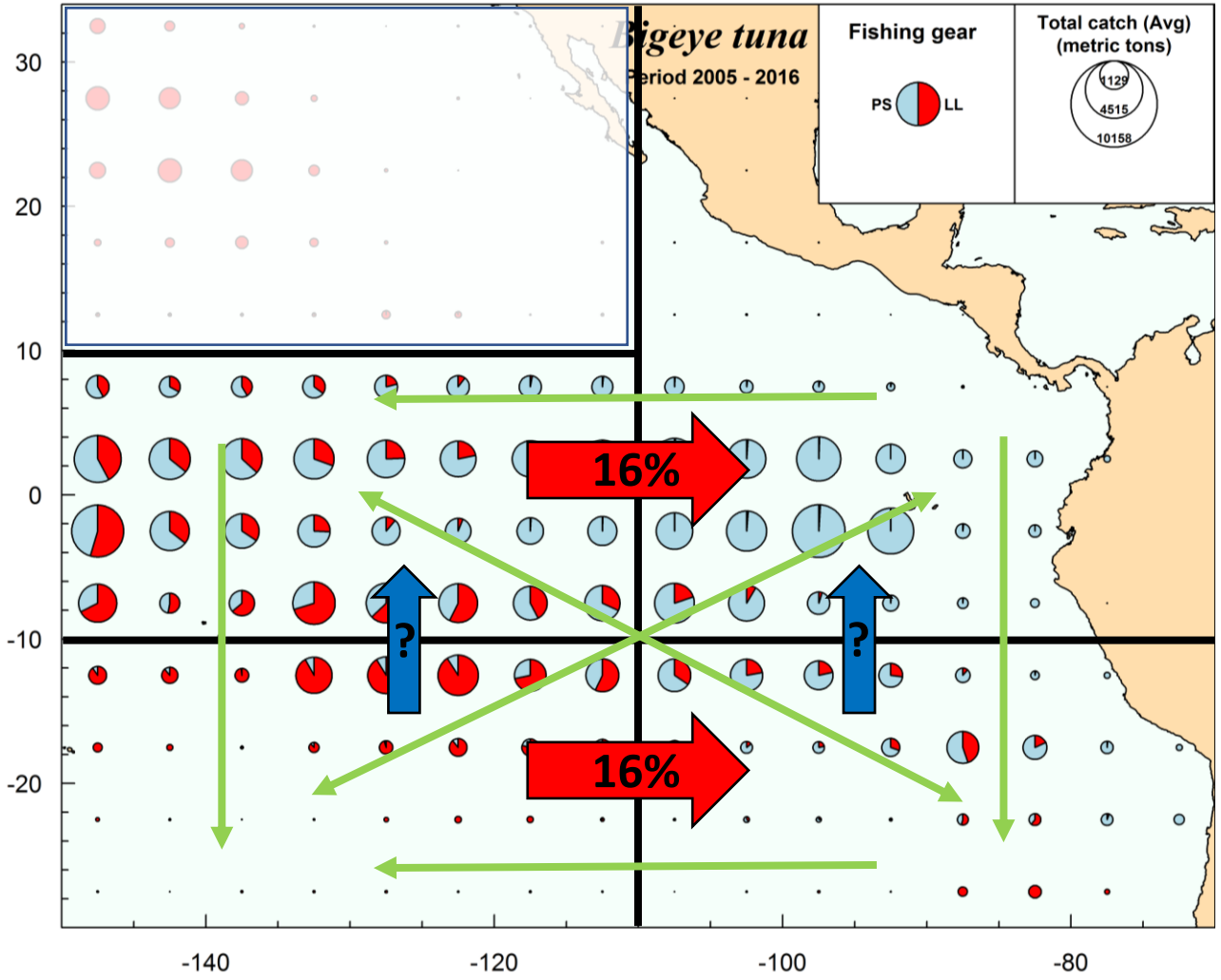
Conventional tagging



Archival tagging



Summary of proposed movement scenarios



Juvenile movement:

- Eastward movement at a rate of ~16% per quarter
- Noticeable northward movement but the rate of which is unknown
- The other movements are relatively minor (fix at 0 or 2%?)

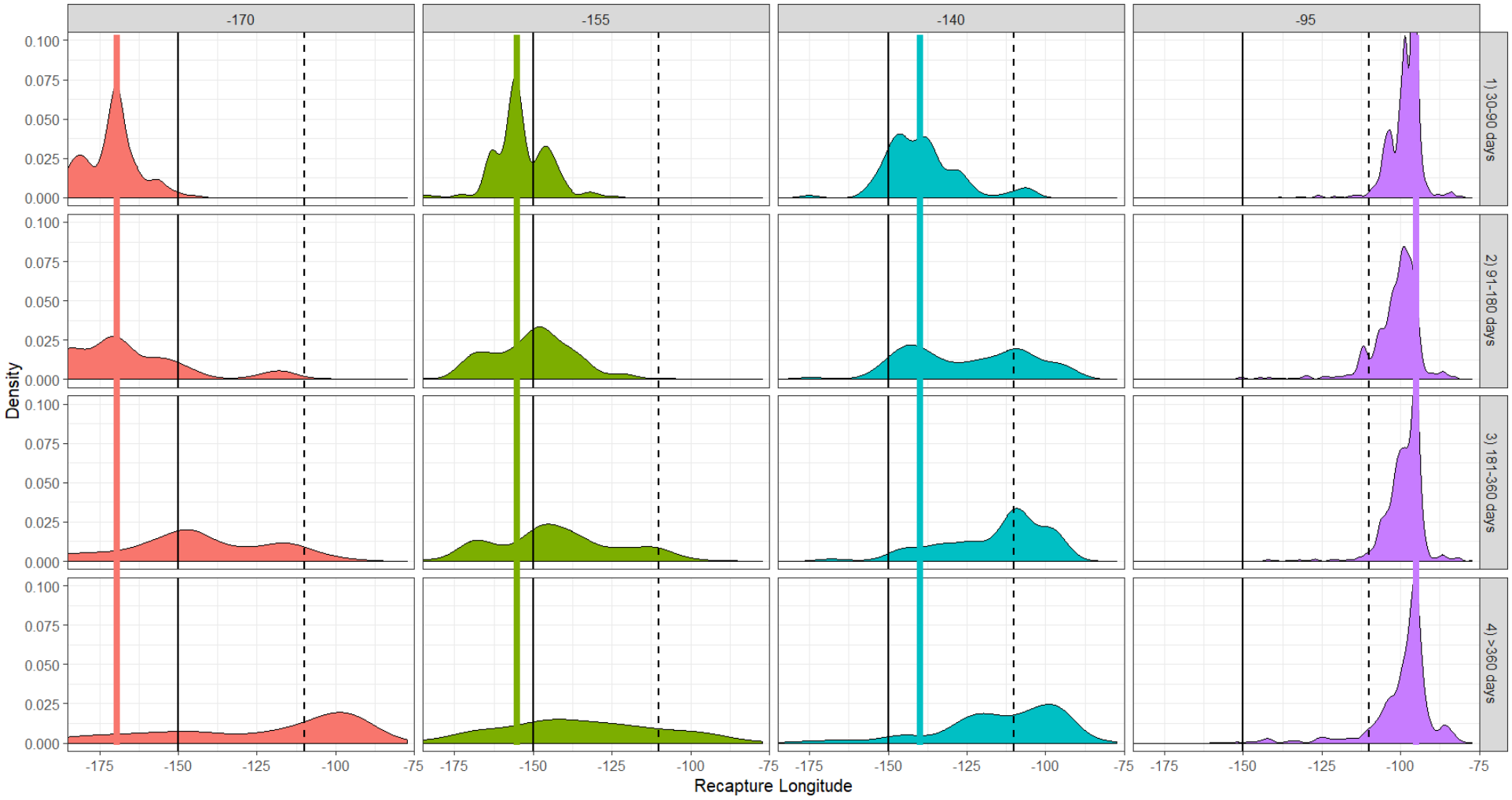
Adult movement:

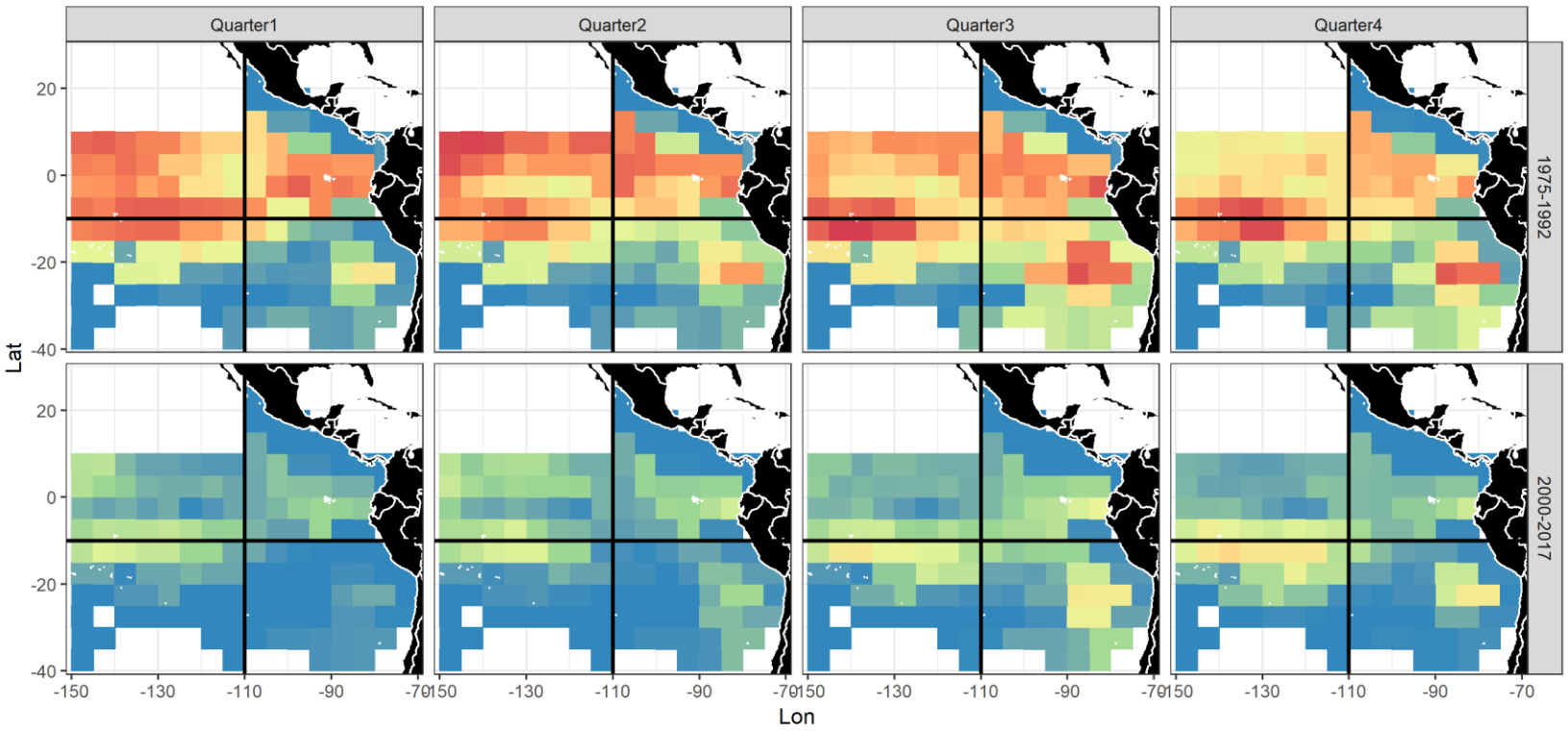
- No informative data are available so assumptions need to be made:
  1. same as juvenile's
  2. east-west diffusion
  3. east-west diffusion and advection

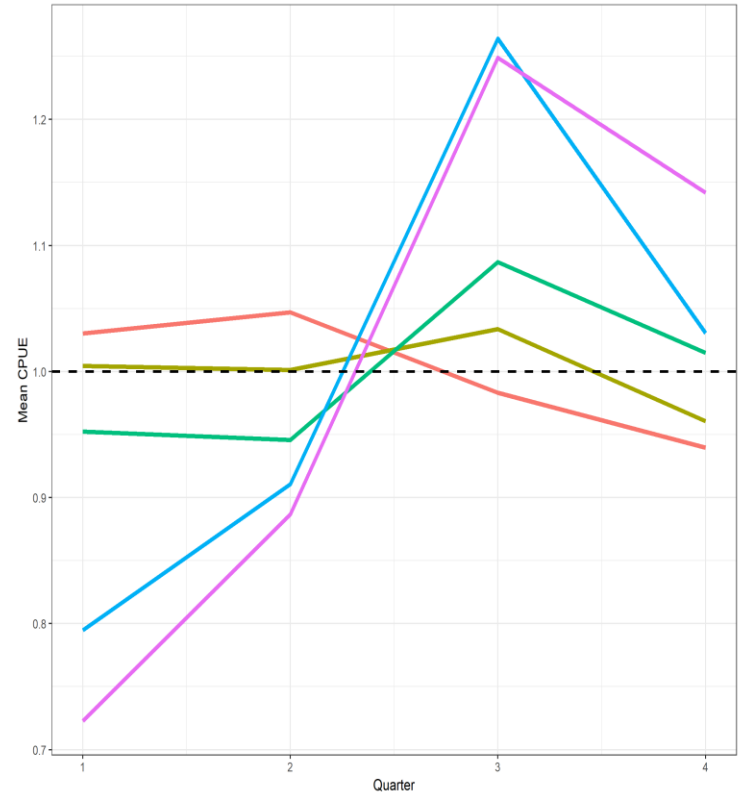
Thank you!

Any questions/comments/suggestions?

Conventional tagging data

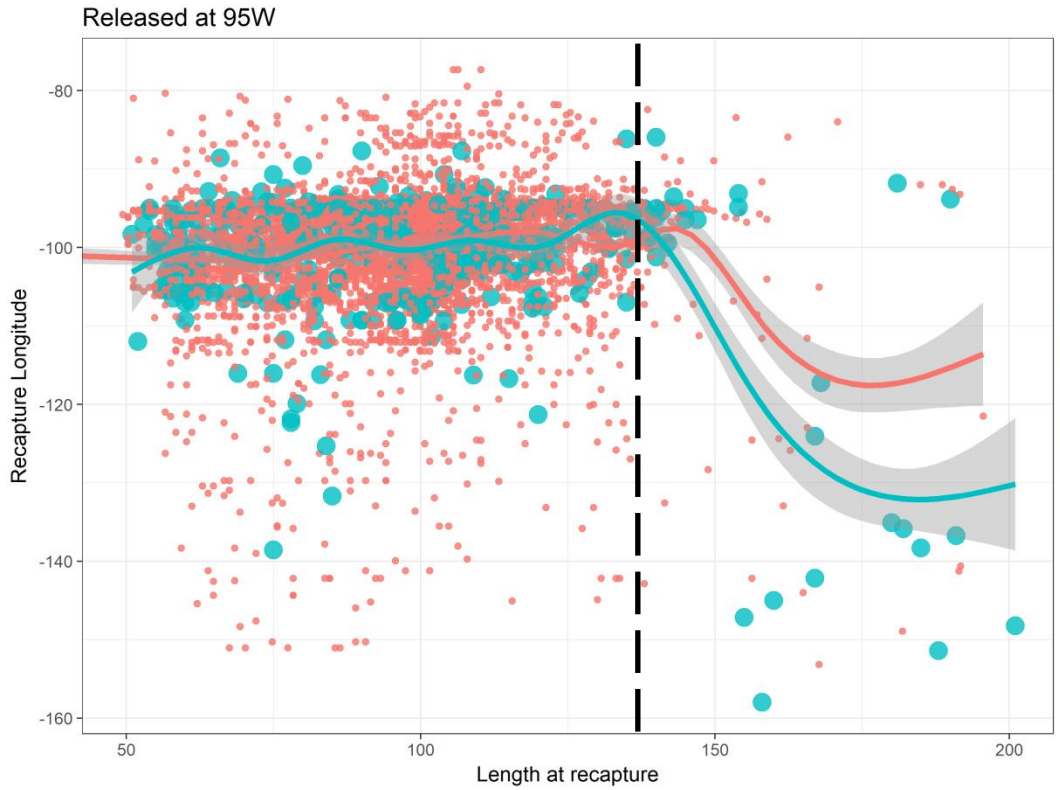


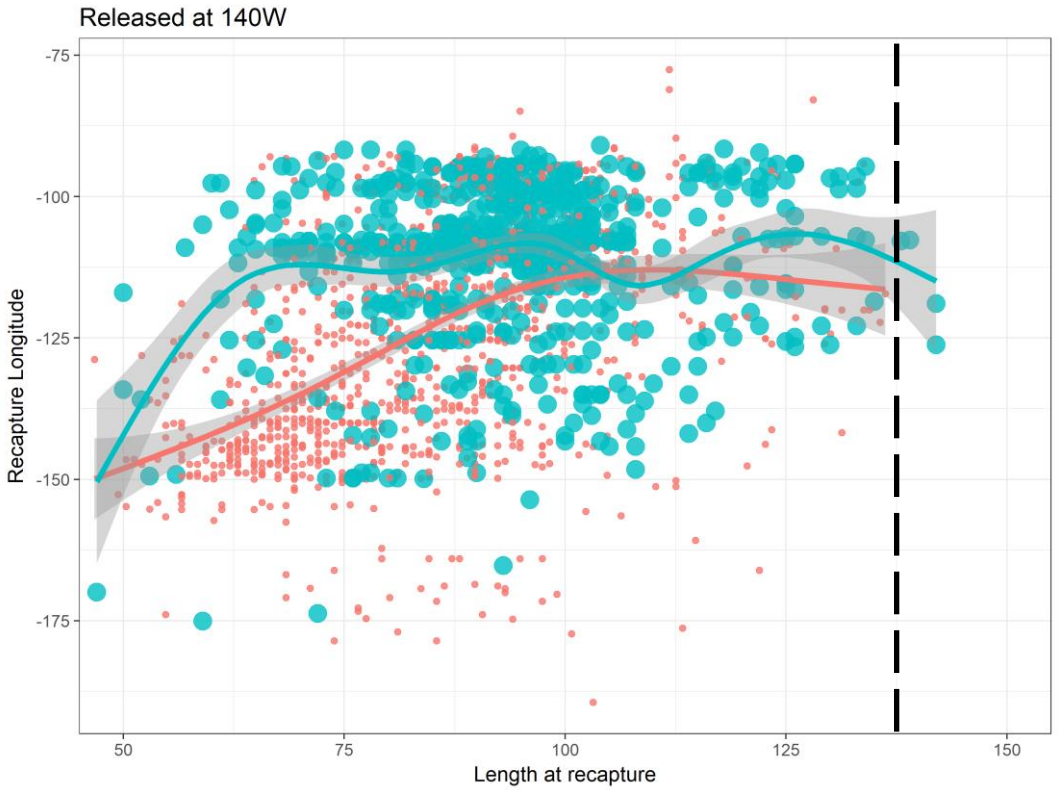

Quarter1
Quarter2
Quarter3
Quarter4
1975-1992
2000-2017
Lat
Lon
20
0
-20
-40
-150
-130
-110
-90
-70
Density
7
6
5
4


Mean CPUE
Quarter
1.2
1.1
1.0
0.9
0.8
0.7
1
2
3
4
Area
A1
A2
A3
A4
A5

Recapture longitude versus Length at recapture

- For those which were released in the CPO, the expected recapture location moved eastward as the length at recapture increases
- For those which were released in the EPO, the expected recapture location stayed in the EPO until reaching maturity





blue dots: measured length
red dots: estimated length
black lines: length at 50% maturity