Informing the spatial management of Silky Shark (*Carcharhinus falciformis*) in the eastern Pacific Ocean

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Melanie Hutchinson, Jon Lopez, Carolina Minte-Vera, Dan Ovando, Salvador Siu, Lyall Bellquist

It is helpful to understand spatial population structure.

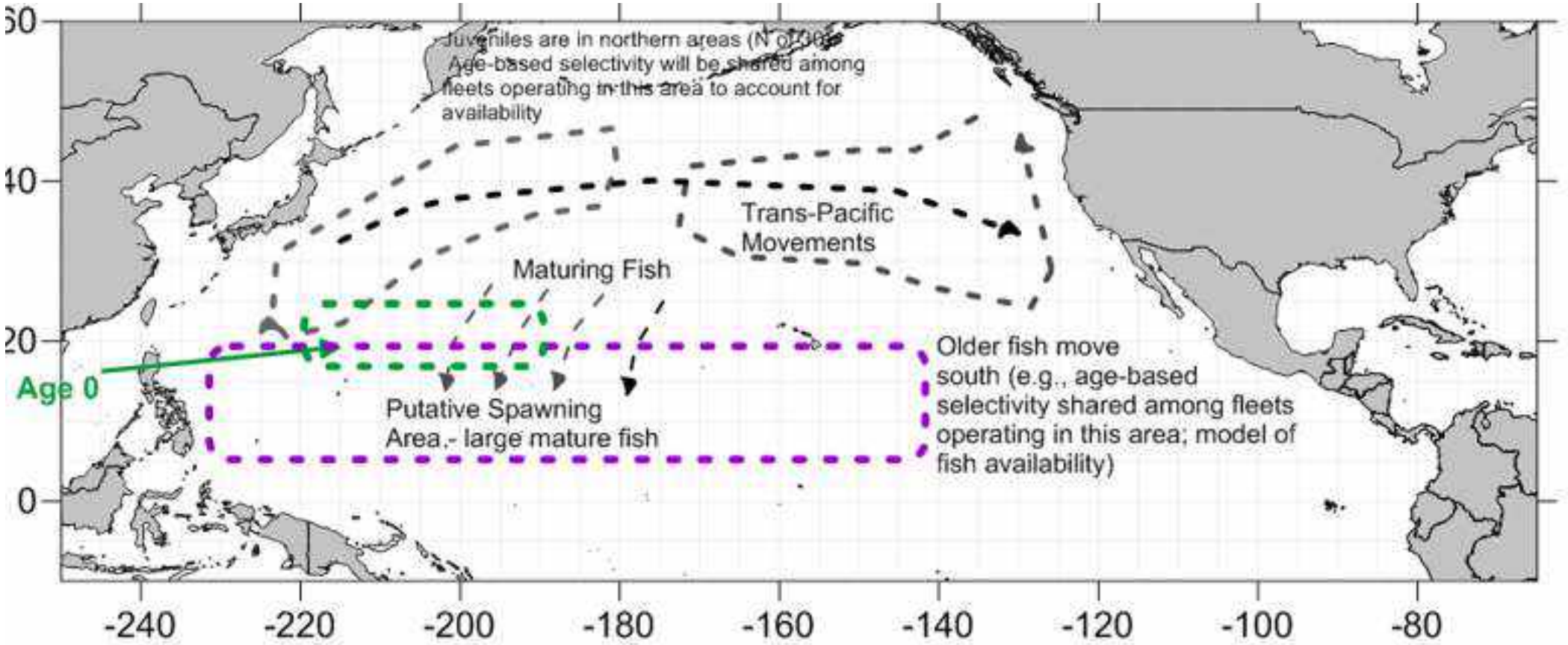


Figure 1. Conceptual model of north Pacific albacore spatial structure and movement patterns.

Minte-Vera[2], 2023

Conceptual models lead to better assessments.

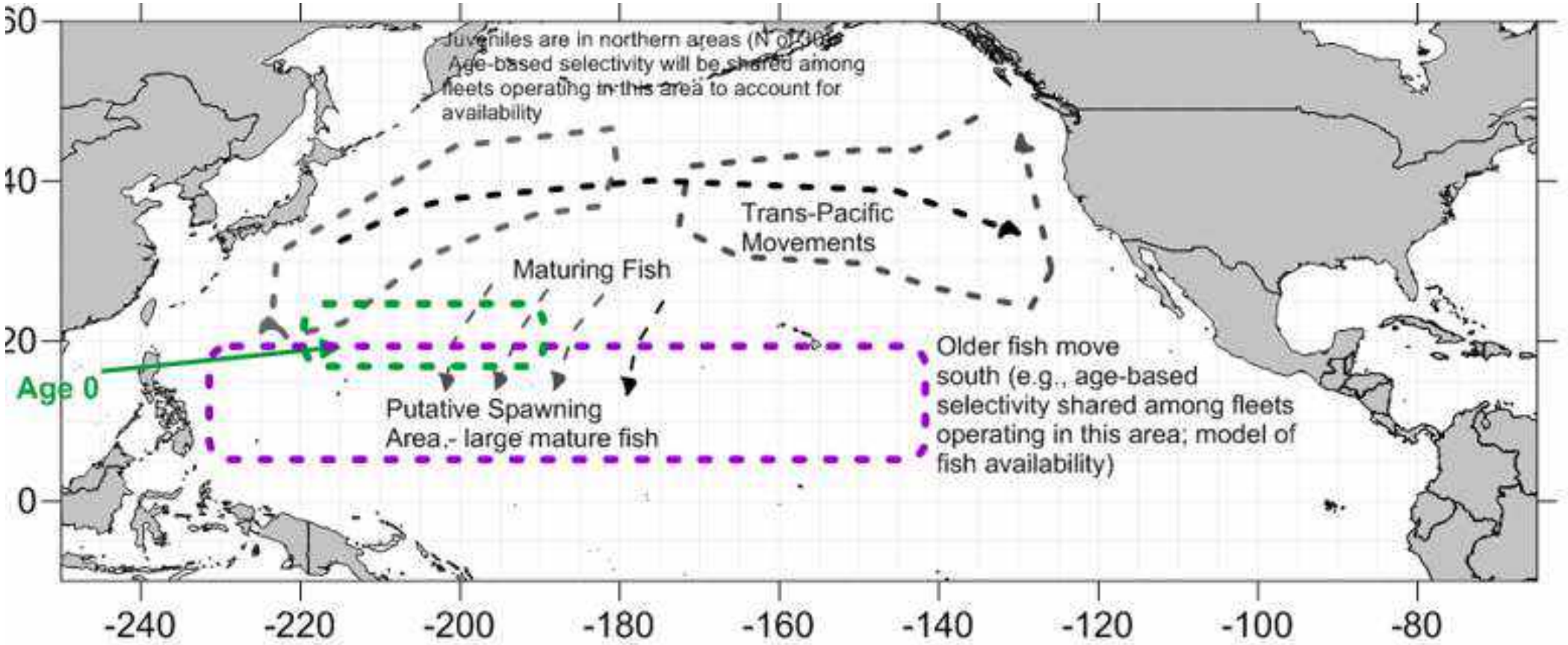
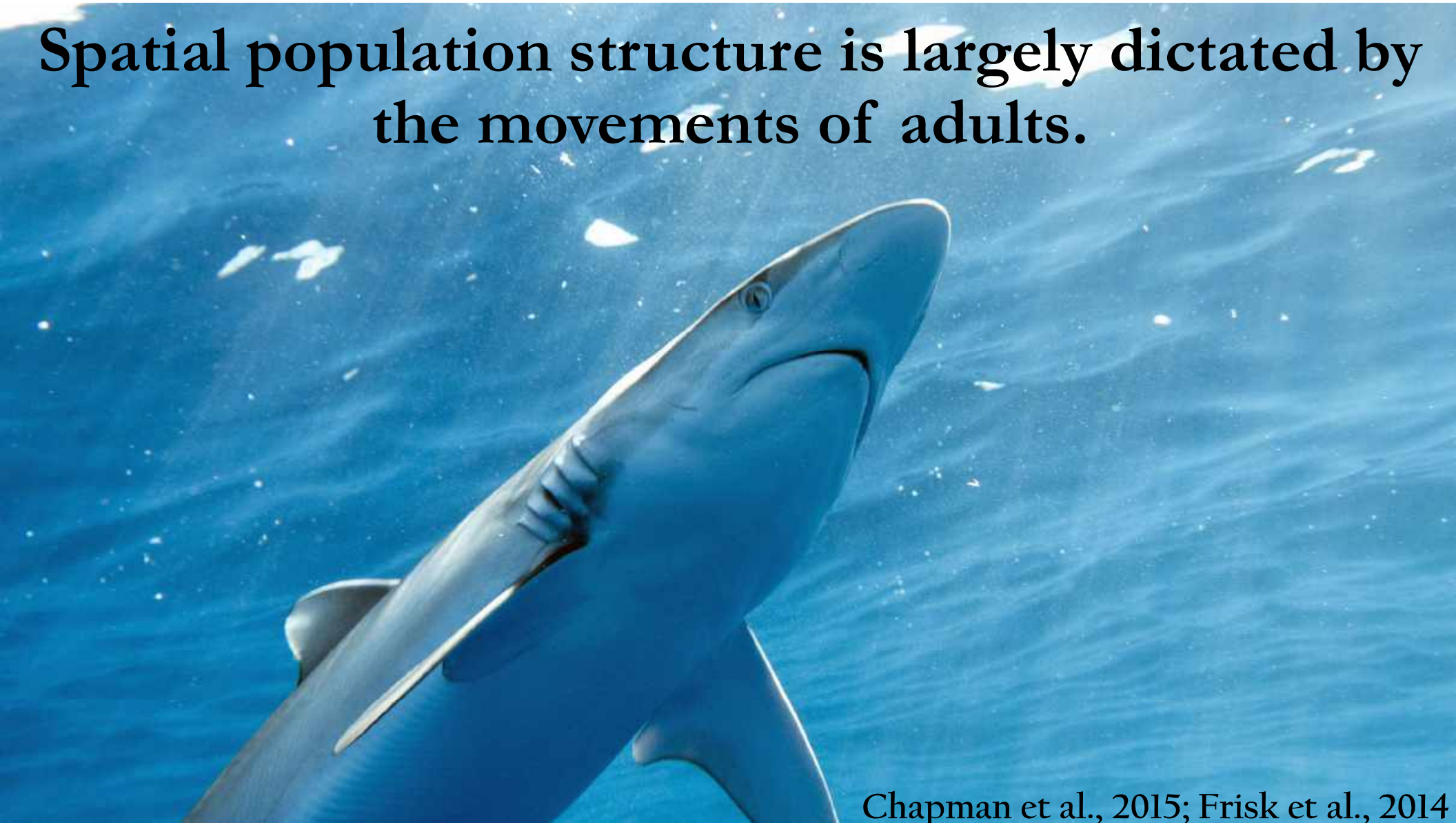


Figure 1. Conceptual model of north Pacific albacore spatial structure and movement patterns.

Minte-Vera[3], 2023


Shane Gross

Spatial population structure is largely dictated by the movements of adults.



Chapman et al., 2015; Frisk et al., 2014

How much genetic and demographic mixing occurs across what spatial scales?


Fishery-dependent data
Tagging data
Local observations
?
Life history information
Population genetics

Spatially explicit 'classic stock delineation'

Units delineated according to spatial boundaries

[tagging, genetics, life history]

Spatially implicit 'Areas-as-fleets'

Units delineated according to selectivity

[gear type, area of operation]

SILKY SHARK MANAGEMENT

Conventional stock assessment impossible: fishery data uncertainty

IATTC attempts assessment

2013

IATTC proposes use of stock status indicators

CMS Appendix II 2014

2016

IATTC no-retention measure, ban on fishing in pupping areas

CITES Appendix II

2017

Low confidence in outputs

Pacific-wide stock status assessment

2018

Key needs: resolve population structure & movements

2023

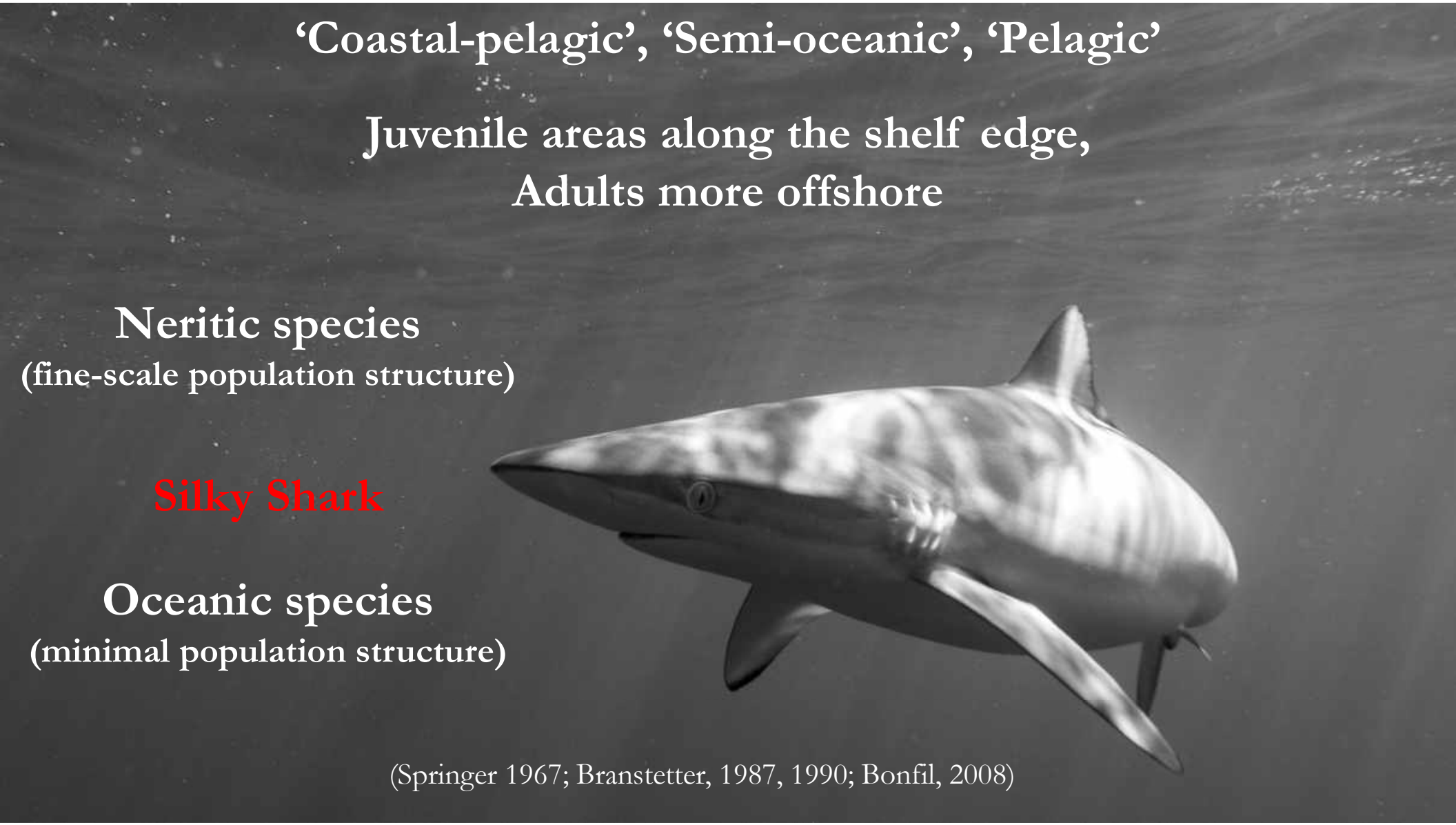
Conceptual model

Biomass has declined & fishing mortality has increased

Silky Shark
Carcharhinus falciformis

Leads shark bycatch in many shelf-edge and open-ocean fisheries

(Bonfil, 2008; Oliver *et al.*, 2015)


‘Coastal-pelagic’, ‘Semi-oceanic’, ‘Pelagic’
Juvenile areas along the shelf edge,
Adults more offshore
Neritic species
(fine-scale population structure)
Silky Shark
Oceanic species
(minimal population structure)
(Springer 1967; Branstetter, 1987, 1990; Bonfil, 2008)

Objective

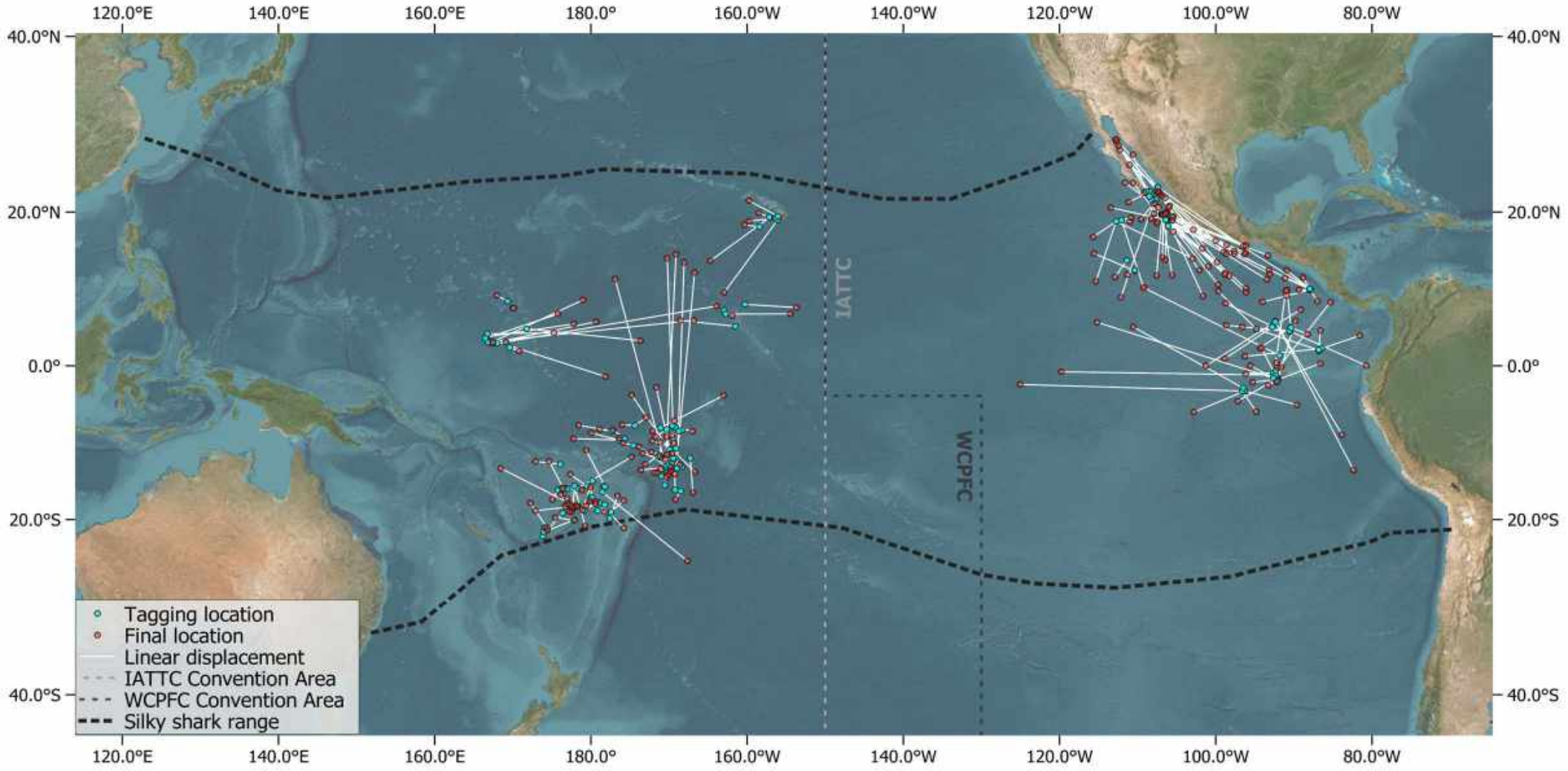
Characterize Silky Shark spatial population structure in the (E)PO (i.e., explore stock structure)

1) Movement data {synthesis}
2) Population genetic data {review}
3) Spatial variation in life history parameters {new}

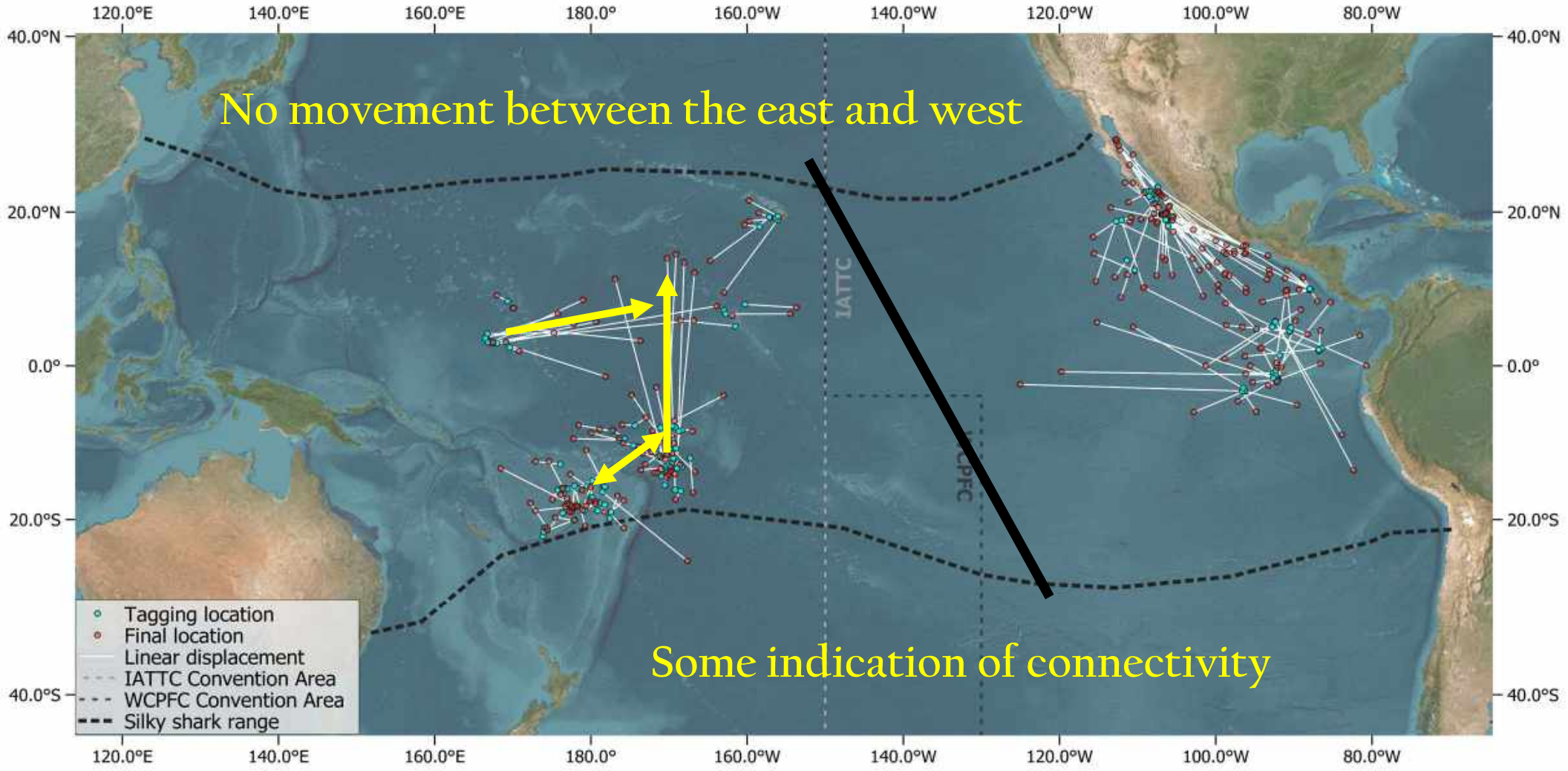
244 individuals

1967-2021

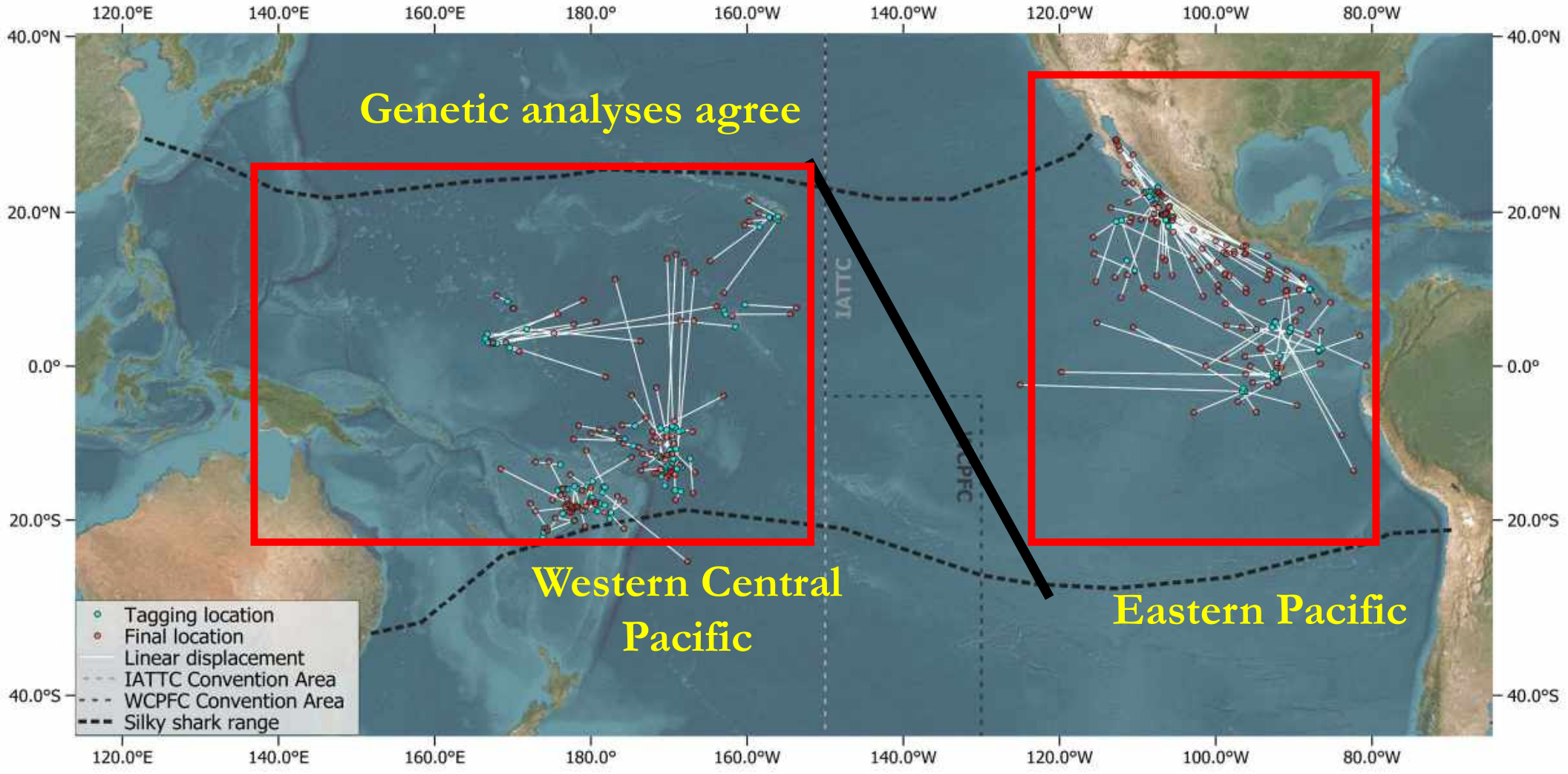
9 studies



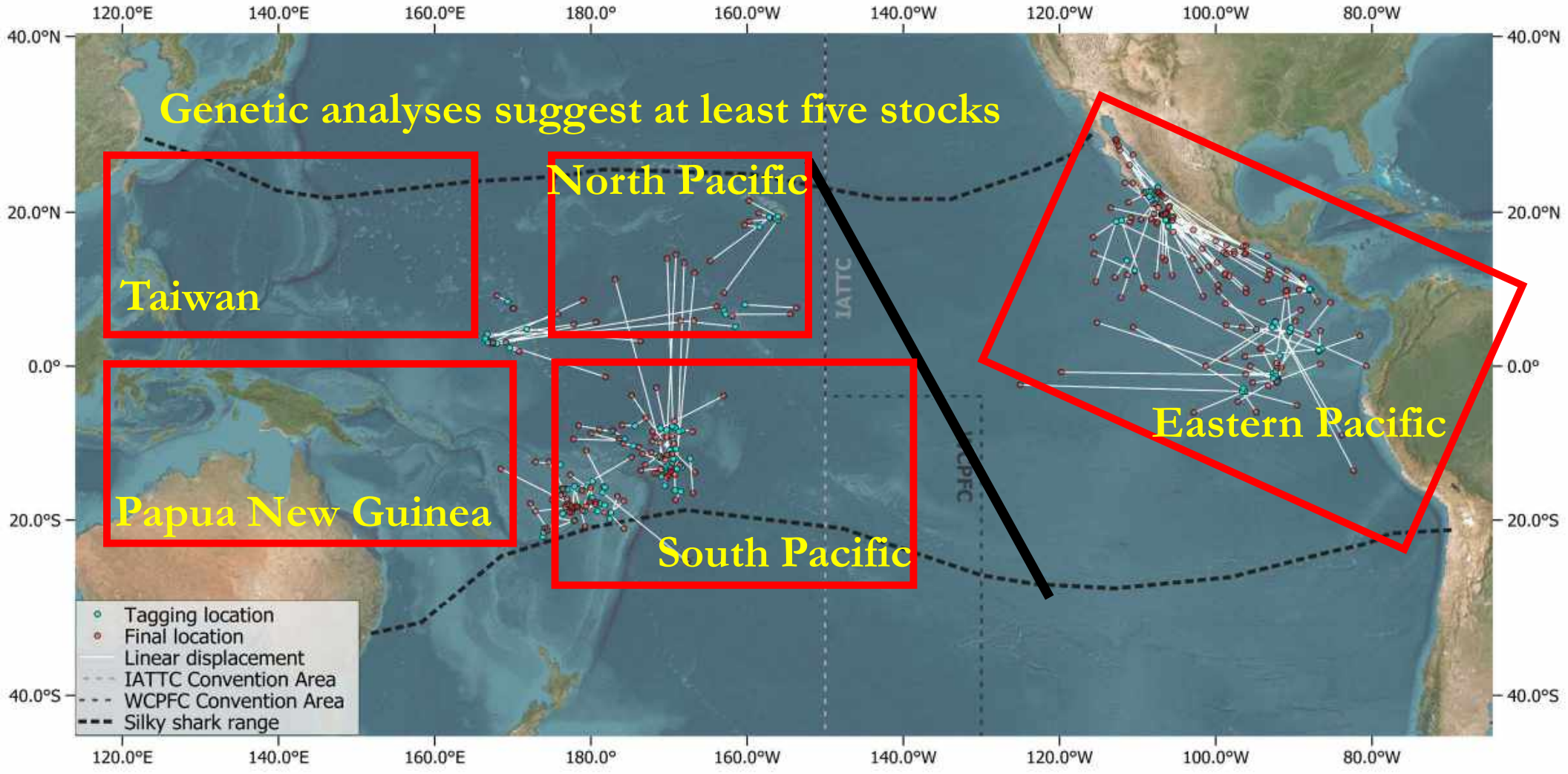
(Francis et al., 2023; Hutchinson et al., 2019, 2021; Kato & Carcallo, 1967; Ketchum et al., 2020; Lara-Lizardi et al., 2020; Musyl et al., 2011; Schaefer et al., 2019, 2021)



(Francis et al., 2023; Hutchinson et al., 2019, 2021; Kato & Carcallo, 1967; Ketchum et al., 2020; Lara-Lizardi et al., 2020; Musyl et al., 2011; Schaefer et al., 2019, 2021)



(Galvan-Tirado et al., 2013; Clarke et al., 2015; Kraft et al., 2018)



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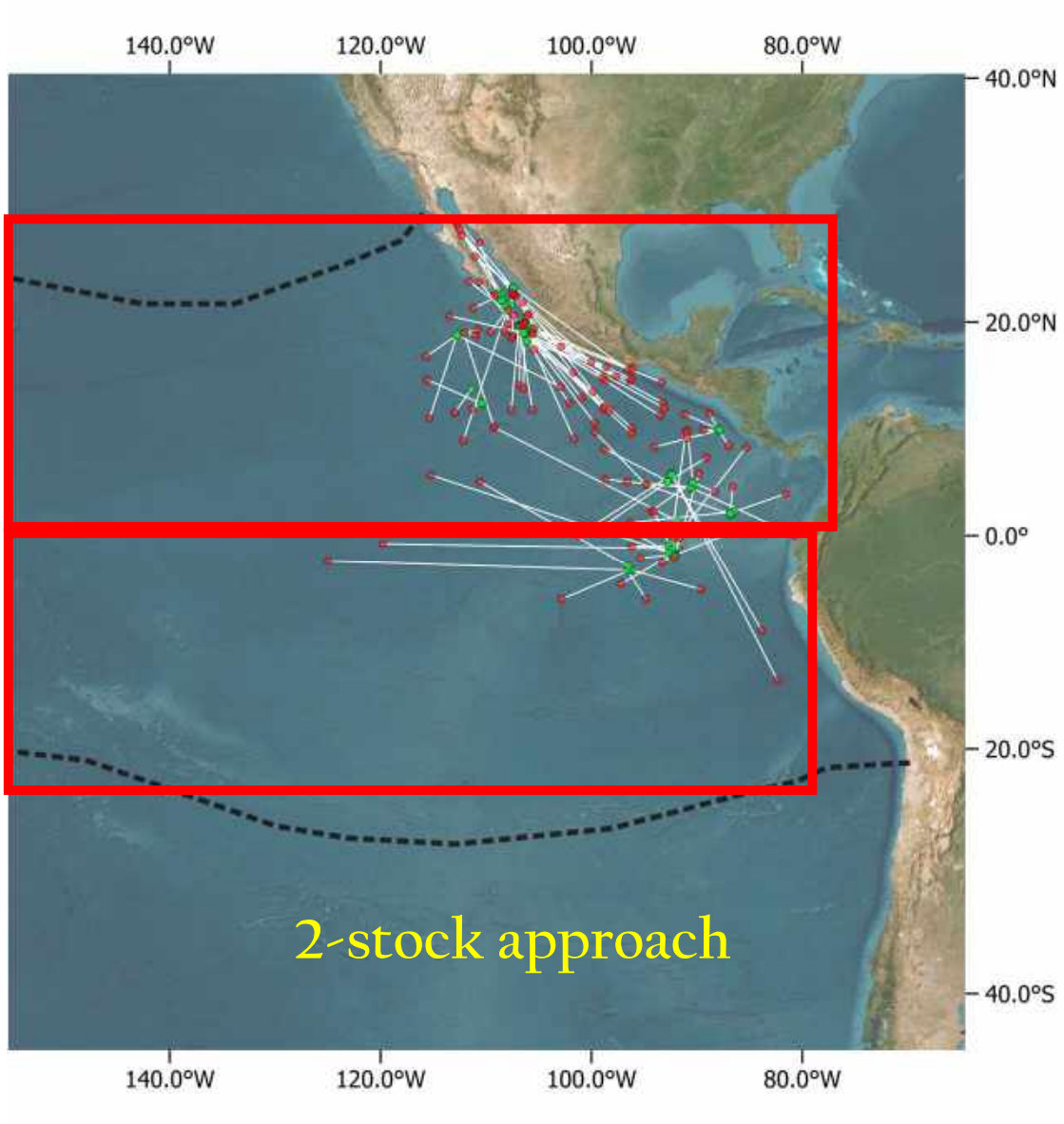
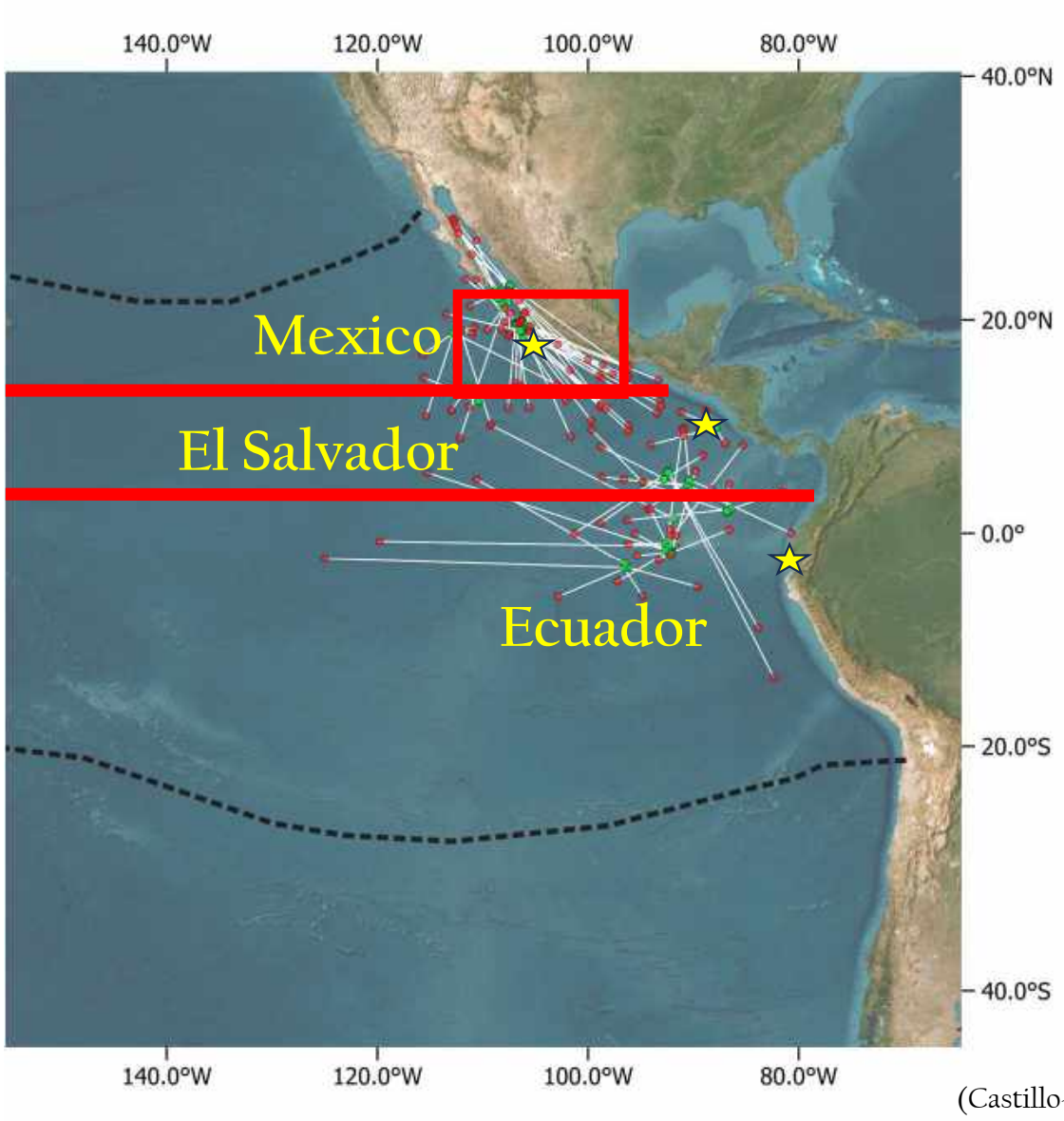
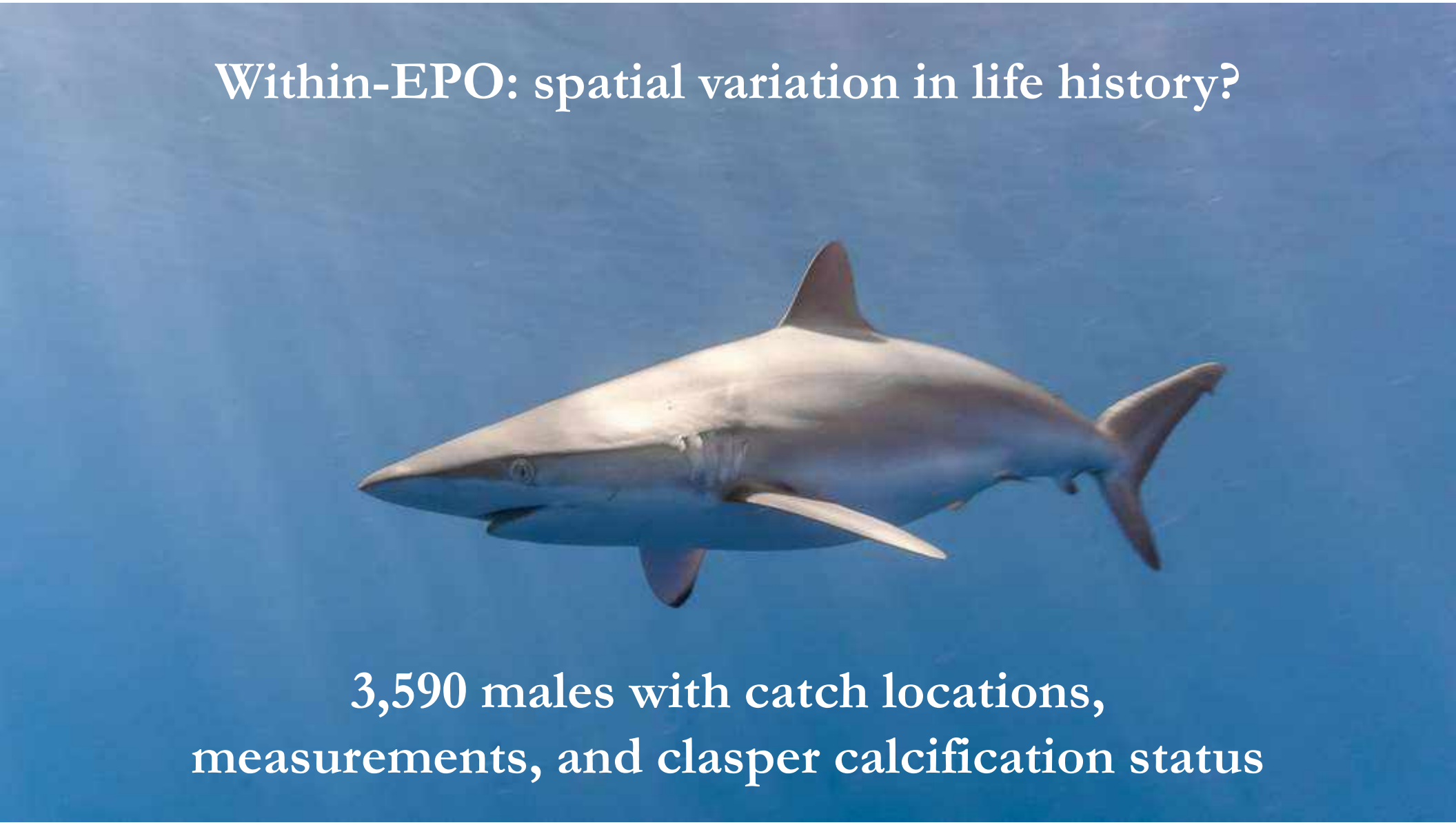

140.0°W
120.0°W
100.0°W
80.0°W
40.0°N
20.0°N
0.0°
20.0°S
40.0°S
2-stock approach

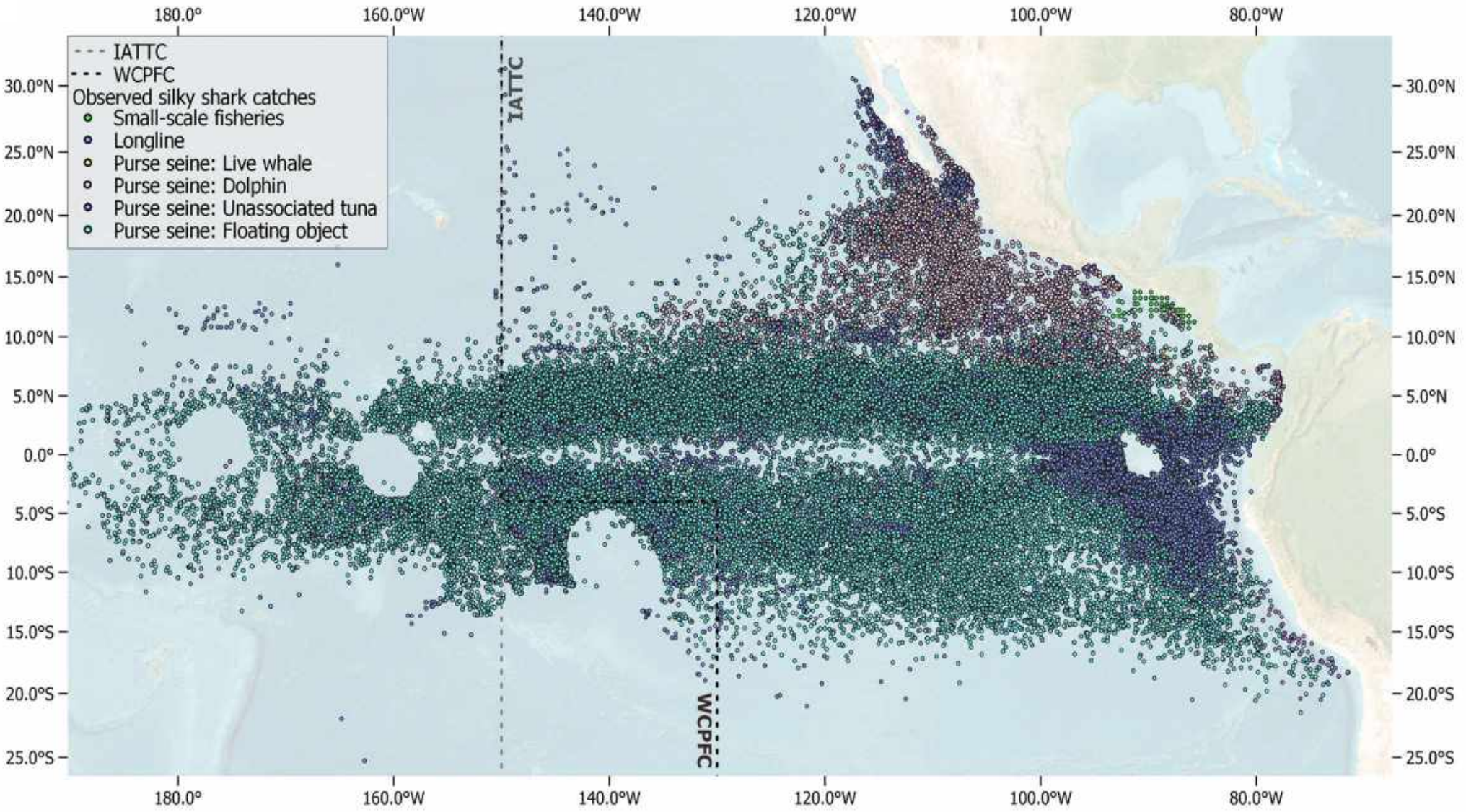


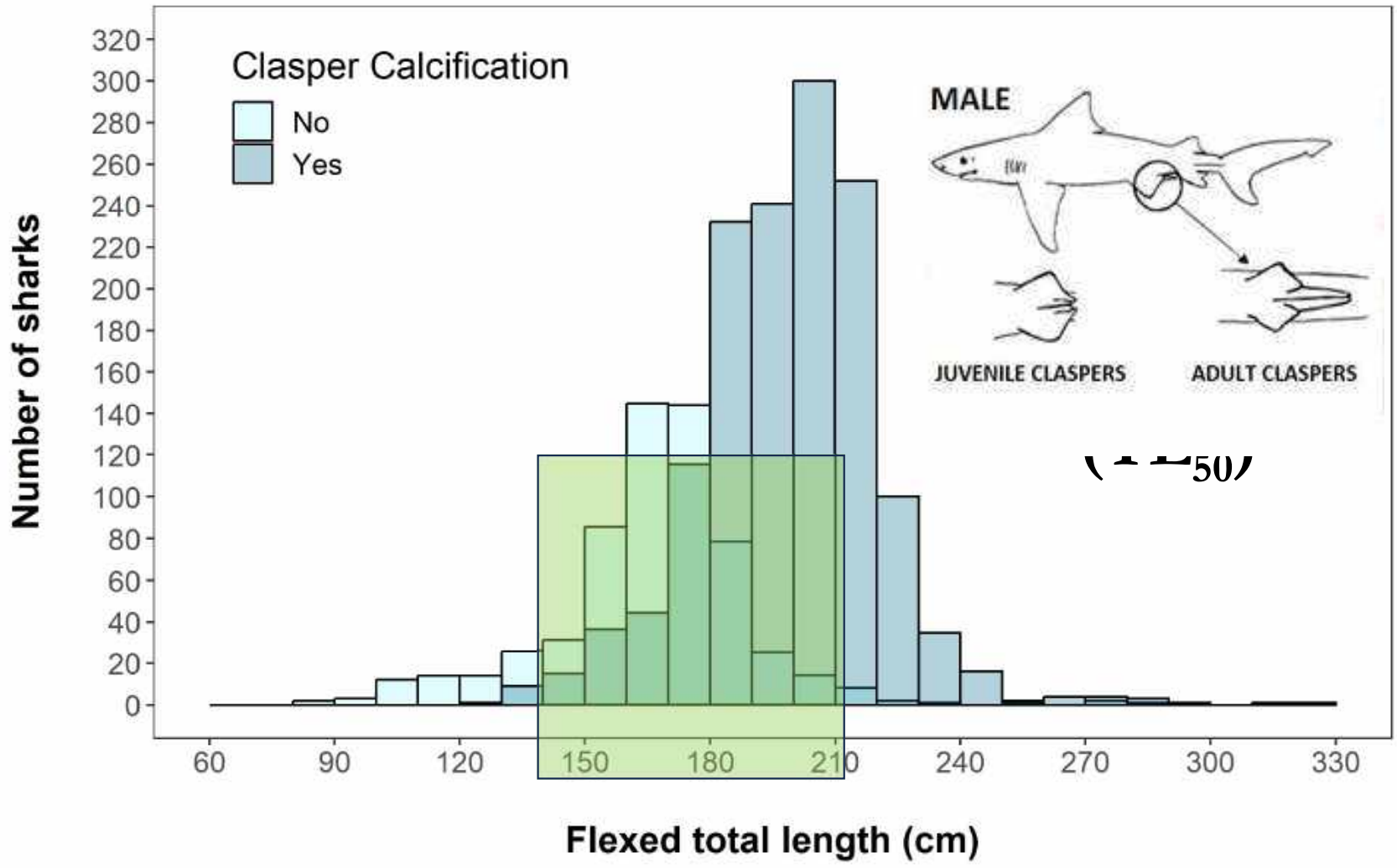
(Castillo-Olguin 2005; Rodriguez-Matus 2020)

Within-EPO: spatial variation in life history?

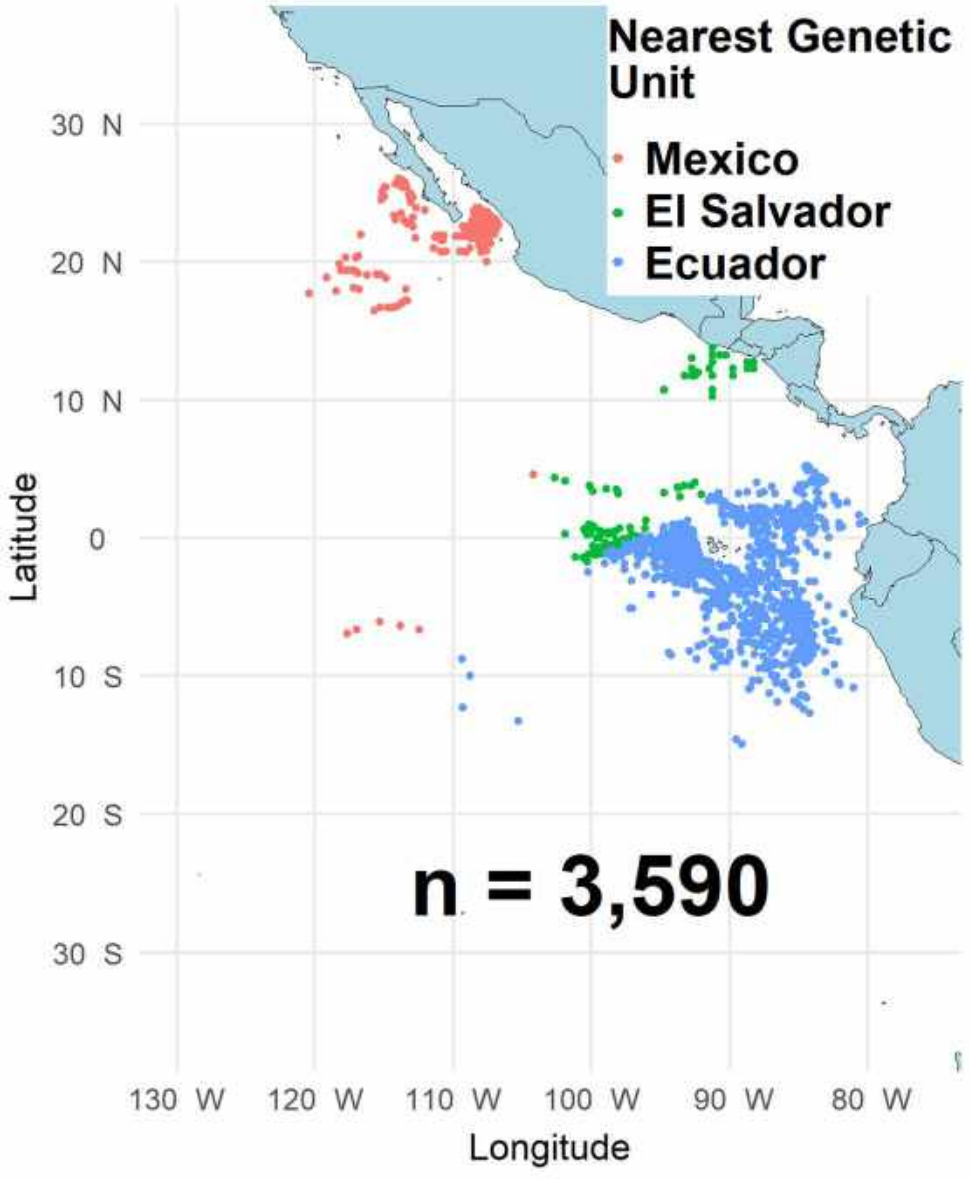


3,590 males with catch locations, measurements, and clasper calcification status


IATTC
WCPFC
Observed silky shark catches
Small-scale fisheries
Longline
Purse seine: Live whale
Purse seine: Dolphin
Purse seine: Unassociated tuna
Purse seine: Floating object
IATTC
WCPFC
180.0°
160.0°W
140.0°W
120.0°W
100.0°W
80.0°W
30.0°N
25.0°N
20.0°N
15.0°N
10.0°N
5.0°N
0.0°
5.0°S
10.0°S
15.0°S
20.0°S
25.0°S

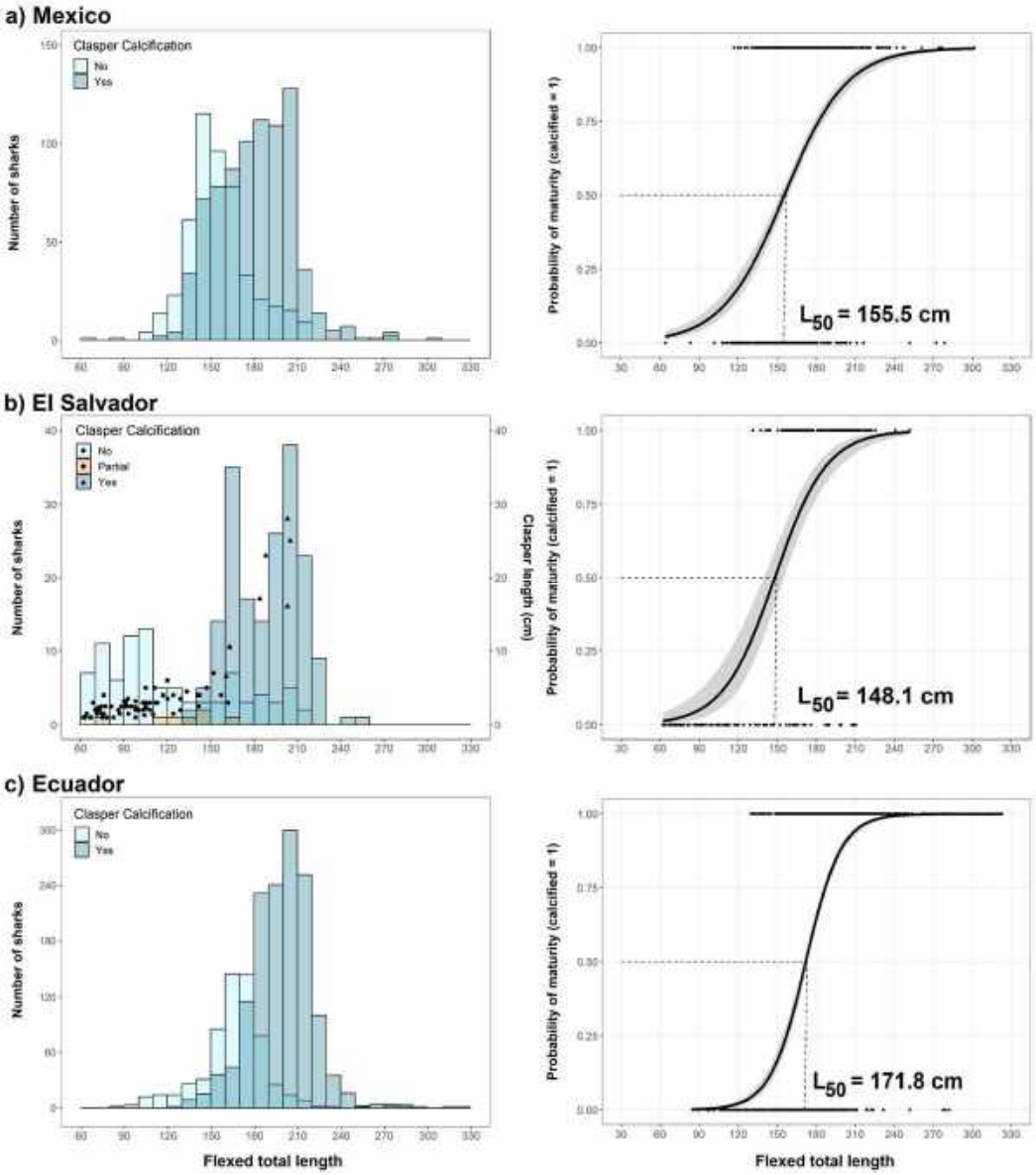


Clasper calcification (binomial) ~ Total length + Total length (spatial group)



Explored 9 candidate spatial structures in estimating male TL_{50}

Highest support for the 'nearest genetic unit' spatial structure



Mexico TL_{50}
156 cm TL

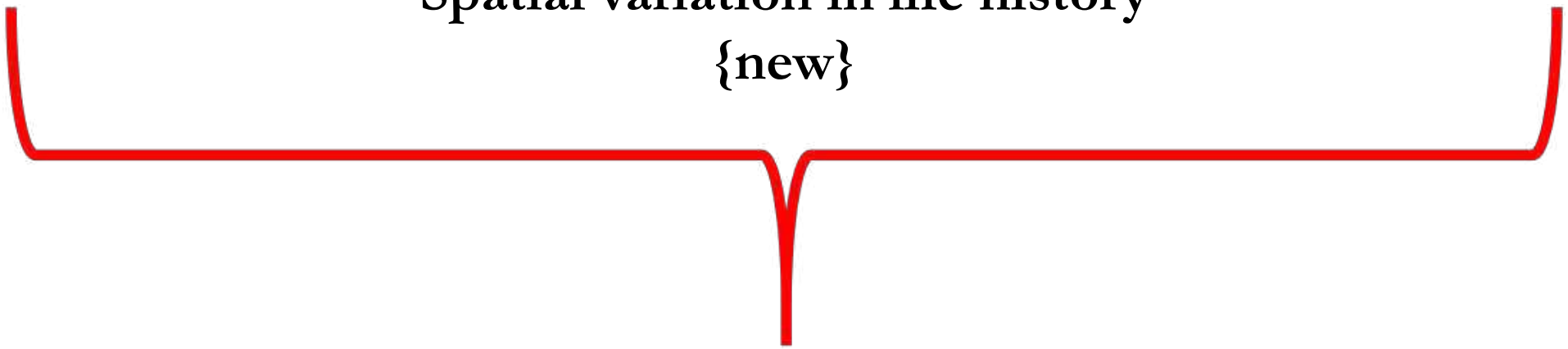
El Salvador TL_{50}
148 cm TL

Ecuador TL_{50}
172 cm TL

Movement data
{synthesis}

Population genetic data
{review}

Spatial variation in life history
{new}



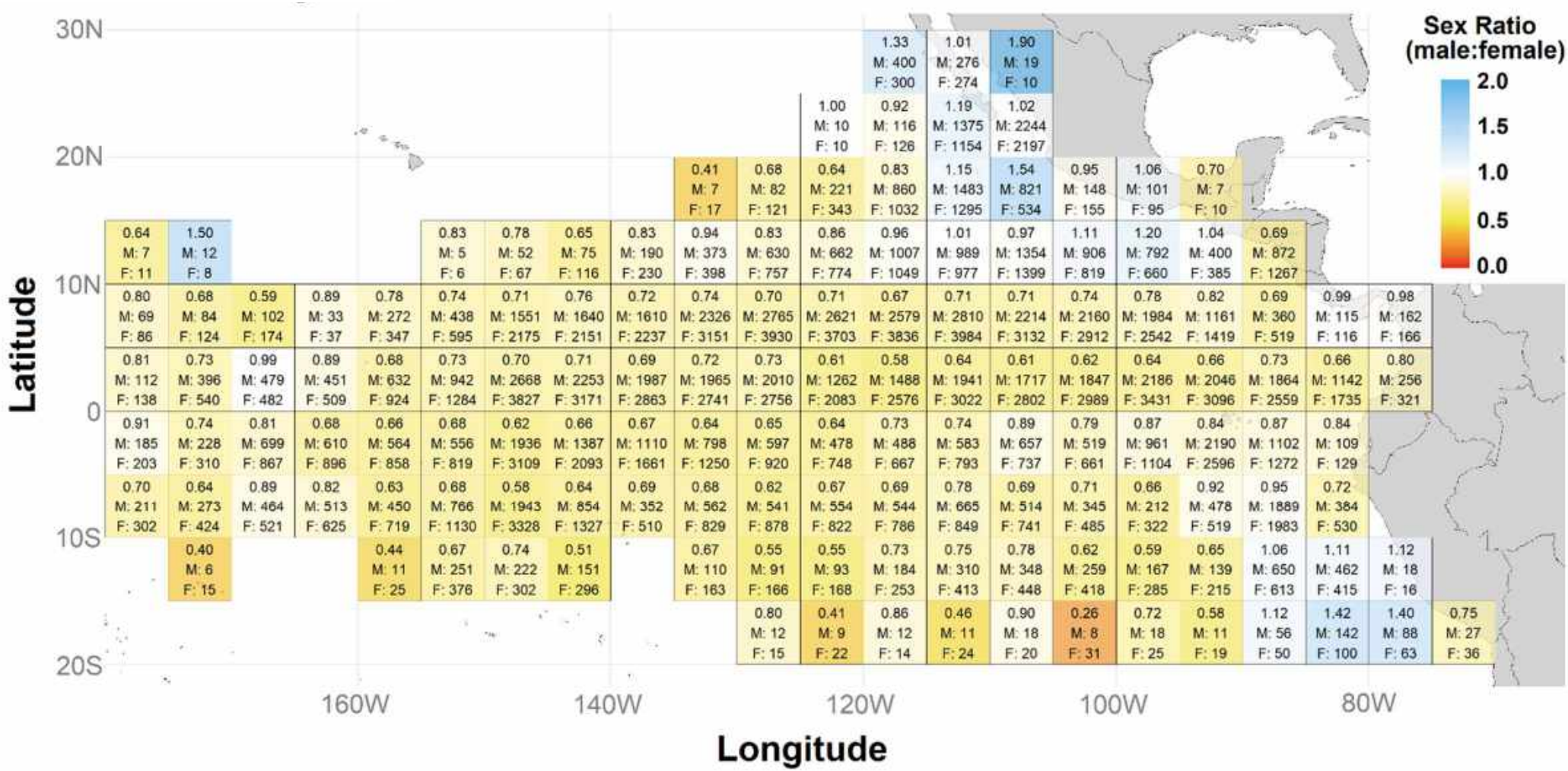
3-stock management approach

Does mating and pupping occur in each?

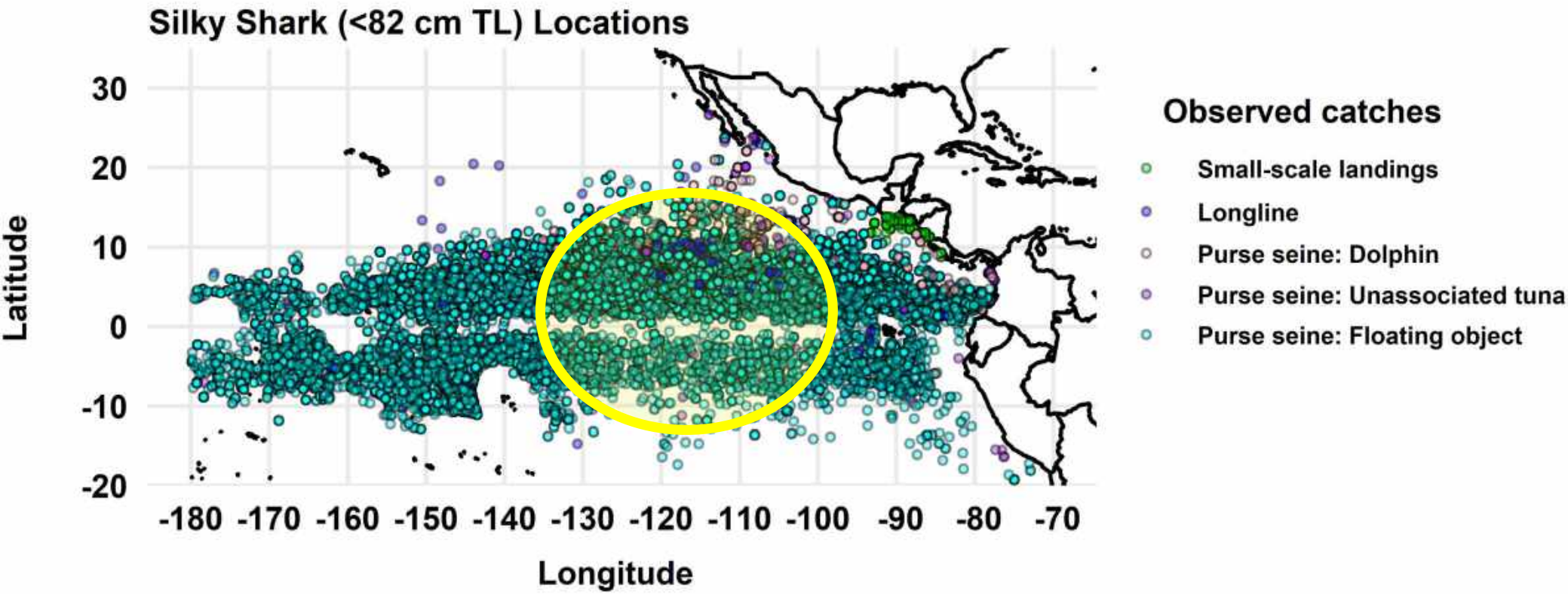
Mating habitats can be suggested by sex ratios.

Balanced sex ratios (1 male: 1 female) =
potential mating habitat

Males and females mix in space – mating habitats widespread?

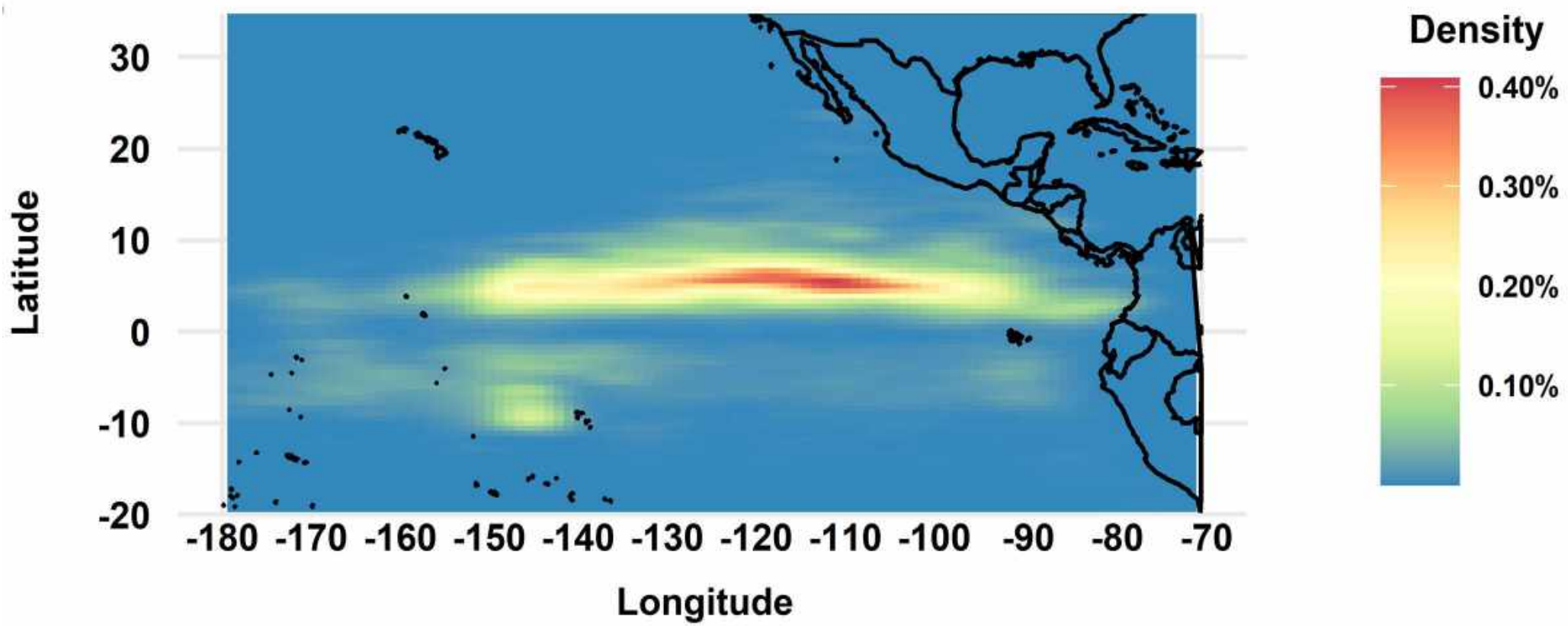


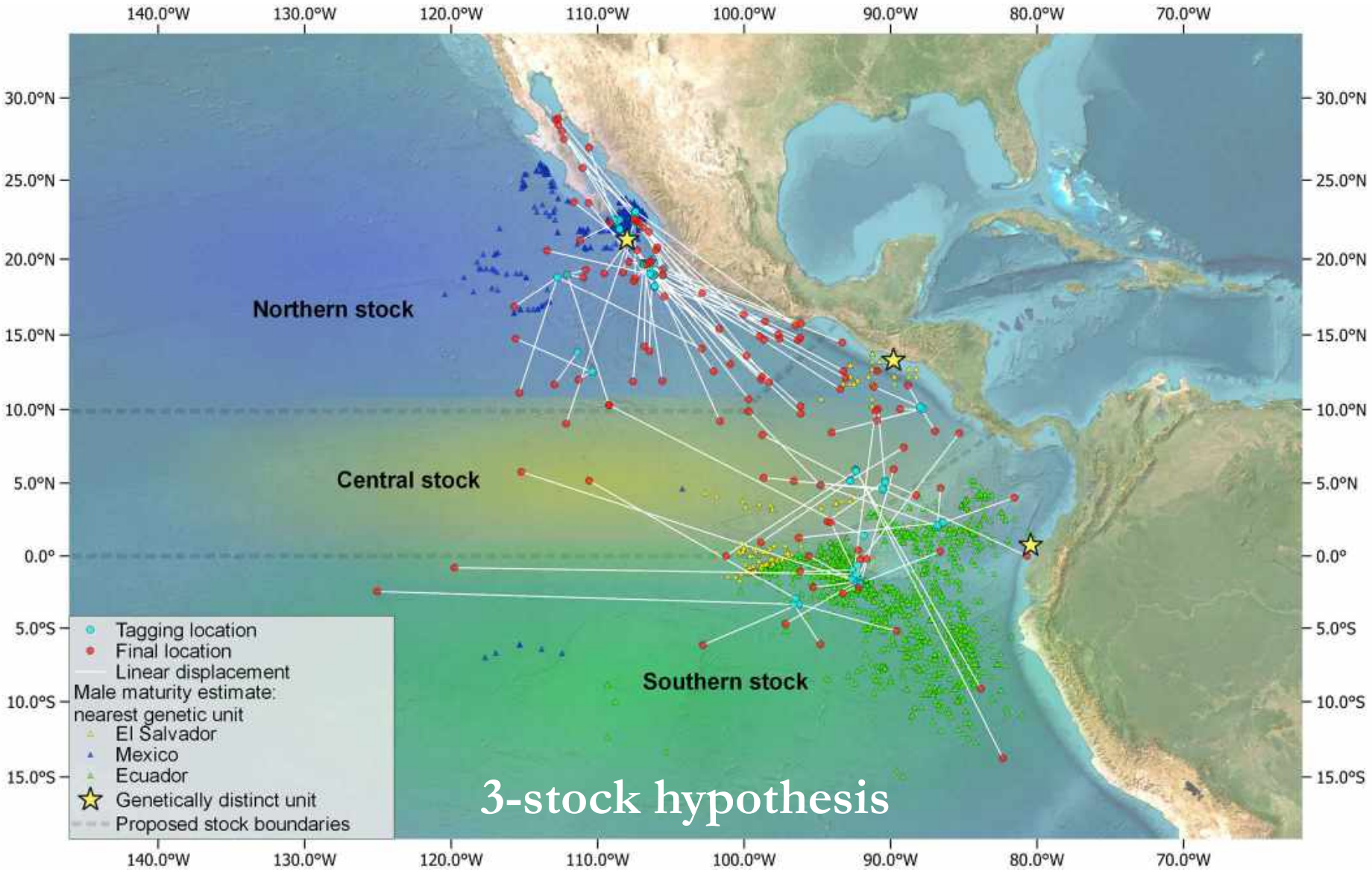
Pups are all over – pupping areas widespread



Including offshore!

Ontogenetic shift from shelf-edge to oceanic habitats is not universal: Silky Sharks probably also pup offshore.




140.0°W
130.0°W
120.0°W
110.0°W
100.0°W
90.0°W
80.0°W
70.0°W
30.0°N
25.0°N
20.0°N
15.0°N
10.0°N
5.0°N
0.0°
5.0°S
10.0°S
15.0°S
Northern stock
Central stock
Southern stock
Tagging location
Final location
Linear displacement
Male maturity estimate:
nearest genetic unit
El Salvador
Mexico
Ecuador
Genetically distinct unit
Proposed stock boundaries
3-stock hypothesis

Spatially explicit 'classic stock delineation'

Units delineated according to spatial boundaries

[tagging, genetics, life history]

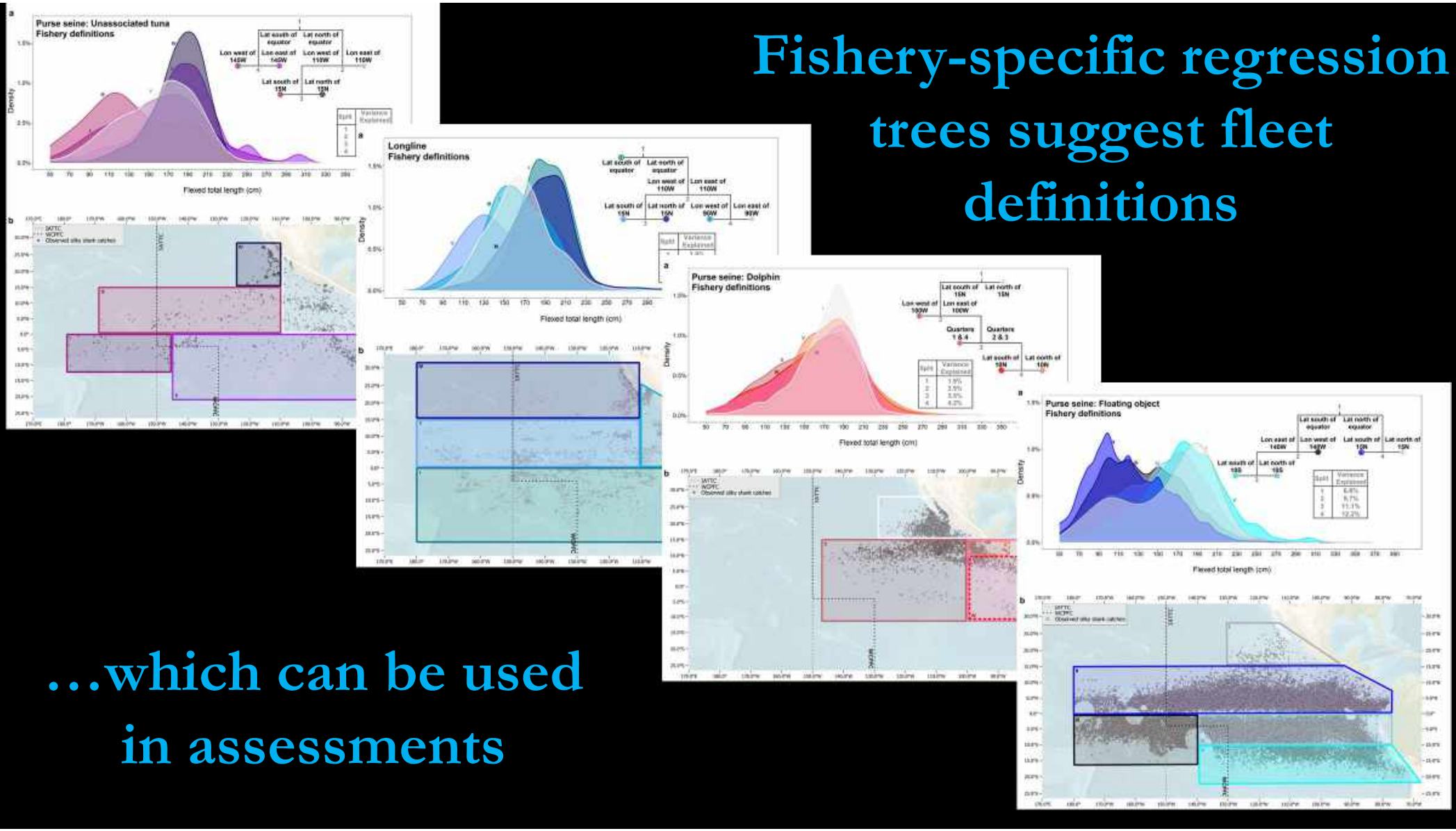
Spatially implicit 'Areas-as-fleets'

Units delineated according to selectivity

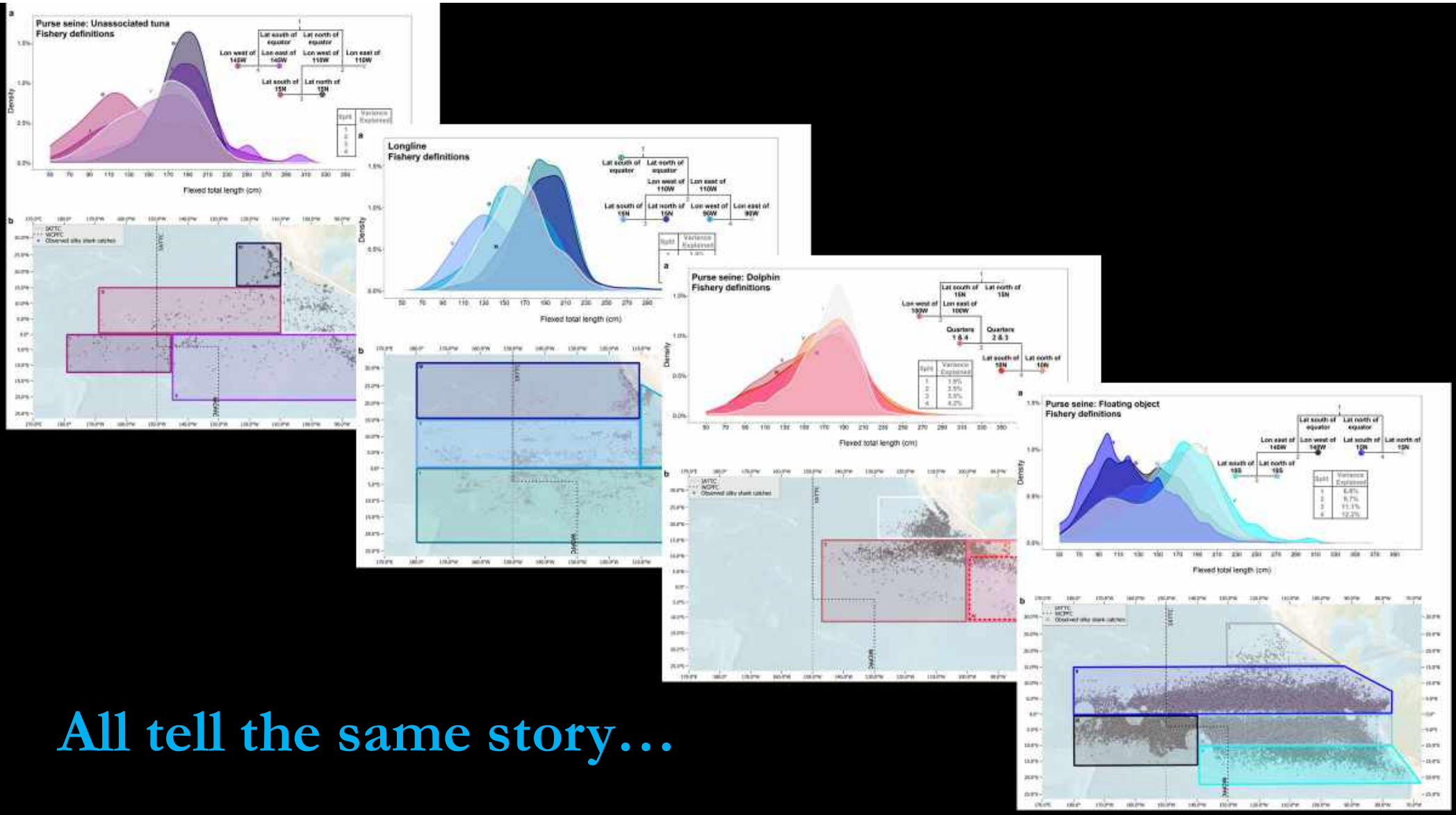
[gear type, area of operation]

(Waterhouse et al., 2014; Hurtado-Gerro et al., 2014; Punt 2019)

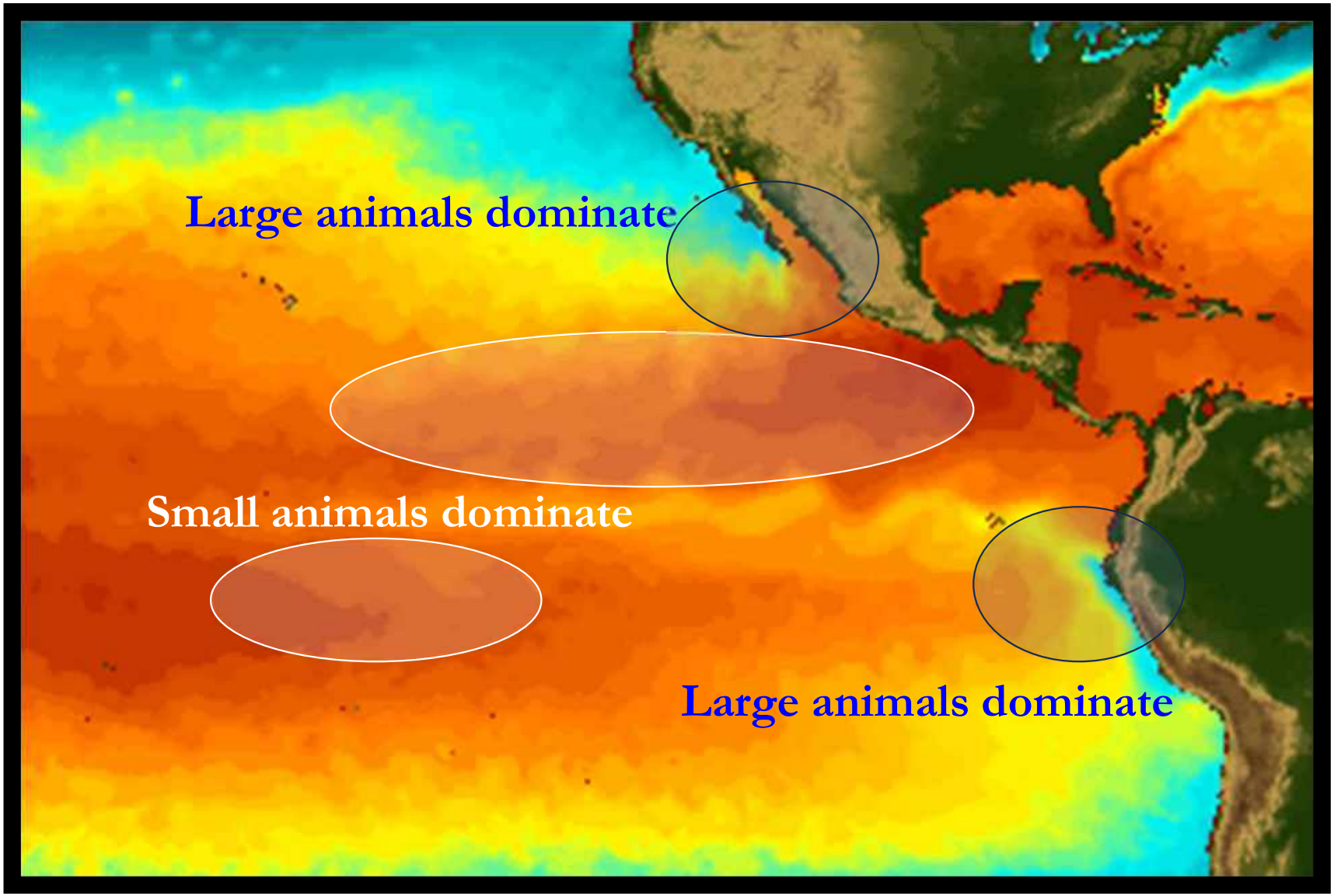
Fishery-specific regression trees suggest fleet definitions

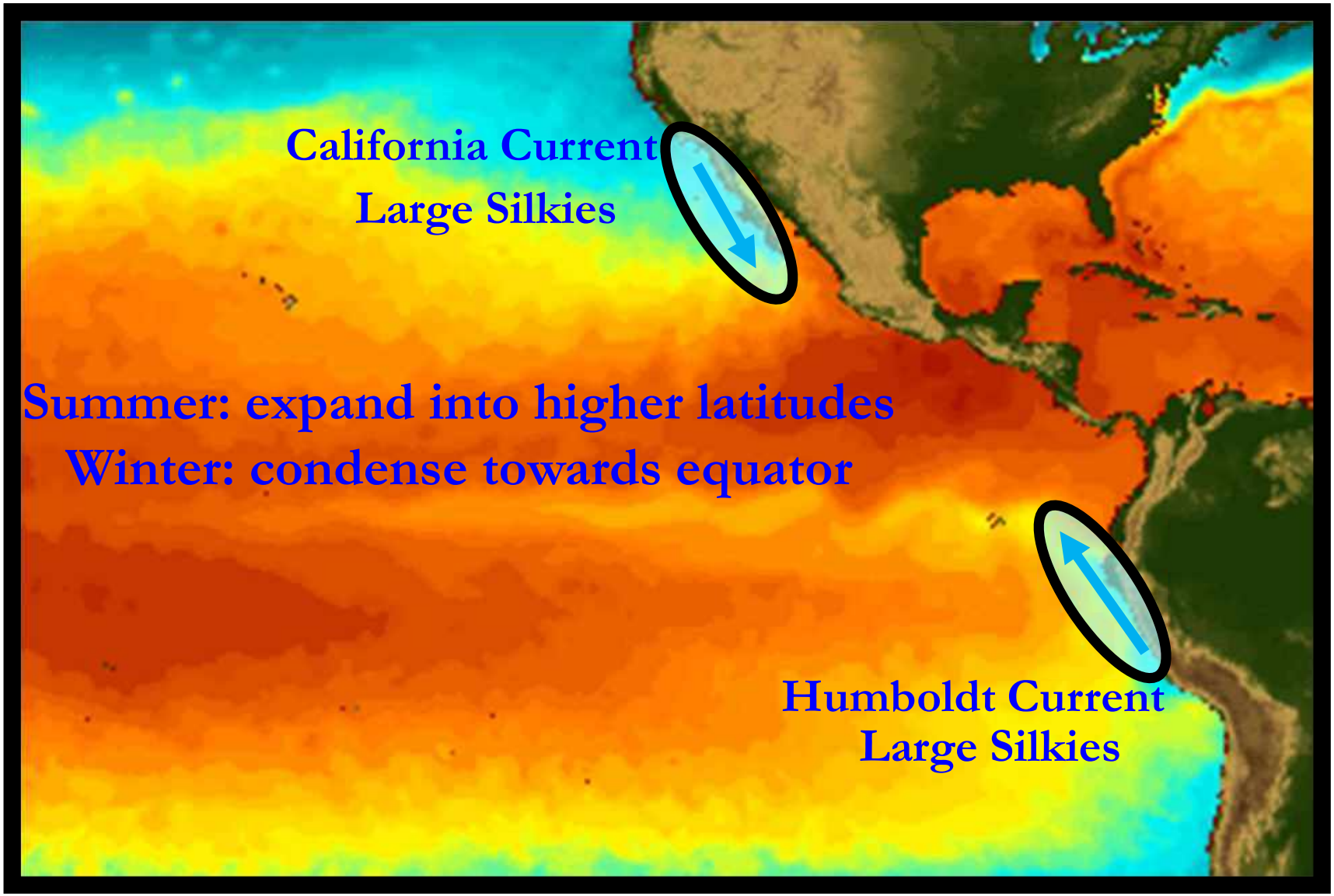


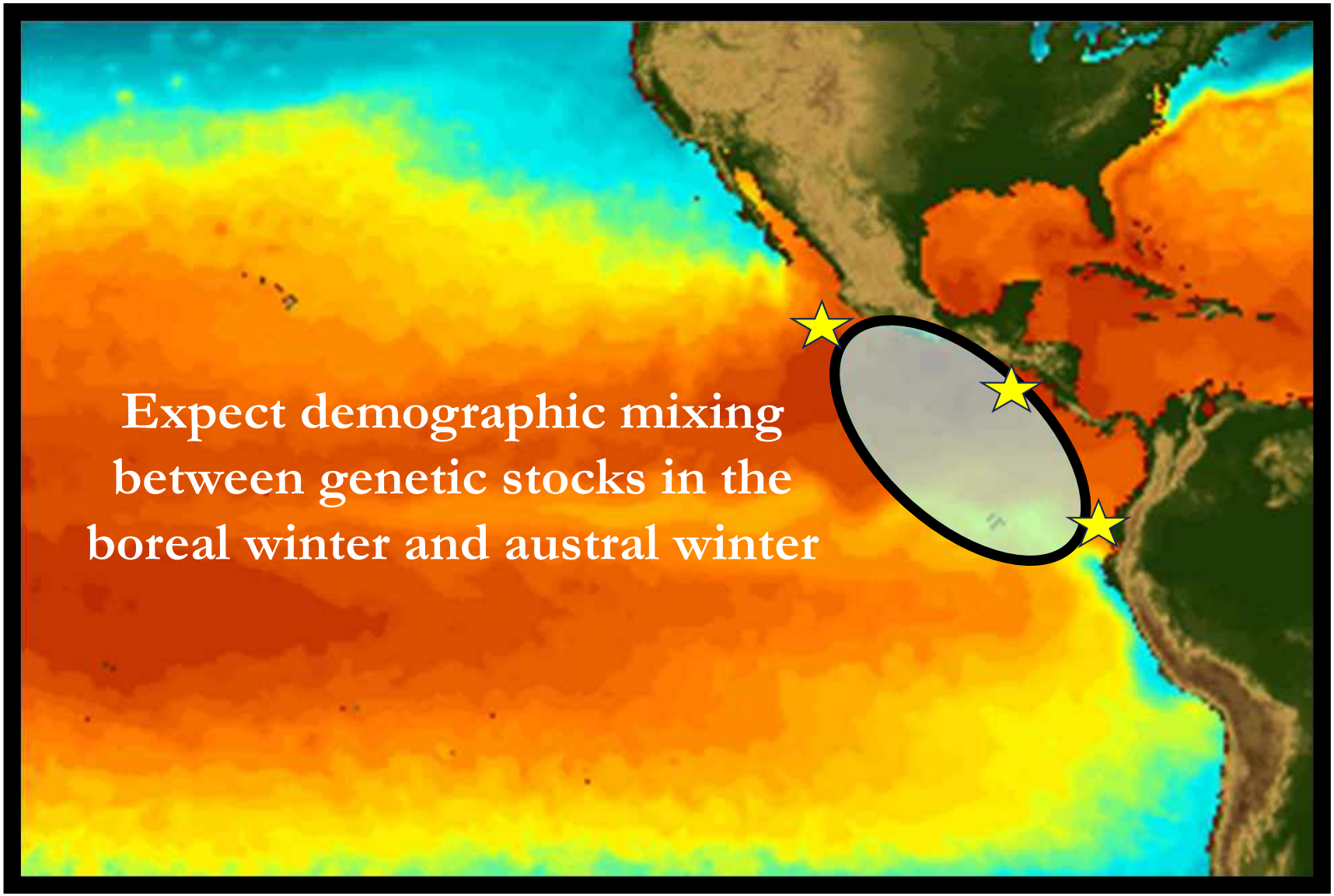
…which can be used in assessments

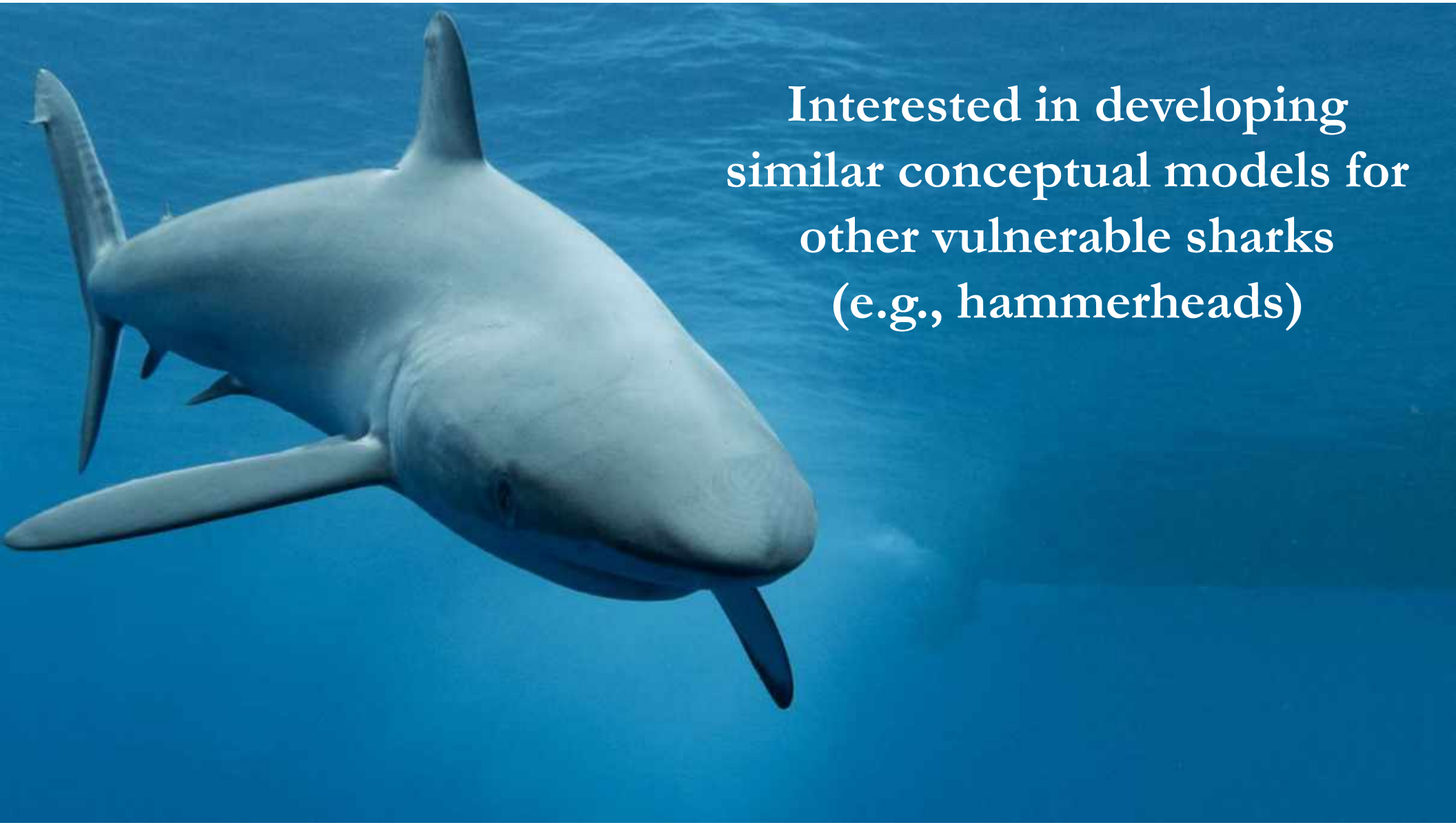


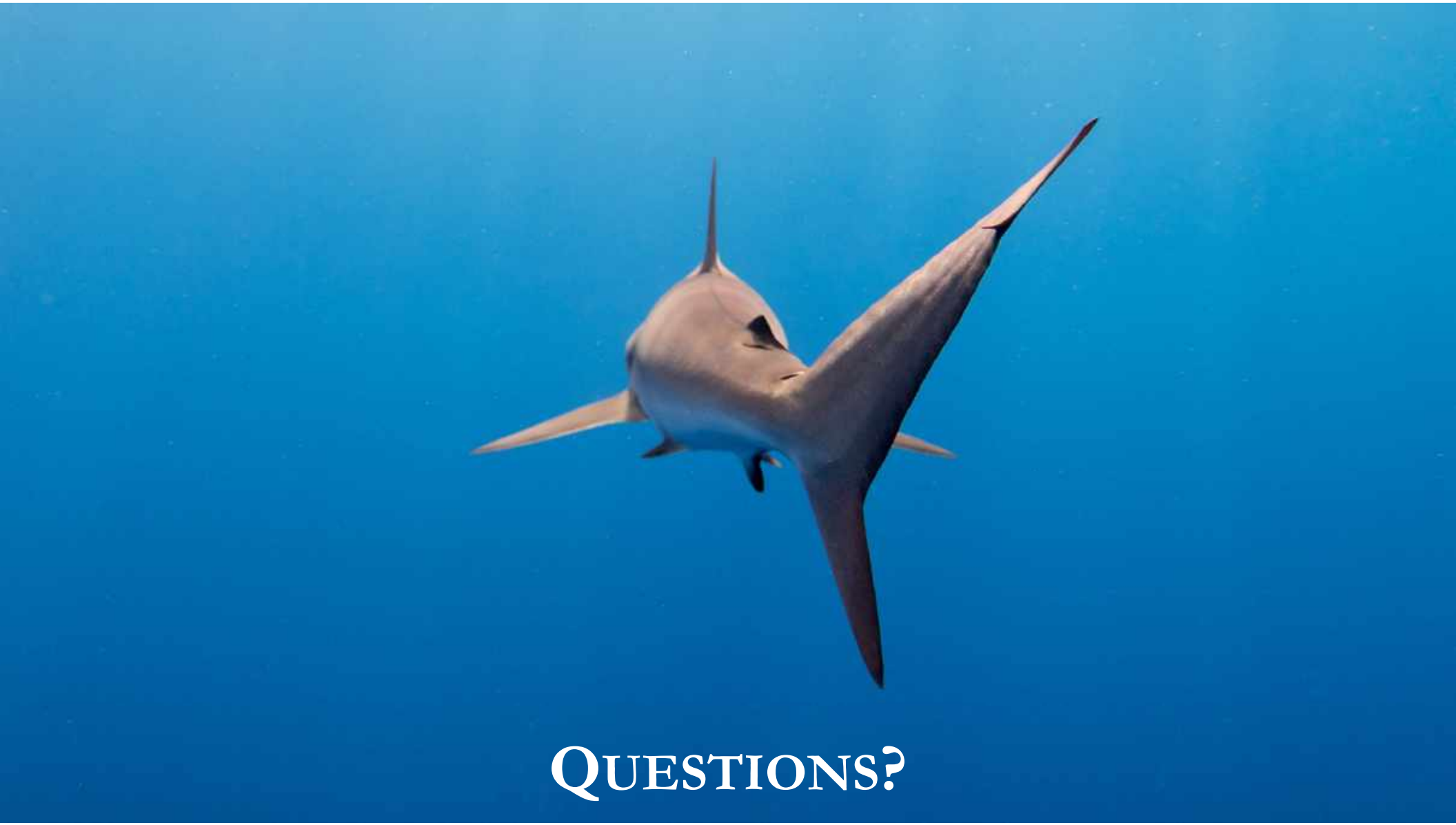
All tell the same story…

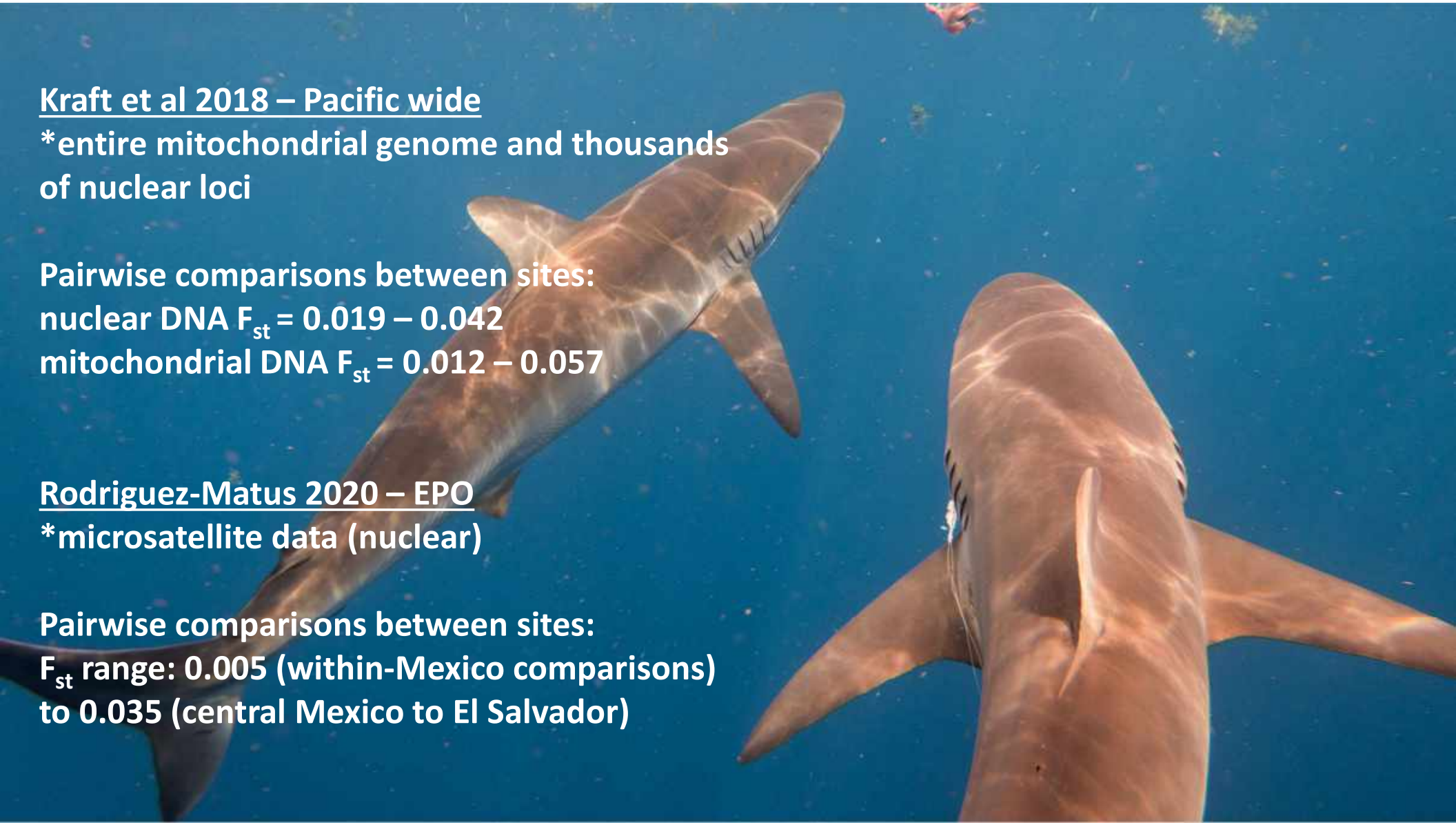

Large animals dominate
Small animals dominate
Large animals dominate


California Current
Large Silkies
Summer: expand into higher latitudes
Winter: condense towards equator
Humboldt Current
Large Silkies


Expect demographic mixing
between genetic stocks in the
boreal winter and austral winter


Interested in developing
similar conceptual models for
other vulnerable sharks
(e.g., hammerheads)


QUESTIONS?



Kraft et al 2018 – Pacific wide

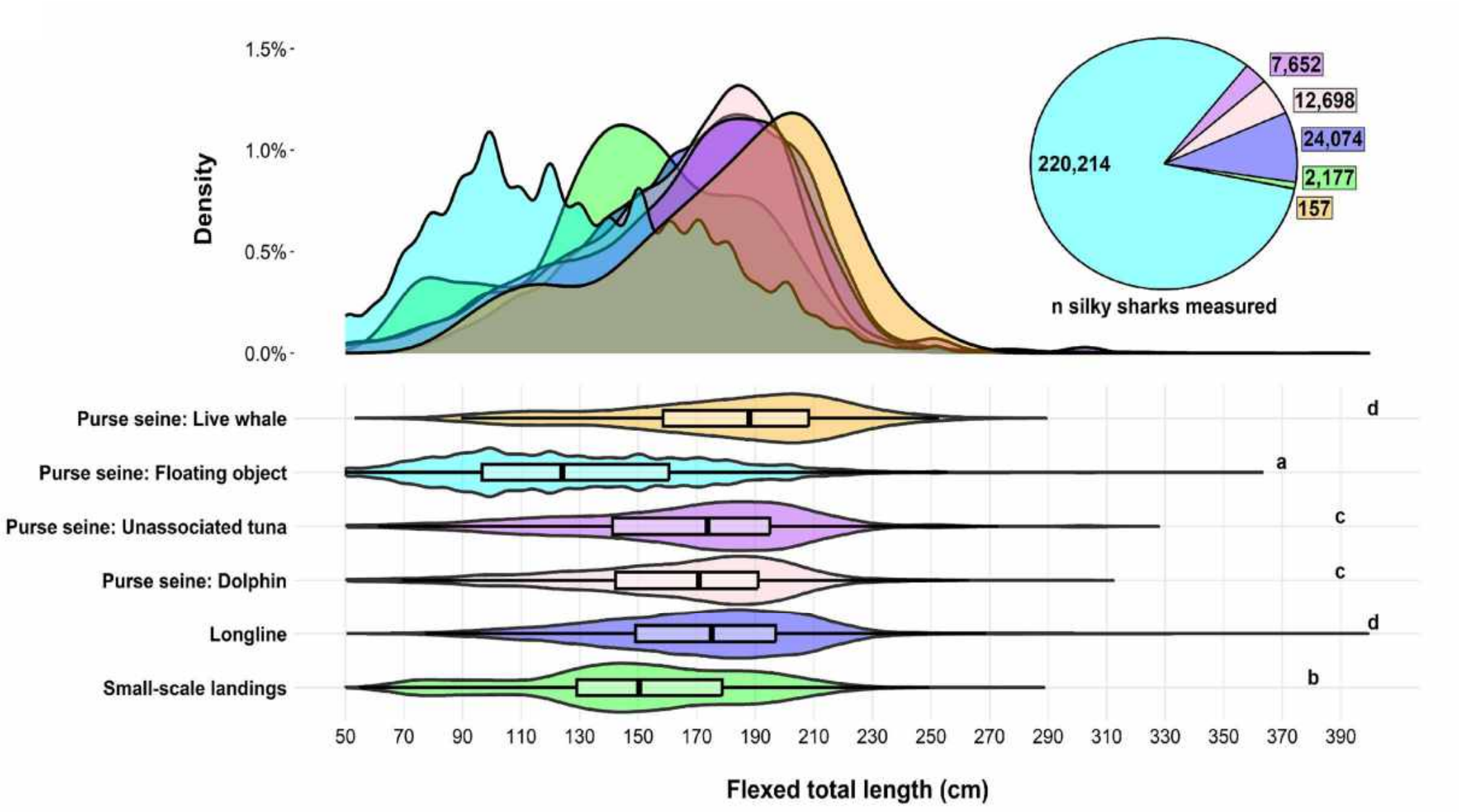
***entire mitochondrial genome and thousands of nuclear loci**

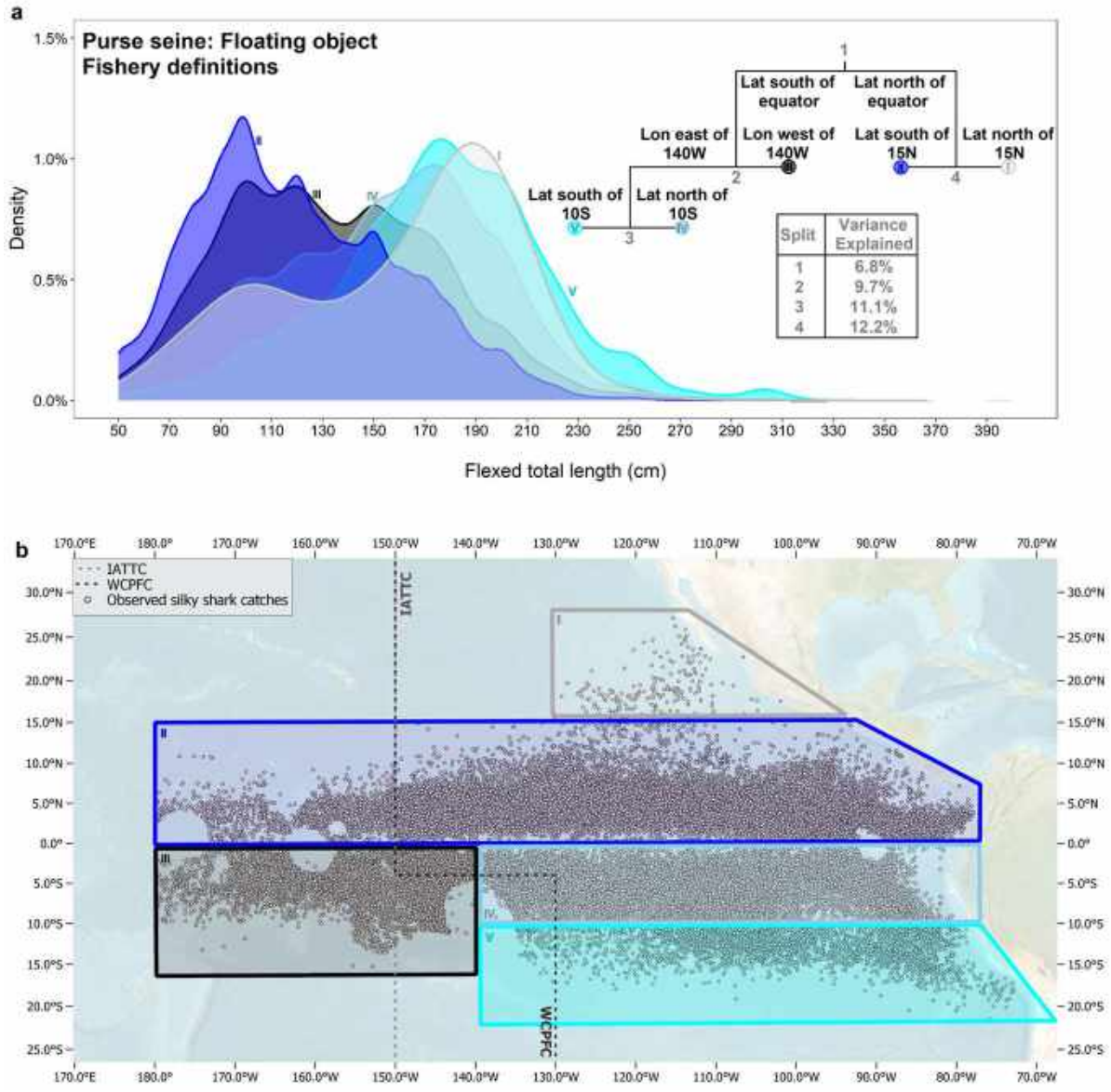
Pairwise comparisons between sites:
nuclear DNA F_{st} = 0.019 – 0.042
mitochondrial DNA F_{st} = 0.012 – 0.057

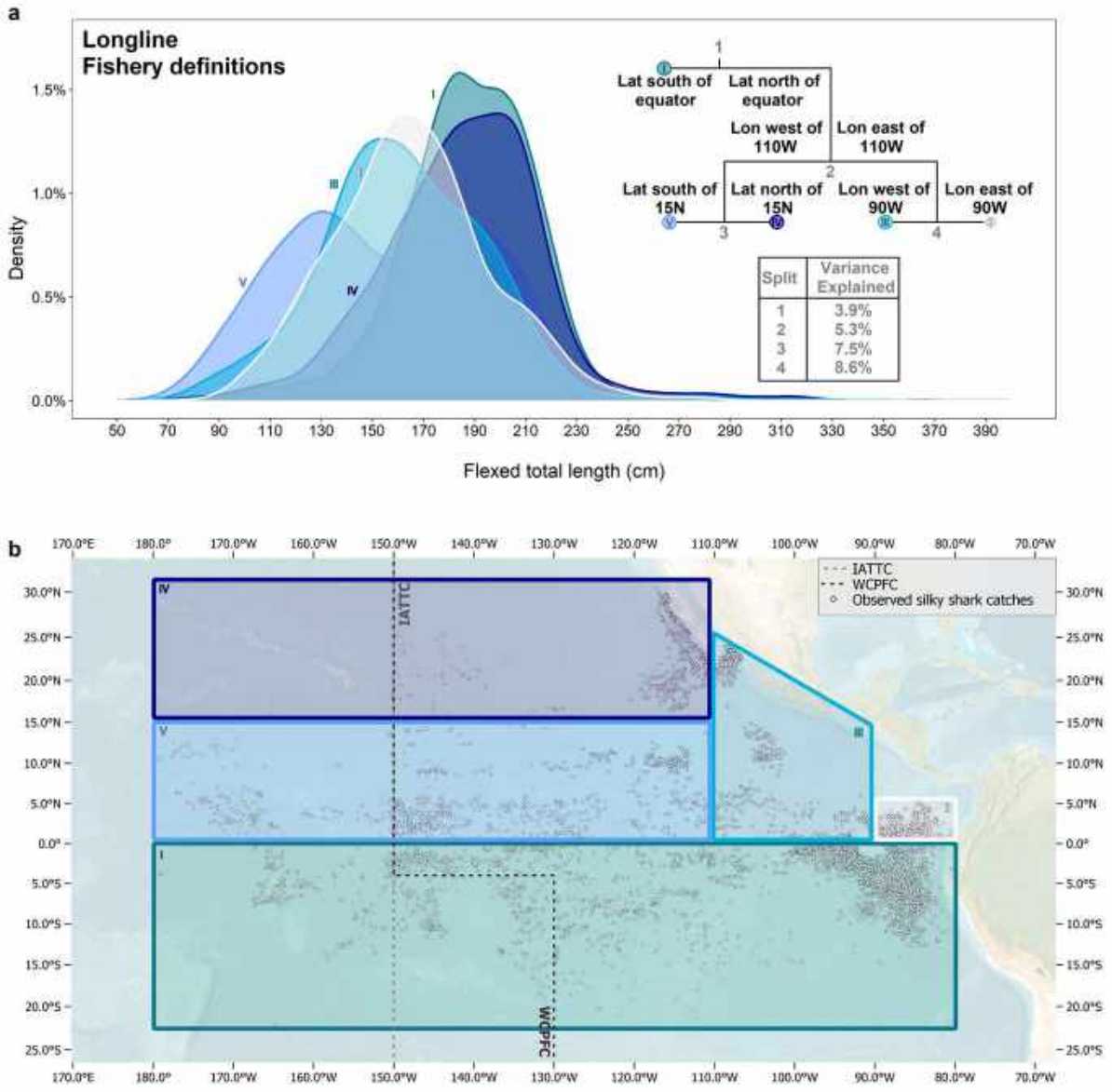
Rodriguez-Matus 2020 – EPO

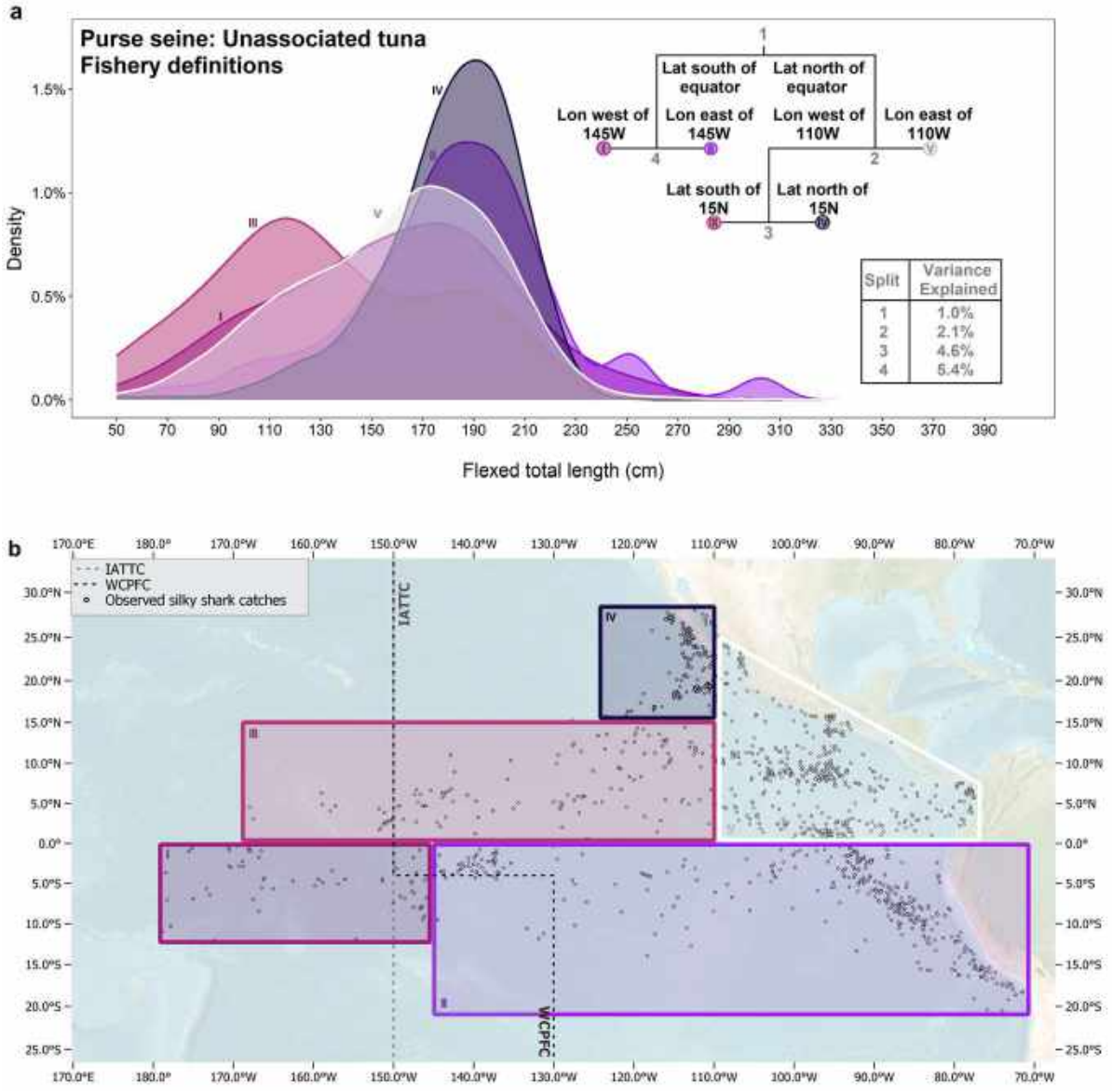
***microsatellite data (nuclear)**

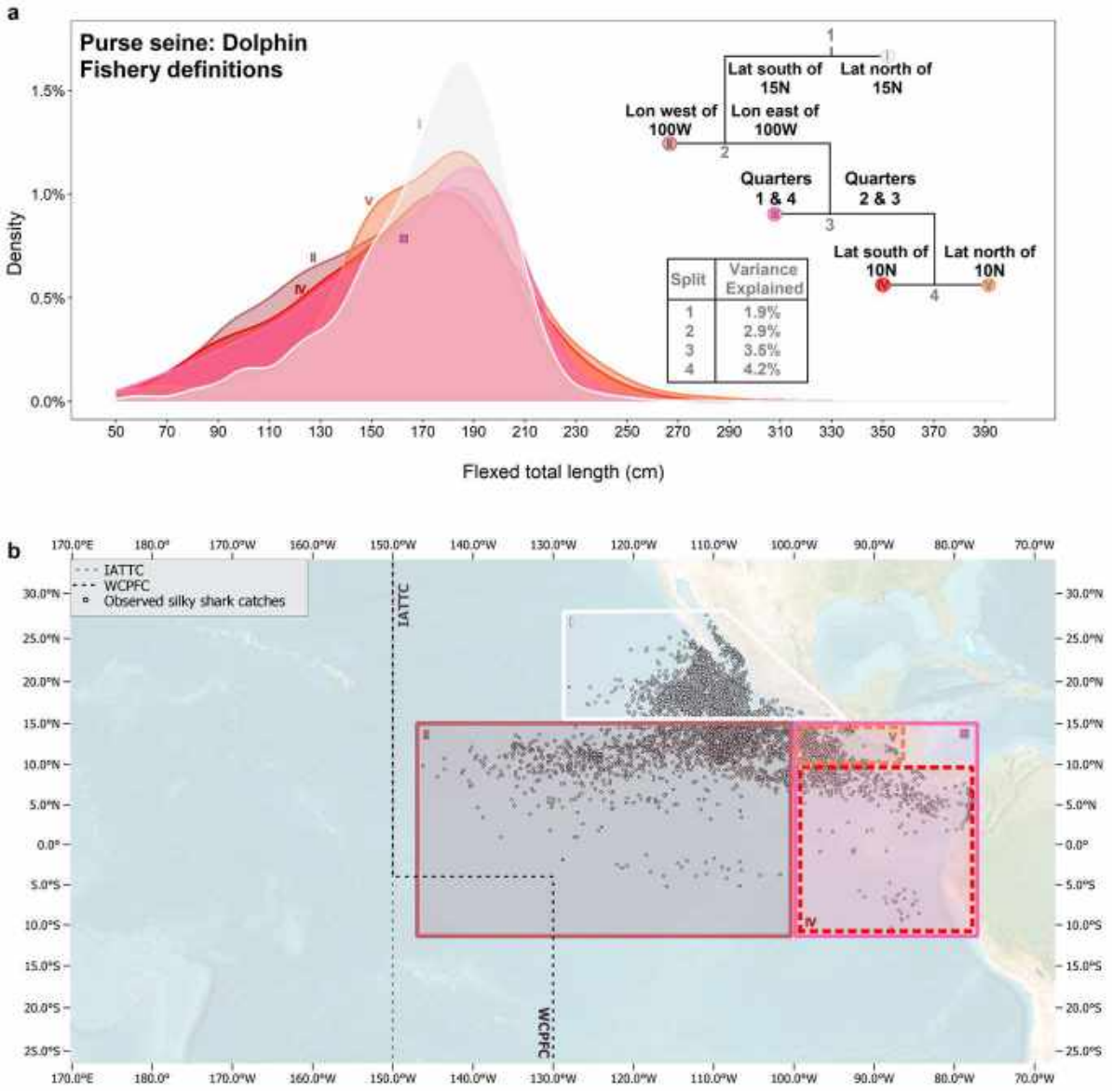
Pairwise comparisons between sites:
F_{st} range: 0.005 (within-Mexico comparisons) to 0.035 (central Mexico to El Salvador)

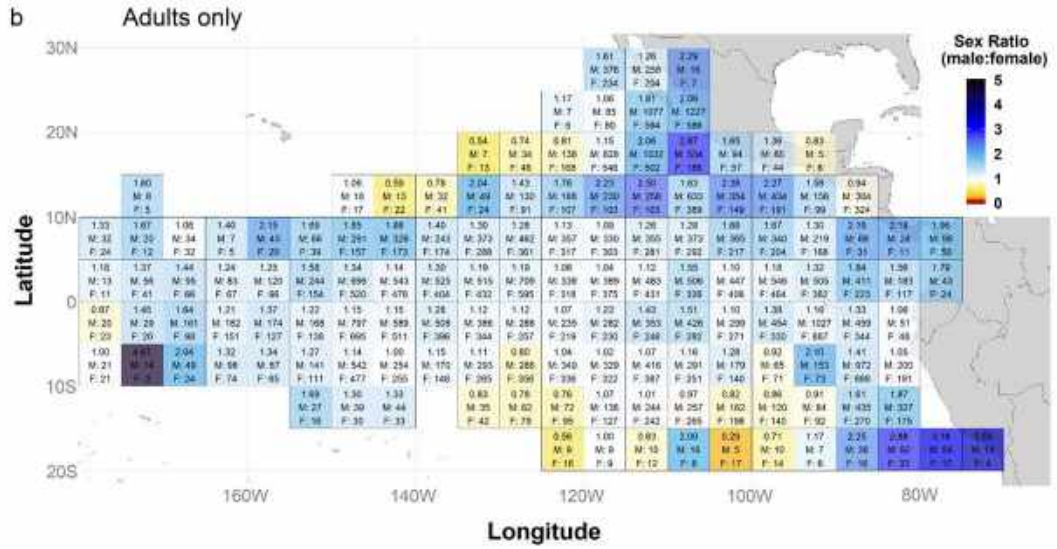

1.5%
1.0%
0.5%
0.0%
Density
7,652
12,698
24,074
2,177
157
220,214
n silky sharks measured
Purse seine: Live whale
Purse seine: Floating object
Purse seine: Unassociated tuna
Purse seine: Dolphin
Longline
Small-scale landings
d
a
c
c
d
b
50
70
90
110
130
150
170
190
210
230
250
270
290
310
330
350
370
390
Flexed total length (cm)

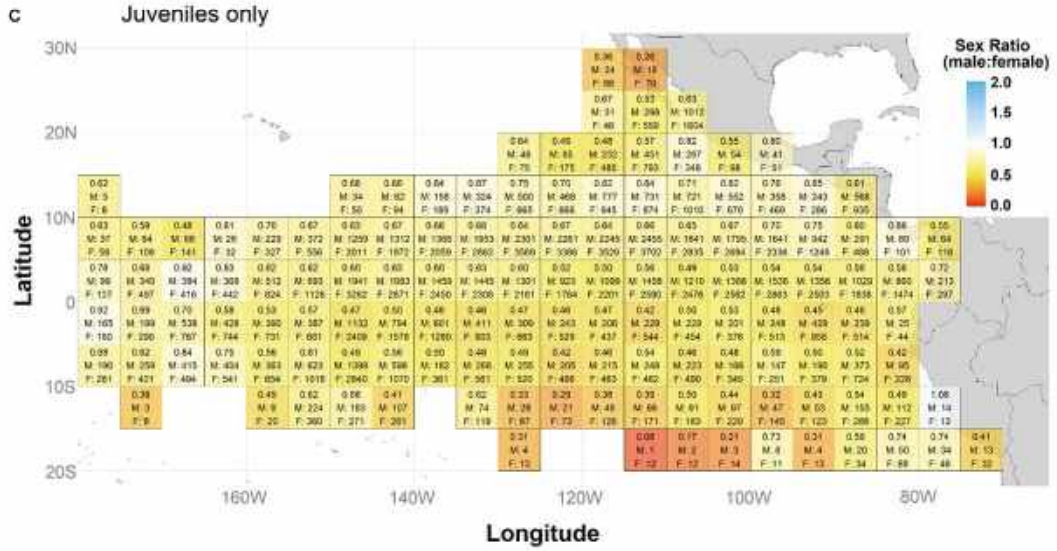

a
Purse seine: Floating object
Fishery definitions
Density
1.5%
1.0%
0.5%
0.0%
50 70 90 110 130 150 170 190 210 230 250 270 290 310 330 350 370 390
Flexed total length (cm)
1
Lat south of equator
Lat north of equator
Lon east of 140W
Lon west of 140W
Lat south of 15N
Lat north of 15N
2
4
Lat south of 10S
Lat north of 10S
3
Split
Variance Explained
1 6.8%
2 9.7%
3 11.1%
4 12.2%
b
IATTC
WCPFC
Observed silky shark catches
170.0°E 180.0° 170.0°W 160.0°W 150.0°W 140.0°W 130.0°W 120.0°W 110.0°W 100.0°W 90.0°W 80.0°W 70.0°W
30.0°N 25.0°N 20.0°N 15.0°N 10.0°N 5.0°N 0.0° 5.0°S 10.0°S 15.0°S 20.0°S 25.0°S


a
Longline
Fishery definitions
Density
1.5%
1.0%
0.5%
0.0%
50 70 90 110 130 150 170 190 210 230 250 270 290 310 330 350 370 390
Flexed total length (cm)
I
II
III
IV
V
1
Lat south of equator
Lat north of equator
Lon west of 110W
Lon east of 110W
2
Lat south of 15N
Lat north of 15N
Lon west of 90W
Lon east of 90W
3
4
Split
Variance Explained
1 3.9%
2 5.3%
3 7.5%
4 8.6%
b
170.0°E 180.0° 170.0°W 160.0°W 150.0°W 140.0°W 130.0°W 120.0°W 110.0°W 100.0°W 90.0°W 80.0°W 70.0°W
30.0°N 25.0°N 20.0°N 15.0°N 10.0°N 5.0°N 0.0° 5.0°S 10.0°S 15.0°S 20.0°S 25.0°S
IATTC
WCPFC
Observed silky shark catches


a
Purse seine: Unassociated tuna
Fishery definitions
Density
1.5%
1.0%
0.5%
0.0%
50 70 90 110 130 150 170 190 210 230 250 270 290 310 330 350 370 390
Flexed total length (cm)
I
II
III
IV
V
1
Lat south of equator
Lat north of equator
Lon west of 145W
Lon east of 145W
Lon west of 110W
Lon east of 110W
4
2
Lat south of 15N
Lat north of 15N
3
Split
Variance Explained
1 1.0%
2 2.1%
3 4.6%
4 5.4%
b
IATTC
WCPFC
Observed silky shark catches
170.0°E 180.0° 170.0°W 160.0°W 150.0°W 140.0°W 130.0°W 120.0°W 110.0°W 100.0°W 90.0°W 80.0°W 70.0°W
30.0°N 25.0°N 20.0°N 15.0°N 10.0°N 5.0°N 0.0° 5.0°S 10.0°S 15.0°S 20.0°S 25.0°S


a
Purse seine: Dolphin
Fishery definitions
Density
1.5%
1.0%
0.5%
0.0%
50 70 90 110 130 150 170 190 210 230 250 270 290 310 330 350 370 390
Flexed total length (cm)
I
II
III
IV
V
1
Lat south of 15N
Lat north of 15N
Lon west of 100W
Lon east of 100W
2
Quarters 1 & 4
Quarters 2 & 3
3
Lat south of 10N
Lat north of 10N
4
Split
Variance Explained
1 1.9%
2 2.9%
3 3.5%
4 4.2%
b
IATTC
WCPFC
Observed silky shark catches
170.0°E 180.0° 170.0°W 160.0°W 150.0°W 140.0°W 130.0°W 120.0°W 110.0°W 100.0°W 90.0°W 80.0°W 70.0°W
30.0°N 25.0°N 20.0°N 15.0°N 10.0°N 5.0°N 0.0° 5.0°S 10.0°S 15.0°S 20.0°S 25.0°S
IATTC
WCPFC
II
III
IV
V


b
Adults only
Sex Ratio
(male:female)
5
4
3
2
1
0
30N
20N
10N
0
10S
20S
Latitude
160W
140W
120W
100W
80W
Longitude


c
Juveniles only
Sex Ratio
(male:female)
2.0
1.5
1.0
0.5
0.0
30N
20N
10N
0
10S
20S
Latitude
160W
140W
120W
100W
80W
Longitude