Kona Billfish Nursery Project
Phase 1 & 2 Updates

13 April 2023

Project Goals & Structure

Phase 1

- Examine literature and historical data in a meta-analysis to determine larval istiophorid abundance patterns and habitat in the Pacific Ocean. Nominate putative spawning areas and develop age & growth models. Spatial data analysis to test for Complete Spatial Randomness and analysis of temperature and salinity data.

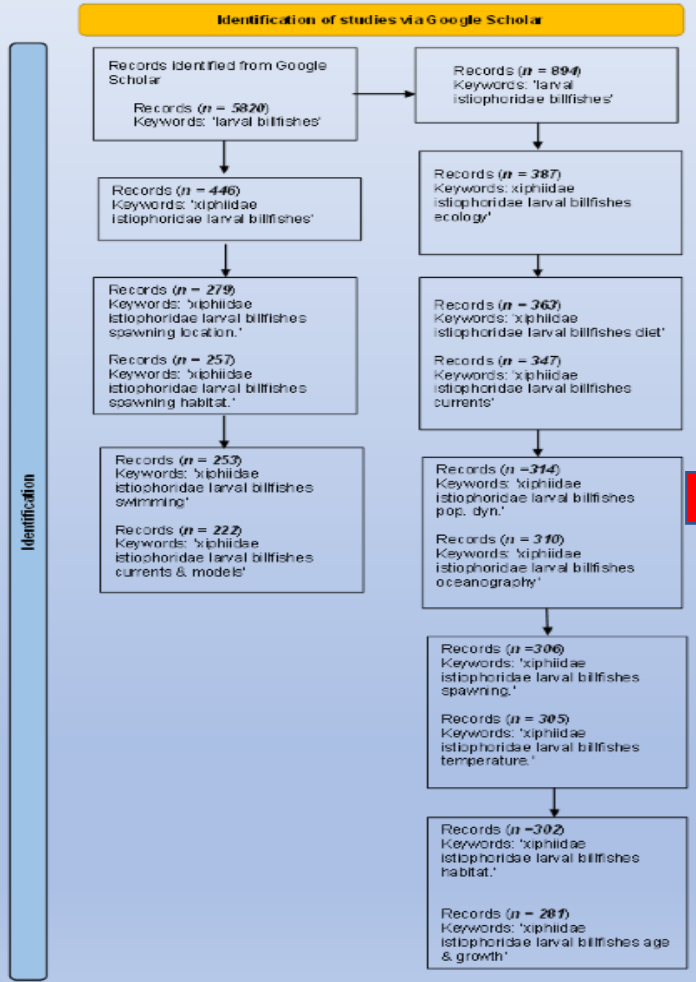
Phase 2

- Data from Phase 1 will be used to inform oceanographic circulation models to estimate patterns in larval diversity and connectivity by conducting simulations.

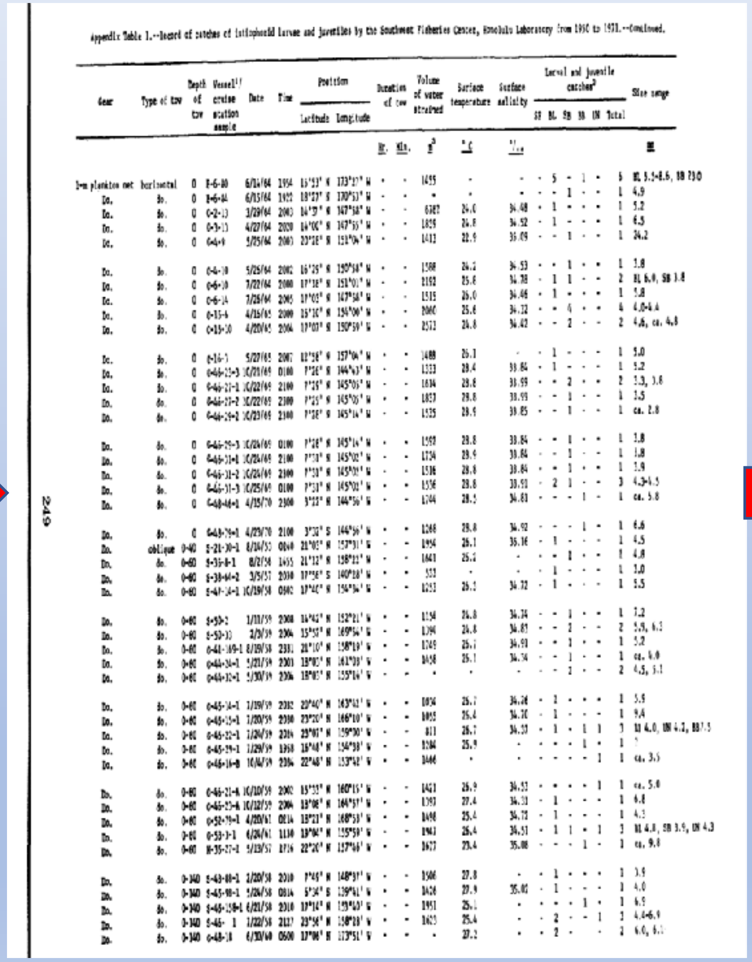
- Using age and growth and circulation models, determine possible spawning sites and larval habitat over temporal-spatial scales.

Phase 1

Search literature

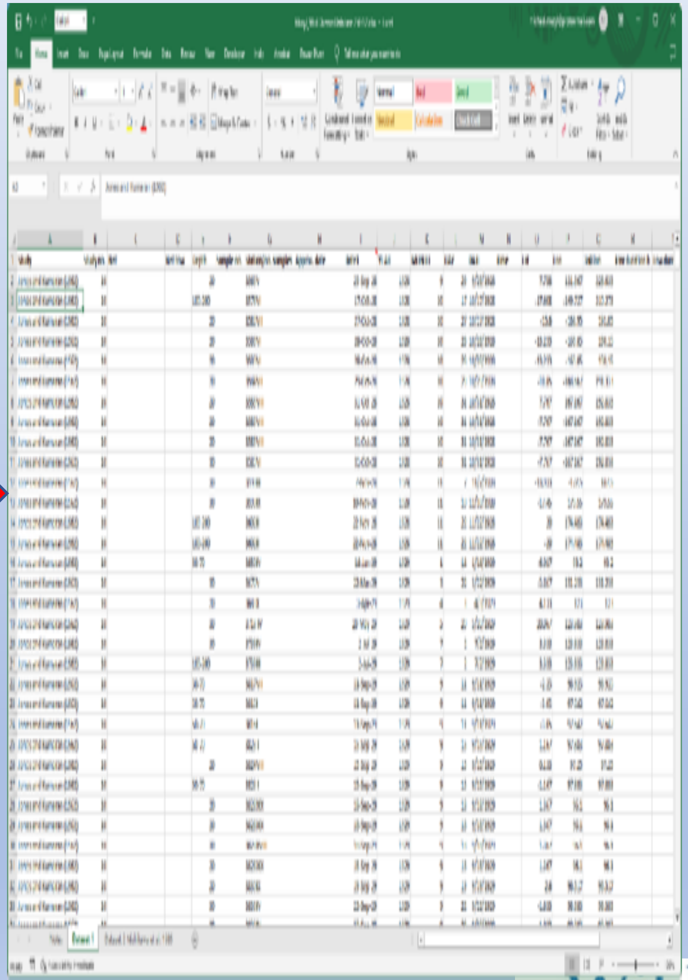


Data extraction



Create database

~80% of available data



Records of larval samples in Dataset 1

Samples from 1928-2019 (various sources)

Species	Count Species	Count Latitude	Count Longitude	Count Salinity	Count Temp	Count size (mm)
Black marlin	92	92	92		1	92
Blue marlin	282	282	282	32	177	282
Istiophorid	146	79	79	5	21	122
Sailfish	86	86	86		22	79
Shortbill spearfish	93	81	81	52	73	93
Striped marlin	94	94	94	7	10	94
Swordfish	95	59	59	26	48	88
Grand Total	888	773	773	122	352	850

Note: It is highly probable that larval istiophorids have been misidentified to species level using morphometric characters. What the rate of misidentification is unknown but blue and striped marlin are mixed-up and occasionally black marlin.

Records of larval samples in Dataset 2

Species	Count Species
Sailfish	292
Swordfish	591
Black marlin	5
Blue marlin	2466
Shortbill spearfish	739
Striped marlin	442
Grand Total	4535

Note: Data spatially aggregated ~1.5°. Sample sizes of larval billfish 1956-1981 (source: Nishikawa et al. 1985)

Wild Oceans
For the future of fishing

Sample Sizes for Species with known collection coordinates (FAO Codes)

YEAR	BLM	BUM	IST	MLS	SPA	SSP	SWO	Total	Cum. %
1928	1	11	0	0	1	0	1	14	0.02
1929	9	25	0	16	46	0	8	104	0.15
1930	0	0	0	3	8	0	0	11	0.17
1937	0	0	0	0	0	0	1	1	0.17
1950	0	36	7	0	0	5	8	56	0.24
1952	0	0	0	0	0	1	0	1	0.24
1953	0	1	0	0	0	0	0	1	0.24
1956	0	1	1	0	0	18	3	23	0.27
1957	0	2	0	0	0	7	18	27	0.31
1958	0	5	1	0	0	1	2	9	0.32
1959	0	4	3	0	0	7	3	17	0.34
1960	0	9	2	0	0	0	0	11	0.36
1961	0	10	4	0	0	7	0	21	0.38
1962	0	34	5	0	2	6	0	47	0.44
1963	0	36	3	0	10	7	0	56	0.52
1964	0	27	2	0	0	7	4	40	0.57
1965	0	1	0	0	0	6	0	7	0.58
1967	0	10	0	0	0	0	0	10	0.59
1969	0	5	0	0	0	8	0	13	0.61
1970	0	0	0	0	0	0	4	4	0.61
1971	0	30	0	0	0	1	0	31	0.65
1983	0	0	0	0	0	0	2	2	0.65
1985	82	35	0	0	12	0	0	129	0.82
1989	0	0	50	0	0	0	5	55	0.89
1990	0	0	1	3	0	0	0	4	0.90
1991	0	0	0	13	2	0	0	15	0.92
1992	0	0	0	49	5	0	0	54	0.99
1993	0	0	0	3	0	0	0	3	0.99
2005	0	0	0	7	0	0	0	7	1.00
Total	92	282	79	94	86	81	59	773	

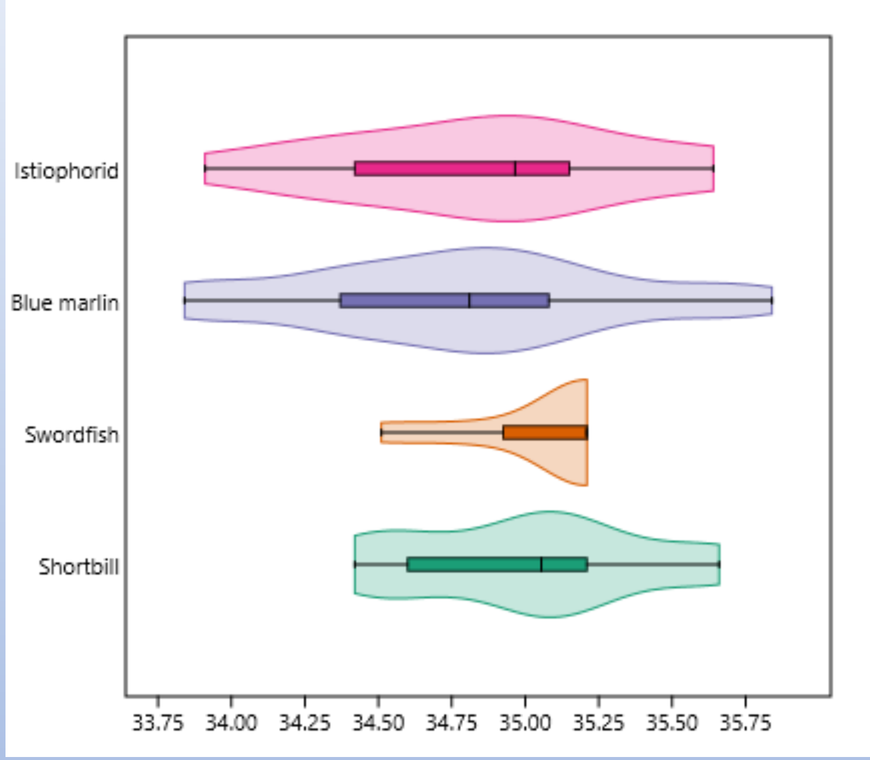
52%
1963

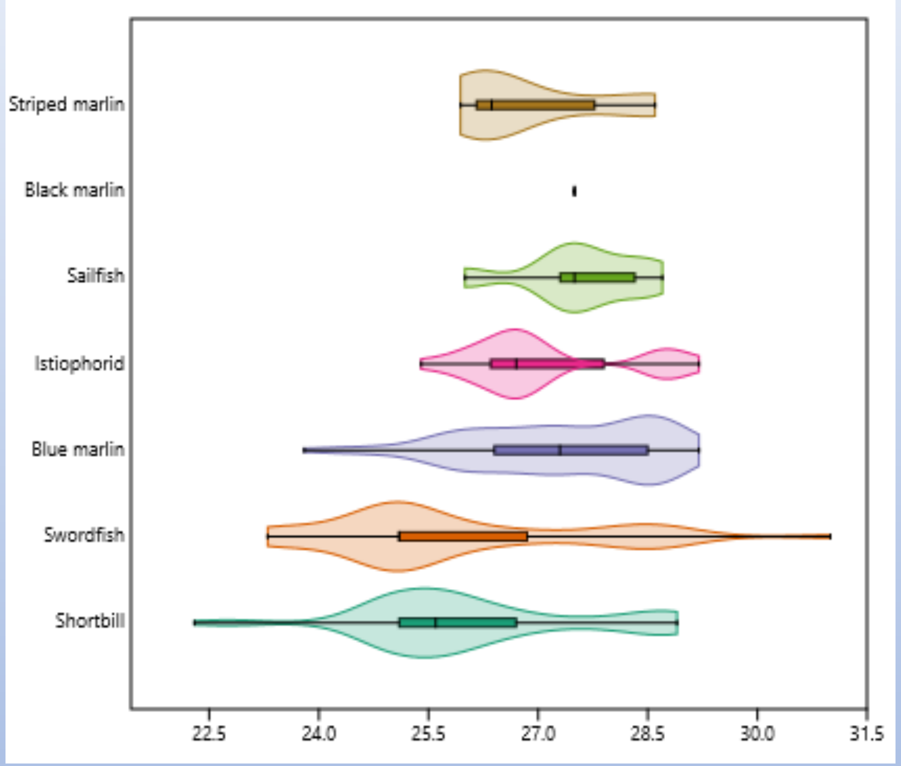
90%
1990

Wild Oceans
For the future of fishing

Catch by Month for Species									
MONTH	BLM	BUM	IST	MLS	SPA	SSP	SWO	Total	%
1	82	44	2	3	17	5	3	156	0.20
2	0	15	2	0	2	3	0	22	0.03
3	0	10	2	0	0	2	1	15	0.02
4	0	4	1	0	4	7	5	21	0.03
5	0	13	0	7	7	16	28	71	0.09
6	0	18	2	24	1	2	5	52	0.07
7	0	32	7	0	1	7	2	49	0.06
8	0	33	7	9	1	11	0	61	0.08
9	0	11	1	7	11	11	6	47	0.06
10	9	61	55	8	24	17	8	182	0.24
11	1	17	0	29	5	0	1	53	0.07
12	0	24	0	7	13	0	0	44	0.06
Total	92	282	79	94	86	81	59	773	

Salinity and Temperature Conditions at Capture

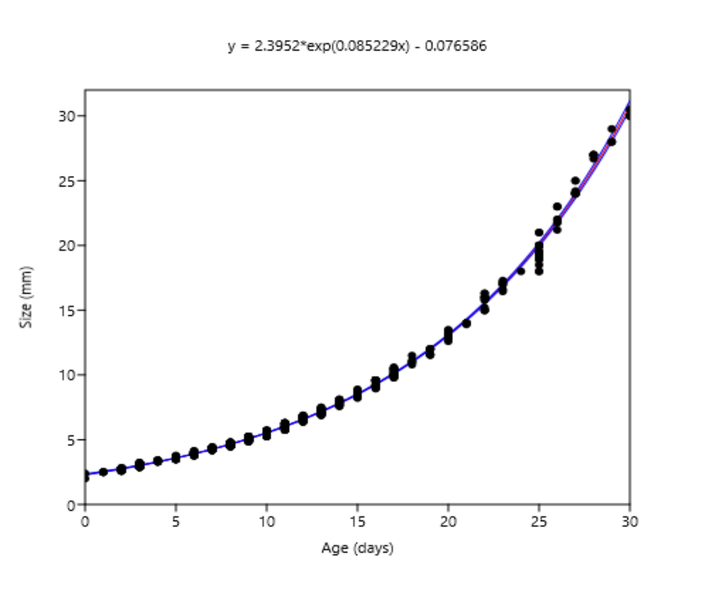




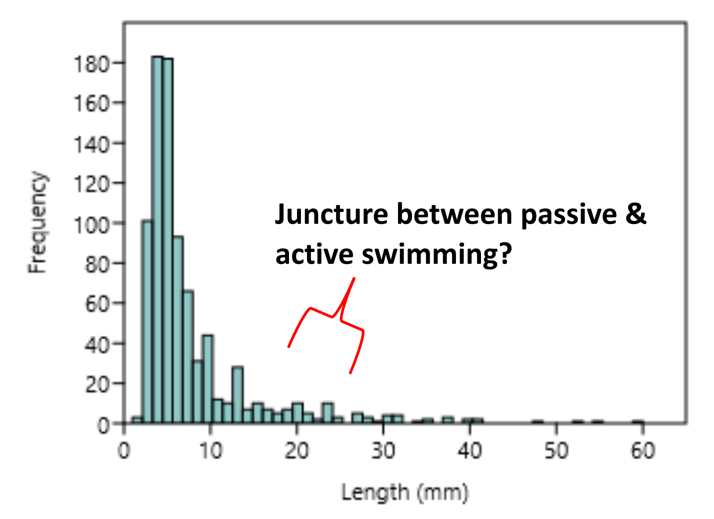
Salinity at capture (‰)
95% CI 34.7 - 34.9 ‰ (all samples)

Temperature at capture (°C)
95% CI 26.7 – 27.0 °C (all samples)

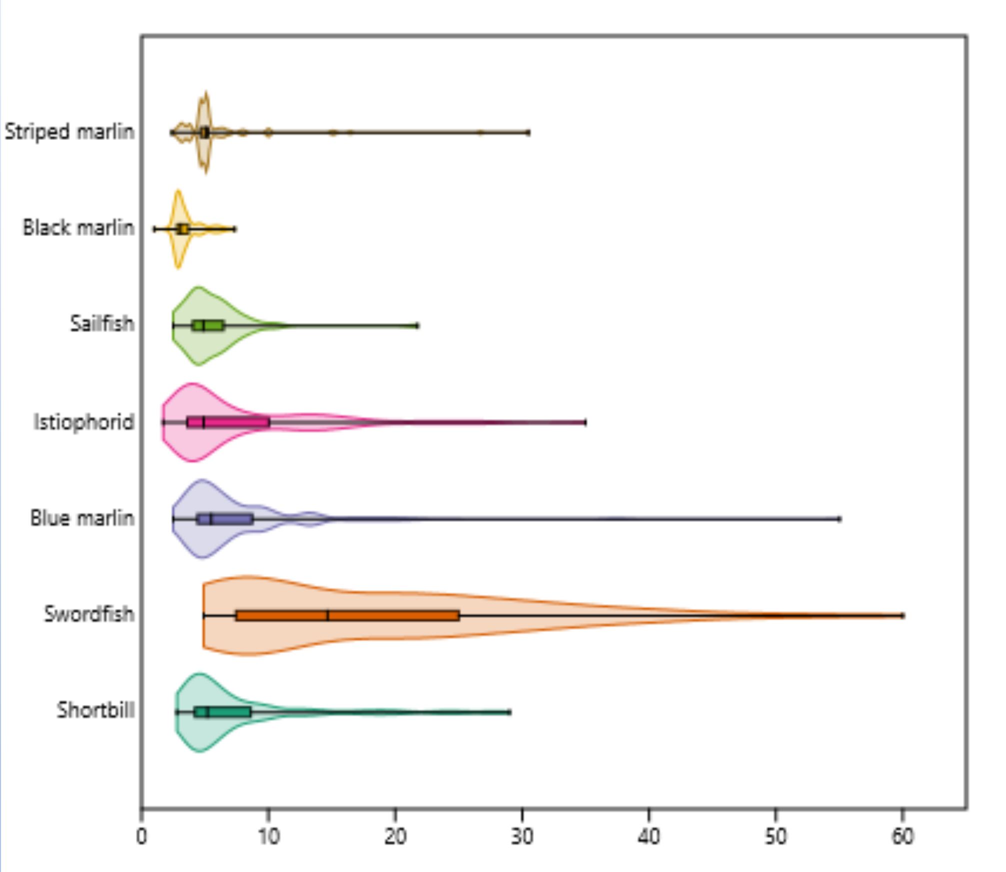
Age & Growth



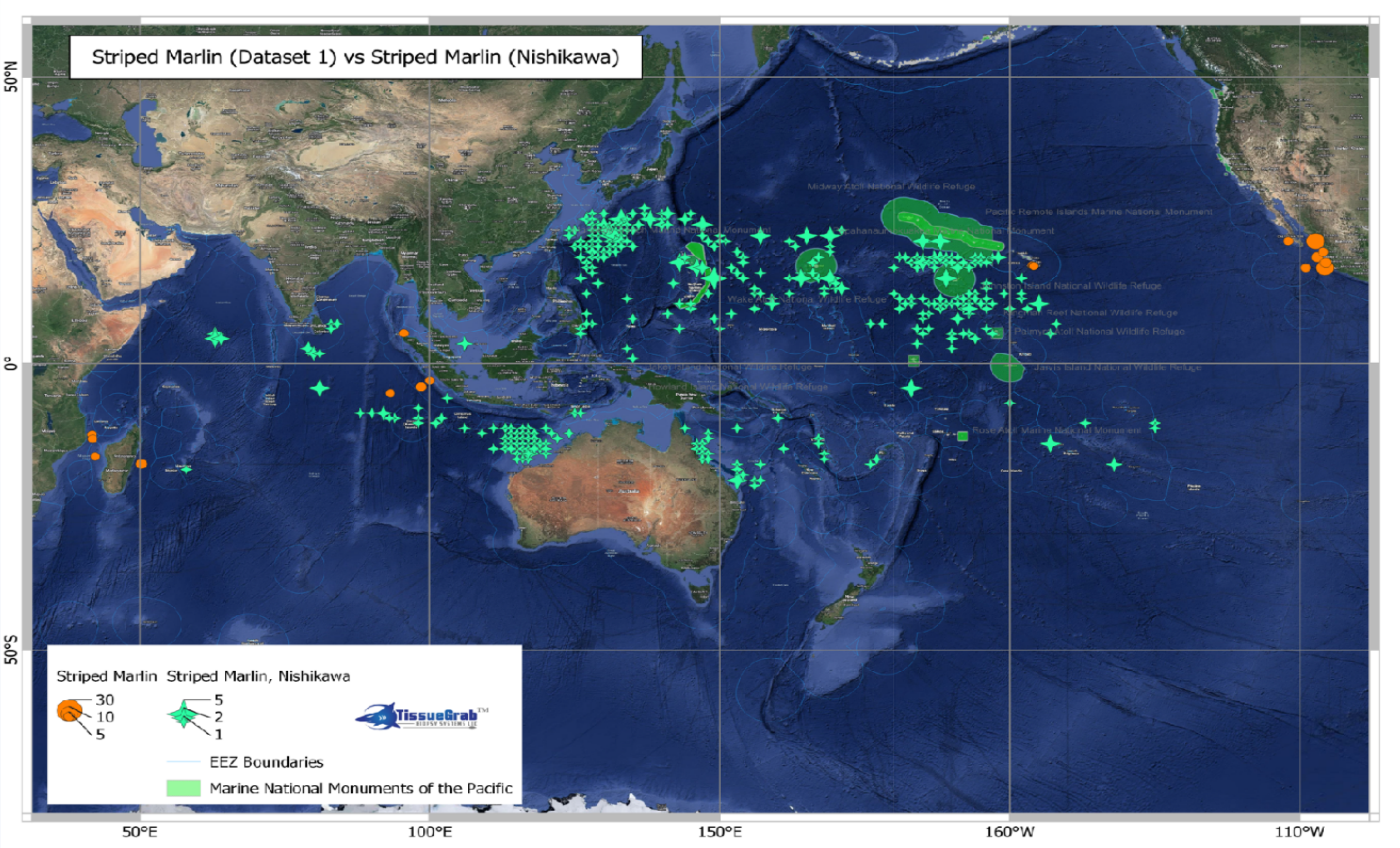
Exponential age model created for project from parameters given for Atlantic billfish larvae
(Sponaugle et al. 2005)

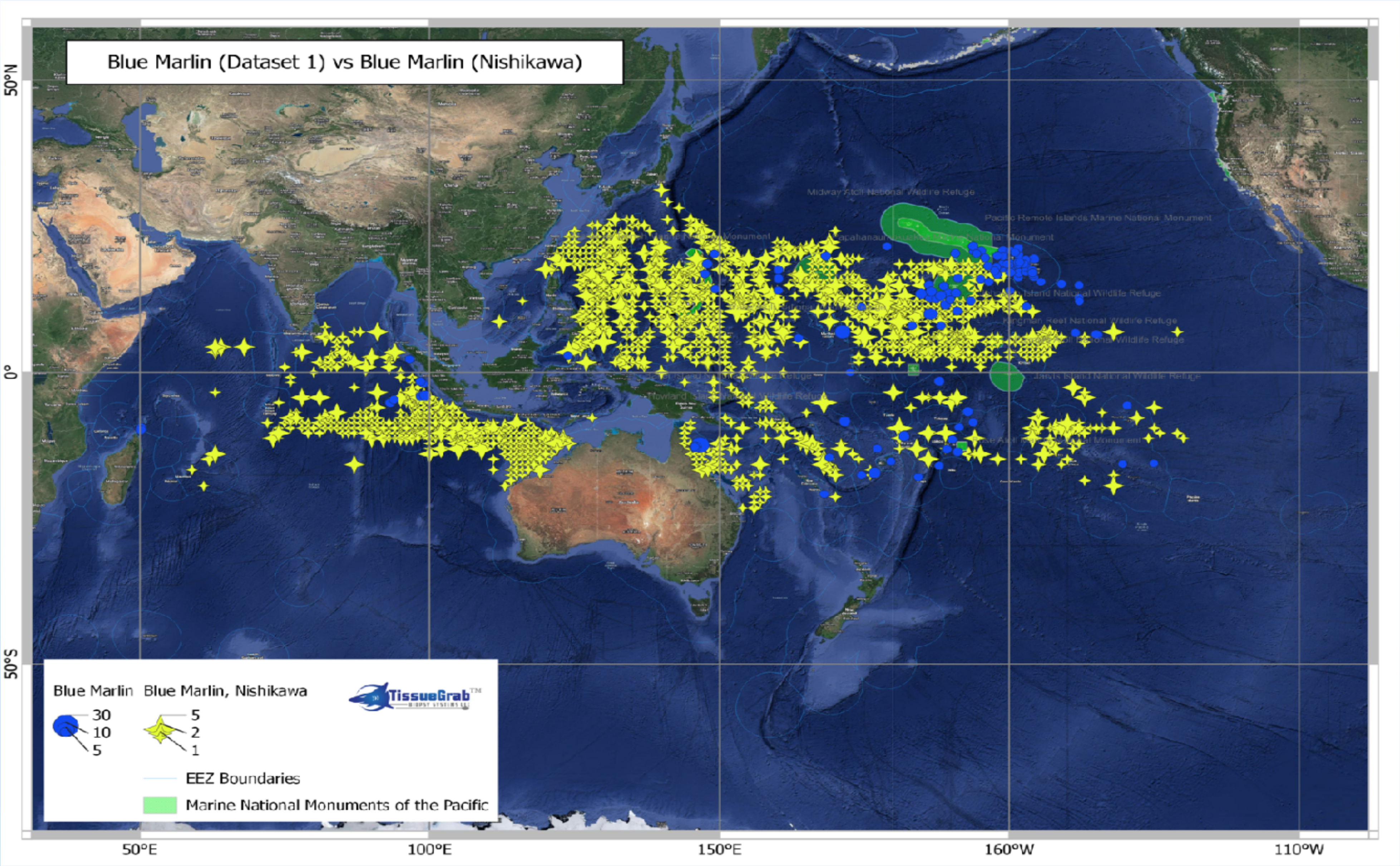


Reduced catch of larvae by method(s) of capture after ~15-20 mm. Catch may not be vulnerable to method(s) of capture and/or may move to habitats not sampled.

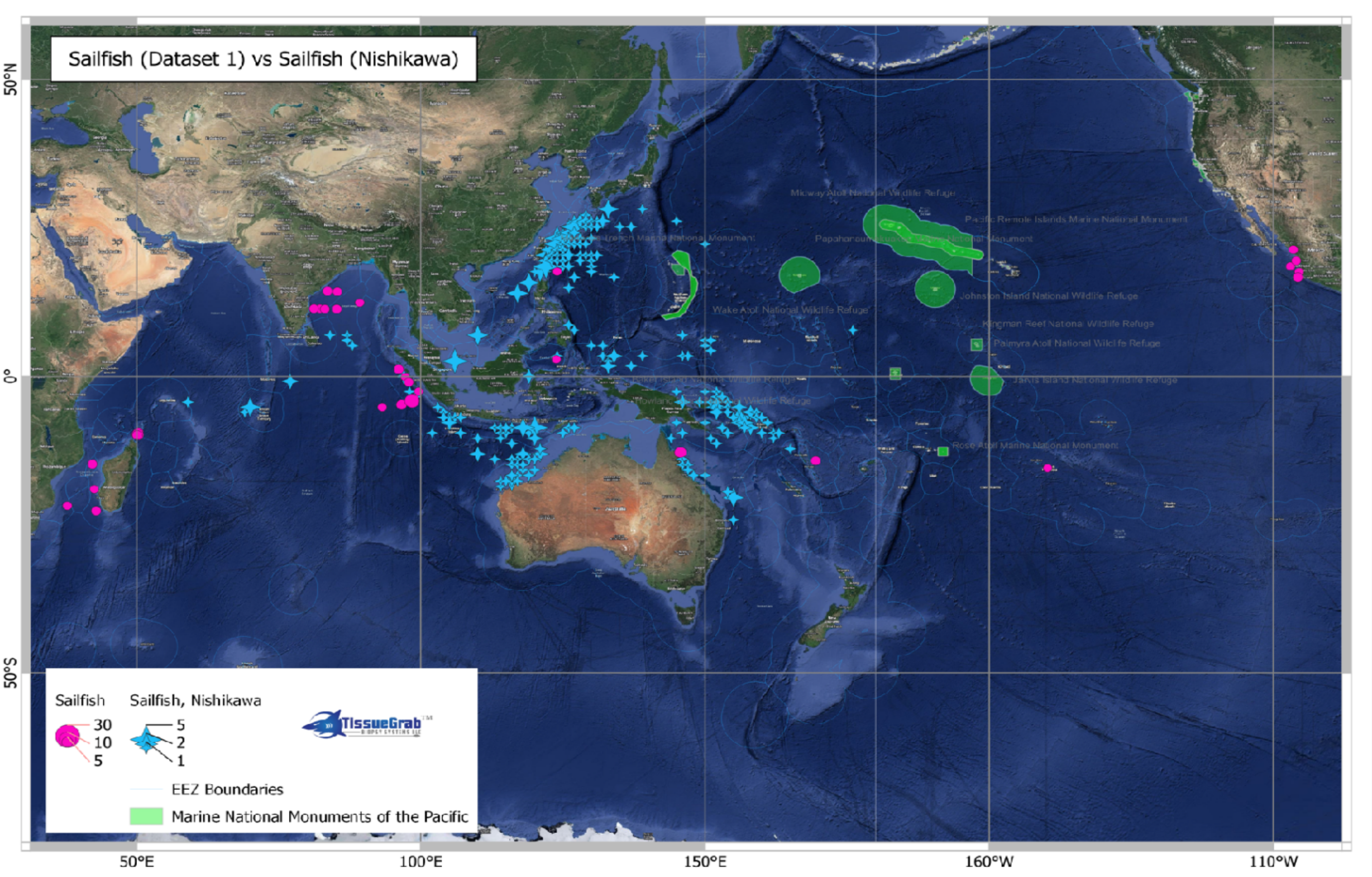


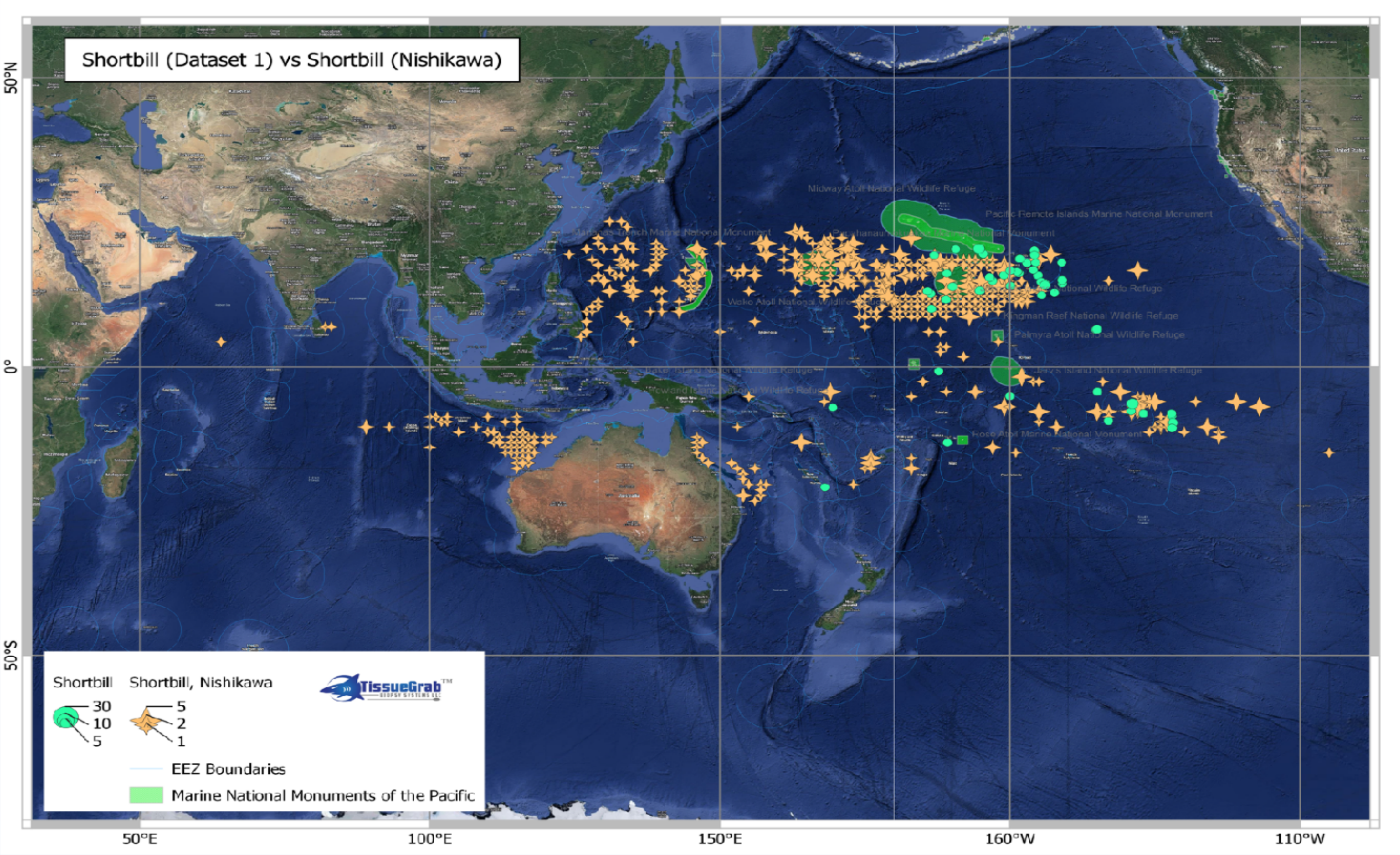
Standard length at capture (mm)


Striped Marlin (Dataset 1) vs Striped Marlin (Nishikawa)
50°N
0°
50°S
50°E
100°E
150°E
160°W
110°W
Striped Marlin
30
10
5
Striped Marlin, Nishikawa
5
2
1
TissueGrab
EEZ Boundaries
Marine National Monuments of the Pacific

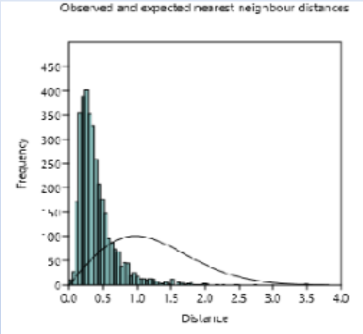


Blue Marlin (Dataset 1) vs Blue Marlin (Nishikawa)
50°N
0°
50°S
50°E
100°E
150°E
160°W
110°W
Blue Marlin
Blue Marlin, Nishikawa
30
10
5
5
2
1
EEZ Boundaries
Marine National Monuments of the Pacific
TissueGrab™

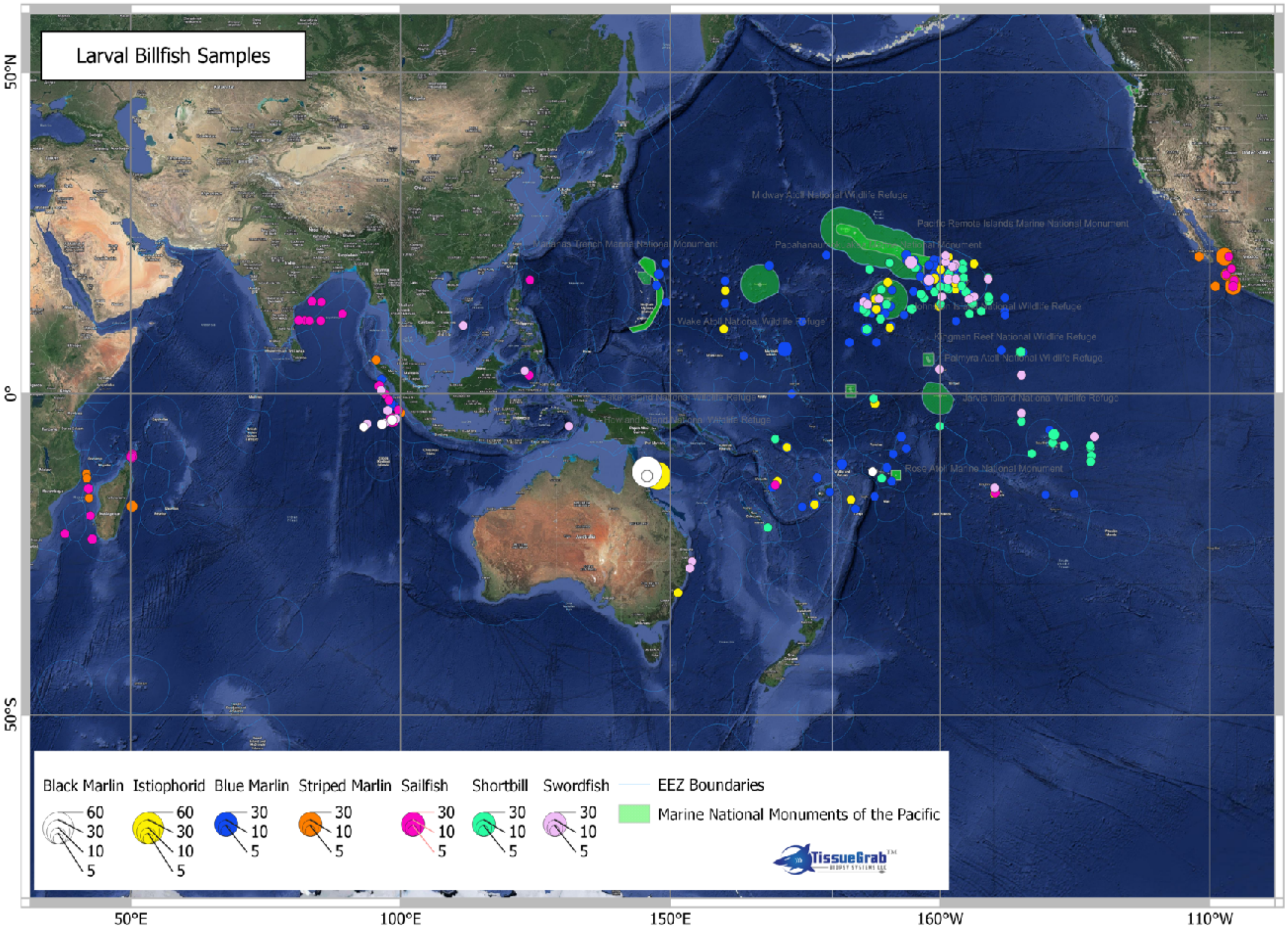

Sailfish (Dataset 1) vs Sailfish (Nishikawa)
50°N
0°
50°S
50°E
100°E
150°E
160°W
110°W
Sailfish
30
10
5
Sailfish, Nishikawa
5
2
1
EEZ Boundaries
Marine National Monuments of the Pacific
TissueGrab


Shortbill (Dataset 1) vs Shortbill (Nishikawa)
50°N
0°
50°S
50°E
100°E
150°E
160°W
110°W
Shortbill
30
10
5
Shortbill, Nishikawa
5
2
1
TissueGrab
EEZ Boundaries
Marine National Monuments of the Pacific

Distribution of larval billfishes in Dataset 1

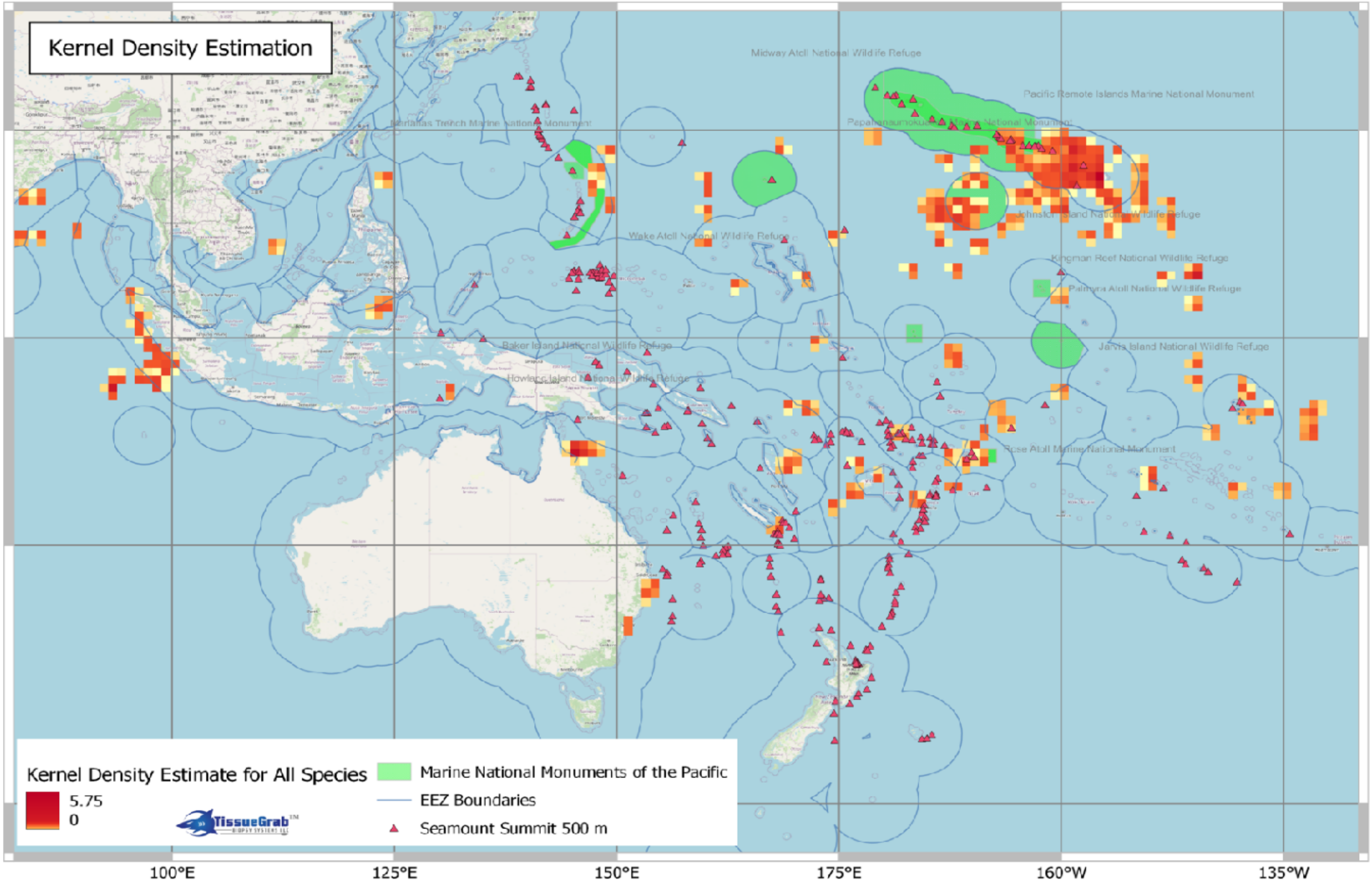


Point pattern analysis for Complete Spatial Randomness (CSR) using Nearest Neighbours and Ripley's K functions indicated samples were not randomly distributed but were significantly clustered.



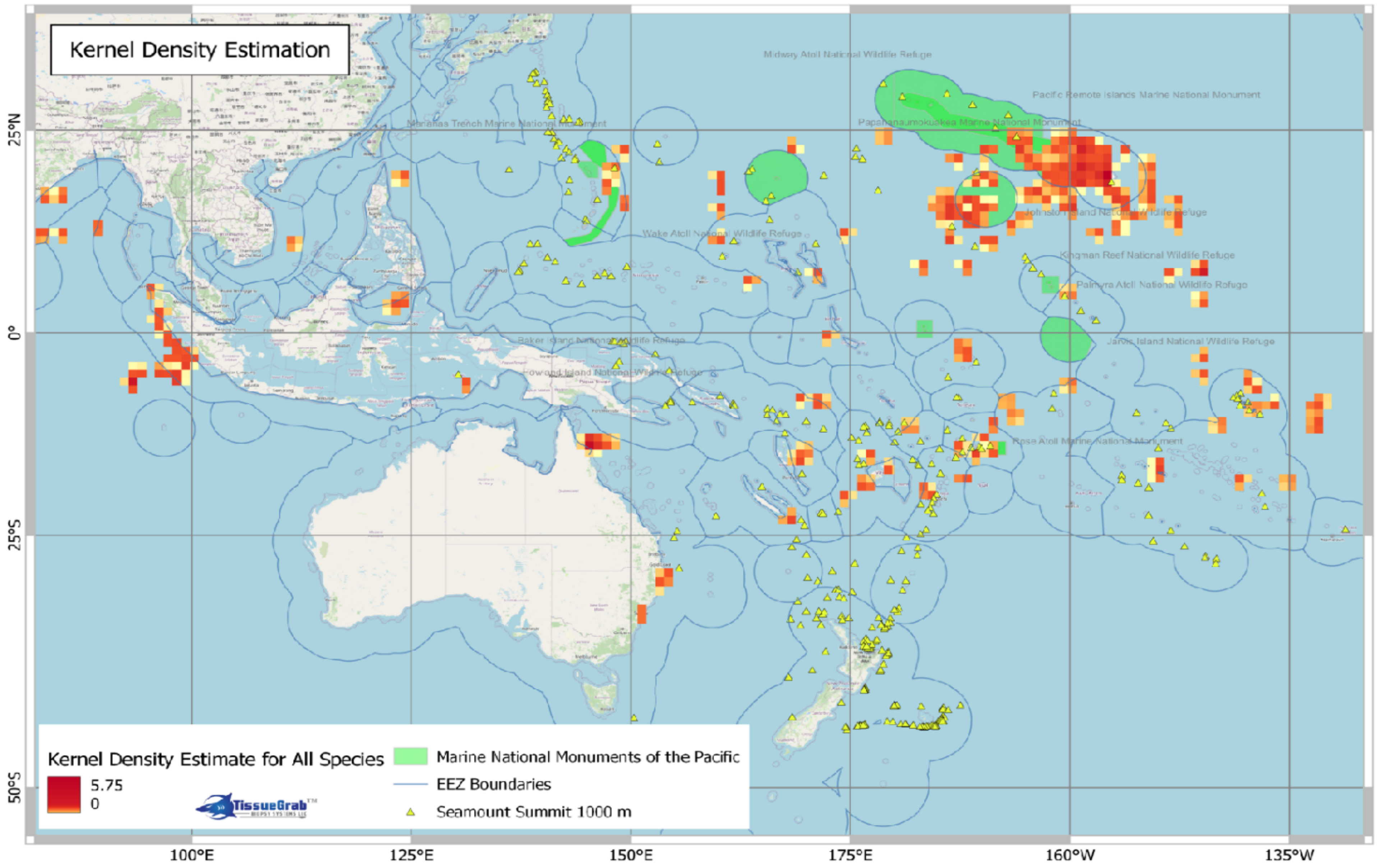
Examining Relationships of larval distribution patterns and seamounts at varying depths

Wild Oceans
For the future of fishing

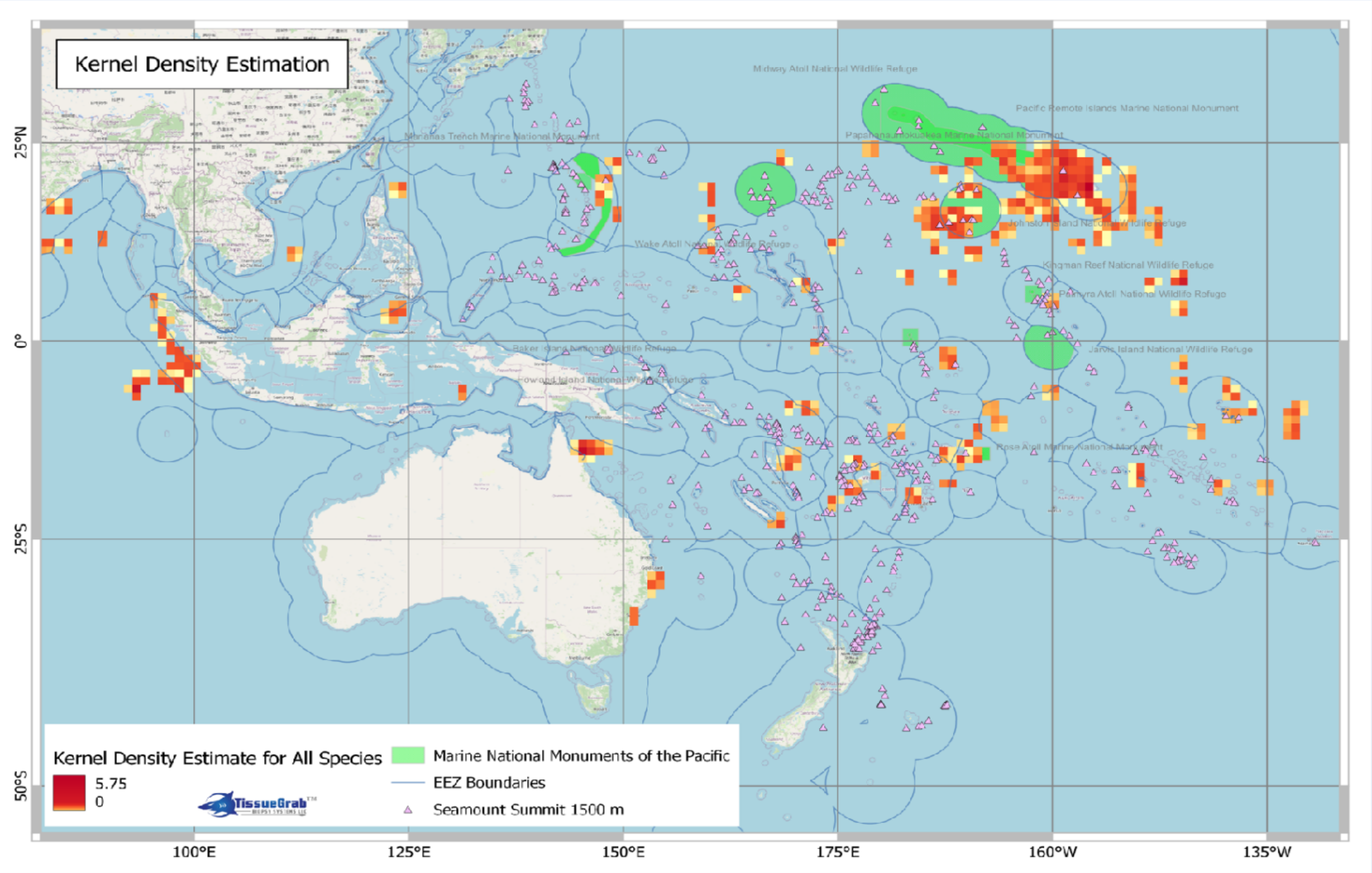


Wild Oceans
For the future of fishing

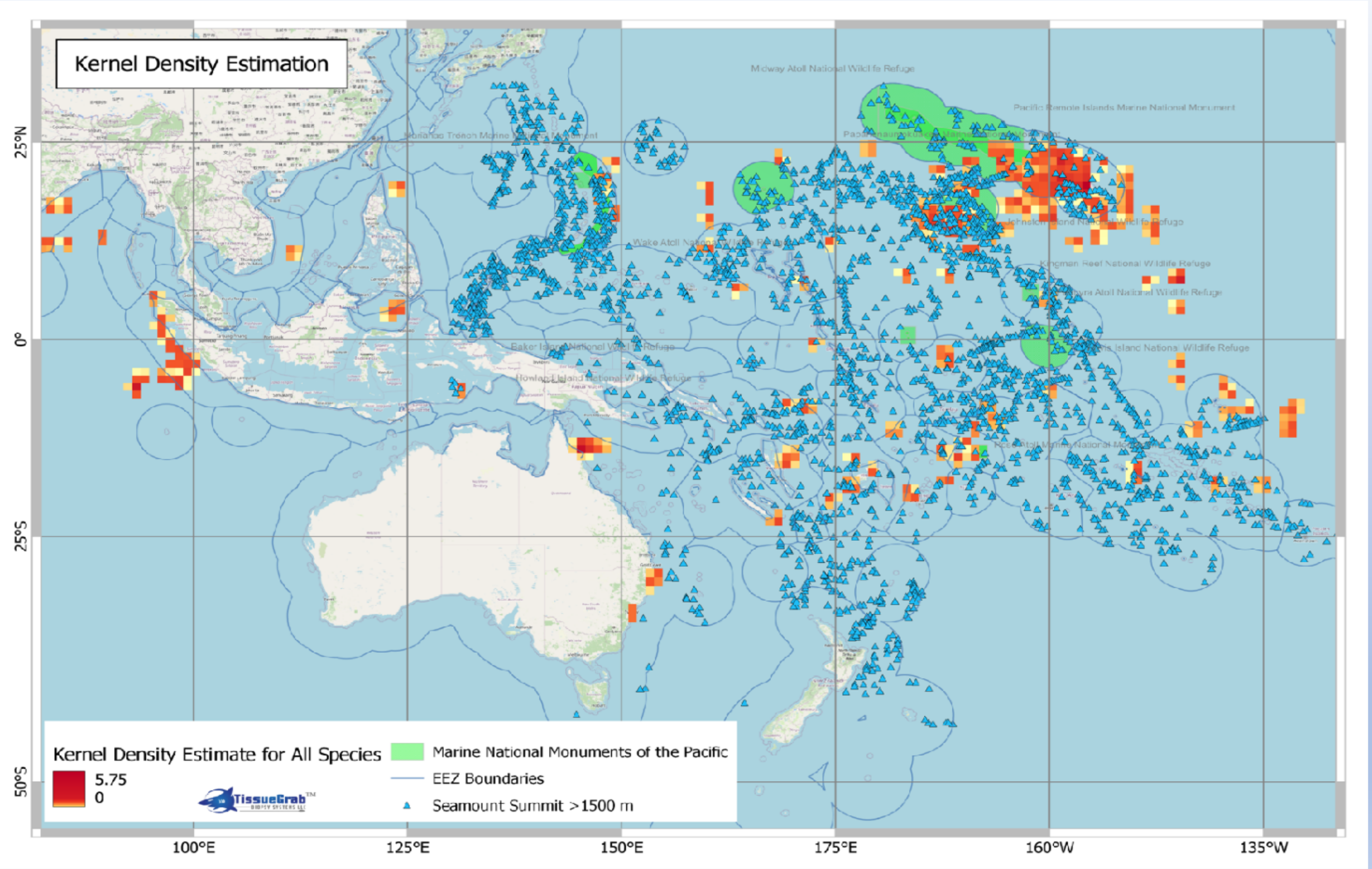
Wild Oceans
For the future of fishing

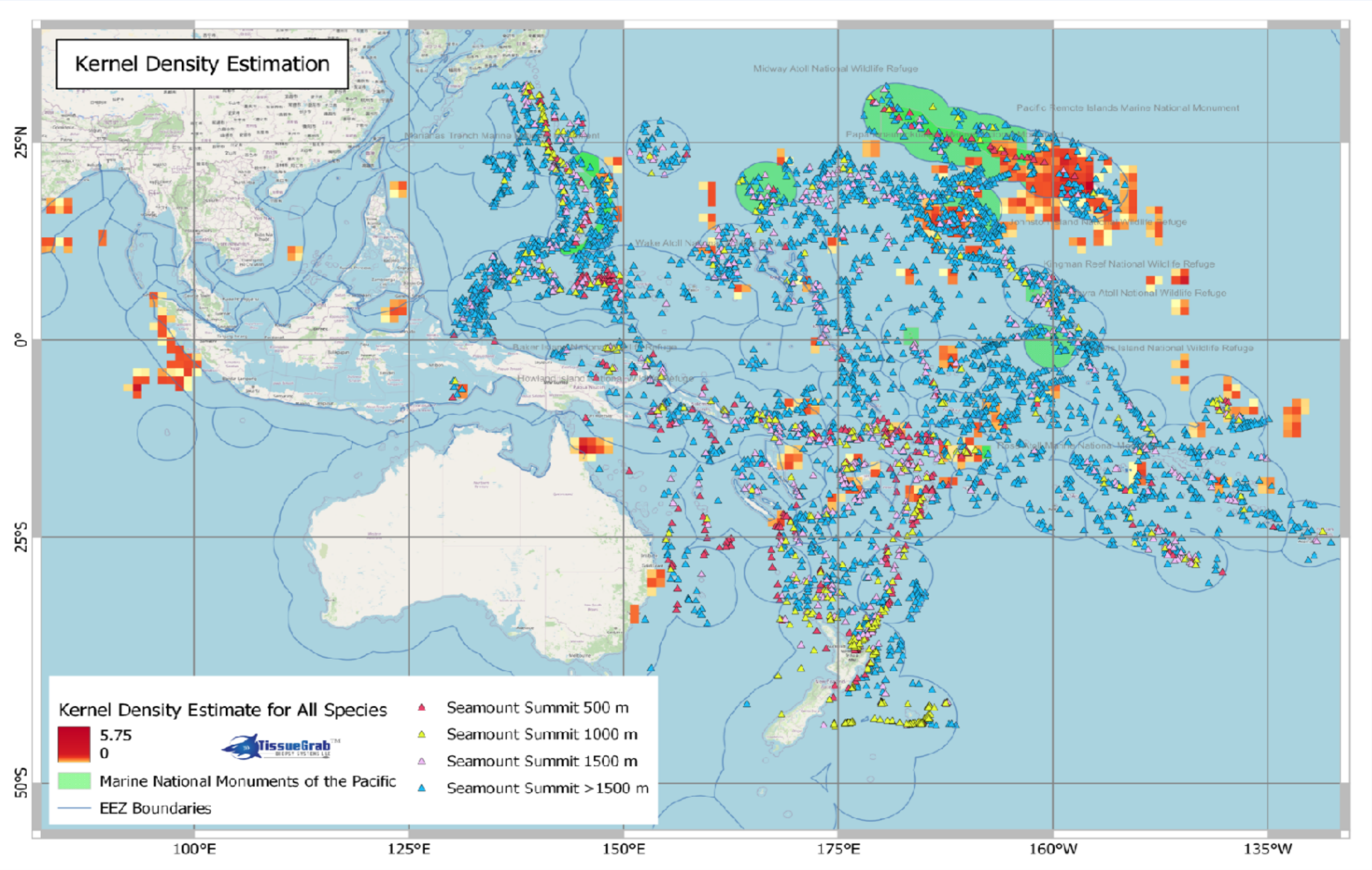


Wild Oceans
For the future of fishing



Kernel Density Estimation
Midway Atoll National Wildlife Refuge
Pacific Remote Islands Marine National Monument
Papahanaumokuakea Marine National Monument
Marianas Trench Marine National Monument
Wake Atoll National Wildlife Refuge
Johnston Island National Wildlife Refuge
Kingman Reef National Wildlife Refuge
Palmyra Atoll National Wildlife Refuge
Jarvis Island National Wildlife Refuge
Baker Island National Wildlife Refuge
Howland Island National Wildlife Refuge
Rose Atoll Marine National Monument
25°N
0°
25°S
50°S
100°E
125°E
150°E
175°E
160°W
135°W
Kernel Density Estimate for All Species
5.75
0
TissueGrab
Marine National Monuments of the Pacific
EEZ Boundaries
Seamount Summit 1500 m


Kernel Density Estimation
Midway Atoll National Wildlife Refuge
Pacific Remote Islands Marine National Monument
Kingman Reef National Wildlife Refuge
25°N
0°
25°S
50°S
100°E
125°E
150°E
175°E
160°W
135°W
Kernel Density Estimate for All Species
5.75
0
Marine National Monuments of the Pacific
EEZ Boundaries
Seamount Summit >1500 m

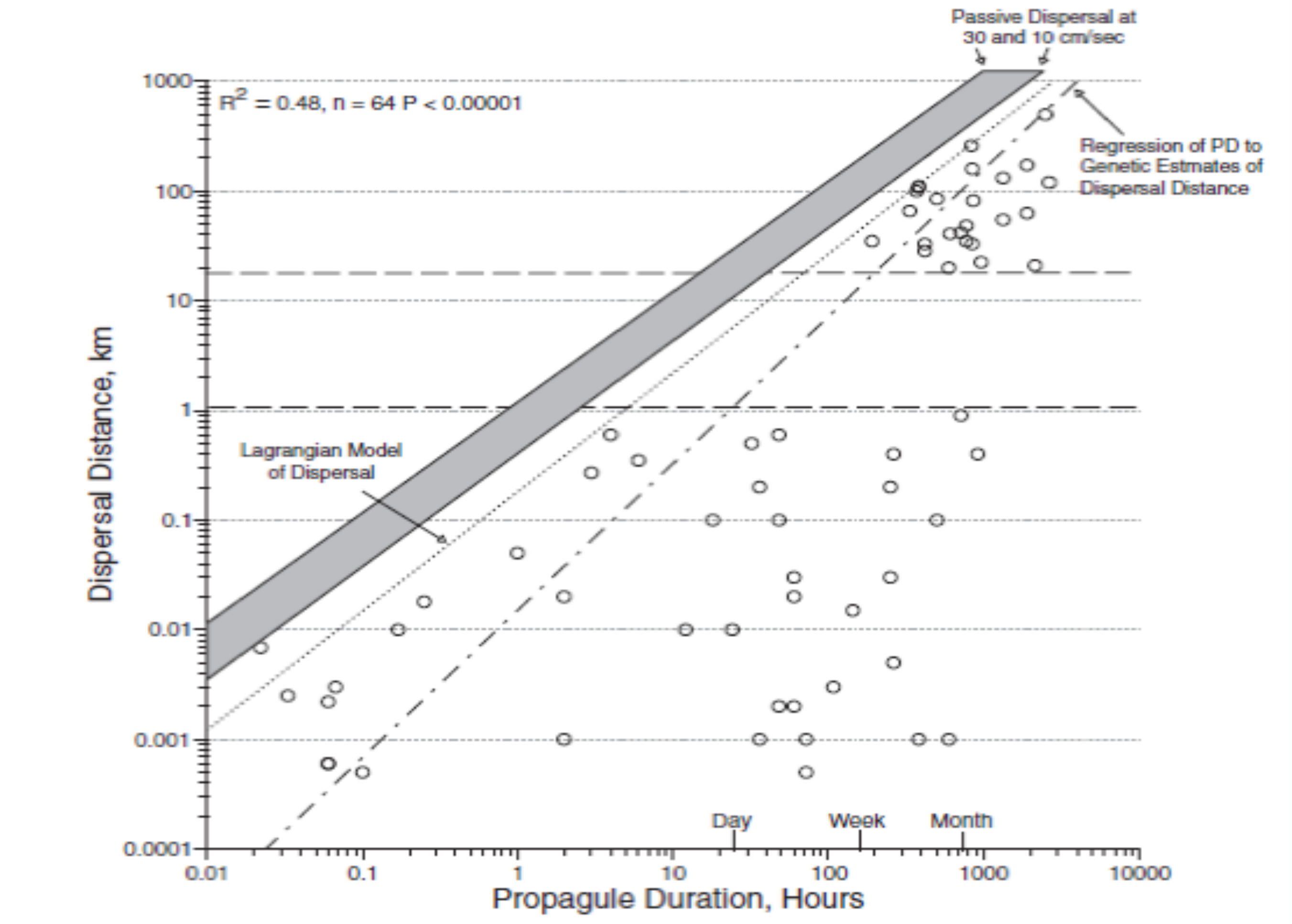

Kernel Density Estimation
Midway Atoll National Wildlife Refuge
Pacific Remote Islands Marine National Monument
Kingman Reef National Wildlife Refuge
25°N
0°
25°S
50°S
100°E
125°E
150°E
175°E
160°W
135°W
Kernel Density Estimate for All Species
5.75
0
TissueGrab
Marine National Monuments of the Pacific
EEZ Boundaries
Seamount Summit 500 m
Seamount Summit 1000 m
Seamount Summit 1500 m
Seamount Summit >1500 m

Seamount summit depth class and numbers of larvae detected within 50 nmi footprint

Summit Depth (m) Classes	No. larval detections within 50 nmi of seamount summit footprint
500	59
1000	26
1500	77
>1500	729
Grand Total	891

Regardless of age, 276 individual larvae were detected in the footprints of several seamounts.
In other words, larvae were found in groups mostly at deep seamounts that were also clustered.

Examining seamounts as possible spawning locations?

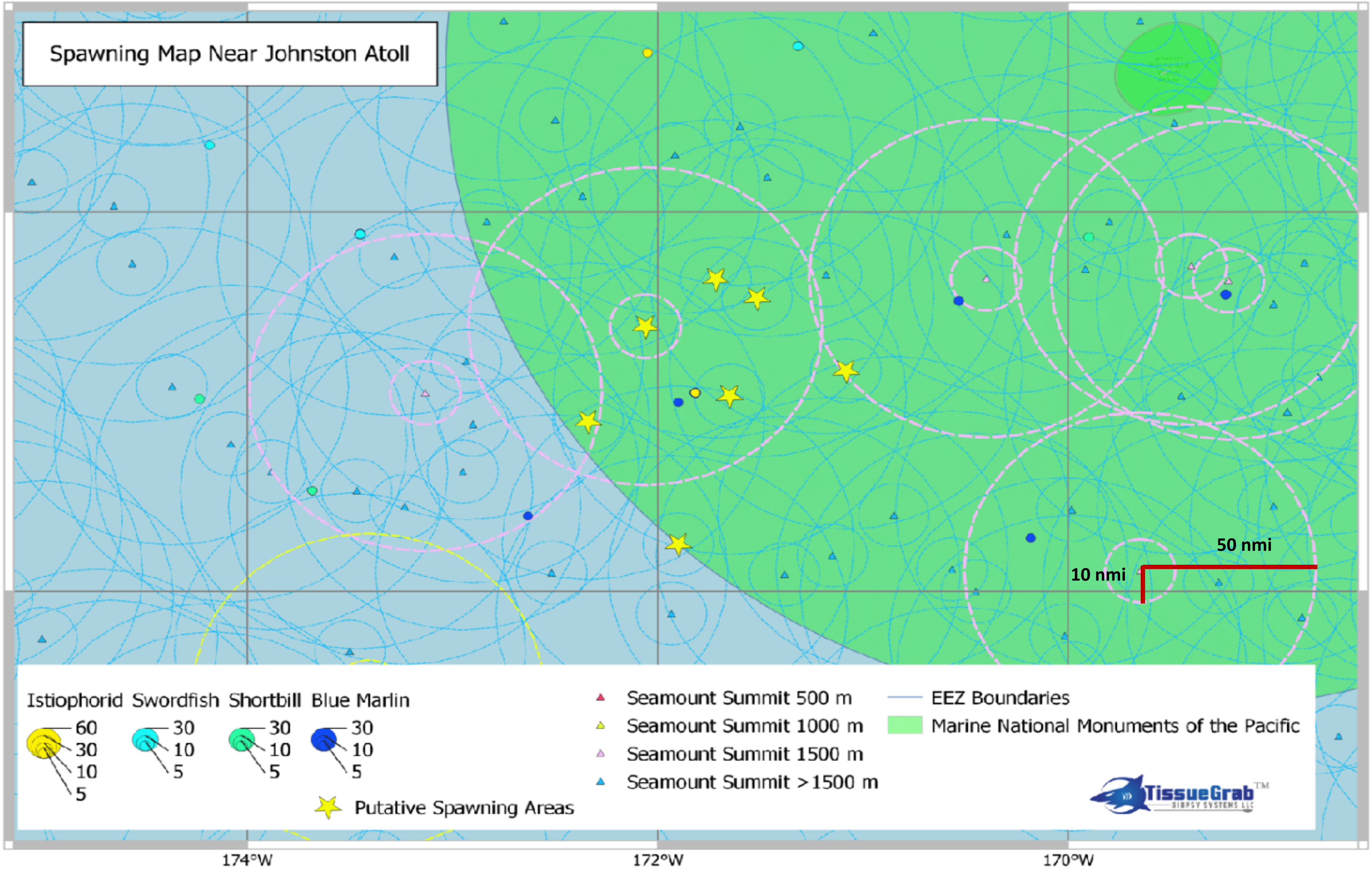


Shanks (2009)

Shanks (2009) modelled pelagic larval duration and dispersal distances for many species.

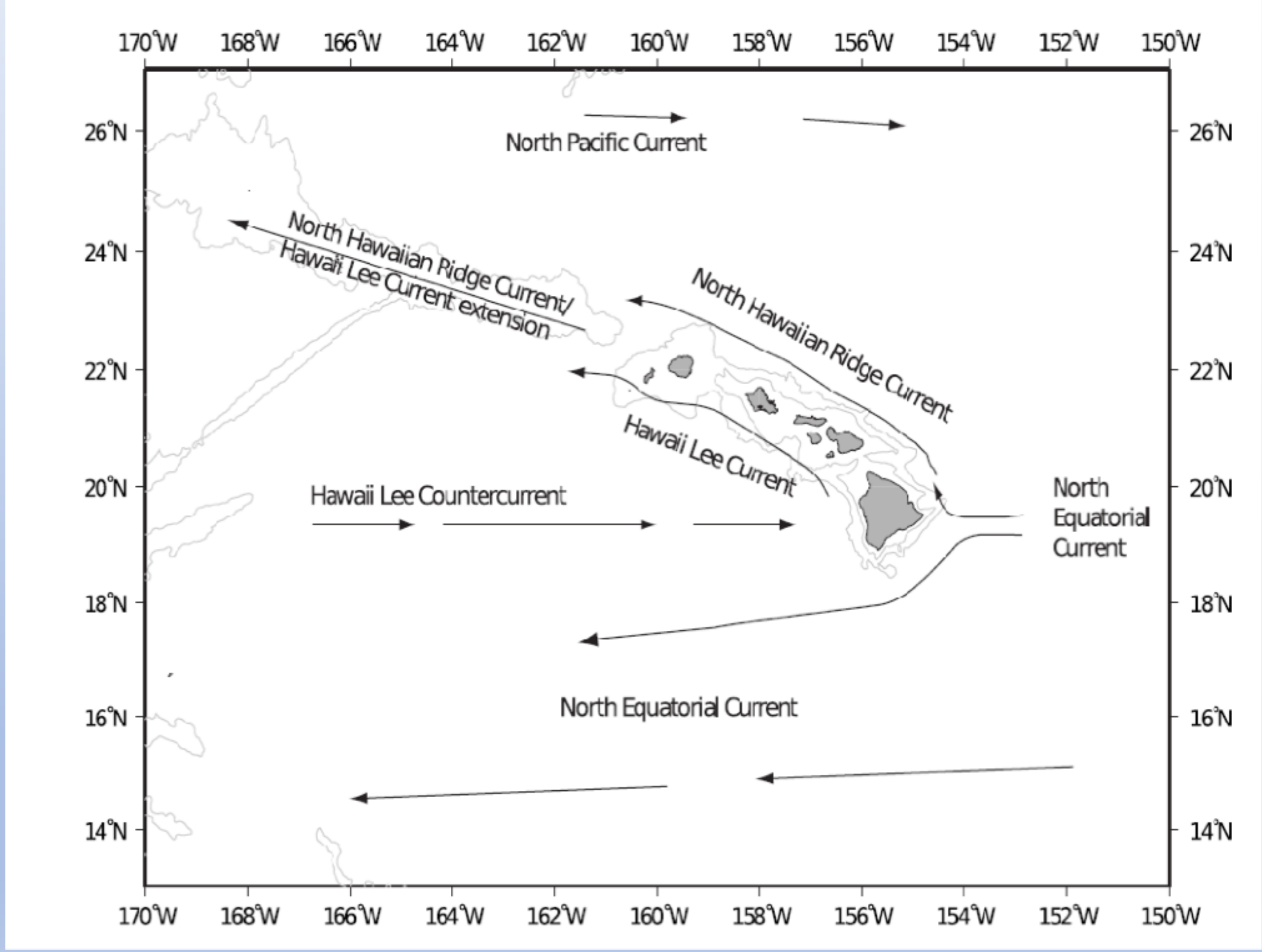
From this, our criteria to nominate a putative spawning area:

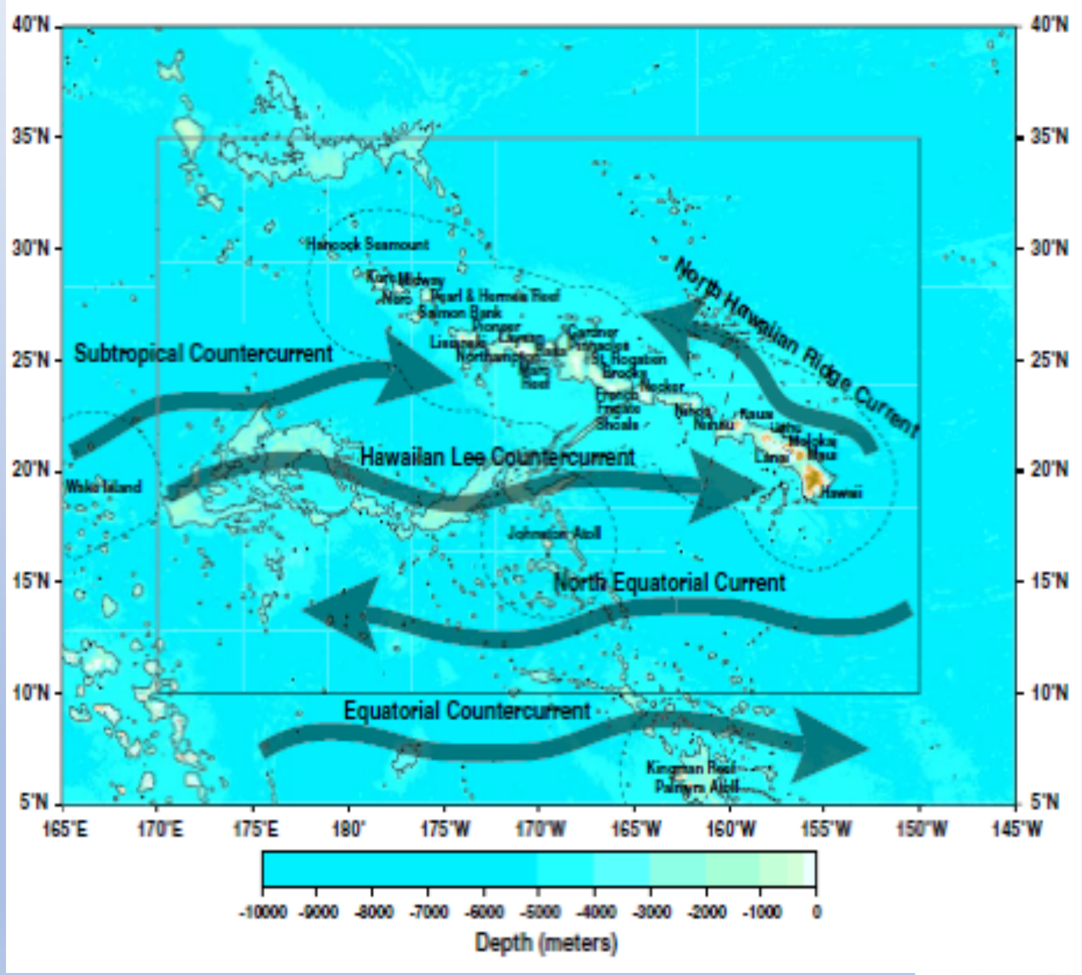
- samples <= 5 days old
- straight-line movements confined to within 50 nmi (93 km) from seamount summits.
- That is, the maximum distance larvae could travel with an assist from a 0.25 m/sec current travelling in a straight-line for 5 days.

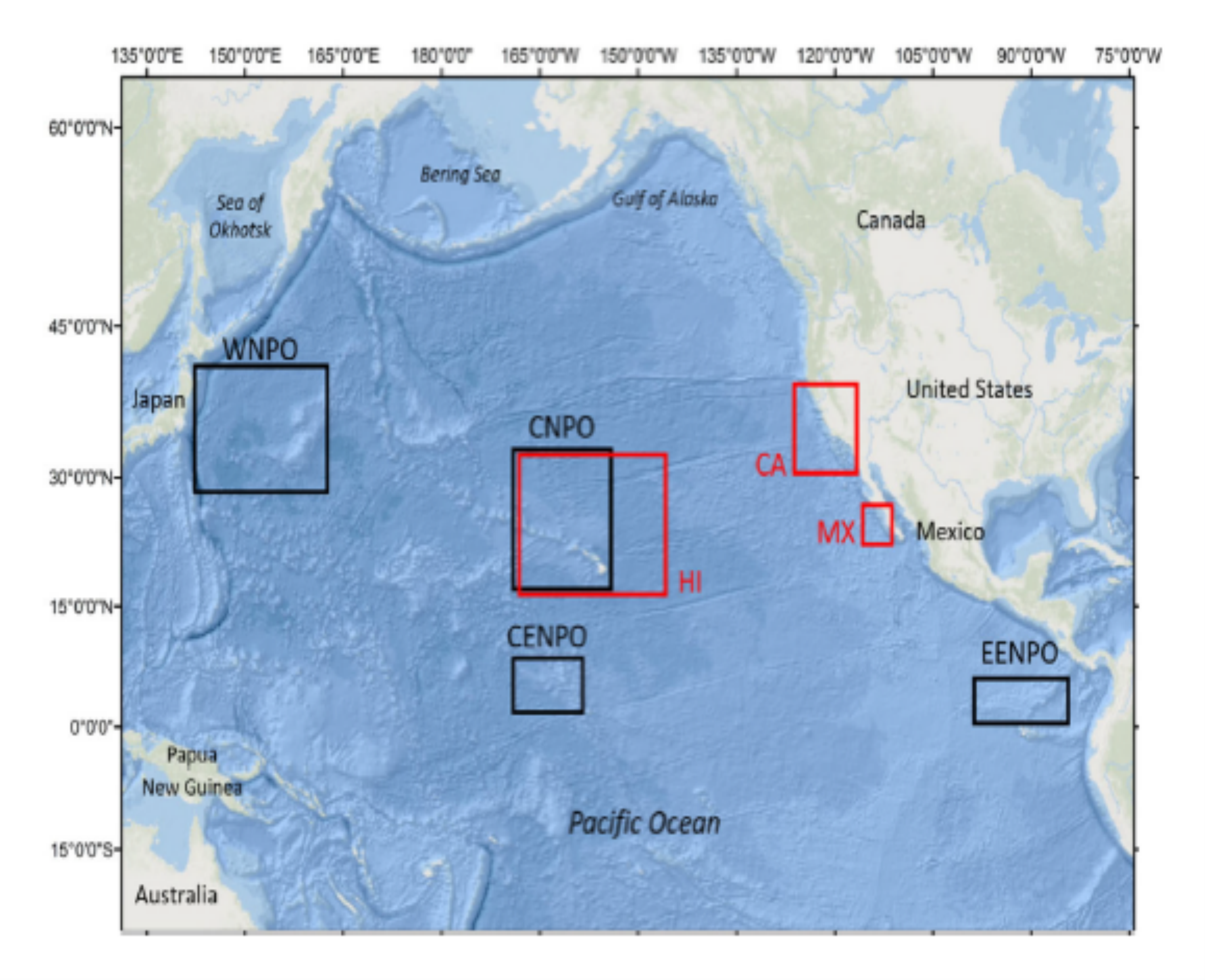


Spawning Map Near Johnston Atoll
16°N
14°N
174°W
172°W
170°W
50 nmi
10 nmi
Istiophorid
60
30
10
5
Swordfish
30
10
5
Shortbill
30
10
5
Blue Marlin
30
10
5
Putative Spawning Areas
Seamount Summit 500 m
Seamount Summit 1000 m
Seamount Summit 1500 m
Seamount Summit >1500 m
EEZ Boundaries
Marine National Monuments of the Pacific

Current vectors around Hawaii have been modelled by Wren & Kobayashi (2016) and Kobayashi (2007). Kobayashi (2007) suggested Johnston Atoll as a possible source and transport corridor of pelagic larvae to Hawaii

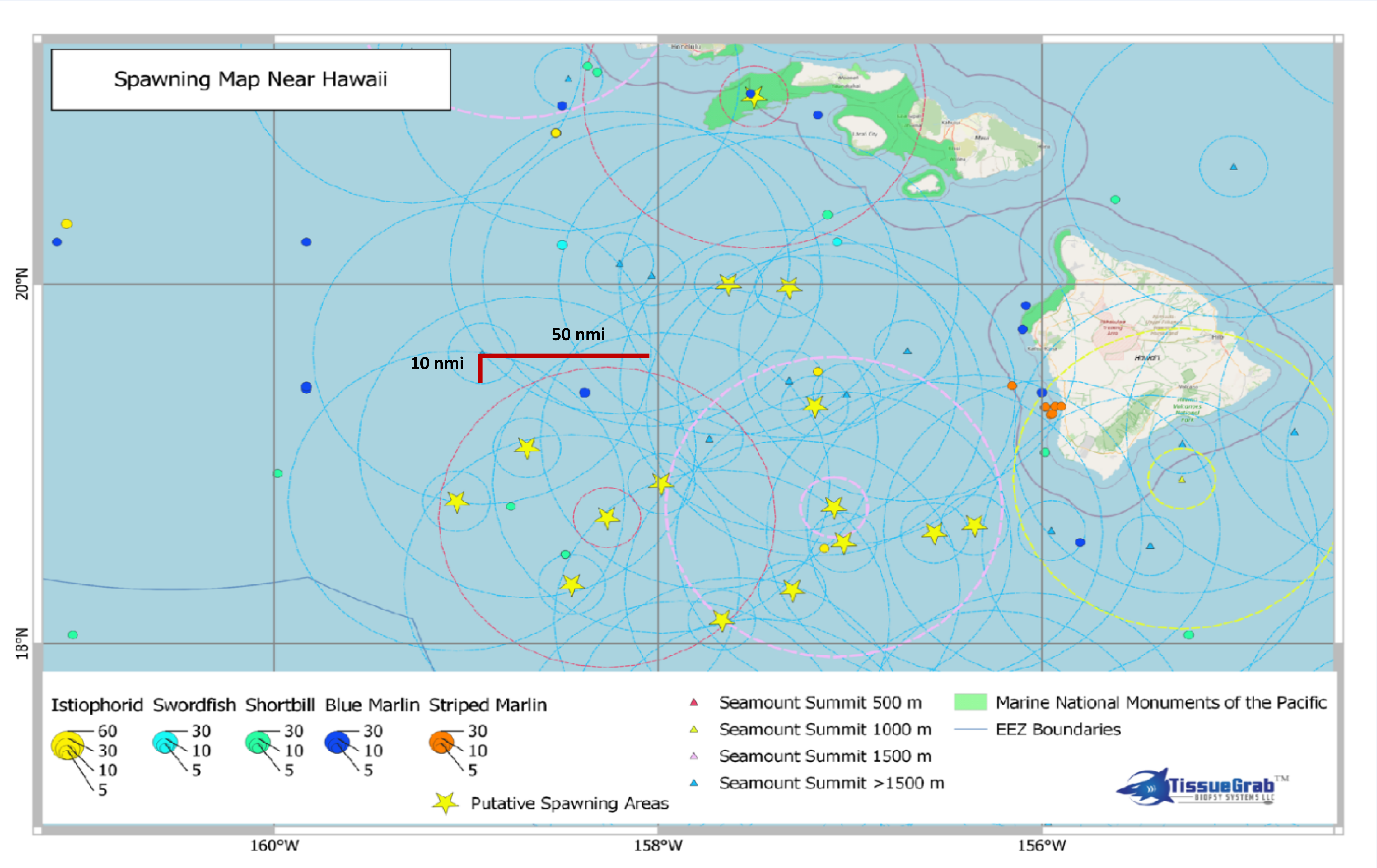






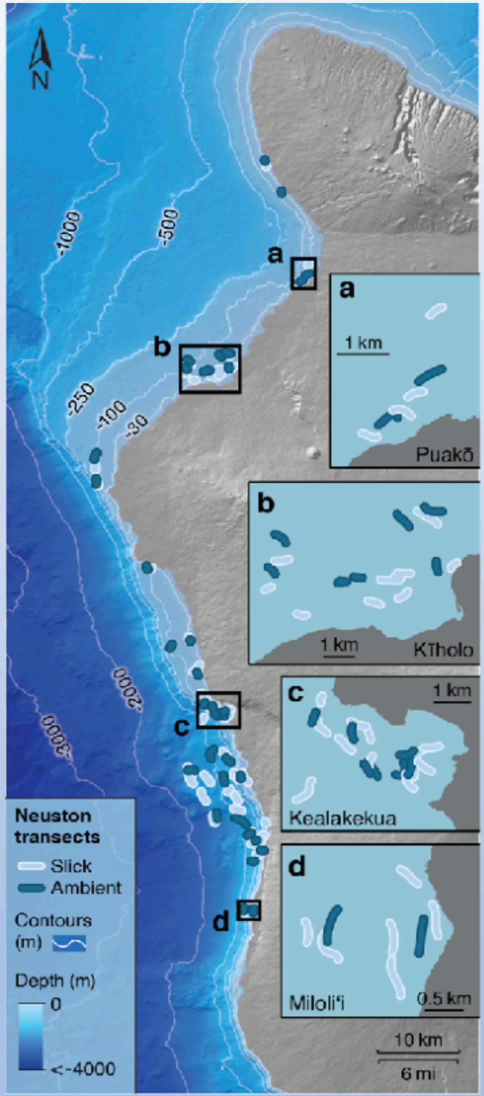
Using elemental analysis, Wells et al. (2021) recently suggested several regional spawning areas (BLACK BOXES) for swordfish (RED BOXES are main longline fishing areas).

These regional nurseries indicate a degree of concordance with genetically discrete populations in striped marlin outlined in "Next Steps"

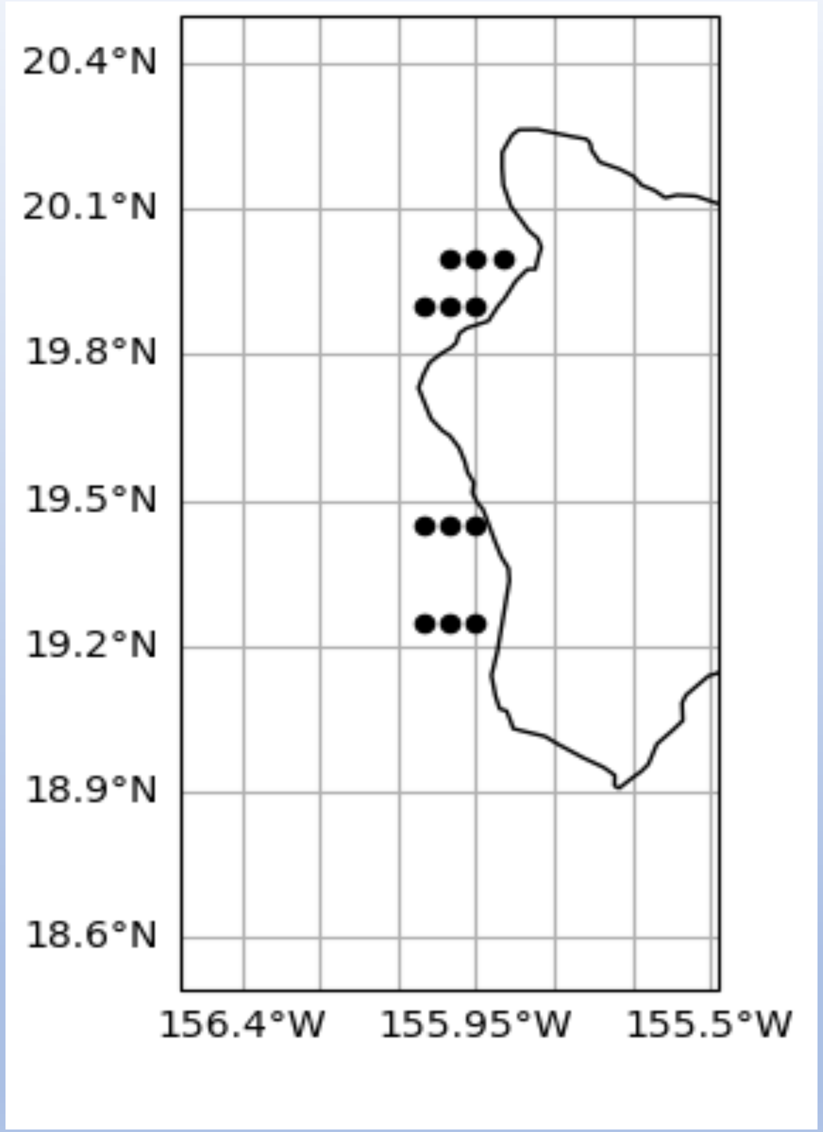

Spawning Map Near Hawaii
50 nmi
10 nmi
20°N
18°N
160°W
158°W
156°W
Istiophorid
60
30
10
5
Swordfish
30
10
5
Shortbill
30
10
5
Blue Marlin
30
10
5
Striped Marlin
30
10
5
Putative Spawning Areas
Seamount Summit 500 m
Seamount Summit 1000 m
Seamount Summit 1500 m
Seamount Summit >1500 m
Marine National Monuments of the Pacific
EEZ Boundaries
TissueGrab™
BIOPSY SYSTEMS LLC

Phase 2 Preliminary Results

Tracking Larval Fish Movements with Ocean Circulation Models



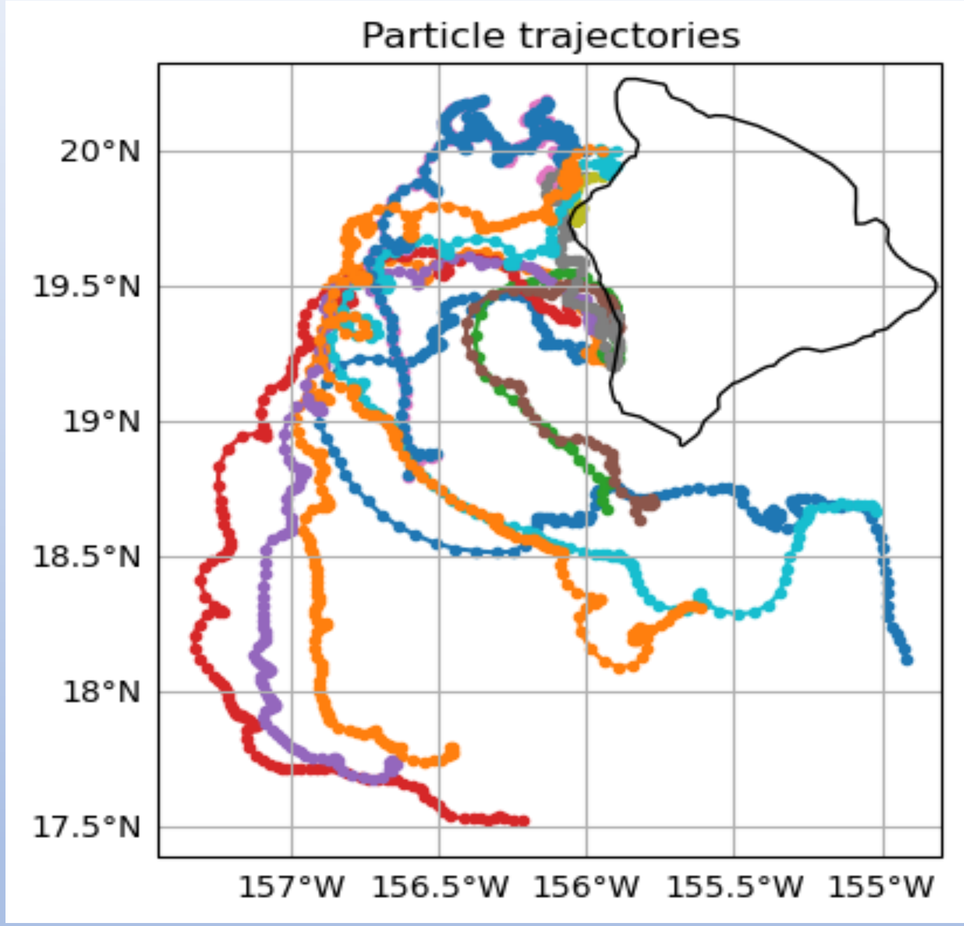
Sites of tows (2016-2018) from Gove et al. (2019)



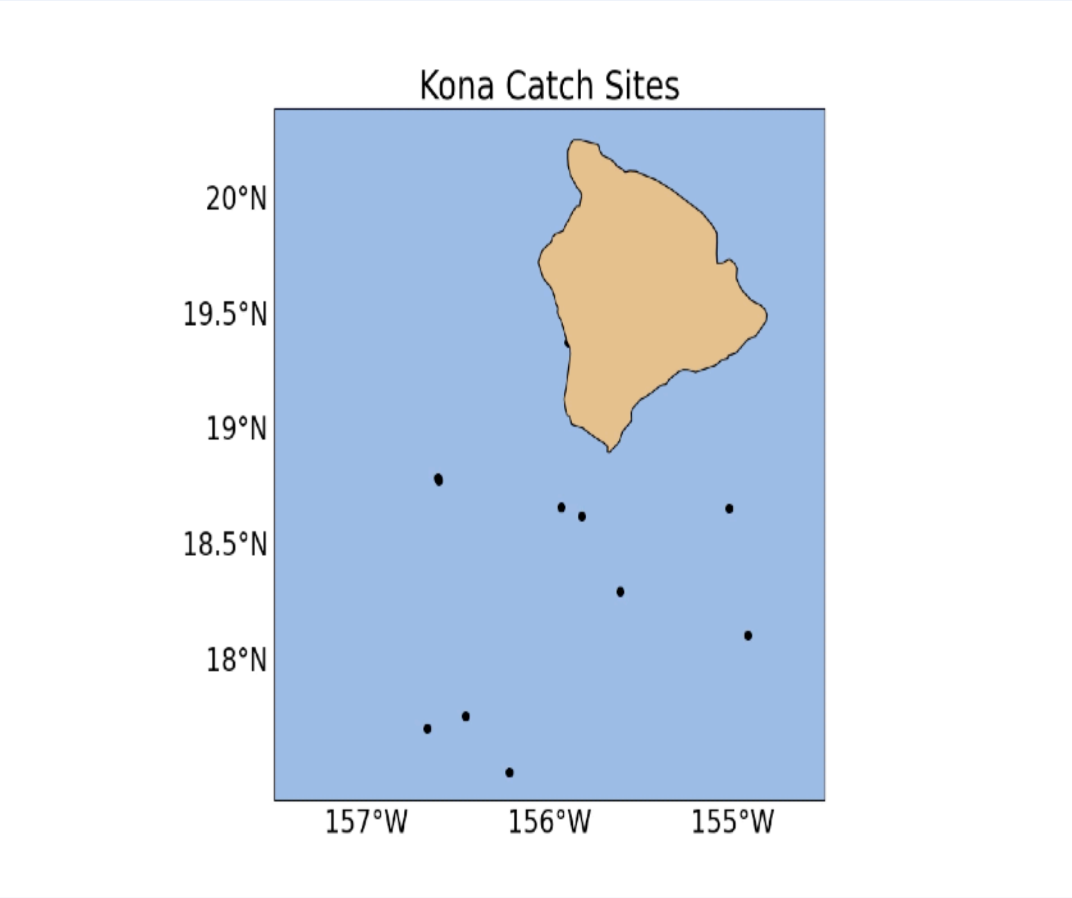
Model placement of catch sites of Larval Istiophoridae

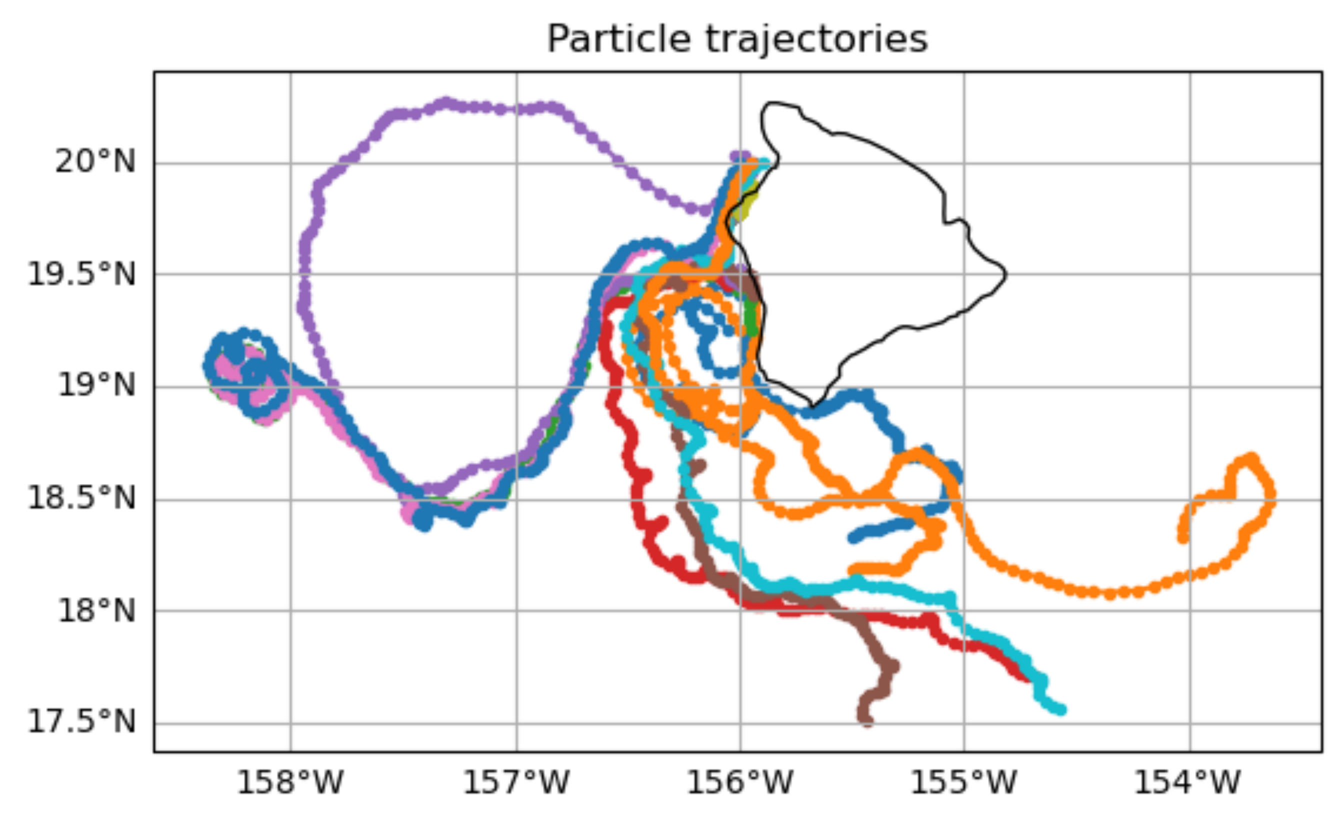
- In 2017, four larval istiophoridae were captured west of Hawai'i
- Catch locations are approximately at the tow sites (a, b, c, and d, far left)
- Dates of capture are unknown
- They measured 12-14 mm in size
- Estimated ages are 19-21 days (from Phase 1)

Tracking Larval Fish Movements with Ocean Circulation Models



Particle positions after 21 days of tracking **backward** in time, assuming a catch date of 31 May 2017





Particle positions after 21 days of tracking **backward** in time, assuming a catch date of 21 May 2017

Particle positions at the end of the trajectories may be considered as possible spawning regions

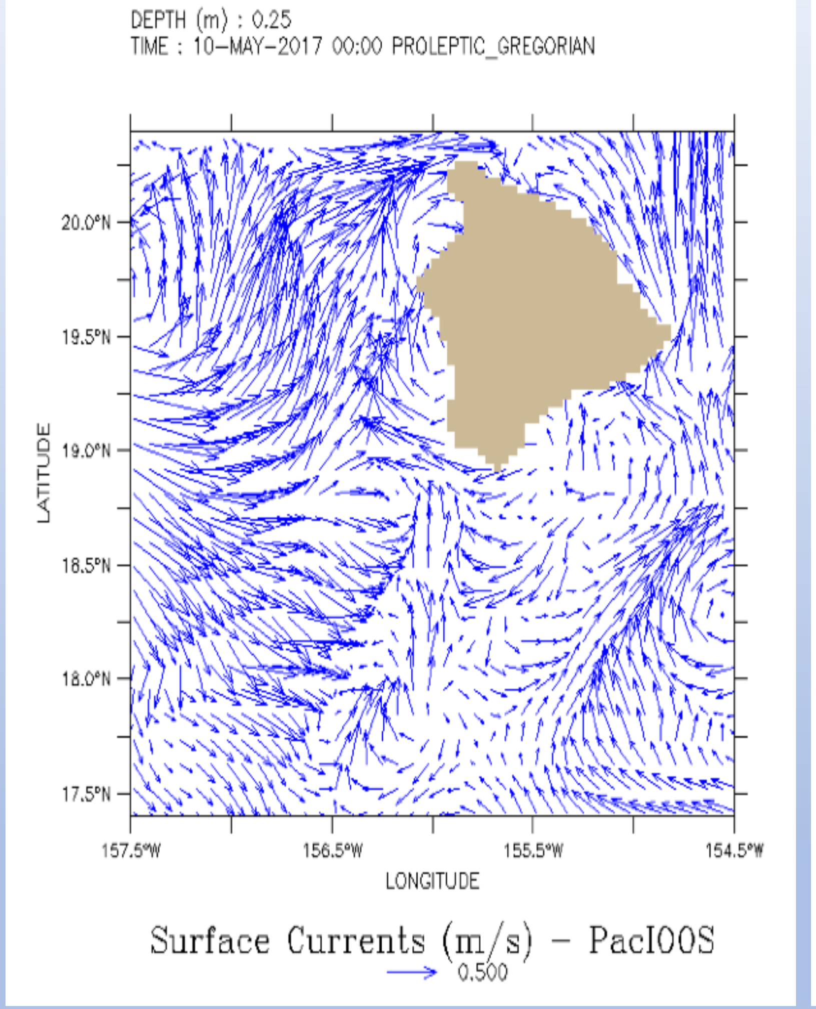
However,

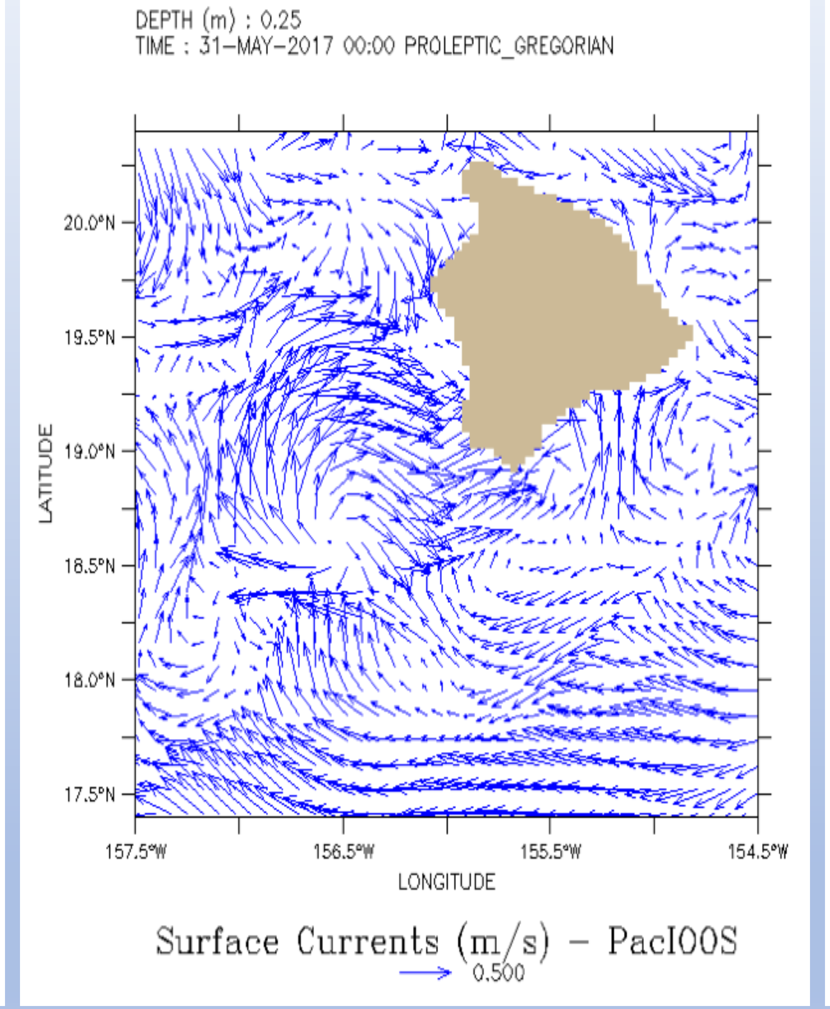
- Variability of the flow field is high from active generation and propagation of ocean eddies west of Hawai'i
- Ocean models produce estimates of ocean conditions
- Ages of Larvae are also estimates

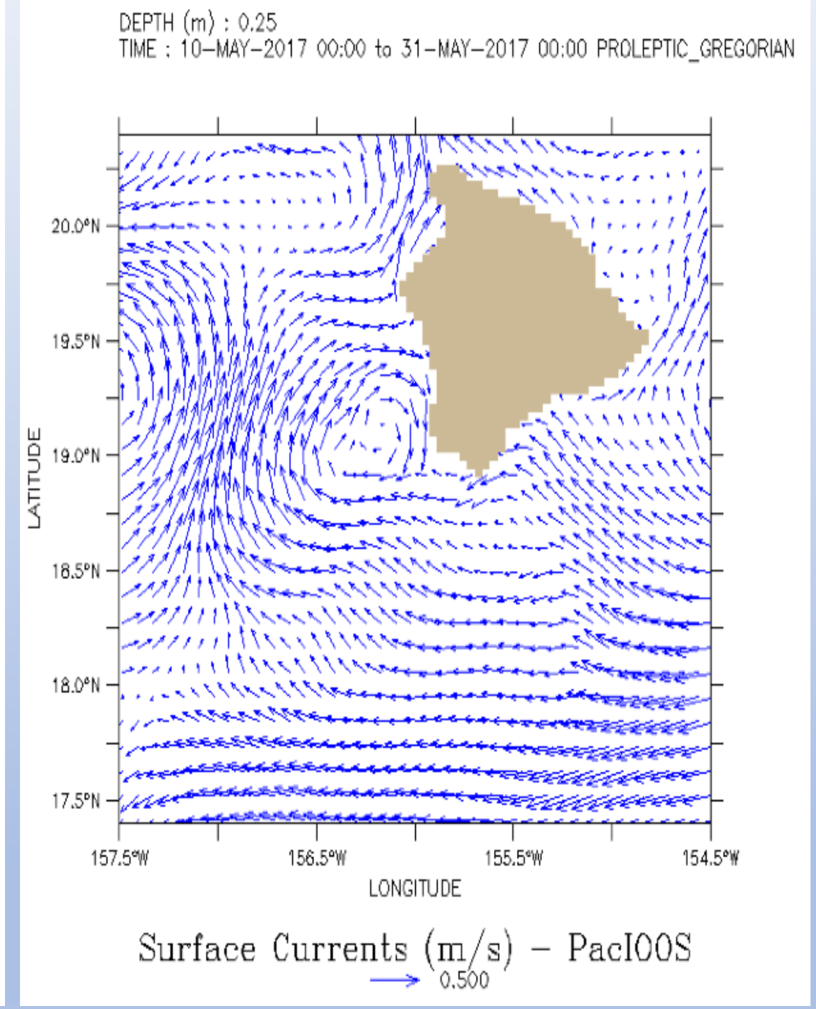
Therefore,

- Ensemble simulations are necessary to determine likely spawning regions

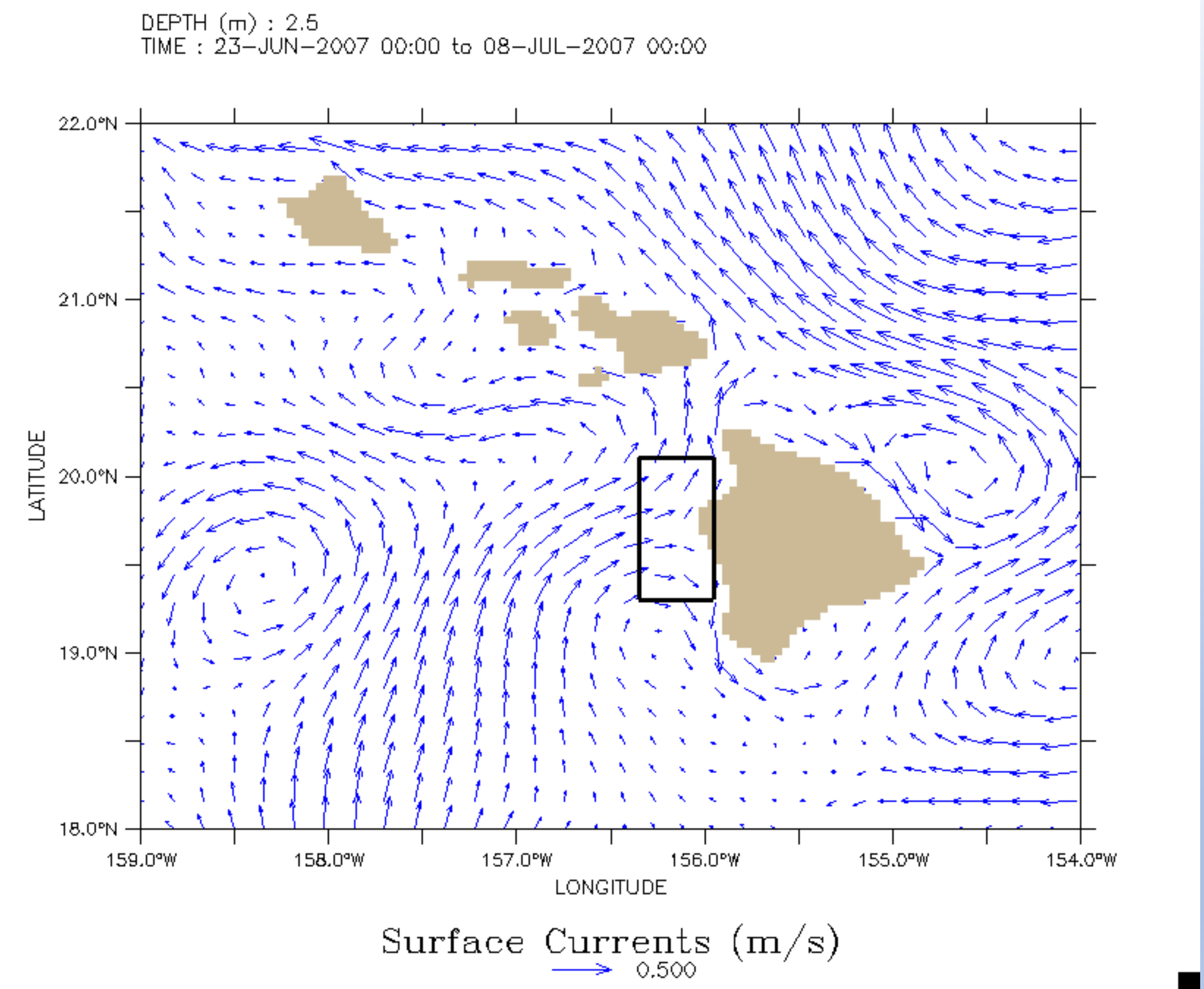
Examples of flow fields and variability in model inputs



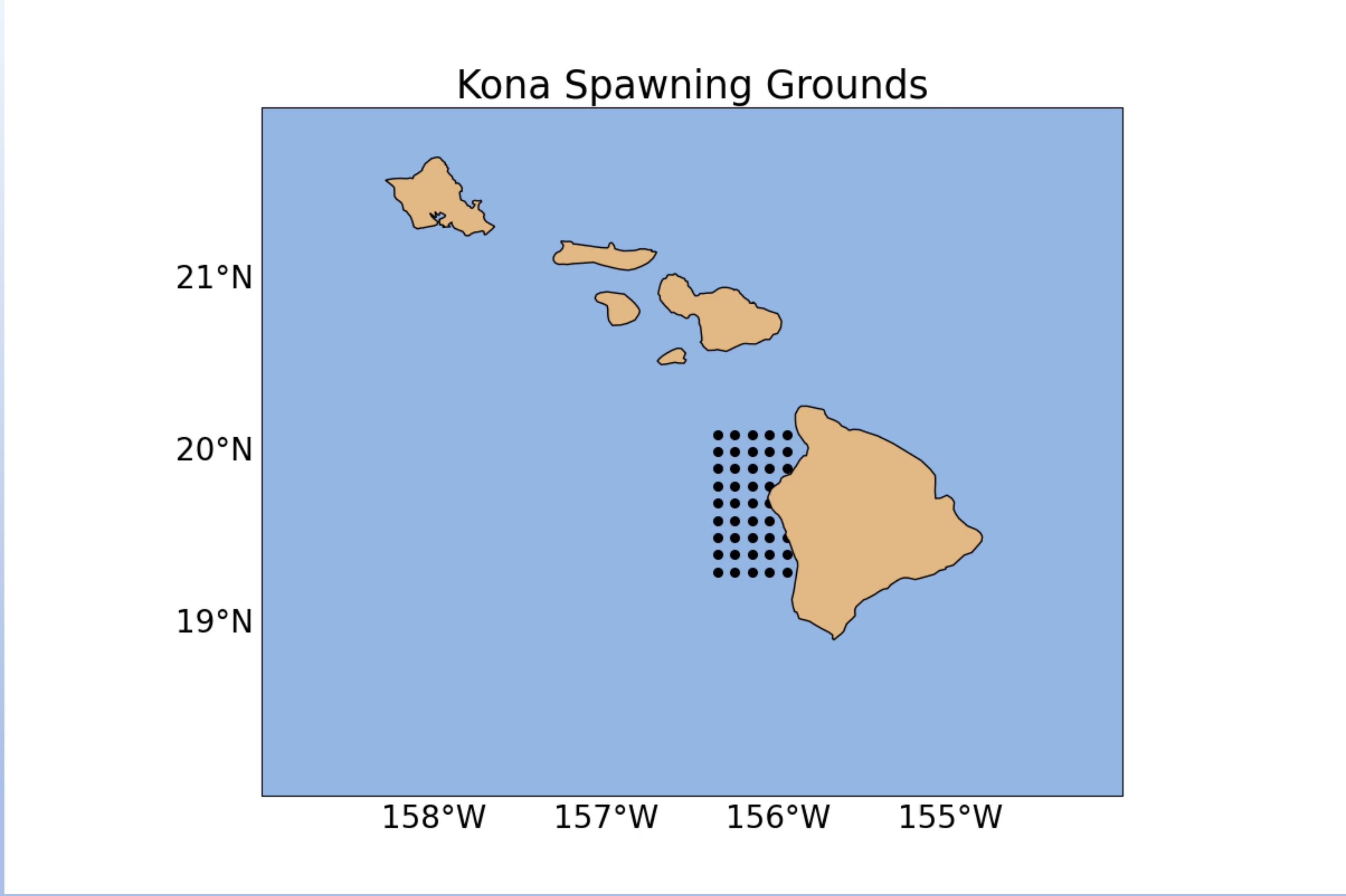




Surface currents for 15 day period



Tracking larval particles forward for 15 day period



Brief Summary of Phase 1 & 2 Findings

Phase 1

- Larval billfish species were not randomly or uniformly distributed but the data strongly suggest a clustered pattern (A parallel finding was also evident in the much larger Nishikawa et al. dataset but it was spatially aggregated at ~1.5°[or higher]).

- Clustering appeared to be associated with seamounts summits >1500 m or grouped by several deep seamounts.

- Project identified several putative spawning areas associated by seamount clusters and in protected areas. The role of deep seamounts with relevance to spawning habitat is not clear but may provide suitable conditions, at least on an ephemeral basis. Taylor columns and currents spinning up nutrients were thought to provide resources for shallow seamounts supporting commercial fisheries and planktonic/larval communities but not for deep seamounts.

- Critical habitat factors such as temperature and salinity appeared to be narrow for larval samples. Temperature has a profound effect on physiology, metabolism, stress, fitness, growth and survival and salinity is import for maintaining osmotic and ionic balance and buoyancy. These variables, along with chlorophyll-a, might be suitable parameters when assessing and/or predicting the quality and quantity of available spawning habitat which can be correlated later with recruitment in the adult population.

- The project developed the first age & growth model for Pacific billfish larvae.

Brief Summary of Phase 1 & 2 Findings

Phase 1

Phase 2

- As outlined, findings in the project have ramifications for identifying potential billfish spawning habitat and managing adult populations. By knowing where larvae spawn and are distributed, this will inform what prognostic factors shape the habitat so it can be preserved. What about near-shore runoff and pollution impacting habitat? Do these putative offshore spawning habitats provide the bulk of recruits?

- Findings in Phase 1 will be incorporated into Phase 2 which will examine potential spawning areas near Hawaii and prognostic factors shaping the spatial-temporal variability in habitat using ocean circulation models. The model can be used to locate possible spawning origins and also to estimate where larvae are propagated through time.

- As an example, do older larvae move to other habitats as they grow? Using information from the age & growth model in Phase 1, can it be determined when larvae switch from passive to active movements? How does variation in current vectors shape the temporal-spatial variability in important oceanographic parameters that influence habitat quality and suitability?

Next Steps

Next Steps

- Given the findings to date, the logical next steps in this research are myriad but can be adequately summarized using striped marlin in the Pacific as an example.

- Firstly, from the literature, it is clear that there are misidentifications of larval billfish samples to species level using morphological characters. The rate of this misidentification is unknown but it is probable striped marlin and blue marlin larvae are mixed-up (the same occurrence happens in adults). Therefore, initiatives should be undertaken to genetically ID preserved samples held in various institutions. This will allow morphological series to be constructed through ontogeny to improve field keys.

- Next, from the presence of larvae, it is clear striped marlin spawn in at least 2 different regions in the Pacific: near Baja and Kona, Hawaii. How much does each region contribute to the fished stock?

- Conventional and satellite tagging indicate movements of adult striped marlin from Baja to New Zealand and from Baja into the Hawaii-based commercial longline fishery. Striped marlin tagged in Hawaii have also been shown to transit to Australia.

Next Steps

Next Steps

- **Reproductive studies in Hawaii indicated that some individuals collected by the Hawaii-based longline fishery were "out of phase" with cohorts. Tagging indicates fish tagged near Baja enter this fishery. Age and growth studies indicated differences in parameters from eastern and central Pacific samples. Is this evidence of a mixed stock fishery?**

- **Genetic studies on striped marlin in the Pacific suggested a complex mixture of populations in Kona, Hawaii that may comprise perhaps two distinct populations. In blue marlin sampled in Kona, a deficiency of heterozygotes at several enzymatic loci led Shaklee et al. to hypothesize the existence of a Wahlund effect or the possible admixture of separate populations. Additional genetic studies and/or otolith fingerprinting may be necessary to figure out boundaries/contributions of the mixed stock. Recent volcanic activity near Hawaii may provide a strong signal in fingerprints. An ISC(2022) stock assessment of striped marlin indicated a decline in age-0 recruits. If spawning habitat is degraded, less fish will enter the fishery. The words "Habitat", "larvae" or "larval" were not found in the assessment.**

- **Studies in Kona indicated that of seven striped marlin larvae collected, all had different mothers. If maintaining genetic diversity requires large numbers of female breeders, how important are older mothers to the contribution of fitness, effective population sizes and reproductive success? Parental biomass may need protection and catch and release in longline and recreational fisheries has been demonstrated an effective management strategy. Recent studies suggest effective population sizes might be large in striped marlin.**

Next Steps

Next Steps

- Either by expanding Phase 2 or in collaboration, investigate what endogenous or exogenous factors are responsible for variation in larval abundance patterns where they are found regularly. From this exercise, it may be possible to outline and describe the quality of and quantity of suitable habitat over temporal-spatial scales.
- In select areas, larval and egg traps could be deployed as a recent study in Florida suggested to gain information on patterns in abundance.
- A repository of larval records on billfish could be designed and maintained where new records could be added (much like IMOS initiative in Australia). It can be as simple as a spreadsheet.
- It is possible examination of gill parasites could shed insights on identifying mixed stocks.
- Given that sex determination in pelagic eggs is influenced by temperature, how will climate change effect sex ratios and what does this portend for the population?

Deliverables

Deliverables

- Phase 1 will complete the final report in April and will submit a draft for publication in the peer-reviewed literature. Publication will take ~2-3 months after submission. The final database will be submitted at the time of publication.
- Phase 2 has plans to complete the initial study simulations and report in ~July/August