MODELING TEMPORAL VARIATION IN KRILL SWARMS: SIZE, INTENSITY, PERSISTENCE AND COHERENCE WITH KRILL PREDATORS

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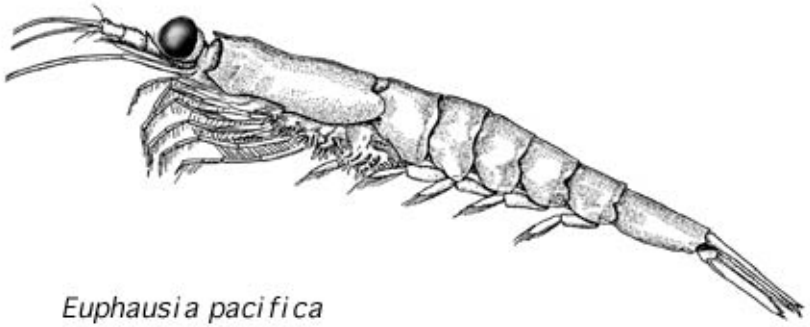
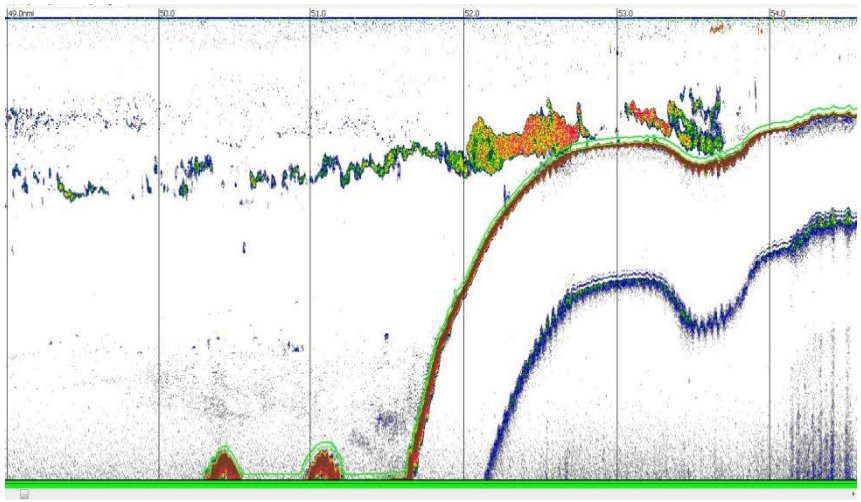
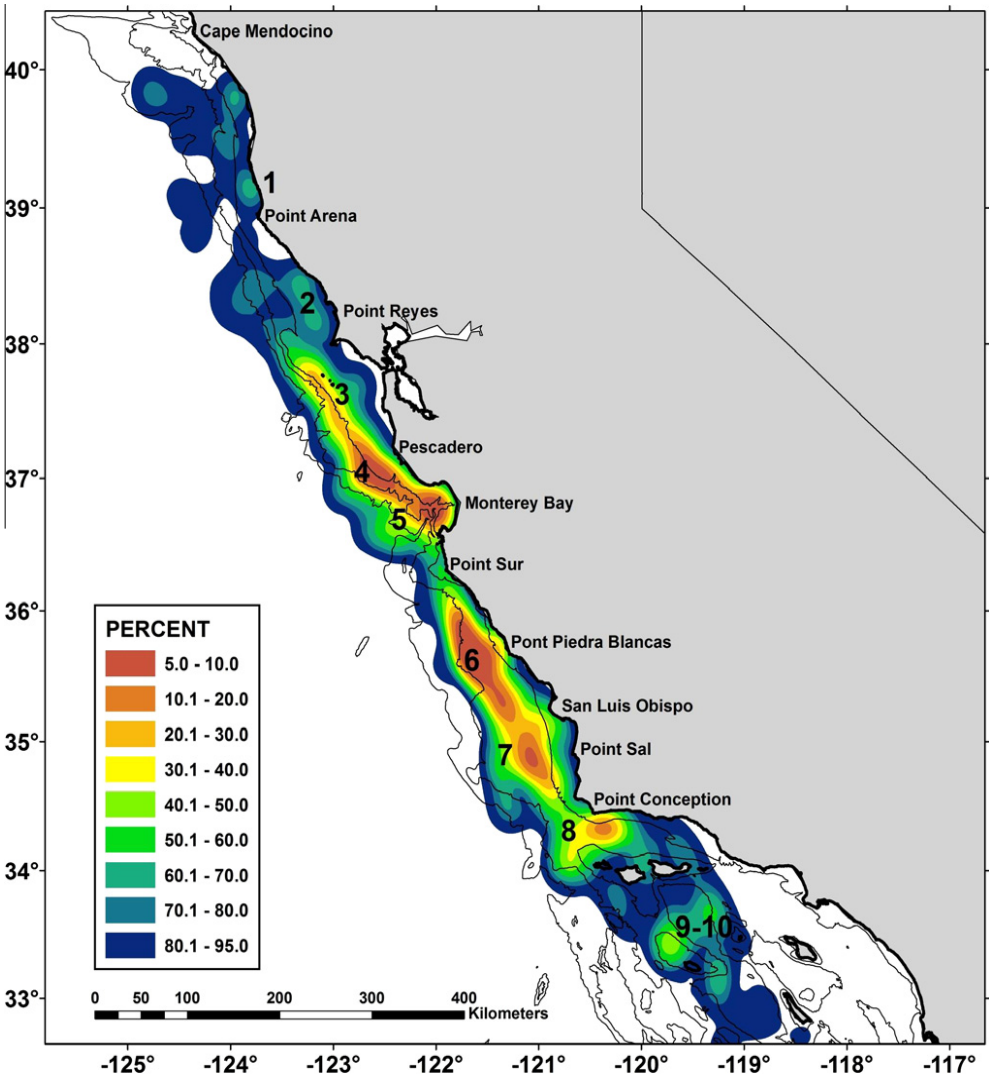
Spatial Climatology: Krill “Hotspots” off California, May-June, 2004-2009

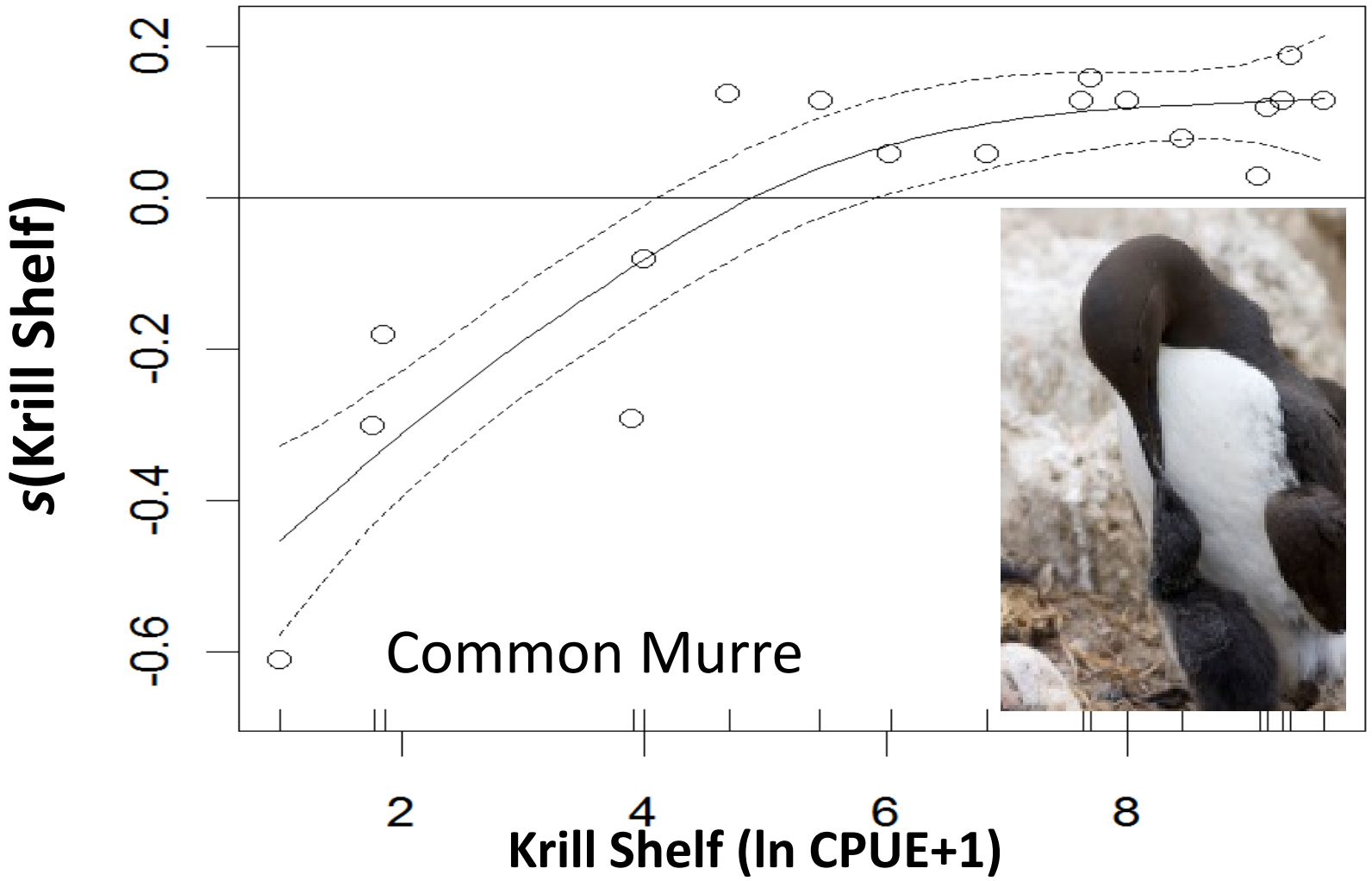






Santora et al. 2011, Progress in Oceanography

Seabird Productivity and Krill Abundance



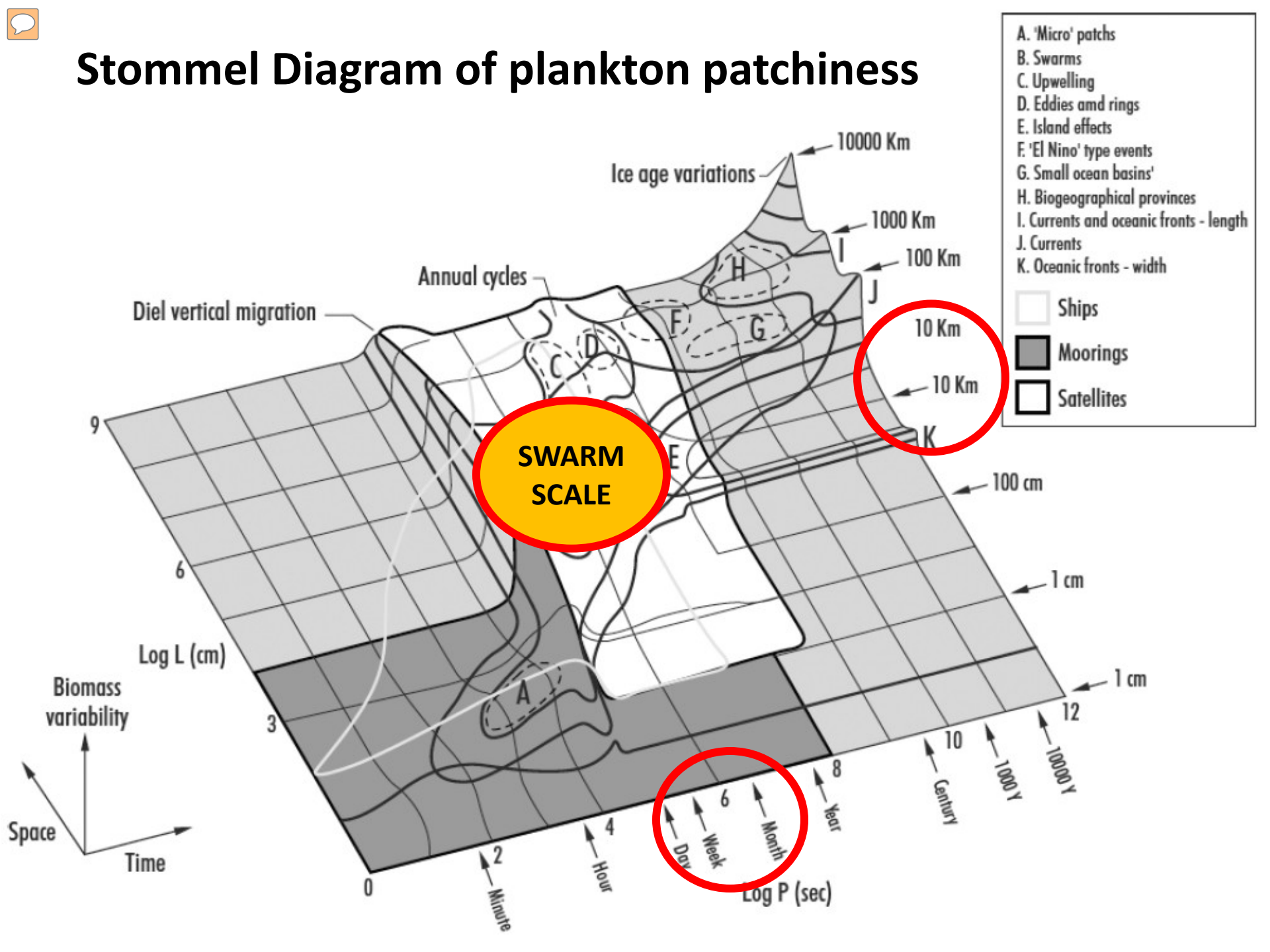
Santora et al. 2014 Ecological Applications

Blue Whales and Krill Swarms in California


FREEZE DRIED
Krill
Color Enhancer
SALLY'S
FOR ALL
FRESH & SALT
CARNIVORES
NET WT 2 OZ (56g)


IM GOIN IN FOR THE KRILL
IM DOIN IT FOR THE THRILL

Stommel Diagram of plankton patchiness



Questions

- **Can we model the krill prey field important to foraging predators?**
  - **Yes (Dorman et al. 2011, Dorman et al. in press PiO) - coupled ROMS-NPZ-IBM reproduces krill spatial climatology (Santora et al. 2013 GRL, Dorman et al. in review MEPS)**

- **Can we model the krill prey field at the "swarm" scale, and if so what are the emergent spatial and temporal statistics of modeled krill swarms?**

- **How do the space/time scales of krill swarms compare to the foraging scales of predator aggregations?**

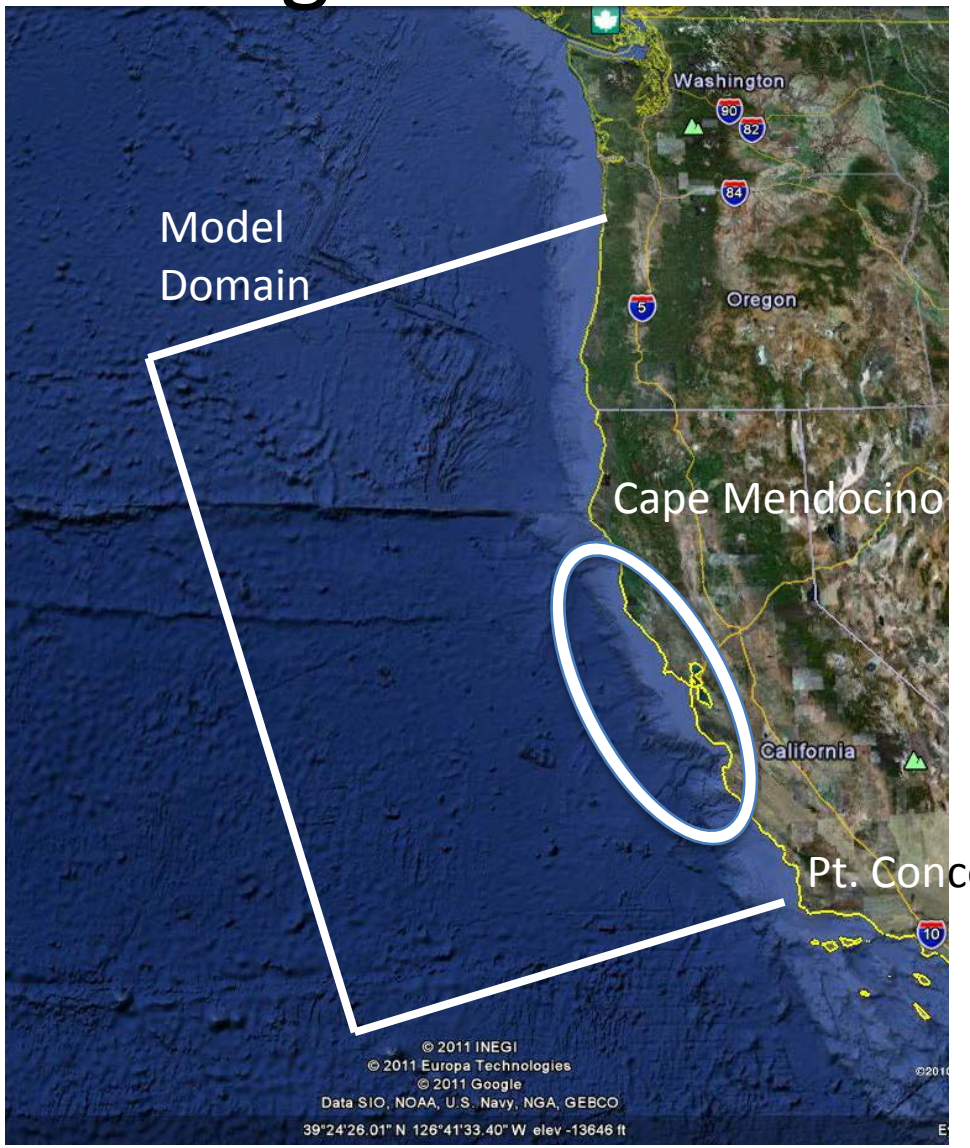
Definitions

- **<u>Swarms:</u> forage/prey patches that have potential for elevated trophic transfer, i.e., use by multiple predator species**
- **<u>Characteristics important to predators:</u>**
  - ***Size*** **(km2; space)**
  - ***Persistence*** **(days; time)**
  - ***Intensity*** **(clustering index, z-score; interaction between space and time)**
    - **as it turns out, these are all positively related…**

Roadmap for Talk

- Introduction to
  - Individual-Based Model (Physical and Biological)
- Results
  - 1: latitude of modeled krill swarm formation and dissolution
  - 2: size, persistence, and intensity statistics
  - 3: intersection with UTL foraging scale; variation between central-place foraging and migratory birds.

Physical Oceanographic Modeling
Regional Ocean Modeling System



(ROMS)

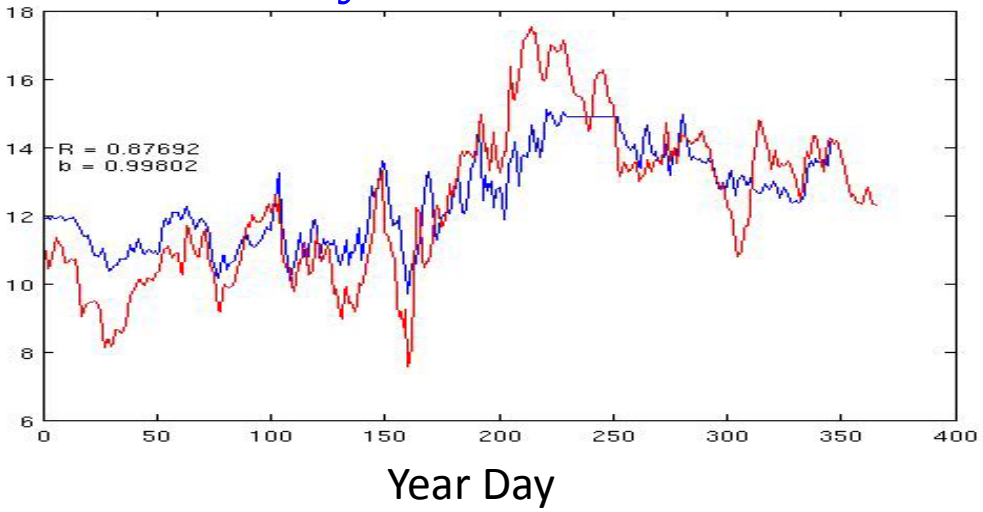
- Years Modeled 2000 – 2008
- NCEP-NARR Forcing (32 km)
  3-hourly
- SODA Boundary Conditions
  Monthly
- 3-6 km grid resolution

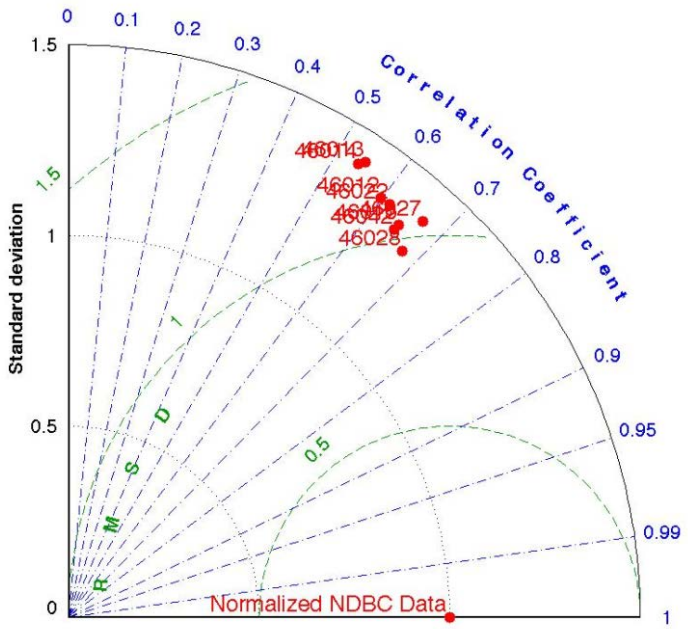
Bathymetry of ROMS Domain

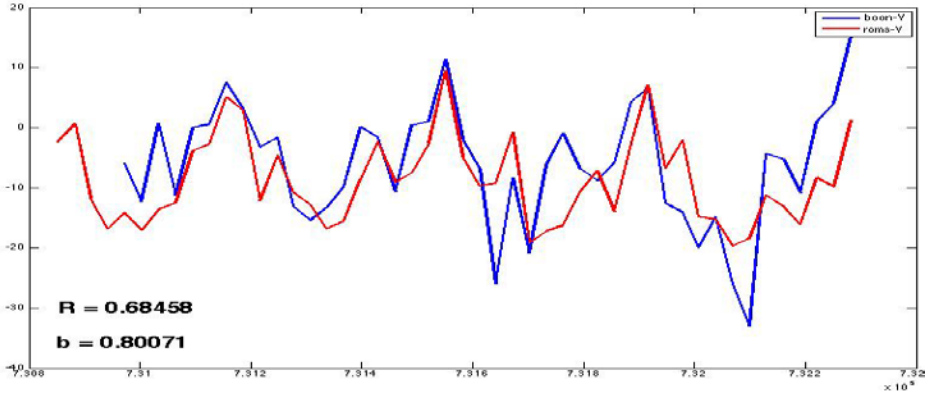
ROMS Results vs. Observation Data

Sea Surface Temperature (1-day)

NDBC Buoy 46012 vs. ROMS SST







Surface Currents (1 mo. avg.)

BOON CODAR vs. ROMS

Individual Based Model

- Particle Tracking with Saved ROMS Data (Runge-Kutta Advection - 4th order)
- No Biology, Other than Diel-Vertical Migration
- Downward Vertical Migration of organisms based on light-levels
- Vertical Migration varied (5, 20 meters (chl max), 40m) --- for this talk used 20m as this matched acoustically-derived data best (Dorman et al. in revision MEPS)

Spring Model Runs

Start Date – Feb 15

40,000 Particles

Uniform Distribution

"Where are swarms formed?"

Summer Model Runs

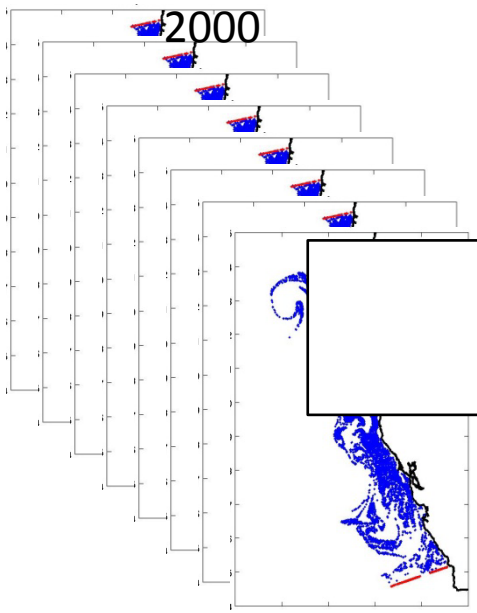
Start Date – May 15

40,000 Particles

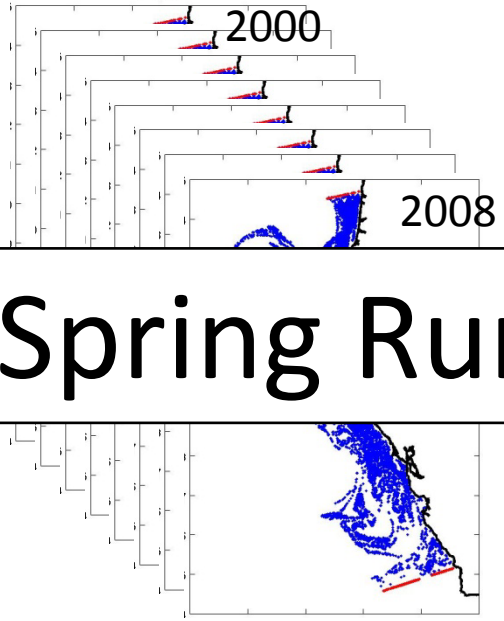
Uniform Distribution

"Where do these swarms go?"

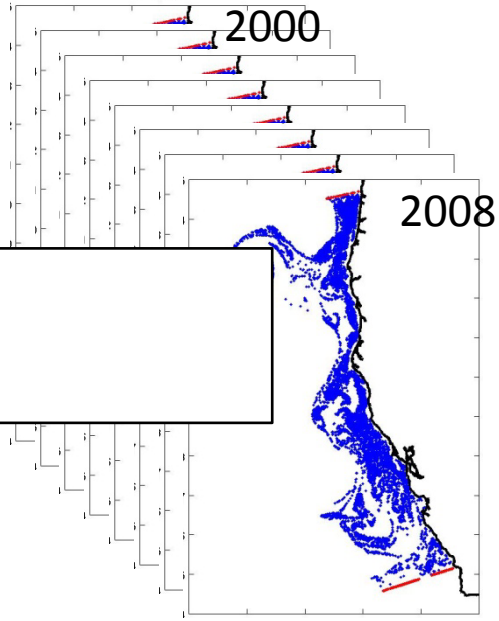
Feb 15 Start – DVM = 5



Feb 15 Start – DVM = 20

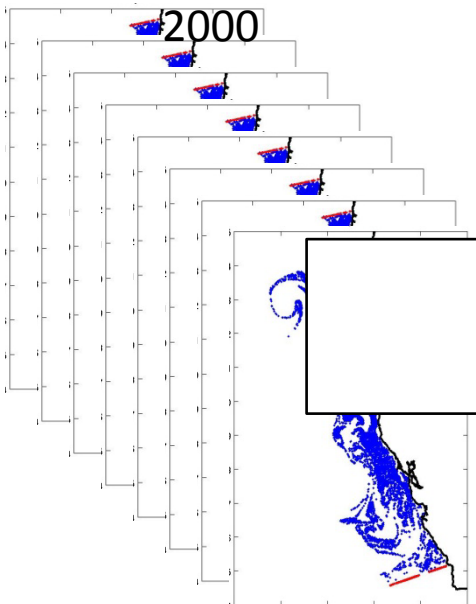


Feb 15 Start – DVM = 40

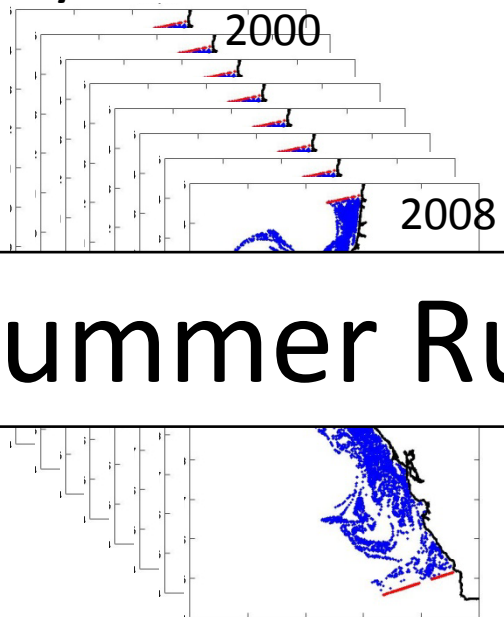


Spring Runs

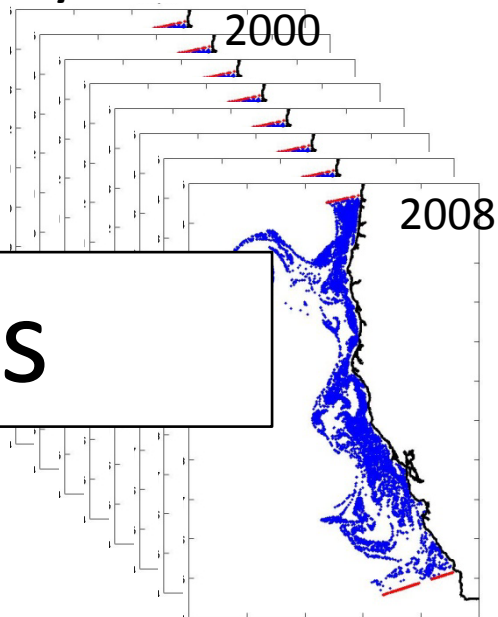
May 15 Start – DVM = 5



May 15 Start – DVM = 20



May 15 Start – DVM = 40

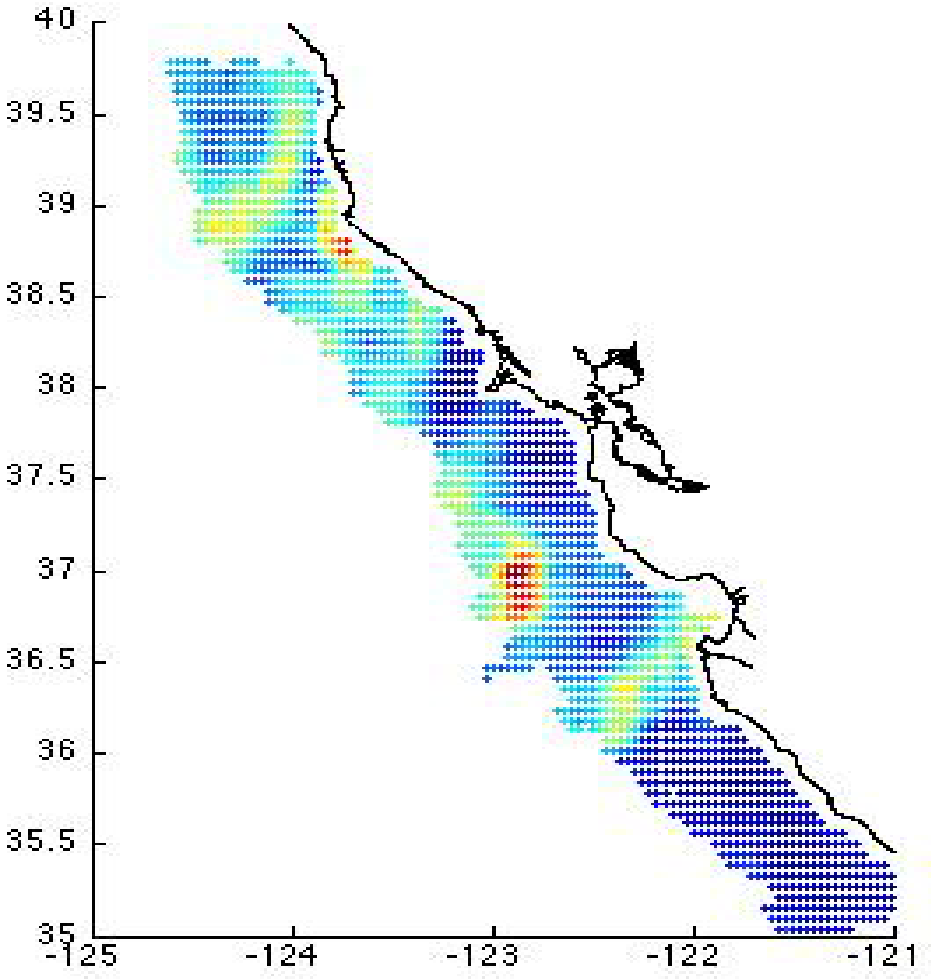


Summer Runs

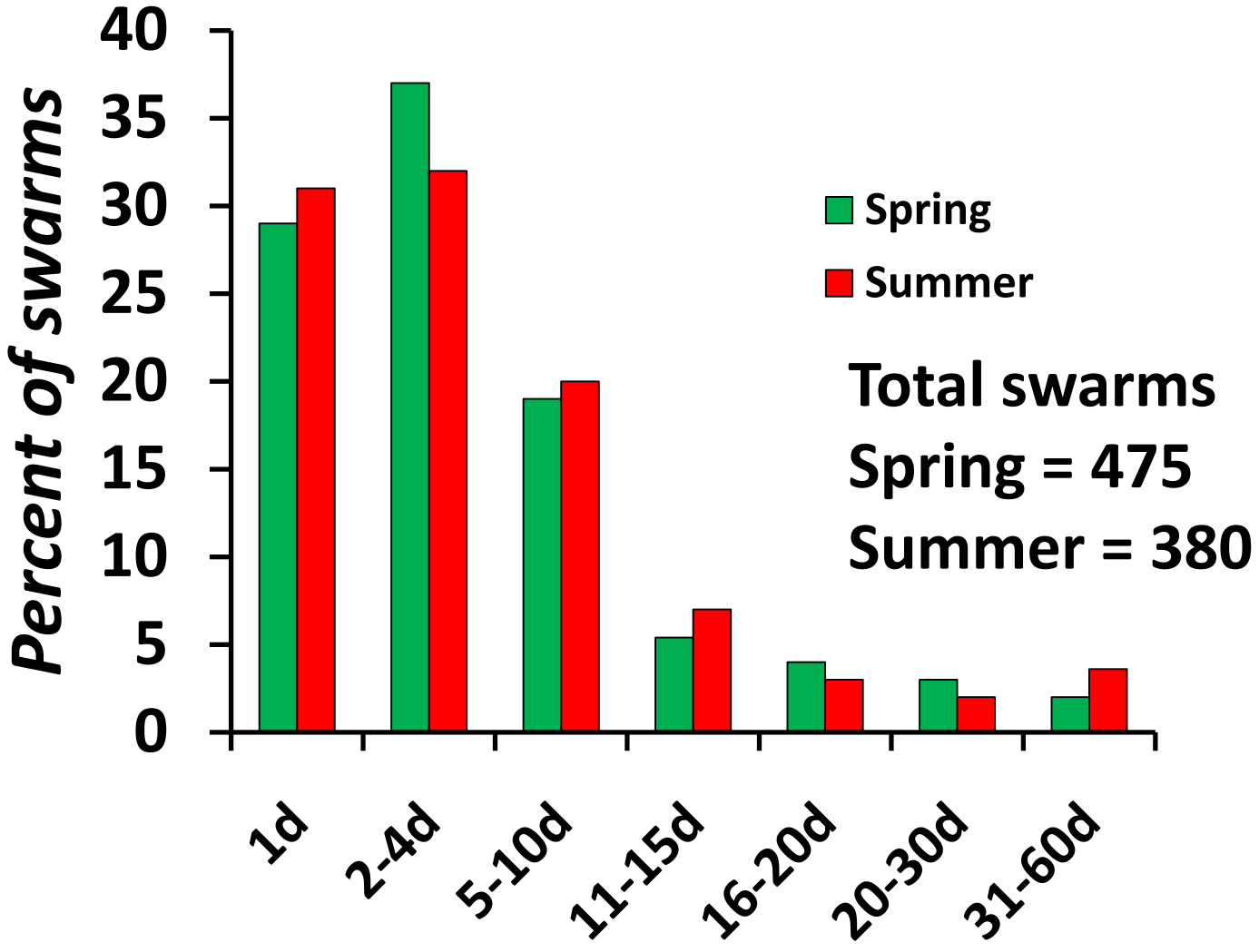
m20_02152000_getisord_5Xby7Y_peaks.avi

Analysis – Identified Swarms Using Getis-Ord Statistic

- **Spatial Statistic (z-score) that highlights clusters of high local values in relation to overall values for the entire area.**

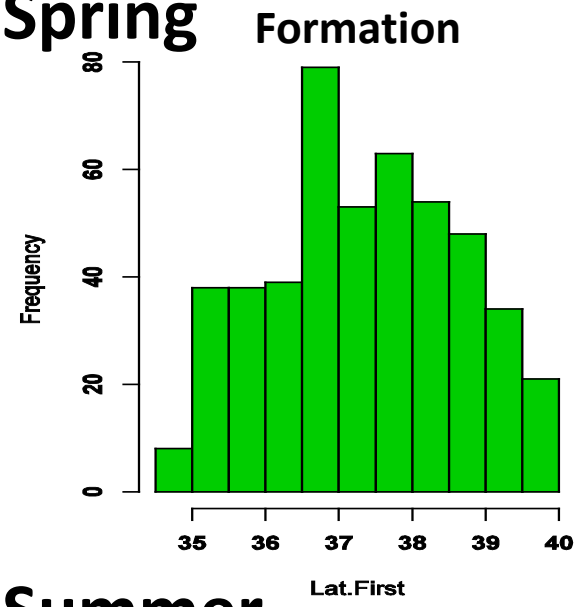


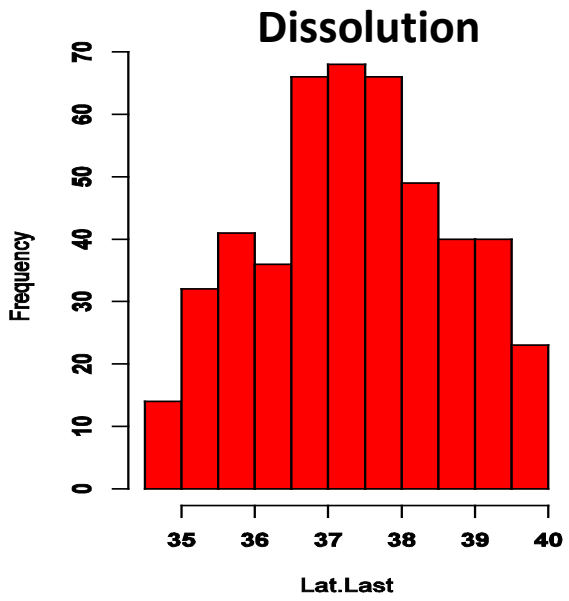
Frequency of Swarm Persistence

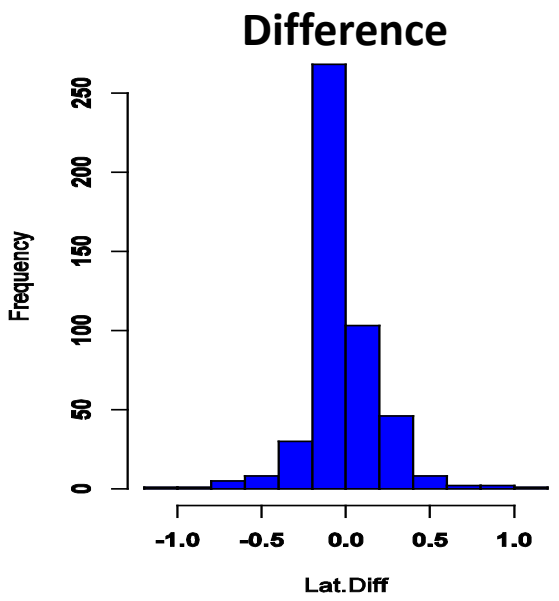


Swarm formation and dissolution by season & latitude (> 2 days only)

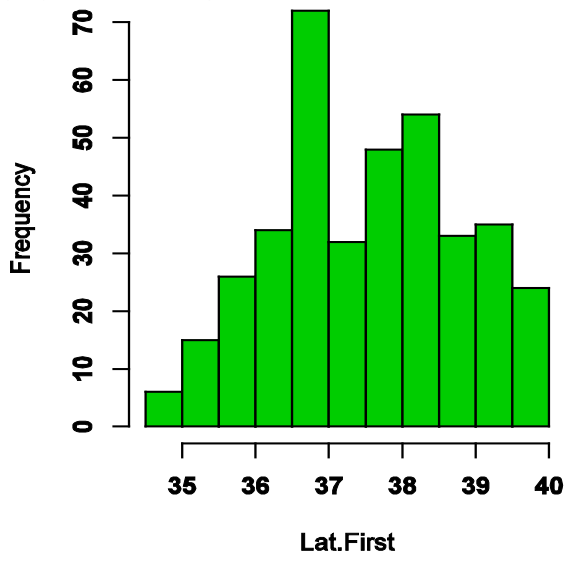
Spring

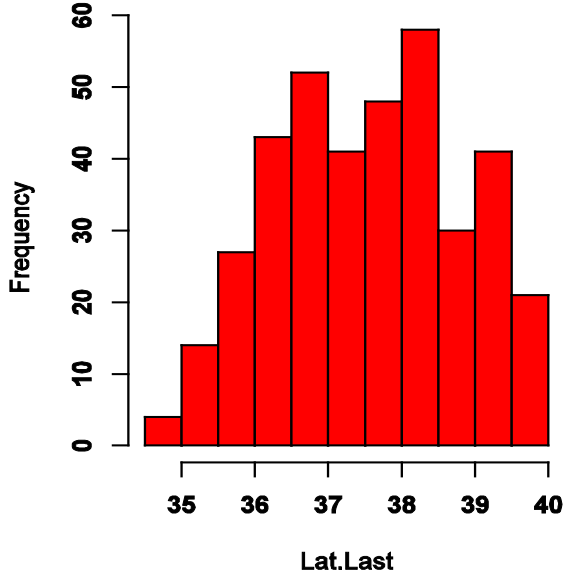


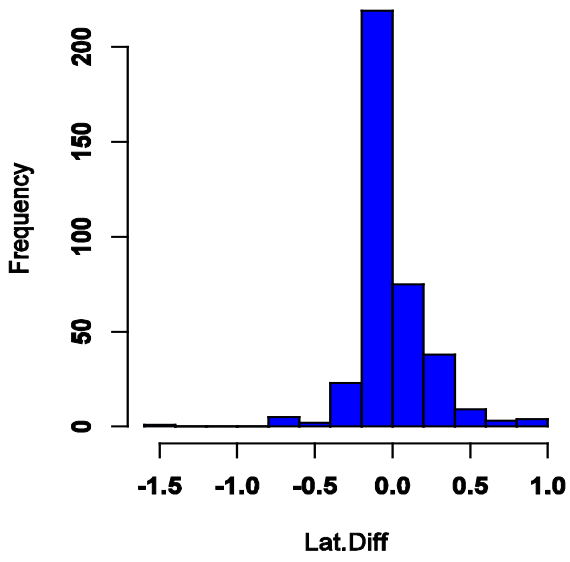




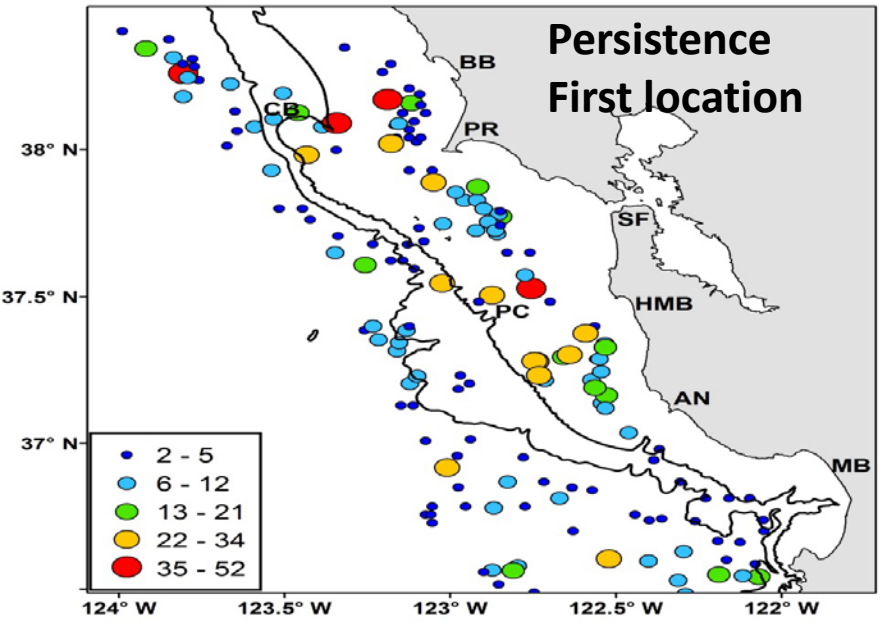
Summer



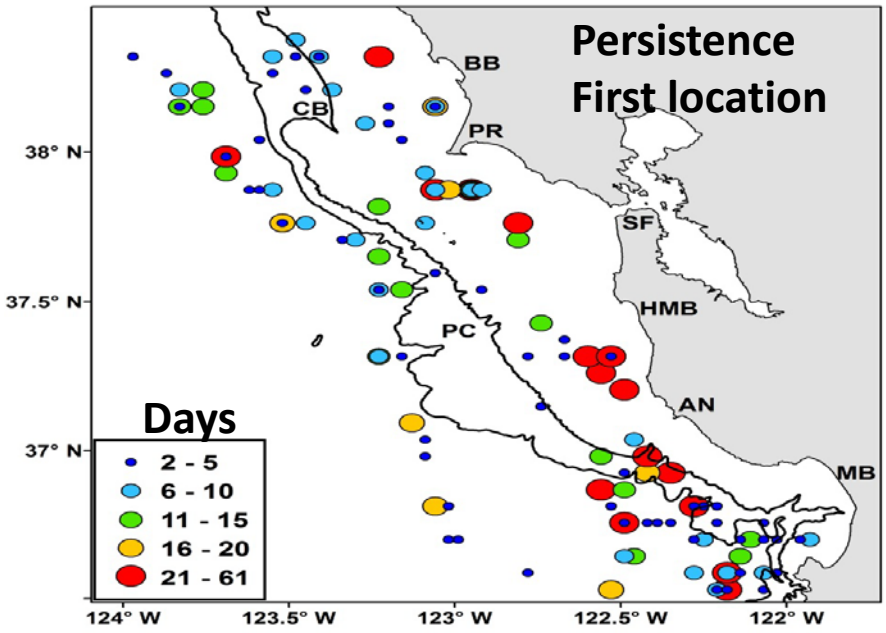


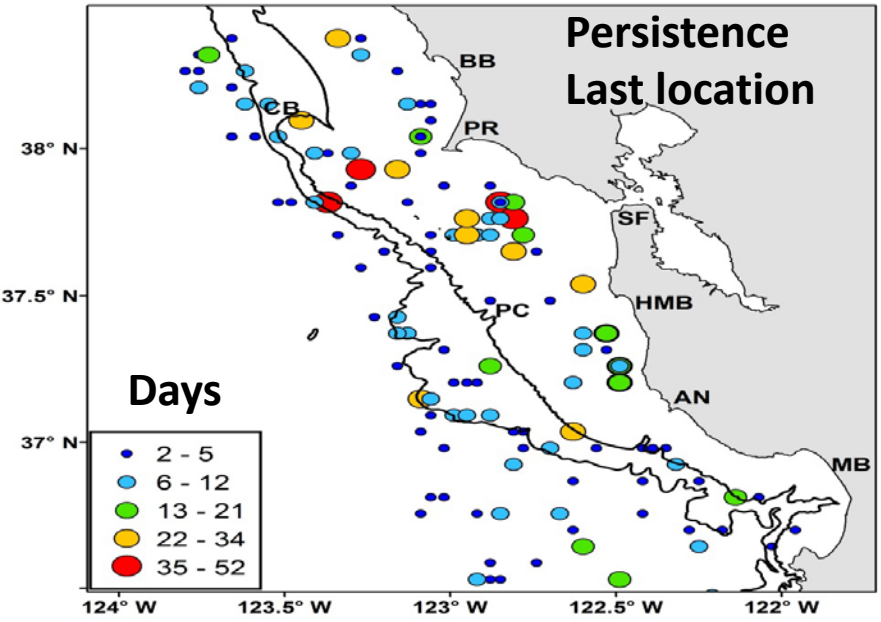


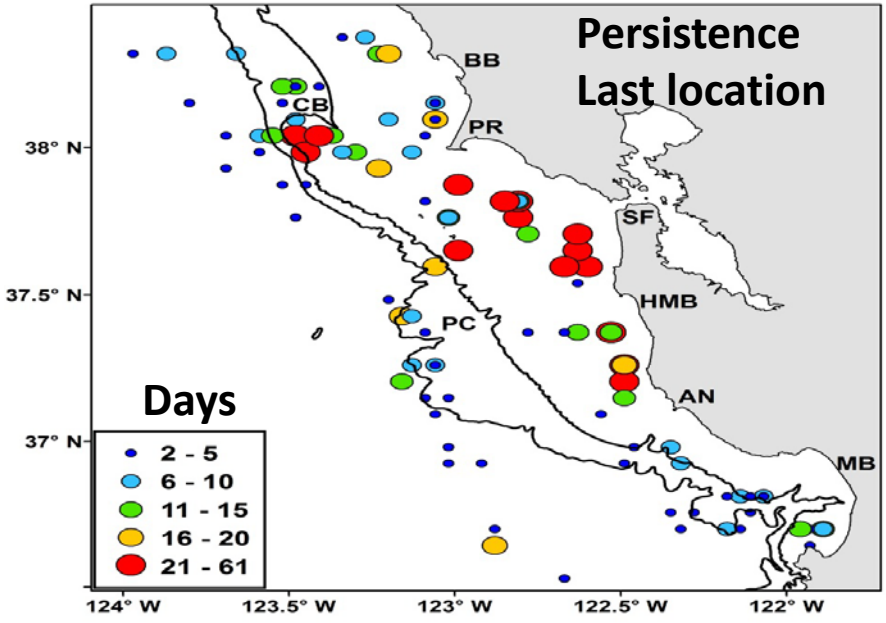
Spring

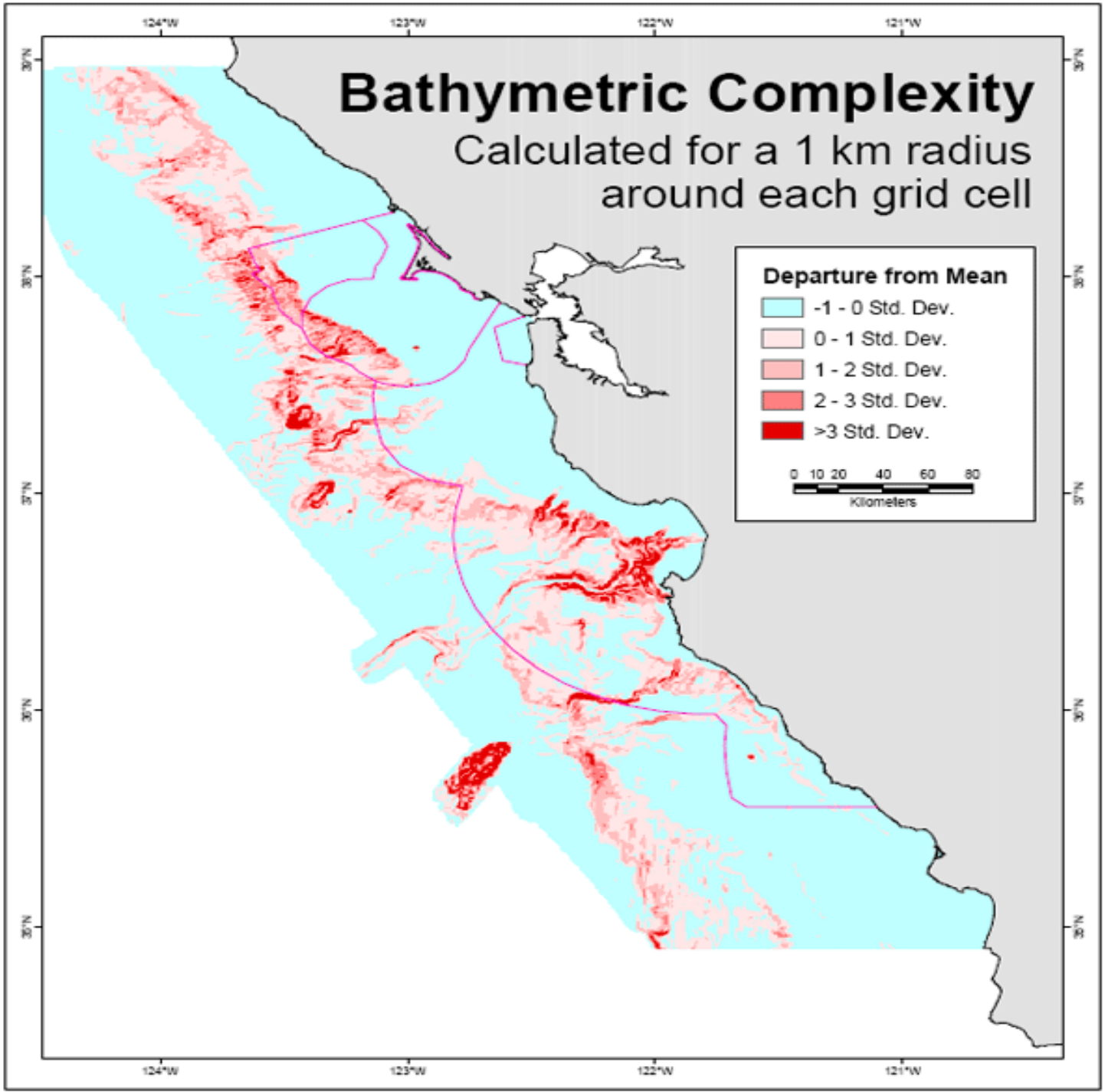


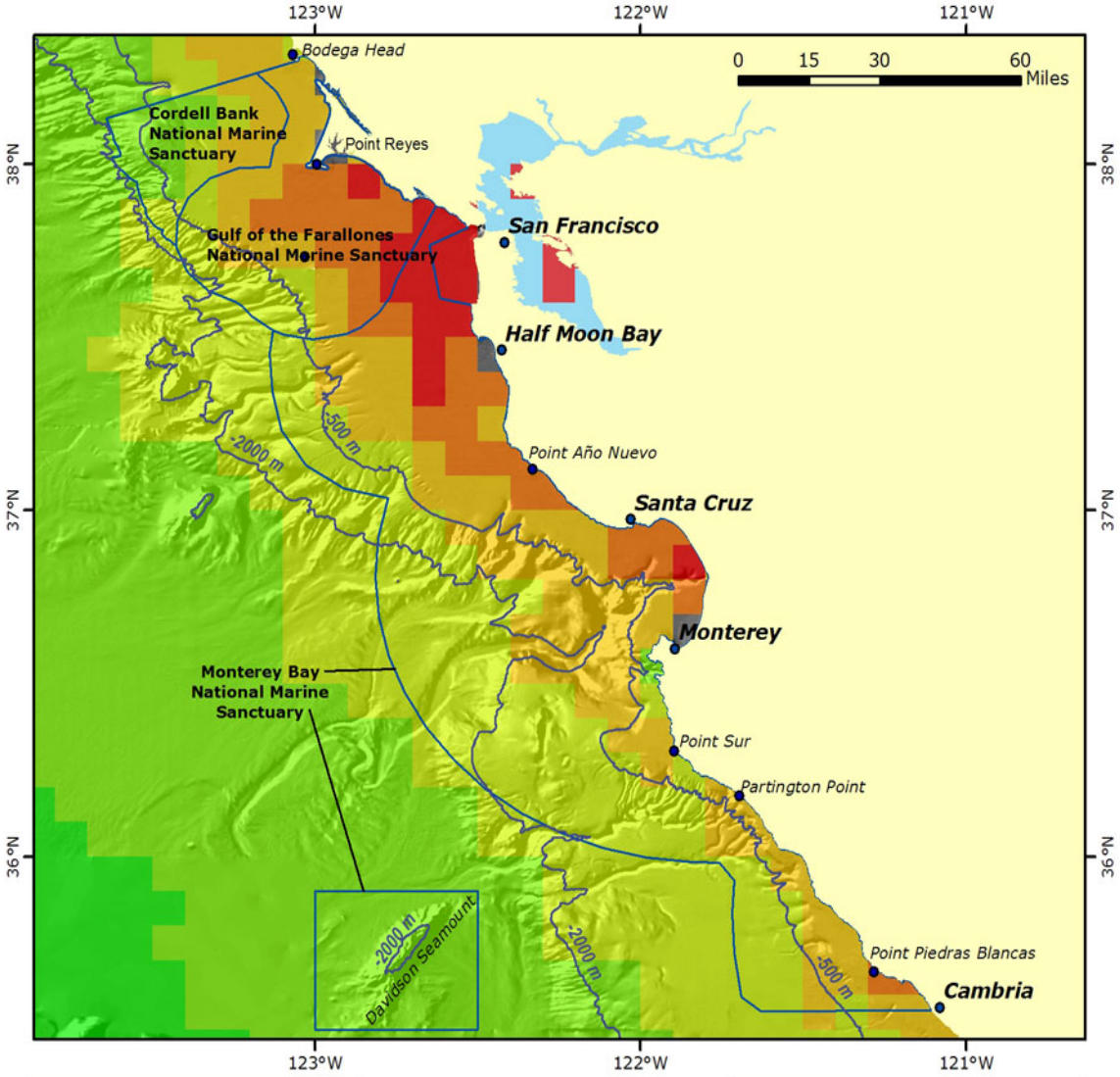
Summer








Bathymetric Complexity
Calculated for a 1 km radius
around each grid cell
Departure from Mean
-1 - 0 Std. Dev.
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
>3 Std. Dev.
0 10 20 40 60 80
Kilometers
124°W
123°W
122°W
121°W
38°N
37°N
36°N
35°N



Legend

Primary Productivity Annual Mean (mg C m-2 d-1)

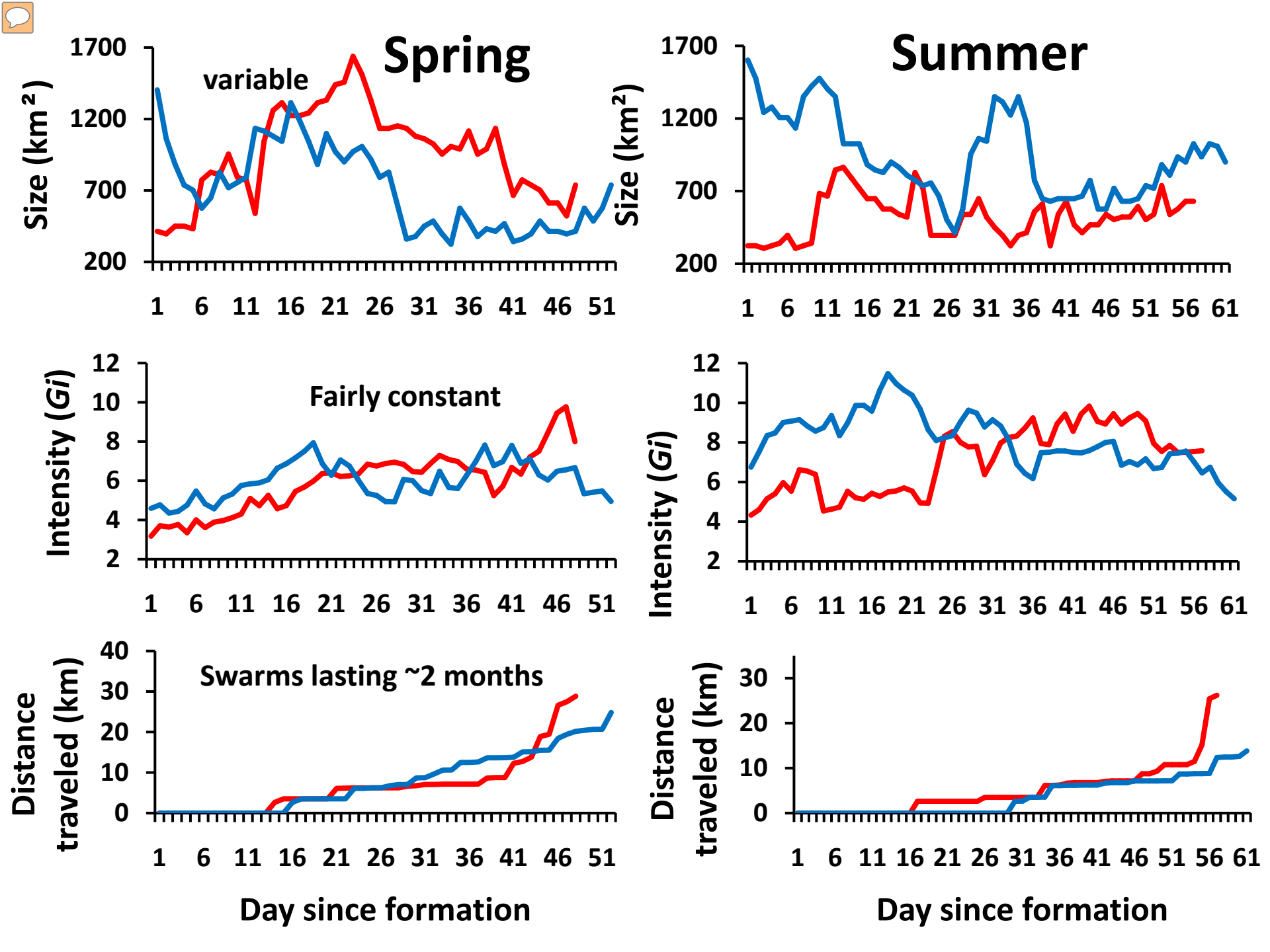
- < 1,000
- 1,001 - 1,500
- 1,501 - 2,000
- 2,001 - 2,500
- 2,501 - 3,000
- > 3,000

Sanctuary Integrated Monitoring Network

Thanks to ocean-observing satellites, we can develop better estimates of primary production. Primary production is the organic material produced through photosynthesis by phytoplankton which are microscopic plants serving as the foundation of the oceanic food web.

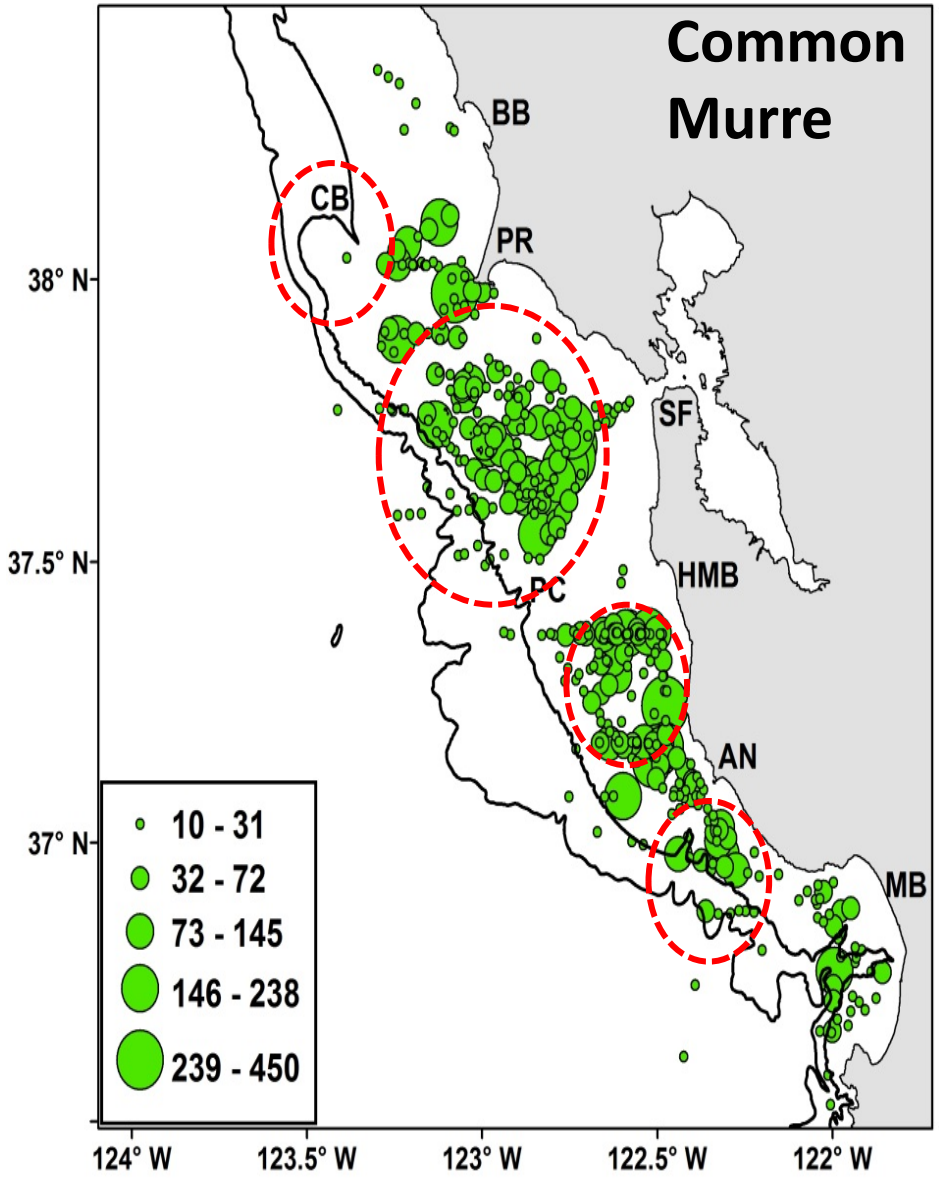
Example of the 2 most persistent swarms observed during spring and summer (top 2% of all modeled swarms)

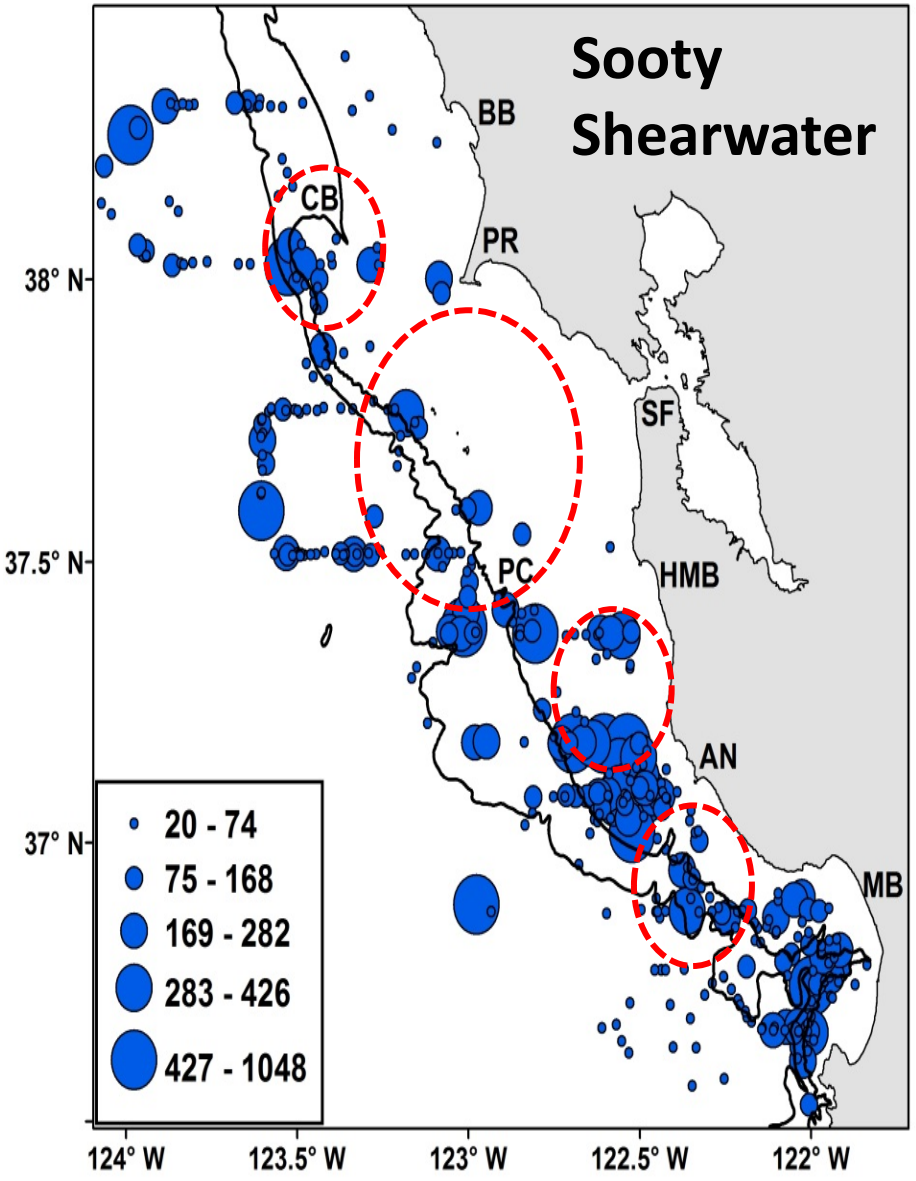
Changes in their Size, Intensity and distance traveled over time.


Spring
Summer
variable
Size (km²)
1700
1200
700
200
1 6 11 16 21 26 31 36 41 46 51
1 6 11 16 21 26 31 36 41 46 51 56 61
Fairly constant
Intensity (Gi)
12
10
8
6
4
2
Swarms lasting ~2 months
Distance traveled (km)
40
30
20
10
0
Day since formation

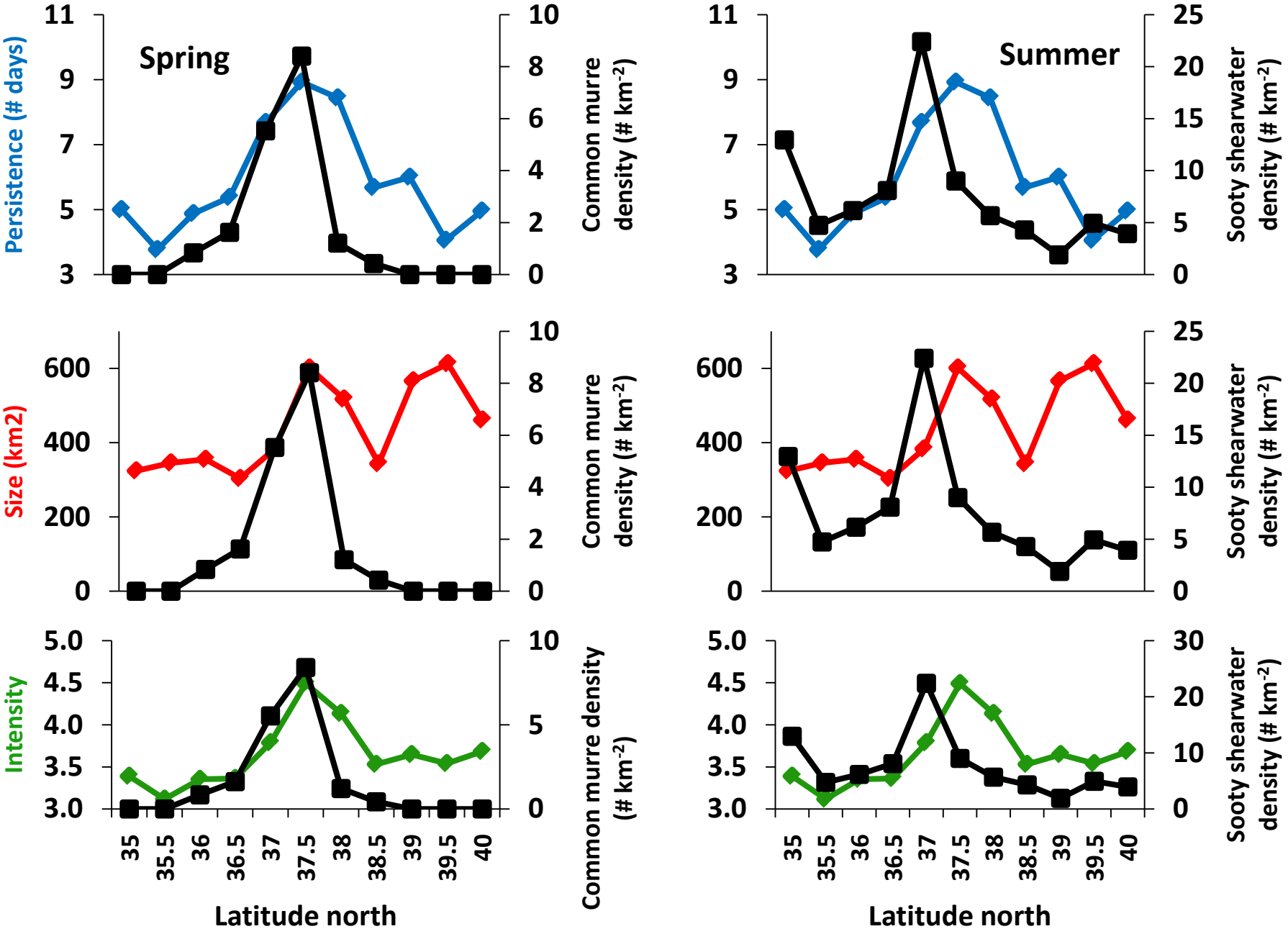
Predator aggregations

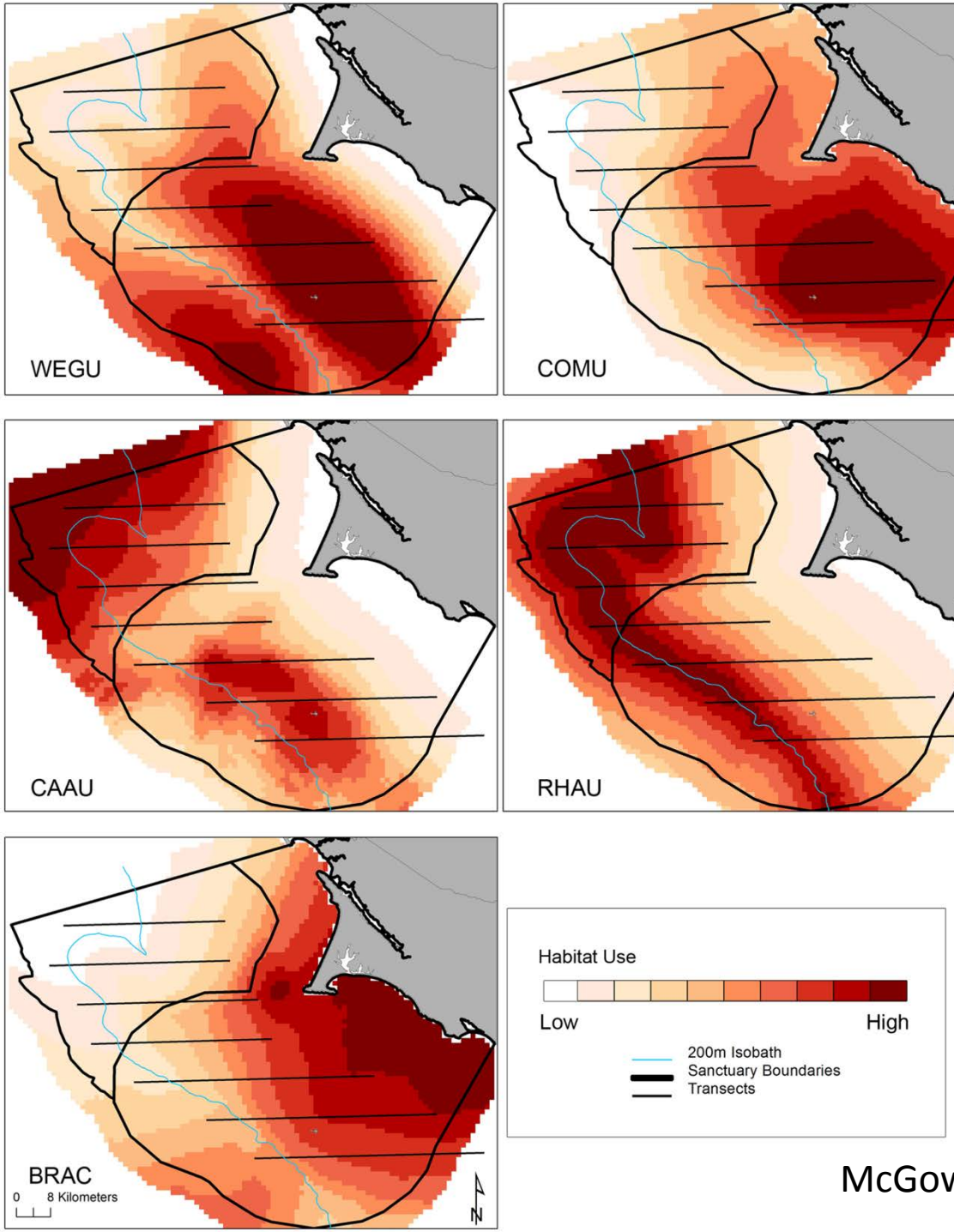
Visual surveys of seabird abundance/distribution
Summer (May-June): Aggregation size (# per 3km)





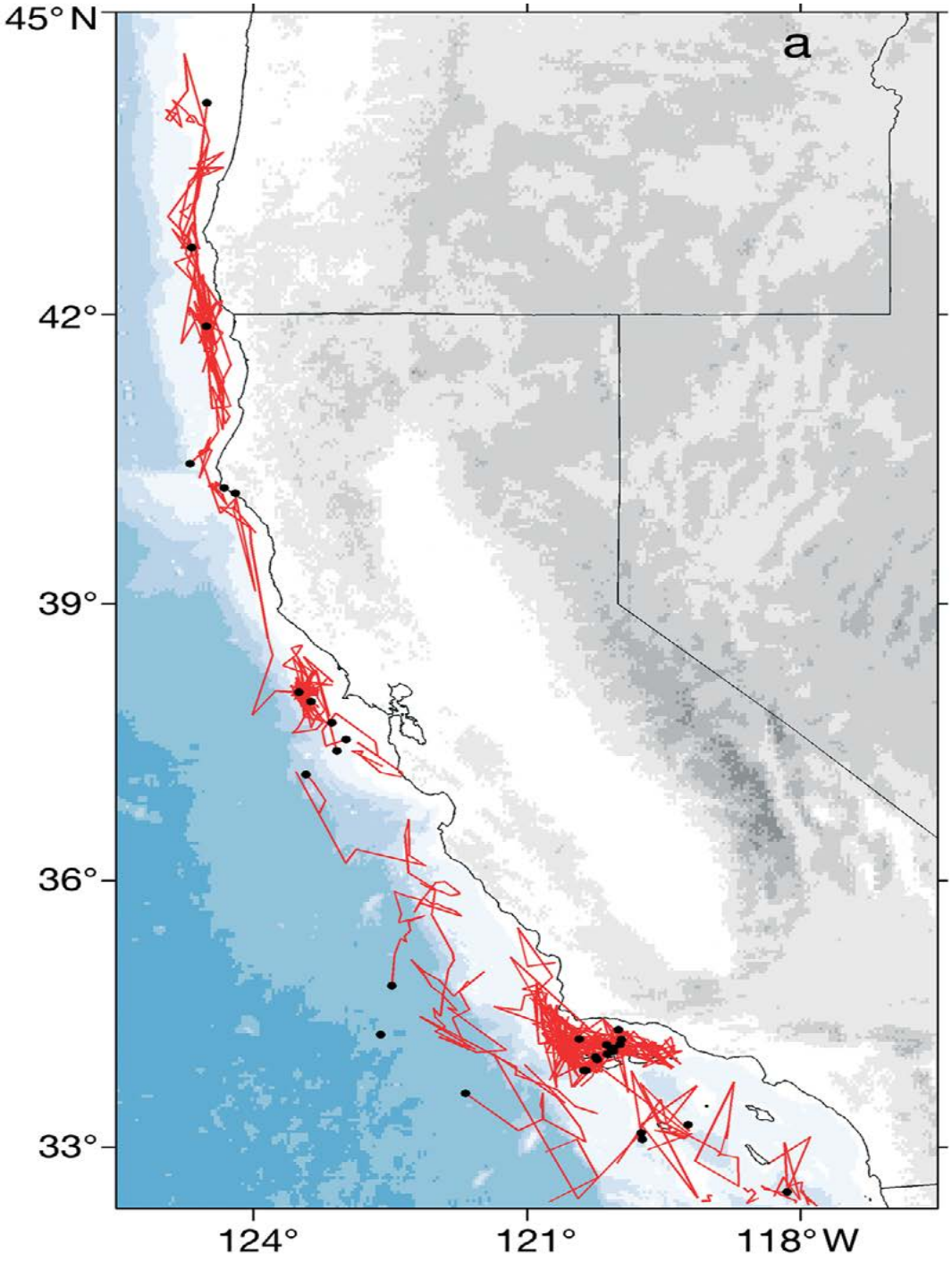
Coherence of Scale in Bird (black) - Swarm (color) Statistics





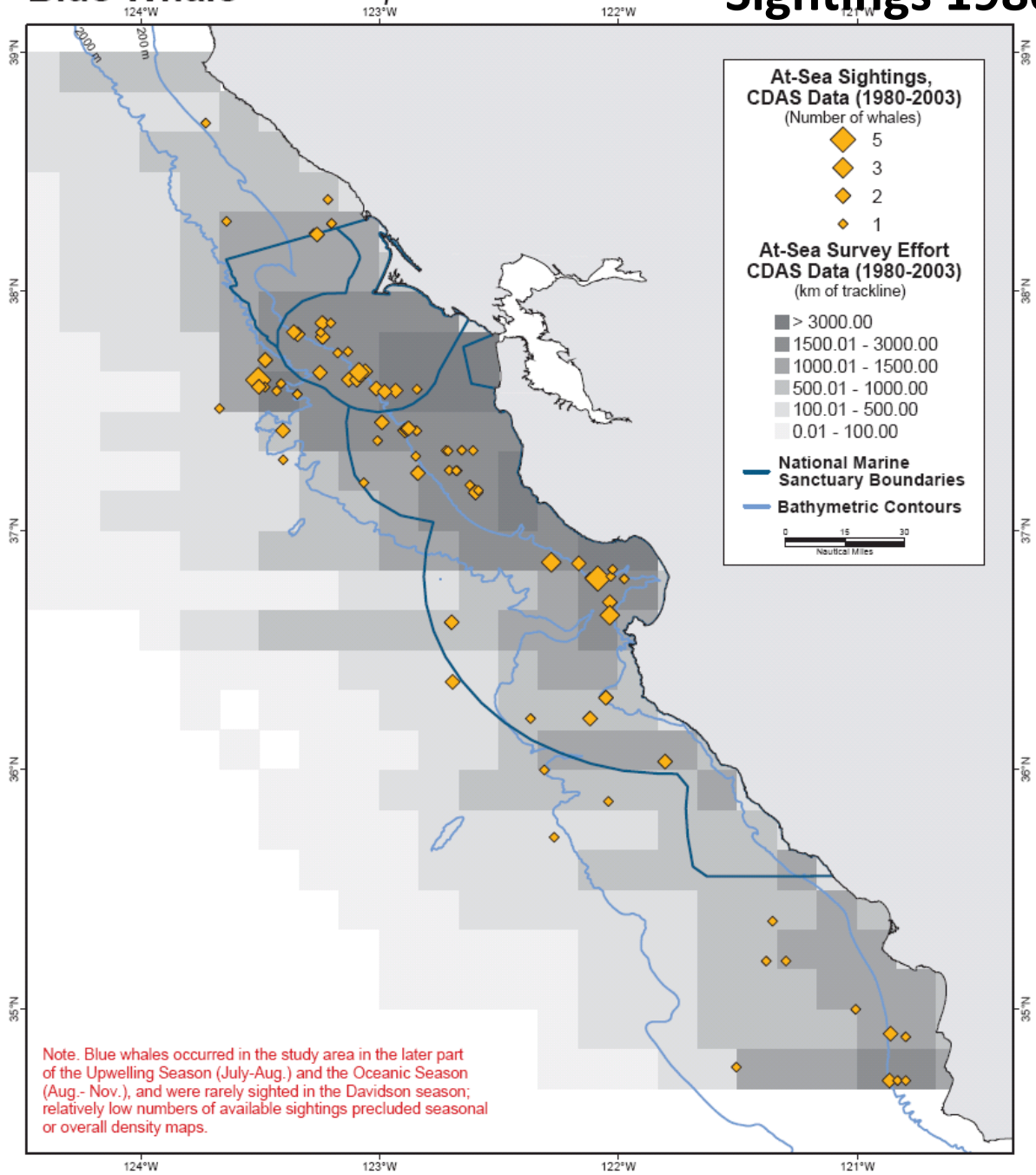
McGowan et al. 2013

Blue Whale foraging tracks (Bailey et al. 2010)



Blue Whale *Balaenoptera musculus*

Sightings 1980-2003



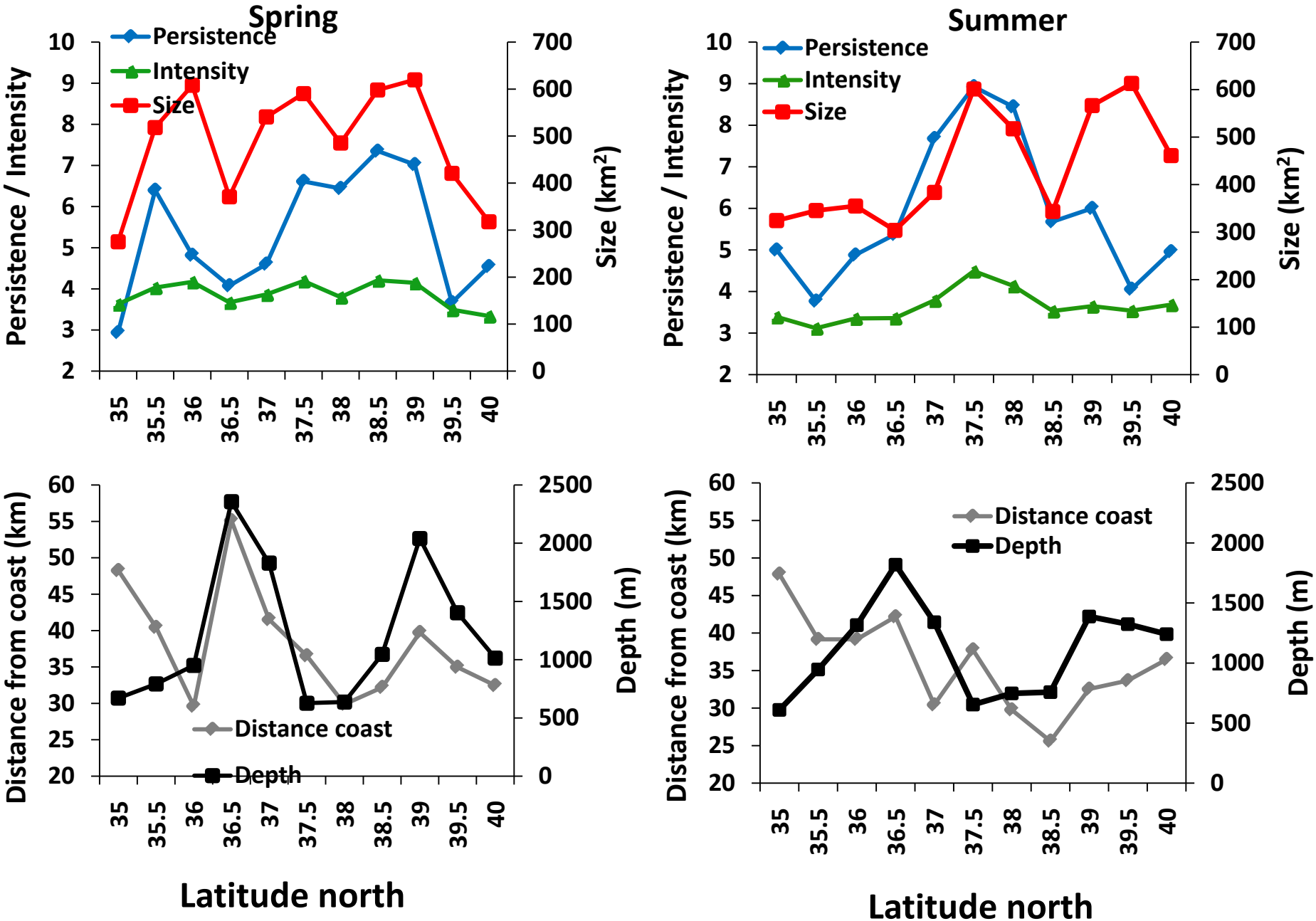
Map Citation: NOAA National Centers for Coastal Ocean Science (NCCOS) 2007. Data Sources: At-sea data from CDAS data set (1980-2003).

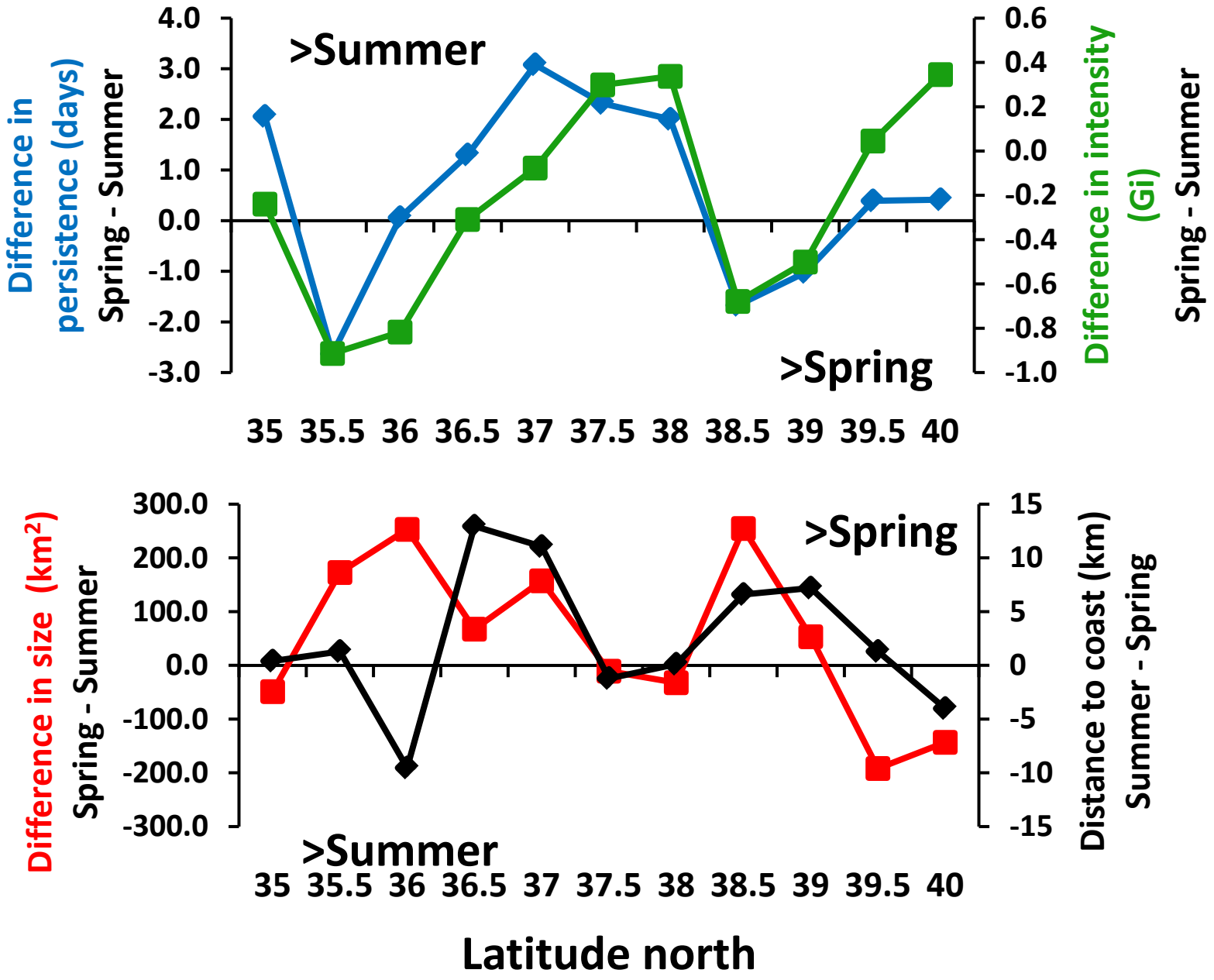
Summary and Conclusions

- **Can we model the krill prey field at the "swarm" scale?**
  - **Yes. Provides information on how food is distributed in the environment and changes on a synoptic scale. Very important.**

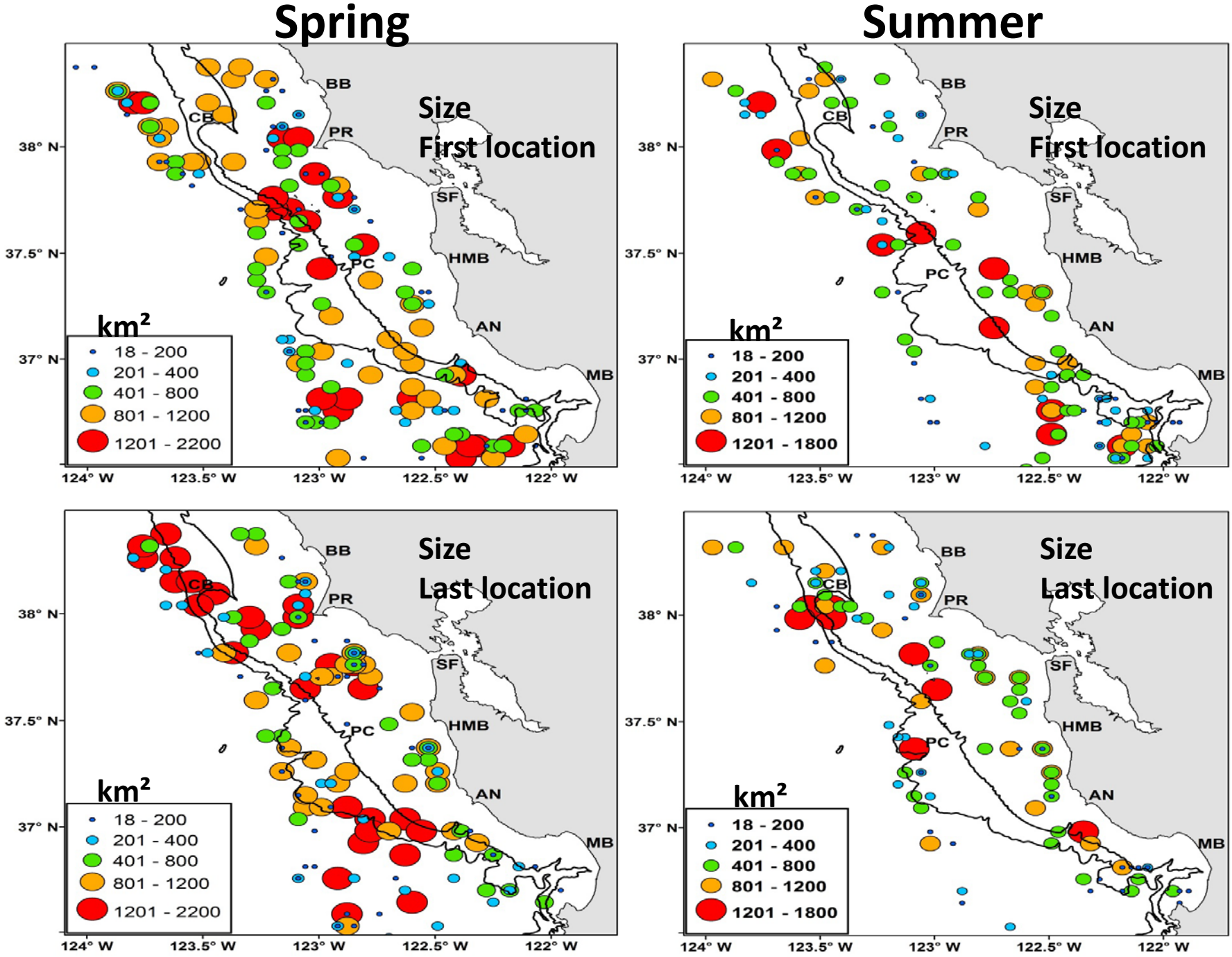
- **How does the space/time scales of krill swarm field compare with the foraging scale of UTL predators?**
  - **Pretty well (persistence and intensity). Not size as much…**
  - **Model presents various opportunities for understanding and prediction of predator foraging and breeding success.**

Changes in Size, Intensity, Depth and Distance from the coast relative to latitude off central CA

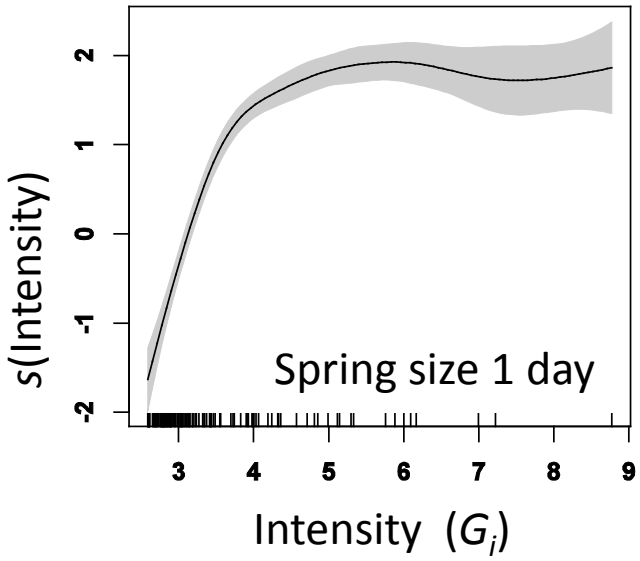

Spring
Persistence
Intensity
Size
Persistence / Intensity
Size (km²)
Summer
Persistence
Intensity
Size
Persistence / Intensity
Size (km²)
Distance coast
Depth
Distance from coast (km)
Depth (m)
Distance coast
Depth
Distance from coast (km)
Depth (m)
Latitude north
Latitude north

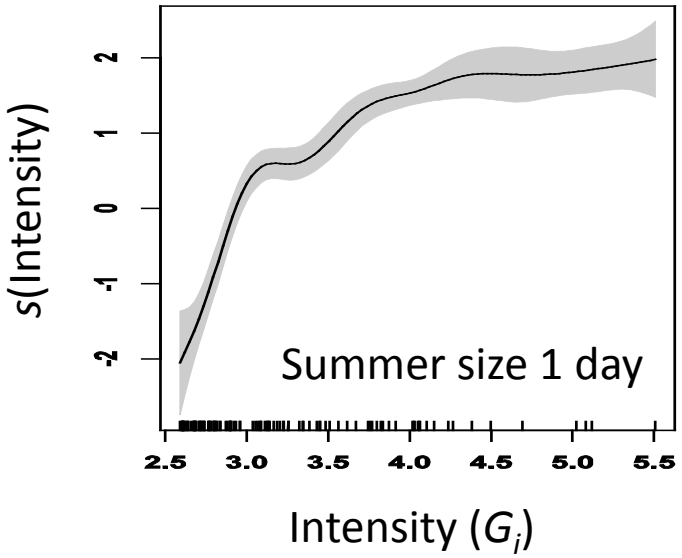

Difference in persistence (days)
Spring - Summer
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
>Summer
>Spring
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Difference in intensity (Gi)
Spring - Summer
35 35.5 36 36.5 37 37.5 38 38.5 39 39.5 40
Difference in size (km²)
Spring - Summer
300.0
200.0
100.0
0.0
-100.0
-200.0
-300.0
>Spring
>Summer
15
10
5
0
-5
-10
-15
Distance to coast (km)
Summer - Spring
35 35.5 36 36.5 37 37.5 38 38.5 39 39.5 40
Latitude north

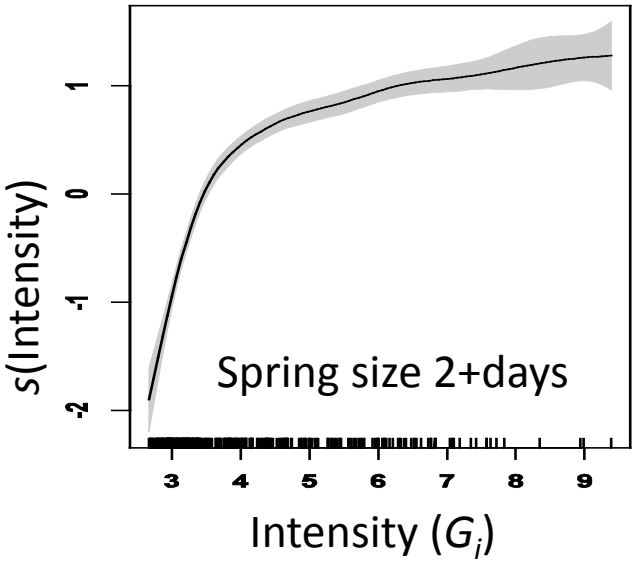
Formation and dissolution of hotspots: Changes in their size and intensity, and emergence of seasonal source/sink dynamics

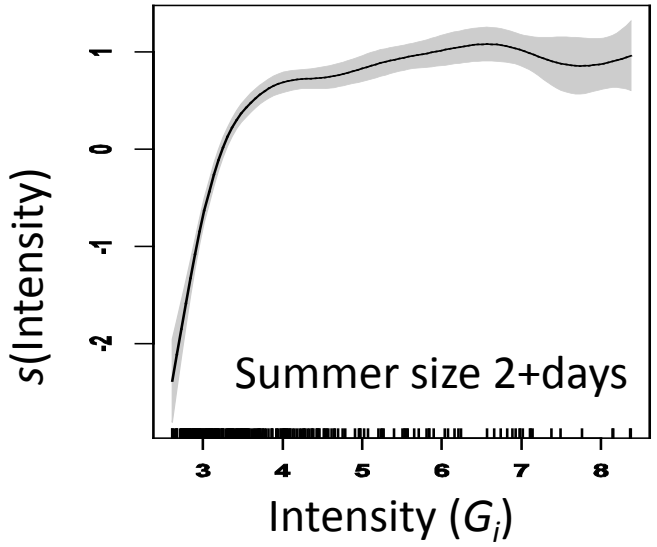

Spring
Summer
Size
First location
Size
Last location
km²
18 - 200
201 - 400
401 - 800
801 - 1200
1201 - 2200
1201 - 1800
BB
CB
PR
SF
HMB
PC
AN
MB
38° N
37.5° N
37° N
124° W
123.5° W
123° W
122.5° W
122° W

Size vs. INTENSITY

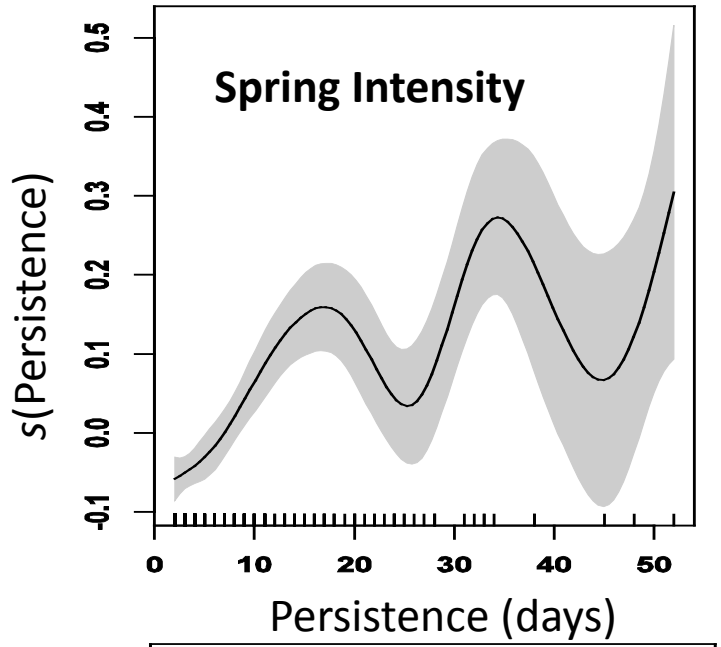


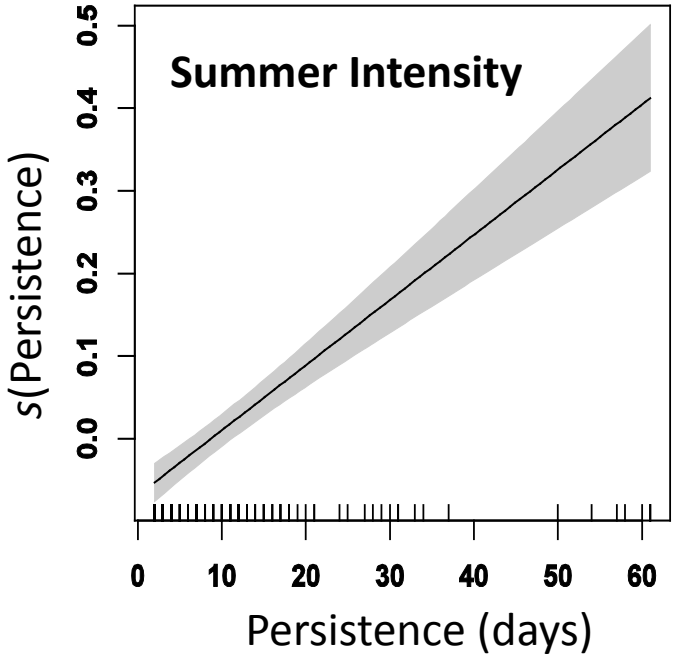


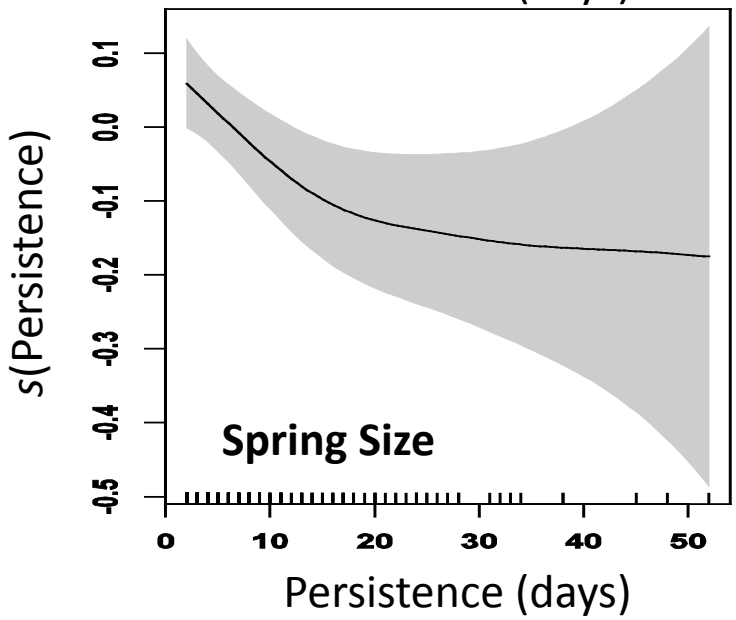




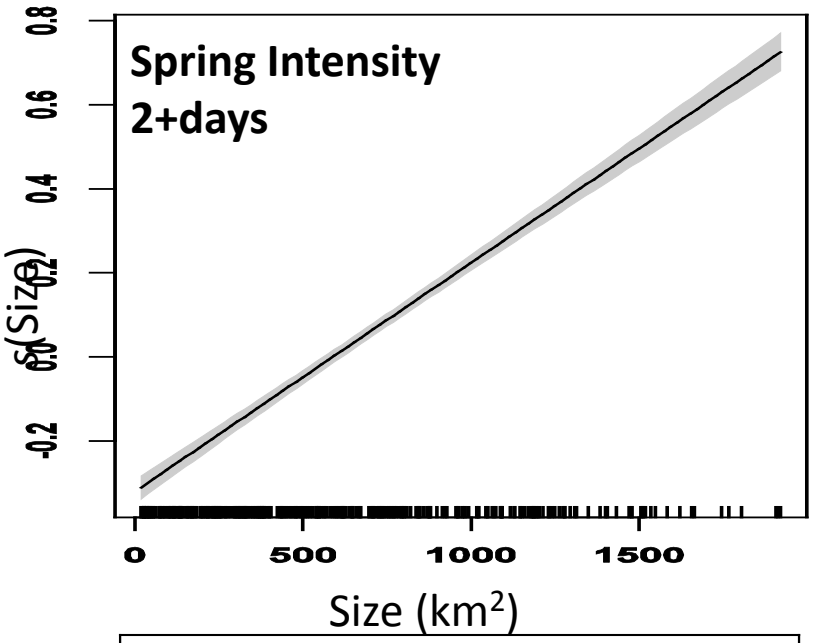
Intensity/Size vs. Persistence

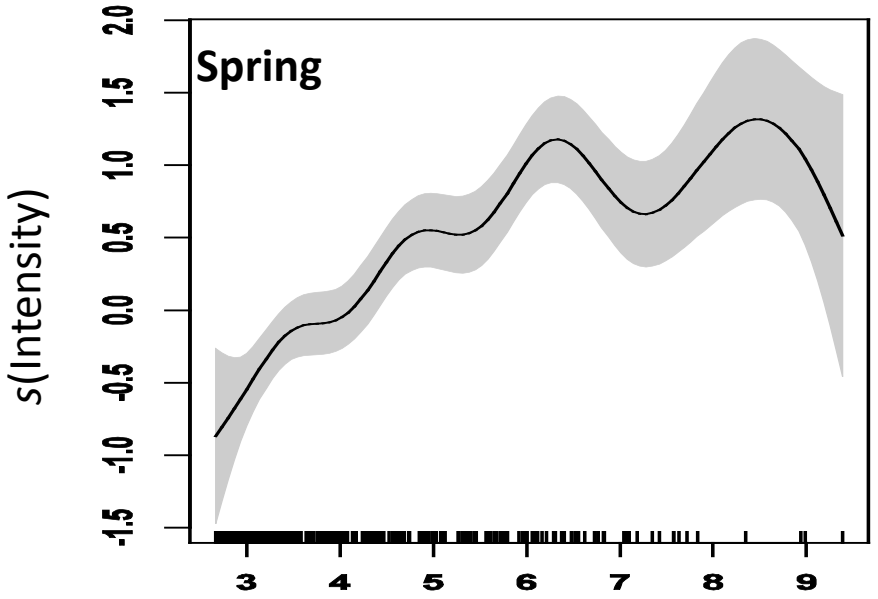


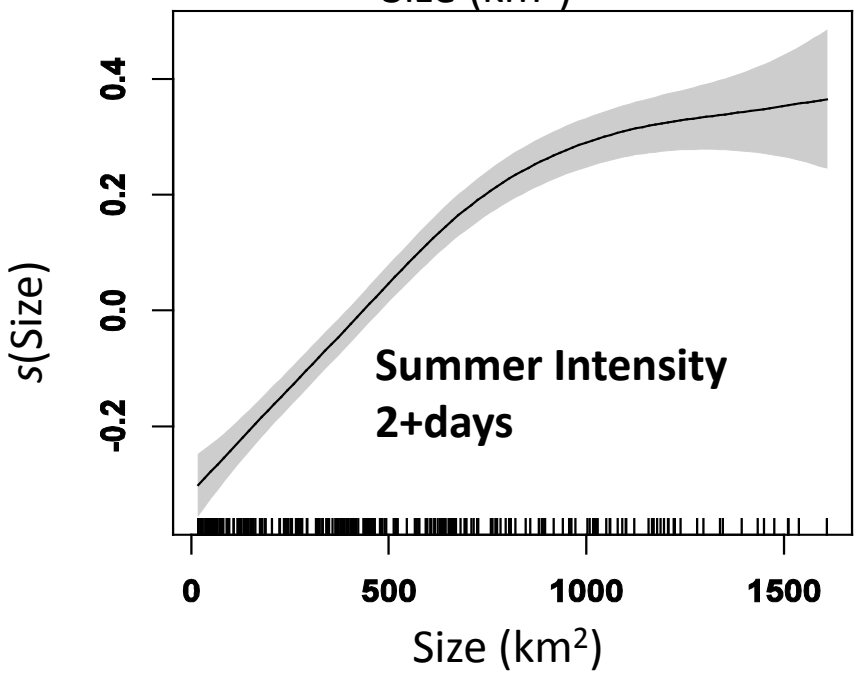


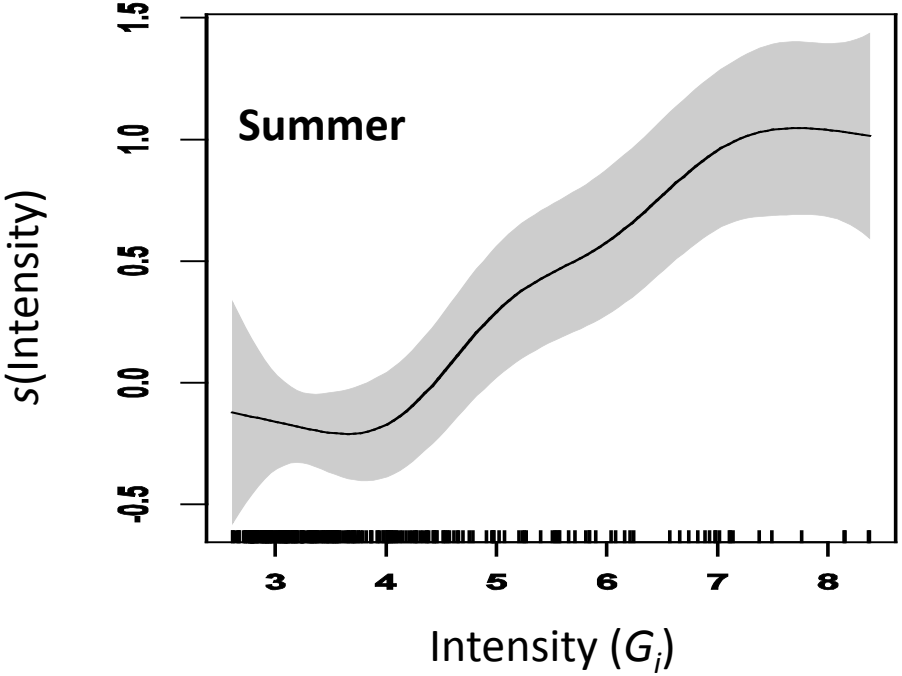


Simulated Swarms: Size vs. Intensity; Intensity vs. Persistence









Scales of swarms during *spring* and *summer*