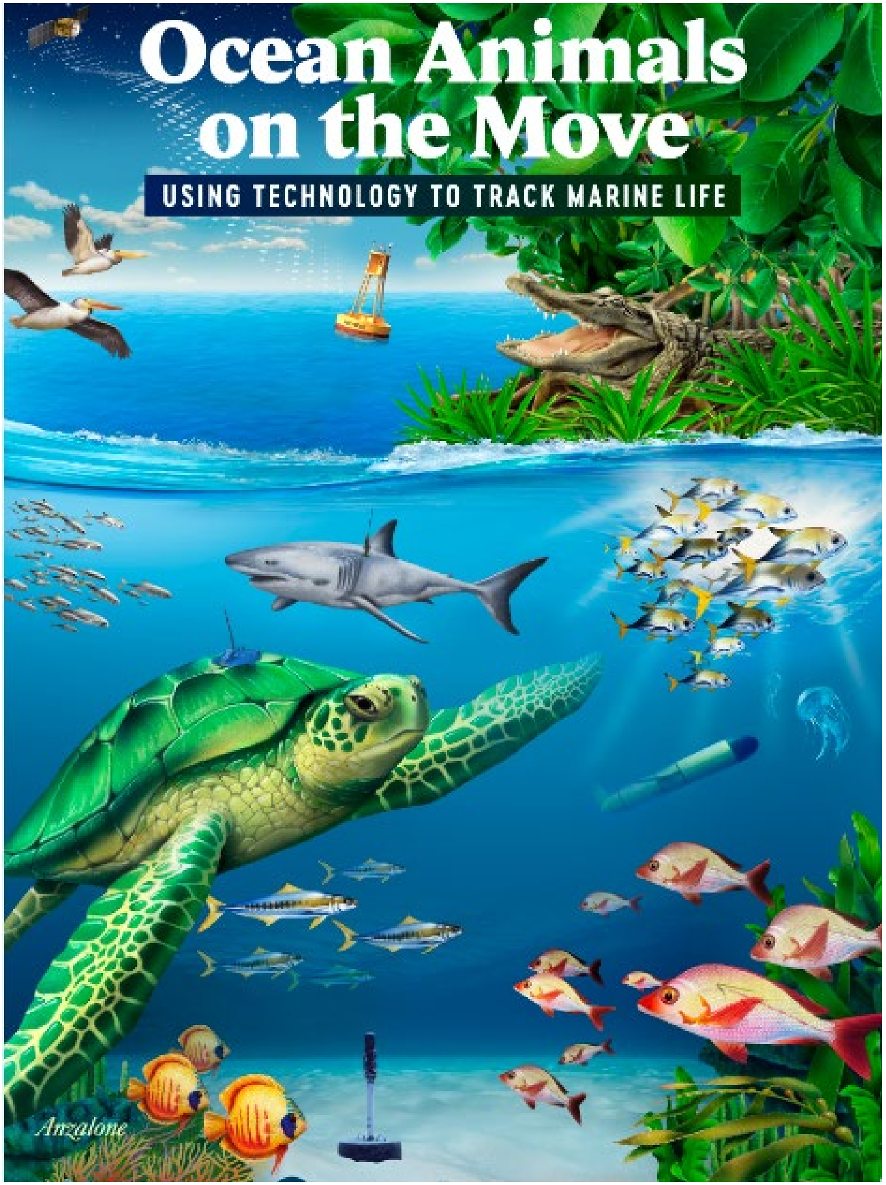

Ocean Animals on the Move

Using Technology to Track Marine Life and Understand Environmental Change

An ESIP FUNding Friday Collaboration

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Objective

To understand the purpose and process of animal tracking, and the data stewardship practices needed to apply the information to real-world challenges.

Three lessons targeting Grades 8-12 support this objective:

Lesson 1 Introduction to Animal Tracking

Lesson 2 Animal Tracking Tools and Technology

Lesson 3 Using Passive Acoustic Telemetry to Study the Movement Ecology of Bull Sharks

Image: Chris Simoniello

Content in this slide deck constitutes Lesson 3 of 3

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National Education Standards

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.

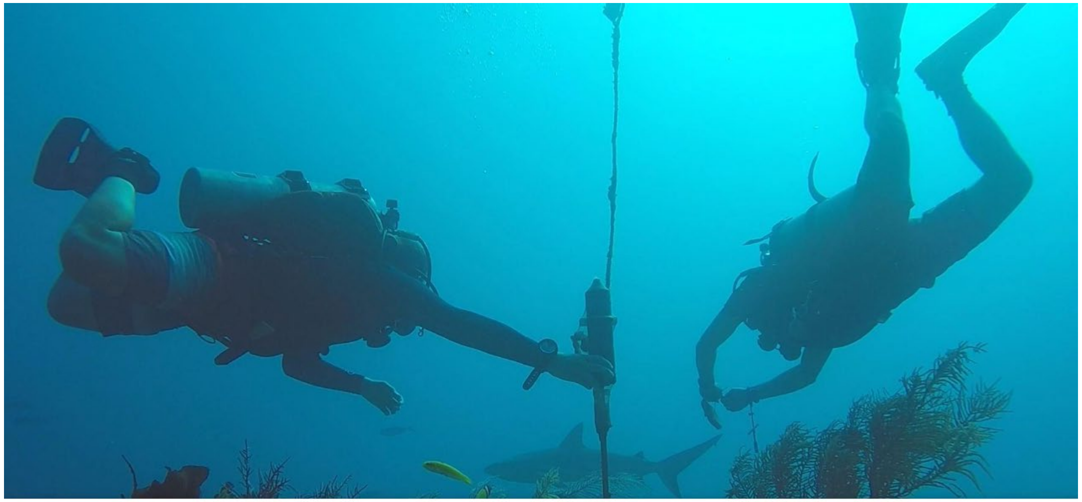
HS-LS2-2.Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

HS-LS2-7.Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-LS2-8.Evaluate evidence for the role of group behavior on individual and species' chances to survive and reproduce.

Disciplinary Core Ideas

LS2.A: Interdependent Relationships in Ecosystems
LS2.C: Ecosystem Dynamics, Functioning, and Resilience
LS2.D: Social Interactions and Group Behavior
LS2.D: Biodiversity and Humans
ETS1.B: Developing Possible Solutions



University of Miami divers replacing an acoustic receiver. Image: Gammon Koval

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National Education Standards

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics (Cont.)

Science and Engineering Practices
Using Mathematics and Computational Thinking

- Use mathematical and/or computational representations of phenomena or design solutions to support explanations. (HS-LS2-1)
- Use mathematical representations of phenomena or design solutions to support and revise explanations. (HS-LS2-2)

Constructing Explanations and Designing Solutions

- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-LS2-7)

Engaging in Argument from Evidence

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS2-6)

Scientific Knowledge is Open to Revision in Light of New Evidence

- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-2),(HS-LS2-3)
- Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation. (HS-LS2-6),(HS-LS2-8)

Crosscutting Concepts
Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS2-8)

Scale Proportion and Quantity

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-LS2-1)

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS2-6),(HS-LS2-7)

Lesson 3

Using Passive Acoustic Telemetry to study the movement ecology of bull sharks

Research Question: How are bull sharks (*Carcharhinus leucas*) moving along the U.S. Southeast Atlantic Coast and Gulf of Mexico over space and time?

This lesson is based on research led by Mitch Rider and presented in the journal Aquatic Ecology.

Rider, M.J., McDonnell, L.H., and Hammerschlag, N. 2021. Multi-year movements of adult and subadult bull sharks (*Carcharhinus leucas*): philopatry, connectivity, and environmental influences. Aquat Ecol. https://doi.org/10.1007/s10452-021-09845-6(0123456789().,-volV)(01234567

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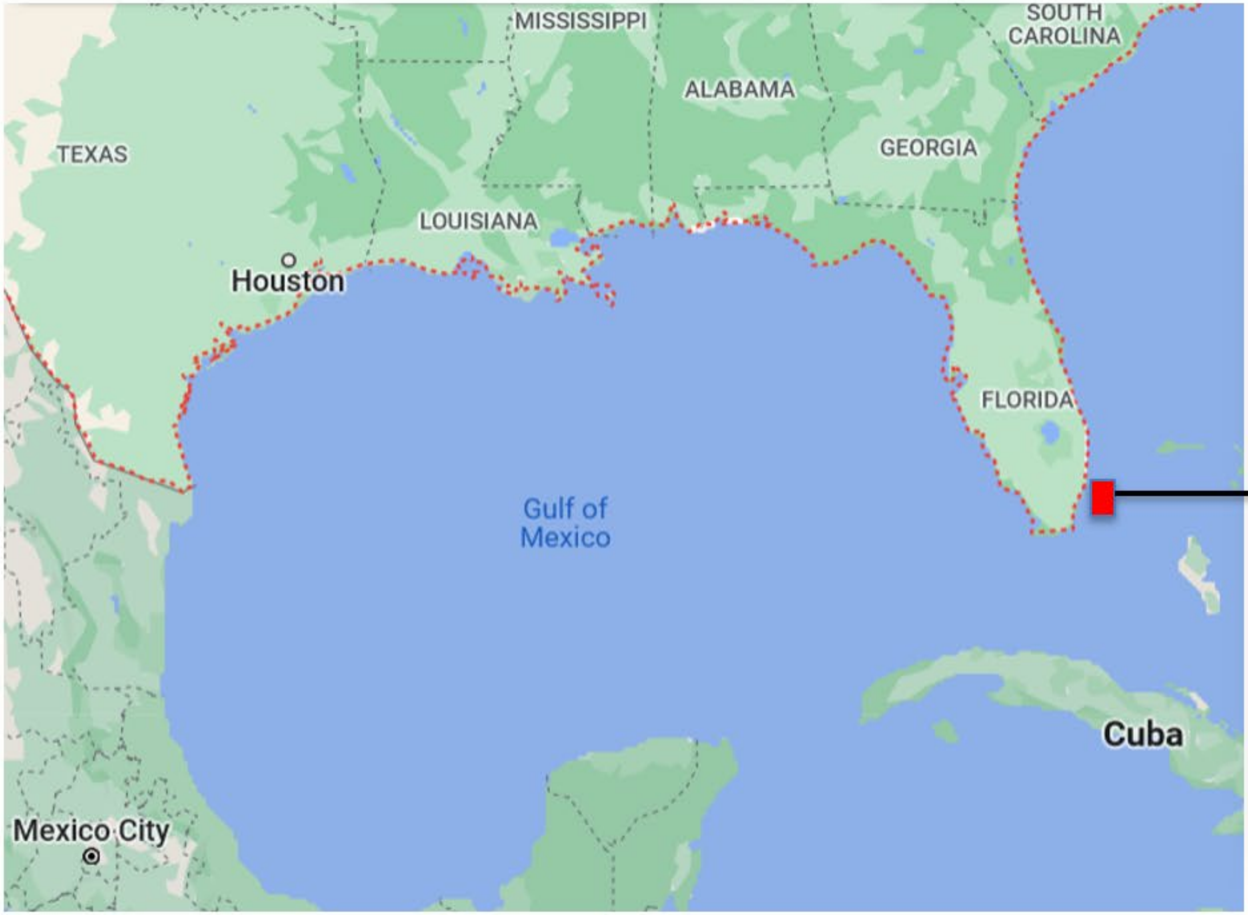
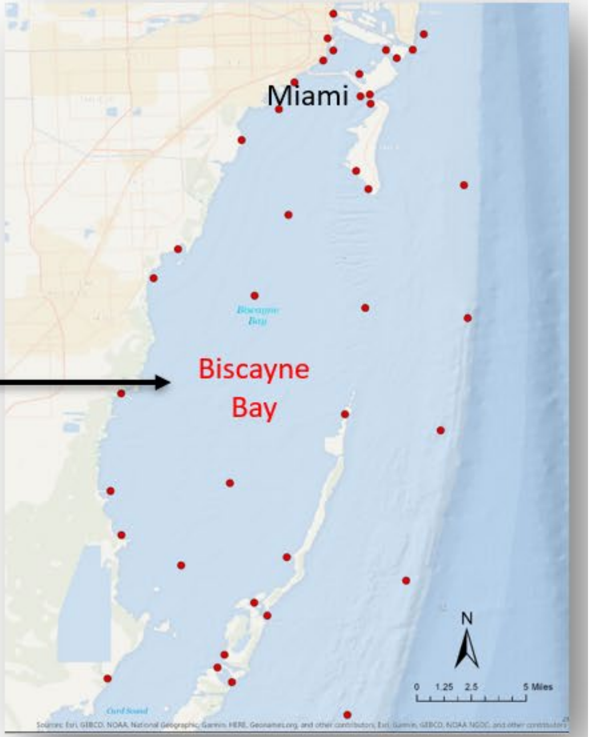
The project plan was to tag bull sharks in Biscayne Bay, FL, and track their movements to determine where they go and what might be driving the observed patterns.





Each dot is an acoustic receiver making up the Biscayne Bay array.

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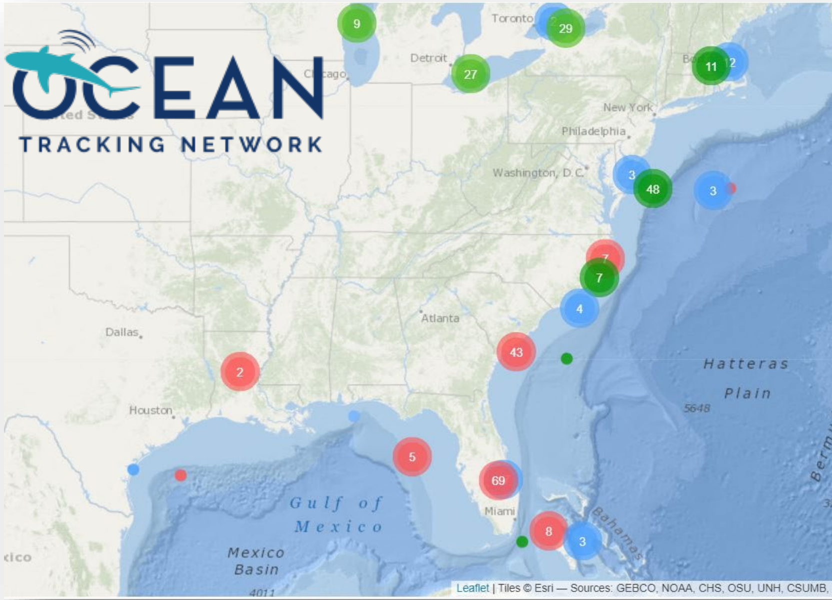
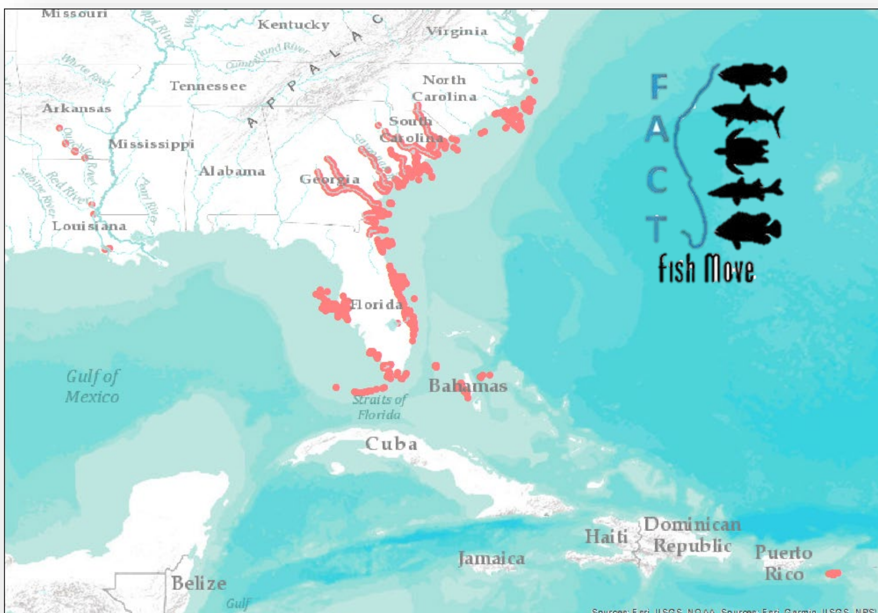
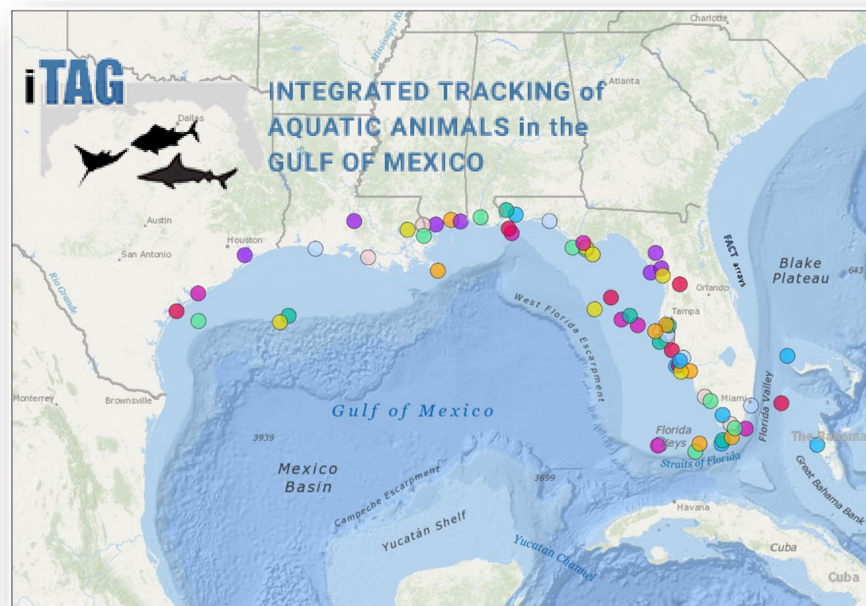


In addition to tagging bull sharks and installing acoustic receivers to detect them in Biscayne Bay, the research relied on existing networks of acoustic receivers. These are **cooperative acoustic tracking networks** where individual researchers share their capabilities to benefit the animal tracking community. This study benefitted from cooperation with the Ocean Tracking Network, Integrated Tracking of Aquatic Animals in the Gulf of Mexico (iTAG), and the Florida Atlantic Coast Telemetry (FACT) array networks. Note that many researchers share their data with more than one of these organizations. Thus, "dots" in the same locations on different maps may be from the same source.





Before tagging animals, the team must determine how and where to set up the receiver stations:

i. How deep is the water in the location of interest? Bull sharks spend a lot of time on the bottom so receivers on the sea floor are probably best.
ii. How will receiver stations be deployed? Do we need a boat and/or divers?
iii. Do we need to build a structure to ensure our receiver stays put? Are there strong waves, currents, a high volume of boat traffic?
iv. How will local conditions affect signal detection? To determine how things like currents, tidal range, anthropogenic noises, and other oceanographic conditions will affect sound detection, a **range test** is performed.

A hydrophone on the seafloor picks up signals from acoustically tagged fish. Image credit: Peter Auster/University of Connecticut

Range testing is done on a subset of receivers to determine the distance that transmitted signals ("pings") from a tag will be picked up by a receiver under local conditions.

In this example, researchers used sentinel range testing tags with a transmitter rate of one ping per minute.
They were deployed at 6 distances from the receiver: 100, 200, 400, 600, 800 and 1000 meters.
Testing was done for a total of 24 hours.

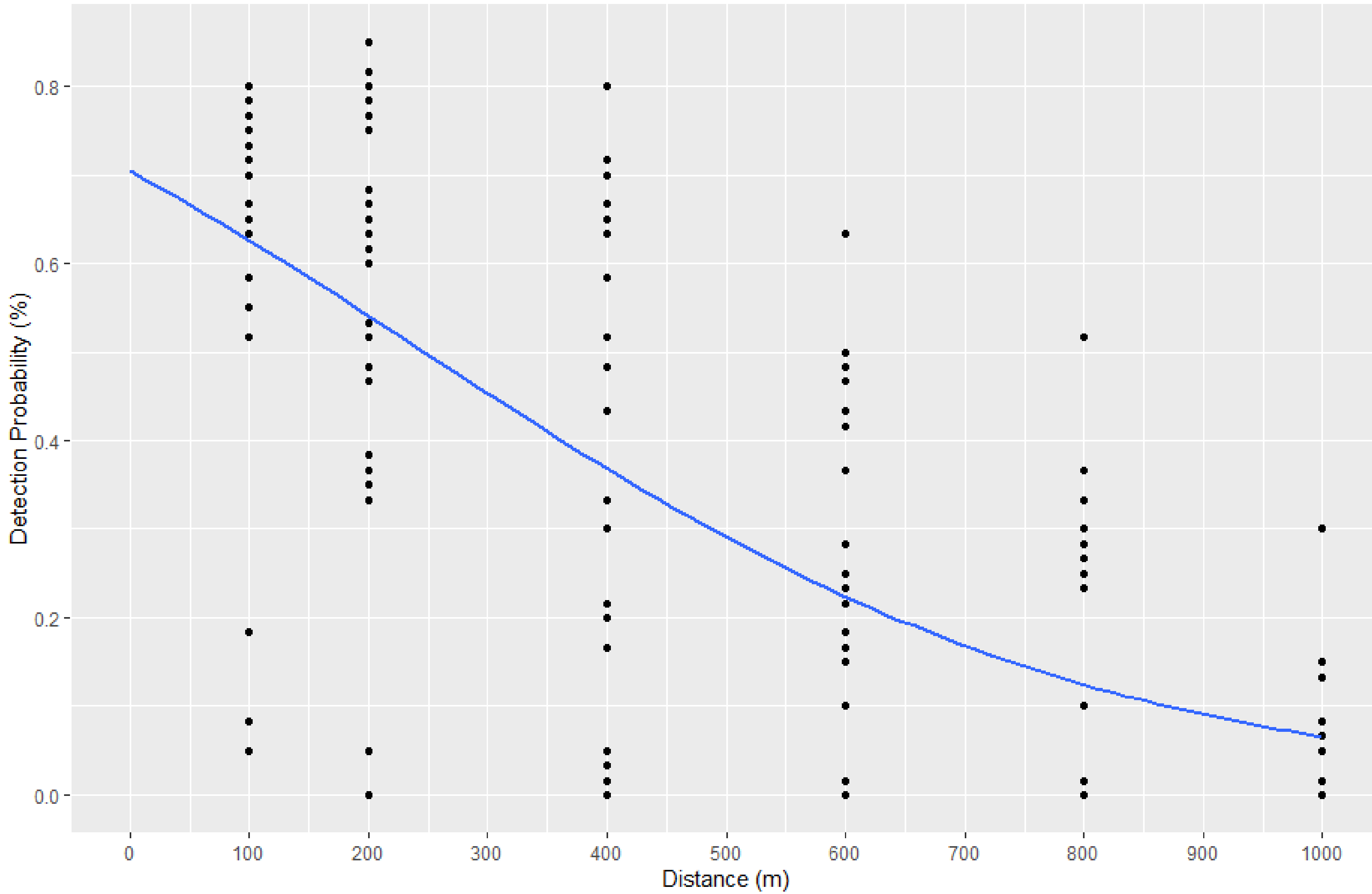
Detection data were then downloaded from the receiver and the rate of detections calculated for each distance using the equation

$$\text{Rate of Detection} = \frac{\text{\# detections per hour from each transmitter tag}}{\text{Total \# hourly detections a receiver could theoretically receive}}$$

Because the testing tags were set to a rate of one ping per minute, a receiver could have theoretically received a maximum of N=60 signals in an hour.

These proportions were then plotted against their associated distance and a curve (logistic regression curve) was fitted to the data points.

Use the range test graph to determine the distance at which 50% of detections are predicted to be received.



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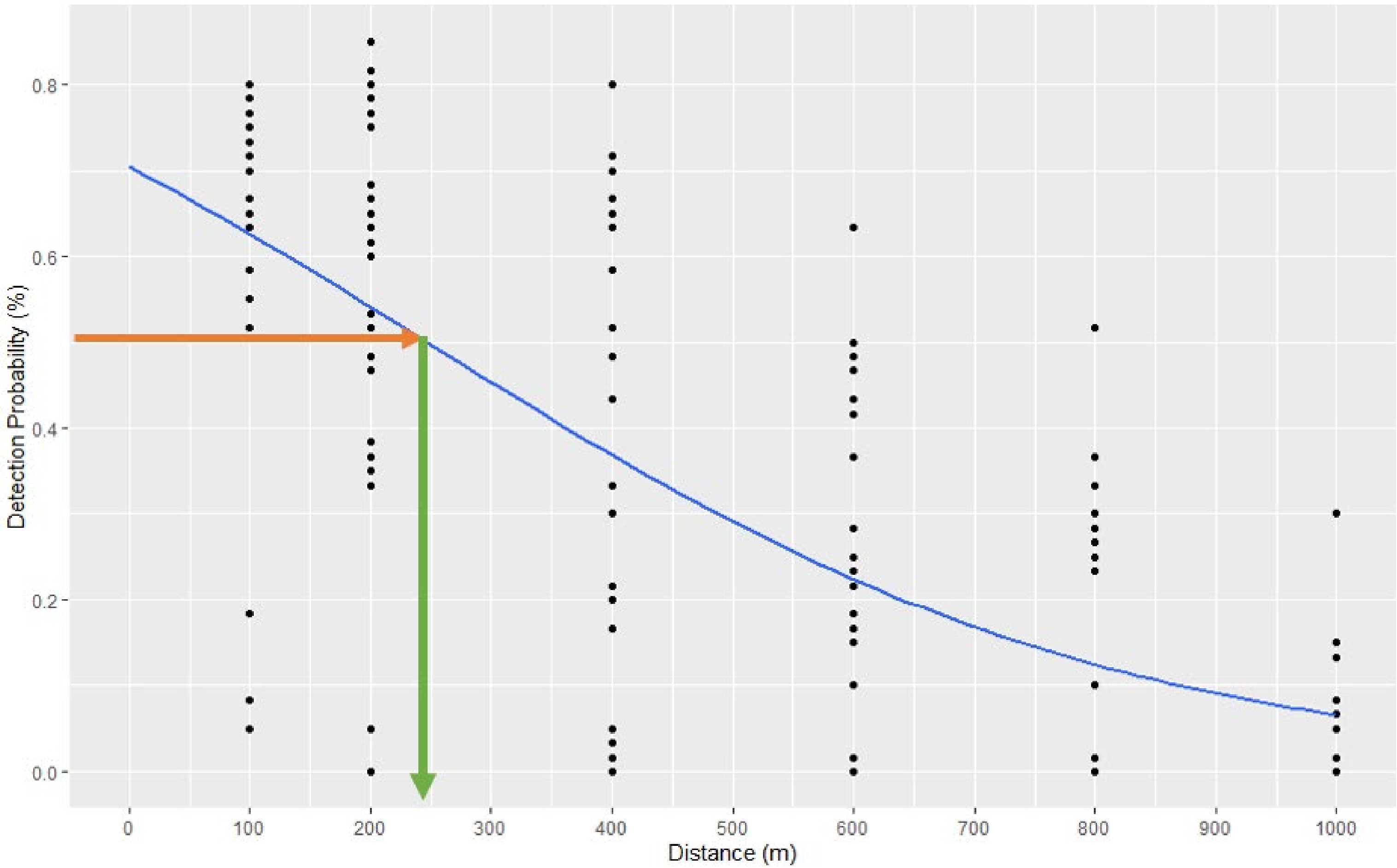
Use the graph to determine the distance at which 50% of detections are predicted to be received.



50% tag detectability is predicted at a receiver distance of 250 m.

The team must also have a data management plan that includes Metadata
Metadata is information about a particular set of data that answers the "who, what, when, where, why and how" of the information provided. For the "who", always use authoritative taxonomic information.*

Metadata is critical to all projects because it provides the context in which information can be used. For example, it would not matter if a receiver picked up 1,000 signals if you did not know its location or when the data were received. All phases of a project require metadata.

The terms used in your metadata (e.g., like the headers in your data table) are also important because they become the terms used when people search for information.

*E.g., the WoRMS record for bull shark https://www.marinespecies.org/aphia.php?p=taxdetails&id=105792.

Attention to metadata is essential for good data stewardship!

Examples
Acronyms or codes used in the dataset
Data processing protocols
Data provenance
Details about units of measure
Details about survey tools
GPS location of instruments
History of changes made to equipment
Project point of contact
Sensor maintenance log

Sample tag data table

Date	USI	Tag type	Species	Sex	Length (cm)	Lat/long	Depth (m)	Method capture	Name
02102018	AB-02102018-1	Fin	C. leucas	M	120	153.32-27.29	15	Line	C. Rigby

Careful record-keeping is essential. The following information should be recorded for all tagged animals:

- Unique tag number(s)
- Type of tag(s)
- Species
- Sex
- Length
- Date of tagging
- Location of capture (place name, latitude and longitude)
- Depth of capture
- Method of capture
- Name and contact details for the person or institution that tagged the animal(s)

Here are examples of tables with metadata created for the bull shark research project

Tag Metadata

Date Tagged	Capture Latitude	Capture Longitude	Capture Site	Species	Sex	PCL (cm)	FL (cm)	TL (cm)	Transmitter ID
12/12/2017	25.73	-80.14	Bear Cut	Bull	F	143	160	196	A69-9001-13487
8/13/2017	25.65	-80.05	Orion Wreck	Bull	F	195	217	261	A69-9001-16324
3/10/2017	25.79	-80.21	Dinner Key	Bull	F	180	202	244	A69-9001-16325
2/7/2017	25.73	-80.22	Dinner Key	Bull	M	146	161	196	A69-9001-16328

PCL=pre-caudal length
FL=fork length
TL=total length

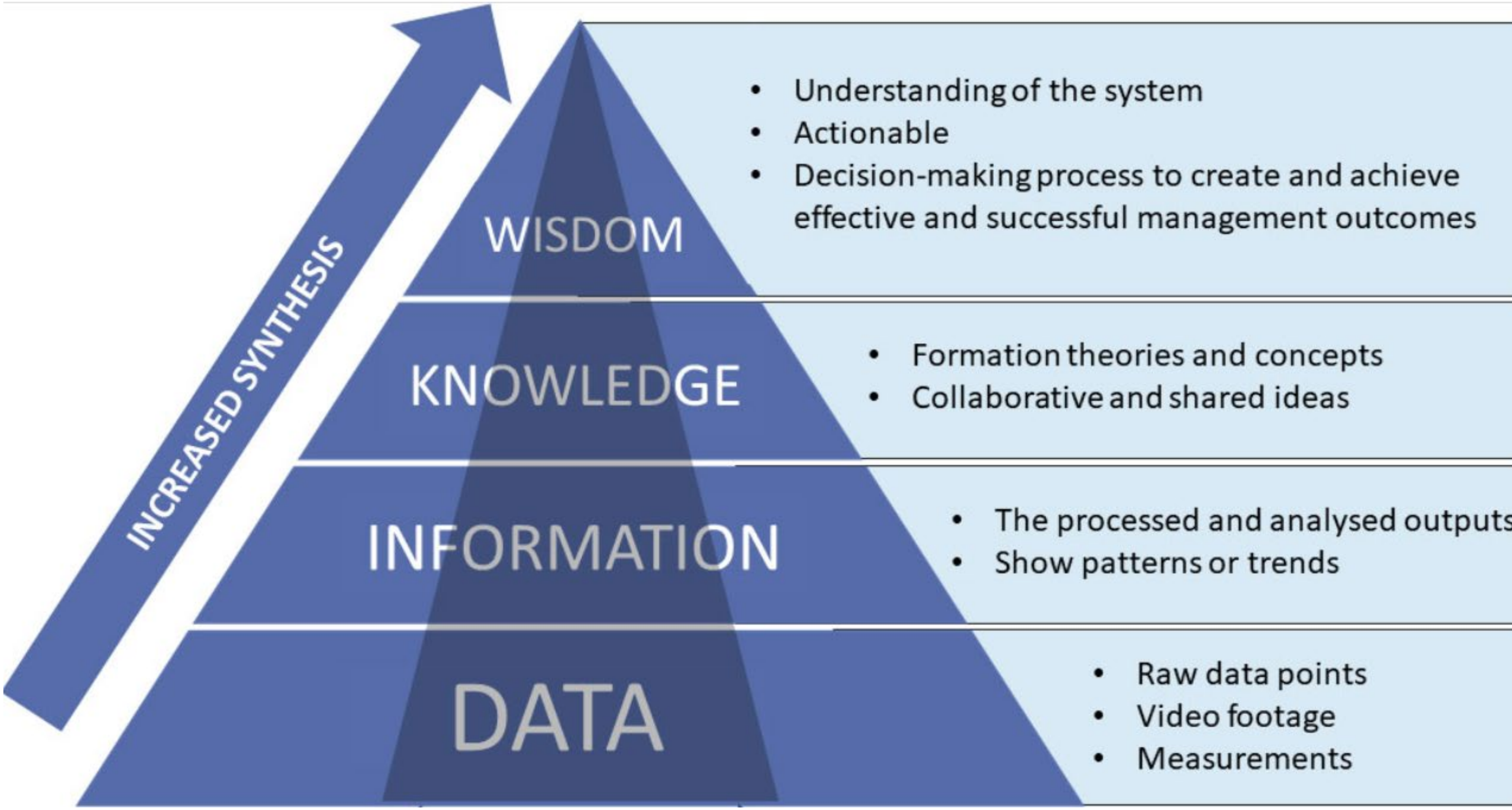
Raw Data

Receiver Serial Number	Transmitter ID	Detection Data & Time	Species	Sex	TL (cm)	Station Name	Bottom Depth (m)
127191	A69-9001-13487	2021-10-16 10:14:34	Bull	F	196	Science Barge	11.2776
127191	A69-9001-13487	2021-10-16 10:22:46	Bull	F	196	Science Barge	11.2776
127191	A69-9001-16324	2022-01-12 21:12:16	Bull	F	261	Science Barge	11.2776
112404	A69-9001-13487	2022-01-13 09:05:08	Bull	F	196	Ajax Reef	7.0104
112404	A69-9001-13487	2022-01-13 09:07:08	Bull	F	196	Ajax Reef	7.0104
127191	A69-9001-16324	2022-01-15 11:15:09	Bull	F	261	Science Barge	11.2776
127191	A69-9001-16324	2022-01-15 12:02:13	Bull	F	261	Science Barge	11.2776

Receiver Metadata

Station Name	Deploy Date & Time	Latitude	Longitude	Bottom Depth (m)	Receiver Model	Receiver Serial Number	Recover Date & Time
Science Barge	2021/03/16 16:02:00	25.71	-80.12	11.2776	VR2W	127191	2022/05/05 19:03:00
Turtle Reef	2021/03/24 16:45:00	25.36	-80.16	9.144	VR2W	112344	2022/05/05 16:21:00
Ajax Reef	2021/03/24 15:43:00	25.46	-80.19	7.0104	VR2W	112404	2022/05/05 15:25:00

Successfully going from data collection to decision making requires good data stewardship!



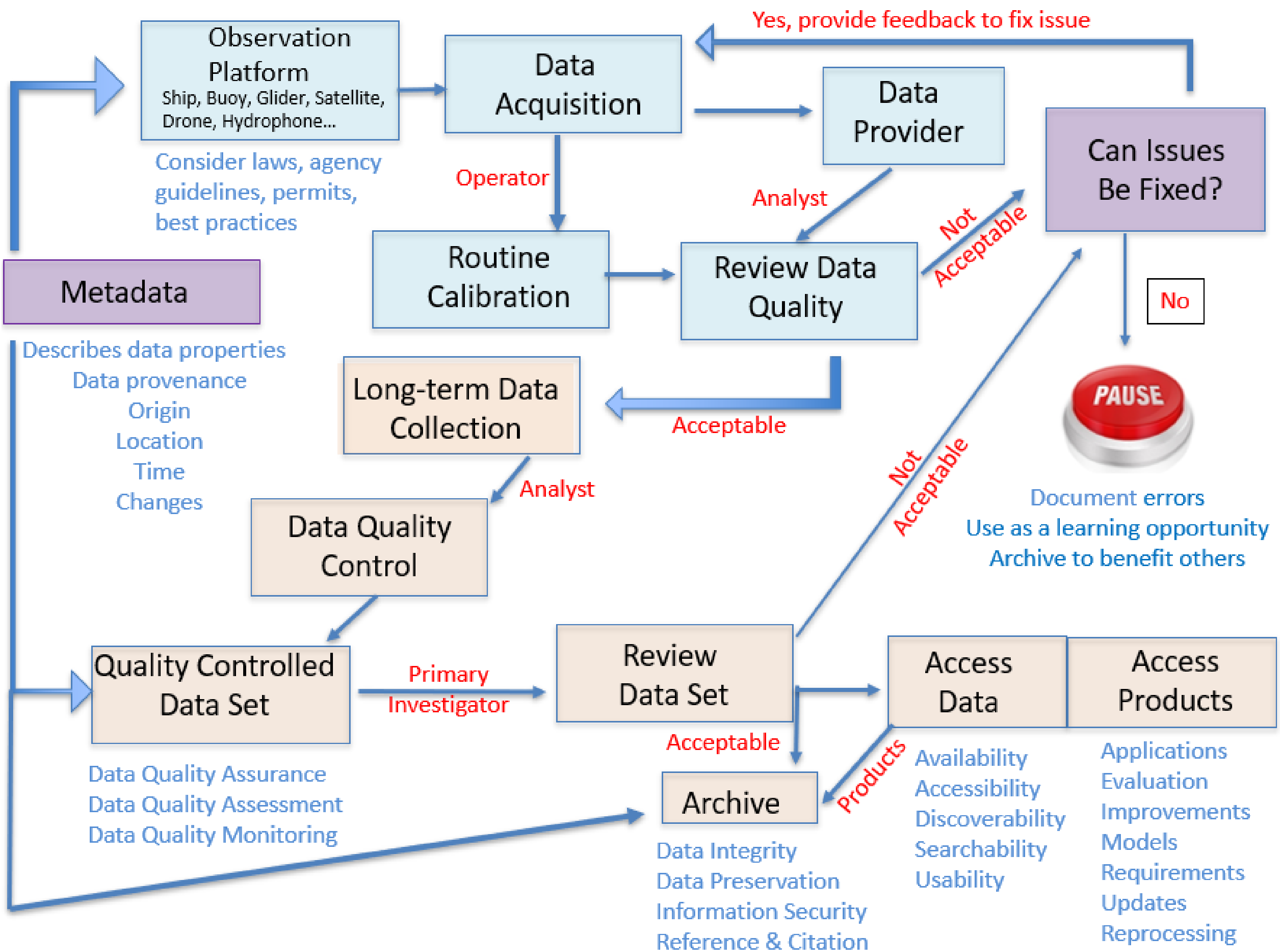
Citation: Ditria EM, Buelow CA, Gonzalez-Rivero M and Connolly RM (2022) Artificial intelligence and automated monitoring for assisting conservation of marine ecosystems: A perspective. *Front. Mar. Sci.* 9:918104. doi: 10.3389/fmars.2022.918104

https://www.frontiersin.org/files/Articles/918104/fmars-09-918104-HTML/image_m/fmars-09-918104-g001.jpg

Some of the many considerations made when processing the project's acoustic data

a. Acquire raw data: Download data after each receiver is retrieved. Receiver is then serviced and redeployed.
b. Provide metadata
    a. Receiver information—e.g., location, date, times deployed and retrieved; note any malfunctions that could bias data
    b. Tags—e.g., make and model, transmission frequency, method of tagging, information on animals tagged such as species, sex and size.
    c. Data—raw data usually consists of location, date/time stamps, receiver number, and transmitter number; need to match to other metadata to determine what shark came by what station at a certain time.
c. Quality Assurance/Quality Control (QA/QC)
    a. False detections? Collision of signals from different tags or other noises in the ocean can cause this. Is relocation of the receiver necessary?
    b. Confirm the receiver was functional the entire time it was deployed to make sure any gaps in signal detection are really from absence of tagged animals. The functional time of each receiver is needed to accurately compare the residence times of sharks between sites.
d. Standardization, scripts: What form is needed to enable analysis with other information (e.g., currents, temperature, salinity, chlorophyll , harmful algal blooms, nutrients…)?
e. Publish/Apply Information: What does the information mean, why does it matter? How will publications be linked to the long-term archive?
f. Archive: What happens to the information after it is processed and validated? How can people access it?

Elements of Good Data Stewardship



Analysis of Project Data:
Who was tagged and where did they go?

Table 1 Summary of acoustically tagged *C. leucas* individuals, detected more than 10 days within the four cooperative networks

Transmitter ID #	Date tagged (mm/dd/yyyy)	Tagging latitude	Tagging longitude	Sex	Total length (cm)	Life stage	Days detected	Days at liberty
24655	02/24/2015	25.7480	−80.1890	F	263	Adult	161	1616
24660	02/27/2015	25.7262	−80.1577	F	219	Subadult	362	1616
24661	02/24/2015	25.7262	−80.1577	F	250	Adult	88	1616
58396	08/11/2015	25.7051	−80.0868	F	211	Subadult	267	1616
58403	01/21/2016	25.6220	−80.1790	F	202	Subadult	282	1588
13487	12/12/2017	25.7294	−80.1581	F	196	Subadult	233	897
16325	03/10/2017	25.7289	−80.2322	F	244	Adult	240	1174
16324	08/13/2017	25.6921	−80.0850	F	261	Adult	17	1018
16328	02/07/2017	25.7145	−80.2082	M	196	Subadult	21	1205
18401	09/11/2016	25.6176	−80.1500	M	188	Juvenile	15	1354
18413	10/17/2016	25.6126	−80.1410	F	242	Adult	30	1318
18415	10/22/2016	25.6380	−80.1968	F	191	Subadult	268	1313
18419	1/20/2017	25.6016	−80.0907	F	236	Adult	61	1223
18421	02/04/2017	25.6223	−80.0980	F	242	Adult	31	1208
20563	12/04/2015	25.7002	−80.9900	F	256	Adult	90	1636
20773	02/16/2016	25.7051	−80.0868	F	245	Adult	119	1562

- **22 bull sharks were tagged in Biscayne Bay, FL, between Feb 2015 and Dec 2017**
    - **4 males, 18 females**
- **Only sharks that were detected >10 days within the four cooperative networks (n=504 individual receivers) over the course of the study (March 2015-June 2020) were included in the analysis.**
    - **2 male and 14 female bull sharks met this requirement**

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Analysis of Project Data
Who was tagged? Where did they go?

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16325	03/10/2017	25.7289	−80.2322	F	244	Adult	240	1174
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20563	12/04/2015	25.7002	−80.9900	F	256	Adult	90	1636
20773	02/16/2016	25.7051	−80.0868	F	245	Adult	119	1562

Use data from Table 1 to calculate the average number of days the female sharks were detected over the course of the study.

How does this compare to the average number of days the male sharks were detected?

What are some possible explanations for the difference?

(e.g., small sample size, different life stage leading to different habitat use patterns. Note the total lengths of the males cf females—they are smaller).

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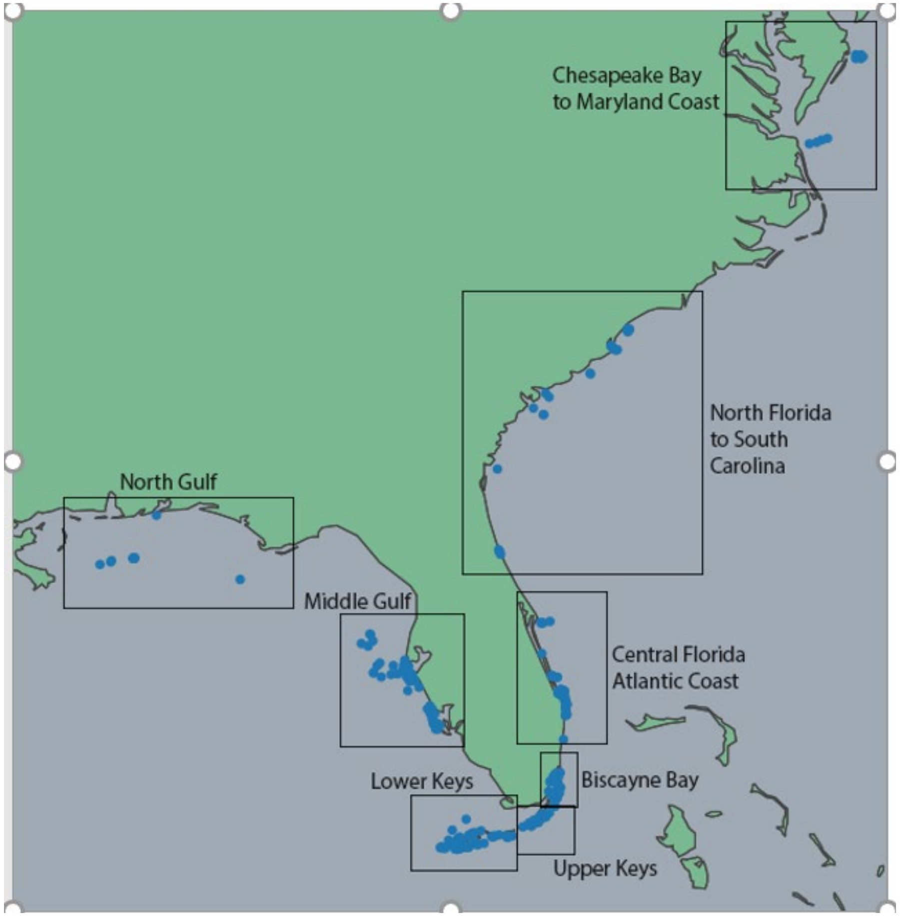
Analysis of Project Data:
Who was tagged and where did they go?

16 of the 22 bull sharks tagged in Biscayne Bay, FL, were tracked between March 2015 and June 2020.

They traveled as far west as Louisiana and as far north as Maryland



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Analysis of Project Data: Where did they go?

Transmitter ID #	Tag date	Florida Keys	Florida Gulf Coast	Northern GoM	Florida Atlantic Coast	Northern Florida to S. Carolina	Chesapeake Bay/ Maryland
24655	02/24/ 2015	0	3	1.5	0	0	0
24660[b]	02/27/ 2015	1	3	0	2	0	0
24661	02/24/ 2015	0	0	1	0.5	0	0
58396[b]	08/11/ 2015	6	1	0	3	1	0
58403[b]	01/21/ 2016	5	1	0	0	0	0
13487[b]	12/12/ 2017	0	0	0	0	0	0
16324	08/13/ 2017	0	0	1	0	1	0
16325	03/10/ 2017	1	2	0	0	0	0
16328[a]	02/07/ 2017	0	0	1	1.5	0	0
18401[a]	09/11/ 2016	0.5	0	0	0	0	0
18413	10/17/ 2016	0	0.5	0	0	0	0
18415[b]	10/22/ 2016	1	0	0	0	2	0
18419	01/20/ 2017	1	1	1	0	0	0
18421	02/04/ 2017	0	0.5	0	0	0	0
20563	12/04/ 2015	3	2	0	0	0	0
20773	02/16/ 2016	0	1	2	3	1	1

Transmitter ID # superscripts: *a* represents males; *b* represents subadult females

This table shows the number of round trips between Biscayne Bay and the other designated regions of the study. One round trip was counted per individual based on the farthest region traveled to on each coast before returning to Biscayne Bay.

Half numbers mean the shark was last detected in that region and not detected again.

How many sharks made at least 3 round trips between Biscayne Bay and the Gulf of Mexico (FL Gulf Coast and N. GoM)?

What percent of the tagged sharks undertook at least one round trip to the FL Keys?

Which tagged shark was detected in the most regions?

Which tagged shark had the most round trips detected?

Analysis of Project Data: Where did they go?

Transmitter ID #	Tag date	Florida Keys	Florida Gulf Coast	Northern GoM	Florida Atlantic Coast	Northern Florida to S. Carolina	Chesapeake Bay/ Maryland
24655	02/24/ 2015	0	3	1.5	0	0	0
24660[b]	02/27/ 2015	1	3	0	2	0	0
24661	02/24/ 2015	0	0	1	0.5	0	0
58396[b]	08/11/ 2015	6	1	0	3	1	0
58403[b]	01/21/ 2016	5	1	0	0	0	0
13487[b]	12/12/ 2017	0	0	0	0	0	0
16324	08/13/ 2017	0	0	1	0	1	0
16325	03/10/ 2017	1	2	0	0	0	0
16328[a]	02/07/ 2017	0	0	1	1.5	0	0
18401[a]	09/11/ 2016	0.5	0	0	0	0	0
18413	10/17/ 2016	0	0.5	0	0	0	0
18415[b]	10/22/ 2016	1	0	0	0	2	0
18419	01/20/ 2017	1	1	1	0	0	0
18421	02/04/ 2017	0	0.5	0	0	0	0
20563	12/04/ 2015	3	2	0	0	0	0
20773	02/16/ 2016	0	1	2	3	1	1

Transmitter ID # superscripts: *a* represents males; *b* represents subadult females

This table shows the number of round trips between Biscayne Bay and the other designated regions of the study. One round trip was counted per individual based on the farthest region traveled to on each coast before returning to Biscayne Bay.

Half numbers mean the shark was last detected in that region and not detected again.

How many sharks made at least 3 round trips between Biscayne Bay and the Gulf of Mexico (FL Gulf Coast and N. GoM)? (3: ID #s 24655, 24660 and 20773)

What percent of the tagged sharks undertook at least one round trip to the FL Keys? (7/16*100=44%)

Which tagged shark was detected in the most regions? (20773; detected in 5 of the 6 regions after traveling from Biscayne Bay)

Which tagged shark had the most round trips detected? (58396 made 11 round trips)

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Analysis of Project Data: Where and When did they go?

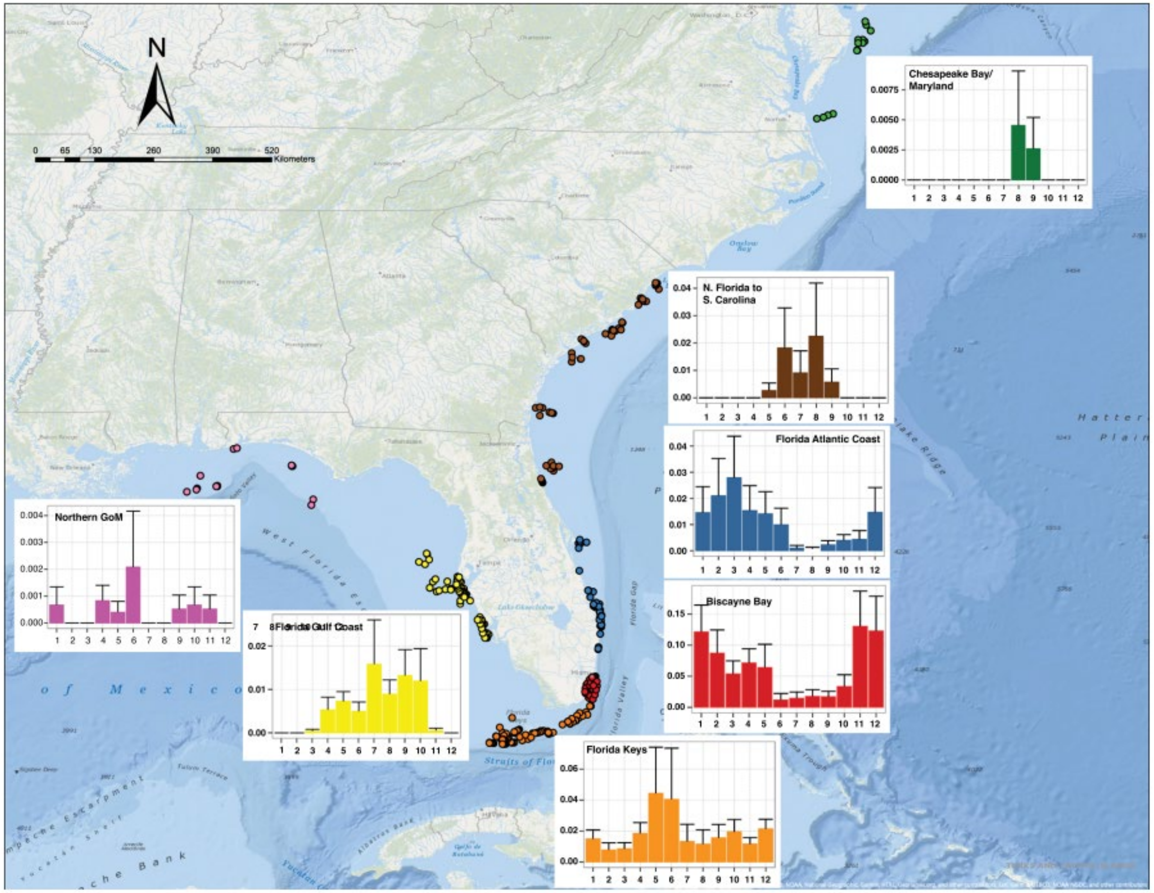

Fig. 1 Locations of receivers (colored by region) with detections of *C. leucas* originally tagged in Biscayne Bay. Mean residency indices of these sharks (y-axis) are plotted as bars + S.D. over months (x-axis) (January–December, 1–12). Each of the 6 general areas considered in this study are displayed: Northern Gulf of Mexico (pink), Florida Gulf Coast (yellow), Florida Keys (orange), Biscayne Bay (red), Florida Atlantic Coast (blue), Northern Florida to South Carolina (brown) and Chesapeake Bay, Maryland (green)

Graphs in this figure show the mean residency indices (y-axis) of the tagged sharks at the different receiver locations. The months, January-December, are shown as 1-12 on the x-axis.

The graphs are enlarged on the next slide.

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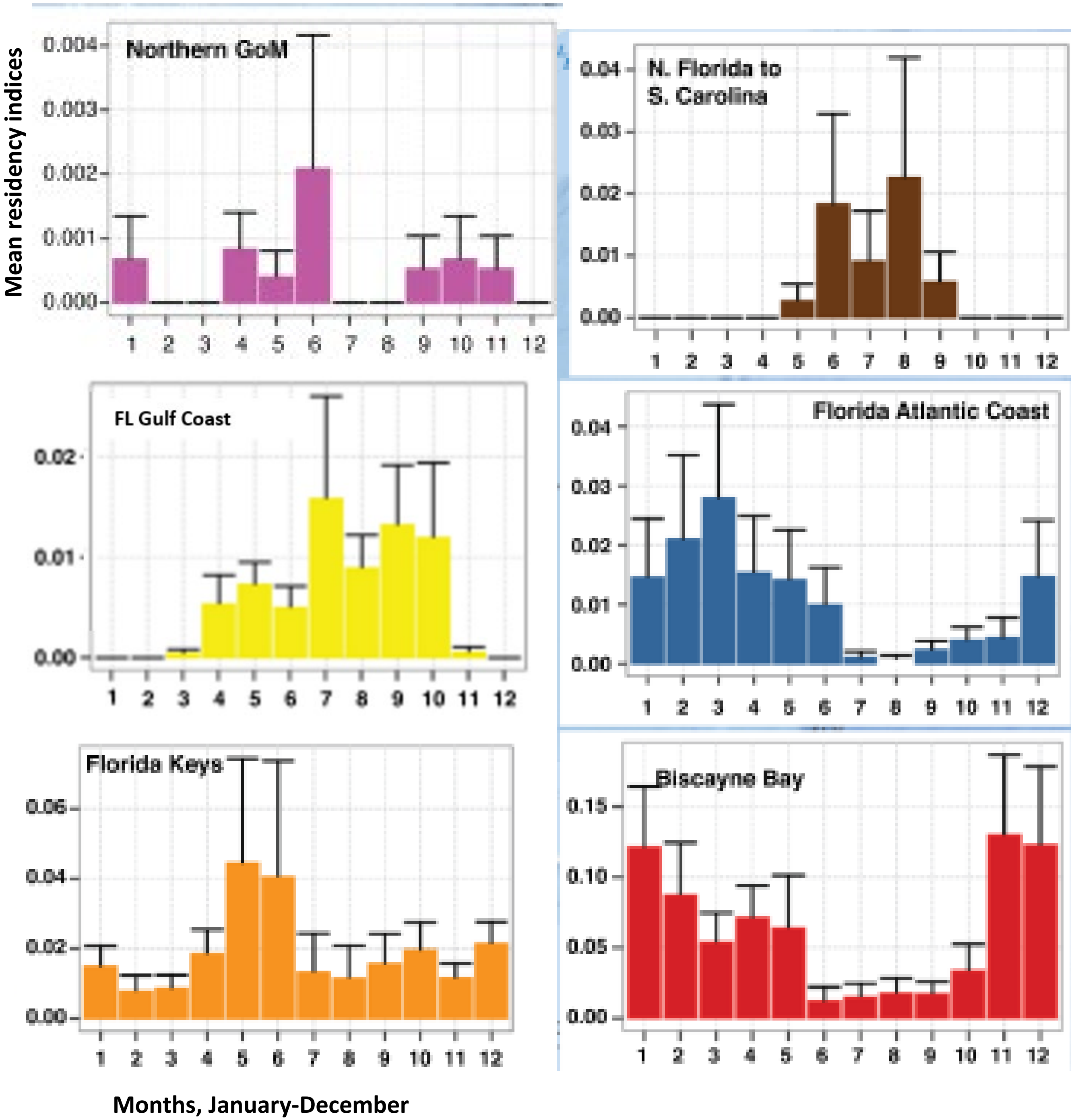
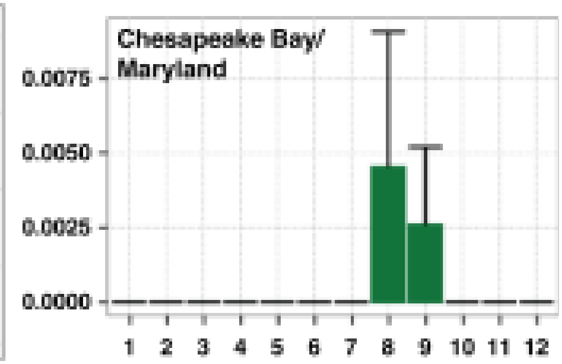
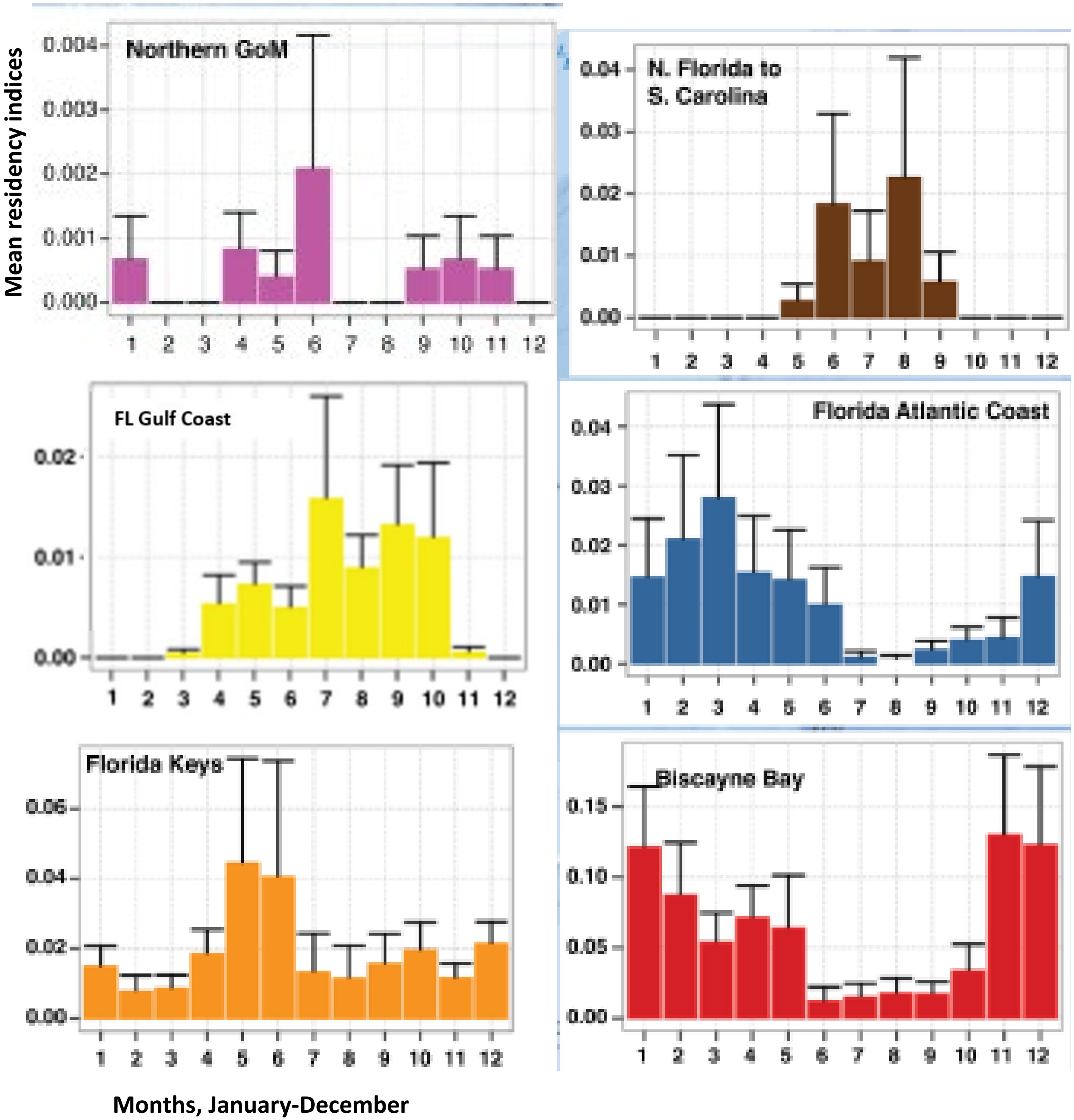




Which location had the highest residency index (RI) in November, December and into January?

Compare month 5 between the Florida Keys and Biscayne Bay. Which has the higher mean RI?

Hint: Always pay attention to the scale of units on the axes of graphs!



Which location had the highest residency index (RI) in November, December and into January? (Biscayne Bay)

Compare month 5 between the Florida Keys and Biscayne Bay. Which has the higher mean RI?

Hint: Always pay attention to the scale of units on the axes of graphs!

Biscayne Bay has the higher RI—about 0.045 for the FL Keys vs. about 0.06 for Biscayne Bay.

Analysis of Project Data: Where and When did they go?

The main take home lesson from these graphs is that residence indices were lowest in the Biscayne Bay array location during spring and summer months.

At this time, other areas, including the Florida Keys, Florida Gulf Coast, and North Florida to South Carolina array locations, reached their peak values.

However, the lowest residency indices in Biscayne Bay were still higher than the highest values of the other locations.

An acoustic tag is surgically implanted in a female bull shark. Image: sharktagging.com

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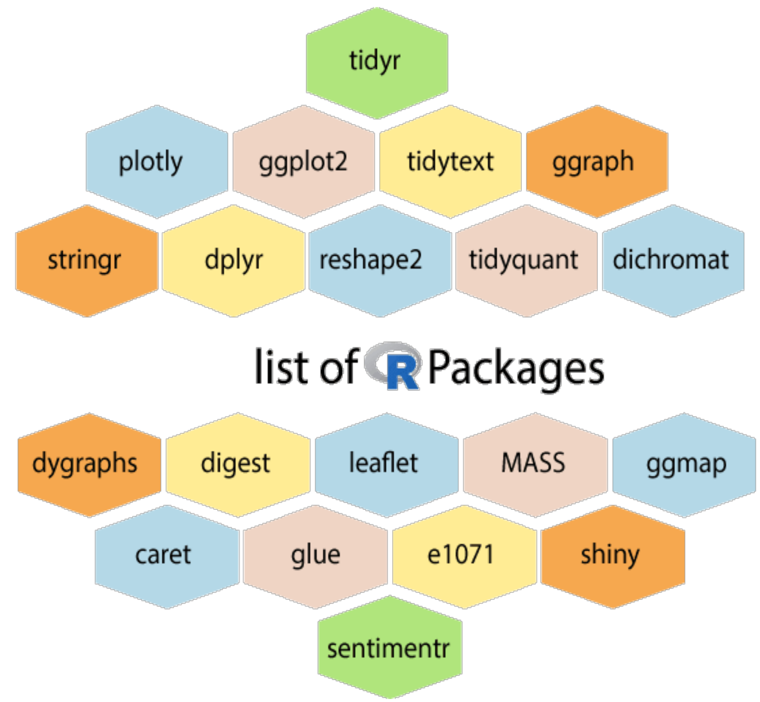
Analysis of Project Data: Why did they go--what is driving the observed movement?

Once the research team determined "where and when" the tagged bull sharks were moving, the next question was "why".

Data science tools are needed to enable the analysis of a variety of environmental variables.

One such tool is R, an advanced language that performs complex statistical computations and can interpret data in a graphical form.

In this study, an R package was used to "scrape" sea surface temperature (SST) and Chlorophyll *a* (Chla) data from a variety of websites. The information extracted corresponded to the times and locations of the tagged sharks.



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Sample of satellite-derived Sea Surface Temperature (SST) & Chlorophyll *a* (chla) data gathered from other websites* using R.

Tag ID	Species	Station	Date & Time Detected	Longitude	Latitude	SST (°C)	chla (mg m-3)
A69-9001-18415	bull shark	BRKY	11/3/2016 16:06	-80.18	25.76	27.0765	NA
A69-9001-18415	bull shark	BRKY	11/3/2016 16:08	-80.18	25.76	27.0765	NA
A69-9001-18415	bull shark	BRKY	11/3/2016 16:10	-80.18	25.76	27.0765	NA
A69-1601-24660	bull shark	BRKY	11/24/2017 8:35	-80.18	25.76	26.279	9.789981
A69-1601-24660	bull shark	BRKY	11/24/2017 8:38	-80.18	25.76	26.279	9.789981
A69-1601-24660	bull shark	BRKY	11/24/2017 8:40	-80.18	25.76	26.279	9.789981
A69-1601-24660	bull shark	BRKY	11/24/2017 8:43	-80.18	25.76	26.279	9.789981
A69-9001-20773	bull shark	Turtle Reef	12/18/2018 2:21	-80.17	25.32	25.0535	1.03304
A69-9001-20773	bull shark	Turtle Reef	12/18/2018 2:22	-80.17	25.32	25.0535	1.03304
A69-9001-20563	bull shark	Turtle Reef	10/26/2018 4:45	-80.17	25.32	28.38525	1.339698
A69-9001-20563	bull shark	Turtle Reef	10/26/2018 4:47	-80.17	25.32	28.38525	1.339698
A69-9001-20563	bull shark	Turtle Reef	10/26/2018 4:48	-80.17	25.32	28.38525	1.339698
A69-9001-20563	bull shark	Turtle Reef	10/26/2018 4:50	-80.17	25.32	28.38525	1.339698
A69-9001-20563	bull shark	Turtle Reef	10/26/2018 4:52	-80.17	25.32	28.38525	1.339698
A69-9001-20563	bull shark	Turtle Reef	10/26/2018 4:53	-80.17	25.32	28.38525	1.339698
A69-9001-20563	bull shark	Ajax Reef	10/26/2018 7:19	-80.13	25.41	28.32275	0.88487
A69-9001-20563	bull shark	Ajax Reef	10/26/2018 7:20	-80.13	25.41	28.32275	0.88487
A69-9001-20563	bull shark	Ajax Reef	10/26/2018 7:22	-80.13	25.41	28.32275	0.88487

Chlorophyll *a* is often used as a proxy for primary productivity and food abundance.

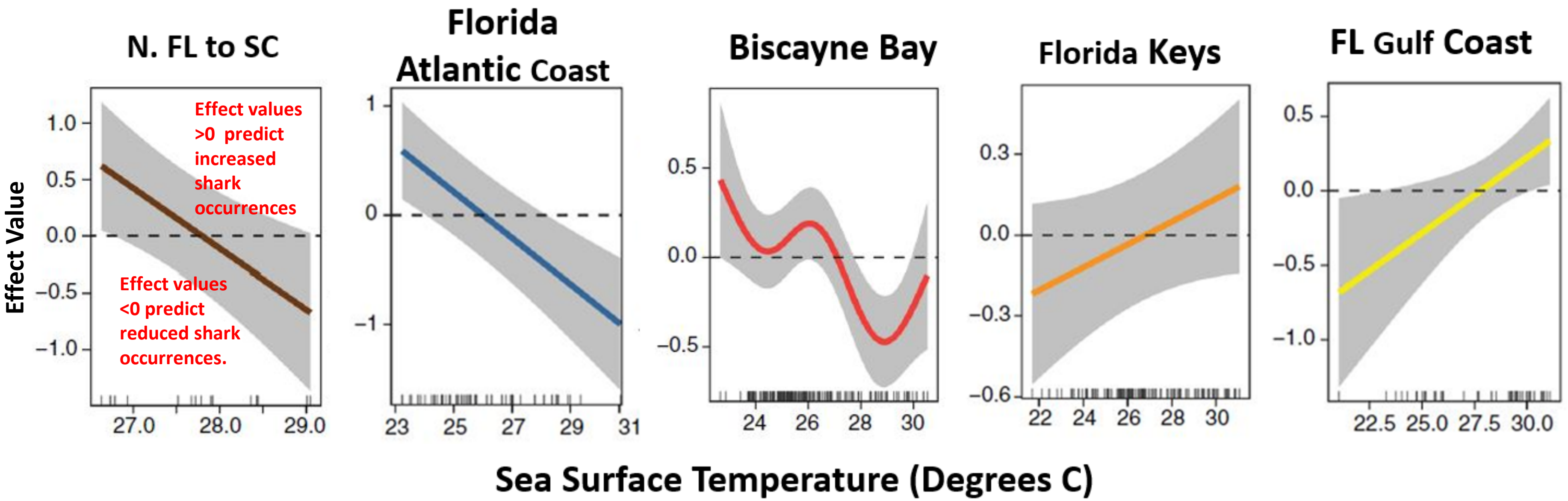
Look at the chla entries for 11/3/2016. NA means no available data. You can't always get environmental data for every time/location of interest. The position of satellites over Earth, cloud cover and other factors can interfere with measurements.

Despite this sampling reality, scientists were able to match 93% of the N=102,592 detections made during this study with SST and chla data!

*Chlorophyll-*a* data from Aqua MODIS satellite accessed via NOAA GEO-IDE UAF ERDDAP server, units are mg per cubic meter)
Sea Surface Temperature is from NASA's SST Multi-Scale Ultra-high Resolution data, accessed via NOAA ERDDAP server, degrees Celsius

Analysis of Project Data: Is SST driving the observed shark movement?

These graphs show the effect of SST on shark detections in each of five regions.



N FL to SC: there was a positive effect of SST on monthly shark residencies when SST was LESS THAN about 28C.

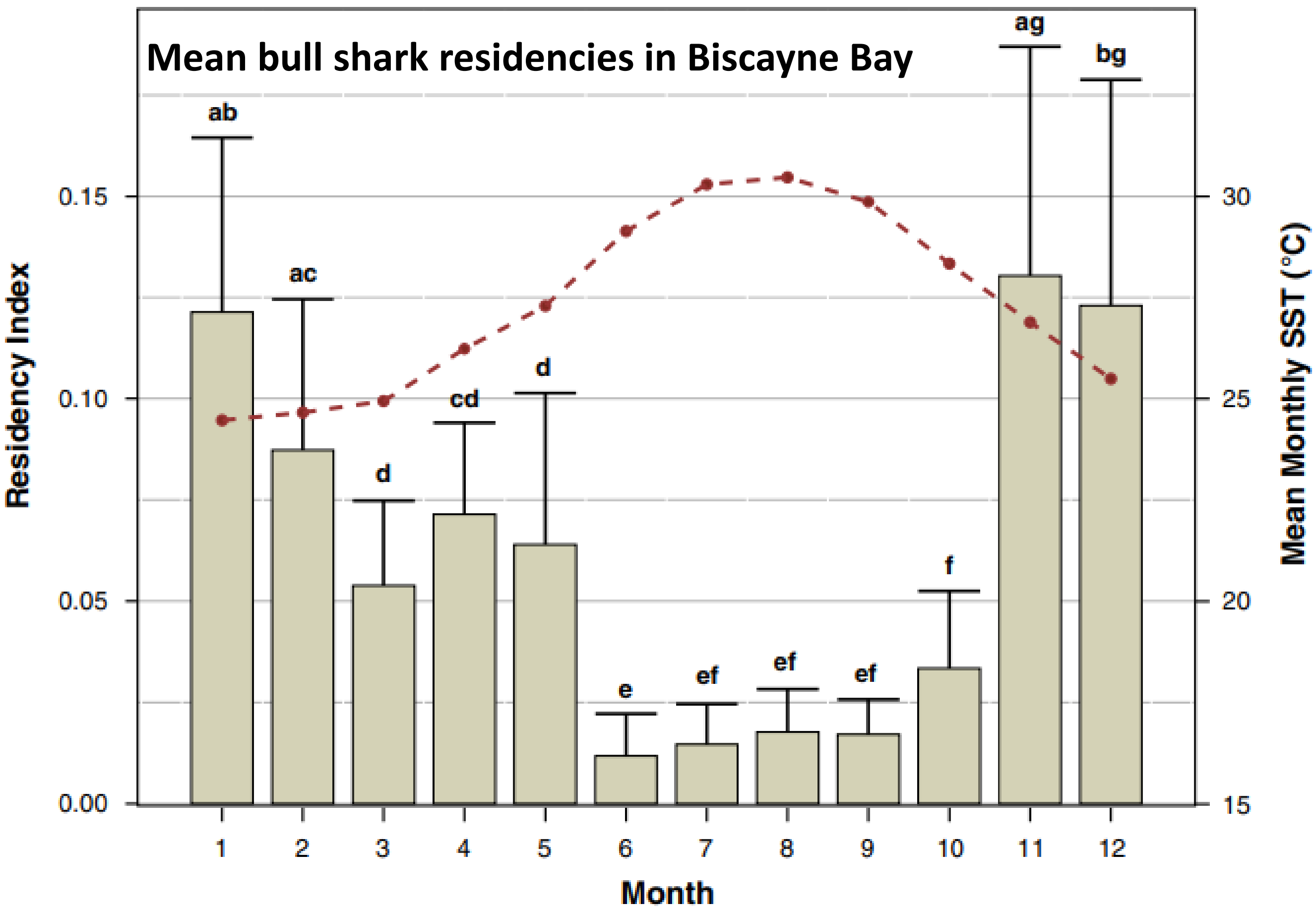
FL Atlantic Coast: there was a positive effect of SST on monthly residencies when SST was LESS THAN about 26C.

Biscayne Bay: the highest mean residencies occurred when mean monthly SST were LESS THAN ~24.5 to 26.8C. SST greater than 27C had a negative effect on shark presence.

FL Keys: there was a positive effect of SST on monthly shark residencies when SST was GREATER THAN about 27C.

FL Gulf Coast: there was a positive effect of SST on monthly shark residencies when SST was GREATER THAN about 28C.

Analysis of Project Data: Is temperature driving the observed shark movement?



Bars represent mean monthly residencies (+1 standard deviation) within the array between June 2015 and June 2020. Bars with the same letter do not significantly differ from one another (*P*>0.05). Mean SST was calculated from average monthly temperatures between 2015 and 2020.

The graph shows the mean bull shark residencies in Biscayne Bay by month (Jan-Dec, 1-12 on the x-axis).

The red trend line shows the mean Sea Surface Temperature by month corresponding to this location .

Which five months had the highest SST?

Which five months had the lowest bull shark residency indices (RI)?

Was the RI in March significantly different than the RI in May?

Was the RI in May significantly different than the RI in June?

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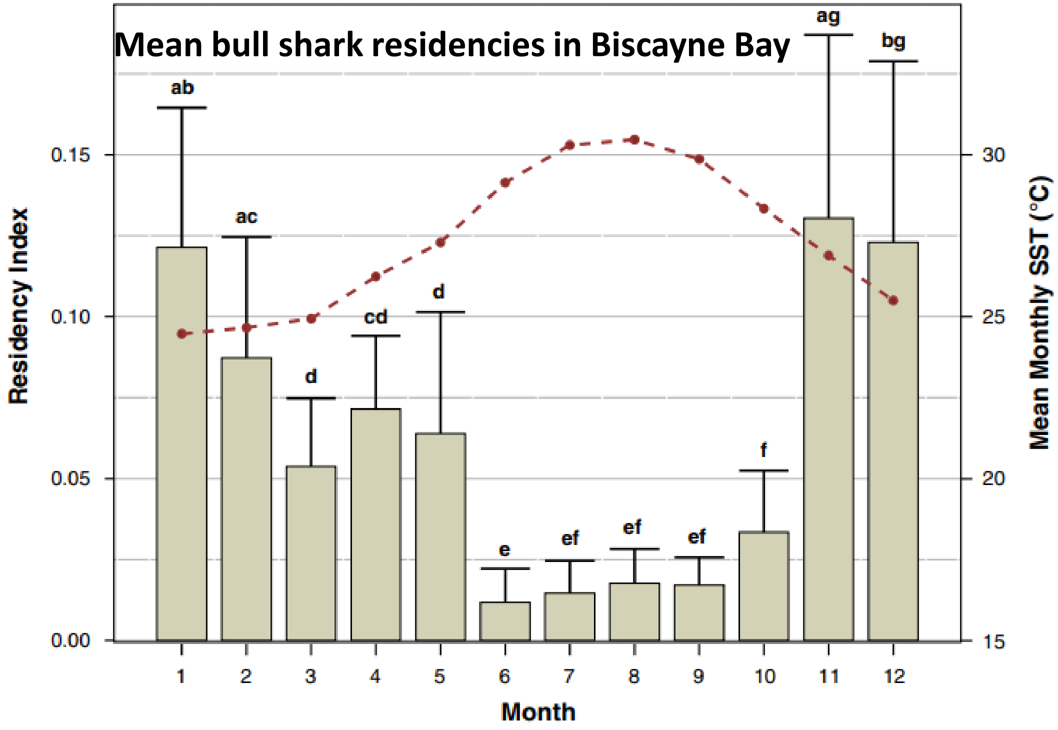
Analysis of Project Data: Is temperature driving the observed shark movement?



The graph shows the mean bull shark residencies in Biscayne Bay by month (Jan-Dec, 1-12 on the x-axis).

The red trend line shows the mean Sea Surface Temperature by month corresponding to this location .

Which five months had the highest SST? (6-10)

Which five months had the lowest bull shark residency indices (RI)? (6-10)

Was the RI in March significantly different than the RI in May? (No—same letter d)

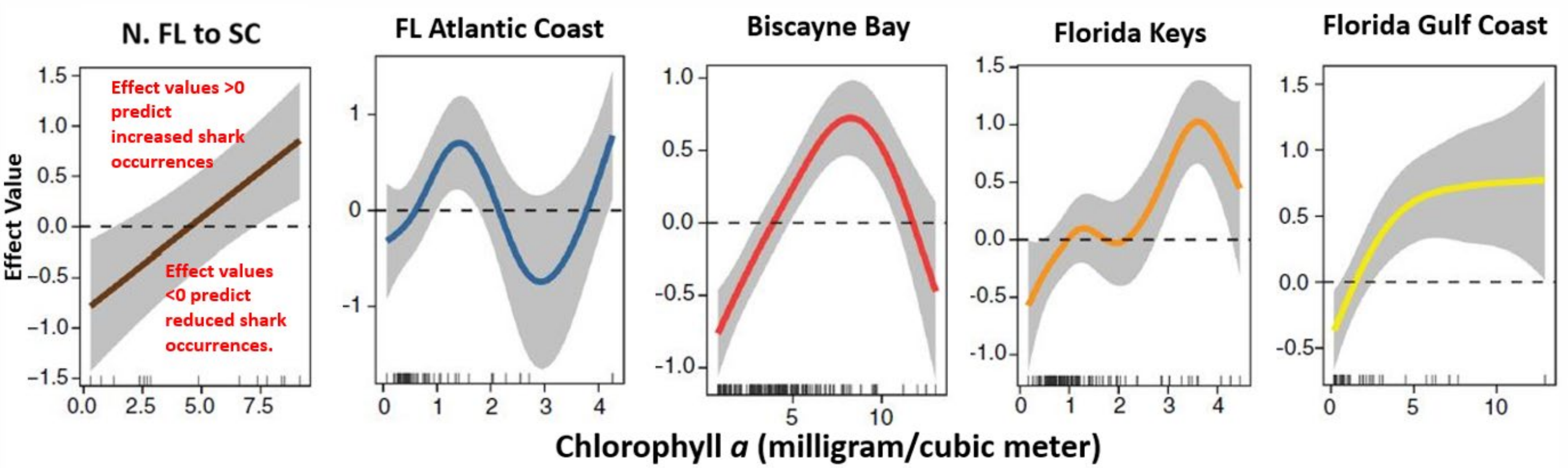
Was the RI in May significantly different than the RI in June? (Yes—letters d vs. e)

Temperature Summary
The highest mean residencies occurred between November and February when mean monthly SST were lower (24.5-26.8C).

SST >27C (e.g., summer) had a negative effect on shark presence.

The significant decrease in residencies from June-Sept occurred during the wet season (mid-May to October) and coincided with the highest mean monthly SST (29.1 to 30.5 C).

These graphs show the effect of Chlorophyll *a* on shark detections in each of five regions.



Like we saw with the SST Effect graphs, these graphs show how likely a shark is to be present at a given Chl *a* concentration. Use the graphs to answer the following questions.

At about what Chl *a* concentration do you start to see a positive effect on shark presence in N. FL to SC?

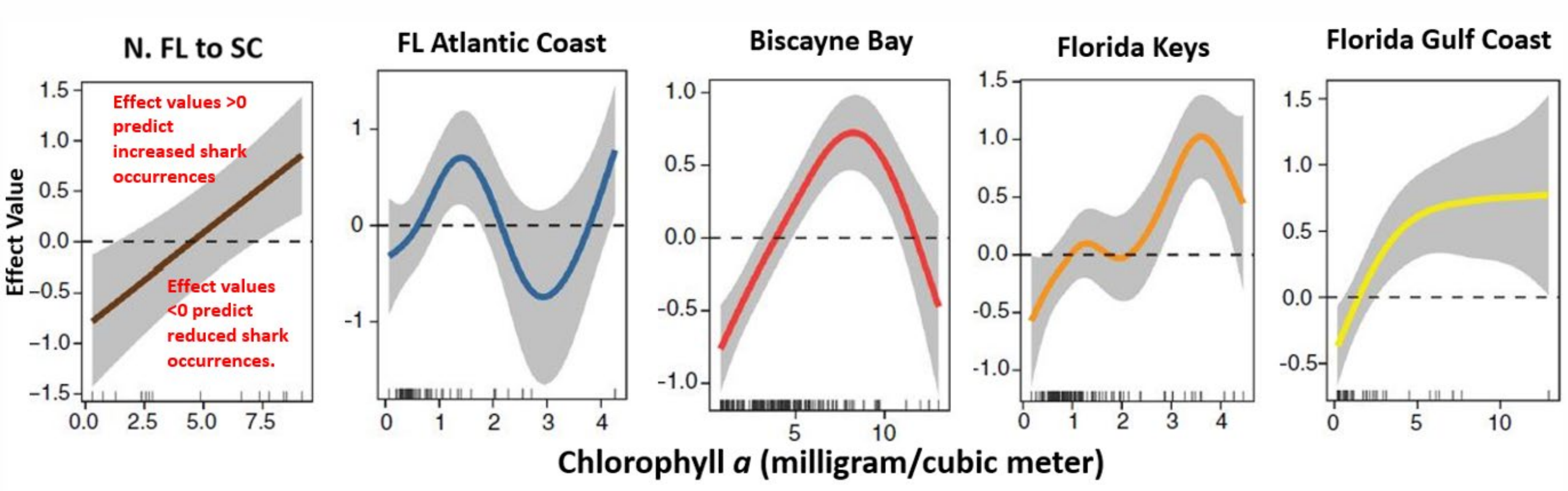
What is the lowest Chl *a* concentration that had a positive effect on shark presence along the FL Atlantic Coast?

Over what Chl *a* concentration range was there a positive effect on the presence of sharks in Biscayne Bay?
What was the effect on shark presence when values were above or below this range?

At the peak Effect value of 1.0 for the Florida Keys, what was the Chl *a* concentration?

For the Florida Gulf Coast, what was the highest Effective value observed, regardless of increasing Chl *a* concentration?

These graphs show the effect of Chlorophyll *a* on shark detections in each of five regions.



At about what Chl *a* concentration do you start to see a positive effect on shark presence in N. FL to SC? Greater than about 4 mg/cubic meter

What is the lowest Chl *a* concentration that had a positive effect on shark presence along the FL Atlantic Coast? About 0.5 mg/cubic meter

Over what Chl *a* concentration range was there a positive effect on the Cpresence of sharks in Biscayne Bay? 4 to 12 mg/cubic meter)
What was the effect on shark presence when values were beyond this range? Chl *a* values outside this range had a negative effect on shark presence.

At the peak Effect value of 1.0 for the Florida Keys, what was the Chl *a* concentration? About 3.5 mg/cubic meter

For the Florida Gulf Coast, what was the highest Effective value observed, regardless of increasing Chl *a* concentration? About 0.75

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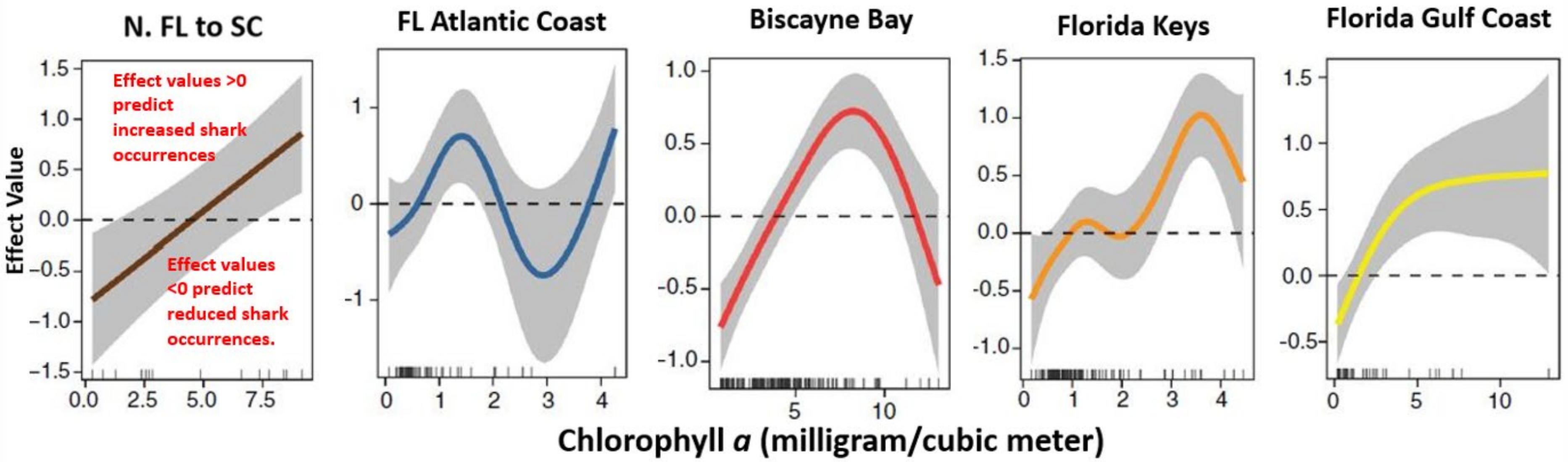
These graphs show the effect of Chlorophyll *a* on shark detections in each of five regions.



Chlorophyll *a* Summary

Most phytoplankton belong to the Kingdom Protista and have Chl *a* as the main pigment used in photosynthesis. Because Chl *a* is readily measured from sensors on satellites, it is conveniently used as a proxy for primary productivity and food abundance.

In this study, the concentration of Chl *a* significantly affected the number of days bull sharks were detected at each of the locations, suggesting that shifts in Chl *a* may serve as cues to initiate movement.

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Lesson Summary

Movement patterns of bull sharks (*Carcharhinus leucas*) acoustically tagged in Biscayne Bay, FL, and tracked along the U.S. Southeast Atlantic coast and Gulf of Mexico between 2015 and 2020 were the focus of this lesson, based on research published by Rider et al., 2021.

This is one of few studies looking at movement patterns over large spatial scales by collaborating across multiple acoustic networks. The Ocean Tracking Network, Integrated Tracking of Aquatic Animals in the Gulf of Mexico (iTAG), and the FACT array were valuable assets in this study. The project demonstrates how coordination of acoustic arrays across large spatial scales can enable understanding of movement patterns not previously possible.

Elements of good data stewardship, including the importance of metadata, were included in the lesson. Data Science Tools were explained, using R as an example of how Sea Surface Temperature and Chlorophyll *a* data corresponding to the times and locations sharks were present at different arrays, were scraped from websites (NOAA ERDDAP servers).

Analyses of project data occurred throughout the lesson, including acoustic receiver range testing to understand how the placement of receivers at a field site is determined. The lesson addressed the five "W"s of the study:

> Who was tagged (22 bull sharks; 16 of which met the criteria for inclusion in data analyses)
> What was the purpose of tagging (to better understand the movement ecology of bull sharks)
> Where did they go (from the northern Gulf of Mexico to as far north as Maryland)
> When did they go (they were tracked year-round, with site-specific patterns emerging)
> Why did they go (environmental effects of SST and Chlorophyll *a* were investigated)

Conclusion: both SST and Chl *a* had significant effects on the presence of bull sharks in all regions investigated, suggesting that shifts in these may serve as cues to initiate movement related to life history events.

Think About It

One of the main conclusions the investigators inferred from the project results was that Biscayne Bay might play an important role in the reproductive cycle of bull sharks.

While they mainly tracked subadult and adult females in this study, they reviewed tracking data from studies they previously conducted and found that they had caught more mature females during the dry season (about December to April).

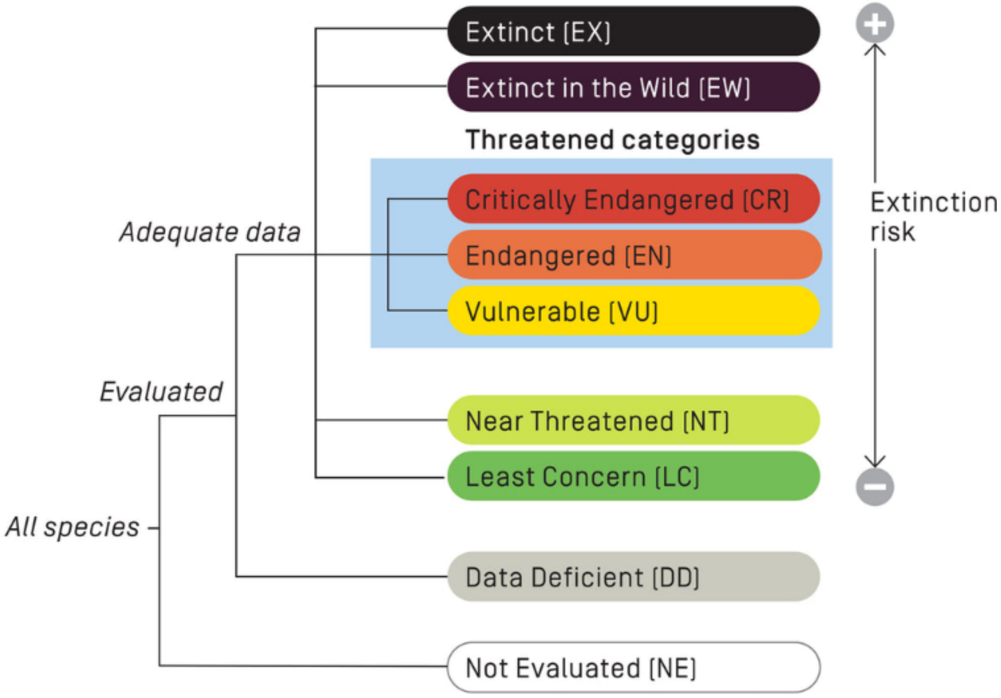
Do you have ideas about how they might corroborate these inferences? Examples to start the dialogue:

- Satellite-tag mature females to get higher resolution tracking information
- Use cameras within the acoustic array to identify specific behaviors
- Take blood samples to determine reproductive status
- Ultrasound captured sharks to determine if pregnant

Next steps: investigate how these findings are important for resource management. Examples:

- Developing species management plans
- Creating policies that limit bycatch
- Establishing protected areas

Note: Lesson 2 in this series has application examples.



The IUCN Red List of Threatened Categories in increasing order of risk from bottom to top. (Source: IUCN, 2012.

- Bull sharks are widely fished for their fins and oil, but not much is known about their population trend.
- Unfortunately, they are also often caught as bycatch.
- The International Union for Conservation of Nature (IUCN) lists the bull shark as near threatened.

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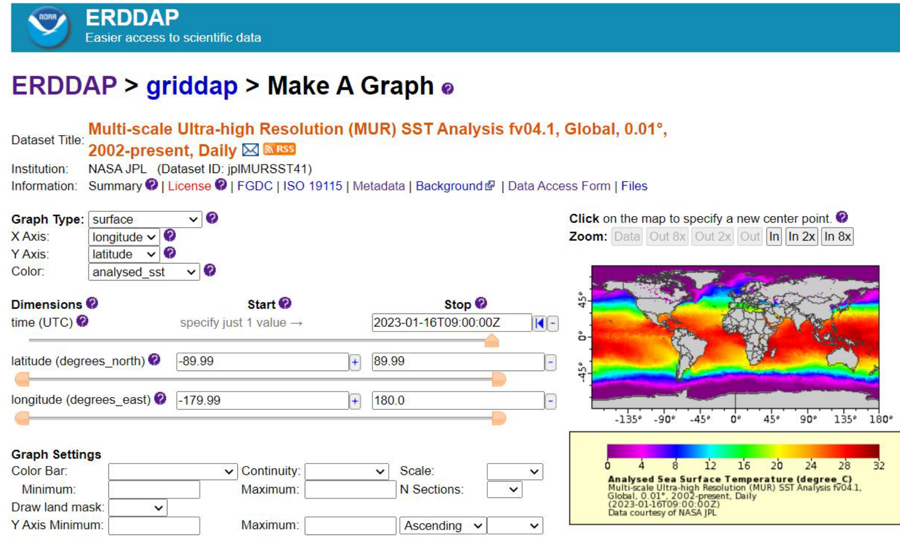
A Deeper Dive into Environmental Data

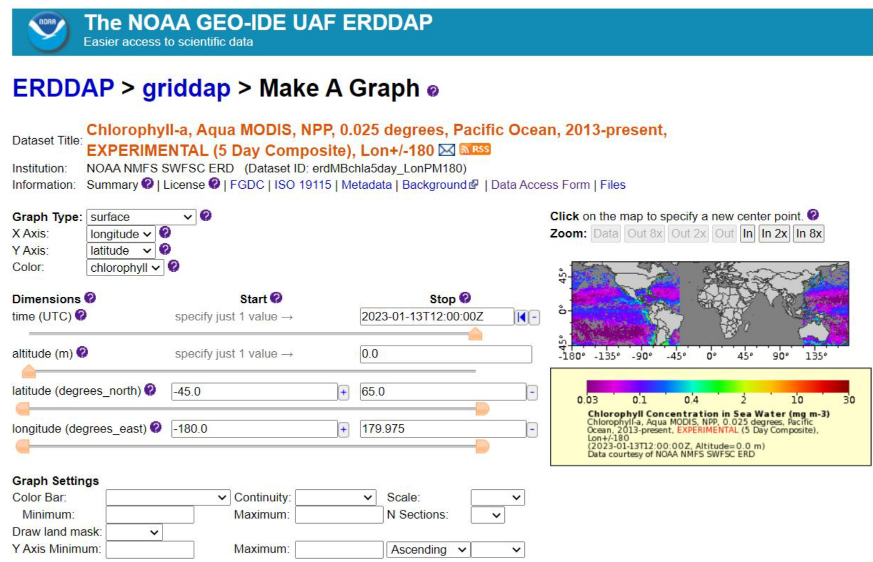
SST and Chlorophyll *a* data used in this study were made available from the NOAA GEO-IDE UAF ERDDAP project.

- NOAA: National Oceanic and Atmospheric Administration
- GEO-IDE Global Earth Observation-Integrated Data Environmental initiative
- UAF: Unified Access Framework project
- ERDDAP: NOAA's Environmental Research Division's Data Access Program.

The ERDDAP program is aimed at providing easier access to all of NOAA's data in a simple, consistent way. You can download subsets of gridded and tabular scientific datasets in common file formats and make graphs and maps.

Learn more at https://upwell.pfeg.noaa.gov/erddap/index.html





Resources

https://www.teachengineering.org/lessons/view/duk_marine_musc_less2

https://nationalzoo.si.edu/migratory-birds/what-satellite-telemetry

https://www.researchgate.net/publication/334044228_Animal-Borne_Telemetry_An_Integral_Component_of_the_Ocean_Observing_Toolkit

https://www.sciencedirect.com/science/article/abs/pii/S0169534719300242

https://link.springer.com/article/10.1007/s10452-021-09845-6

https://www.frontiersin.org/articles/10.3389/fmars.2020.608848/full?&utm_source=Email_to_authors_&utm_medium=Email&utm_content=T1_11.5e1_author&utm_campaign=Email_publication&field=&journalName=Frontiers_in_Marine_Science&id=608848

https://necoopunit.unl.edu/downloads/Publications/Joseph%20TJ%20Fontaine%20publ/Laskowski%20et%20al%202016-1.pdf

https://masweb.vims.edu/bridge/index.cfm

https://sharks.panda.org/images/RAT/pdf/WWF_RAT_Tool5_TaggingTracking.pdf

https://graysreef.noaa.gov/science/research/fish_tagging/faqs.html

https://www.fisheries.noaa.gov/new-england-mid-atlantic/atlantic-highly-migratory-species/tagging-instructions-and-resources-volunteers

Types of tags: Australia/Hueple https://sharks.panda.org/images/RAT/pdf/WWF_RAT_Tool5_TaggingTracking.pdf
NOAA info about tags https://graysreef.noaa.gov/science/research/fish_tagging/faqs.html

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