Exploring the Blue Planet With PNT (Biologging) Technology

Barbara Block, Stanford University

PNT Symposium 2015

Grand Challenges: Observing Stress on Our Ocean Ecosystems

FISHING

- Overexploitation
- By-Catch
- Habitat Degradation

CLIMATE CHANGE

- Thermal, pH, CO_2
- Hypoxia, Acidity
- Stress, Disease
- Sea Level Rise
- Habitat Loss

Challenges for Ocean Science:

Will We Know When Our Seascapes are Changing?

The Ocean is Not Transparent
How Can We Observe Ocean Ecosystems?

Marine Domain Awareness
How Can We Monitor Marine Protected Areas

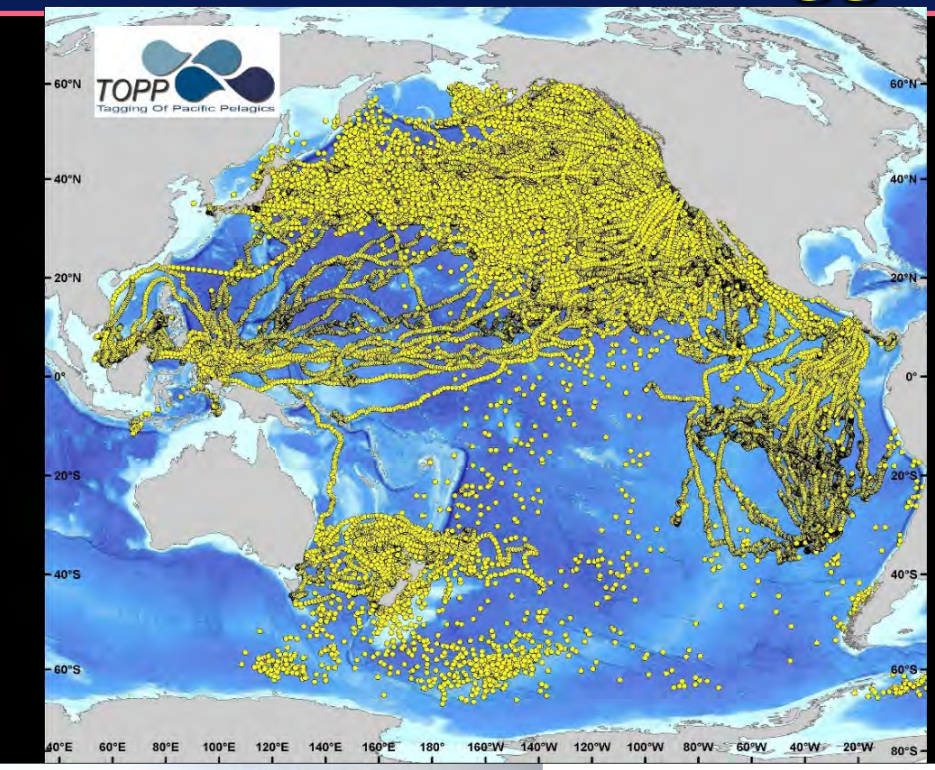
MPA Environmental Monitoring

Active Wildlife Tracking & Anti-Poaching

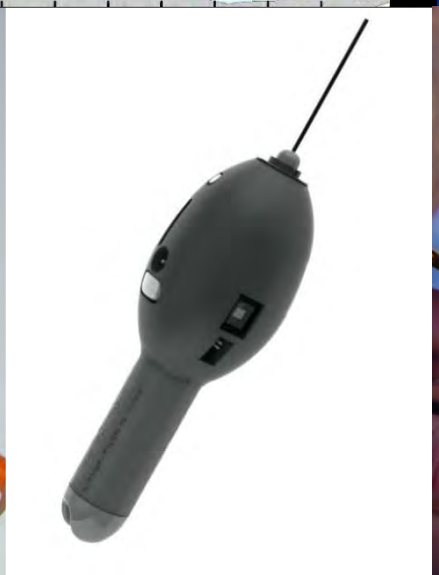
Fish and Shark Tracking

Ocean Observation for
Detecting Climate Change

Biologging Science

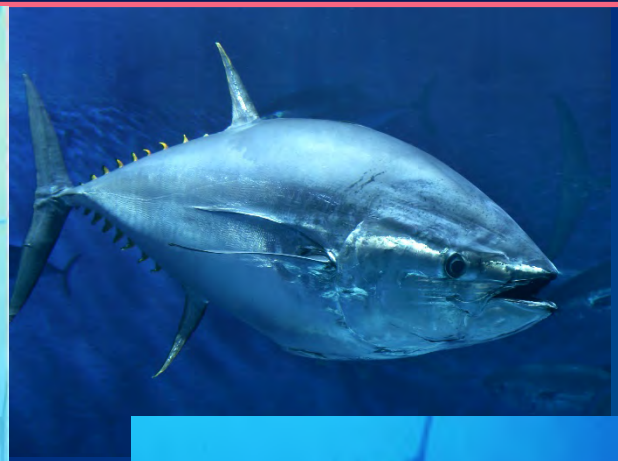


- **Position:** Argos, GPS, Light, Acoustic
- Migration s
- Habitat Use
- Foraging & Spawning Biology
- Population Structure
- Management & Assessment
- Climate Change
- Physiology: How Animals Work



Conservation Technology

Motivation: Global Decline of Marine Resources



- *Myers & Worm, 2003*

Bluefin Tunas: Ferrari of the Sea

The Global Hunt for Tunas

Massive Bluefin Tuna Sells for $1.76 Million at Tokyo Auction

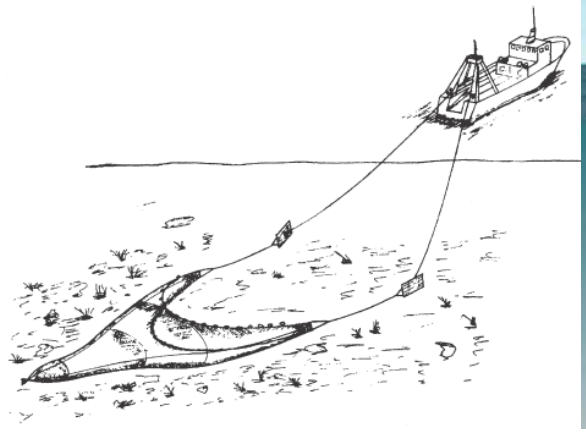
1/7/13 at 1:25 PM | Comment

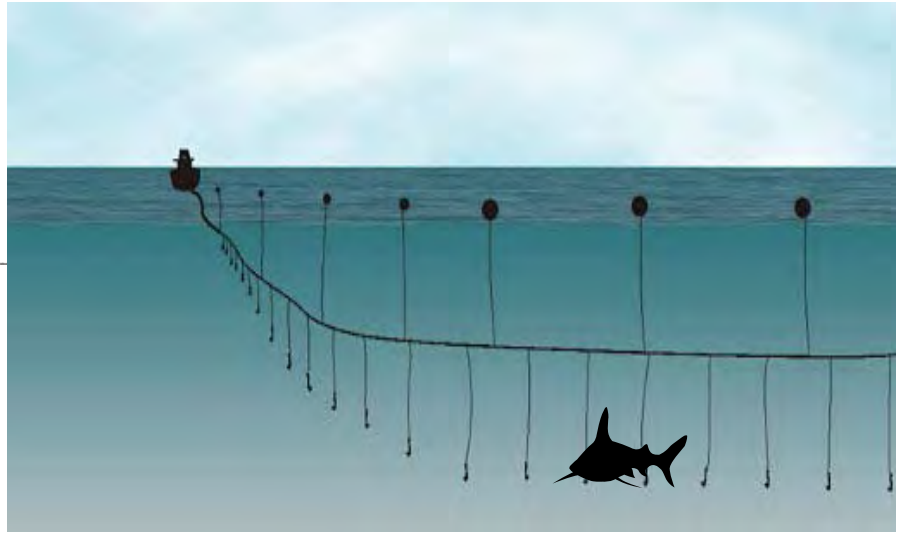
Even the buyer admits the price was 'a bit high.'
Photo: ntd.tv

Saturday was the first tuna auction of the year at Tsukiji Fish Market in Tokyo, and a single, 489-pound bluefin tuna sold to a sushi restaurant magnate for a staggering 155 million yen – that would be $1.76 million, or $3,600 per pound. The buyer, as multiple outlets have reported, was Kiyoshi Kimura, owner of the Sushi-Zanmai restaurant chain; and some customers at one of his restaurants

Predators in Decline

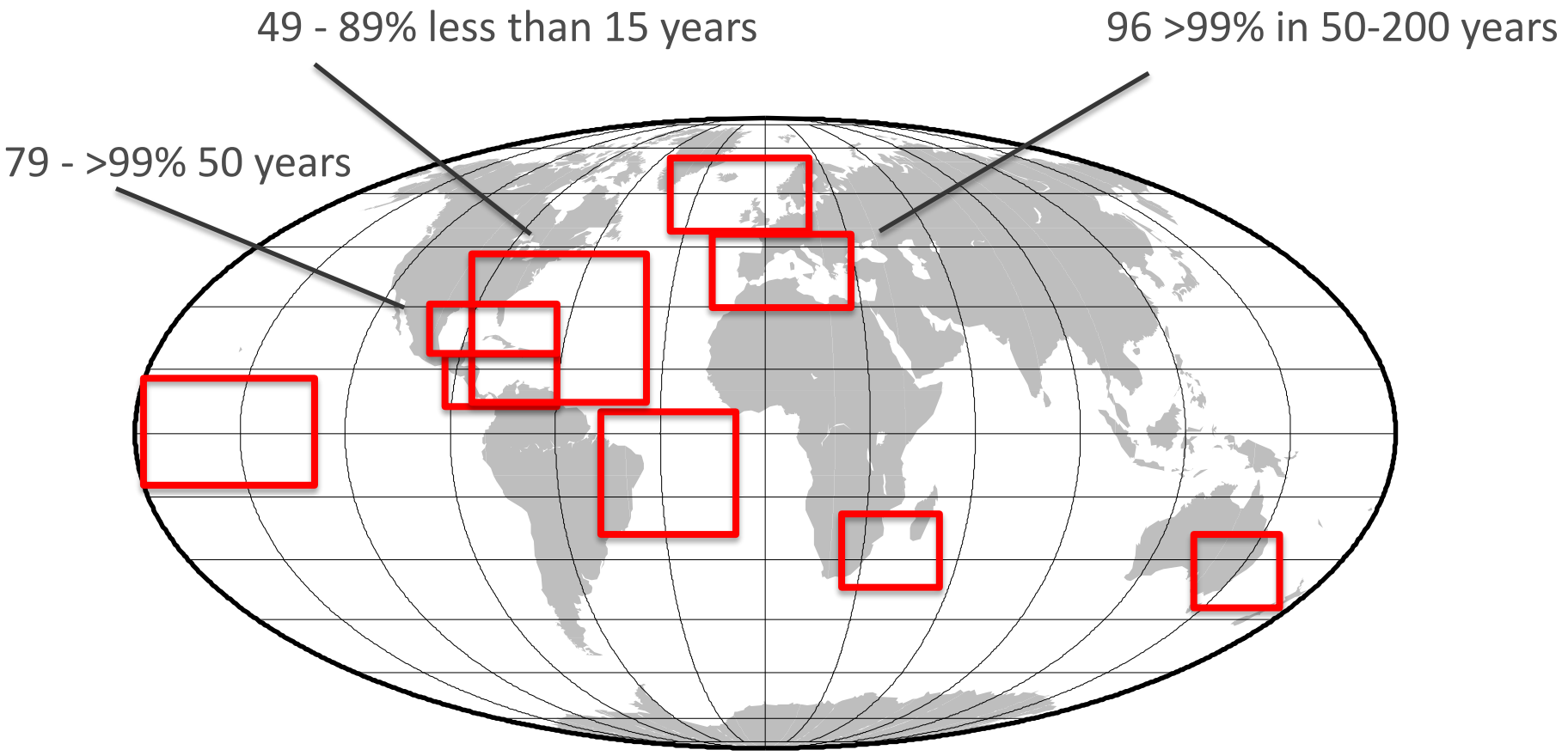
Sharks are declining worldwide (By-catch)

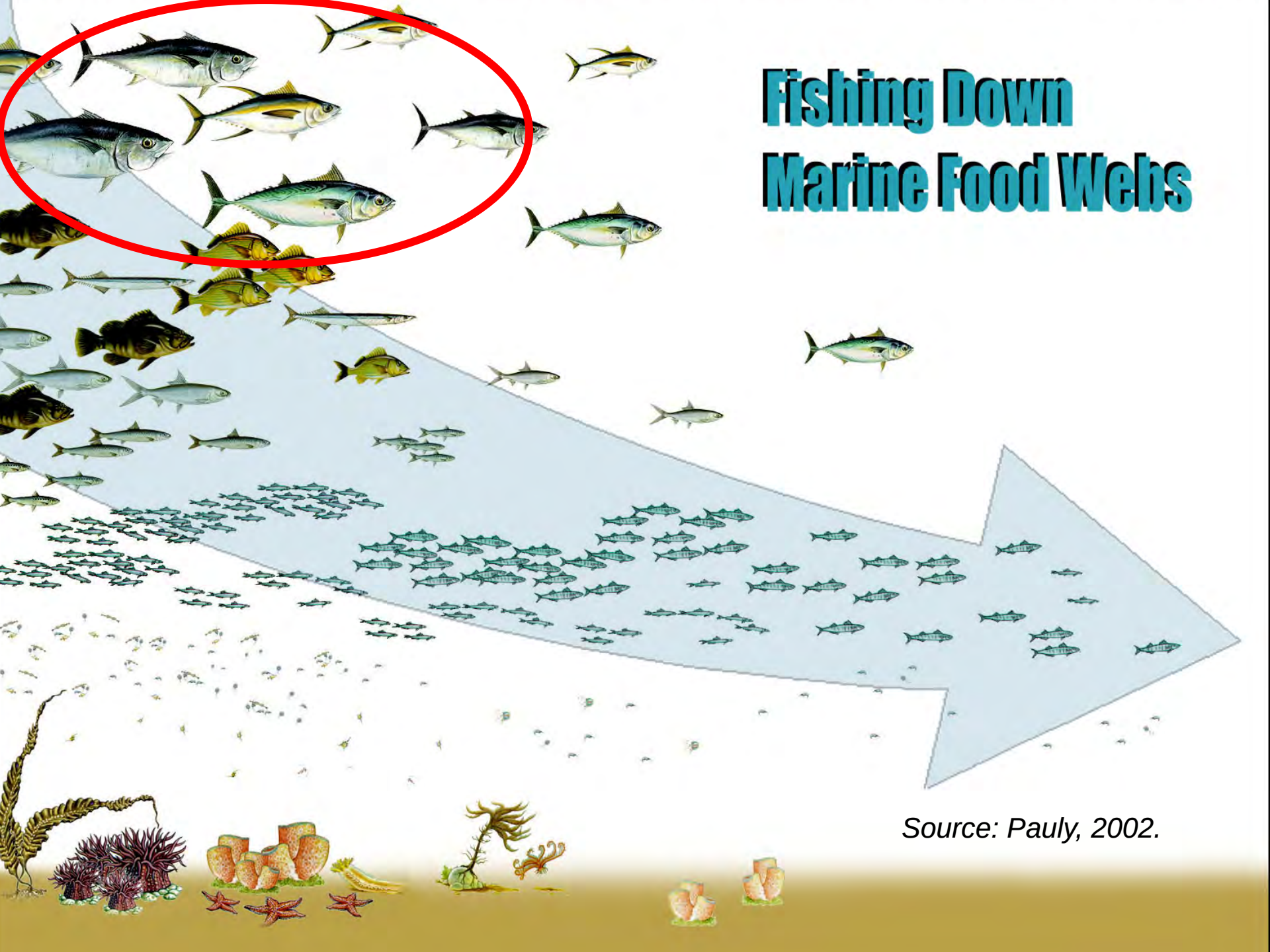




Sharks are declining worldwide (New target species)

Estimates of decline





Source: Pauly, 2002.

Terrestrial vs. Open Ocean Carnivores

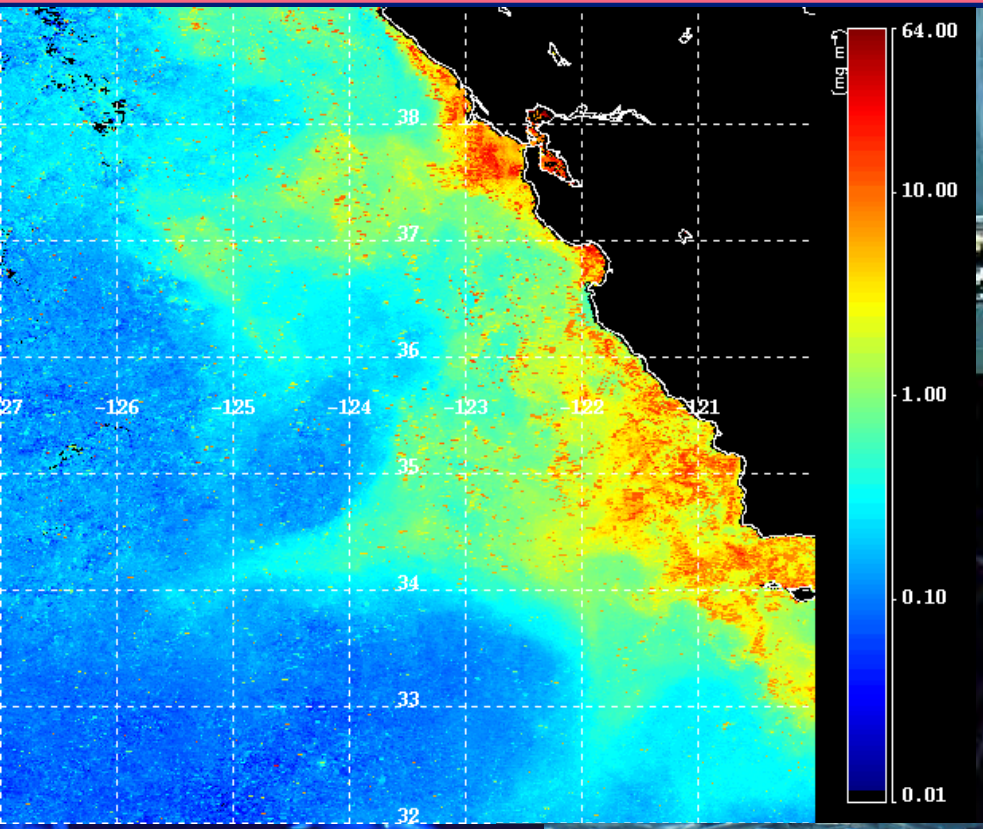
Why Do We Know So Little?

B.Skerry
NGS

Basic Questions: How Many White Sharks are there In the Northeastern Pacific?

Photo credit: Oceans

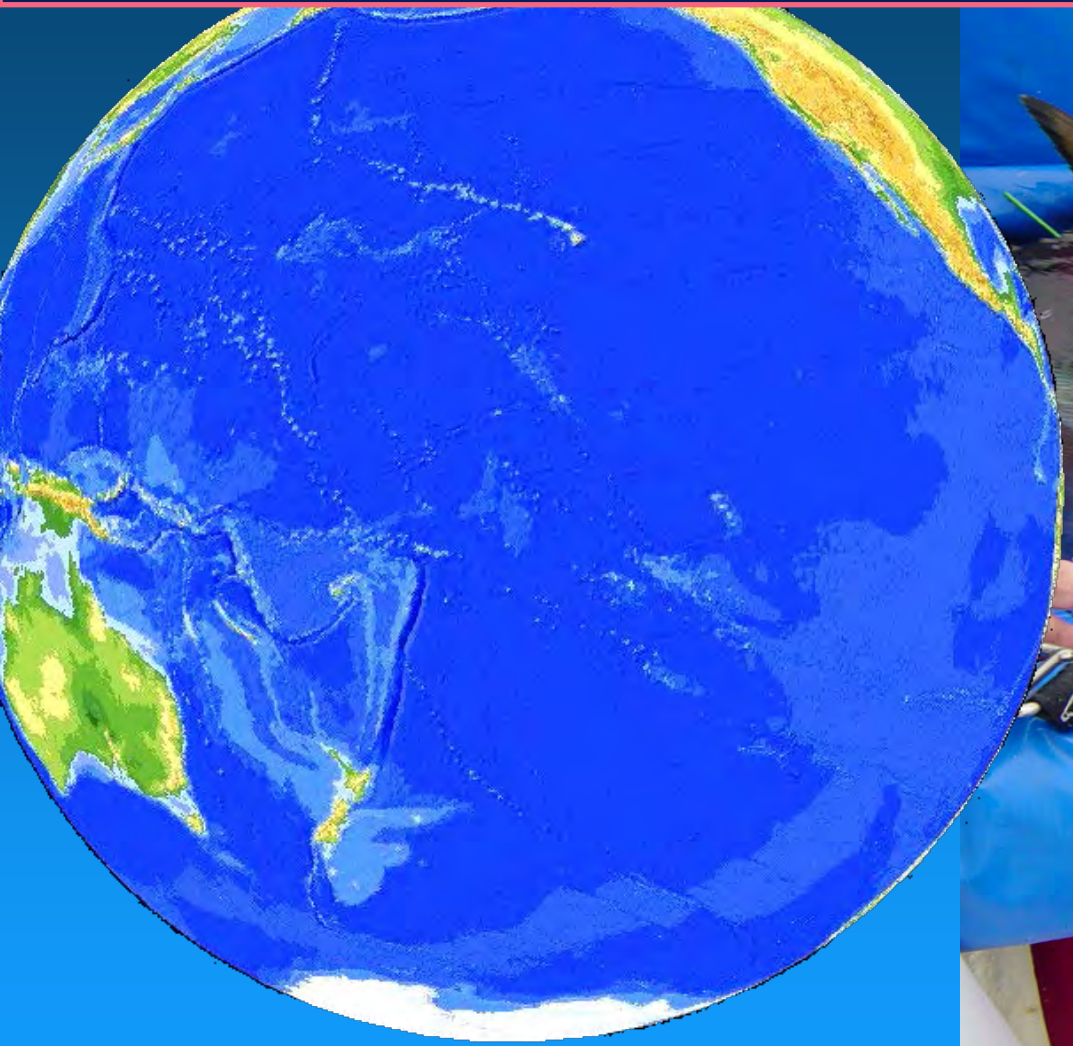
Where are the Hot Spots in a Dynamic California Current Ecosystem & Why?



Where are the Migratory Highways & Watering Holes in the Oceans

The Challenge: Fish are submerged

Large Home Ranges & Difficult to Retrieve Electronic Devices



Challenges: How Do You Catch and Tag a Large White shark?

The Engineering Challenge: Attaching Tags to Fast Moving Animals

B. Mate, OSU

Pelagic Habitats Move

Credit: E. Hazen NOAA

Tuna Research & Conservation Center
1994-2015

TAG & TOPP TECHNICAL APPROACH

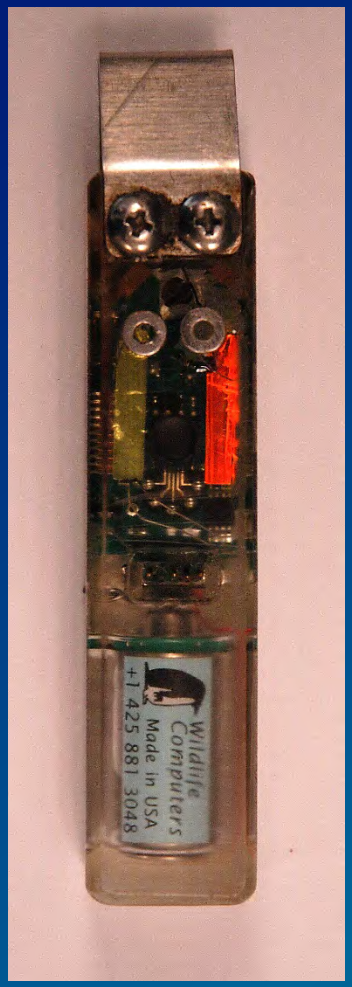
Engineering Partnerships Focused on Tag Development

National Oceanographic Partnership Program
Promoting Partnerships for the Future of Oceanography

CTD Tag

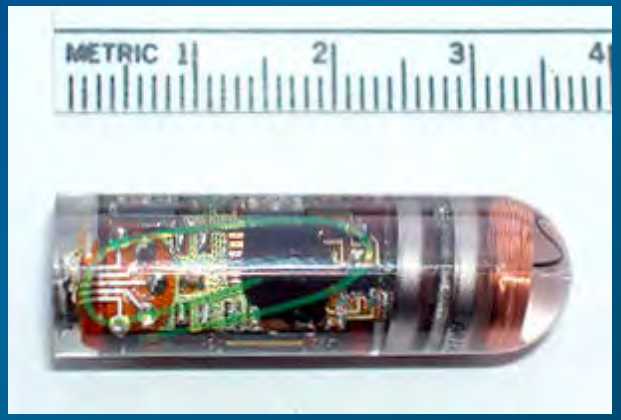
Prototype GPS Tag

Dual Wavelength Tag



Rapid Temperature TDR

Geolocation Tag (6 g)



Archival Tags: Data Loggers

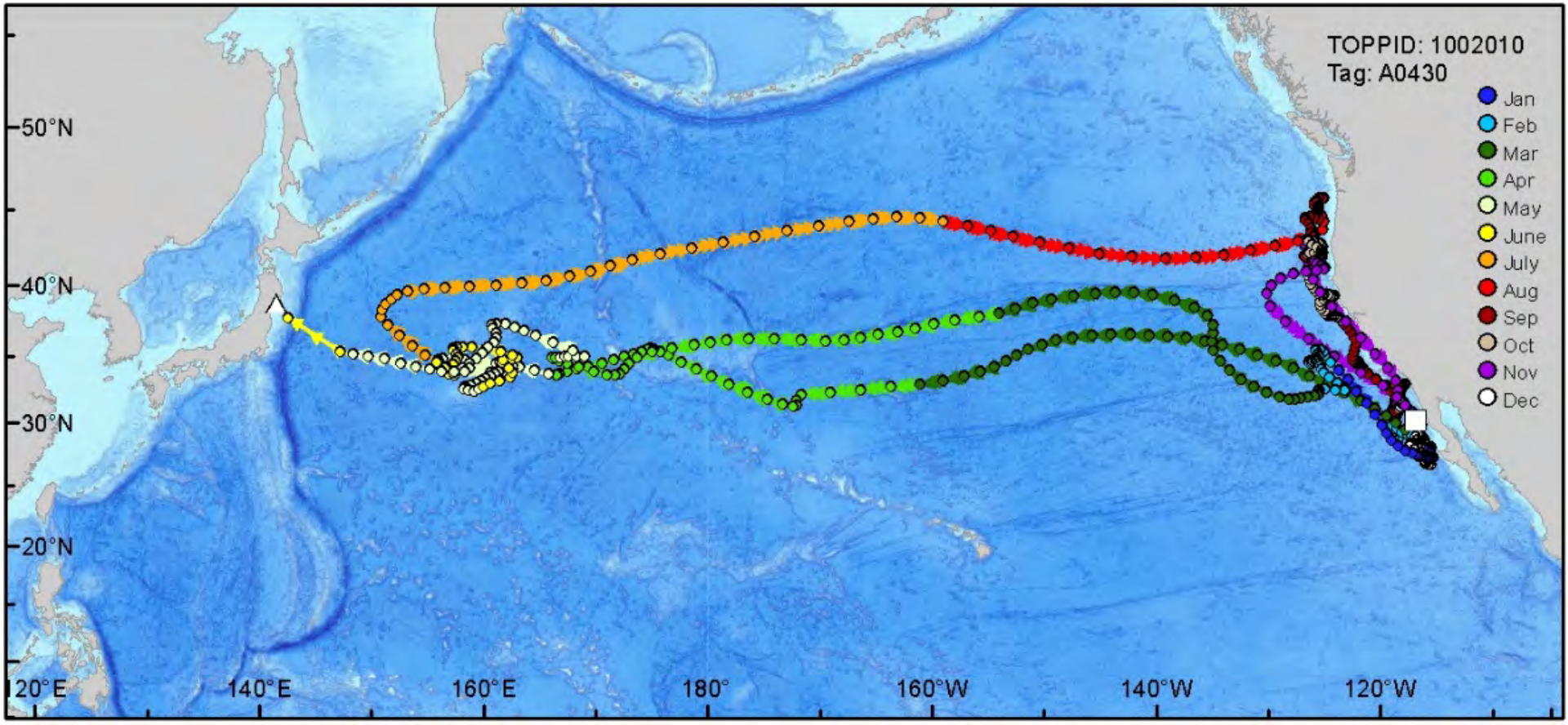
2mm Teflon Sensor stalk

3.6 V Lithium Batter

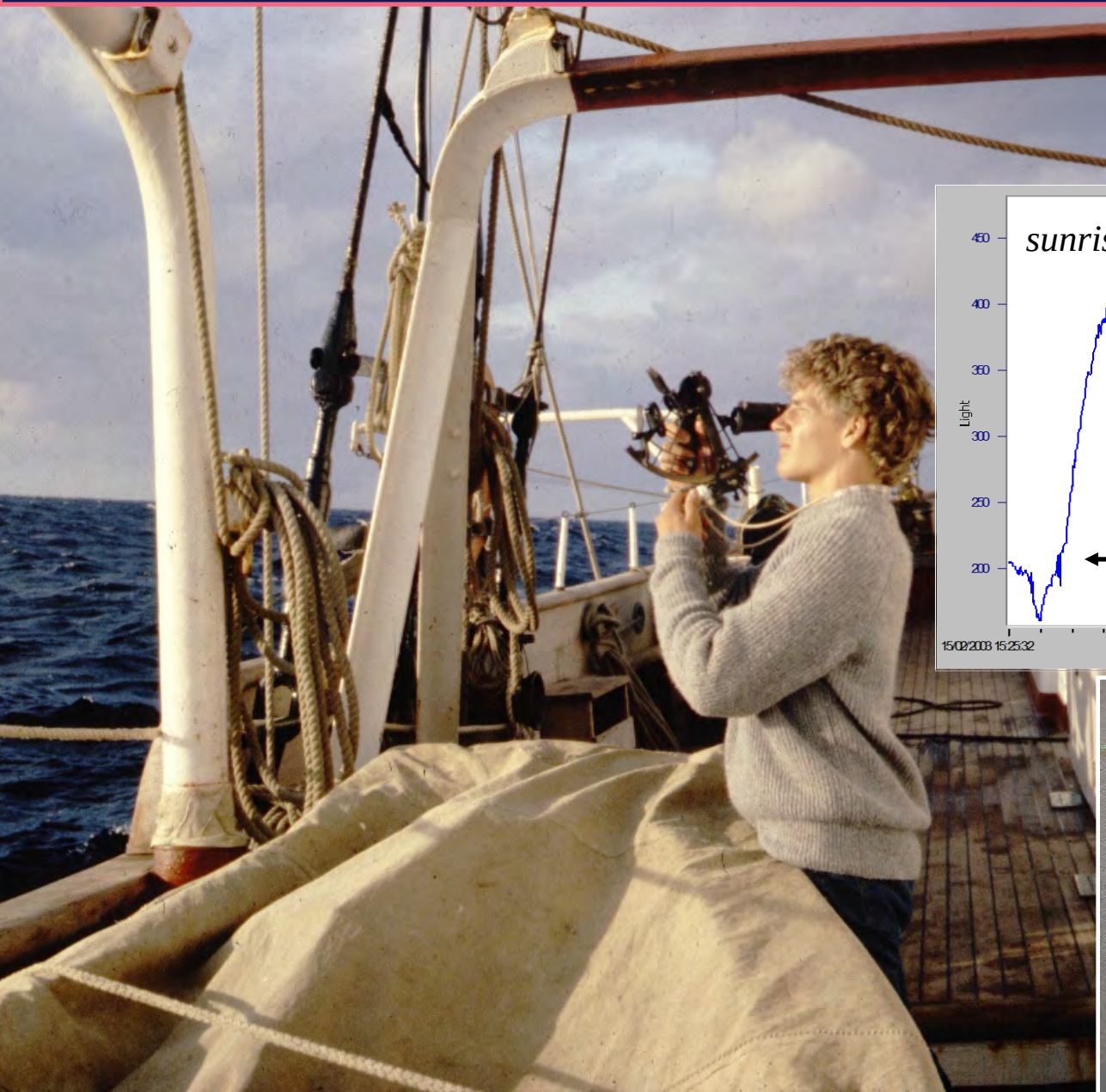
- *16-128 MBytes*
- *Pressure, 2000m*
- *Temperature –5°C/40°C*
- *Light 470nm*
- *Salinity*
- *Real time clock*
- *Physiology*
- *Position*
- *Oceanography*
- *16 million readings*

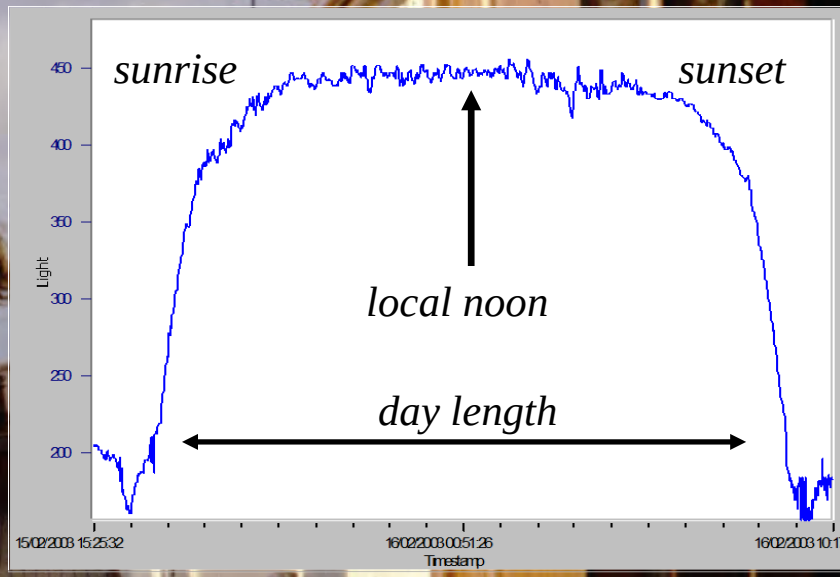
Examples of Trans-Pacific Migratory Behaviors

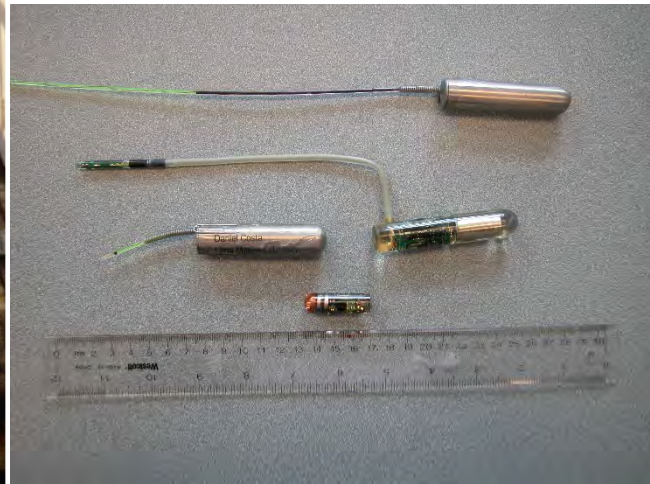
TOPP ID 1002010, TAG A0430, ~640 days at Liberty (from ~2.3-4.1 years of age)



Archival Tags Use Light Collected Under the Sea to Calculate Astronomical Based Geolocations

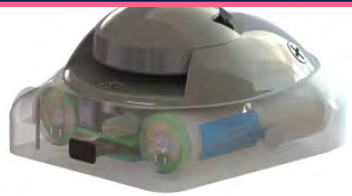






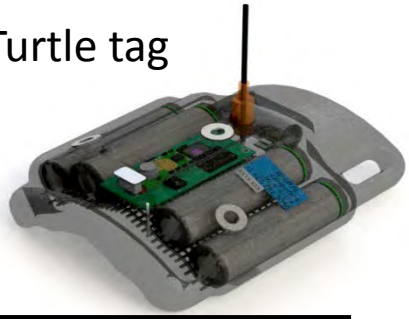
Conservation Technology: Ecosystem Monitoring With Animal Tags

"Environmental Intelligence"



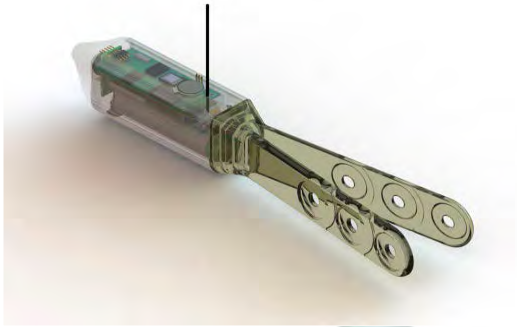
Daily Diary

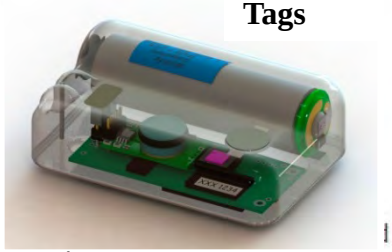
Turtle tag



MiniPAT Pop-up

Acoustic Tags

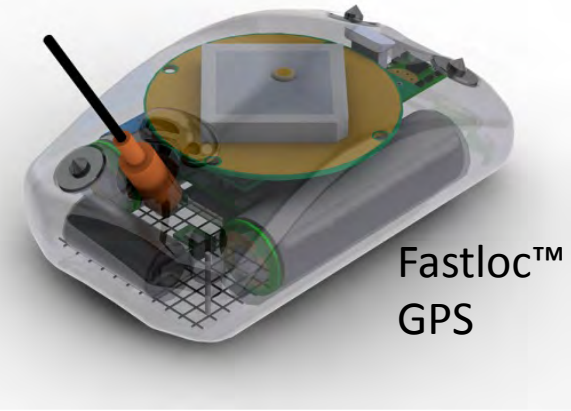




Accelerometer

Satellite Relay Data Logger (SRDL)

Archival Tag

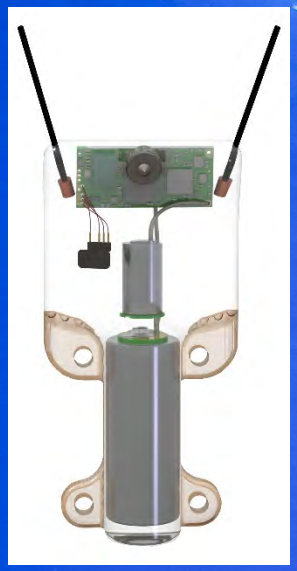


Wildlife Computers

Argos Satellite Telemetry

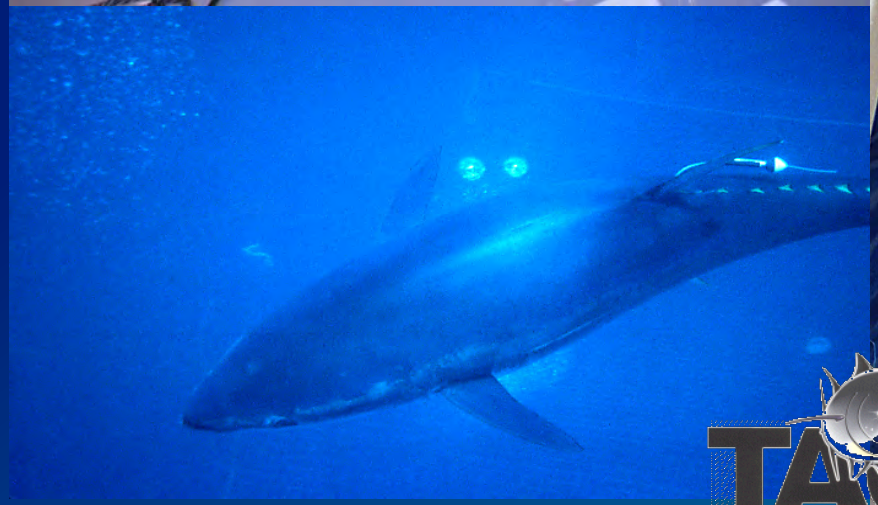
- Radio Telemetry
- Position
- Oceanography
- Behavior & Physiology
- Life History (mortality, survivorship data)
- Population Abundance

Fastloc GPS on Sharks



Daily Diary & Camera Tags: Behavior

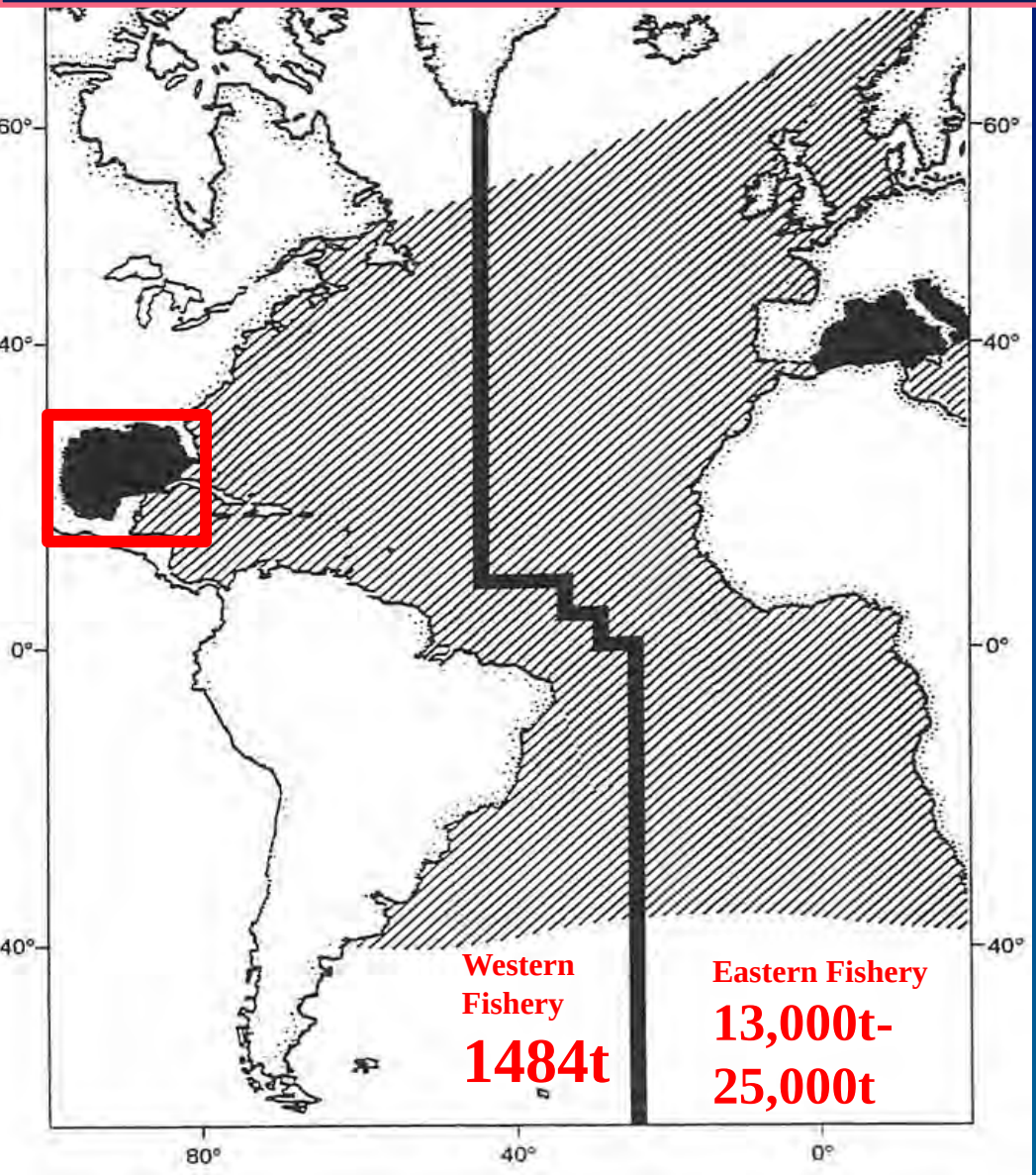
TAG A GIANT CAMPAIGN 1996-2015
~2000 Atlantic & Pacific Bluefin Tuna Tagged



TAG
TAG A GIANT

Critical Questions for International Management (ICCAT)

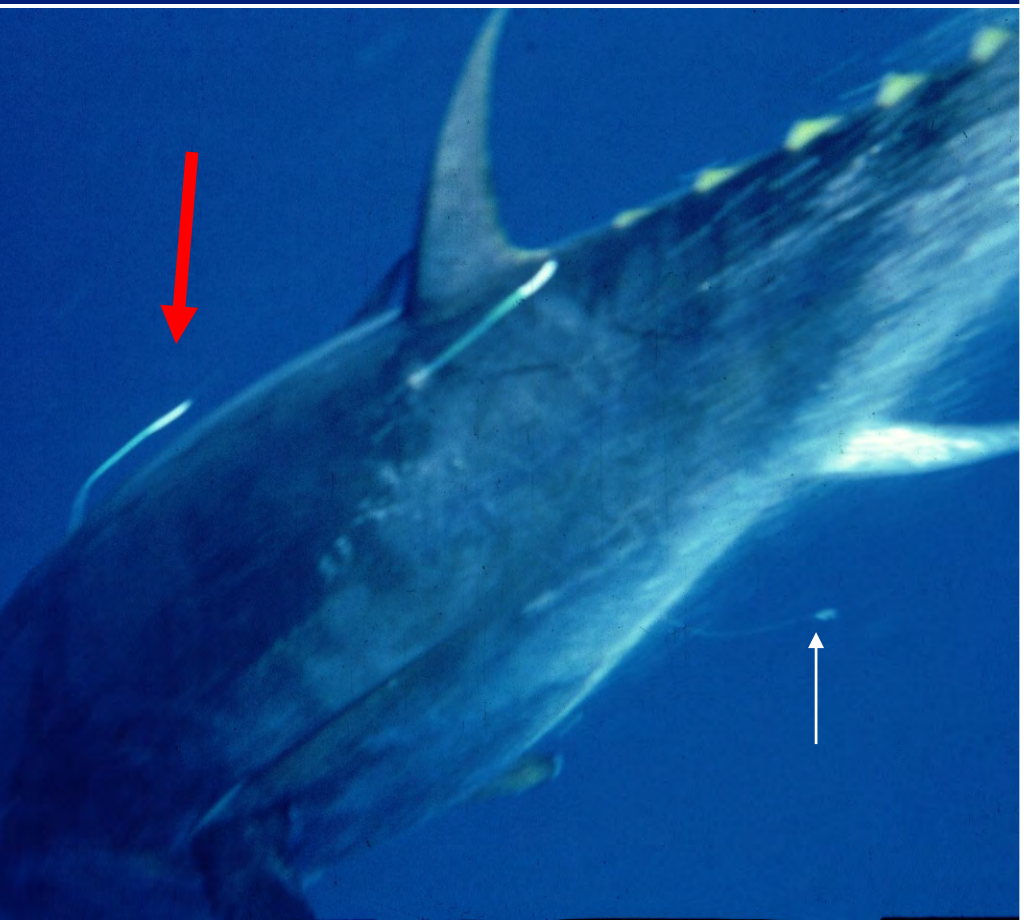
Uncertainty of Population Mixing Limits Management Actions



Areas of Uncertainty

1. How Many Stocks
2. Mixing
3. Ages to Maturity
4. Where are Breeding Grounds
5. Natal Homing
6. Population Numbers

Archival Tagged Fish Marked Externally



Archival Recaptures of Bluefin Tuna Are 22% in Atlantic; 54% in Pacific Ocean

Canada

Spain

Cuba

Taiwan

France

Tunisia

Italy

United States

Japan

Morocco

Libya

Russia

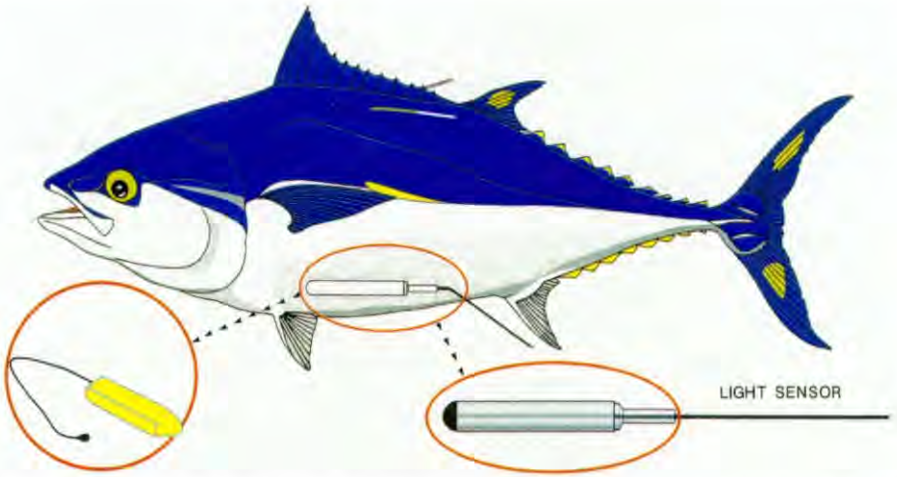
Malta

Portugal

Bahamas

OFFERED FOR

ARCHIVAL TAGS FROM ATLANTIC BLUEFIN TUNA



What are archival tags? Archival tags are electronic data-logging devices that provide location estimates by measuring light intensity through a light sensor. They also provide data on swimming depth, water temperature, and body temperature of the fish. This information is collected on a daily basis and stored in the tag for several years.

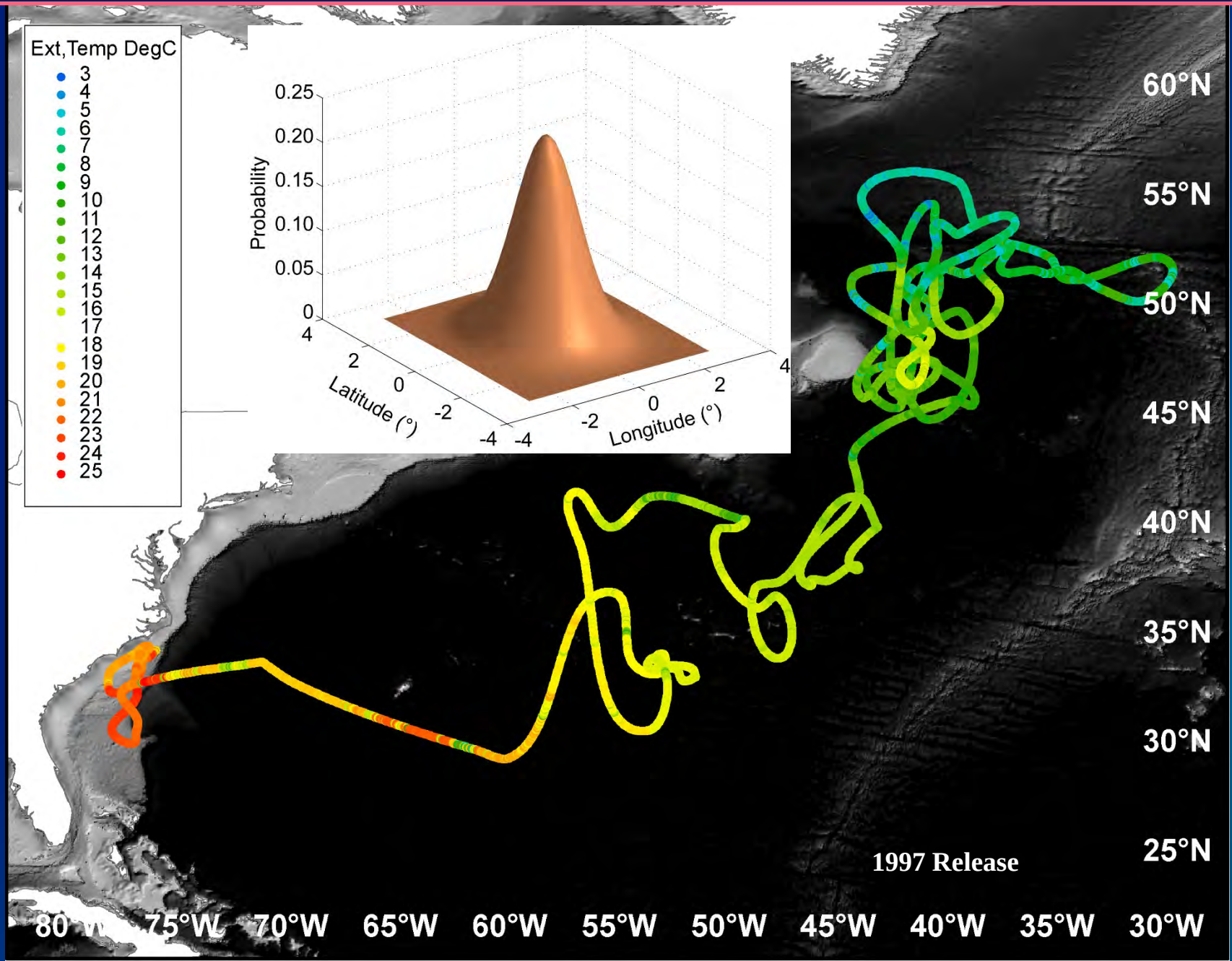
How do you determine that a bluefin tuna has an archival tag? Archival tags are implanted in the body cavity of the tuna and only the light sensor protrudes out of the body. However, these specially equipped bluefin tuna also carry unique external conventional streamer tags, with two-tone coloration, to help fisherman recognize these fish and return the archival tags. The external tags are placed about an inch off the dorsal midline on each side of the fish. On the white portion of the streamer tag it says "electronic tag inside cavity" and on the green side it says "Big $$$ reward".

PROCEDURE FOR GETTING YOUR REWARD:

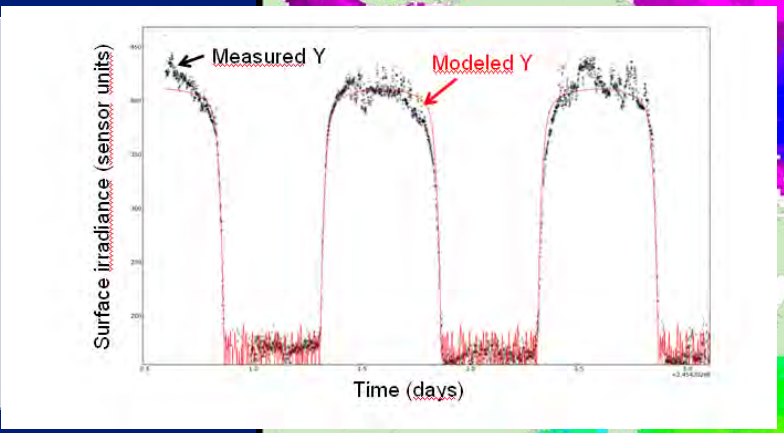
1. Report all archival tagged bluefin tuna to **YOUR LOCAL FISHERIES AGENCY**, or in the West Atlantic call the toll free number 1-800-437-3936 [1]. In the East Atlantic/ Mediterranean call the International Commission for the Conservation of Atlantic Tunas (ICCAT), Madrid, Spain, at 34-1-579-3352. Additional instructions will be provided regarding where and how the tags should be mailed. Inquires can also be made to Dr. Eric Prince at his email address: eric.prince@noaa.gov

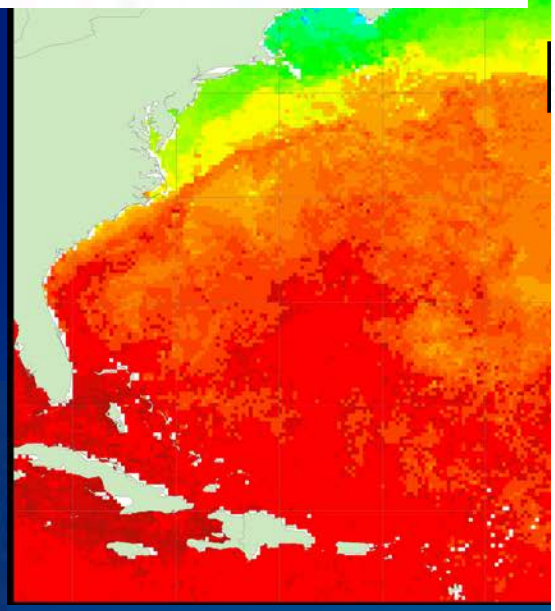
2. **DO NOT REMOVE THE ARCHIVAL TAG BY PULLING ON THE LIGHT SENSOR.** To remove the archival tag, make a carefully placed 6 inch incision in the belly cavity, in front of the area where the sensor enters into the fish. Remove the silver or yellow archival tag (with light sensor attached) by hand. Wash the tag with water and keep it at room temperature. Streamer tags can be cut off the fish and the portion of the tag with writing or information should be kept. In addition to saving both the archival and streamer tags, data on location and date of recapture, fishing gear used, length, weight of fish, and your name and address are also important.

Bluefin: Tracking Animals that Remain Submerged

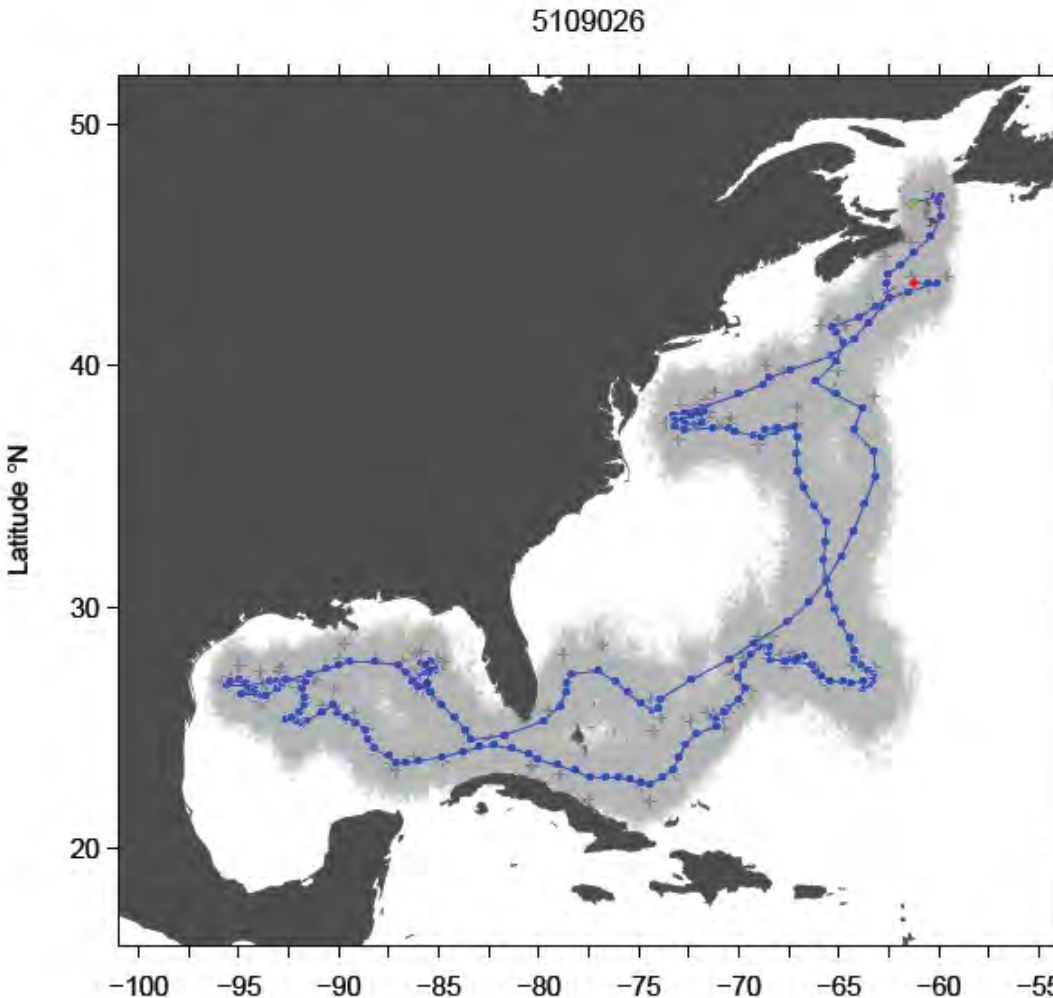


Longitude by Light, Latitude is Determined Comparing Archived Sea Surface Temperature (SST) vs. Remotely Satellite SST



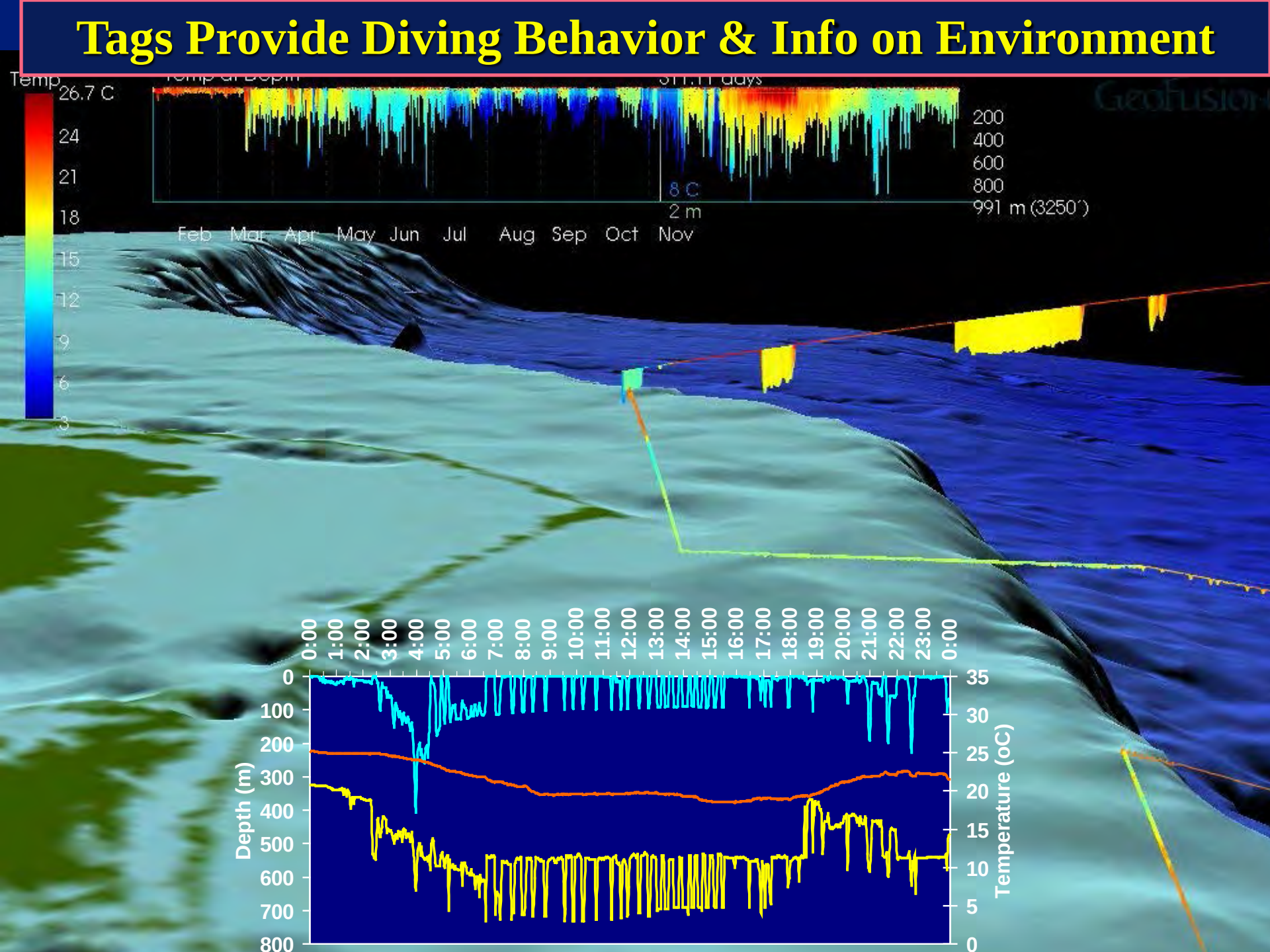


Probability



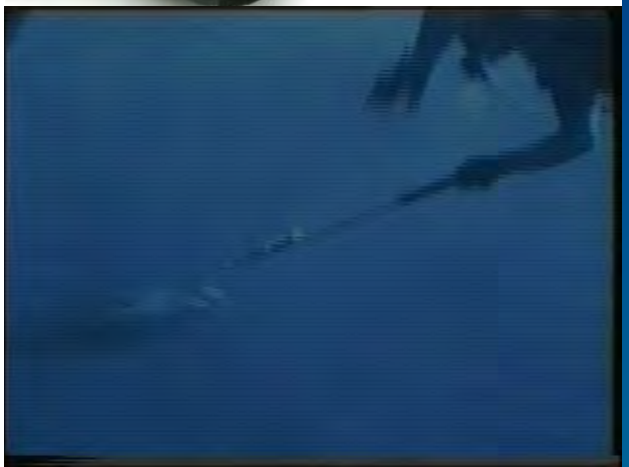
Tuna Research and Conservation Center
Hopkins Marine Station • Monterey Bay Aquarium

Tags Provide Diving Behavior & Info on Environment



Pop Up Satellite Archival Tags

Radio Transmissions to Argos, 4 Generation of Tags

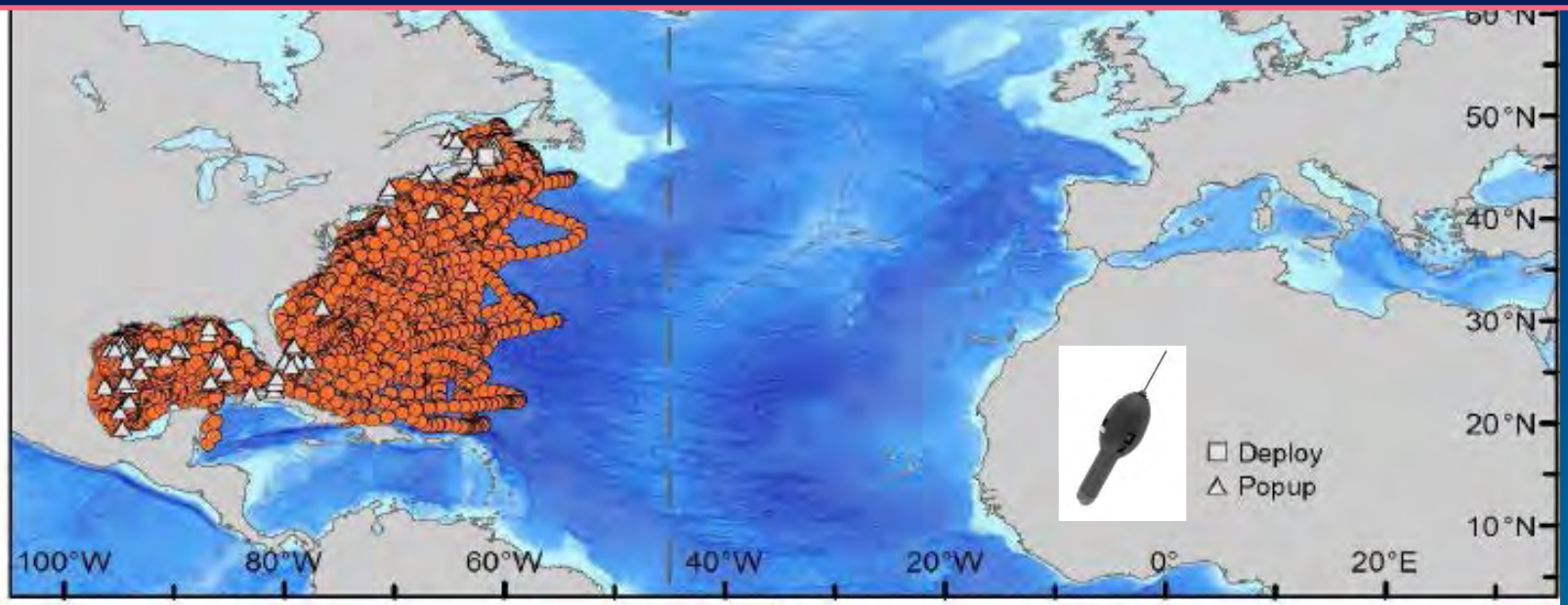


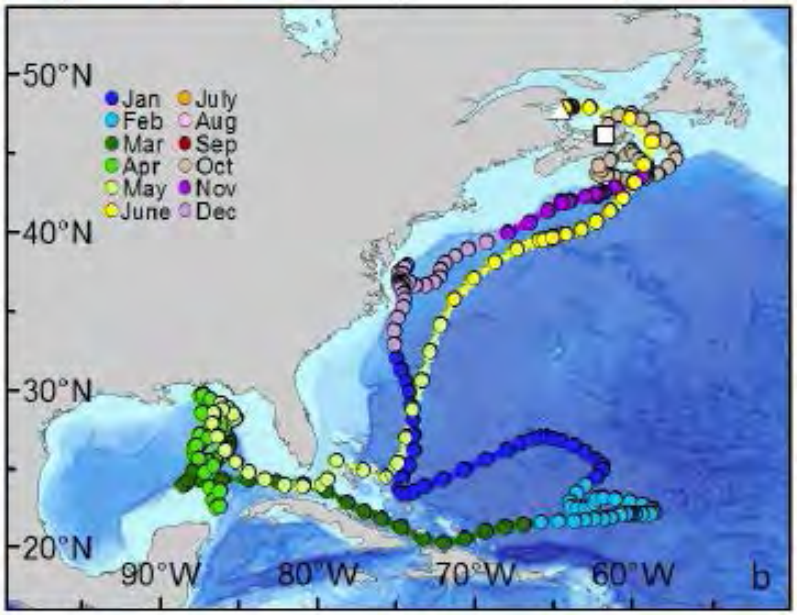
- Pressure
- Temperature
- Light
- Position on Earth
- Oceanography
- Fisheries

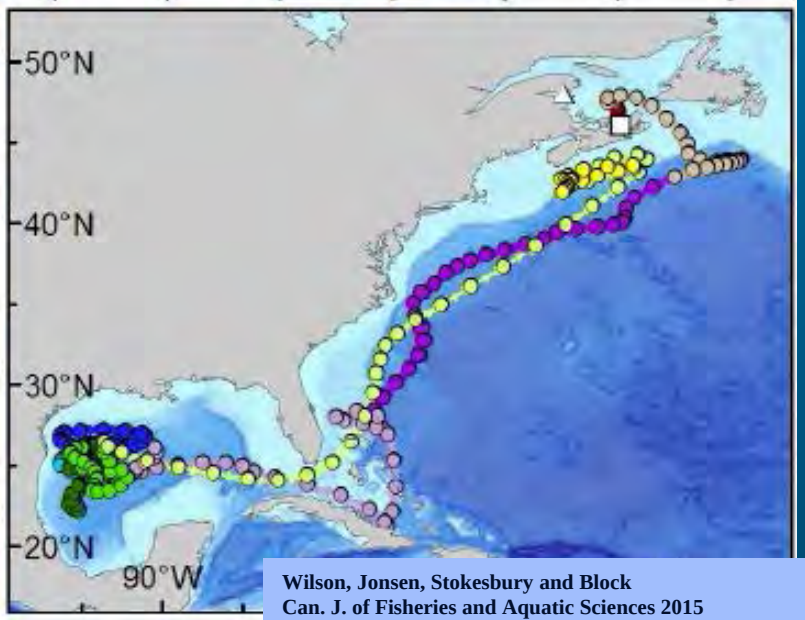
Independent

Pop-Up Tags Externally Placed: Fish Are Tagged & Released

Canadian Tagging Data Set:
Mature Fish Have a Western Bias to Their Movements
50 New Satellite Archival Tracks of Giant Bluefin tuna Post Oil Spill to the GOM

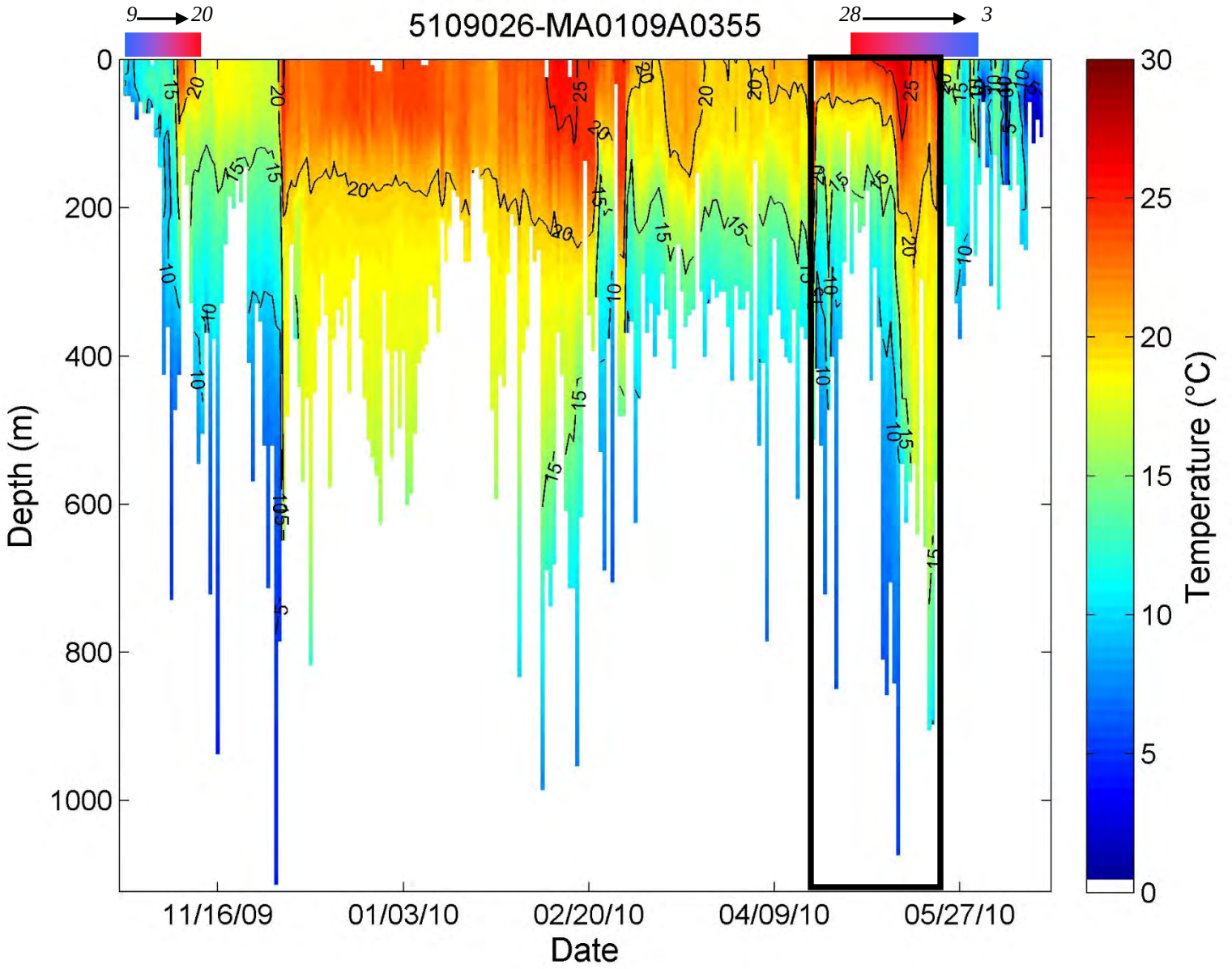






Wilson, Jonsen, Stokesbury and Block
Can. J. of Fisheries and Aquatic Sciences 2015

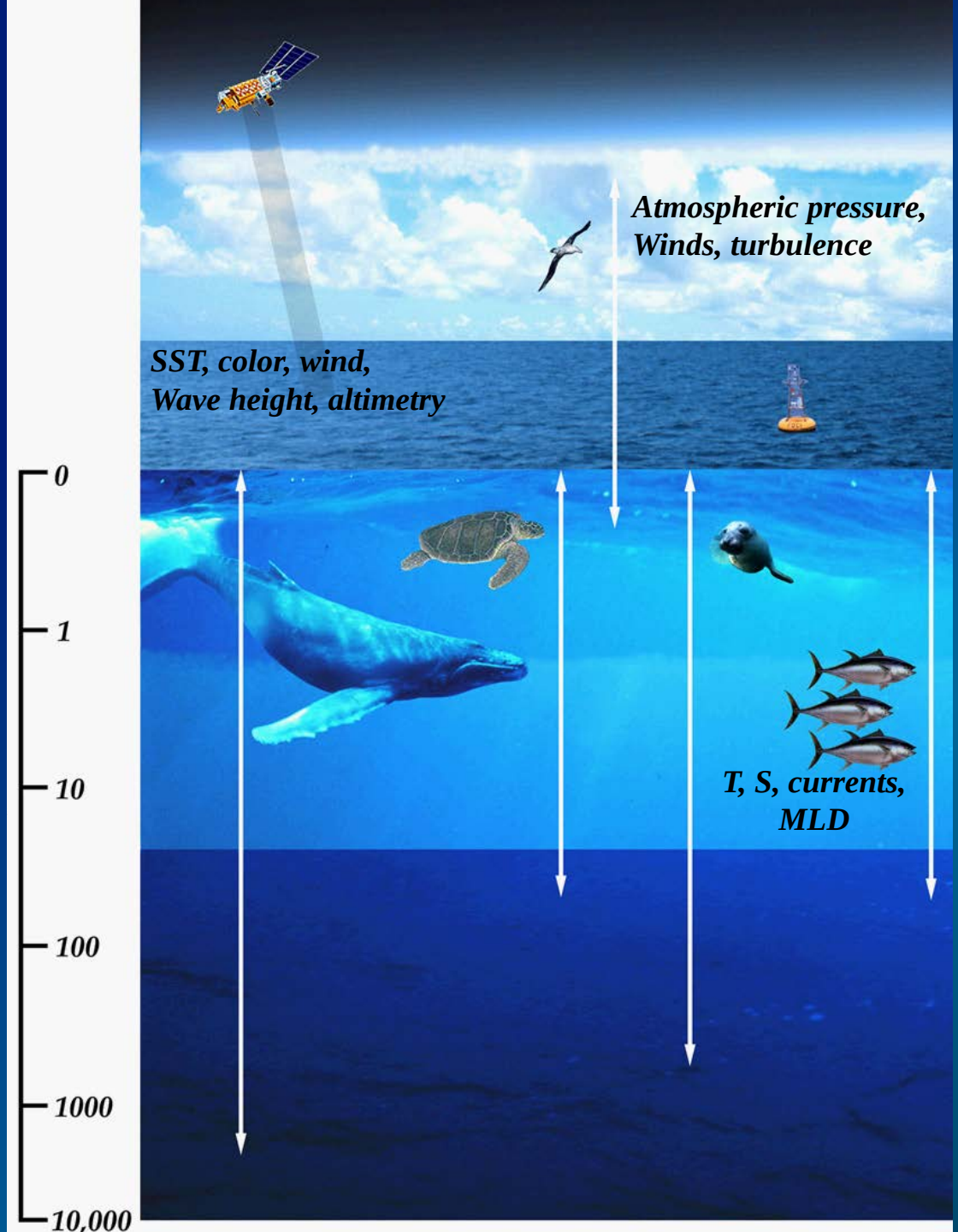
Transmit Ocean Profiles - for Reconstruction of Ocean Habitat



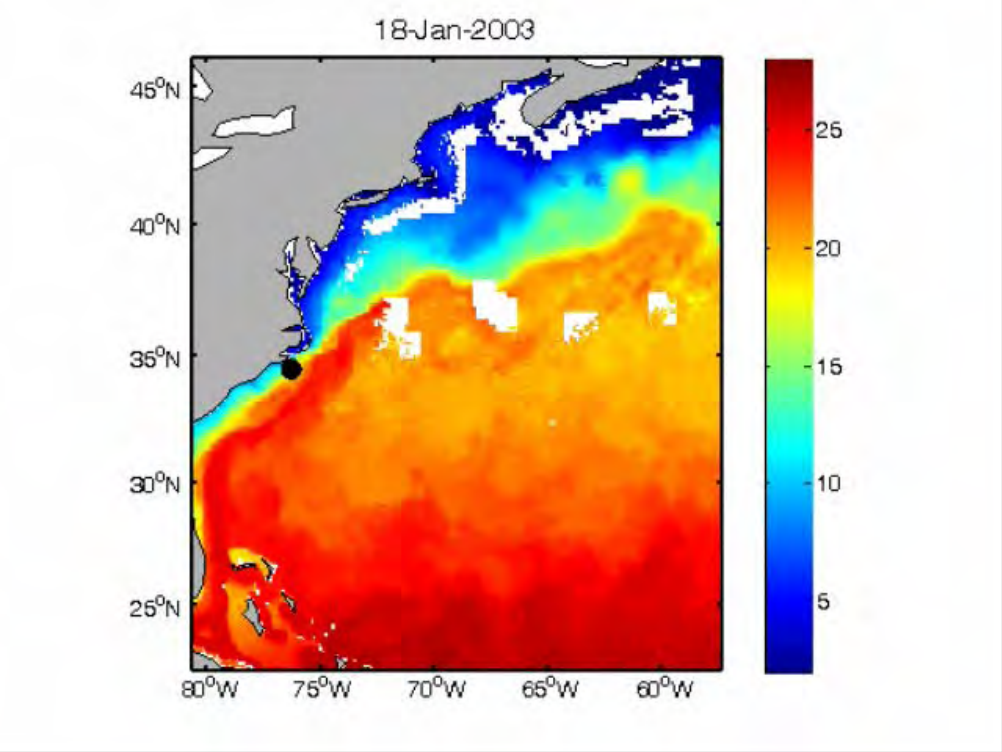
CENSUS OF MARINE LIFE

Integration with Environmental Information

More than skin deep

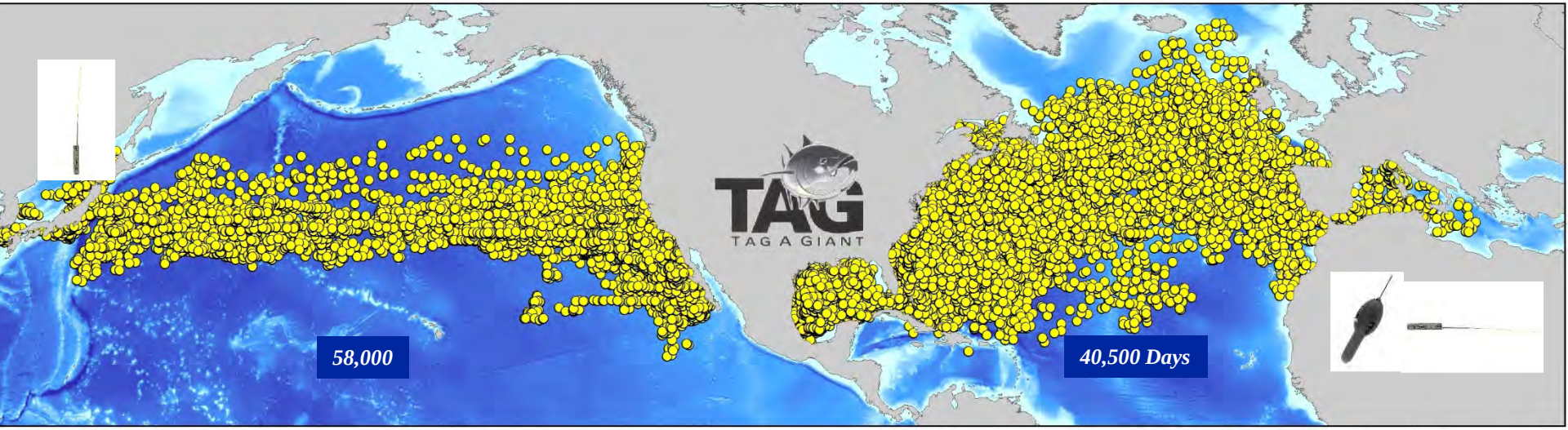


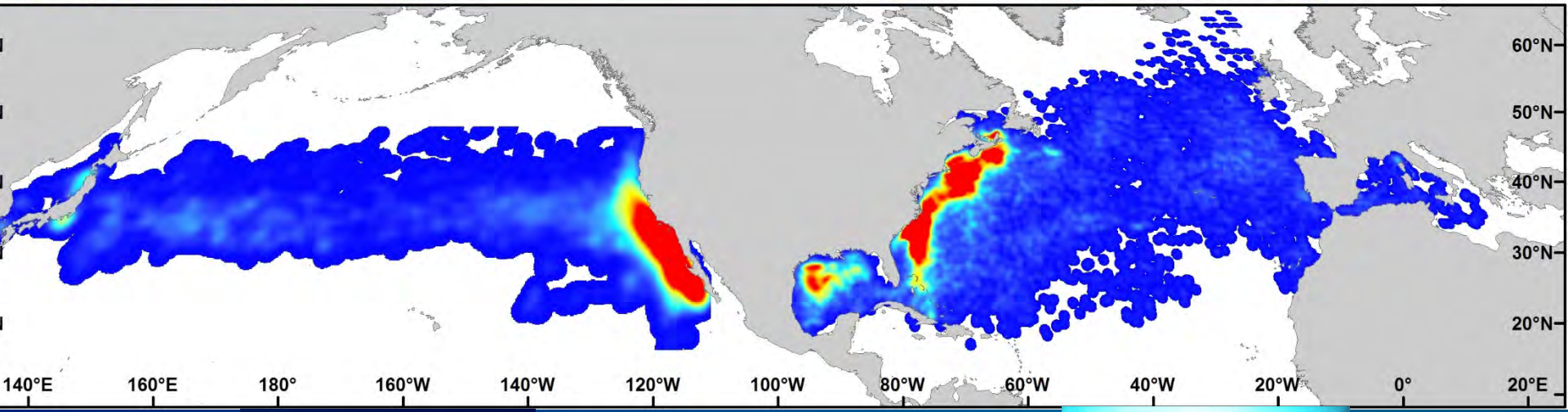
Tracking Where Tunas Go Under the Sea



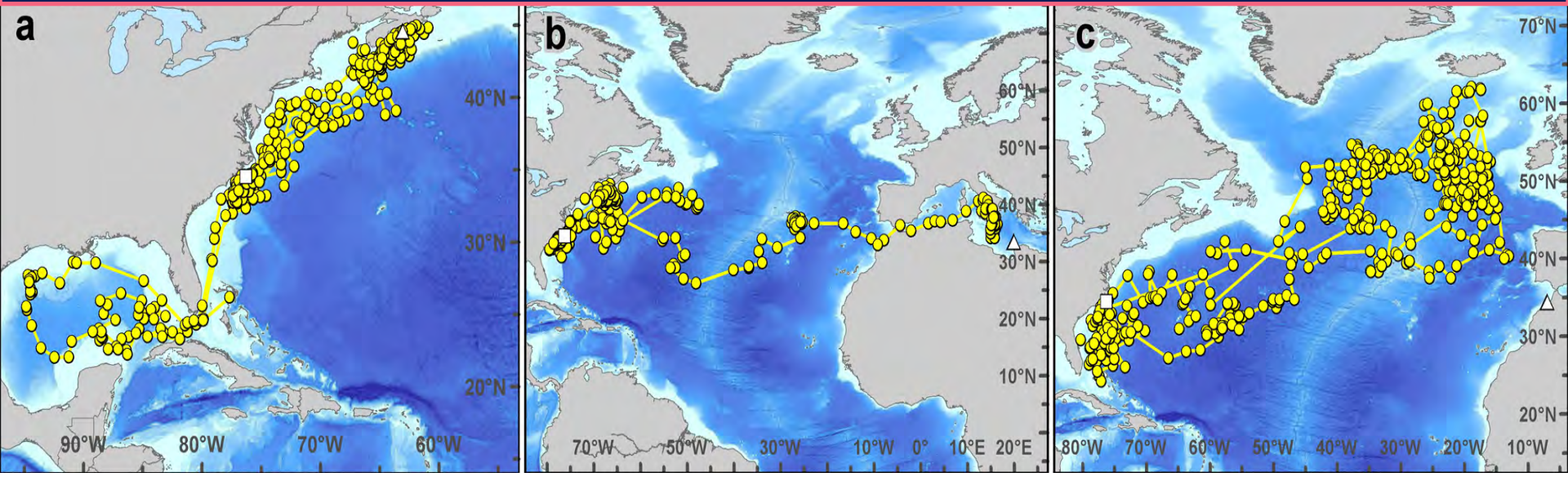
- *Position*
- *Distribution/Abundance*
- *Oceanography*
- *Physiology*
- *Population Biology*

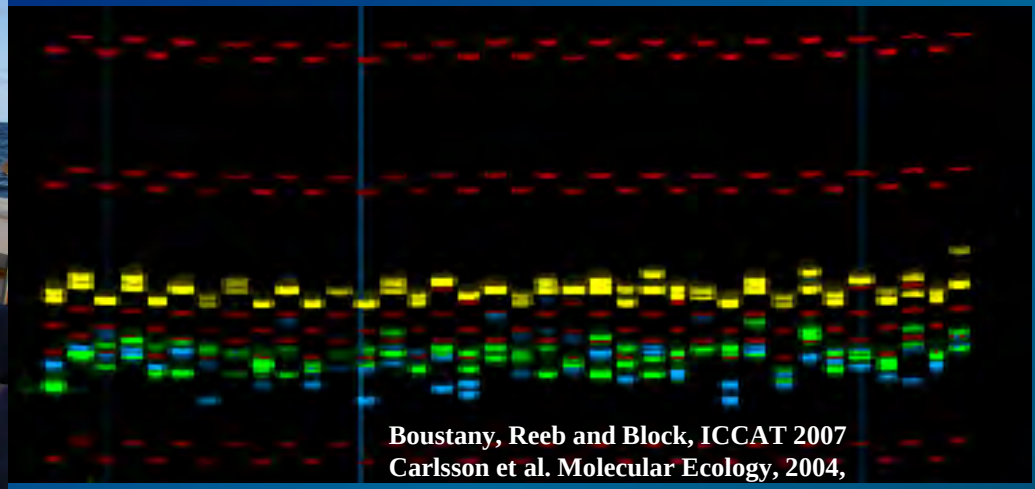
Can Electronic Tagging Data Improve Bluefin Tuna Population Assessments? Mortality, Maturity, Population Structure, Life History





Tracks Identify Specific "Tribes" of Tunas Define Population Genetics Associated with Track

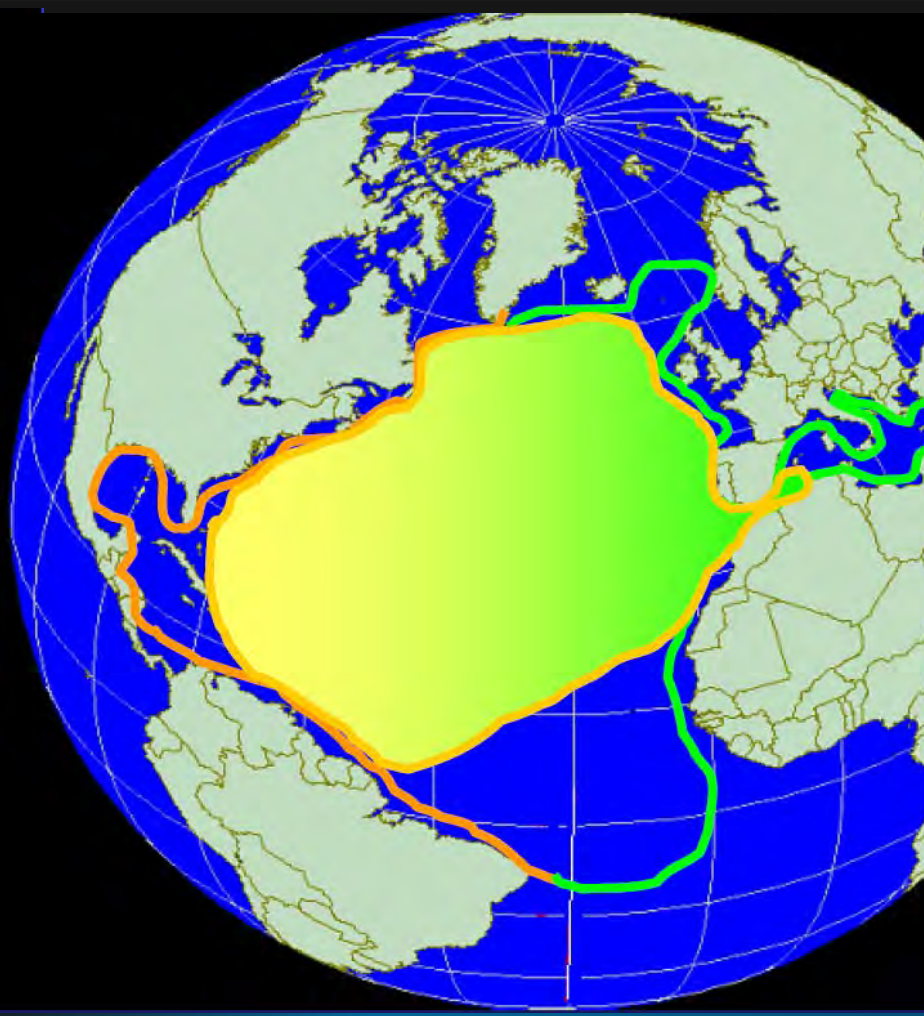




Boustany, Reeb and Block, ICCAT 2007
Carlsson et al. Molecular Ecology, 2004, 2007
Boustany, Reeb & Block, Marine Biology 2008. Riconni et al. PNAS, 2010
Reeb PNAS, 2010

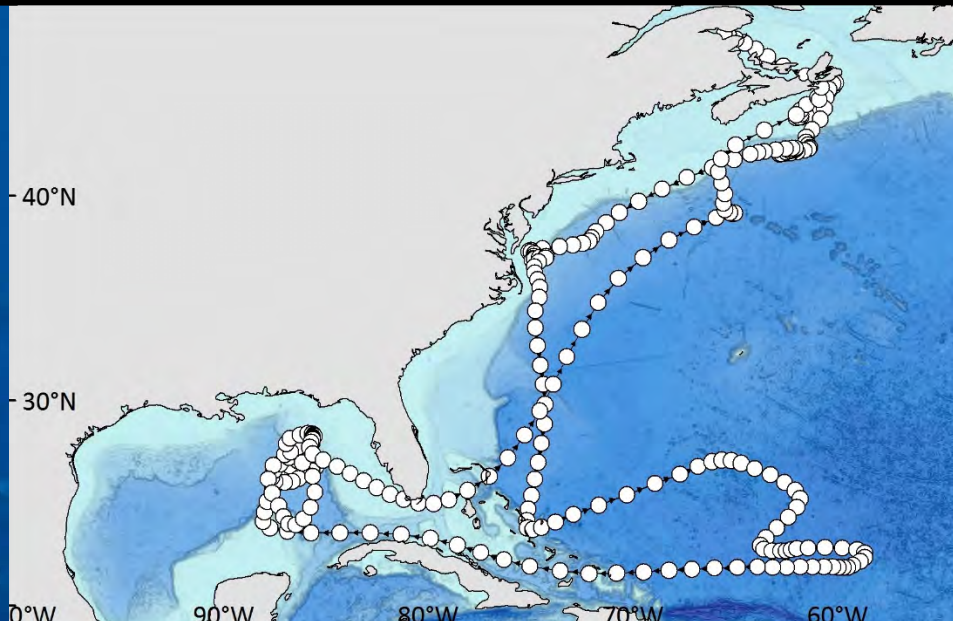
Tagging Has Led to Population Overlap Models for Atlantic Bluefin

2 Stocks



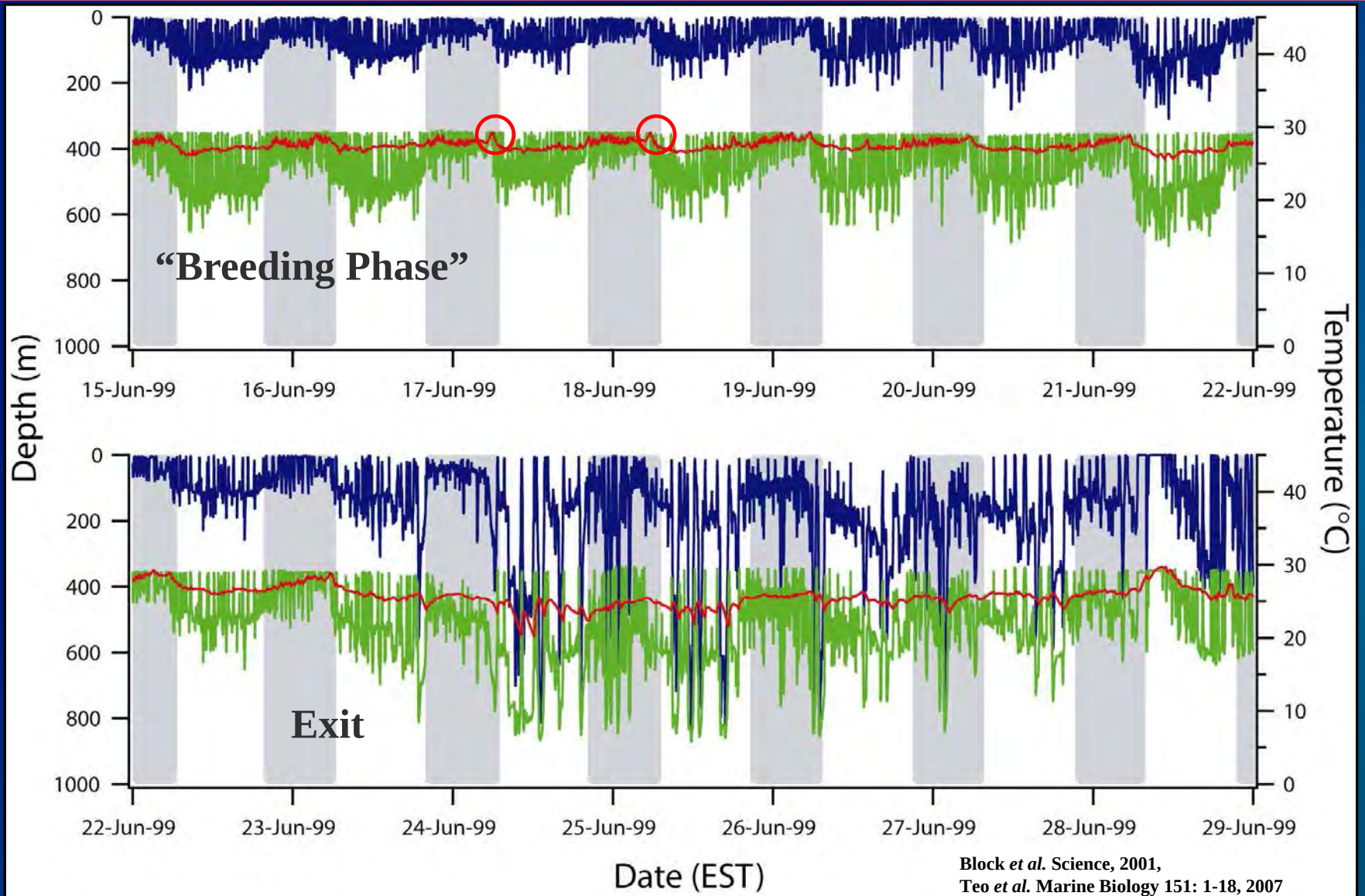
Overlap Models

Environmental Disasters: *Role for Biologging Increases*
Did the Gulf of Mexico Ecosystem Change?



Unique Spawning Behavior

"Breeding Phase": Shallow Depths @ Surface Preferred
Exit Depths are Deep

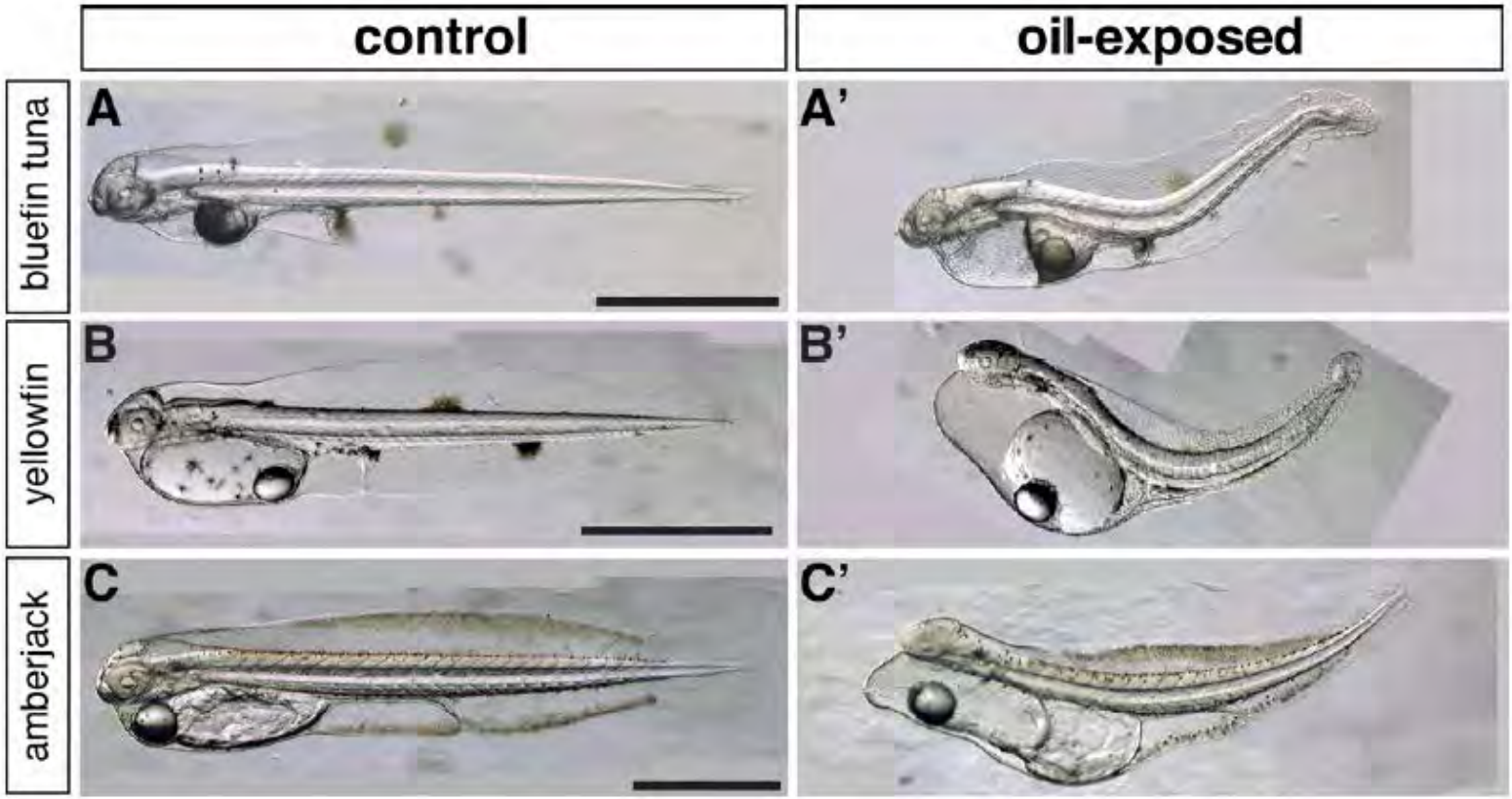


Block *et al.* Science, 2001,
Teo *et al.* Marine Biology 151: 1-18, 2007

What Is the Impact of Oil on Fish Larvae?

Oil is Cardiotoxic to Larvae

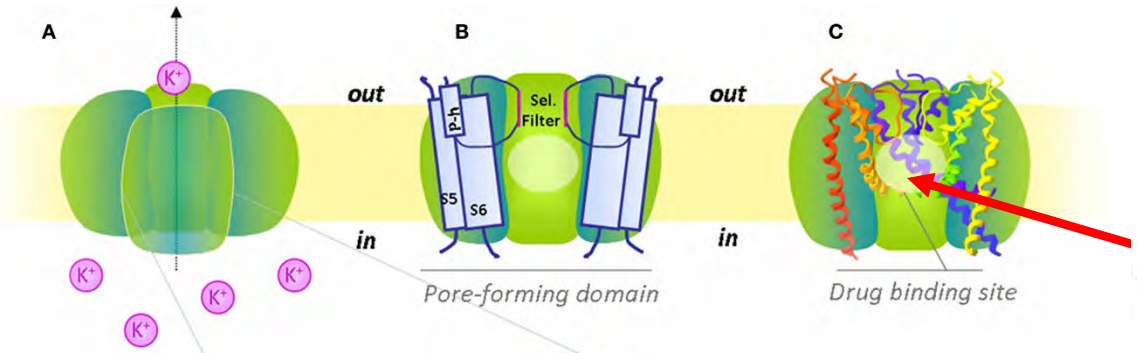
Brette, Incardona, Cros and Block,, Science 2014; Incardona et al. Proceedings of the National Academy2014

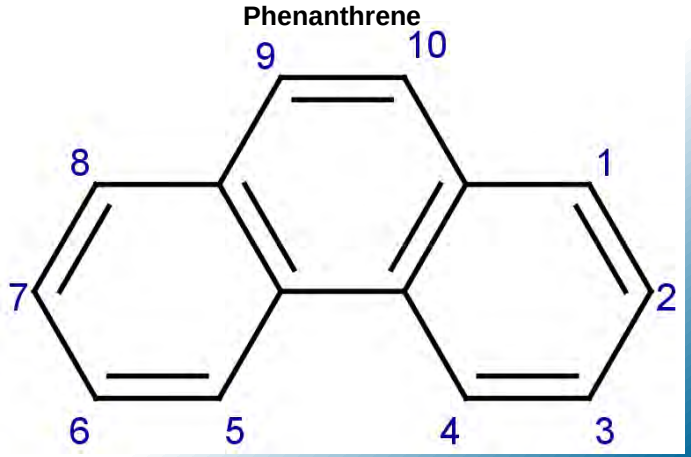


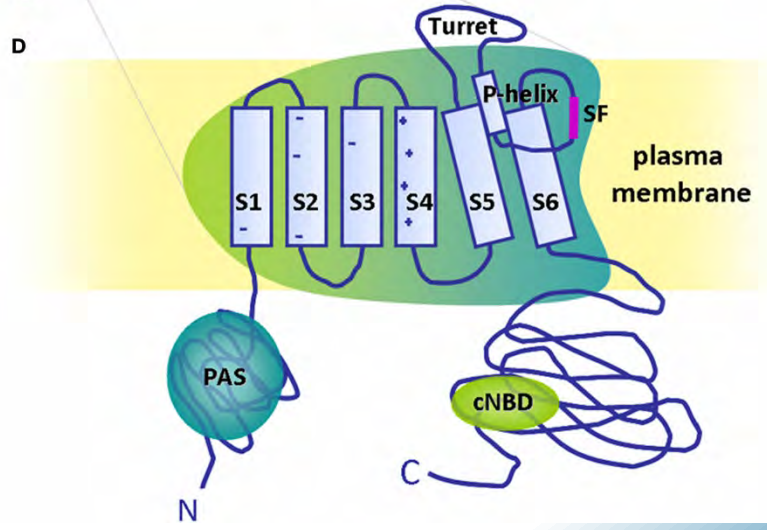
Cardiotoxin is Oil PAH: Phenanthrene

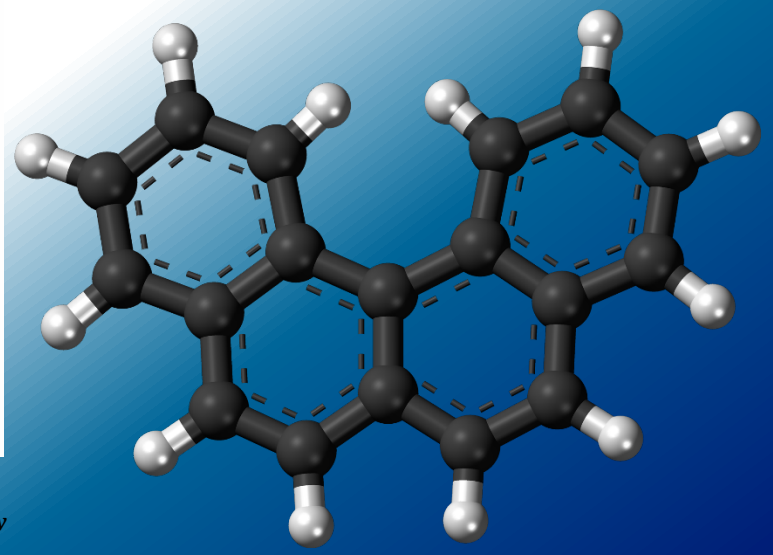
Polycyclic Structures are More Cardioactive

- **Hypothesis: PAH Aromatic Rings May Increase Affinity for Binding in Potassium Channel (Ikr) Pore**



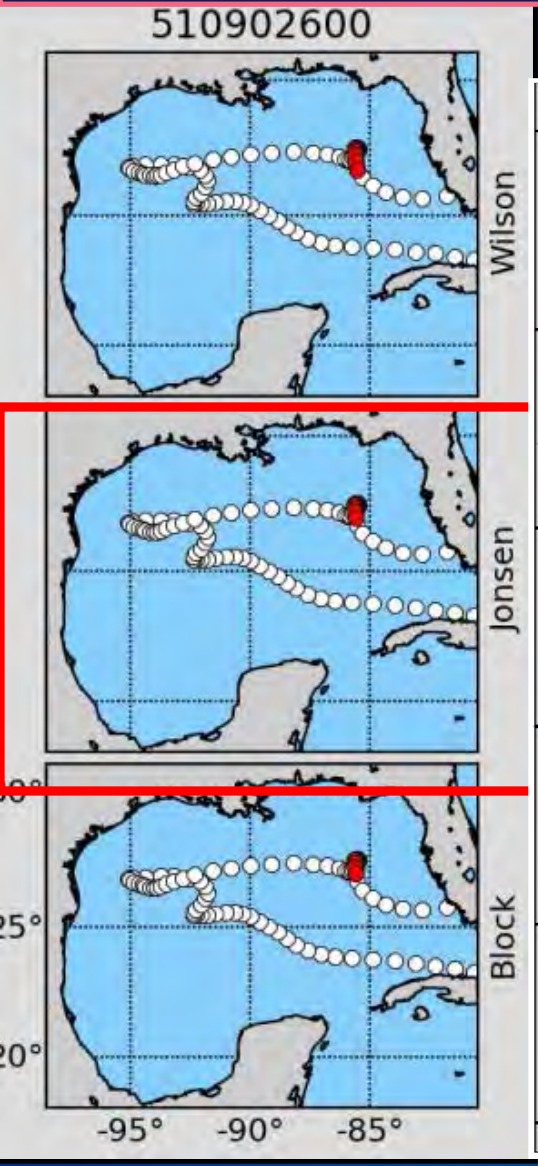


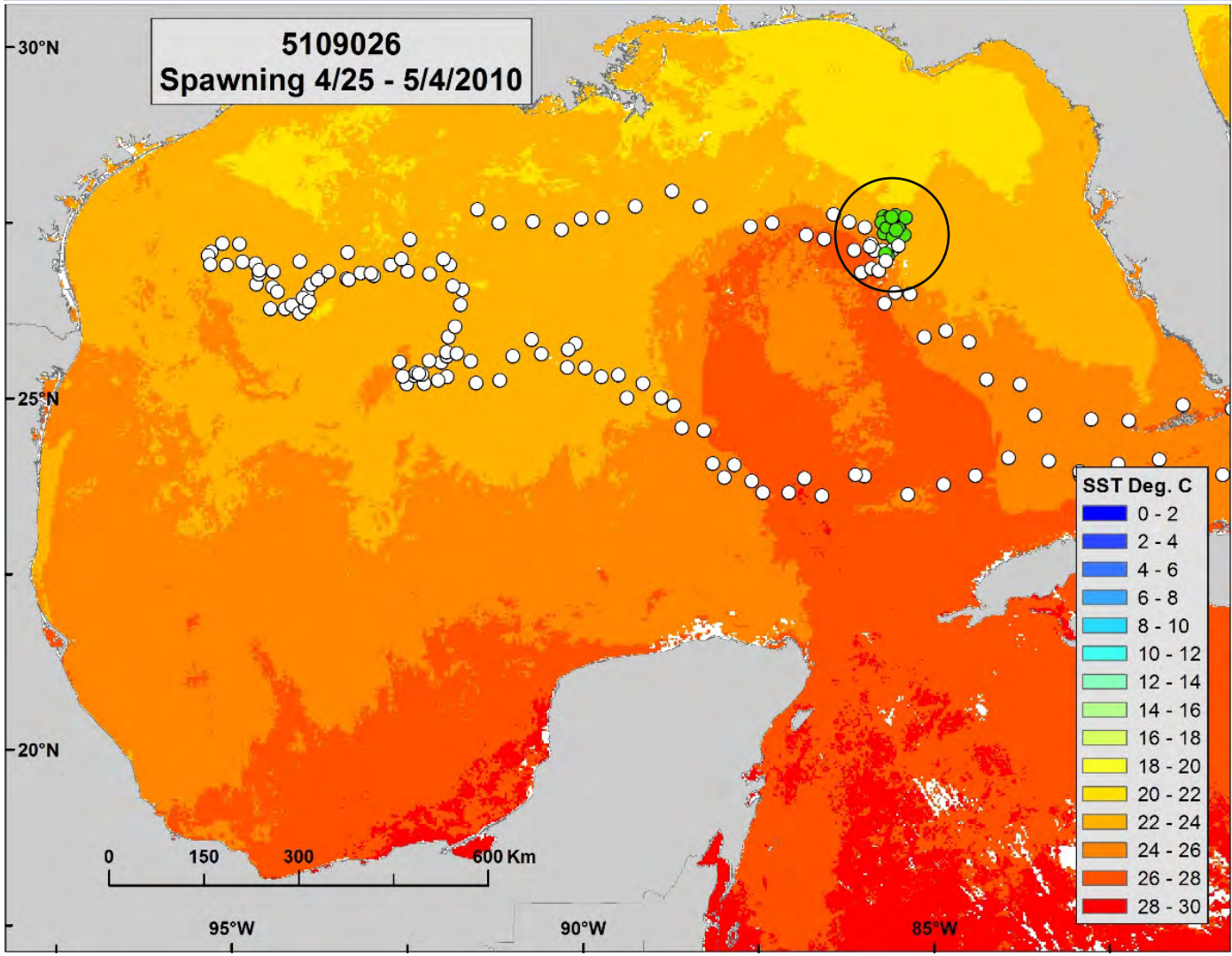




Brette, Scholtz, Incardona and Block, Science 2014, Brette et al. 2015 PNAS In Review

State Space Switching Models To Indicate Spawning Habitat



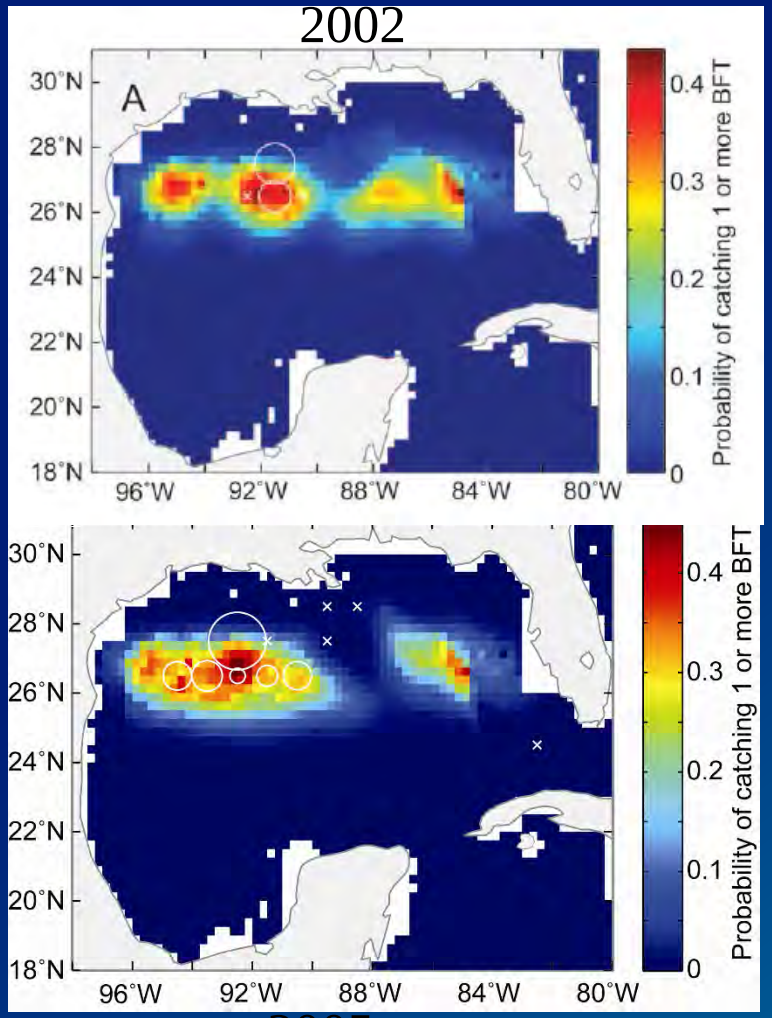


Block et al. Unpublished Data

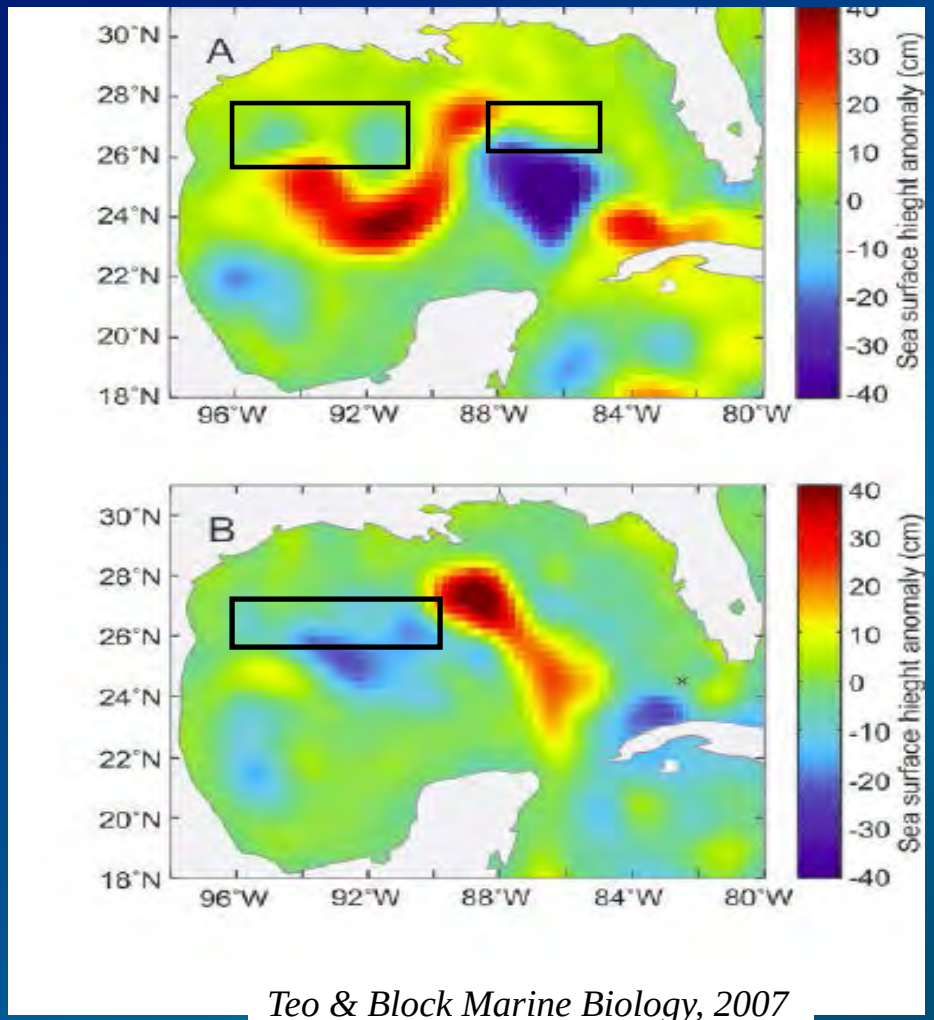
Probability of Catching a Bluefin can be Predicted based on Oceanography

Dynamic Closed Areas are Possible

2002

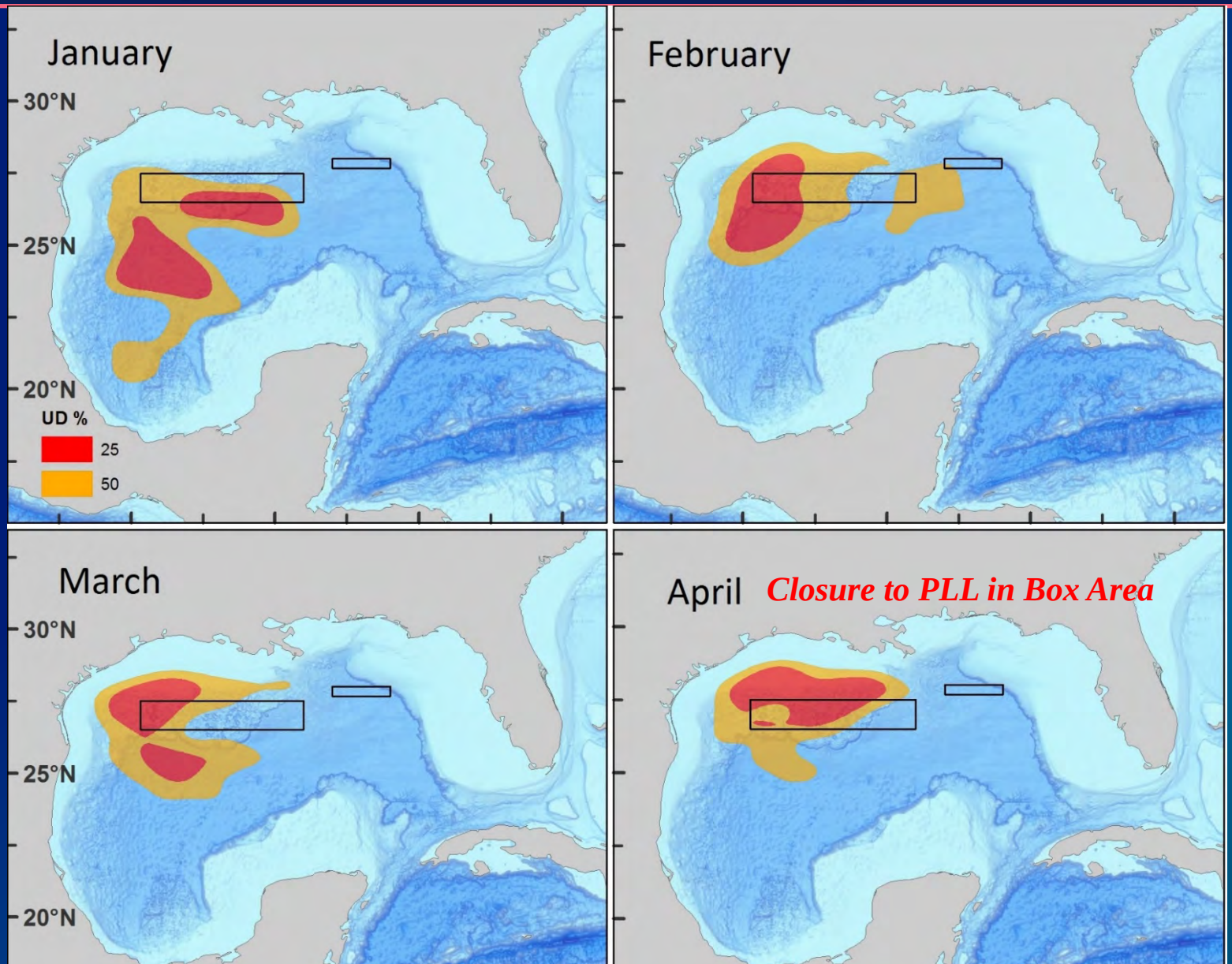


2005



Teo & Block Marine Biology, 2007
Teo & Block, PLOS one 2010

Ammendment 7: Static Closed Areas to Reduce Bluefin Bycatch Go in Place in April and May 2015

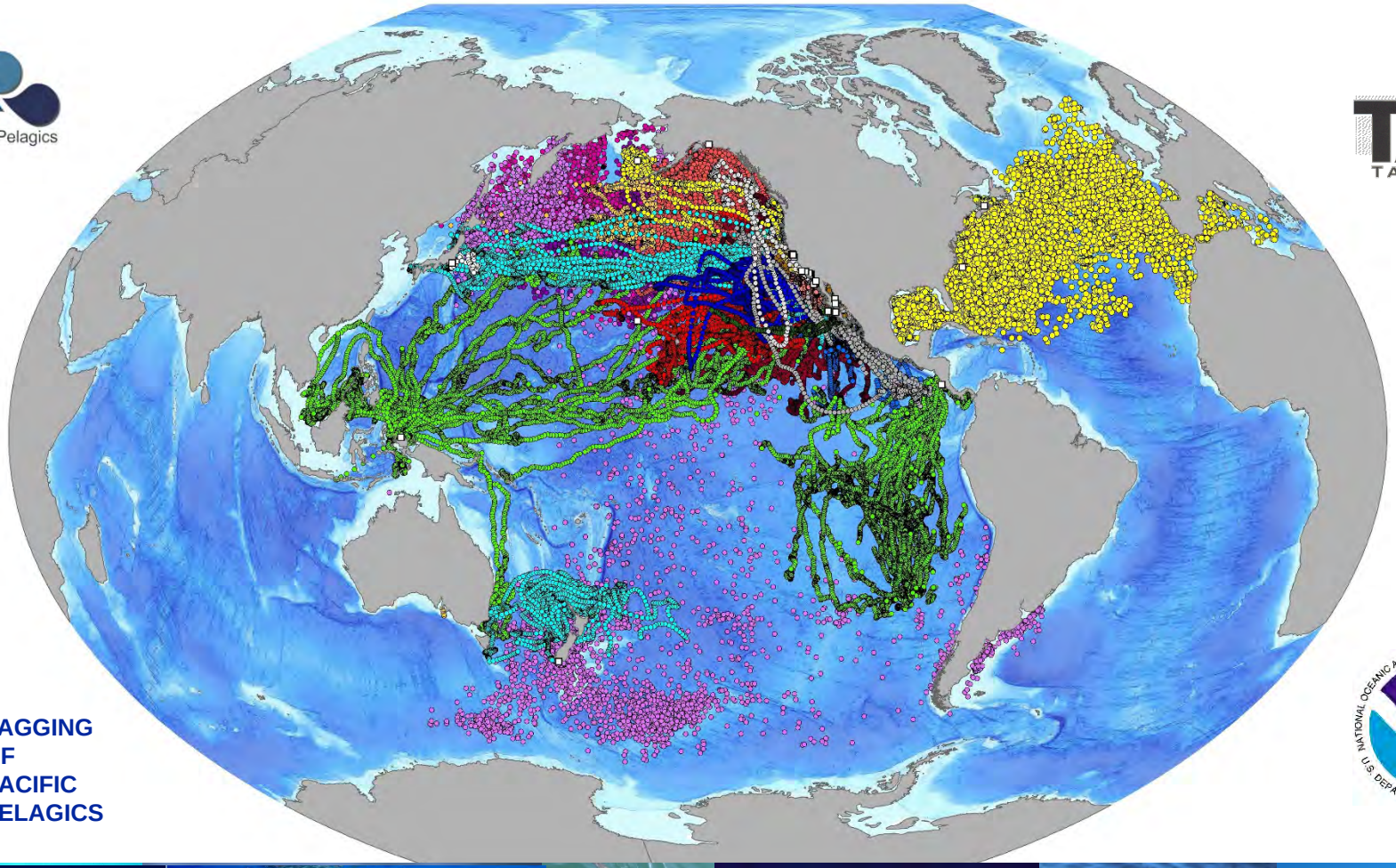


Observing, Monitoring and Protecting the Blue Serengeti off Our California Shores

Tagging of Pacific Pelagics

Tagging of Pacific Pelagics:
Census of Marine Life Global Effort

TOPP
Tagging Of Pacific Pelagics

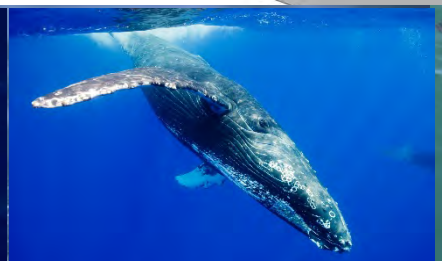
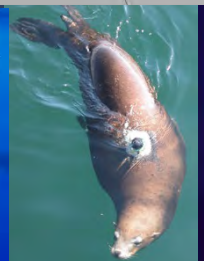


TAG
TAG A GIANT

Tuna Research and Conservation Center
Hopkins Marine Station • Monterey Bay Aquarium

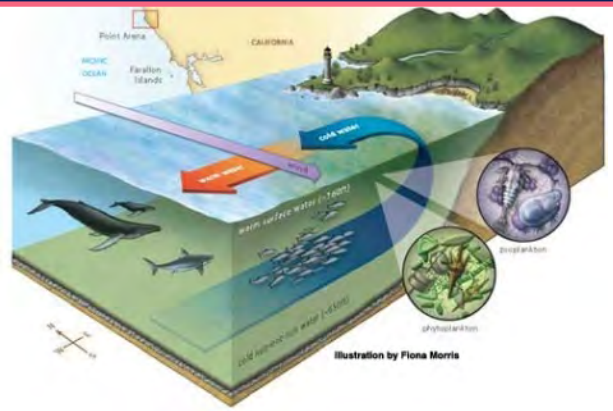
TAGGING
OF
PACIFIC
PELAGICS

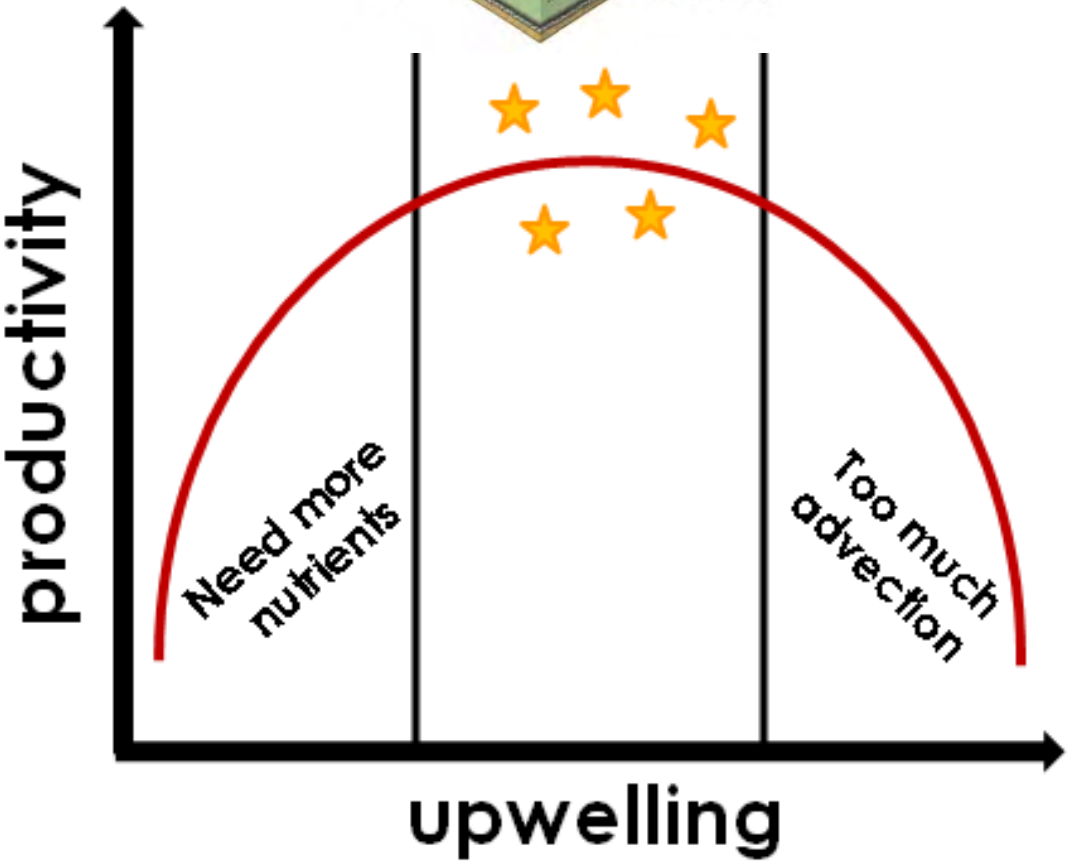
NOAA
National Oceanic and Atmospheric Administration
U.S. Department of Commerce


Biologging: Tag, Track, & Monitor Marine Animals

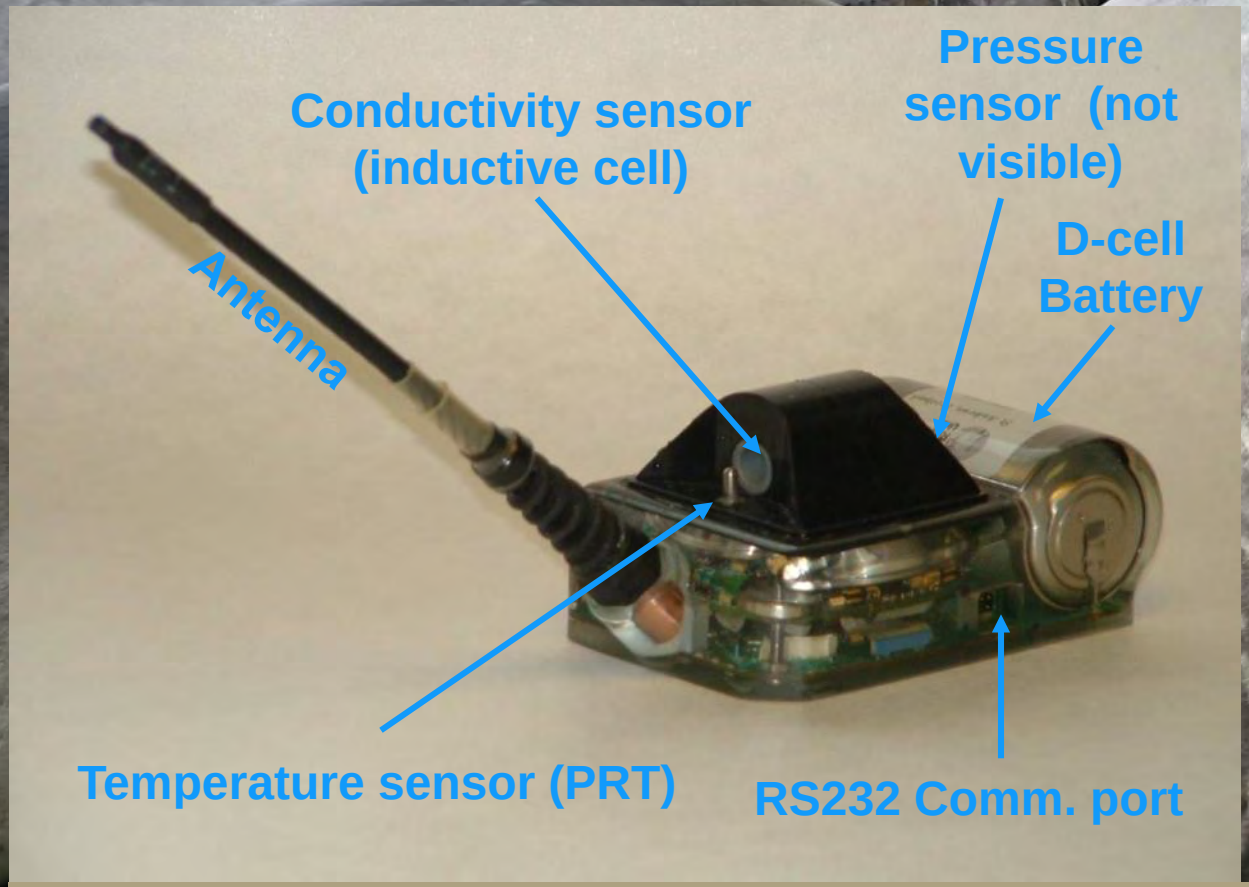
Where are Windows of Optimal Habitat?





based on Cury and Roy 1989

Oceanographic Quality Salinity Temperature Profiles Satellite Delayed Relay Tags (CTD-SRDL)



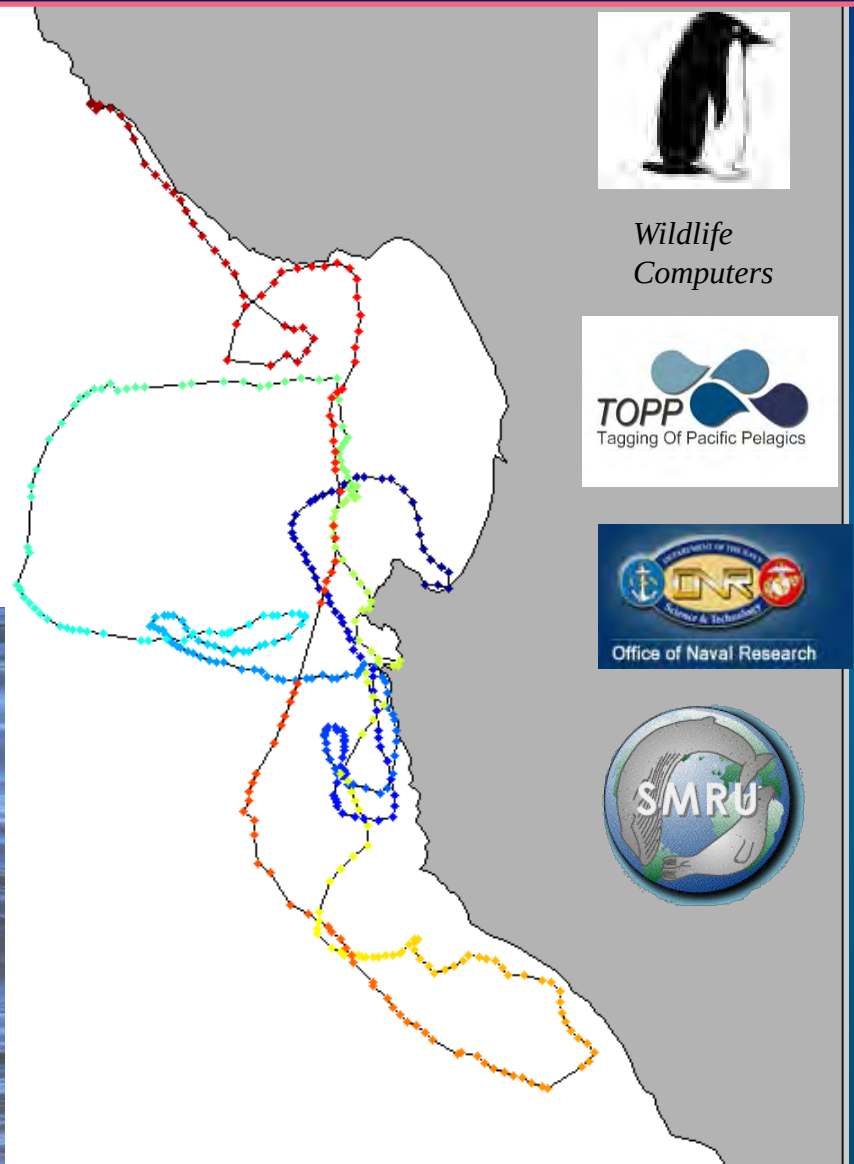
Office of Naval Research

NOPP funding

SMRU

Sensor performance: Temperature: ± 0.01°C
Salinity: ± 0.01
Pressure: 1% of full scale (~2000 dBar)

GPS Investments during TOPP in in Fastloc Technology (Snapshots in 1 sec)

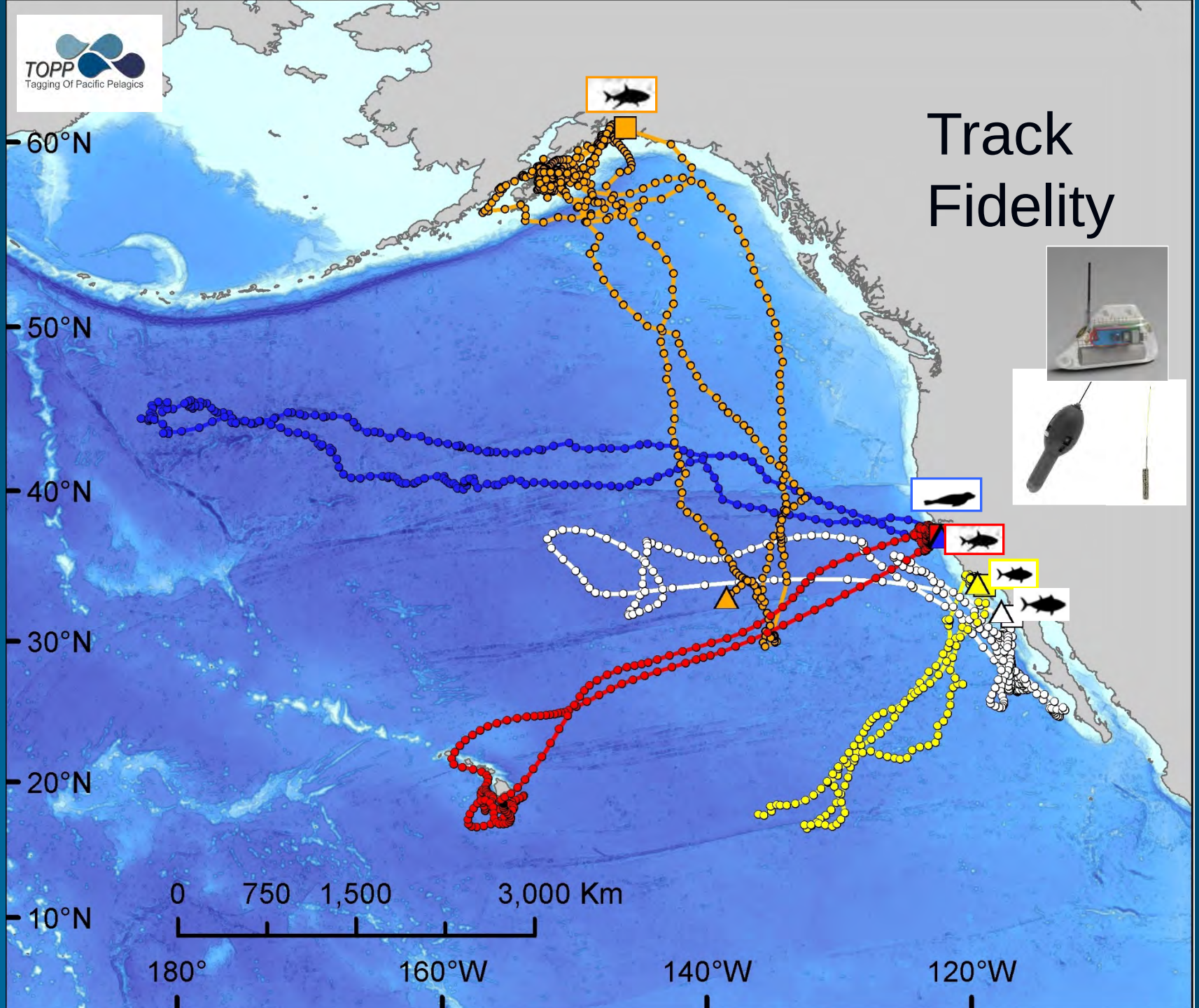


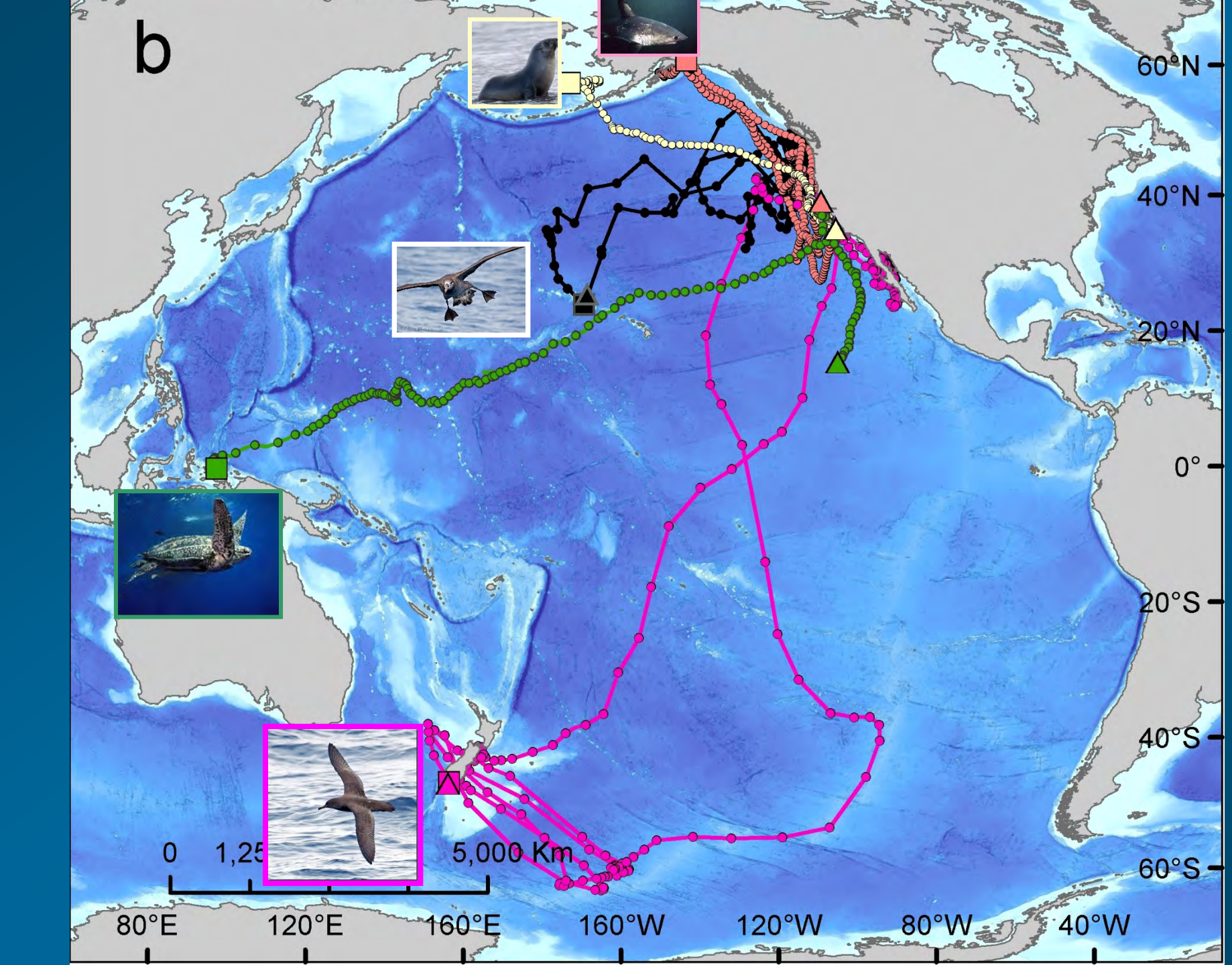
Wildlife Computers

TOPP
Tagging Of Pacific Pelagics

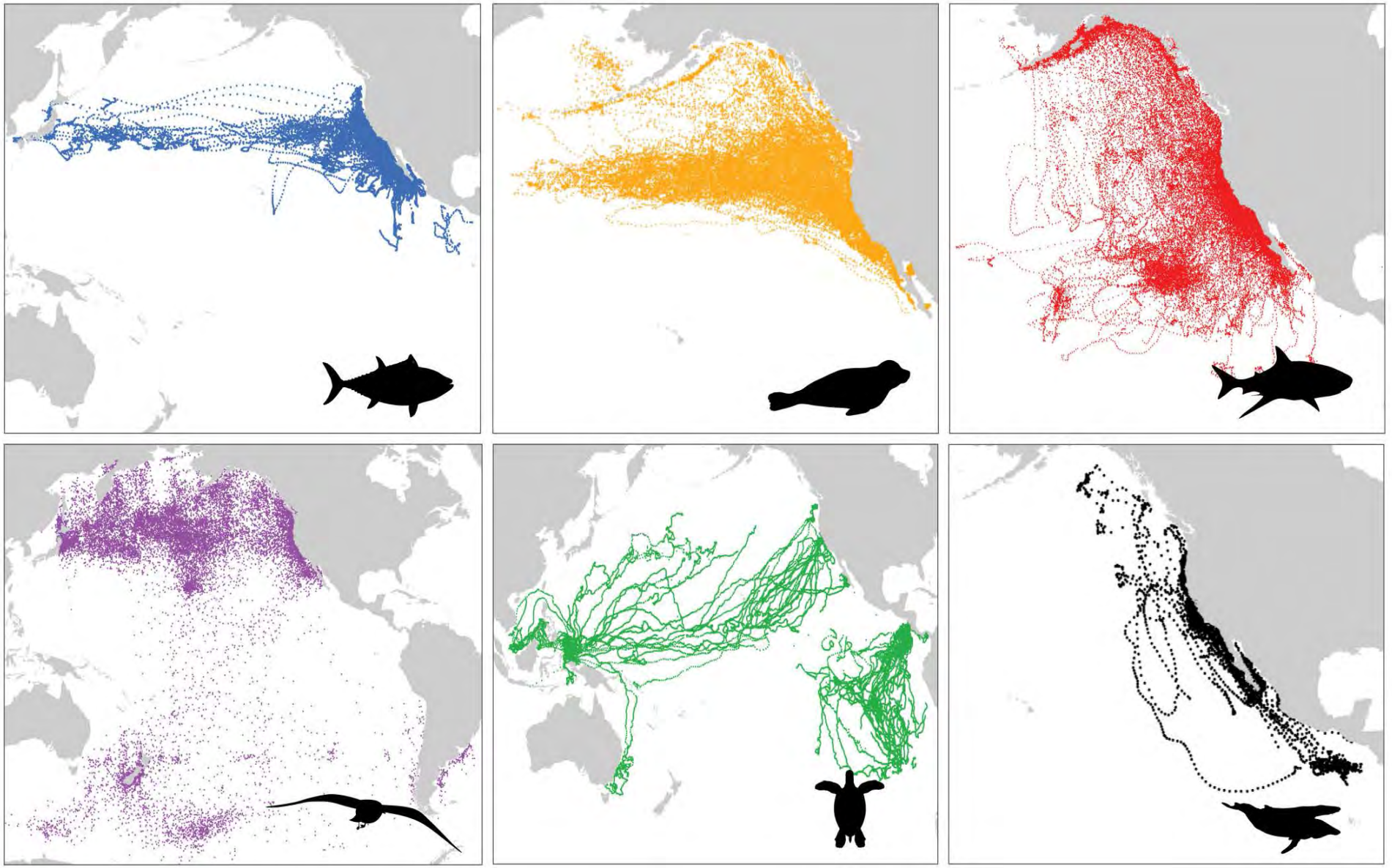
Office of Naval Research

SMRU

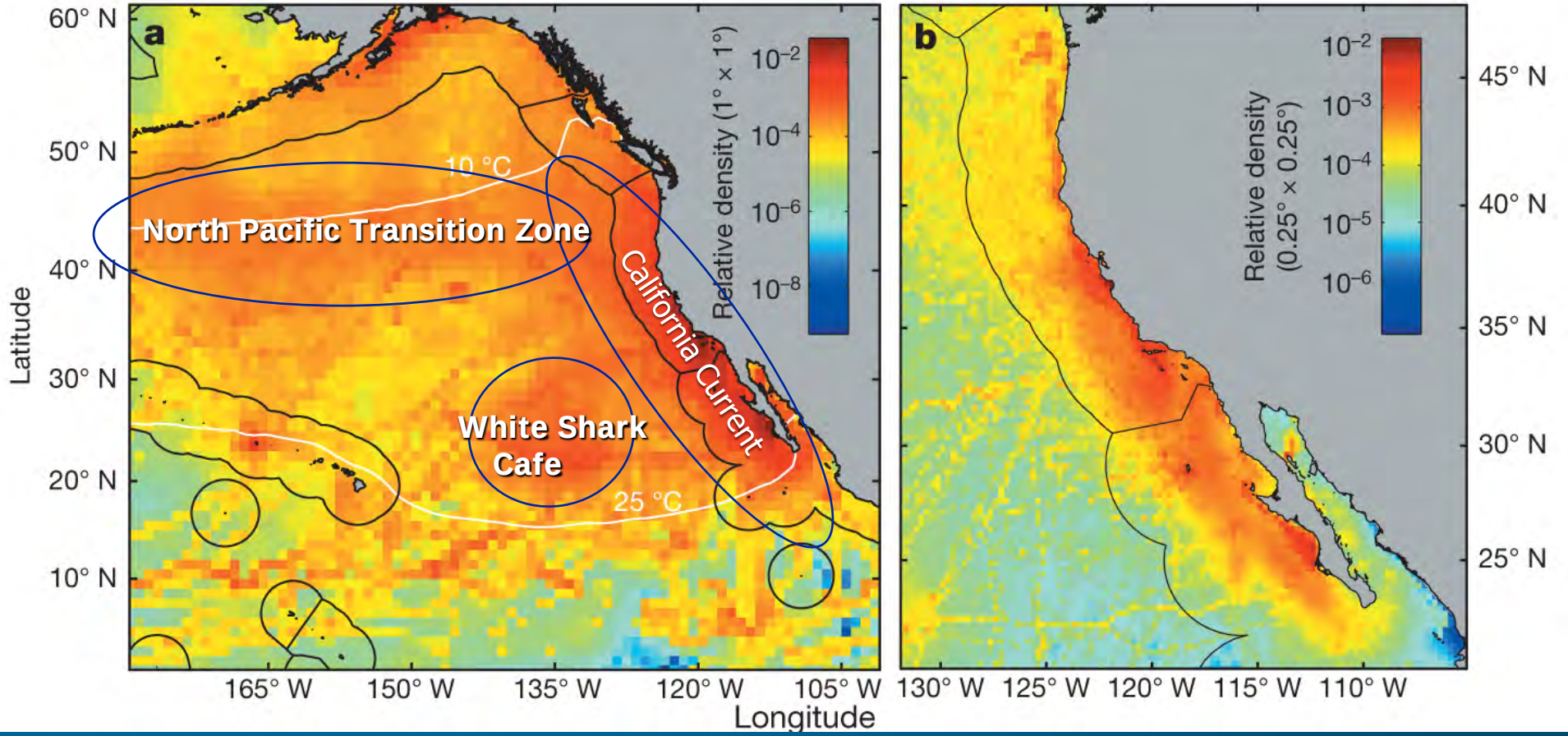

TOPP
Tagging Of Pacific Pelagics
Track Fidelity
60°N
50°N
40°N
30°N
20°N
10°N
0
750
1,500
3,000 Km
180°
160°W
140°W
120°W


b
60°N
40°N
20°N
0°
20°S
40°S
60°S
0
1,25
5,000 Km
80°E
120°E
160°E
160°W
120°W
80°W
40°W

TOPP: Tagging Guilds of Animals & Mapping Hot Spots in the Pacific Ocean: 4800 Deployments

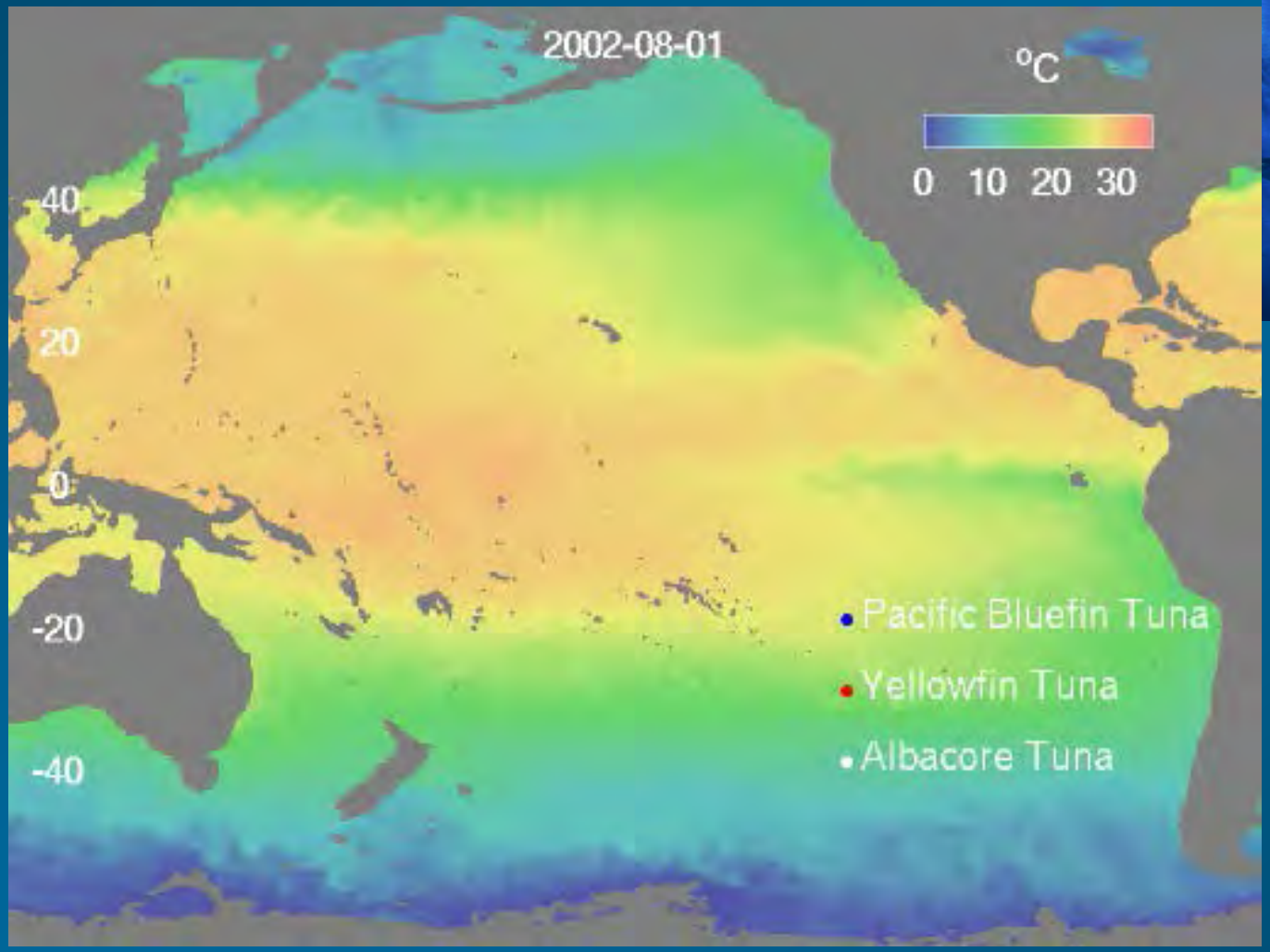


TOPP Biological Hot Spots (Density) in the CCLME: Where the Predators (23 Species) Roam

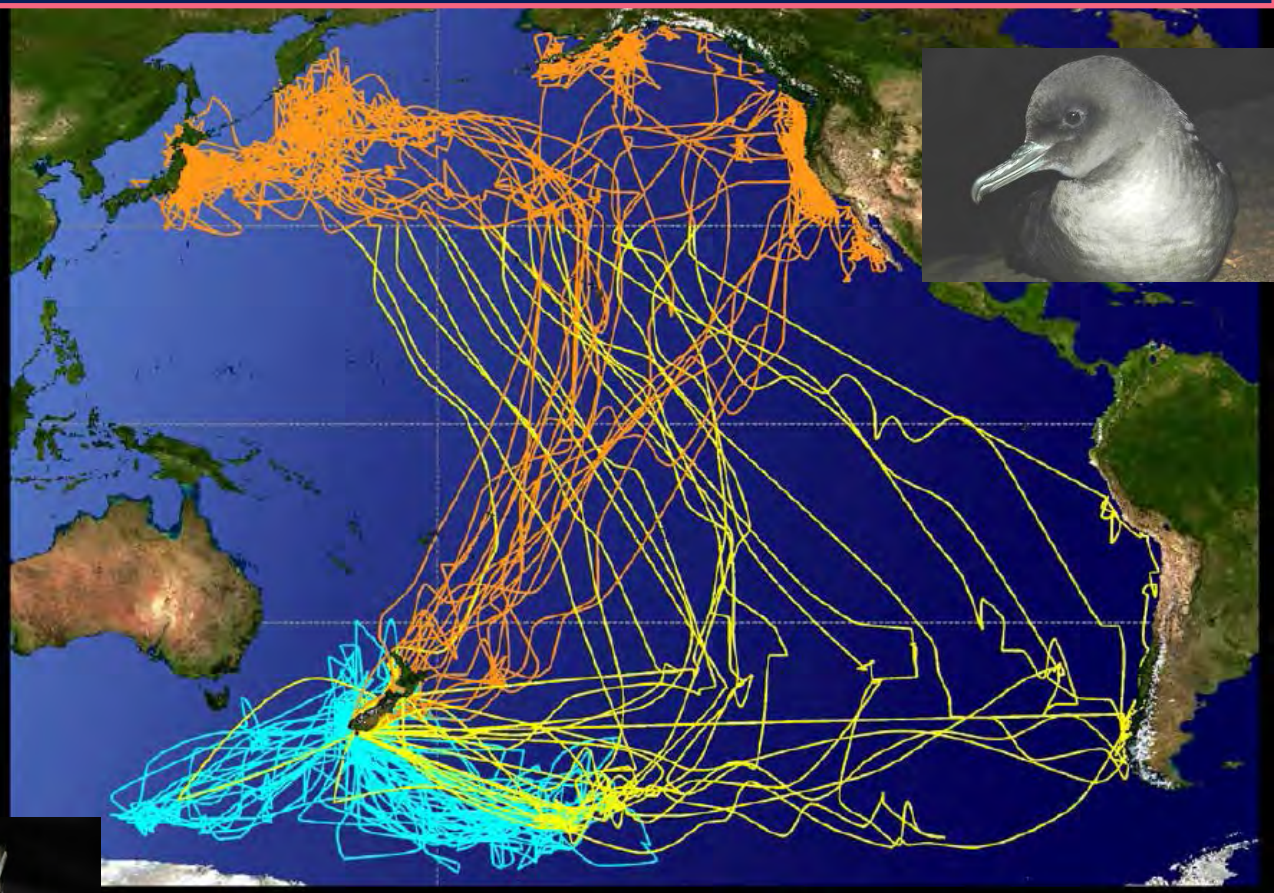


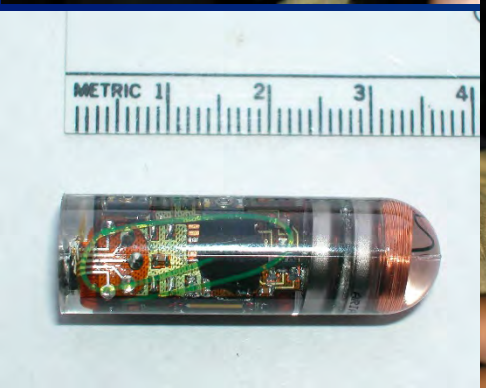
Block et al Nature 2011

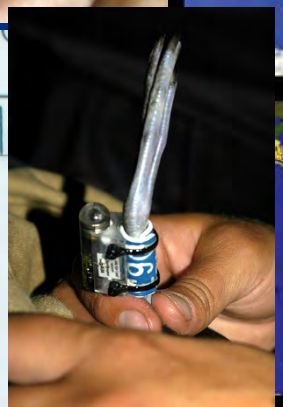
2000 Archival Tags Deployed in TOPP
Stanford, NOAA, IATTC



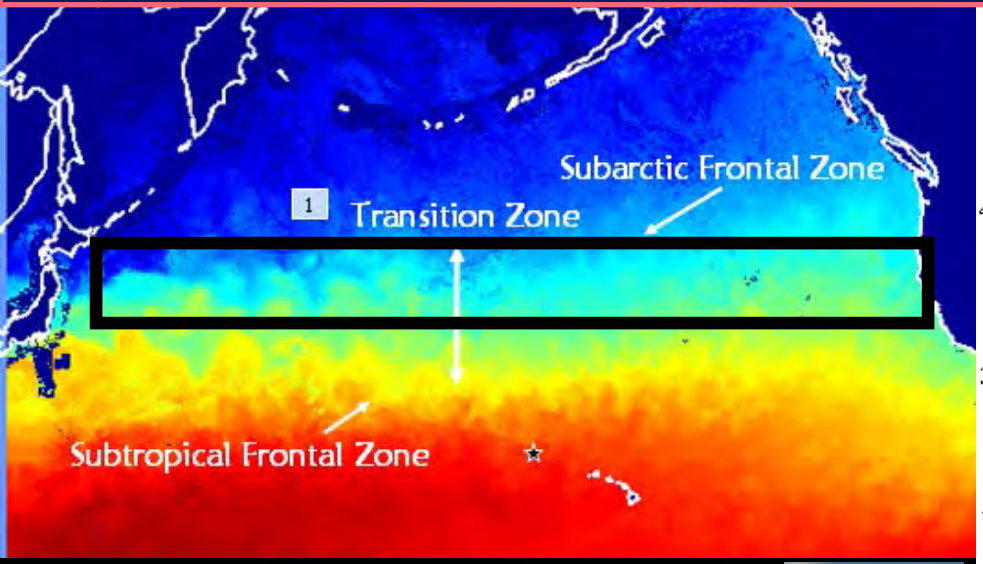
Archival Tags on Sooty Shearwaters
100,000 Km Migrations (*Shaffer et al. PNAS 2006*)

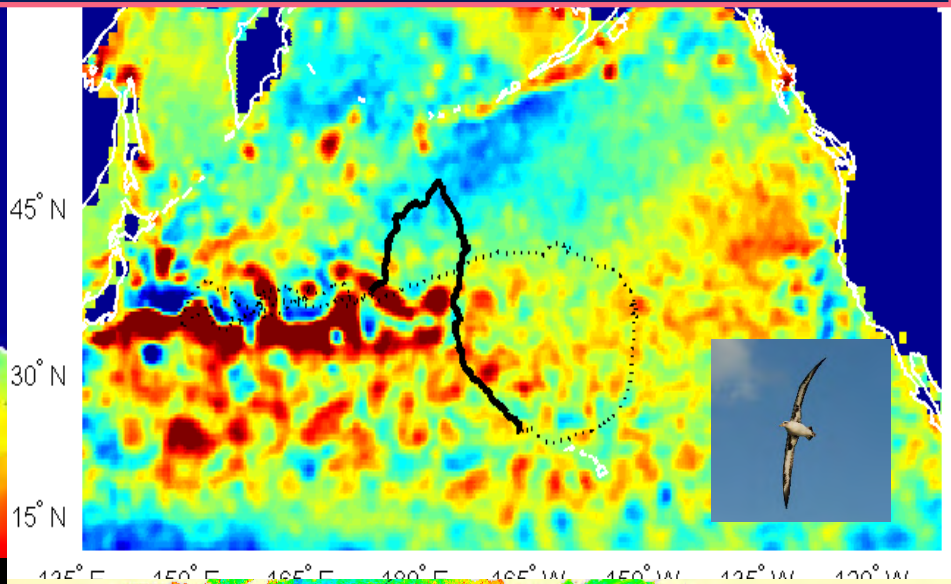


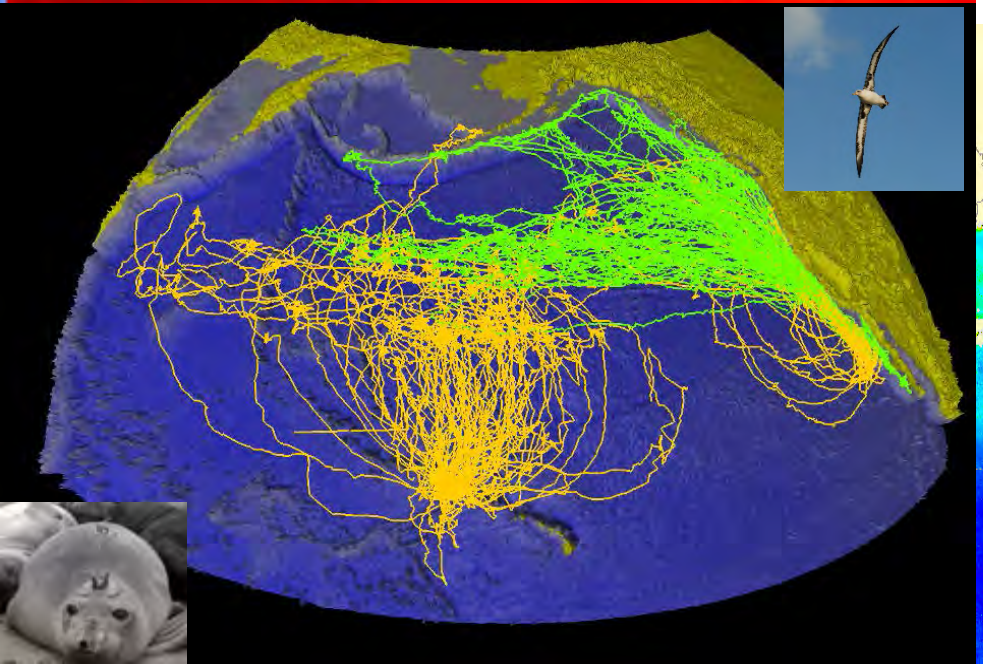


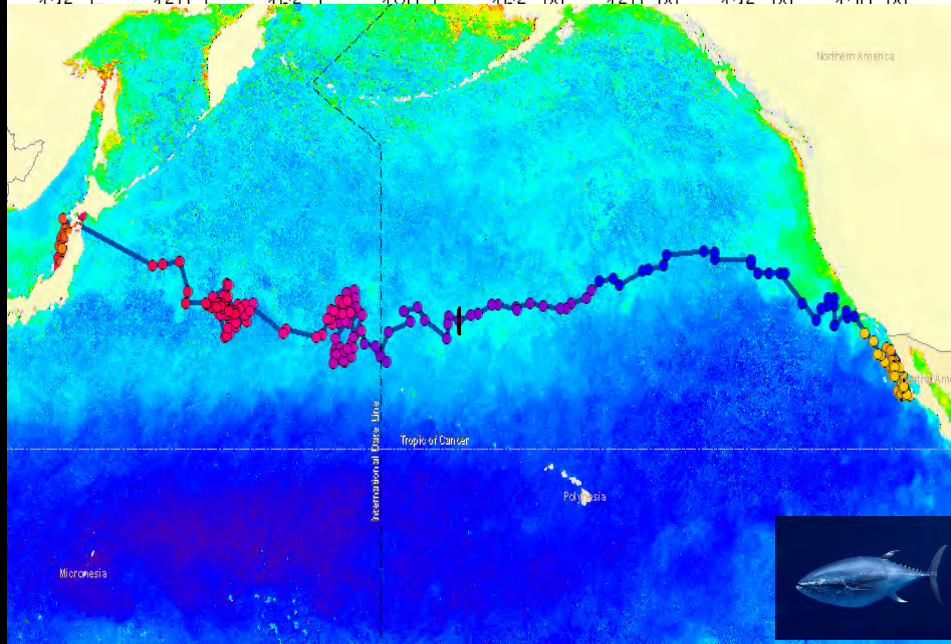


Highways: Use of Common Oceanic Features Across Species: North Pacific Transition Zone

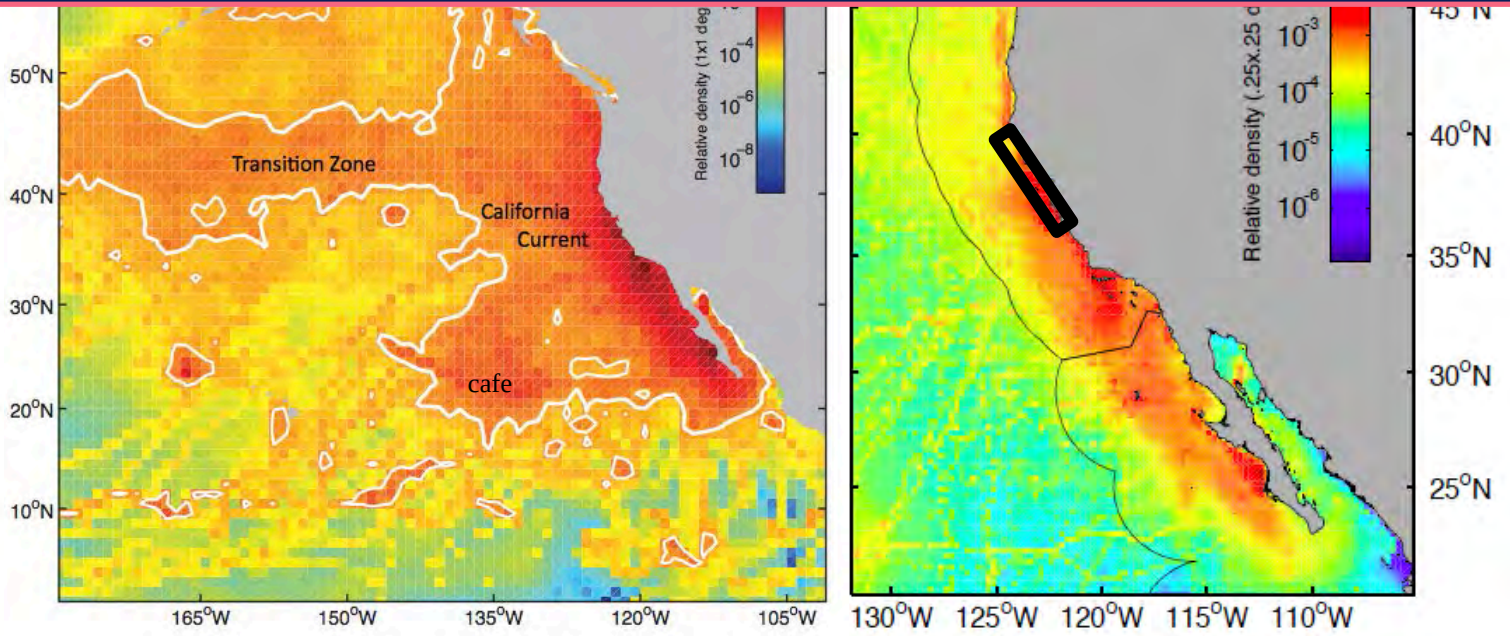


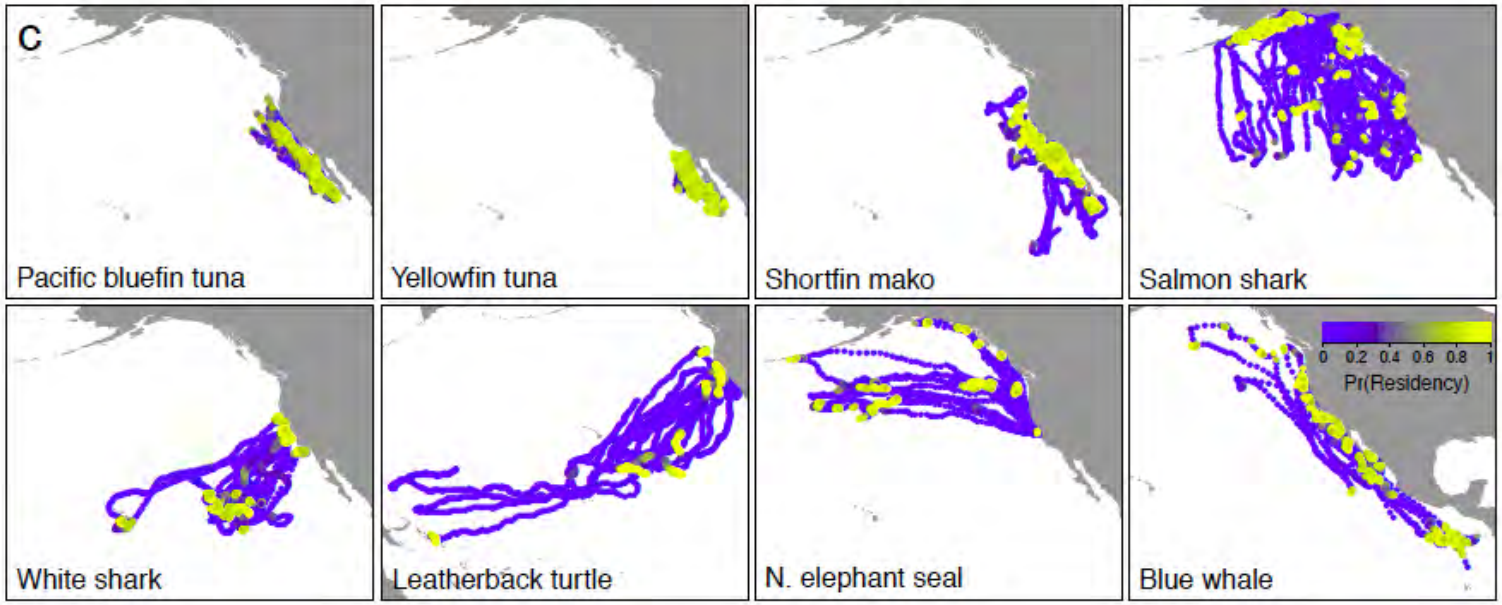




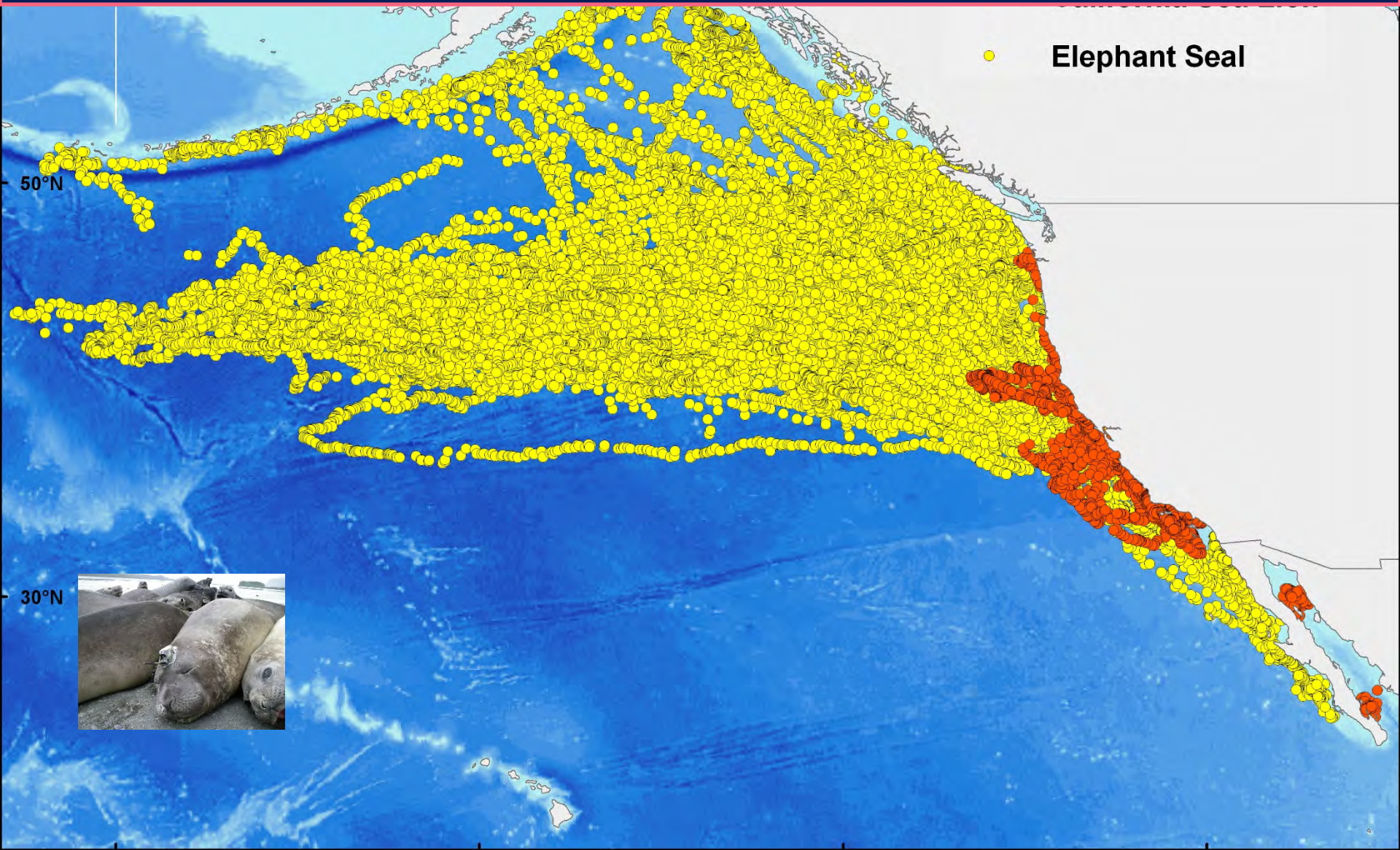


Challenge will be Protecting the Offshore Regions: How Big Does an MPA Have to Be to Protect Pelagic Sharks or Sea Turtles?

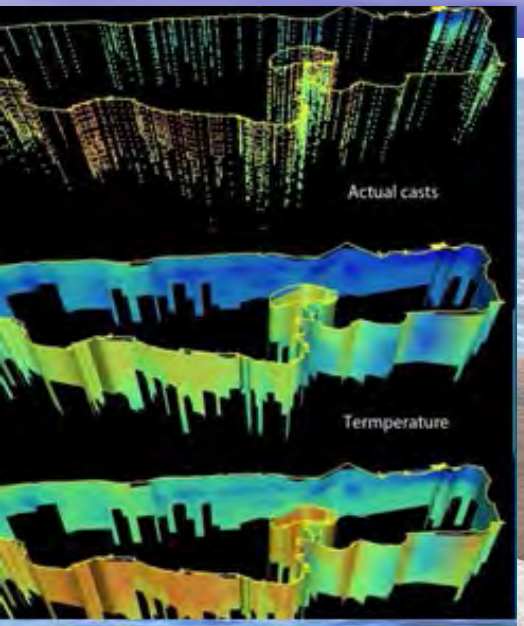


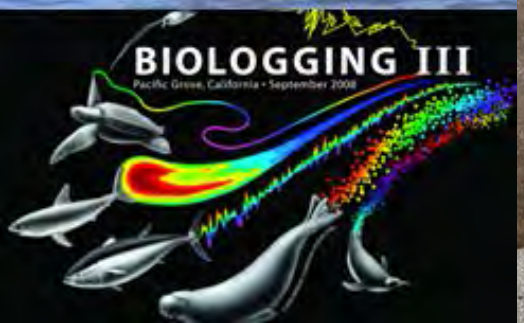


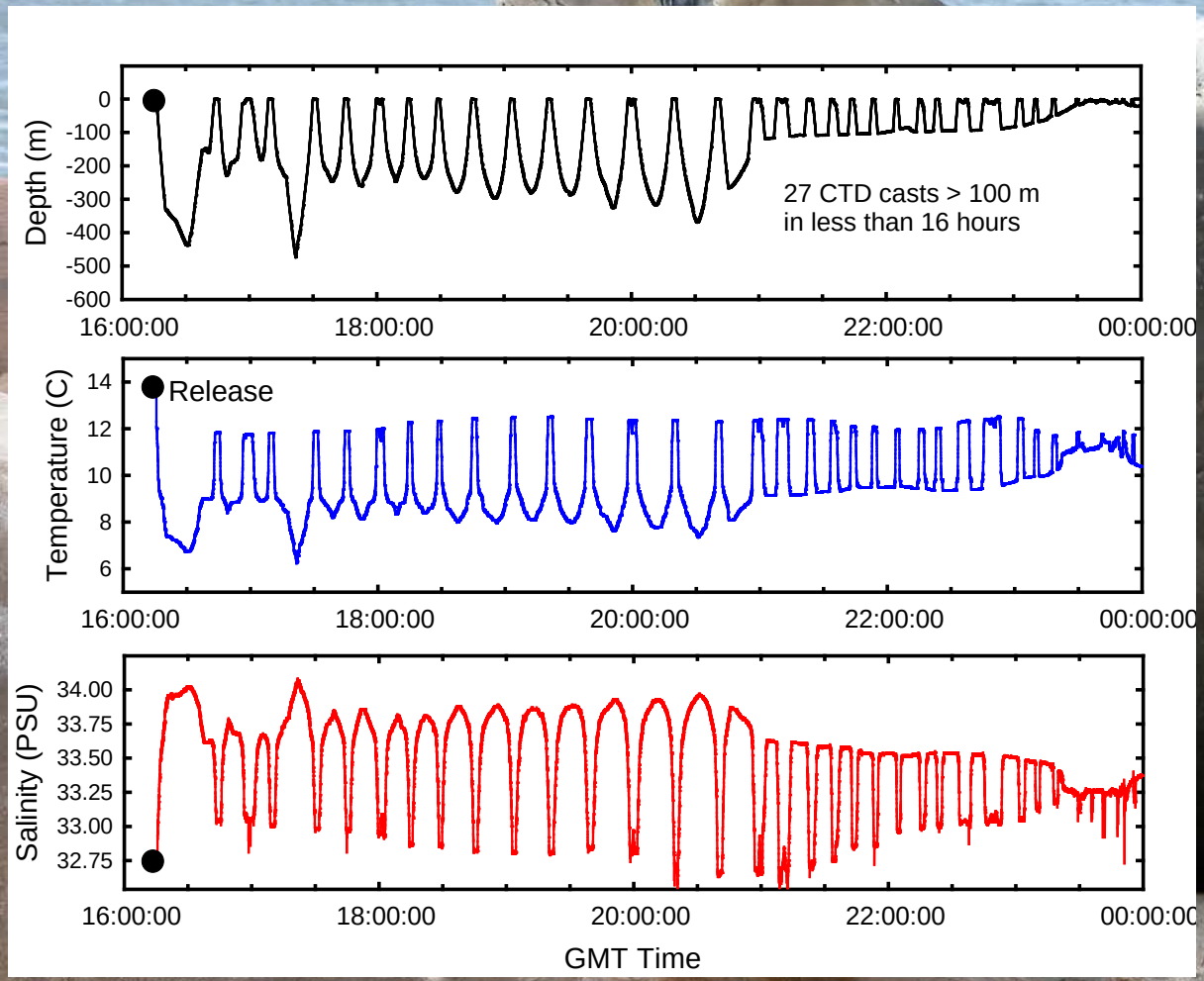
Elephant Seals & Sea Lions Travel into North Pacific Gyre



Animals As Ocean Sensors





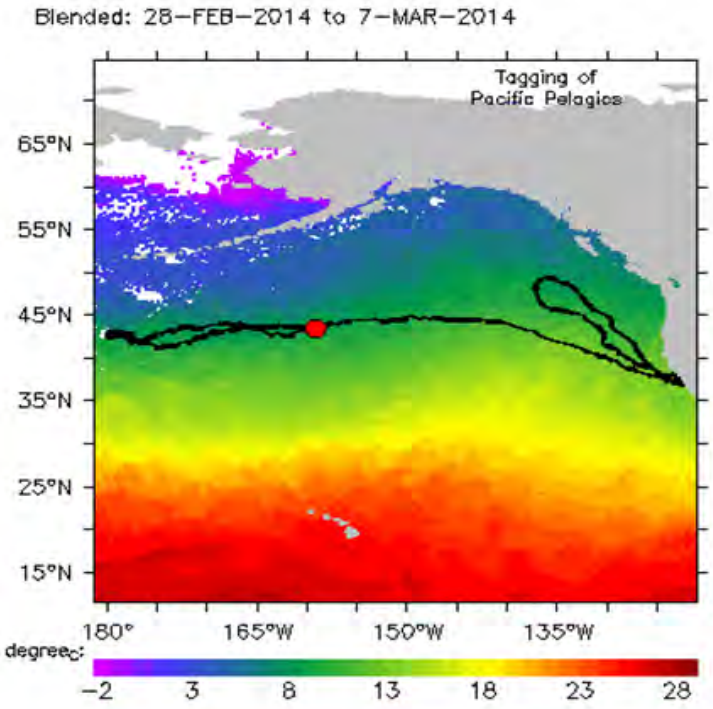


TOPP Tracked Animals Across the Northeastern Pacific Ocean

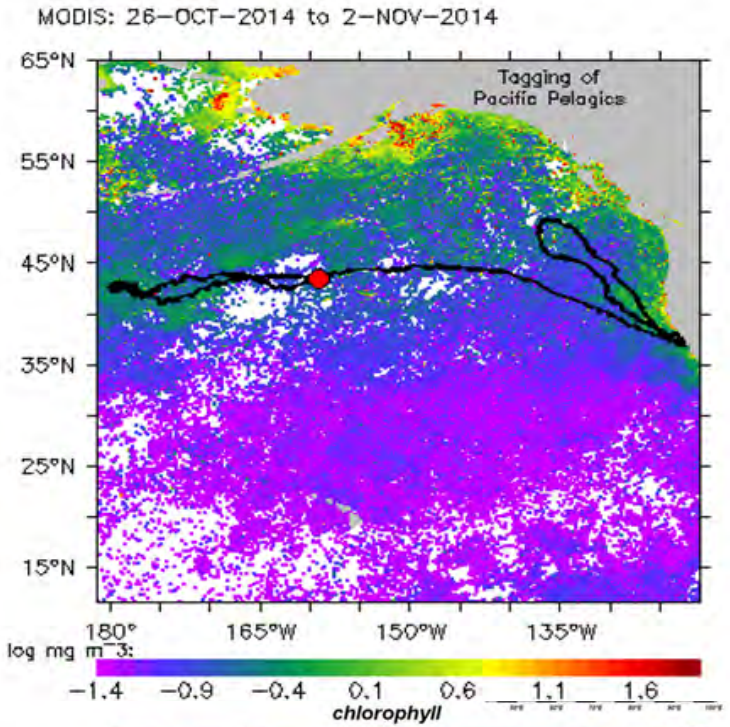
Northern Elephant Seal 133773 2014011 30 Jan 2014 to 4 Nov 2014

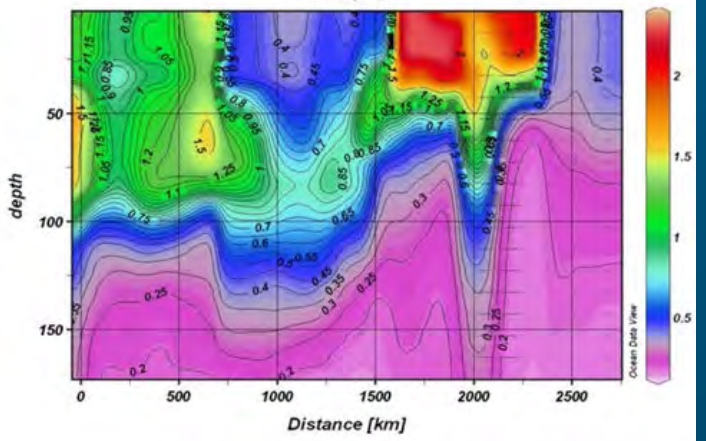
Costa Lab
UCSC

Sea Surface Temperature



Chlorophyll-a

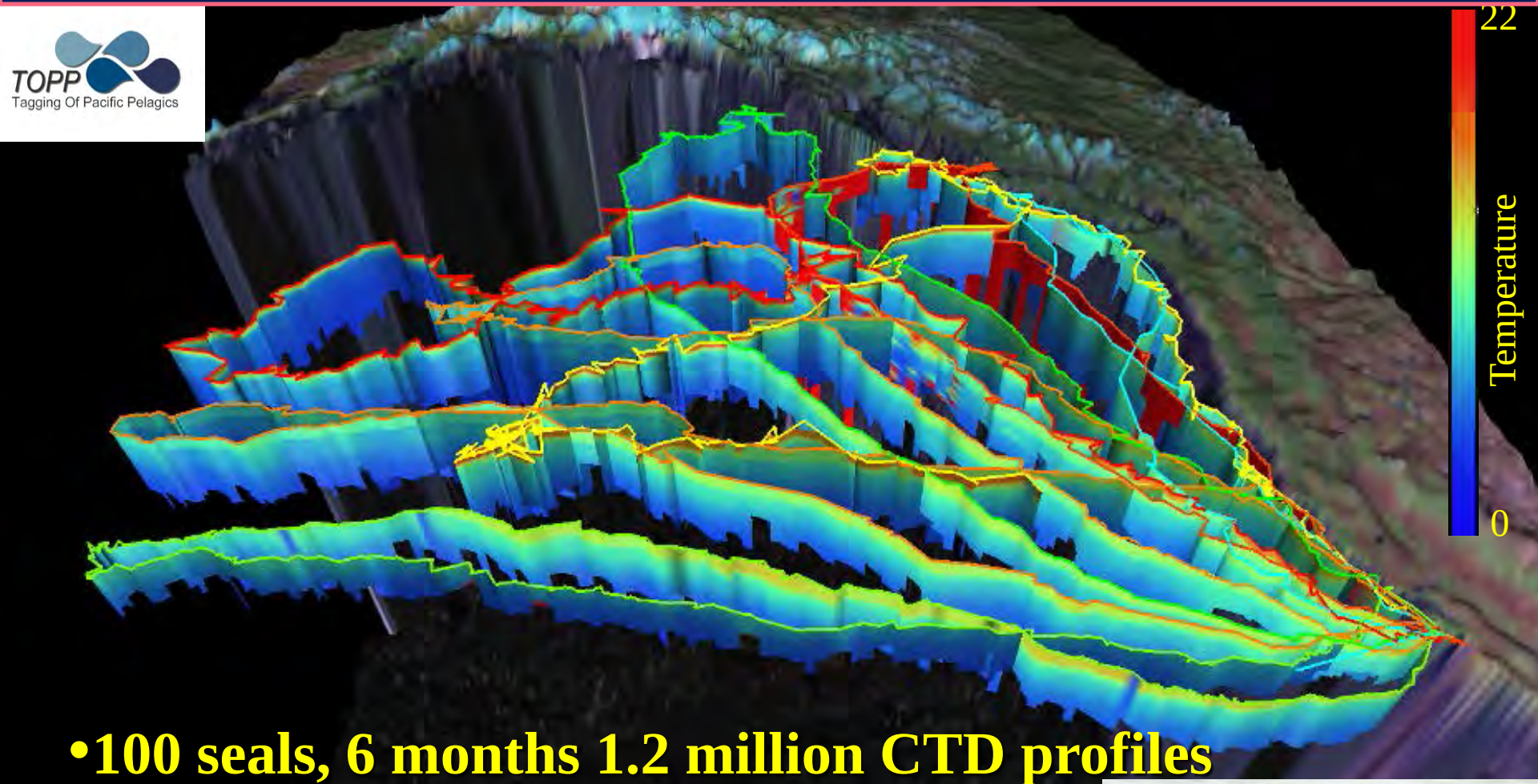




CTD TAGS on Elephant Seals

Temperature, Salinity, Chlorophyll

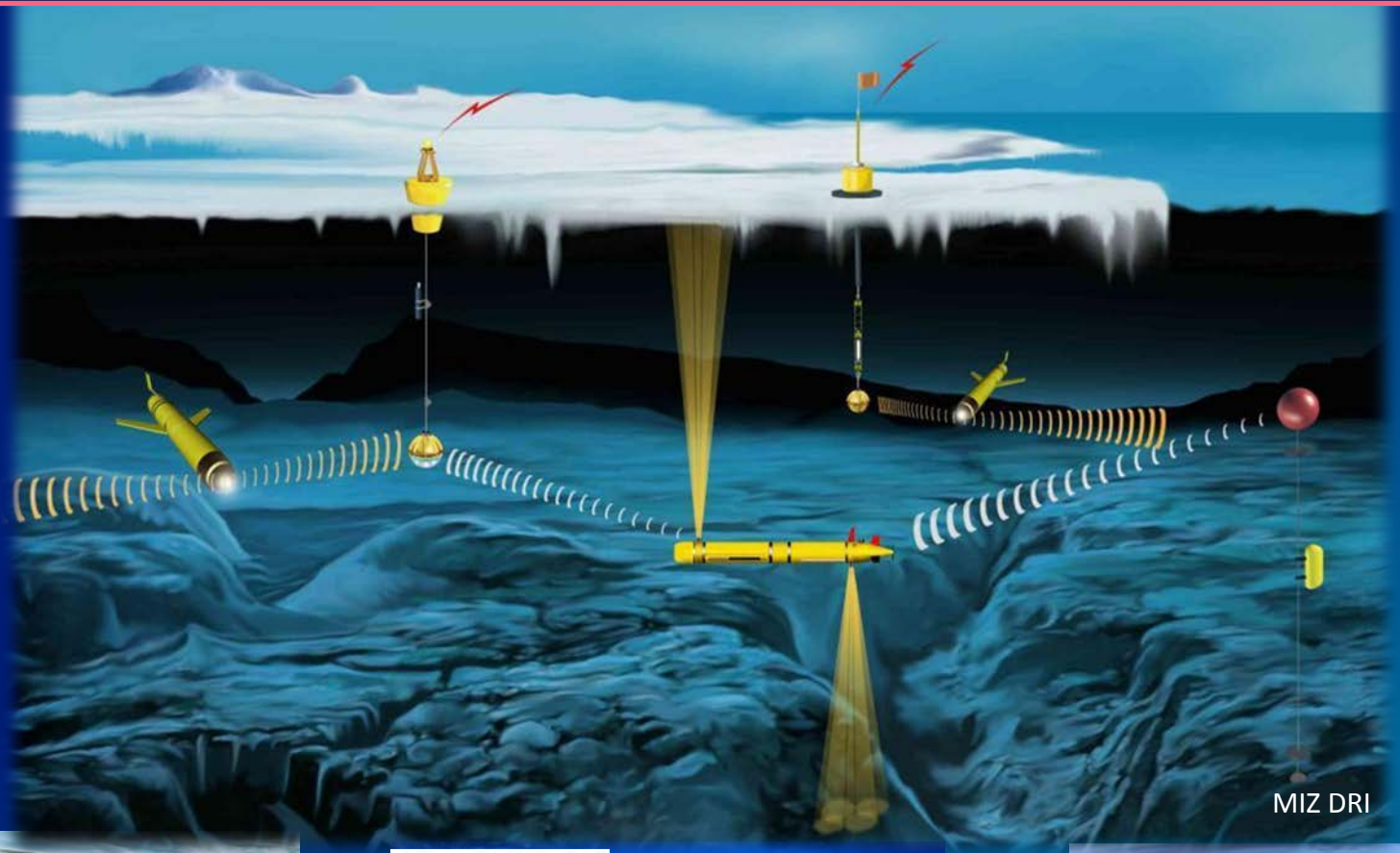
TOPP
Tagging Of Pacific Pelagics

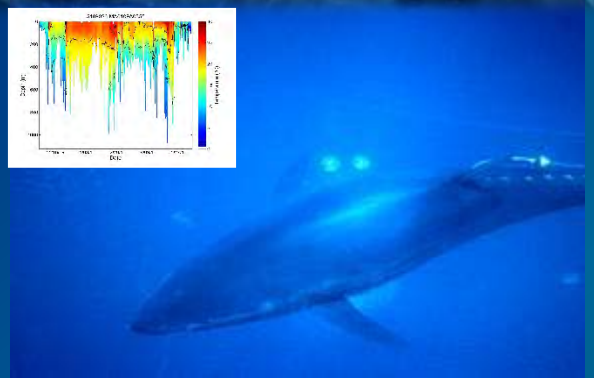


- 100 seals, 6 months 1.2 million CTD profiles of North Pacific

Animals are Ocean Sensors

Oceans are Vastly Undersampled and Animals Provide In Situ data





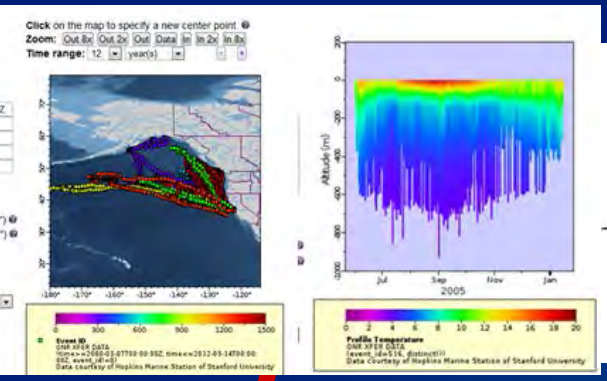
IOOS/ONR Sponsored Data Integration Projects with TOPP Program to Deliver Seal Data

Real-time data flow from animals

Met Office

Coriolis
OPERATIONAL OCEANOGRAPHY

user



Global Telecommunication System

NOAA

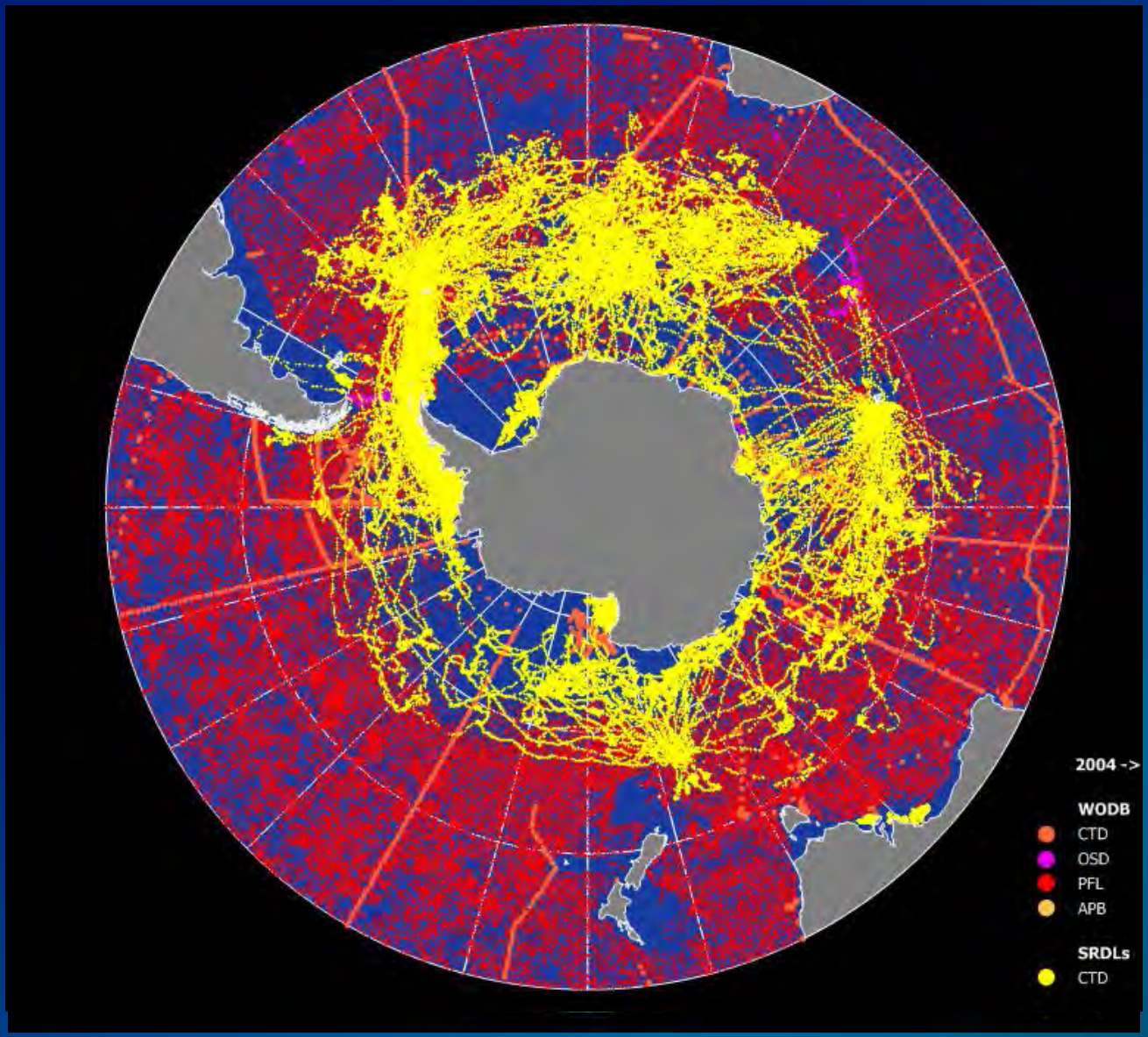
TOPP
Tagging Of Pacific Pelagics

BODC

British Oceanographic Data Centre

NRL Stennis Space Center

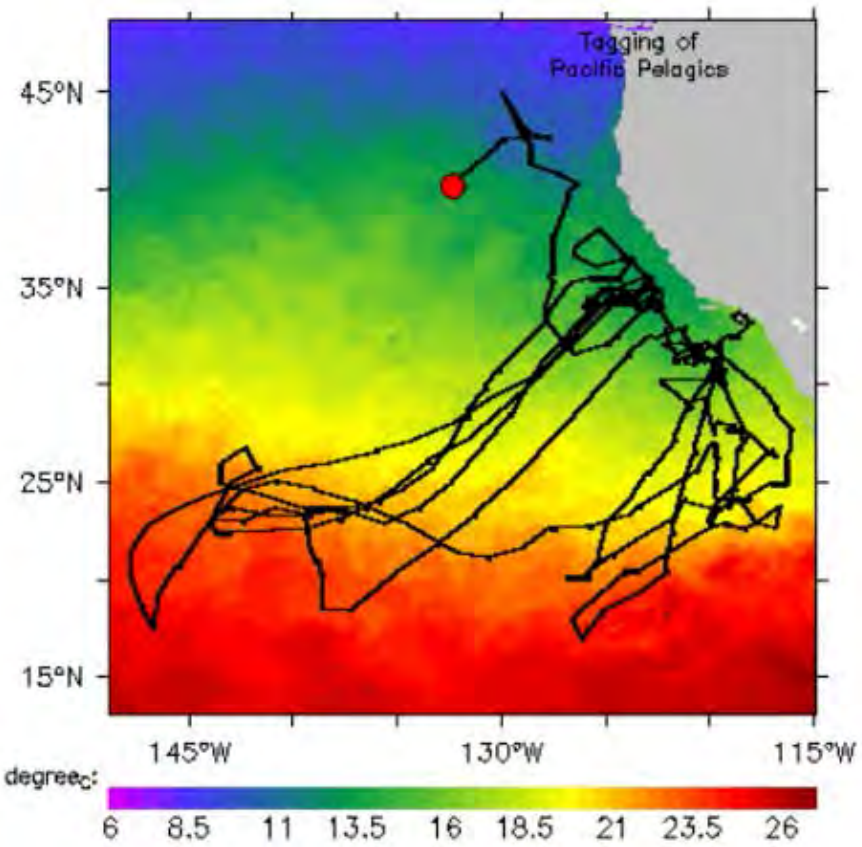
Southern Ocean: Animal Ocean Observing Data



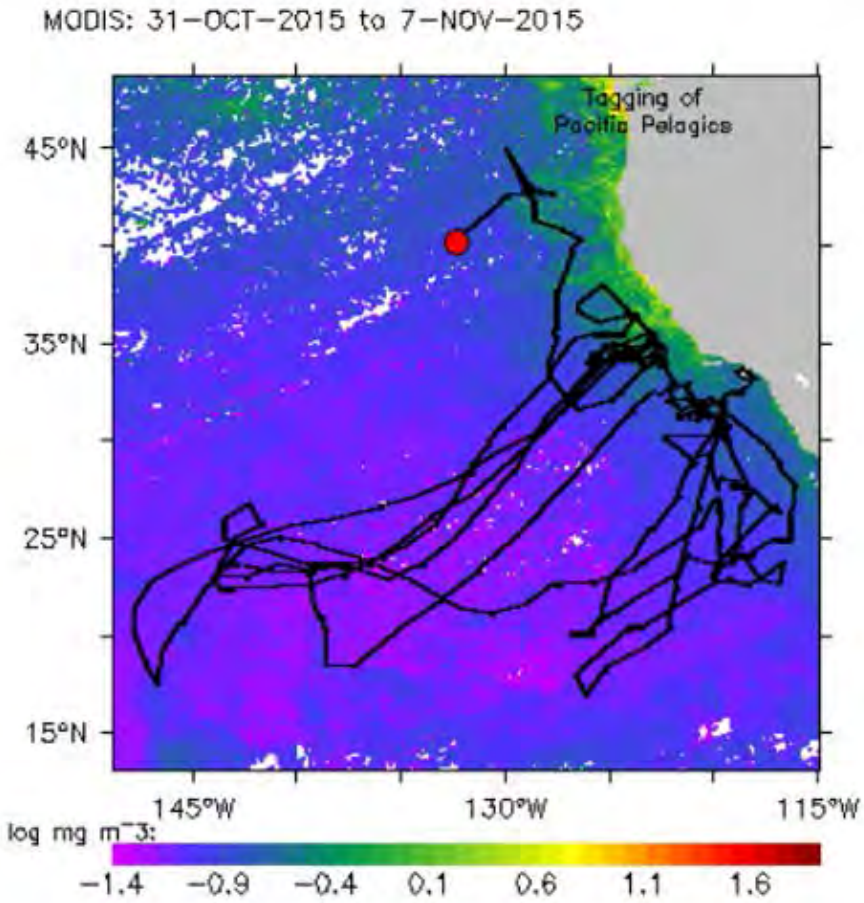
SPOT Tags: Sharks that "Phone" Home

Shortfin Mako Shark 120687 1513002 8 Jul 2013 to 5 Nov 2015

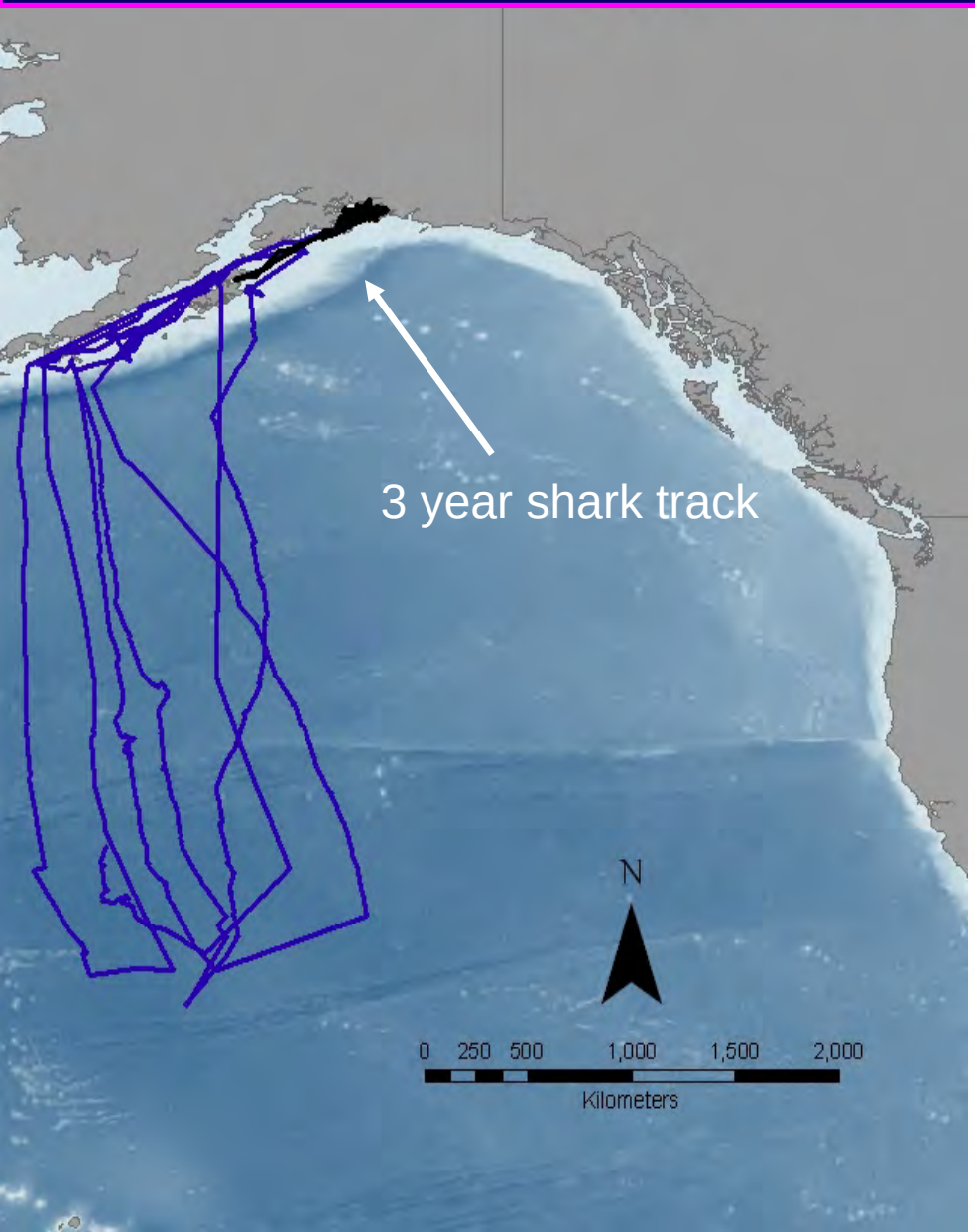
Sea Surface Temperature

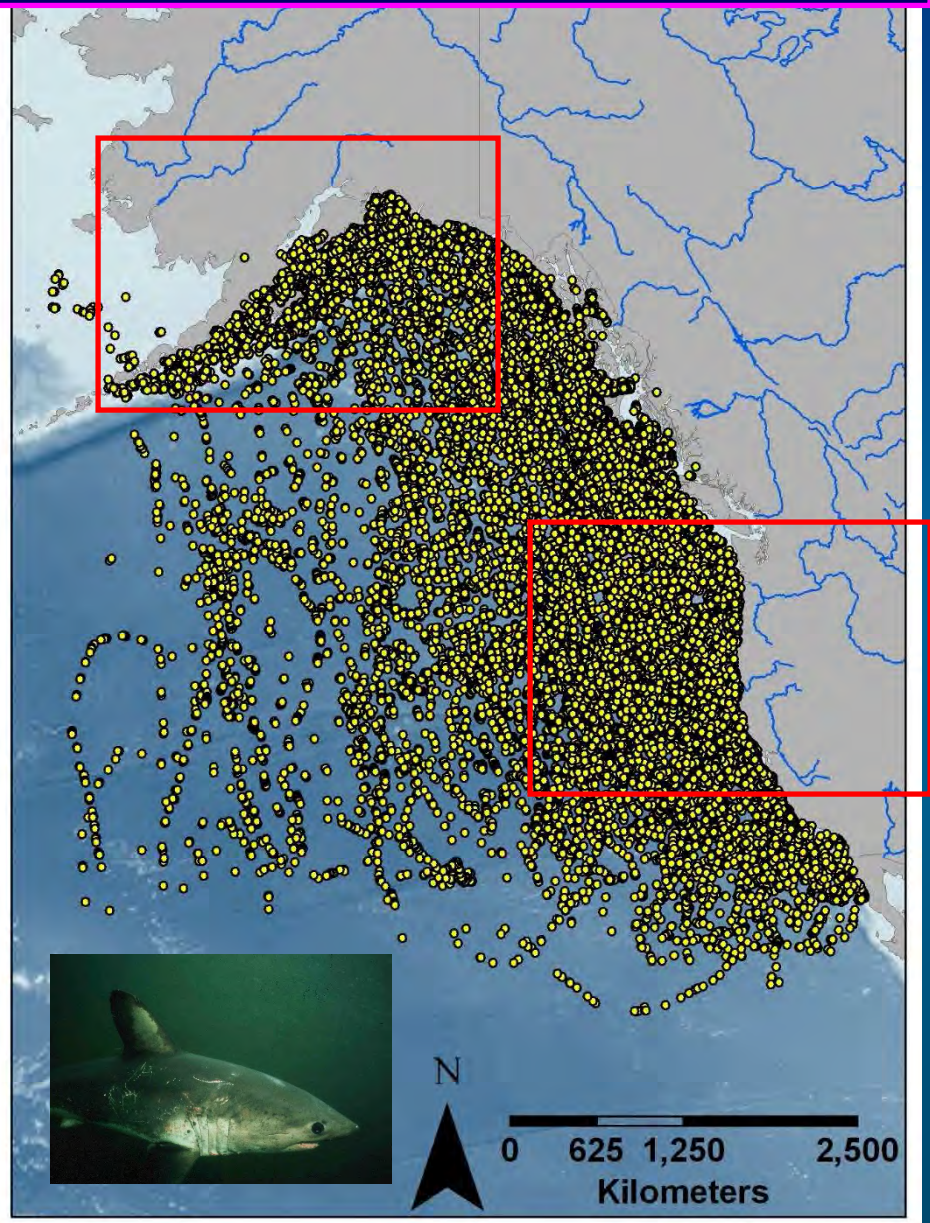


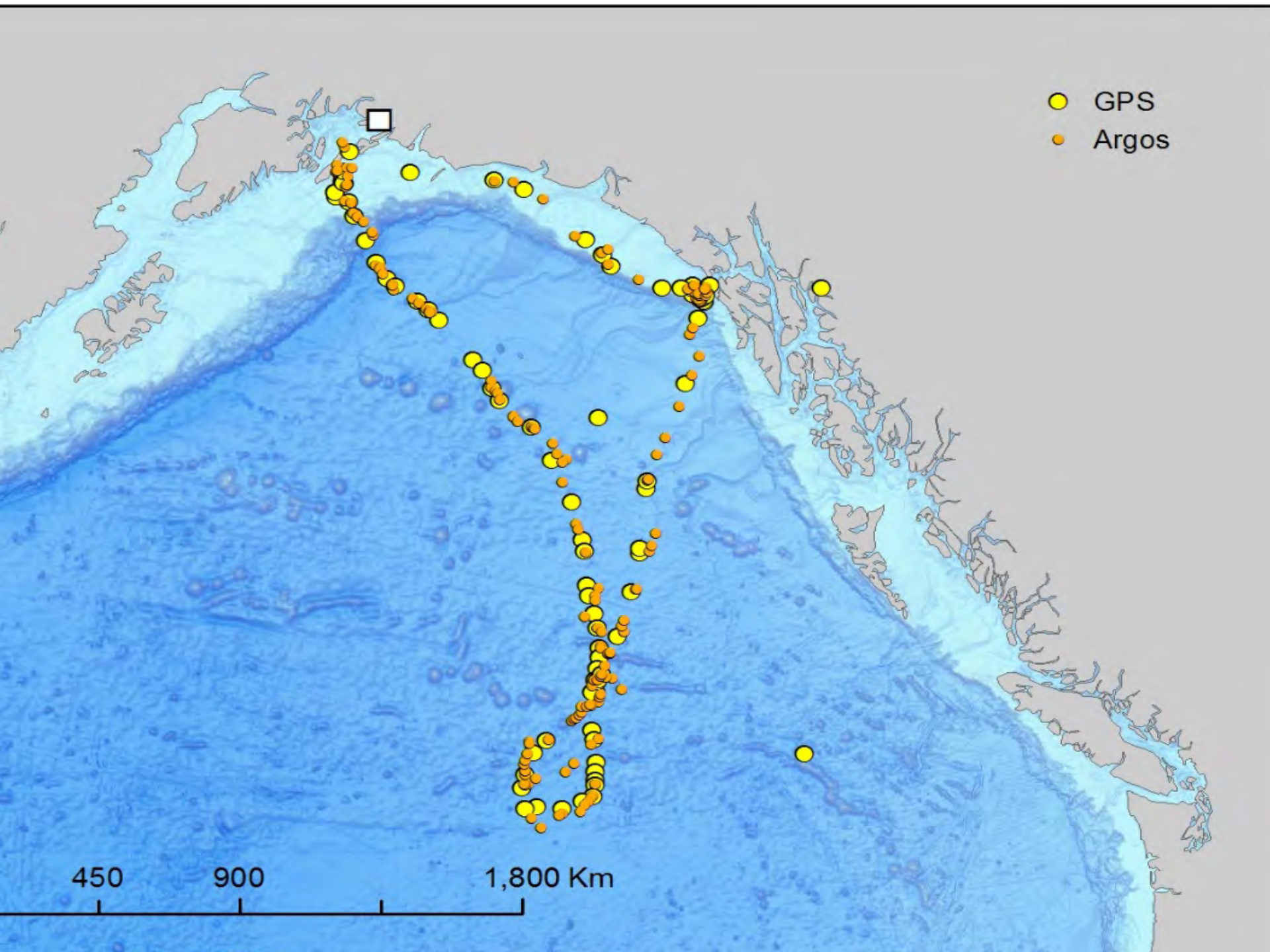
Chlorophyll-a



Satellite Positions for Salmon Sharks (N=76)
Repetitive Migrations from Arctic to Subtropics



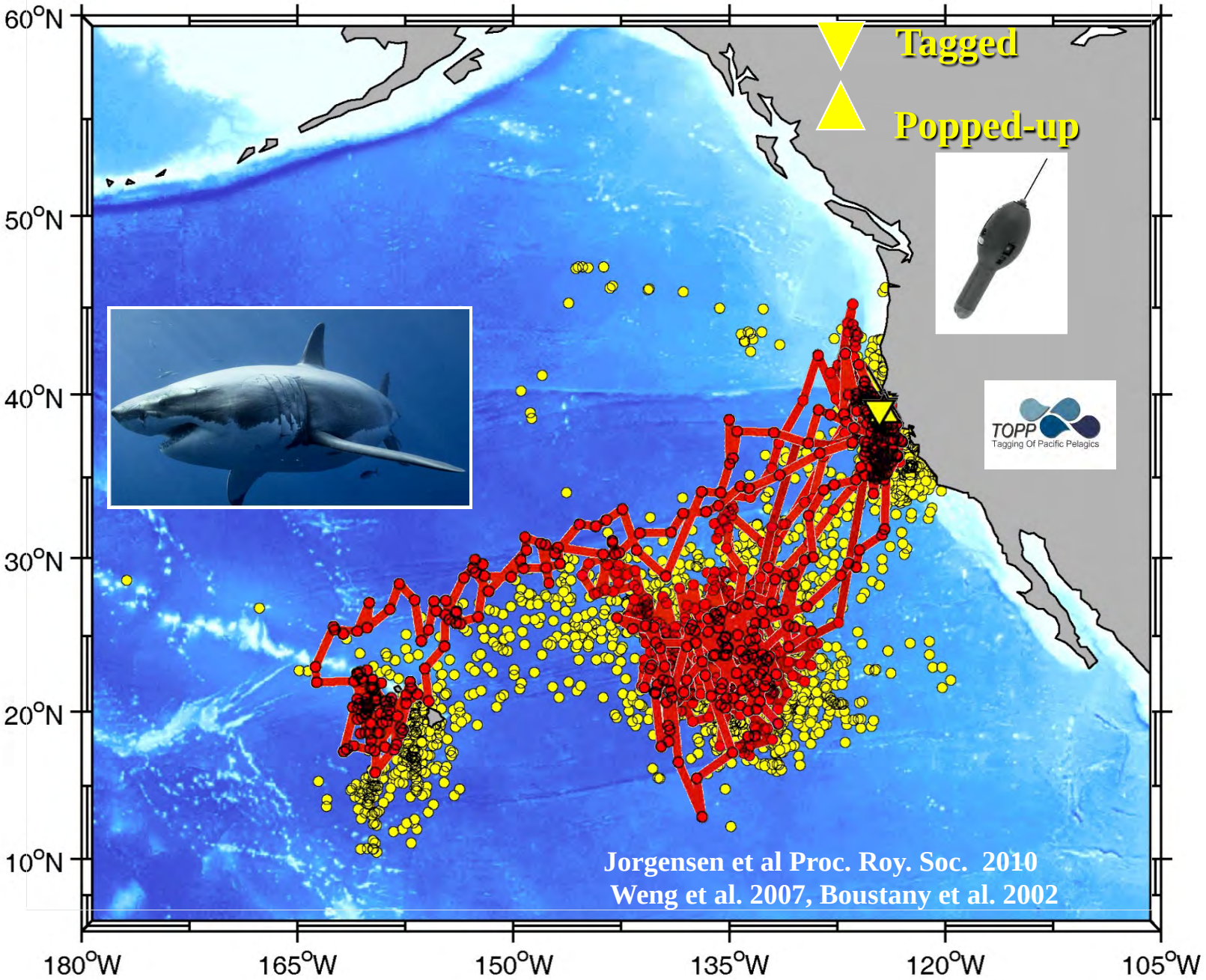



GPS
Argos
450
900
1,800 Km

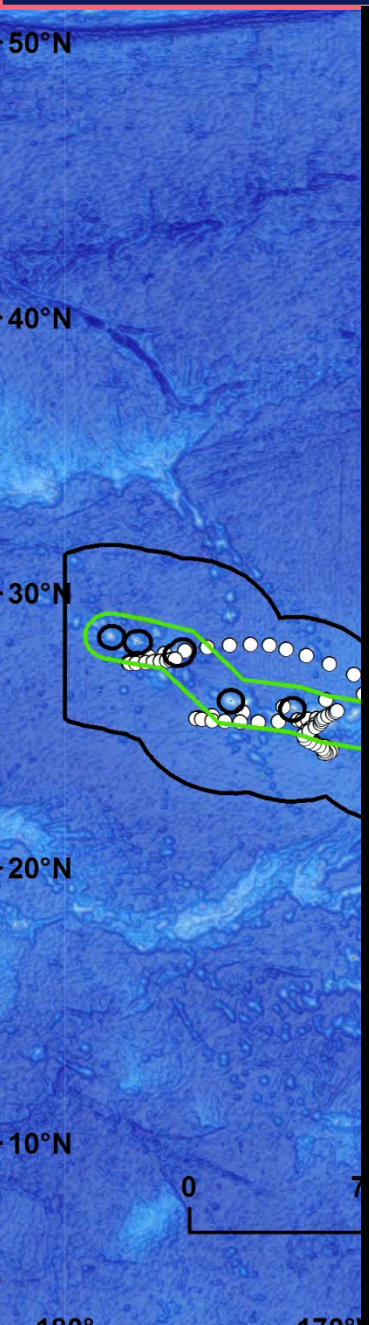
Pop-Up Satellite Tagging White Sharks

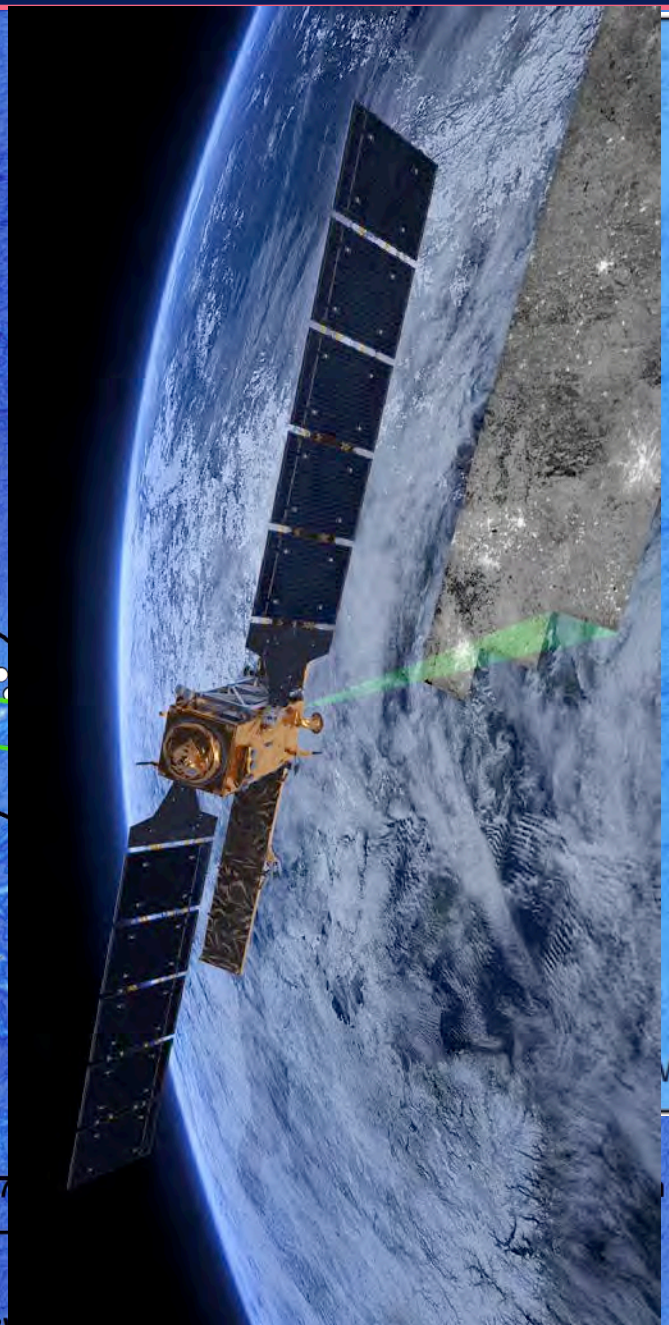
Tagging 1000 kg White Sharks

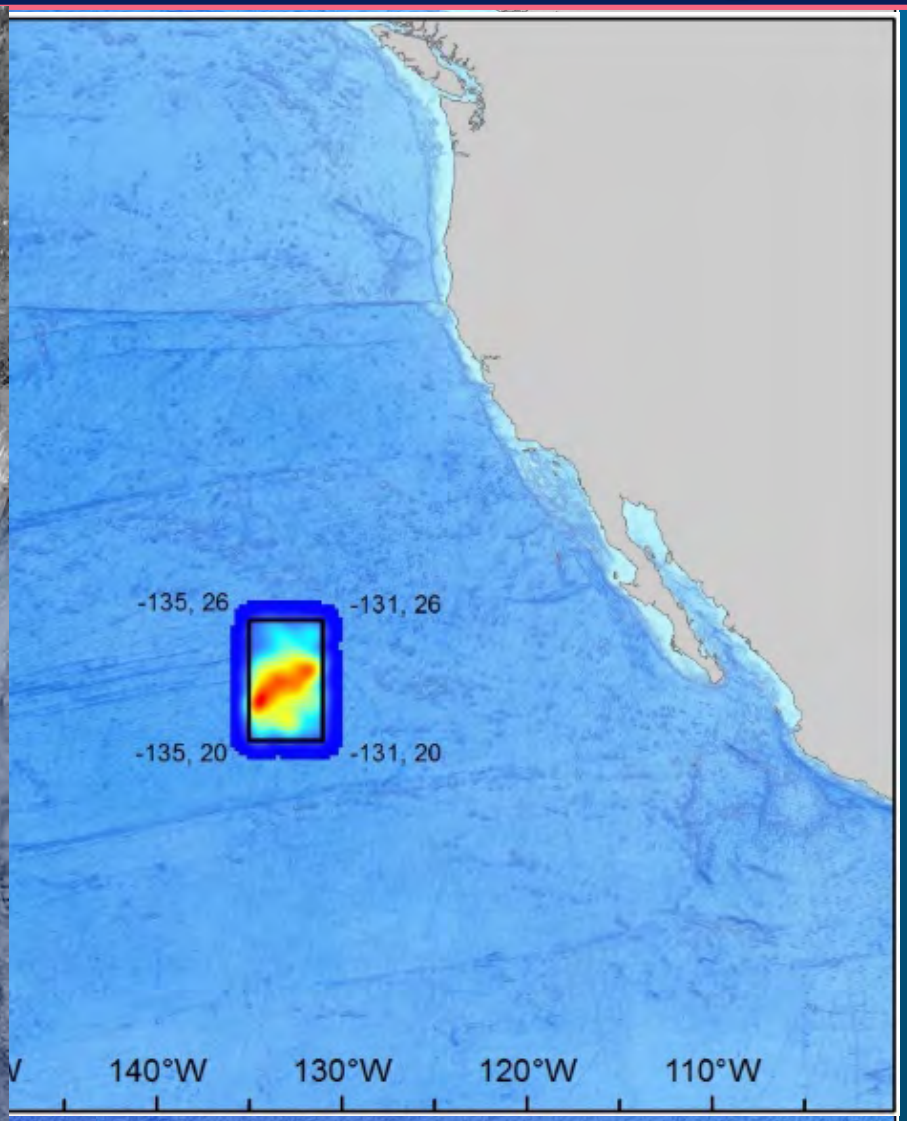
Pop-up Satellite Tags Reveal White Shark Fidelity to California Coast



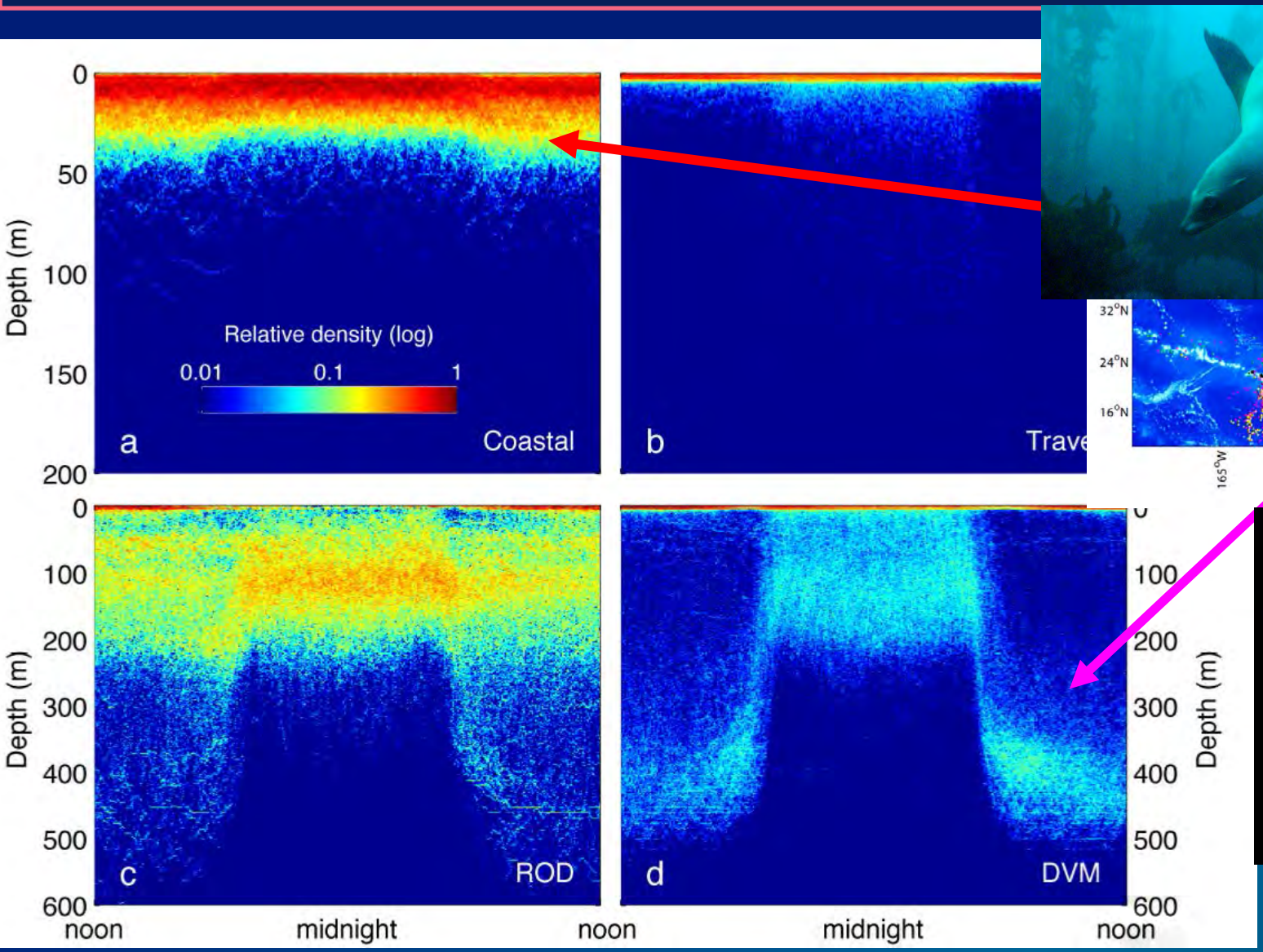
How Can We Dynamically Protect Café? Catapult

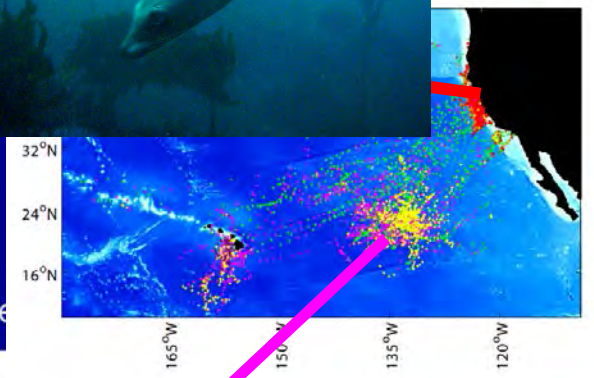






Tags Record Change of Dive Behaviors



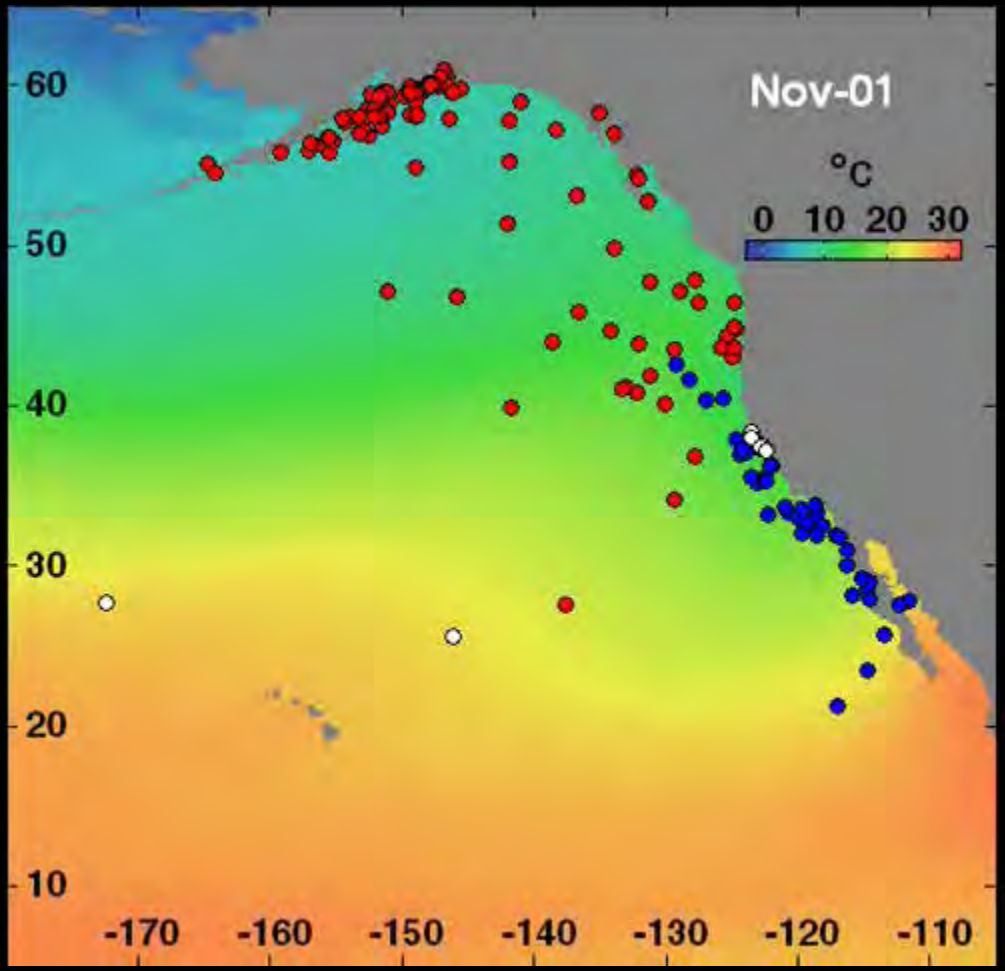


Jorgensen et al. PLos One 2013
Weng et al. Marine Biology, 2007

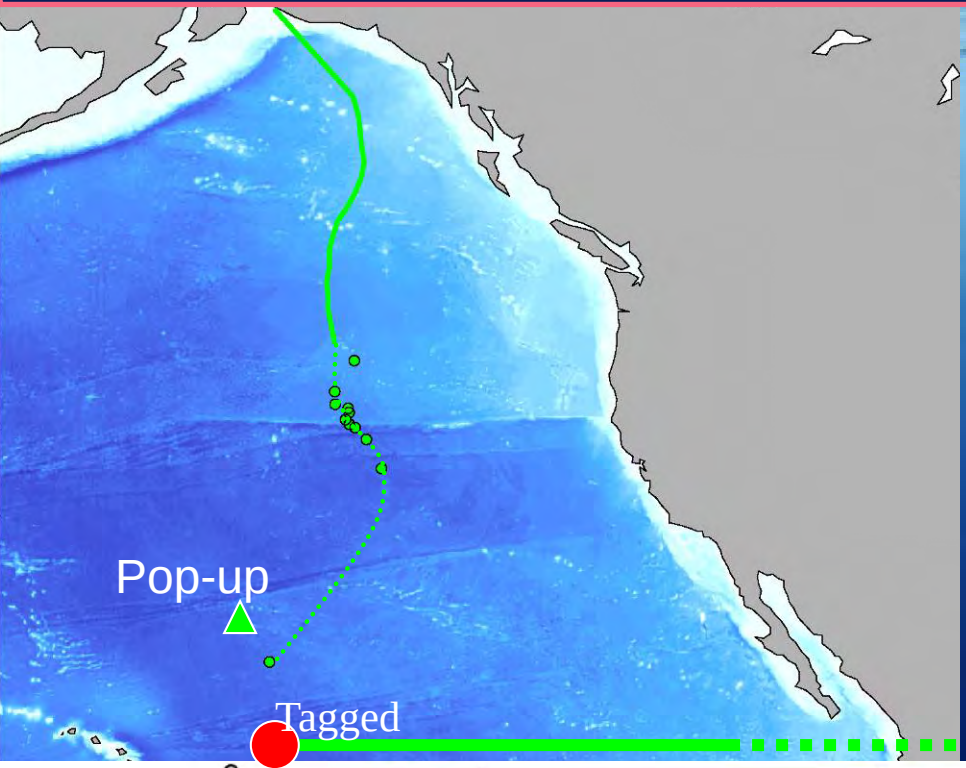
>400 Lamnid Sharks Tagged Reveal Habitat Utilization

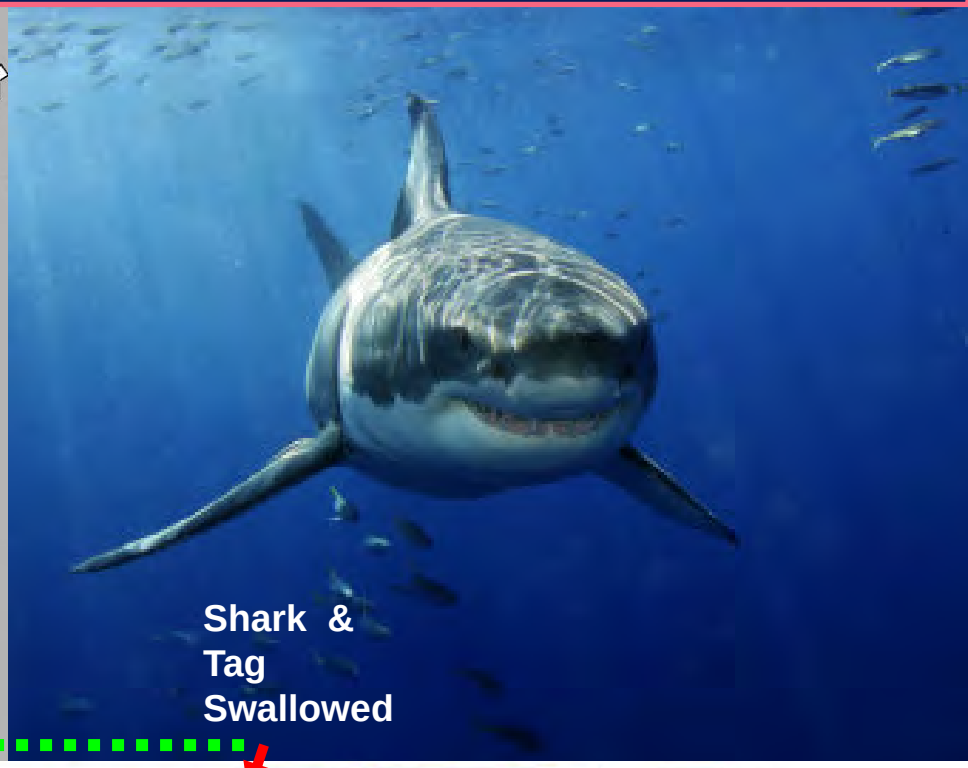
TOPP
Tagging Of Pacific Pelagics

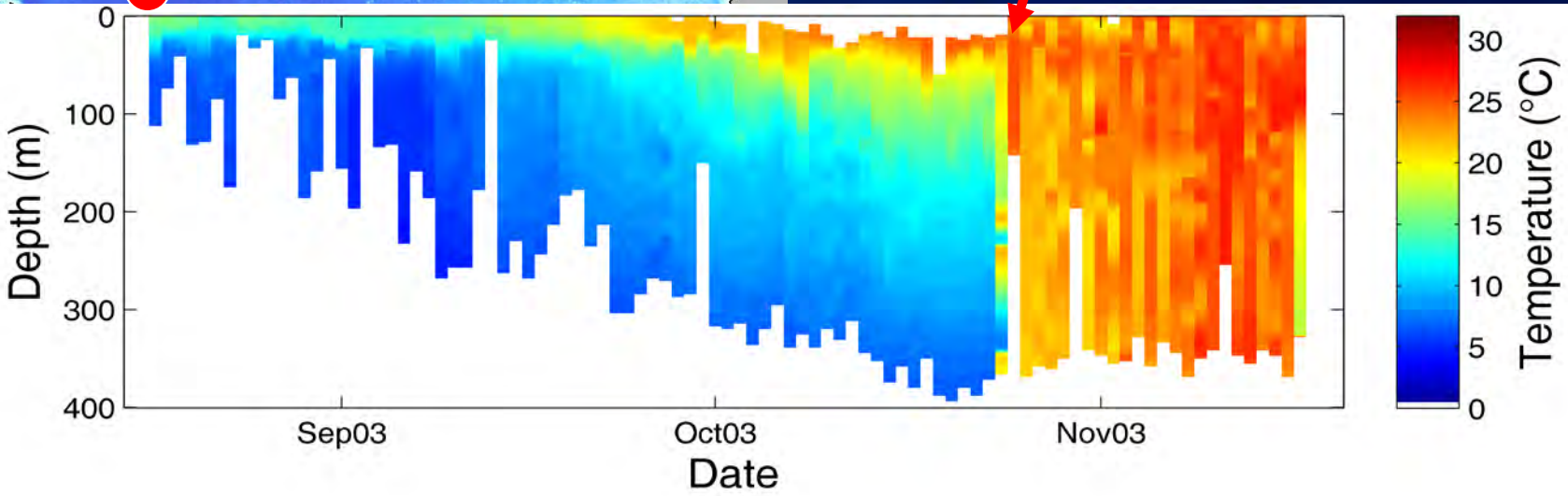
Salmon, White & Mako Sharks



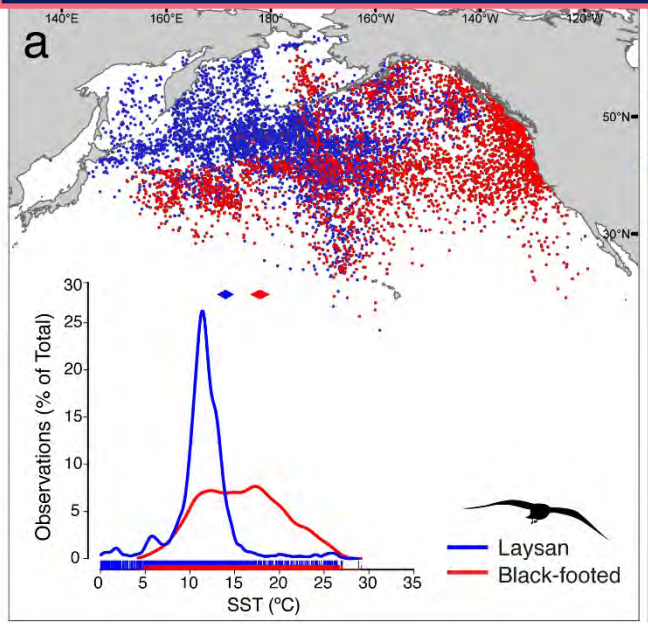
HOT SHARKS: PREDATION EVENTS ON TAGS

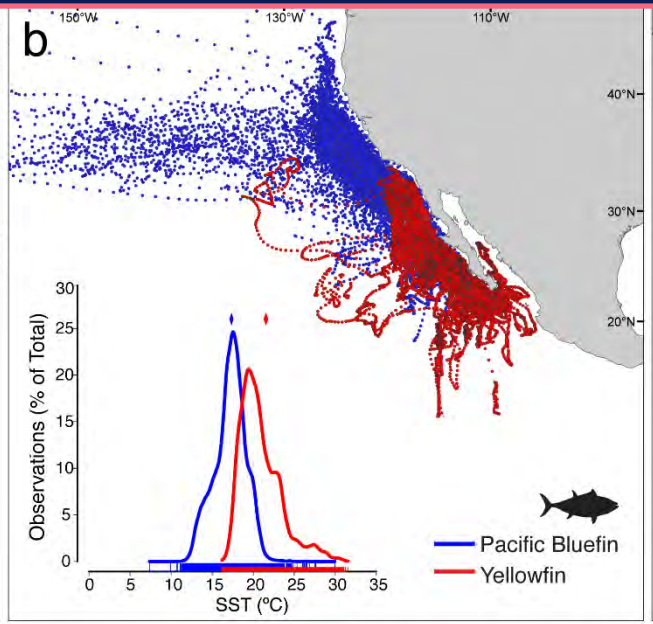


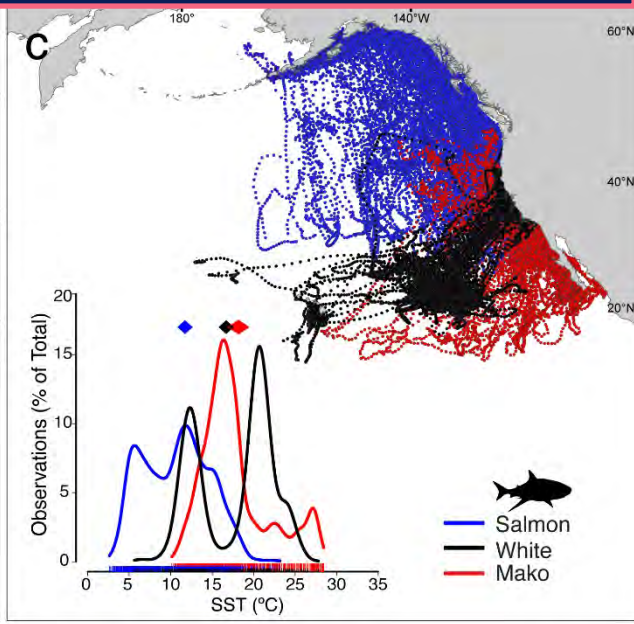




Tagging Reveals Niche Utilization
Thermal Niche Separation: Albatross, Tunas, Sharks

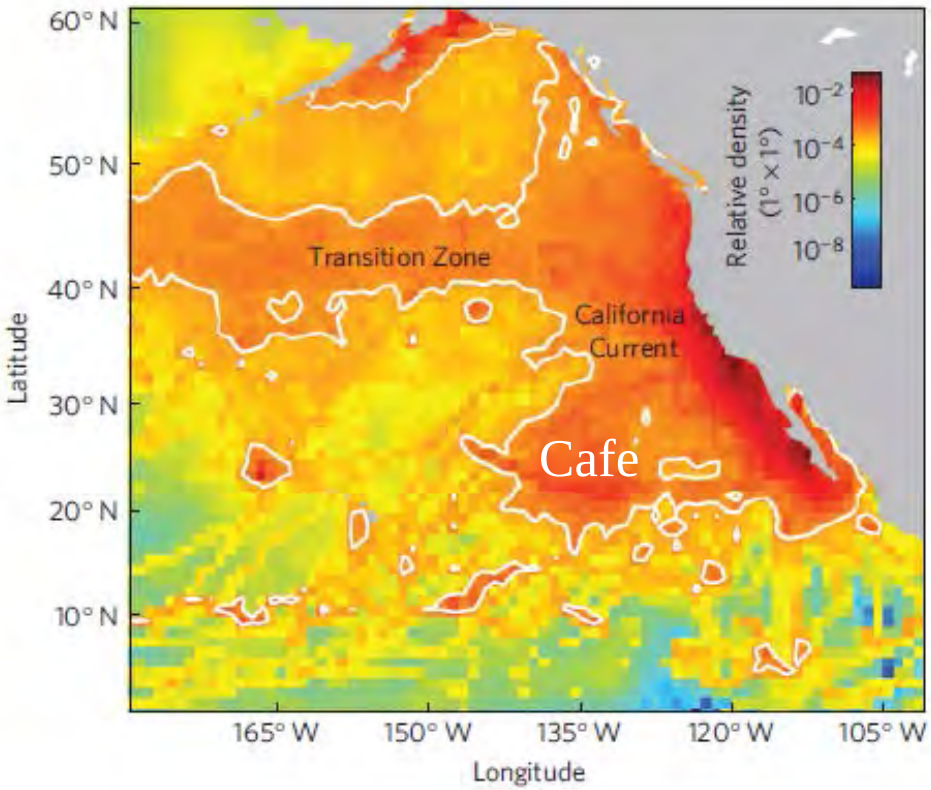






California Current World Heritage Site?
Blue Serengeti Initiative: Build/Expand Pelagic MPAs

Density of Top Predators



All Species All Positions

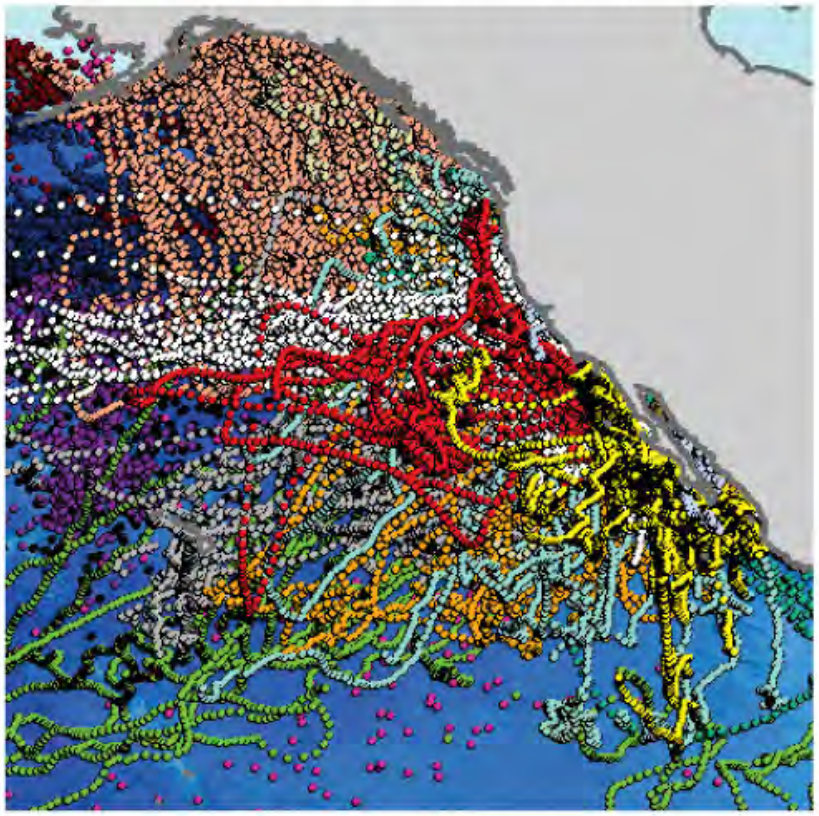
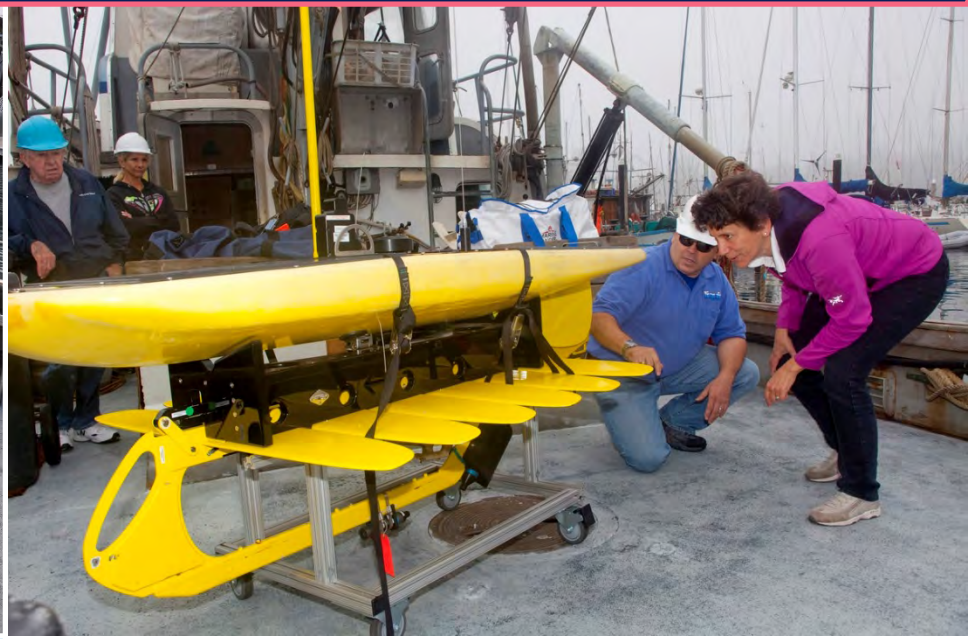
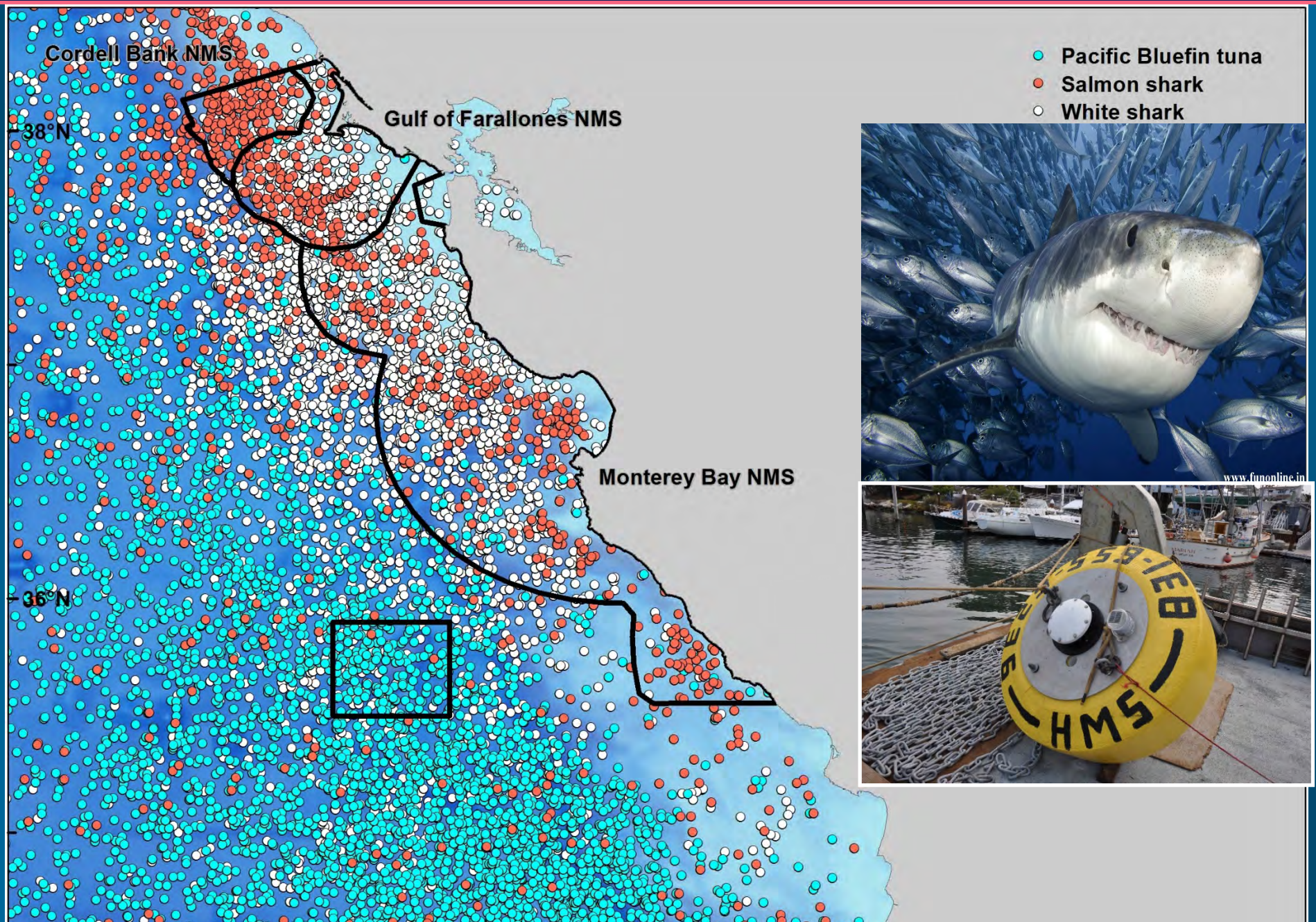


Figure 1 | Density of top predators within the eastern North Pacific.

Can We Monitor Apex Predators in Real Time? Yes



Can We Monitor Sharks in our National Sanctuaries?



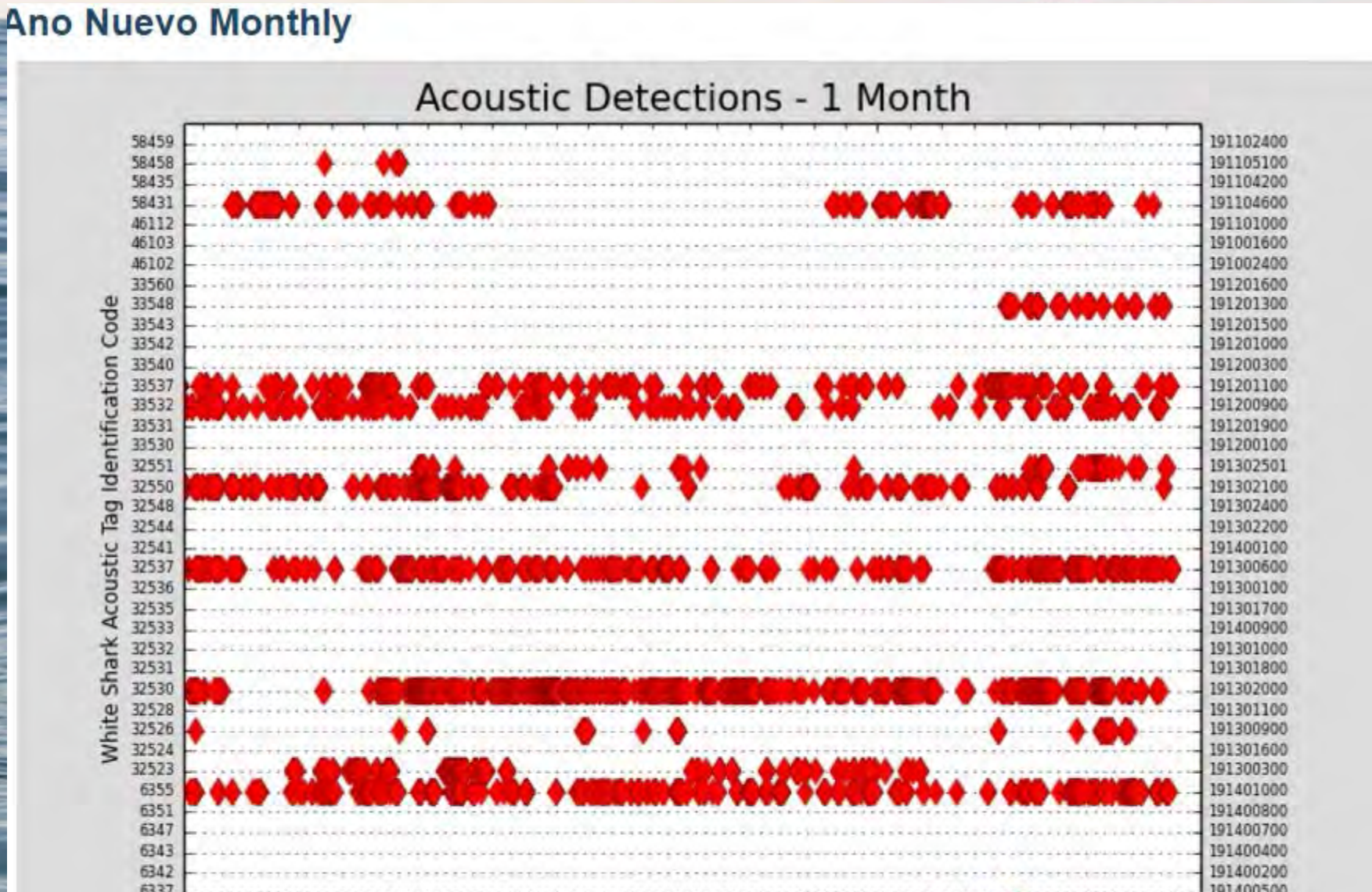
SharkNet: Live Shark Detection Buoys

bob.doiron@amirix.com, bdoiron74@gmail.com, glen.robinson@
bblock@stanford.edu, tkchapple@ucdavis.edu, alans@mola.stan
salvo@stanford.edu, paulkanive@gmail.com, mrcastle@stanford
monique@mbari.org, Kochevar@stanford.edu, sharkman1137@

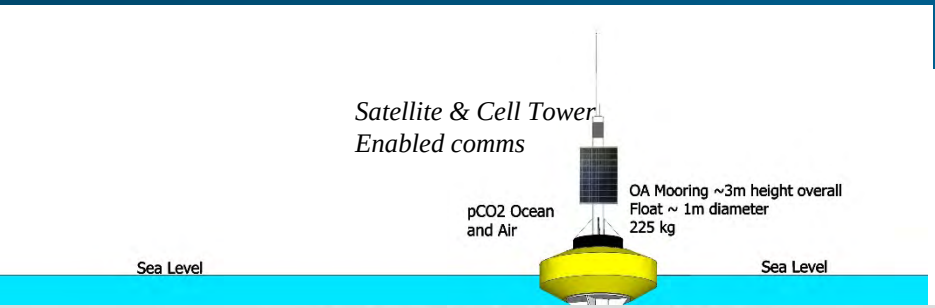
Date: Tue, 23 Sep 2014 13:35:03 -0300
Subject: VR4G-200075: A69-1303-32528, Interval Count = 49

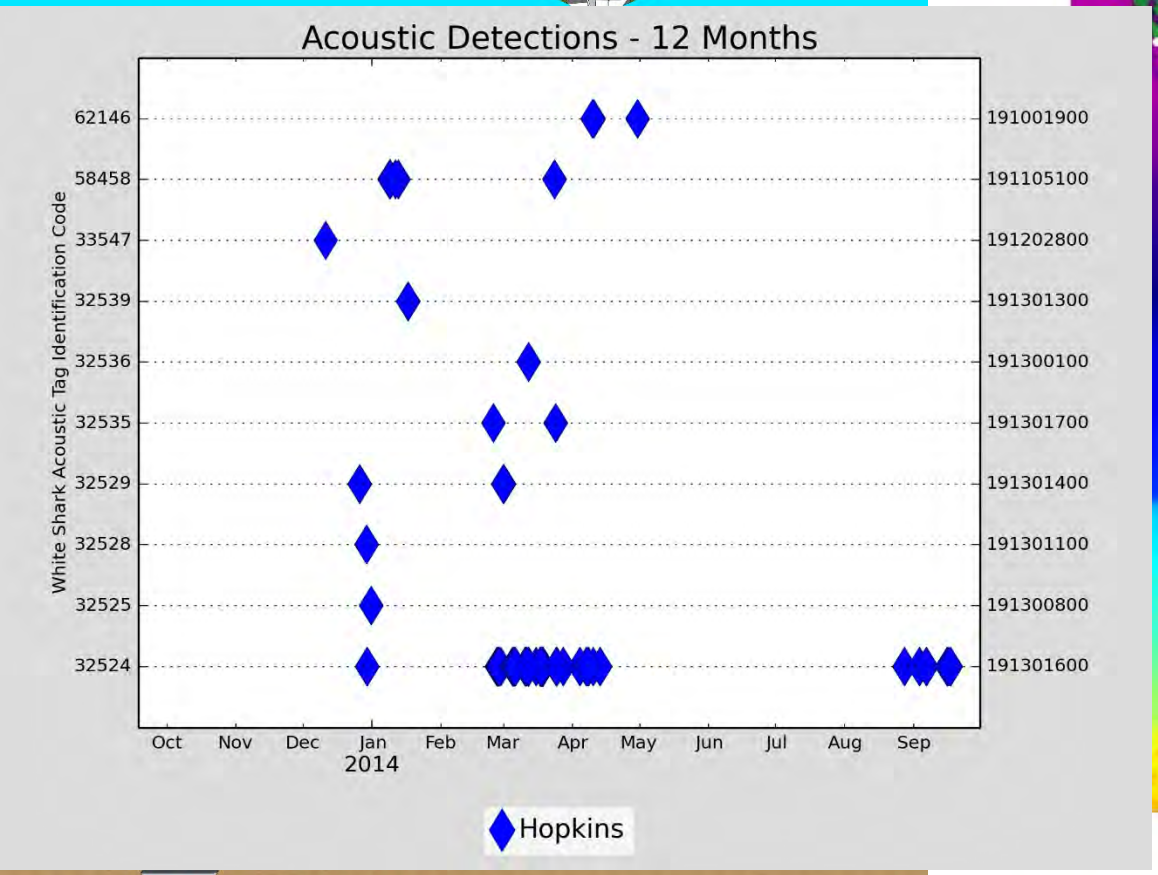
Tag ID: A69-1303-32528
Last Detect Time: 2014-09-23 16:34 +0000
Interval Count: 49
Notifcation ID: 6811
IMEI: 30-002501-092478-0

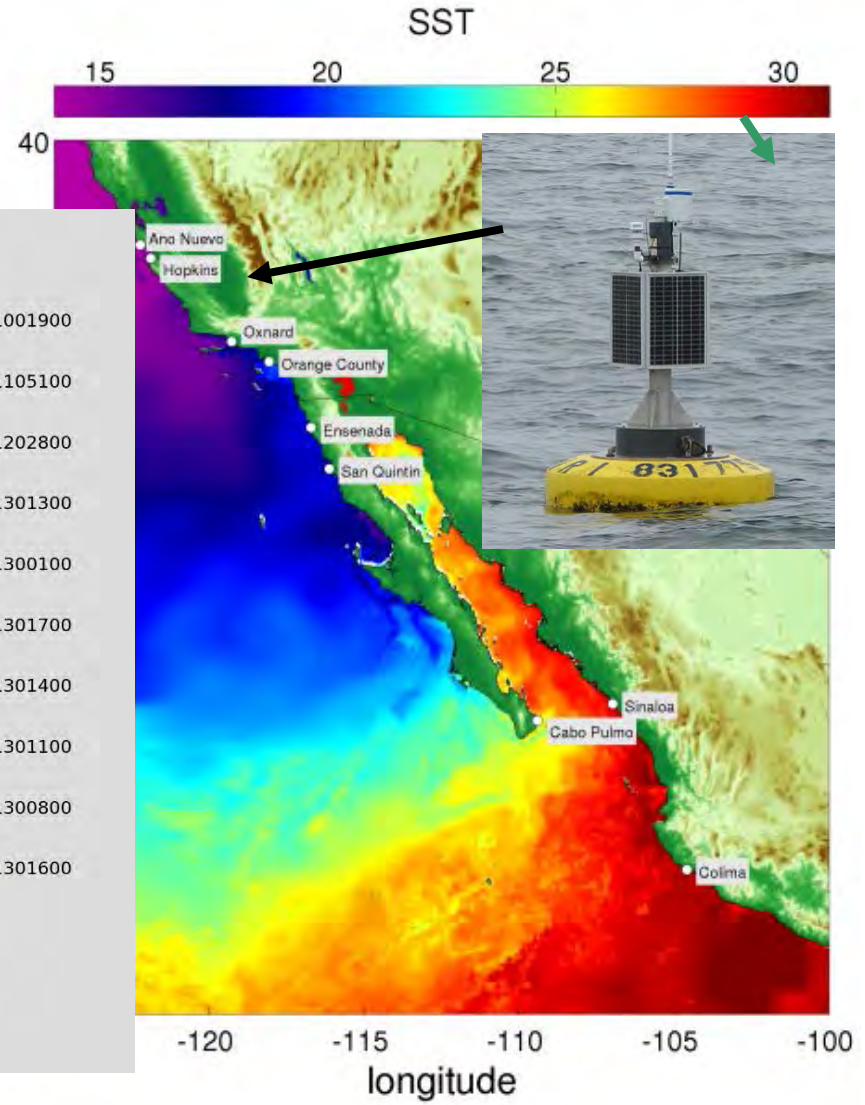
Arrival of White Shark at Irridium Detection Buoy- Central California Coast



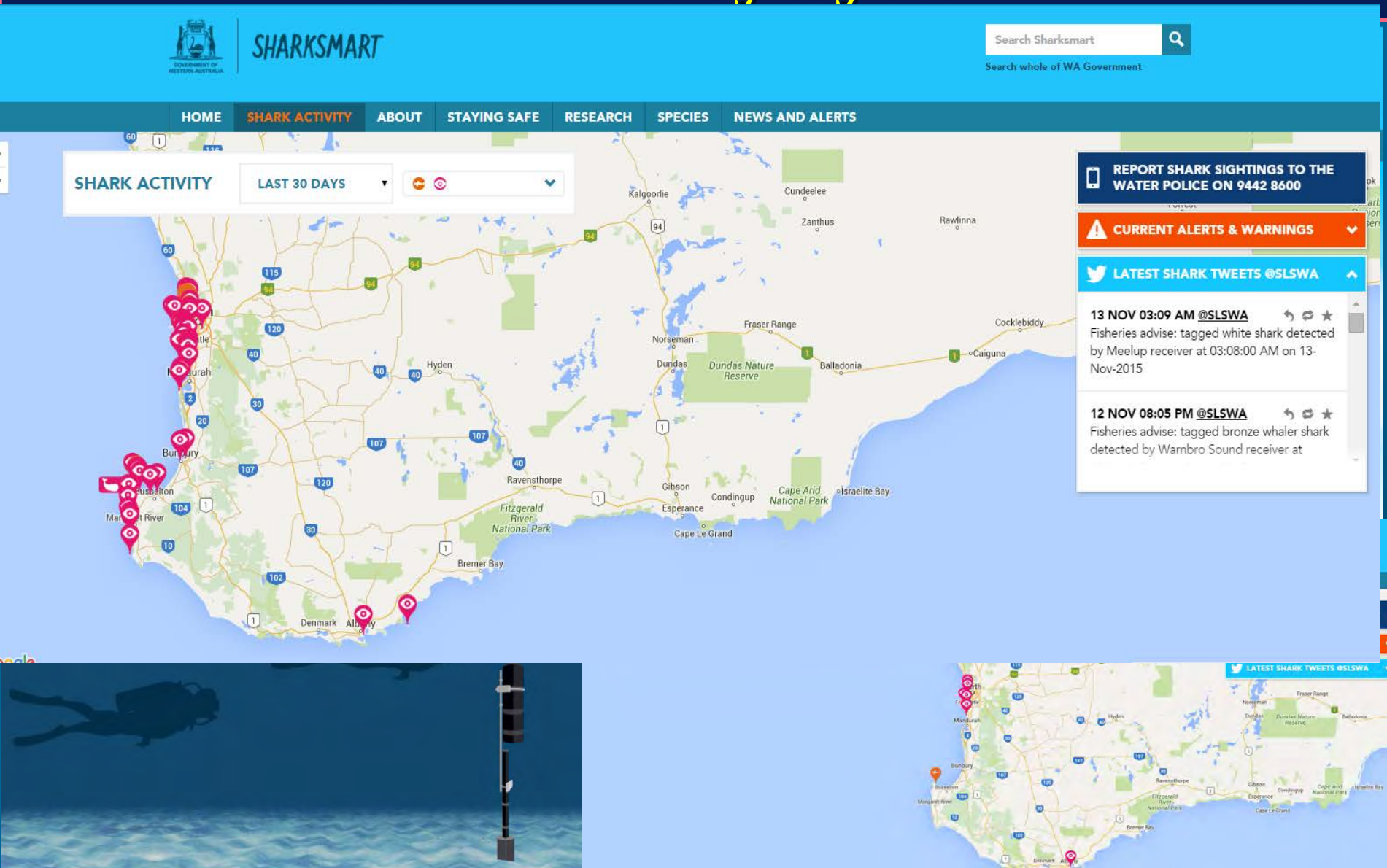
Ocean observation Buoys



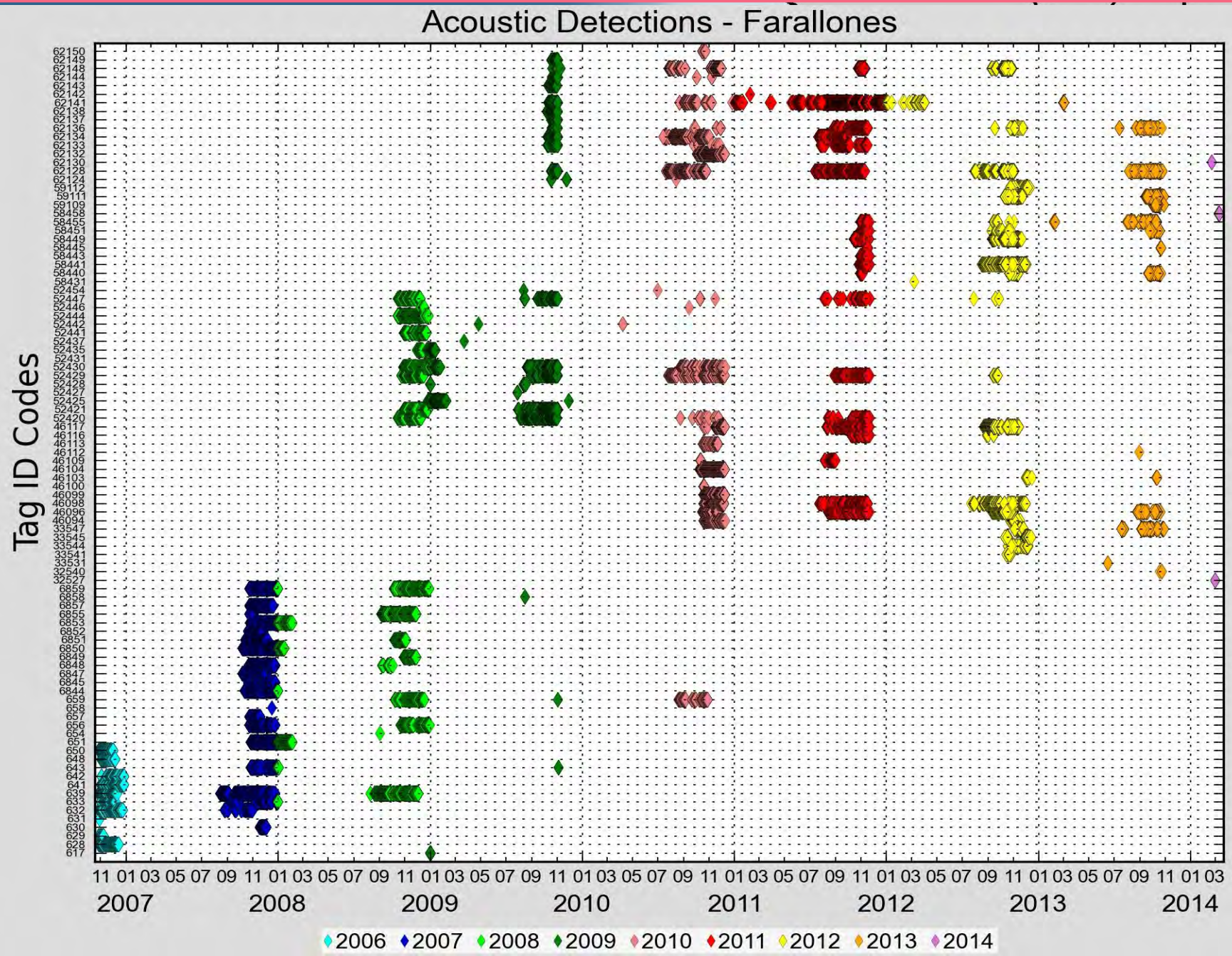




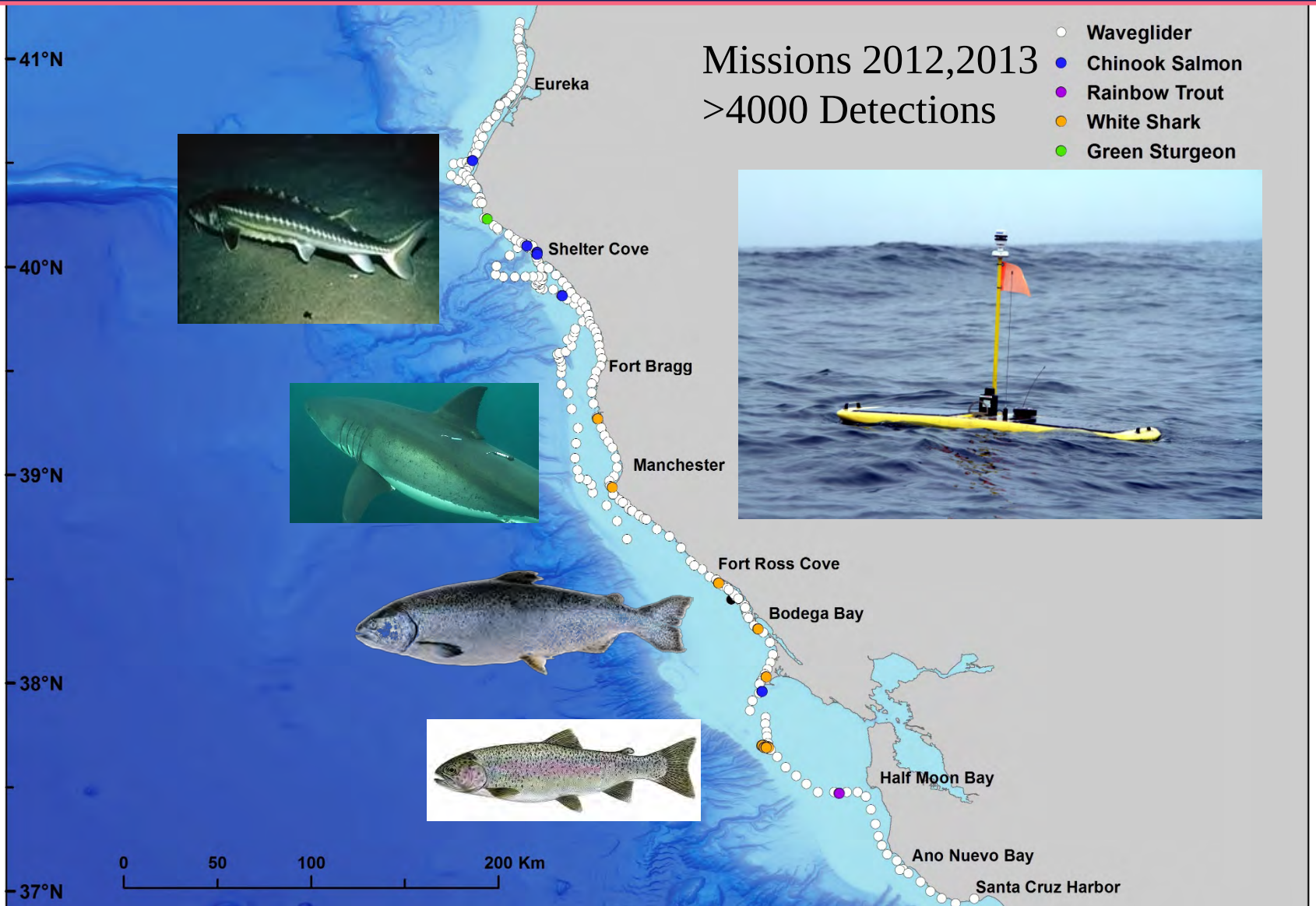
Commercialization: Australia Shark Smart Buoy System



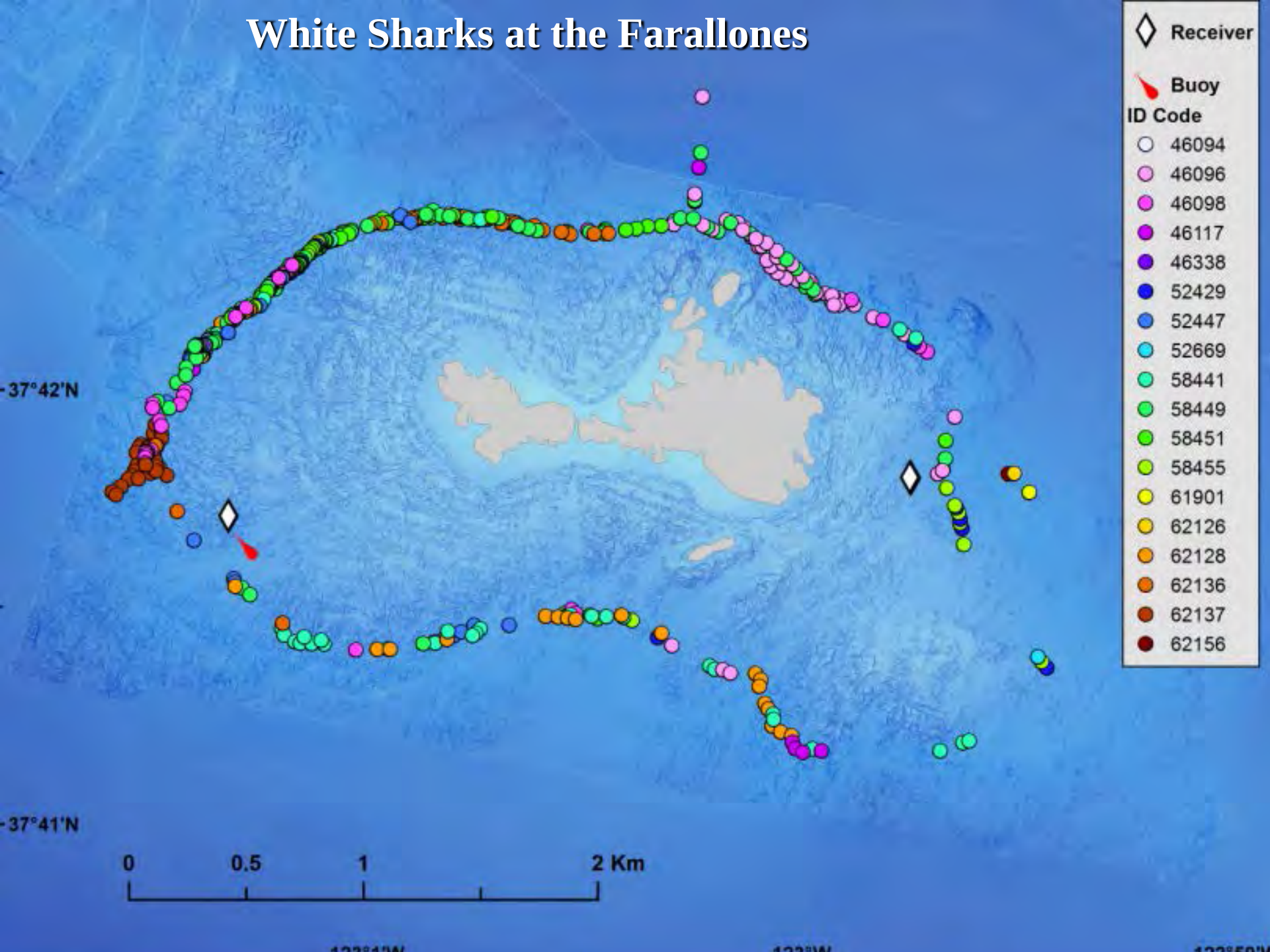
Acoustic Tags: Reliable Long Term Monitoring



Coastal Glider Missions for Detections of Tagged Animals



White Sharks at the Farallones




14P0543
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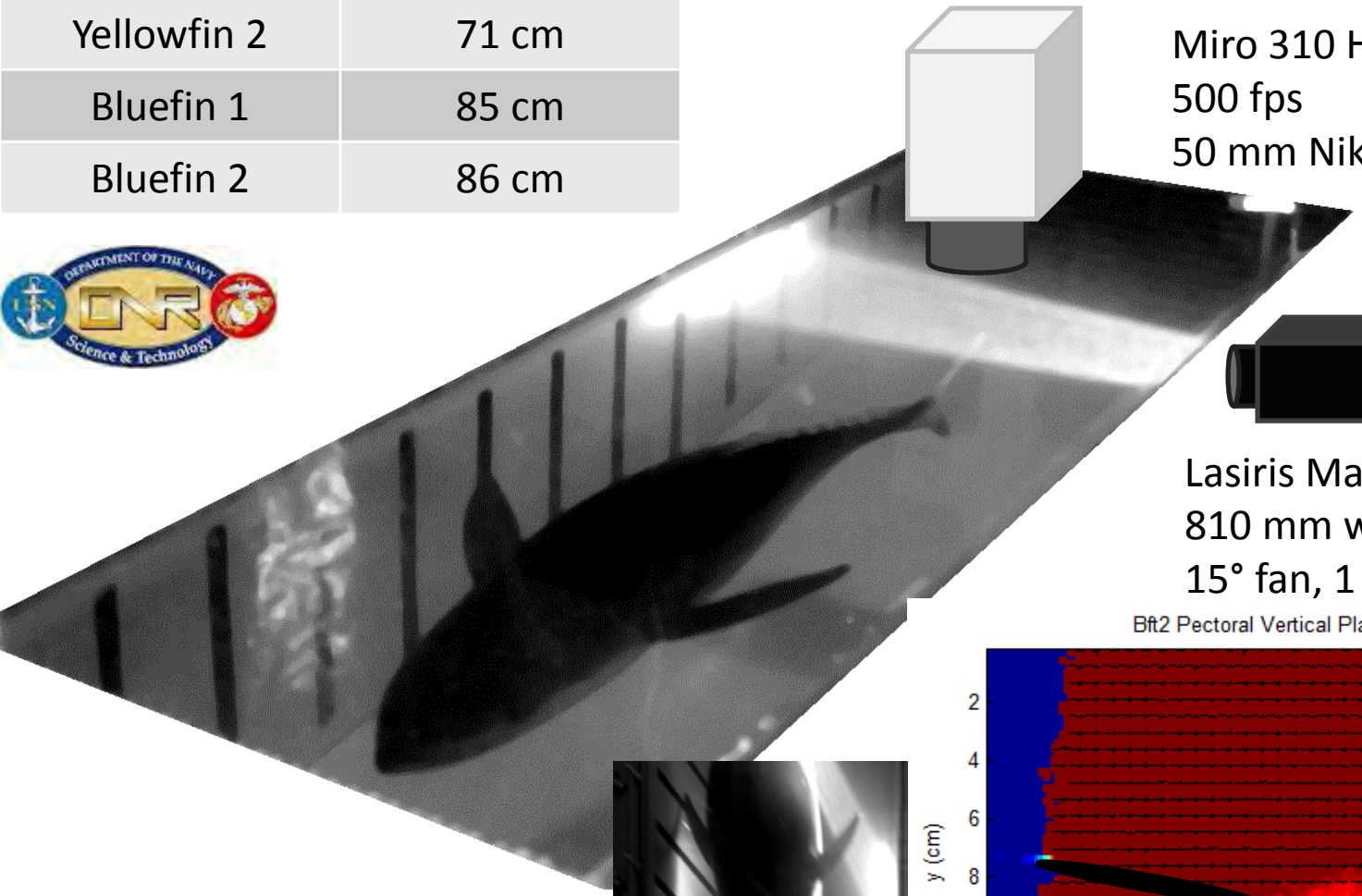
© Gaelin

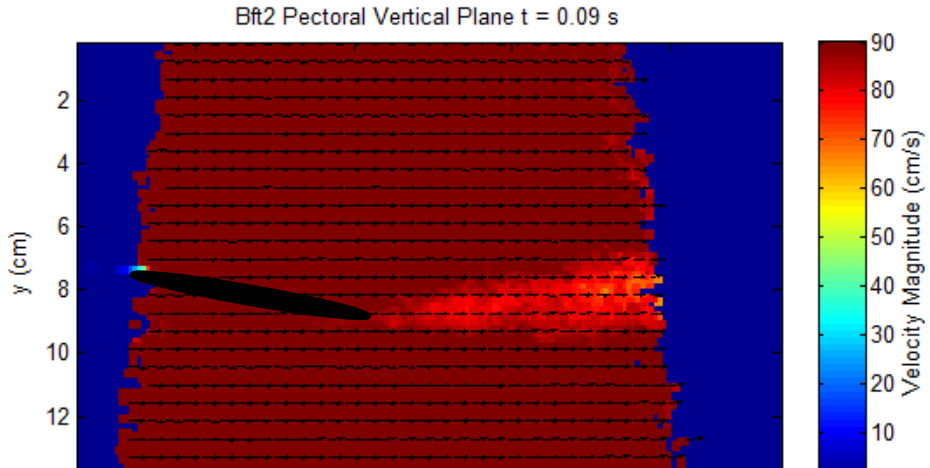
Hydrodynamics of Swimming Tuna
Flow Diagnostics with (PIV) Particle Image Velocimetry

Yellowfin 1	78 cm
Yellowfin 2	71 cm
Bluefin 1	85 cm
Bluefin 2	86 cm



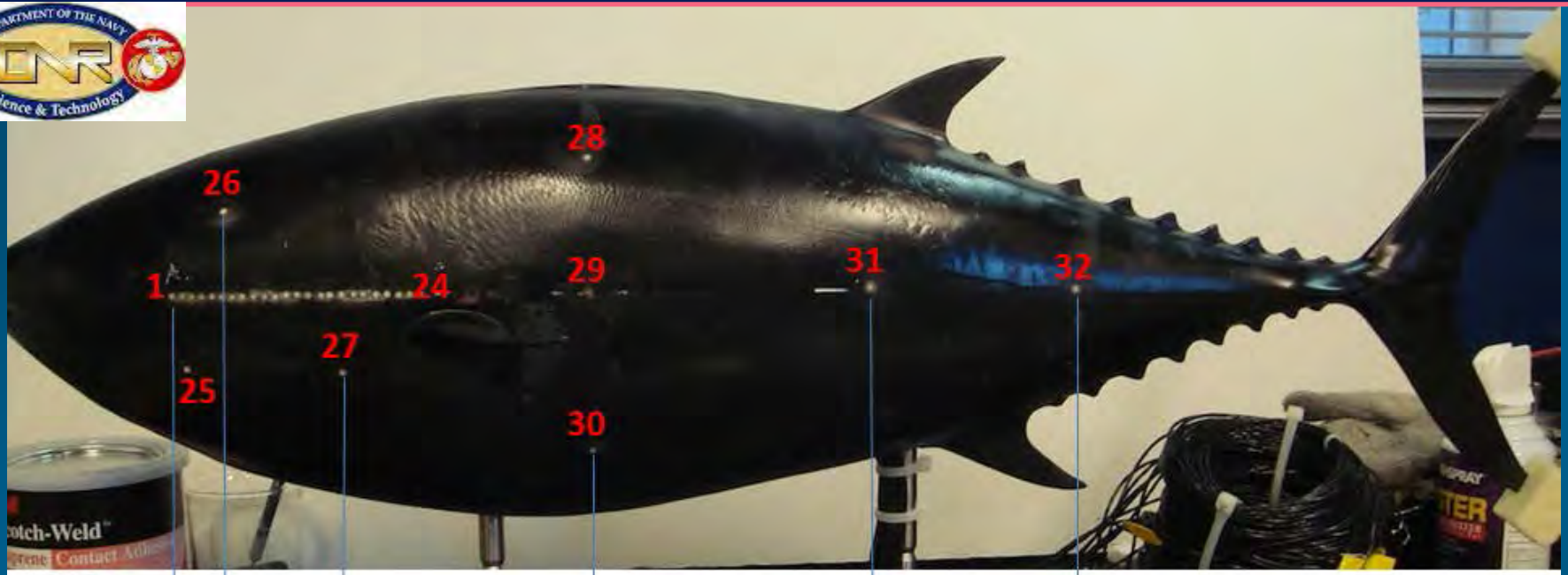
Miro 310 High-Speed Camera
500 fps
50 mm Nikon Nikkor Lens

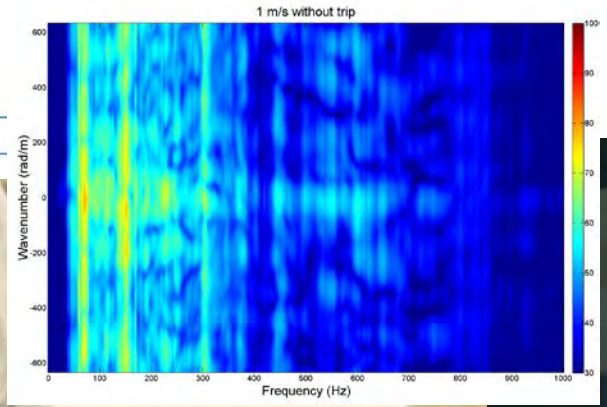
Lasiris Magnum II Near-IR Laser
810 mm wavelength
15° fan, 1 mm thick

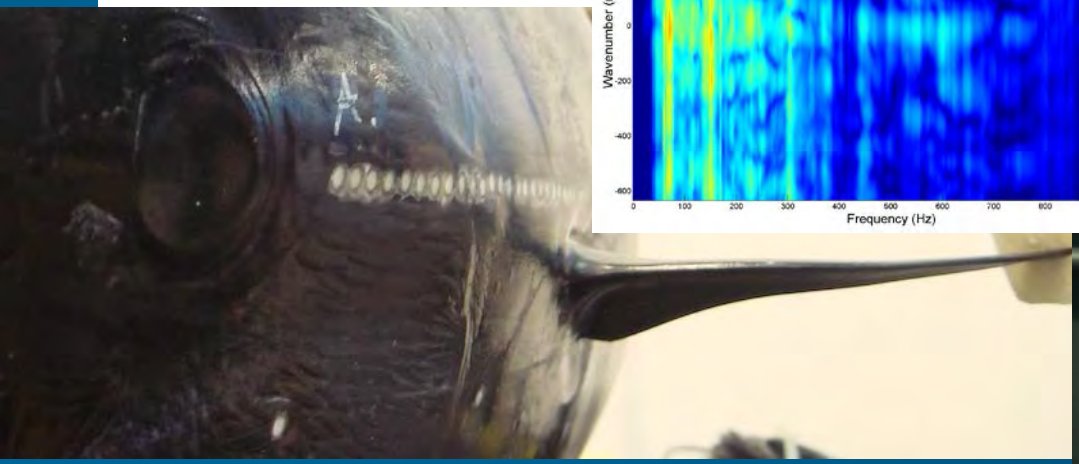


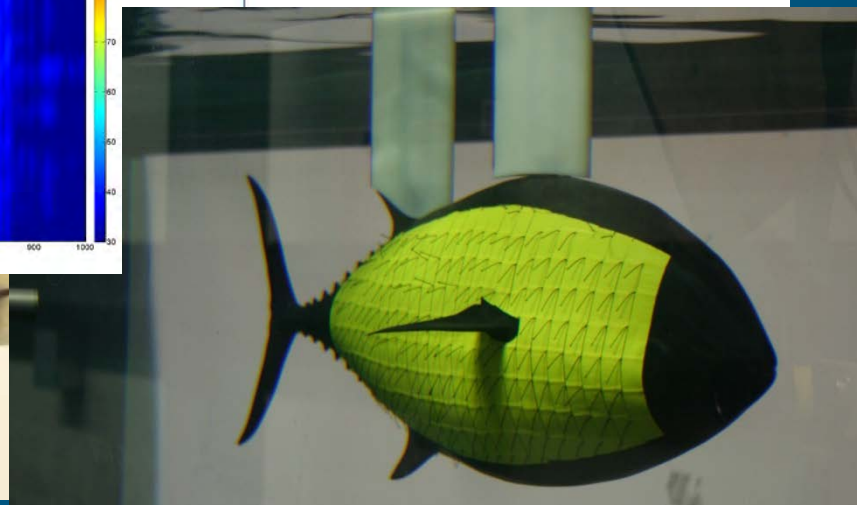
Massachusetts Institute of Technology

Hydrodynamics of Tuna Swimming And Flow Visualisation

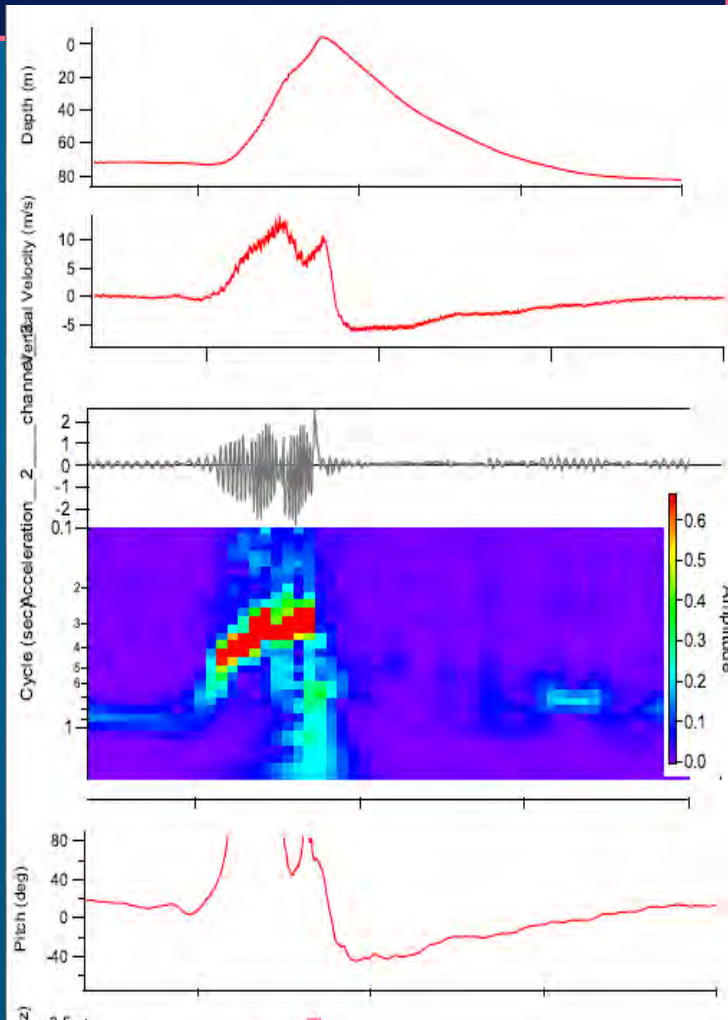




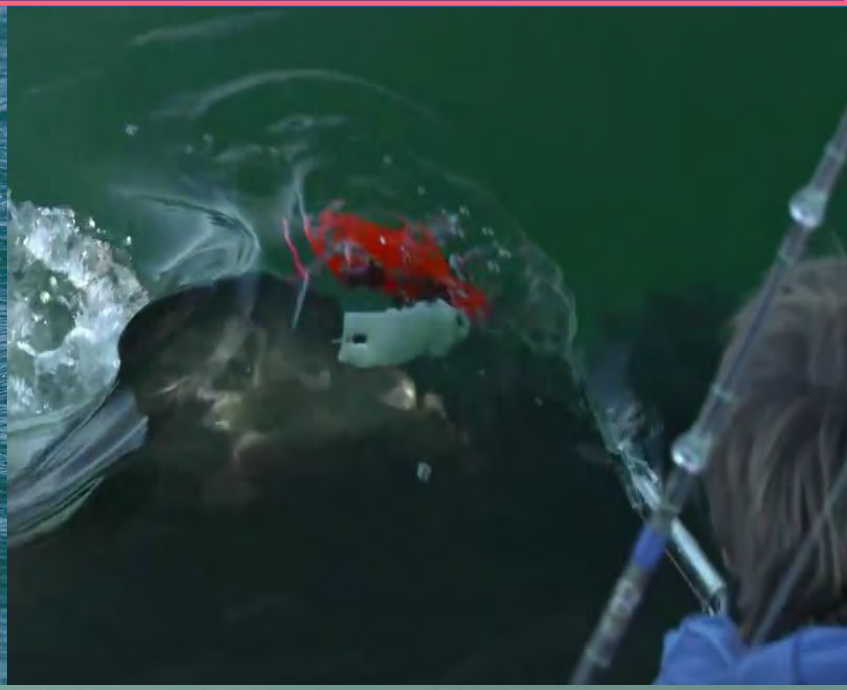




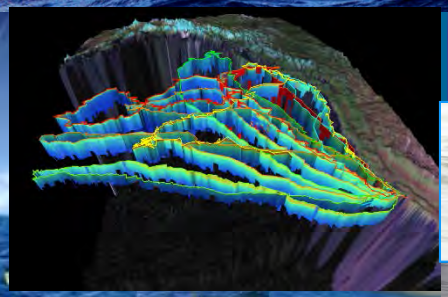
Accelerometer, Speedometer, Magnetometer, & Camera Tag on Giant Bluefin
Burst speeds: 12 m/Sec



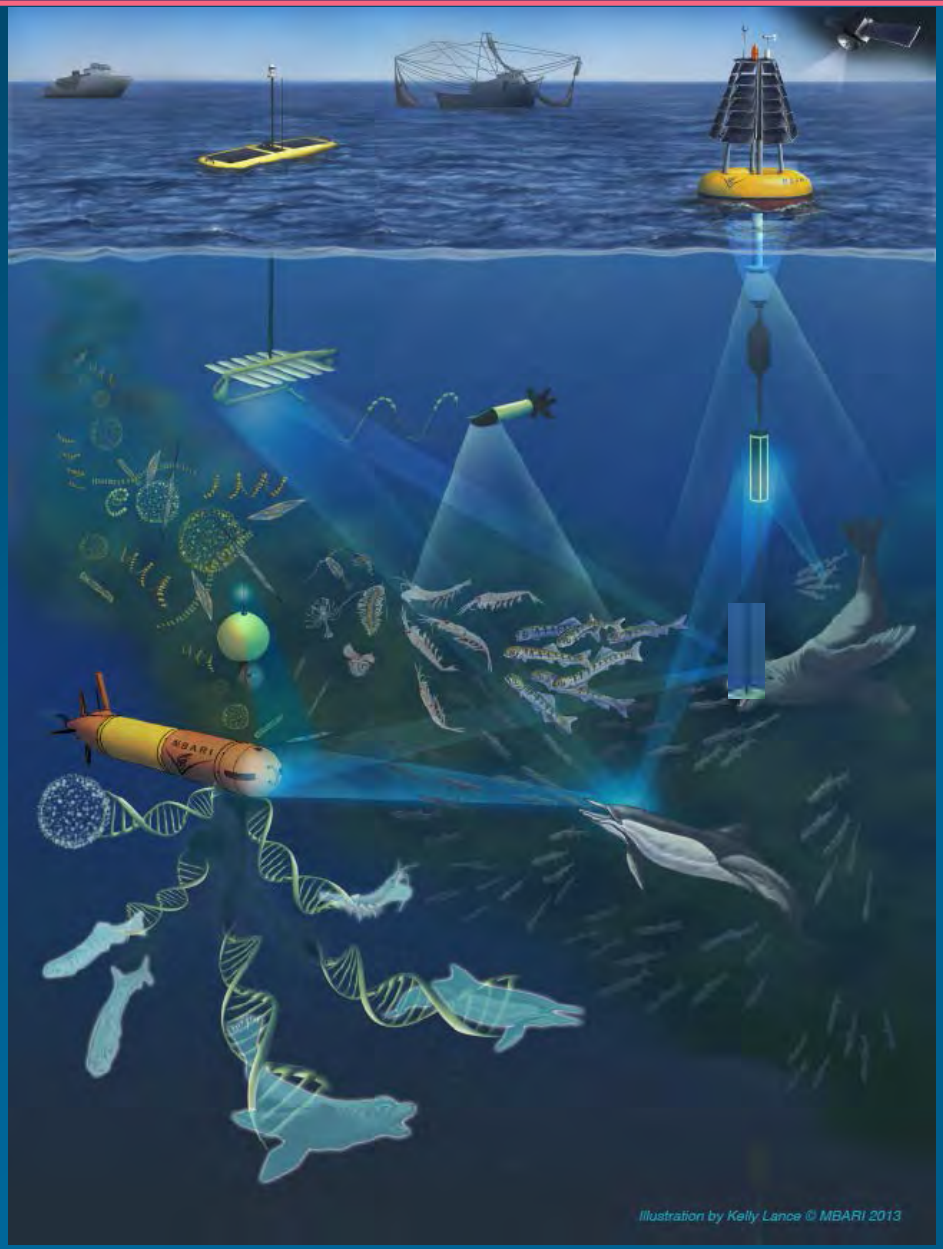
Accelerometer & Camera Tag on a 4000 lb White Shark



Real Time Animal Monitoring of California Current: Sanctuary Tests in 2015

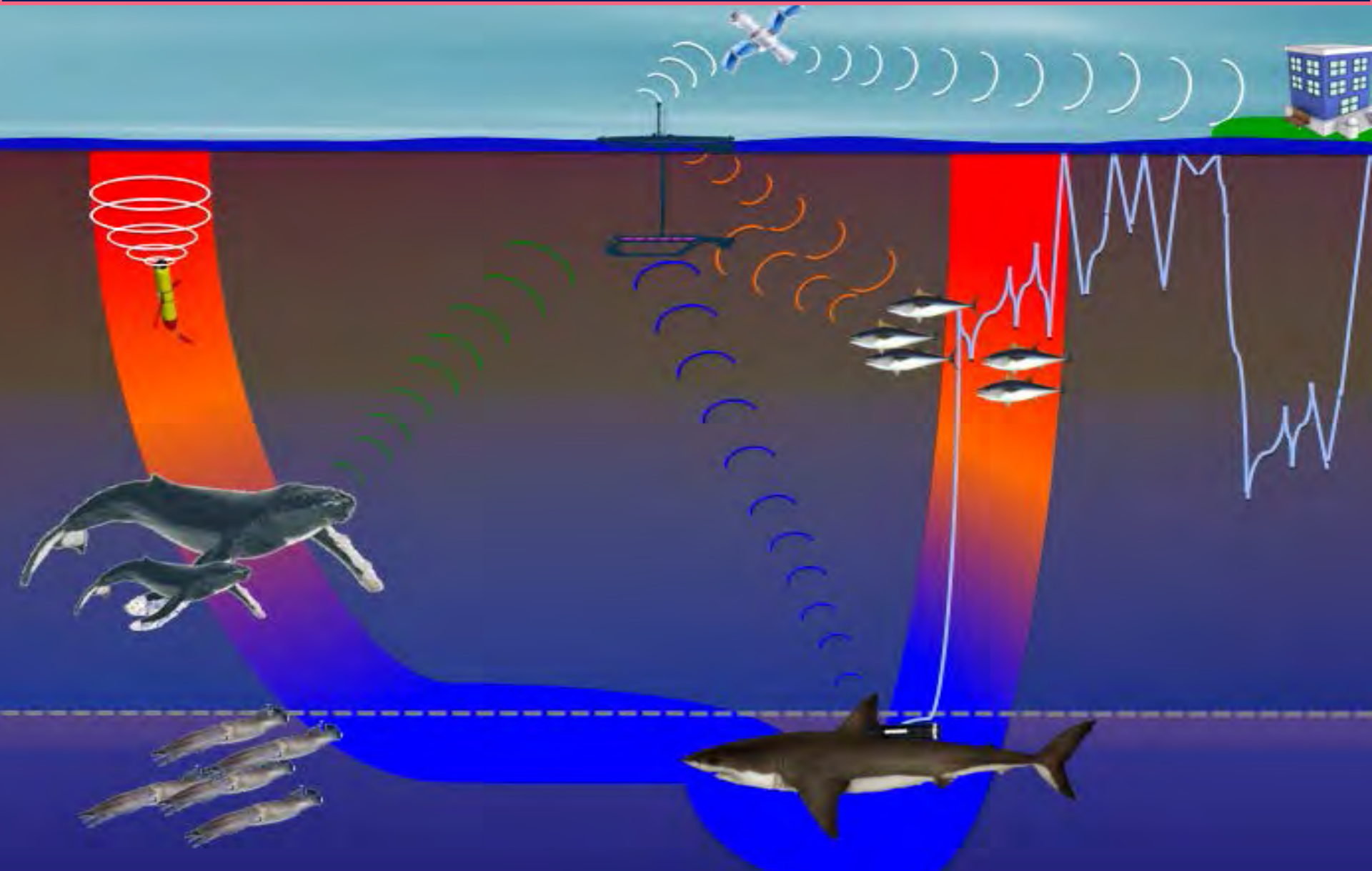


Can We Monitor Ecosystems?



- Biologging (ARGOS)
- Gliders/ Drones
- Buoys
- eDNA
- Environmental Monitoring for Oil?
- Look for Eggs
- Identify Genes that Indicate exposure

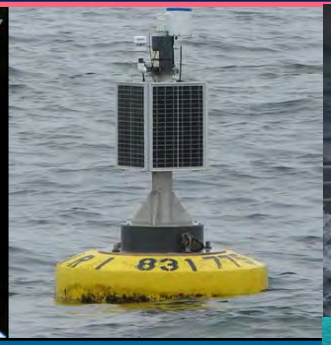
Frontier: Can We Monitor Ecosystem Remotely To Improve Protections

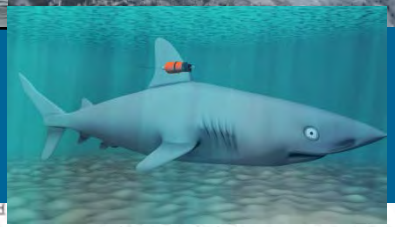


Illegal fishing at Chagos

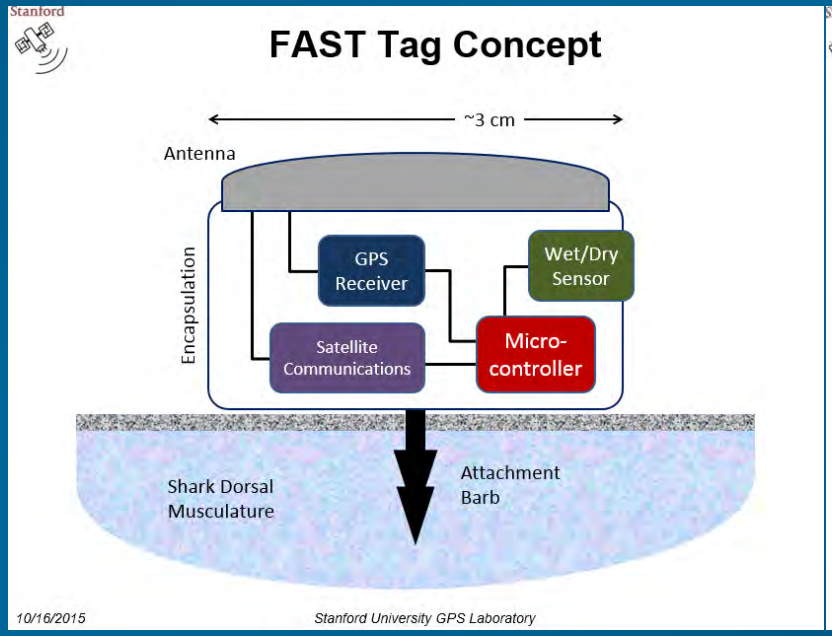
Red Dots Confiscated Vessels 2014

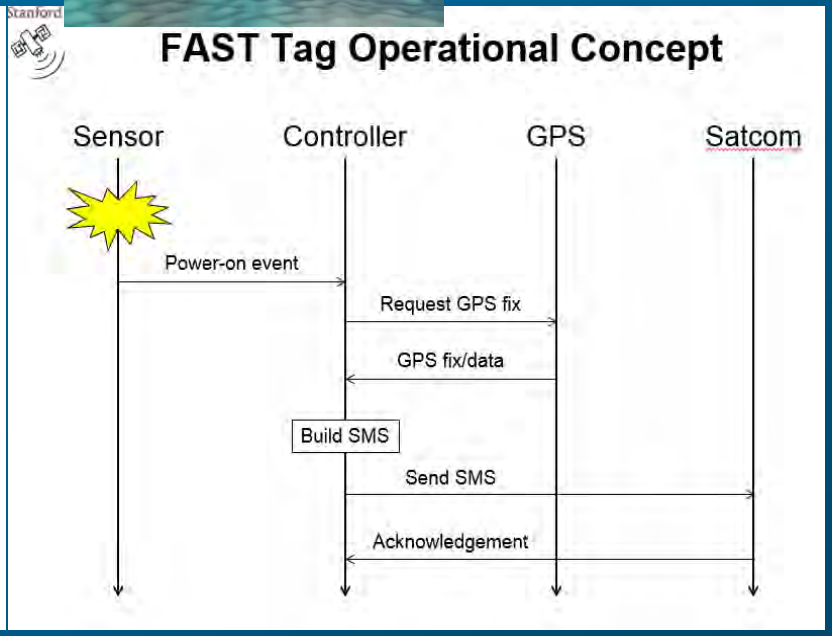
The Frontier: New Technology for Improving Ocean Protection





FAST TAG Shark Anti-poaching Tag

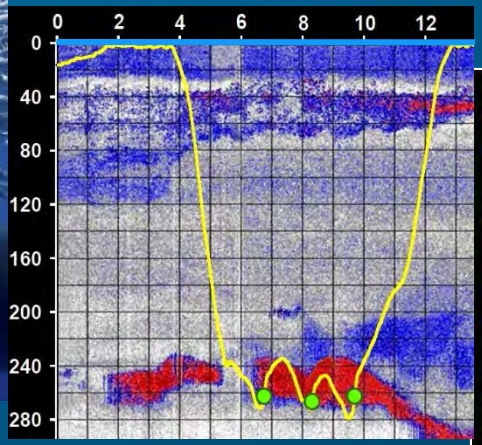


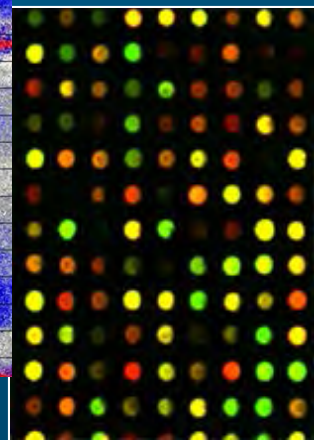


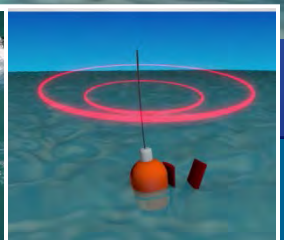
Creating Next Generation Biologging & Glider Tools

- Passive & Active Listening
- CTD
- Adaptive Sampling: Camera Trigger w/Detections
- Oxygen, pH, $C0_2$
- Echo Sounder (Prey Fields)
- Plankton Samplers
- Ecogenomic Sampling
- Camera Loggers &

Daily Diary Tags That Do More!







Monitoring MPAs With Biologging Technology

Environmental Intelligence

- Know What your Protecting
- Census of Residents
- Map Dynamic Nature of MPA Animal Movements

Active Management

- Iridium/Cell Enabled Buoys
- GPS Tagged Residents
- Mobile Gliders Patrols
- Camera Tags for Transects
- Anti-Poaching Technology
- Vessel Intrusion Monitoring