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, CO₂
- 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
- Habitat Use
- Foraging & Spawning Biology
- Population Structure
- Management & Assessment
- Climate Change
- Physiology: How Animals Work

Fish & Chips
Conservation Technology
Motivation: Global Decline of Marine Resources

Net losses
Industrialized fishing hits fish stocks

Financial markets
You can’t buck the physics

Jupiter’s moons
Headed for a hundred

Functional genomics
The power of comparison

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

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

49 - 89% less than 15 years

96 >99% in 50-200 years

79 - >99% 50 years
Fishing Down Marine Food Webs

Terrestrial vs. Open Ocean Carnivores

Why Do We Know So Little?
Basic Questions: How Many White Sharks are there In the Northeastern Pacific?
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
TAG & TOPP TECHNICAL APPROACH

Engineering Partnerships Focused on Tag Development

CTD Tag

Dual Wavelength Tag

Rapid Temperature TDR

Geolocation Tag (6 g)

Prototype GPS Tag
Archival Tags: Data Loggers

- 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”

- MiniPAT Pop-up
- Daily Diary
- Turtle tag
- Archival Tag
- Acoustic Tags
- Accelerometer
- Fin Mount
- Satellite Relay Data Logger (SRDL)
- Fastloc™ GPS
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
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

- Eastern Fishery: 13,000t-25,000t
- Western Fishery: 1484t
Archival Tagged Fish Marked Externally
Archival Recaptures of Bluefin Tuna Are 22% in Atlantic; 54% in Pacific Ocean

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, those specially equipped bluefin tuna also carry unique external conventional streamer tags, with two-tone coloration, to help fishermen 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 "Tag $500 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 1-800-457-3535. 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. Inquiries 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
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
Integration with Environmental Information
More than skin deep
Tracking Where Tunas Go Under the Sea

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

© Richard Herrmann / Galatee Films
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
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

“Breeding Phase”

Block et al. Science, 2001,
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 Academy 2014
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

510902600
5109026

Block et al. Unpublished Data
Probability of Catching a Bluefin can be Predicted based on Oceanography

Dynamic Closed Areas are Possible

Teo & Block Marine Biology, 2007
Teo & Block, PLOS one 2010
Amendment 7: Static Closed Areas to Reduce Bluefin Bycatch Go in Place in April and May 2015

Closure to PLL in Box Area
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
Biologging: Tag, Track, & Monitor Marine Animals

© Jason Bradley
Where are Windows of Optimal Habitat?

Based on Cury and Roy 1989
Oceanographic Quality Salinity Temperature Profiles
Satellite Delayed Relay Tags (CTD-SRDL)

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

Conductivity sensor (inductive cell)
Temperature sensor (PRT)
Antenna
Pressure sensor (not visible)
D-cell Battery
RS232 Comm. port

NOPP funding
GPS Investments during TOPP in Fastloc Technology (Snapshots in 1 sec)
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?
Animals As Ocean Sensors

**GMT Time**

<table>
<thead>
<tr>
<th>Time</th>
<th>Depth (m)</th>
<th>Temperature (°C)</th>
<th>Salinity (PSU)</th>
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<tbody>
<tr>
<td>16:00:00</td>
<td>270</td>
<td>16</td>
<td>32.75</td>
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<tr>
<td>18:00:00</td>
<td>240</td>
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<tr>
<td>00:00:00</td>
<td>180</td>
<td>24</td>
<td>33.75</td>
</tr>
</tbody>
</table>

27 CTD casts > 100 m in less than 16 hours
Northern Elephant Seal 133773 2014011 30 Jan 2014 to 4 Nov 2014

Sea Surface Temperature

Blended: 28-FEB-2014 to 7-MAR-2014

Chlorophyll-a

MODIS: 26-OCT-2014 to 2-NOV-2014

Tagging of Pacific Pelagics

Costa Lab
UCSC
CTD TAGS on Elephant Seals
Temperature, Salinity, Chlorophyll

• 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
Real-time data flow from animals

Global Telecommunication System

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

MODIS: 31-OCT-2015 to 7-NOV-2015
Satellite Positions for Salmon Sharks (N=76)
Repetitive Migrations from Arctic to Subtropics

3 year shark track
Pop-Up Satellite Tagging White Sharks

Tagging 1000 kg White Sharks
Pop-up Satellite Tags Reveal White Shark Fidelity to California Coast

Weng et al. 2007, Boustany et al. 2002
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

**Salmon, White & Mako Sharks**
HOT SHARKS: PREDATION EVENTS ON TAGS

Tagged

Pop-up

Shark & Tag Swallowed

Tagged

Depth (m)

Date

Temperature (°C)

Sep03

Oct03

Nov03

0 5 10 15 20 25 30

0 50 100 150 200 250 300 350 400

10 15 20 25 30
Tagging Reveals Niche Utilization
Thermal Niche Separation: Albatross, Tunas, Sharks
California Current World Heritage Site?

Blue Serengeti Initiative: Build/Expand Pelagic MPAs

Figure 2: California Current Eastern North Pacific Focus

Figure 1 | Density of top predators within the eastern North Pacific.
Can We Monitor Apex Predators in Real Time? Yes

Shark Acoustic Detection Buoy

The Wired Ocean
WiFi Buoys for Ocean Predator Hotspots

Wave Glider
Robot that Listens for Sharks
Can We Monitor Sharks in our National Sanctuaries?
SharkNet: Live Shark Detection Buoys

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
Notification ID: 6811
IMEI: 30-002501-092478-0
Arrival of White Shark at Irridium Detection Buoy - Central California Coast
Commercialization: Australia Shark Smart Buoy System
Monterey Bay
Hopkins
Ano Nuevo Is.
Farallon Is.
Pt. Reyes
Tomales Pt.

Acoustic Tags: Reliable Long Term Monitoring

Acoustic Detections - Farallones

Tag ID Codes

2007 2008 2009 2010 2011 2012 2013 2014
Coastal Glider Missions for Detections of Tagged Animals

Missions 2012, 2013
>4000 Detections
White Sharks at the Farallones
**Hydrodynamics of Swimming Tuna**

**Flow Diagnostics with (PIV) Particle Image Velocimetry**

<table>
<thead>
<tr>
<th>Test Specimen</th>
<th>Fork Length</th>
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<tbody>
<tr>
<td>Yellowfin 1</td>
<td>78 cm</td>
</tr>
<tr>
<td>Yellowfin 2</td>
<td>71 cm</td>
</tr>
<tr>
<td>Bluefin 1</td>
<td>85 cm</td>
</tr>
<tr>
<td>Bluefin 2</td>
<td>86 cm</td>
</tr>
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</table>

- 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
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**

**FAST Tag Concept**

![Diagram of FAST Tag Concept](image)

**FAST Tag Operational Concept**

![Diagram of FAST Tag Operational Concept](image)
Creating Next Generation Biologging & Glider Tools

- Passive & Active Listening
- CTD
- Adaptive Sampling: Camera Trigger w/Detections
- Oxygen, pH, CO₂
- 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