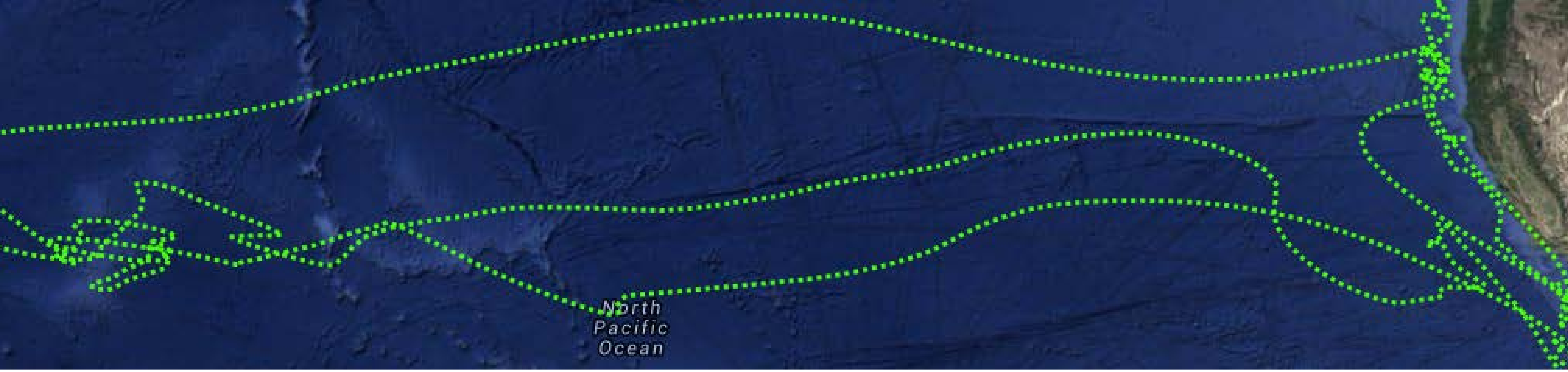


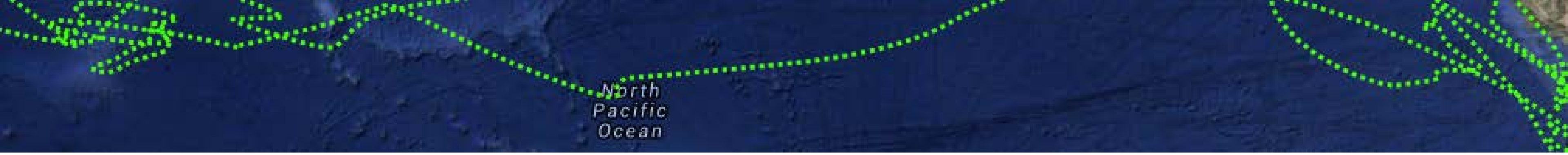
What's UP in the Pacific Ocean?

In this module, you will follow a bluefin tuna on a spectacular migratory journey up and down the West Coast of North America and back and forth across the Pacific Ocean to investigate the hypothesis that Bluefin Tuna #201000 migrates to areas of the Pacific Ocean with high productivity.

Learning Objectives

- Interpret color maps
- Use data to identify and describe coastal upwelling
- Integrate information from color maps and tracking data
- Use data to make and support claims about relationships between oceanographic conditions and animal behavior

OCEANTRACKS



Pre-Lab Assignment

Satellite SST and CHL overlays

Earth-orbiting satellites have the capacity to measure ocean conditions at almost any point on the surface of the ocean, at almost any given time of day. Prior to the advances in technology that made this possible, scientists collected measurements of ocean conditions from buoys or boat-based sensors only. Given the practical limitations of covering Earth's surface with sensors, measurements were only available for a limited number of places and for limited points in time.

The creation of global maps of ocean conditions following the advent of satellite technology opened up a whole new world of possibilities for what can be learned about how ocean conditions change over time and how this influences marine life.

To learn more about how ocean conditions such as sea surface temperature (SST) and chlorophyll concentrations (CHL) are measured and why they are important for marine life, visit the Ocean Tracks Library:

- Sea Surface Temperature: http://oceantracks.org/library/oceanographic-factors/sea-surface-temperature/
- Chlorophyll: http://oceantracks.org/library/oceanographic-factors/chlorophyll/

and these NASA websites:

- PODAAC Sea Surface Temperature: https://podaac.jpl.nasa.gov/SeaSurfaceTemperature
- GOES/POES Ocean Color: https://science.nasa.gov/earth-science/oceanography/living-ocean/ocean-color

OCEANTRACKS

Pre-Lab Assignment

SATELLITE OVERLAYS

Knowing how to interpret SST and CHL overlays in the Ocean Tracks interface is important for your explorations of how marine productivity influences the migration patterns of Bluefin Tuna #201000 because these environmental parameters are useful for describing where and when marine productivity is high.

In this Pre-Lab Assignment, you will inspect SST maps from January and August of 2008 to learn what these data sources can tell you about ocean conditions and what their limitations are.

- Go to http://oceantracks.org/map.
- Display the SST overlays from January 2008 by clicking on **Overlays** in the **Data & Tools** tab and selecting the year and month from the drop-down menu as shown in Figure 1.
- Familiarize yourself with what the colors represent on the scale at the bottom of the map.
- Zoom in and out of the map to try and discern areas with data from areas with data gaps.
- Once you've taken a look at the overlay from January 2008, inspect the SST overlay from August 2008.
- Answer the questions on the following slide.

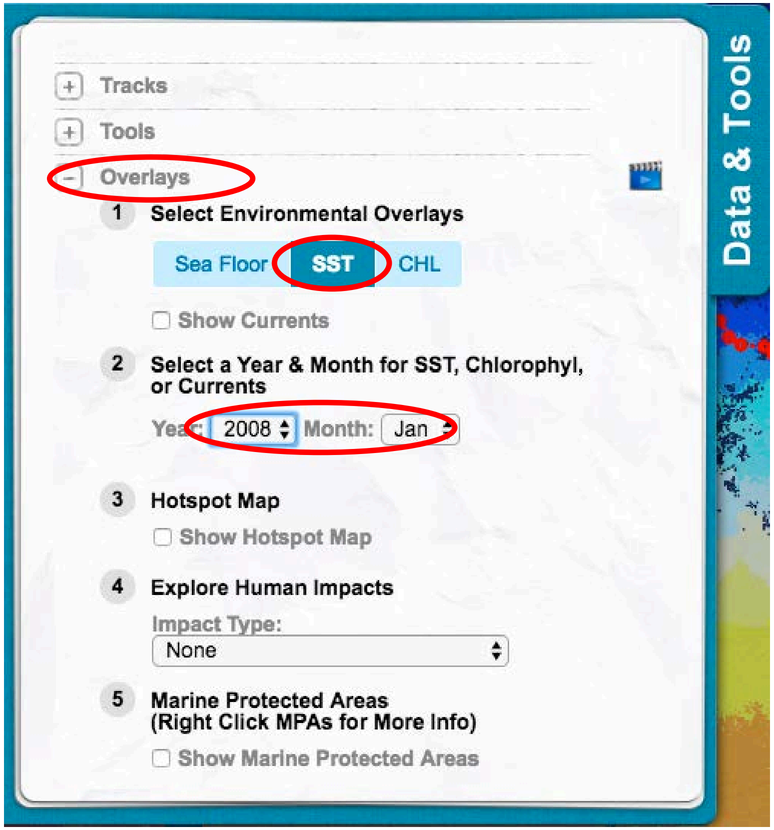
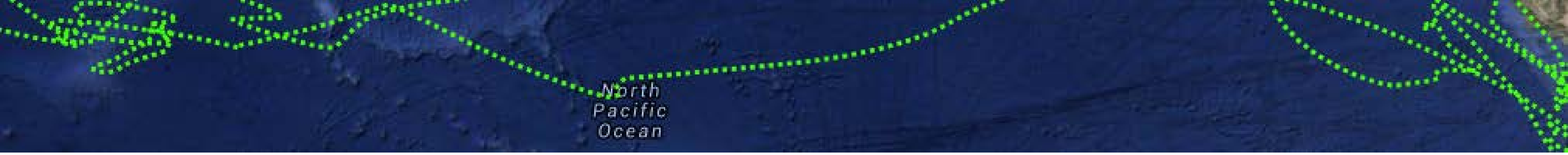


Figure 1. How to display SST Overlays

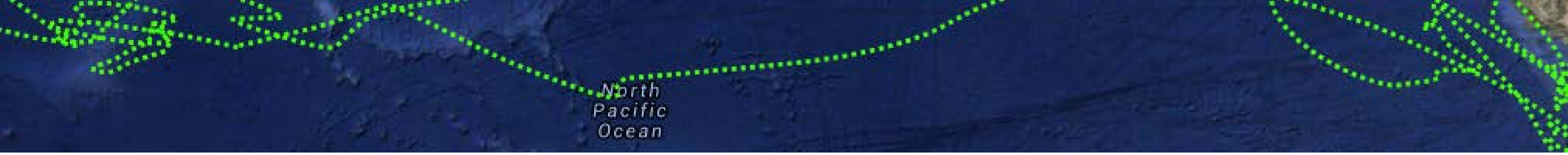


Pre-Lab Assignment

PRE-LAB QUESTIONS

1. *What do the colors on the map scale represent?*
2. *Take a screenshot ([http://www.take-a-screenshot.org/)](http://www.take-a-screenshot.org/) of the SST map from August 2008 and mark (1) a location where the highest temperature value was recorded and (2) a location where the lowest temperature value was recorded.*
3. *Notice the gaps in the overlays where you can see the underlying bathymetry layer (as shown in Figure 2). Where do these gaps most commonly occur?*
4. *Which month has more data gaps, January or August?*
5. *Focusing on Arctic areas with data gaps around Alaska, what are the weather and ocean conditions likely to be in these two months?*
6. *Using the information you've read in the library about how these data are collected, what do you think the connection is between weather and ocean conditions and the location and seasonal timing of these gaps in the SST overlays?*
7. *Despite these gaps, there is still a lot we can learn from the data available. For example, we can compare temperatures between geographic locations and identify changes through time. Looking back at the January and August 2008 SST maps, describe what you see in the data. For each map, record the following:*
    - *The range of temperature values observed*
    - *The change (or trend) in the sea surface temperature as you move from north to south*

Figure 2. Data gaps

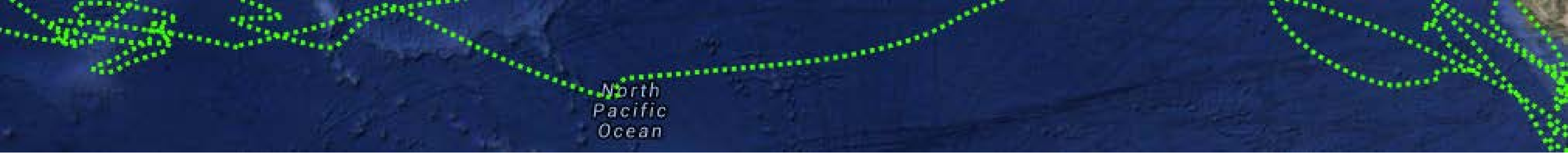


Engage

Electronic tagging has given scientists unprecedented insight into how large marine species, like tunas and sharks, use the ocean environment and how incredibly far these migratory animals travel in their lifetimes.

The image below shows the spectacular 41,830.41 km journey of a bluefin tuna from August 8, 2002, to May 31, 2004. In less than two years, this animal not only traveled up and down the West Coast of North America several times, but it also crossed the Pacific Ocean three times! After seeing tracks like this, scientists began to wonder: What drives these animals to make such incredible migrations?

- Go to http://oceantracks.org/map.
- **Hide** the track from Elephant Seal #302 by unclicking **Show** in the track dropdown menu. **Show** and **Graph** Bluefin Tuna #201000.
- Animate the track by clicking the **Show Animal Movement** icon under **Tools**.
- Observe where the tuna goes over its nearly 2-year journey.
- Inspect the speed, depth, and curviness graphs under the **Tools** menu in the **Data & Tools** tab.



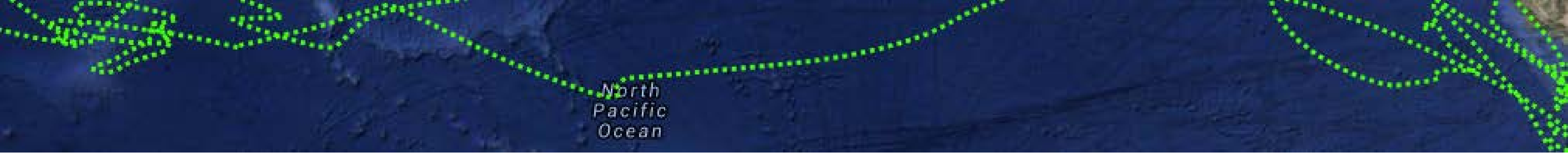
Engage

CLASS DISCUSSION

As a class, discuss some reasons why marine species migrate and what factors might influence migration patterns. Specifically:

1. *What physical processes and/or conditions (e.g., temperature) might influence where and when species migrate?*
2. *What biological processes (e.g., feeding) might influence migration patterns?*
3. *Look at the tuna's track. Where does Bluefin Tuna #201000 go during its migration? What evidence do you see for different behaviors along the track?*
4. *What might the tuna be doing in the regions it travels to? Include some possible explanations based on your discussions (and/or information you find in the Ocean Tracks Library: http://oceantracks.org/library) for why the animal traveled or lingered where it did.*

Next, you'll explore sections of the tuna track as well as SST and CHL data to help you determine what factors might be influencing this animal's incredible migrations.



Explore

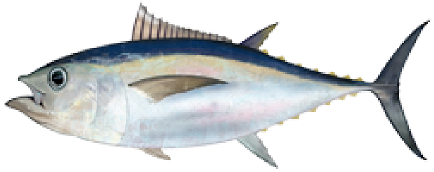
Notice two important features of the tuna’s track:

1. The tuna migrates north and south along the West Coast of North America.
2. The tuna migrates to an area of the ocean east of Japan.

What might cause the tuna to travel to these places? Food is a powerful motivator. Without it, animals cannot survive. Since primary production forms the base of the food web, we might reasonably hypothesize that areas of high primary production will attract zooplankton and other organisms at higher trophic levels (like tuna!), and may be a driving factor behind observed migration patterns for this tuna.

In this section, you’ll use Ocean Tracks data to test the following hypothesis:

Bluefin Tuna #201000 migrates to areas of the Pacific Ocean with high productivity.



Explore

PART 1: IDENTIFY AREAS OF HIGH AND LOW PRODUCTIVITY

The central hypothesis for this module focuses on productivity, so let's first take a look at how you can identify areas of high productivity in the ocean.

Chlorophyll Concentrations (CHL)

CHL at the surface of the ocean is used as a proxy for primary production by phytoplankton. Satellites measure the amount of green light reflected from the ocean's surface to generate maps of global chlorophyll concentration.

In the Ocean Tracks interface, CHL is represented using color map overlays as shown in Figure 3. Each color corresponds to a different range of chlorophyll concentrations. Areas that are dark red have the highest concentrations (20–35 mg m^{-3}), and areas that are purple have the lowest concentrations (0.03–0.05 mg m^{-3}). **NOTE**: This scale is unique to the specific data source used in the Ocean Tracks interface. You should always check the scale before interpreting a map.

Areas with data gaps (i.e., where you can see the underlying bathymetry layer) result when clouds and/or ice obstruct the satellite's view of the surface of the ocean.

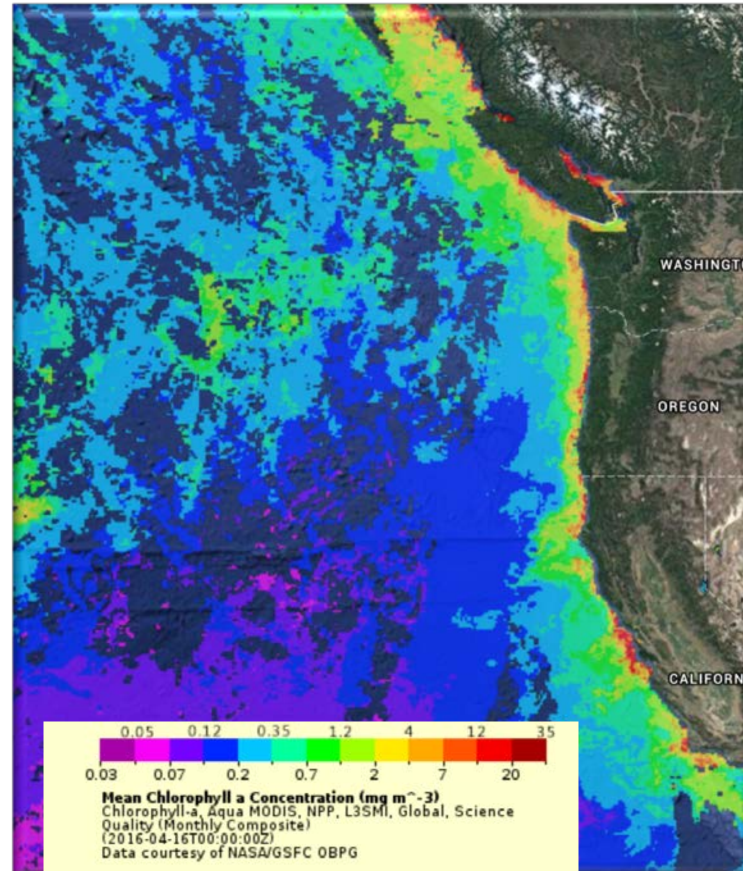
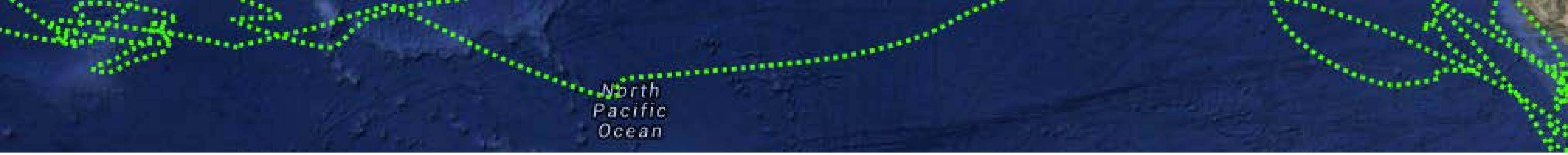


Figure 3. Map showing CHL for the western coast of North America in June 2010

(See http://oceantracks.org/library/oceanographic-factors/chlorophyll/ for more information about chlorophyll maps.)



Explore

Sea Surface Temperature (SST)

SST is another important oceanographic property to consider when looking for evidence of productivity.

Temperature is linked to the concentration of nutrients in the water, which together with the amount of solar radiation influence the amount of primary production at the surface of the ocean. Areas with colder water generally have higher nutrient concentrations and, therefore, productivity.

CHL is a more direct indicator of primary production in the ocean, but SST can provide clues about the underlying oceanographic processes that determine where high productivity occurs.

For more information on the SST overlays in Ocean Tracks, visit http://oceantracks.org/library/oceanographic-factors/sea-surface-temperature/.

For more information on the relationship between SST and CHL, visit https://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MY1DMM_CHLORA&d2=MYD28M.

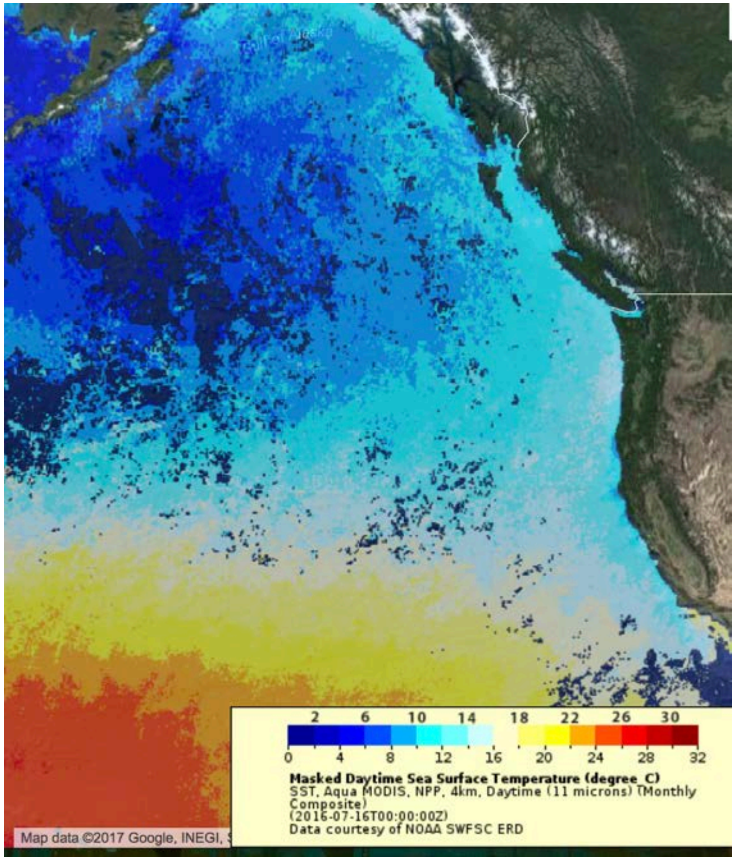
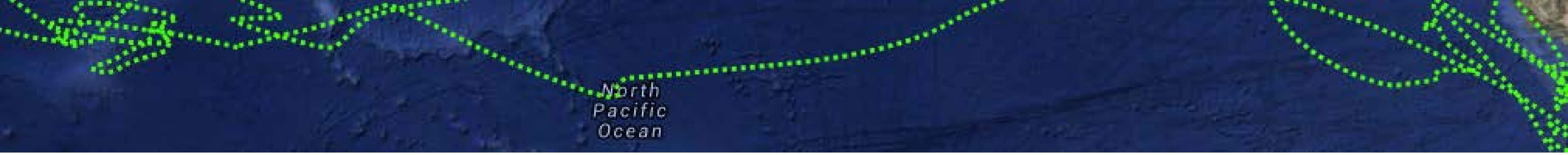


Figure 4. Map showing SST for the West Coast of North America in June 2010



Explore

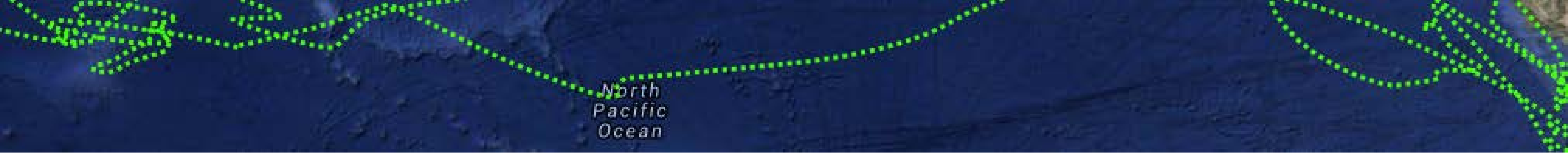
EXPLORE PART 1 QUESTIONS

Display the SST overlay from August 2008 by clicking on the **Overlays** menu in the **Data & Tools** tab, and selecting the year and month from the drop-down menus. Be sure to click **SST** under the **Select Environmental Overlays** heading.

1. *What regions of the globe have the coldest temperatures? the warmest?*

Now, select **CHL** under under the **Select Environmental Overlays** heading.

2. *What regions of the globe have the highest CHL? the lowest CHL?*
3. *What is the relationship between SST and CHL in these maps?*
4. *You might have noticed that more-northerly locations have colder temperatures and higher CHL values, but do the data always follow this pattern? Describe one exception.*



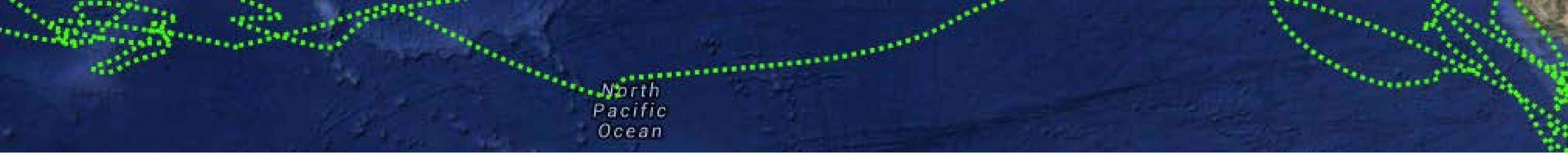
Explore

PART 2: IDENTIFY EVIDENCE OF COASTAL UPWELLING

One oceanographic process that creates high productivity is coastal upwelling. Upwelling occurs when winds blowing across the ocean's surface result in the movement of water away from land and the rising of **cold**, **nutrient-rich** water from below to replace the displaced surface water. This process also stimulates primary production by phytoplankton, which means we would expect to see colder sea surface temperatures and higher chlorophyll concentrations **compared with areas farther offshore** during a coastal upwelling event.

This **inshore-to-offshore increase** or **decrease,** also known as a **gradient** in SST and CHL, is important to consider when determining whether upwelling is occurring—even *more* important than the SST and CHL values themselves. The stronger the gradient (i.e., the bigger the difference between inshore and offshore), the more likely upwelling is occurring.

You should also consider the **relative amount of area** over which high chlorophyll occurs. Months with a large area of high chlorophyll relative to other months have stronger evidence for upwelling.



Explore

You're now going to practice identifying areas with high productivity associated with the process of coastal upwelling. Look at the example maps on Slide 14 that show CHL and SST overlays side by side for two different months in the same year (September and January 2006), focusing on the area encompassed by the markers drawn on the map. You may also wish to visit the Ocean Tracks map interface to explore the overlays in more detail ([http://oceantracks.org/map)](http://oceantracks.org/map).

- Carefully examine the data values inshore (within ~200 km of coastline) and offshore (~200–500 km from coastline) to look for patterns that provide evidence for upwelling.

- Make a table like Table 1 on Slide 15. Complete the table with the ranges of CHL and SST values found inshore and offshore during these two months.

NOTE: When using the discrete scale to identify ranges, use the smaller number encompassed by a color at the bottom end of the range and the larger number encompassed by the color at the higher end of the range. For example, if the CHL colors on the map range from to , the range is listed as 0.2–7 mg m^{-3} using the scale in Figure 5 below.

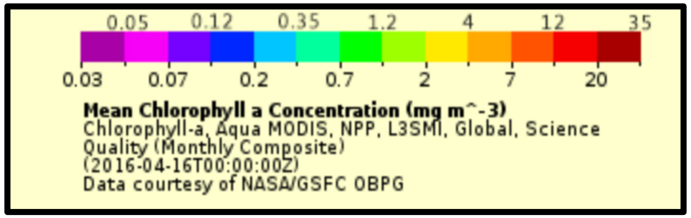


Figure 5. CHL color scale

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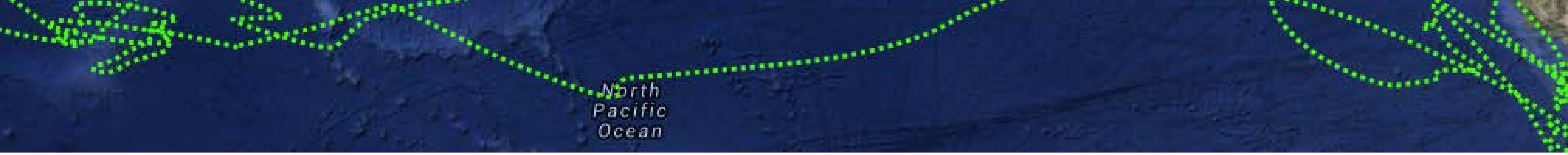


Explore

- Calculate the **CHL gradients** from inshore to offshore during each month by subtracting the max CHL value offshore from the max CHL values inshore. **For example** (using a different month)**:**

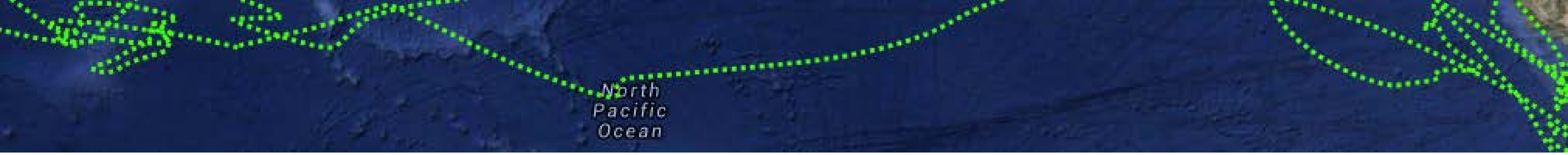
  max CHL inshore (35 mg m^{-3}) – **max CHL offshore** (1.2 mg m^{-3}) = **CHL gradient** (33.8 mg m^{-3})

- Calculate the **SST gradients** from inshore to offshore during each month by subtracting the min SST value offshore from the min SST value inshore. **For example** (using a different month)**:**

  min SST inshore (10°C) – **min SST offshore** (16°C) = **SST gradient** (–6°C)

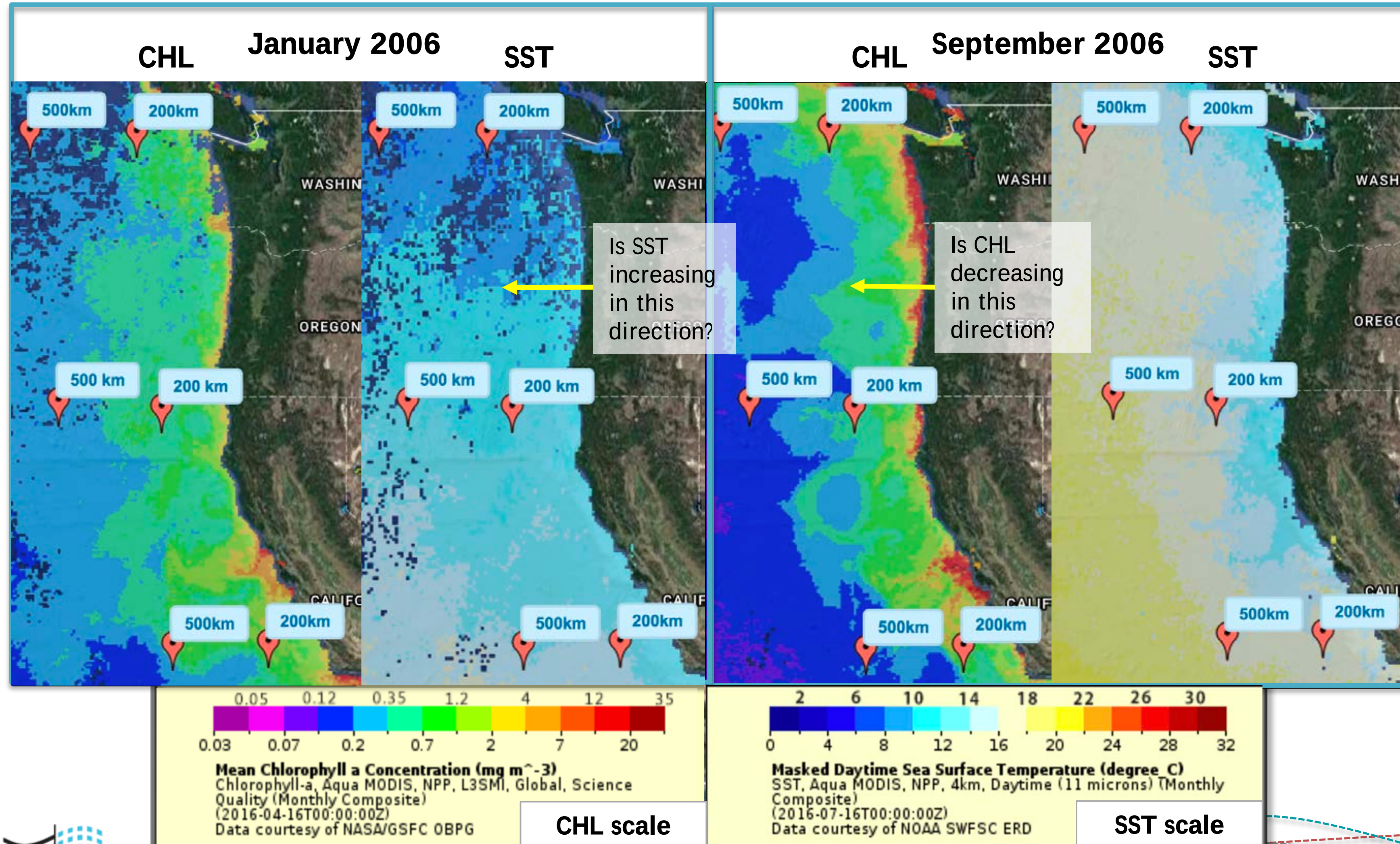
- You should also consider the **relative amount of area** that has high chlorophyll values.

NOTE: There's no rule for how big the gradient should be or how much area should have high chlorophyll. Interpret these parameters in a **relative** sense. That is, does one month have a stronger gradient than another? A larger area of higher chlorophyll than another? If so, that month has stronger evidence for upwelling. Making your interpretations about the strength of upwelling requires you to think critically about the data at hand.



Explore

Figure 6. Maps showing side-by-side CHL and SST maps for January and September 2006



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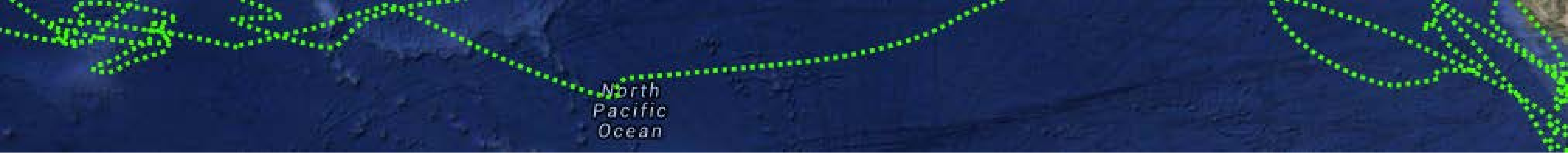

Explore

Table 1.

Month and Year	CHL Range Inshore (mg m^{-3})	CHL Range Offshore (mg m^{-3})	CHL Gradient	SST Range Inshore (°C)	SST Range Offshore (°C)	SST Gradient
January 2006				8–16		
September 2006		0.12–1.2			14–20	

EXPLORE PART 2 QUESTIONS

1. *Which month has a larger area with high chlorophyll concentration?*

2. *Considering the information in Table 1 and your answer to Question 1, which month (January or September 2006) has the most evidence for coastal upwelling? Refer to specific pieces of evidence (e.g., gradient calculations) to support your answer.*

3. *Remember, upwelling is a process that creates high productivity. Using the data you collected and your answer to Question 2, describe how coastal productivity compares for these two months.*

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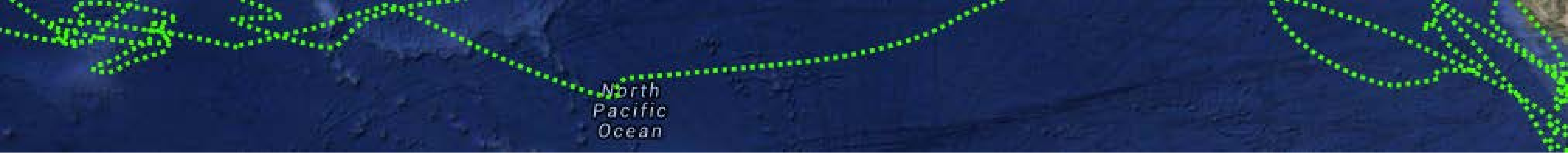


Explore

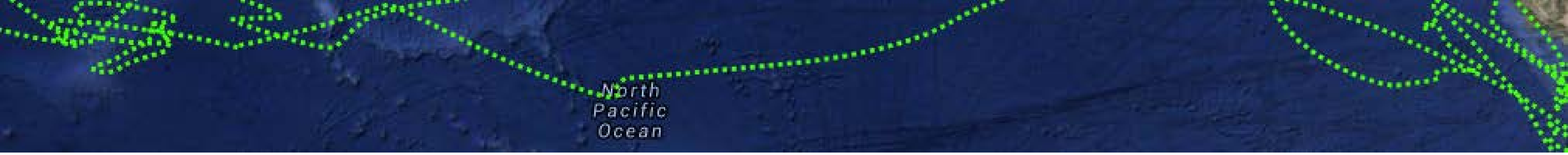
PART 3: MAKE A PREDICTION: *WHAT DO YOU EXPECT?*

Now that you’ve had some practice identifying areas of high productivity caused by upwelling, you will test the central hypothesis for the module: ***Bluefin Tuna #201000 migrates to areas of the Pacific Ocean with high productivity.*** First, though, you’re going make some predictions about what you expect to see in the data if the hypothesis is supported or not supported.

- Make a table like Table 2 below. Consider each data feature, and complete your table with explanations of what data patterns you would expect if the hypothesis is supported or not supported.

Table 2.

Data Feature	Expected Data Pattern If Hypothesis Is Supported	Expected Data Pattern If Hypothesis Is Not Supported
SST gradient from inshore to offshore when tuna is near coast	Large SST gradient	
CHL gradient from inshore to offshore when tuna is near coast		
Relative amount of inshore area with high chlorophyll when tuna is near coast		
Location of tuna on coast relative to area of highest chlorophyll	Overlapping	
CHL in vicinity of tuna when tuna in area of ocean east of Japan		



Explore

PART 4: HYPOTHESIS TESTING

Now that you've made a prediction about what you expect to see, let's revisit **Bluefin Tuna #201000** to to test the hypothesis. You will inspect the SST and CHL overlays along the West Coast of North America when the tuna is returning to shore and when it is near shore to see if there is evidence for coastal upwelling during this time.

- Go to http://oceantracks.org/map.
- **Show** and **Graph** Bluefin Tuna track #201000.
- Look at the CHL and SST map **Overlays** for **August, September, October,** and **November 2003,** and **January 2004**. These can be selected in the Overlays drop-down menu, or by clicking on a track point on the map that is in that month and selecting **Show CHL Map** or **Show SST Map.**
- Inspect the SST and CHL maps to determine how these parameters vary from inshore areas (within ~200km of the coastline) to offshore areas (~200–500 km from the coastline) along the West Coast of North America in two areas: **north of San Francisco to Washington**, and **south of San Francisco to Los Angeles** (see Figure 7).
- Record ranges of data values for SST and CHL for inshore and offshore areas in a table like Table 3 on the next slide. **NOTE:** It might be helpful to use the ruler and markers or polygon tool to mark the inshore and offshore ranges along various parts of the coast (see Figure 7).

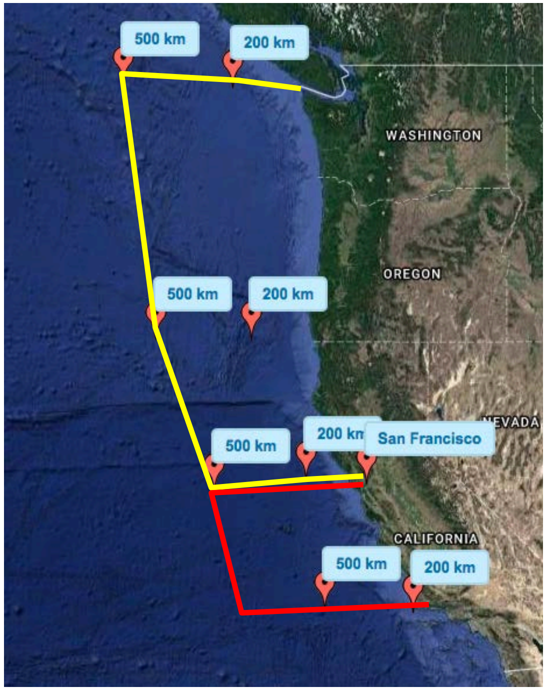


Figure 7. Map delineating the two upwelling regions along the West Coast of North America

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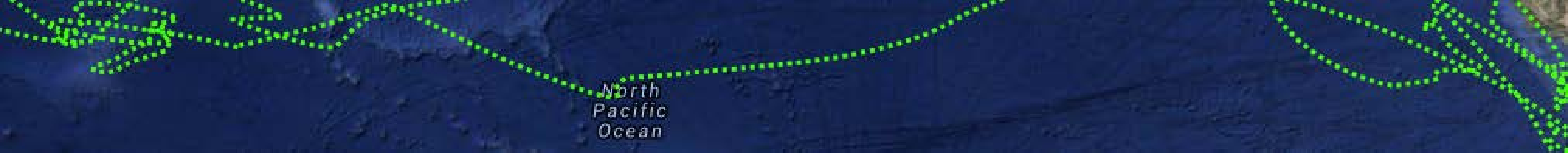
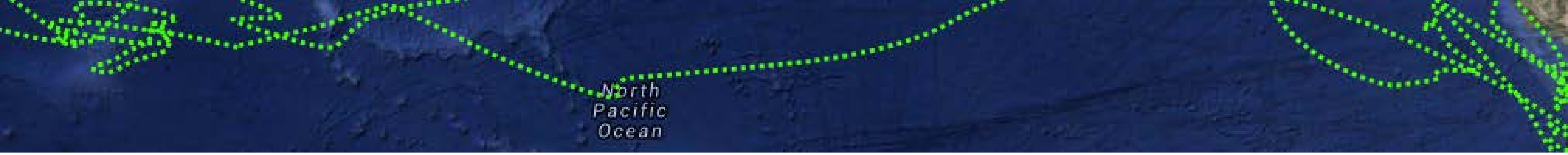


Explore

- To complete your table, you will also need to compute gradients as follows:
  - **For SST:** min inshore value – min offshore value
  - **For CHL:** max inshore CHL value – max offshore CHL value
- While looking at the maps, you should also record the **relative amount of inshore area with high chlorophyll**. To do this, you may need to click through a few months to develop your own frame of reference for what is “high” vs. “low.”

Table 3.

Month and Year	Location	Inshore CHL range (mg/m^3)	Offshore CHL range (mg/m^3)	CHL gradient (diff max)	Inshore SST range (°C)	Offshore SST range (°C)	SST gradient (diff min)	Rel. inshore area with high CHL
August 2003	N. of SF	0.12-20	0.03-0.35	19.65	10-20	12-20	0	Moderate
	S. of SF	0.2-20	0.12-0.7	19.3	10-20	16-22	6	High
September 2003	N. of SF							
	S. of SF							
October 2003	N. of SF							
	S. of SF							
November 2003	N. of SF							
	S. of SF							
January 2004	N. of SF	0.2-7	0.12-0.7	6.3	6-14	6-14	0	Low
	S. of SF	0.2-4	0.2-2	2	10-14	10-14	0	Low



Explore

- Now that you've made some observations from the CHL and SST overlays, summarize the evidence for upwelling in a table like Table 4 below. Gradients and evidence for upwelling should be labelled as "strong," "moderate," "weak," or something in the middle (e.g., "moderate to strong"). Remember that these assessments should be done by considering the values relative to one another. In other words, look at all the gradient values in the table—the higher gradients should be labeled "strong," whereas the smaller gradients should be labeled "weak."

NOTE: You should copy and paste your assessment of relative inshore area from Table 3. Once you've done this, take a look at **Bluefin Tuna #20100** and mark the location of the tuna relative to the coast in each month.

Table 4.

Month and Year	Location	SST gradient	CHL gradient	Rel. inshore area with high CHL	Strength of evidence for upwelling	Tuna location
August 2003	N. Of San Francisco	Moderate	Moderate	Moderate	Moderate	Returning to the coast off Oregon
	S. Of San Francisco	Strong	Strong	High	Strong	
September 2003	N. Of San Francisco					
	S. Of San Francisco					
October 2003	N. Of San Francisco					
	S. Of San Francisco					
November 2003	N. Of San Francisco					
	S. Of San Francisco					
January 2004	N. Of San Francisco	Weak	Weak	Low	Weak	Moving away from coast
	S. Of San Francisco	Weak	Weak	Low	Weak	

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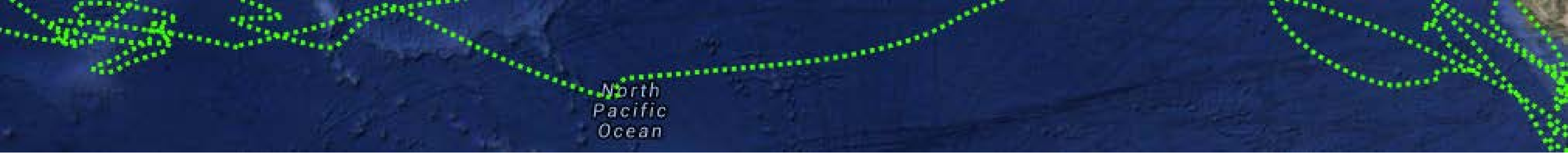


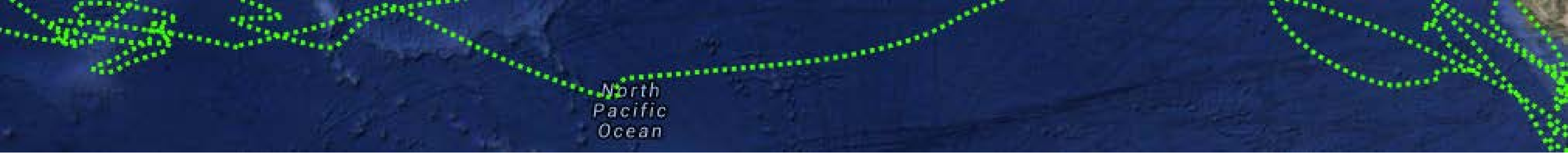
Explore

EXPLORE PART 4 QUESTIONS

1. *Using the data in Tables 3 and 4, how strongly do the data you collected suggest a relationship between the tuna's movements and ocean productivity? Your assessment of strength should be based on how consistently there is a relationship between where the tuna is located and where productivity is high (i.e., where there is strong evidence for upwelling). Also consider the timing of the tuna's movements in relation to where and when upwelling is occurring.*

2. *What additional information or data would you need to further explore the hypothesis that* ***Bluefin Tuna #201000 migrates to areas of the Pacific Ocean with high productivity****? List two additional sources of data in your response.*

OceanTracks



Explore

PART 5: MAKING COMPARISONS

Now, compare the sections of the track where the tuna is near the coast to sections where the tuna is in an area of open ocean east of Japan (May 1–June 30, 2003). Making this comparison will help you evaluate whether the tuna always moves to areas of the ocean with high productivity.

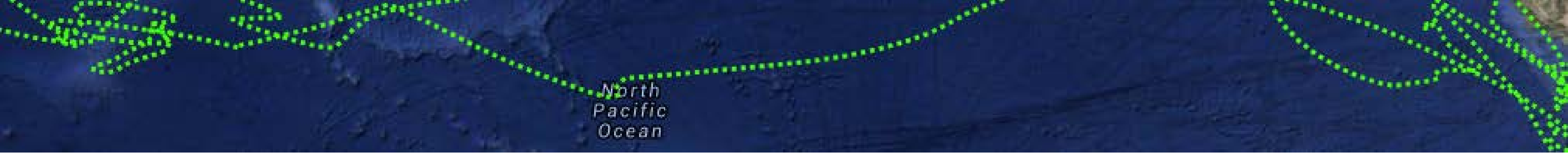
- Display the **SST** and **CHL Overlay** maps for May and June 2003.

EXPLORE PART 5 QUESTIONS

1. *Describe the ranges of SST and CHL in the vicinity of the tuna during these two months using specific data values.*
2. *Using the data in Table 3, how does the level of productivity (indicated by SST and CHL values) off Japan compare to the level of productivity when the tuna is present along the coast?*
3. *Based on this comparison, how strongly do the data support the hypothesis that the tuna migrates to this area of the ocean because of high productivity?*
4. *Why else might the tuna migrate to this area of the ocean? Provide two alternative explanations. (See http://oceantracks.org/library/species/northern-bluefin-tuna/ for more information.)*
5. *What additional data or information would you need to understand what the tuna is doing in this location during this time? **NOTE**: Don't limit yourself to what is available on the Ocean Tracks interface.*

(CONTINUED ON NEXT SLIDE)

OCEANTRACKS



Explore

Next, compare these findings to a larger sample size (more tunas) studied by a group of scientists at Hopkins Marine Station.

- Click on the link below to open the article *Movements of Pacific Bluefin Tuna (Thunnus orientalis) in the Eastern North Pacific Revealed with Archival Tags* by Boustany, Matteson, Castleton, Farwell, and Block. http://www.tagagiant.org/media/Boustany_et_al_PBFT.pdf

- Read the abstract, which summarizes the results of their analysis.

EXPLORE PART 5 QUESTIONS (CONTINUED)

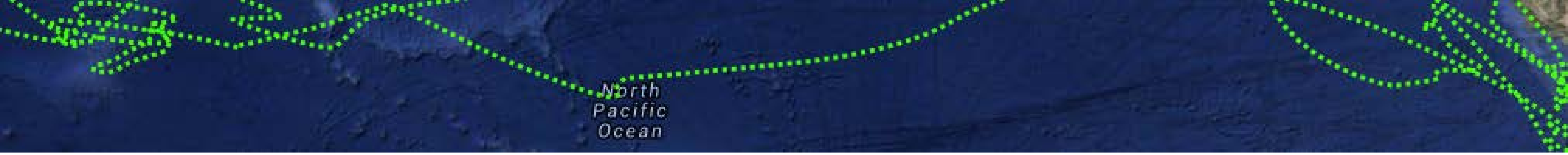
6. *What seasonal migration patterns are described for Pacific bluefin tuna in the abstract?*

7. *Does Bluefin Tuna #200100 follow the patterns described in this paper? List one way in which this tuna's movement patterns are similar and one way in which they are different.*

8. *What explanation do the authors provide for why the tuna might not always migrate to areas of high primary productivity? Does their explanation match one of the two you suggested in Explore Part 5, Question 4?*

9. *Display all of the tuna tracks on the Ocean Tracks interface. List two common migration patterns among the tracks displayed (e.g., locations frequented by the tunas). How do these patterns compare with those of the 143 tuna tracks analyzed in the paper?*

OCEAN TRACKS



Synthesize

Using the abstract you just read as a model, write a 300-word scientific abstract summarizing your research in relation to the following hypothesis:

Bluefin Tuna #201000 migrates to areas of the Pacific Ocean with high productivity.

Your abstract should contain the following sections:

1. *A **brief background statement** to set up some of the key concepts informing this study (e.g., ocean productivity and/or bluefin tuna migrations) (1 or 2 sentences). To help you with this, think about these questions:*
   - *What factors influence bluefin tuna migrations?*
   - *How do physical processes like upwelling influence coastal productivity and organisms at higher trophic levels (like tuna)?*
2. *The **main research hypothesis.***
3. *A **description of your methods** (1 or 2 sentences), including the following:*
   - *What data did you look at?*
   - *What did you look for in the data?*
   - *What comparisons did you make?*

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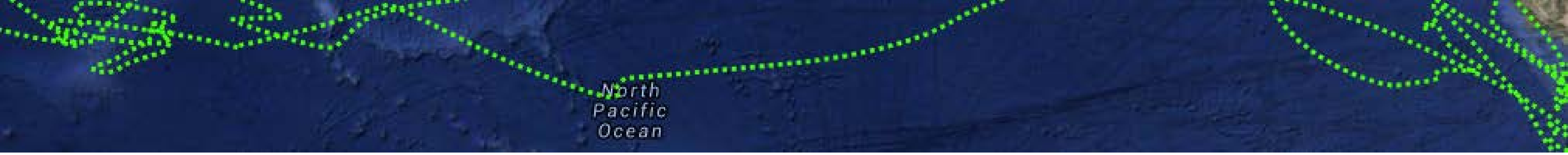

Synthesize

4. Your ***main results/conclusions*** *relating to the central hypothesis (2 or 3 sentences). Specifically, include a description of* ***how strongly your data support the central hypothesis.*** *To evaluate this, refer back to your predictions in Table 2 on Slide 16. Weigh the amount of evidence that does and does not support the hypothesis when deciding how strongly it is supported. A hypothesis is strongly supported if all collected evidence validates it. Refer to this evidence, including specific data values (i.e., numbers) in your descriptions.*

5. *A* ***summary statement of your findings*** *relating to the hypothesis above, including a sentence to connect these findings with the research findings of Boustany et al., and a description of any alternative explanations for data patterns that do not support the hypothesis (3 sentences).*

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