That’s Amazing! Worksheet

Shark Trails

with Dr. Michael Heithaus

Teacher Notes and Answers

BACKGROUND
Western Australia’s Shark Bay is one of the last marine sanctuaries on the planet. It is home to a myriad of species including sea turtles, dugongs, stingrays, dozens of species of fish, and perhaps its most important inhabitant—tiger sharks. Unlike in other parts of the world, where shark populations have declined by 90 percent or more, the sharks here are thriving! And, they are important for the health of the bay. By limiting the number of herbivores, tiger sharks are crucial for keeping the ecosystem in balance. But recently their population numbers have begun to decline, and Mike Heithaus and doctoral student Cindy Bessey need to find out why. Could they be swimming beyond the safety of Western Australian waters into the dangers of the open Indian Ocean, where longliners await? In this video, Mike and his team deploy high-tech satellite tags to track the movements of the sharks. No matter where these sharks go, the scientists can follow their movements. Mike has discovered that not all sharks behave in the same way. Some stay close to home, while others journey thousands of miles across the Indian Ocean to South Africa (in just a matter of months!).

Back in Florida, Mike travels to the Guy Harvey Research Institute at Nova Southeastern University to meet with Mahmood Shivji. They will conduct genetic analyses on the tissue samples taken from tiger sharks in the wild. The information from genetic testing is used to determine whether populations of tiger sharks found in different locations around the world are exchanging genetic information.

INVESTIGATION
Sharks are much more vulnerable to overfishing than bony fishes for a number of reasons:

- They grow slowly and take many years—often more than a decade—to mature.
- Once they do start reproducing, females don’t have many pups. Some only have two pups every other year. Even sharks that produce lots of pups—tiger sharks may produce four to eight pups every couple of years—don’t produce nearly as many offspring as bony fish that produce thousands (or many more) every year.
1. **Table 1.** GPS locations of the furthest position fix away from the release point of ten female tiger sharks in Shark Bay, Western Australia. Sharks were tracked for 180 days and were tagged at a latitude of 25°44'39.00"S and a longitude of 113°43'52.00"E.

<table>
<thead>
<tr>
<th>Shark number</th>
<th>GPS position of furthest point</th>
<th>Distance moved (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Latitude</td>
<td>Longitude</td>
</tr>
<tr>
<td>1</td>
<td>24°52'24.27&quot;S</td>
<td>113°5'0.68&quot;E</td>
</tr>
<tr>
<td>2</td>
<td>25°13'29.83&quot;S</td>
<td>113°6'39.62&quot;E</td>
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<td>3</td>
<td>26°10'16.58&quot;S</td>
<td>112°56'31.69&quot;E</td>
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<td>5</td>
<td>11°42'49.00&quot;S</td>
<td>129°45'41.00&quot;E</td>
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<td>6</td>
<td>24°37'52.90&quot;S</td>
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<td>7</td>
<td>24°43'44.00&quot;S</td>
<td>113°12'31.50&quot;E</td>
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<td>8</td>
<td>28°12'19.00&quot;S</td>
<td>113°19'38.63&quot;E</td>
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<td>9</td>
<td>29°0'47.00&quot;S</td>
<td>45°34'15.00&quot;E</td>
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<tr>
<td>10</td>
<td>22°0'11.50&quot;S</td>
<td>113°30'52.00&quot;E</td>
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</tbody>
</table>

**Note.** The distances moved will vary depending on how students draw the tracks. Student values should be near ones shown in the table.

2. ![Movement of Sharks Graph](image)
3. No, they don’t. Some sharks don’t move very far. Some swim medium distances, and others swim very long distances—one went across the Indian Ocean!

4. Yes. At least two female sharks moved far enough north or west to be at risk. Several others were close to moving far enough west to be at risk.

5.

6.
CONCLUSION

7. It appears that males probably move around within oceans quite a bit because the nuclear DNA is very similar among the different areas within oceans. However, the males don’t seem to move between the Atlantic and Indo-Pacific very much. The Atlantic populations group together and are a bit different from the populations in the Indo-Pacific, which are similar to each other. There are big differences in mtDNA between Western Australian and South African populations and between Hawaiian and Western Australian populations. There are also differences between North and South American populations and big differences between the Atlantic and Indo-Pacific populations. These data suggest that females may not move around much to breed.

**Note.** This is a fairly common pattern in nature—males tend to disperse widely, while females remain closer to where they were born or hatched. Interestingly, a similar pattern of male and female movements and population structure occurs for white sharks.

8. Probably for feeding, because the mtDNA suggests that females are not moving much to breed and there are separate genetic populations. Female tiger sharks move across the ocean (at least sometimes), but there doesn’t seem to be much genetic exchange.

9. No, tiger sharks are not safe. Male sharks appear to be moving widely throughout the area. Females also are at risk; though they don’t seem to go as far as males, the satellite tags show they move outside of protected waters.

**Note.** This issue is a common theme for many large marine species. Because they move such vast distances and cross international boundaries, it is hard to create protected areas that keep them safe throughout their lives.
Problem
Not all sharks are long distance swimmers. But tiger sharks, the species Mike and Mahmood study in this video, are known to travel long distances. Figuring out how far sharks might roam is important for two reasons. First, populations of many large sharks are dropping—fast! In fact, in some areas, shark populations may be down more than 90 percent! If we want to set up protected areas for sharks, we need to know if they will stay in them or wander out into waters where they would be unprotected and prone to being caught. The major reason for the decline of sharks is overfishing—especially for shark fin soup, an Asian delicacy. Often, fishermen catch sharks for fins, cut the fins off, and then throw the rest of the fish back into the water.

Another reason we want to know how far sharks move is to understand the structure of their populations. In other words, we want to know whether sharks (of a specific species) that are distributed across broad geographic regions are genetically related. If sharks move across entire oceans and interbreed, maybe there is just one big population for an entire ocean. If they don’t, there could be lots of genetically different populations and each one may be more vulnerable (or more protected).

Let’s get started.

INVESTIGATION
Advances in technology let us track the movements of animals over huge areas. The satellite tags that Mike and the team put on tiger sharks send a signal to satellites passing overhead each time the animals break the surface. Luckily, most tiger sharks in Shark Bay tend to swim near the surface, and the satellites send us the approximate location of the sharks every few days. The problem with satellite tags is that they are expensive. Mike and Mahmood could only deploy ten satellite tags.

Table 1 provides a summary of the data Mike and Mahmood have received from the sharks’ satellite tags.
Google Earth provides an online tool to find locations on the planet and to calculate distances. This tool is much like the Geographic Information Systems (GIS) that scientists use to analyze data on animal movements.

1. **Data Analysis** You can get data for the “Distances moved” column in Table 1, above, by using Google Earth. Use the following instructions:
   a. Open Google Earth or go to www.google.com/earth.
   b. In the “Fly to” box on the left, type in “Western Australia” and hit enter.
   c. Once the map has flown to Western Australia, click on the pushpin button.
   d. When the box pops up, enter the latitude and longitude for the starting point of the track. Rename the marker as “Start Track” for the first shark.
   e. Click OK.
   f. Repeat the pushpin procedure for the end location of the track.
   g. Click on the ruler tool.
   h. Change the units to kilometers
   i. Click on the “Path” button.
   j. Move the cursor to the map and click on the starting location of the track.

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**Shark Trails continued**

**Table 1.** GPS locations of the farthest position fix away from the release point of ten female tiger sharks in Shark Bay, Western Australia. Sharks were tracked for 180 days, and were tagged at a latitude of 25°44'39.00"S and a longitude of 113°43'52.00"E.

<table>
<thead>
<tr>
<th>Shark number</th>
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</tr>
<tr>
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<td>113°63'92&quot;E</td>
</tr>
<tr>
<td>3</td>
<td>26°10'16.58&quot;S</td>
<td>112°56'31.69&quot;E</td>
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<td>22°0'11.50&quot;S</td>
<td>113°30'52.00&quot;E</td>
</tr>
</tbody>
</table>
k. Move the cursor to the ending location of the track and click again. The distance will appear in the box.

l. DON’T MEASURE DISTANCE OVER LAND. If you have to, create a series of points—the ruler will keep adding the distance with every point you click—that is the shortest path a shark could have taken without crossing land.

2. **Data Analysis** Use the data in Table 1 to create a histogram that shows the number of tiger sharks that moved <100 km, 100–200 km, 200–500 km, 500–1000 km, 1000–2000 km, and >2000 km.

3. **Data Analysis** Based on the map you created and the histogram you drew, do all sharks move in a similar way? Explain your answer using the data and your graph.

4. **Data Analysis** If tiger sharks move more than 1500 km north of Shark Bay or 300 km offshore, they are at risk from fisheries. Based on the data you have, are female tiger sharks that use Shark Bay at risk from fisheries? Explain.
Shark Trails continued

Our tracking data have given us an idea of how far tiger sharks might range. But we only have data on female sharks, and we don’t know why they are swimming to far-off places. Is it to mate, or just to feed before coming back to the same area they were born to mate and/or give birth? Luckily, using the DNA in the small clips of the sharks’ dorsal fins we can find out this information. One way to find out how populations are structured is to see how genetically similar or different animals from different areas are. If individuals from different places have similar DNA signatures, it suggests that they are part of the same population. If the individuals from different areas are quite different genetically, it suggests that they are from different populations.

It turns out that DNA can give us even more information. Mitochondria (organelles inside cells) are only passed down from mother to offspring (fathers don’t contribute their mitochondria to their offspring). That means that if we compare the DNA inside mitochondria (called mtDNA), it tells us whether females are moving between different areas. If mtDNA is similar in sharks in different places, then females are part of the same population. But if the mtDNA in sharks is different between individuals in different locations it means that females don’t move between those areas for breeding. The DNA inside the nucleus tells a different story. Because both mother and father contribute nuclear DNA to their offspring, patterns of nuclear DNA, compared to patterns of mtDNA, tell us about the movement of males.

Mahmood has analyzed the mtDNA and nuclear DNA from many tiger sharks around the Indian and Pacific Oceans. He used these analyses to calculate a similarity value for each location. A similarity of 1.0 means that the populations are exactly the same genetically (that is, they are part of the same populations). Low values mean that populations are separate, and individuals are probably not moving between areas to breed very often.

We can represent the relationships between groups using a type of graph called a dendrogram. On a dendrogram, groups are linked by lines at their level of similarity, with the most closely related groups linked first, and progressively less related groups linked later. Figure 1 below is an example of a dendrogram that is based on the example data in Table 2 (see next page). In this figure, groups of sharks at Locations 2 and 3 share 97.5 percent of their DNA in the portion of DNA examined. Thus, they are linked together first. Sharks at Location 1 share, on average, 70 percent of the DNA examined with sharks at Locations 2 and 3. Based on these data, sharks at Locations 2 and 3 are likely a part of the same population while sharks at Location 1 are a separate population (remember they are the same species, so they should still share a lot of their genes).
Note. In the dendrogram illustrations, only the horizontal scale provides information on comparative genetic similarity. That is, the horizontal connecting lines are drawn scaled to the percent similarity between geographic locations. The vertical scale does not provide any information and is therefore unlabelled.

Table 2. Genetic similarity data used to create Figure 1

<table>
<thead>
<tr>
<th></th>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 2 – Location 3</td>
<td>0.975</td>
</tr>
<tr>
<td>(Location 2 – Location 3) – Location 1</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Figure 1. Genetic similarity of groups collected from three locations
Shark Trails continued

Table 3 provides the similarity of tiger sharks sampled in five locations based on nuclear DNA, which gives us an idea if male sharks are moving between locations. High similarity values indicate that male sharks probably move between areas to breed.

Table 3. Genetic similarity of nuclear DNA in tiger sharks sampled at two sites in the Atlantic Ocean (AO) and three sites in the Indian Ocean and Pacific Ocean, which is sometimes called the Indo-Pacific Region (IP)

<table>
<thead>
<tr>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America (AO) – South America (AO)</td>
</tr>
<tr>
<td>Western Australia (IP) – Hawaii (IP) – Africa (IP)</td>
</tr>
<tr>
<td>(N. America – S. America)-(W. Australia – Hawaii – Africa)</td>
</tr>
</tbody>
</table>

5. **Data Analysis** Use the data in Table 3 to create a dendrogram in the space provided below.

```
   North America
       |
       v
   South America
       |
       v
   Africa
       |
       v
   Hawaii
       v
   Western Australia
```

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Shark Trails continued

Table 4 shows the degree of similarity between tiger sharks sampled in the same five locations based on mitochondrial DNA. This gives us an idea whether female sharks are moving between locations to breed. High similarity values mean that female sharks probably move between areas to breed. Low values mean that females tend to not move between areas to breed.

<table>
<thead>
<tr>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America (AO) – South America (AO) 0.85</td>
</tr>
<tr>
<td>Western Australia (IP) – Africa (IP) 0.80</td>
</tr>
<tr>
<td>(Western Australia – Africa) – Hawaii (IP) 0.75</td>
</tr>
<tr>
<td>[(Western Australia – Africa)–Hawaii] – (N. America – S. America) 0.50</td>
</tr>
</tbody>
</table>

6. **Data Analysis** Use the data in Table 4 to complete the dendrogram below.

```
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
```

North America

South America

Africa

Hawaii

Western Australia
CONCLUSION

7. Based on the data on mtDNA and nuclear DNA that you graphed above, what inferences can you make about the structure of tiger shark populations and the relative distances that males and females likely swim?

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________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

8. What do the genetic data tell you about the movements of female sharks that you mapped above? Are these long-distance movements for breeding or feeding? Support your answer using genetic data.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

9. Shark Bay and the coastal waters of Western Australia 1000 km north of the bay are protected for sharks—there is no commercial fishing, but outside of this area, fisheries catch sharks. Based on your analysis, are tiger sharks safe? Use the different types of data you have analyzed to support your answer.

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