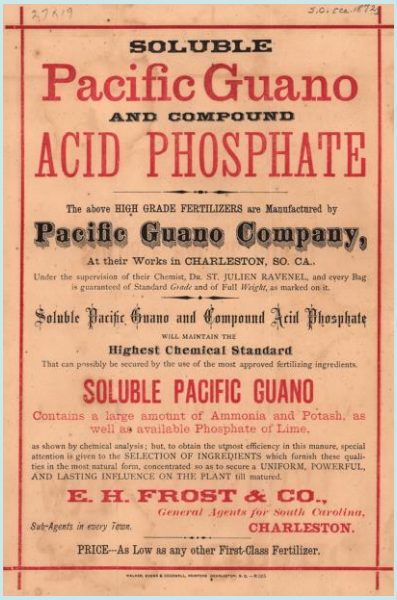
Pacific Remote Island Marine National Monument: Guano and Nutrient Cycling



Early Guano Advertising Poster Source: Duke Advertising Ephemera Collection

Grade Level

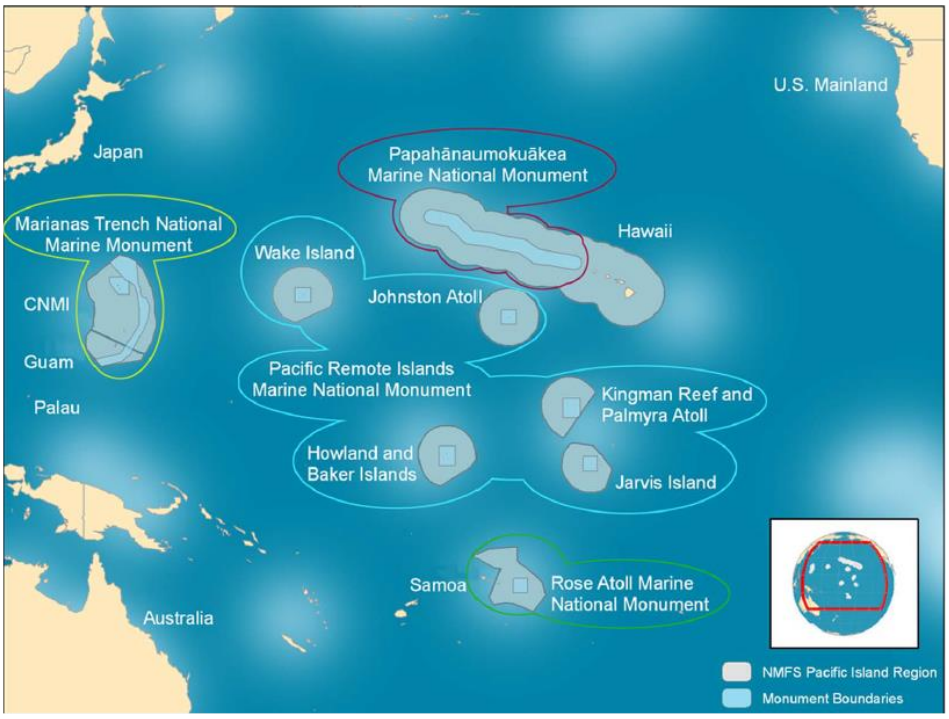
- 7-12

Timeframe

- 2.5 – 3 hours

Materials

- Large blank paper
- Colored pencils
- Sooty tern food web cards
- Sooty tern simulation cards
- "Nutrients" paper/cotton balls
- Containers for holding nutrients



Source: NOAA

Activity Summary

This lesson introduces students to the Pacific Remote Islands Marine National Monument (PRIMNM) through the lens of seabird guano. Students will orient themselves using a mapping exercise to locate the islands within the PRIMNM. Once oriented they explore nutrient flow through ecosystems by developing a food web for the sooty tern and use that to trace the movement of nutrients from source (the ocean) to sink (islands). This concept will be further reinforced and extended with a physical simulation exercise that introduces the variability of climate as a control on guano development. Students then use climate data from their mapping exercise to make inferences about which islands within the PRIMNM are likely to have the best developed guano resources. Finally they use source data on seabird populations in the past to calculate rates of guano development to determine the sustainability of this resource.

Learning Objectives

Students will be able to:

- Explore the geography of the PRIMNM
- Understand the relationship between food webs and nutrient flows

If you need assistance with this document, please contact NOAA Fisheries at (808) 725-5000.

Key Words

- Guano
- Food web
- Nutrient reservoirs
- Jarvis Island
- Invasive Species

Outline

ENGAGE – Where are we?

EXPLORE – Food Webs and Nutrient Flows

EXPLAIN – Food Webs and Nutrient Flows

ELABORATE- Focus on Jarvis Island, Climate Mapping, Guano Calculations.

EVALUATE- Summary

Vocabulary

BIOAVAILABLE – Compounds and elements that are in a form usable by organisms. For example elemental nitrogen (N_2) is inert but when converted to ammonium (NH_4^+) or nitrate (NO_3^-) via microbial or other processes, it becomes bioavailable.

CARRYING CAPACITY – The maximum population size of a given species that can be sustained indefinitely in a particular environment.

EQUATORIAL DRY ZONE – An arid region near the equator that forms as air masses sink and spread away from each other.

GUANO-The excrement of sea-birds (or bats and others). Under the right environmental conditions guano can form large deposits. These deposits have historically been mined for fertilizer because guano is very high in bioavailable nitrogen and phosphorus.

- Understand how climate helps control resource development
- Use data to calculate resource availability
- Be able to discuss sustainability of natural resources

Background Information

Guano

Source: US Fish and Wildlife

Webster's Dictionary defines guano broadly as "excrement especially of seabirds or bats", but more specifically as "a fertilizer containing the accumulated excrement of seabirds or bats". It is this second definition that explains the historical importance of guano and the US possession of many of the small islands in the Central Pacific.

Increasing populations in the 18th and 19th centuries and the need to maintain productive soils led to a suite of advances in agricultural techniques both in the US and abroad. Among them was the idea of replacing essential nutrients lost during crop production by adding nutrients from another source, a "fertilizer". In the early days of commercial fertilization, one of the most prized types of fertilizer was seabird guano with its high concentrations of nitrate, phosphate and potassium. However, the development of large quantities of seabird guano occurs only in a limited number of locations in the world. This is because in addition to needing a large numbers of seabirds to concentrate marine derived nutrients and long periods of time for accumulations to occur, the climate must be dry. Bioavailable nitrogen, in the form of nitrogen oxides (NOx) or ammonia (NH_3), is incredibly mobile and is easily removed from an environment by leaching, erosion, volatilization or bacterial denitrification. Leaching is also the primary way that phosphorus is removed from the environment, so the best guano for agricultural purposes came from areas with very little rain.

Seabird guano was so essential to US agriculture development that in 1856 the US passed the Guano Act which declared:

"Whenever any citizen of the United States discovers a deposit of guano on any island, rock, or key, not within the lawful jurisdiction of any other government, and not occupied by the citizens of any other government, and takes peaceable

Vocabulary (continued)

RESERVOIRS – Places where essential element/nutrients are stored for long periods of time without being recirculated. For example, coal is a reservoir for carbon and guano deposits are a reservoir for nutrients.

SYNTHETIC FERTILIZERS – Fertilizers with bioavailable nutrients created by laboratory and industrial processes.

Remnants of guano tramway on Jarvis Island with guano stockpiles in the background. Source: Wikipedia

possession thereof, and occupies the same, such island, rock, or key may, at the discretion of the President, be considered as appertaining to the United States." - US Guano Act 1856, 48 U.S. Code § 1411

All of the islands that now make up the PRIMNM, with the exception of Wake Island, became US positions under this Act.

Details of historical ownership are not the only legacy of guano mining on these islands. Rats and mice came to the islands aboard the guano ships and quickly adapted to a diet of seabird eggs and chicks. In addition, domesticated cats introduced in the 1930s to control the rodent populations easily adapted to a bird- based diet once the rodents were exterminated. Ground nesting birds were especially susceptible to predation by rats and cats and many seabird species were extirpated (localized extinction) altogether.

Indeed by 1966 only three species of seabirds remained on Jarvis Island when the Pacific Ocean Biological Survey Program visited. The ecological devastation resulting from these invasive species remains a lasting legacy of the guano mining era and one of the major challenges faced by the managers of the monument today.

Sooty Terns:

Source: US Fish and Wildlife

Sooty terns, with colony sizes in the millions, are a good example of seabirds that helped develop the guano resources on the small remote islands in the PRIMNM. By feeding in the productive waters upwelled around the islands, and returning food to their land bound chicks, nutrients sourced from the sea build up over time on the islands (sources and sinks). These birds also clearly demonstrate the resilience of a species in the face of invasive threats. Locally extirpated from a number of the PRIMNM islands, sooty terns have made a

remarkable comeback once the predation and human disturbance pressures were removed. Their breeding colonies again number in the millions.

This lesson plan uses the feeding relationship of Sooty terns to demonstrate how nutrients can flow from source (ocean and atmosphere) to sink (islands). Additionally, students use climate data to make observations about where guano resources might develop, and calculate rates of guano development to investigate the concept of sustainable resources.

Preparation

- Read background.
- Print and cut out Sooty tern food web cards for each student.
- Print student worksheet for each student.
- Print plotting sheets in color, enough for each pair of students.

Learning Procedure

Engage

- Hand out the lat/long coordinates of all seven islands in the PRIMNM (or display on the overhead) without indicating what these locations represent. Ask student to work with a partner to brainstorm where on the planet these places might be and what they might have in common.
- After some discussion time, hand out the student plotting sheets and have students plot the coordinates. After they plot the locations ask them to revise their answers from before.
- After further discussion, introduce them to the Marine National Monument (MNM) in general and the Pacific Remote Islands Marine National Monument specifically (short PowerPoint PRIMNM Guano Monument Overview).
- Have students complete ***Part 1: Where are we?*** on their worksheet.

Explore/Explain – Food Webs and Nutrient Flows

Part 1: Food webs, trophic levels and nutrient flow

This can be done as a whole class brainstorming activity, or with small groups/pairs, or as an individual review. Students should already be familiar with the concept of food webs.

1. As a class briefly discuss the food webs and trophic levels so everyone has a good understanding of the concepts.
2. Present the food web cards, except for the sooty tern chick card, a large sheets of paper and two colored pencils to the each student or group and ask them to create a food web. You may need to introduce phytoplankton as the primary producers in marine food webs if the students are not familiar with marine ecosystems. In one color lightly draw feeding relationships that exist within this food web and label the

trophic levels for each species. Note that some species may occupy more than one trophic level.

3. Now ask the students how these organisms get their nutrients. In a different color trace the nutrient flow into, out of and through the food web. Use the following question to help guide understanding:
    a. Where do the nutrients for the primary producers come from?

        Primarily ocean upwelling of nutrient rich waters, drawdown from the atmosphere, release by decomposers and inputs from land. Note, upwelling is not coved in this lesson and may need to be discussed if the students are not familiar with this concept.

    b. How do those nutrients move through the food web?

        Primary producers extract nutrients from the surrounding waters, and consumers get their nutrients from their food. Students should understand that the food ingested in one form is released as waste in a different form, but that nutrients are present in both forms.

    c. Do organisms use 100% of the nutrients they take in?

        No, large amounts of nutrients are excreted as waste.

    d. Are 100% of nutrients transferred between trophic levels?

        No, most organisms are messy eaters and many of the nutrients are lost during eating and become part of the "marine snow". Other nutrients are lost when animals excrete waste or "fecal pellets".

4. Now introduce the Sooty tern chick card and ask the students to include this in the food/nutrient web. Use the guiding questions to help students:
    a. Where must the chicks be located given that they cannot fly?

        Mostly on islands. Fledging take ~60 days after hatching.

    b. How will nutrients get to them and what will happen to their excess nutrients?

        Chicks must be fed by their parents and excess nutrients from both chicks and parents are excreted and remain on the island rather than falling back into the sea. Over time, nutrients in the waste will start to build up on the islands.

Part 2: Nutrient accumulation simulation

This simulation will show the students how nutrients can be concentrated on oceanic islands. Begin by designating a portion of the classroom as an "island". The area should be large enough to fit a couple of student comfortably. Designate the area all around the island as "ocean". This region should be large

enough to fit the majority of students participating in the activity with space for them to move around. Around the edges of the "ocean" designate a couple of places as "atmosphere". Divide the students up using food web cards making sure that there are at least twice as many bacteria, phytoplankton, and zooplankton as squids, anchovies, and terns. Chicks are restricted to the island. Begin by scattering a few nutrients (cotton balls) around the "ocean" region (not on the island) and in several places designated to be "atmosphere". Simulation follows these rules…

1. Bacteria: for every four nutrients you ingest, discard three back into the water as waste. You can get nutrients from the water (by decomposing materials found in the water), or from the atmosphere (some bacteria are nitrogen-fixers).
2. Phytoplankton: for every four nutrients you ingest, discard two as waste into the water. You get your nutrients from the water (nutrients returned to the water by you or other organisms).
3. Zooplankton, Anchovy, Squid: For every four nutrients you "ingest" two must be discarded into the water as waste. You can get your nutrients from eating other animals. Use the relationships on the food web to determine which animals you eat. If you are eaten by another animal, give them all of your nutrients and then start collecting nutrients again.
4. Sooty tern: For every four nutrients you take in, discard two as waste. You can get your nutrients from eating other animals. Use the relationships on the food web to determine which animals you eat. Once you have built up six nutrients in your reserve, go and give three to your chick on the island.
5. Sooty tern chick: for every four nutrients you get, discard two as waste on the island. You get your nutrients from your parent sooty terns.

Run the simulation for two minutes to see what happens.

6. Stop the simulation and ask the students what is happening with the nutrients.
   Students should begin to see an accumulation of nutrients on the island.
7. Run the simulation for several more rounds and then ask what is happening.
   The nutrient accumulation on the island should become bigger with time.
8. Stop the simulation and ask the students what will happen if it rains on the island.
   They should be able to determine that the nutrients on the island will wash back into the ocean.
9. Now introduce a precipitation event that washes most of the nutrients off the island during every two-minute period (you can simulate the effect of precipitation on the accumulation of nutrients on the island by giving one student a broom and instructing them to sweep off the whole "island"

once during the two minute round). Nutrients that run back into the water are fair game again. Run the simulation this way for several rounds.

10. Run the simulation both ways until it is clear to the students that nutrients build up much more slowly when there is rain on the islands. Stop the simulations and have students discuss the different dynamics they observed. Where did the nutrients come from? How hard was it for the higher trophic level organisms to get the nutrients they needed? What were the best sources of nutrients?

End the day by having the students complete **Part 2: Food Webs and Nutrient Flows** of their worksheet.

Elaborate – Jarvis, Climate Mapping, Guano Calculations

This sections asks students to study the environmental consequences of guano mining and to investigate the environmental conditions needed for the development of guano reserves. They will use that information to determine where the largest guano reserves are likely to be and will do some basic calculations to get a better understanding of the sustainability of guano as a harvestable resource.

Part 3: Focus on Jarvis Island

To re-engage students with the lesson have them read ***Part 3: Focus on Jarvis Island*** in their student worksheet. This will give them some background on guano mining operations and the lasting ecological damage resulting from those operations. In addition this short video http://youtu.be/haoqvgPzFsQ of sooty terns on Johnston Atoll gives a good sense of what it is like to be in a sooty tern colony and how the terns feed their young.

Part 4: Climate Mapping

Have students use their map of island locations from **Engage: Part 1 – Where are we?** to determine the monthly average rainfall and to calculate the annual average rainfall for each island in the PRIMNM. They should record their answers in the table provided in their worksheet. Once they have completed the table they should use that information to help them answer the subsequent questions.

Part 5: Poop Calculations

Using published seabird survey numbers, have students calculate the maximum annual rate of guano development for two points in time, before and after invasive cat removal. The follow up questions ask about the time it might take to replace all the guano mined from the islands and serves as a basis for students to think about the sustainability of this resource.

Evaluate – Summary

As a summative assessment have the students answer the short answer questions found in **Part 6: Summary** of their worksheet. As appropriate ask students to share their answer to stimulate a summary discussion around the important topics.

Extending the Lesson

There are numerous options for extension to this lesson.

- In the nutrient accumulation simulation you can add the element of carrying capacity in the system by allowing the organisms to replicate if they are able to get enough nutrients (e.g. six nutrients). Start with only one of each organism and begin by allowing only the bacteria and the phytoplankton to play for one or two rounds. Once there is a pool of these organisms, bring in all the other organisms. After several rounds, it should become clear that those organisms that have many food sources, the ones that are very quick, or the ones with no predators in this simulation (i.e. sooty terns) will come to dominate the scenario. This can lead to an excellent discussion of carrying capacity.

- Nitrogen fixation: both bacteria and blue green algae are able to fix N_2 from the atmosphere. Additionally bacteria are the main decomposers within the system. What happens to the food web and nutrient flow if bacteria are removed from the picture? Run several simulations without the bacteria to get a sense of how important these organisms are to the nutrient cycle. Instead of having discarded nutrients going back into the ocean, have them go into a "undecomposed material container" that is off limits as a nutrient source. Very quickly the students should see that the bacteria are essential to the functioning of the food web.

Connections to Other Subjects

- Math
- Ecology
- Biology
- Oceanography
- Geology

Related Links

Jarvis Island
NOAA Fisheries Pacific Remote Islands MNM
NOAA Fisheries Pacific Islands Regional Office
Guano Islands Act
NY Times article on Guano and Pacific Islands

For More Information

NOAA Fisheries Pacific Islands Regional Office
NOAA Marine National Monument Program
1845 Wasp Blvd., Building 176
Honolulu, HI 96818

(808) 725-5000, (808) 725-5215 (fax) pirohonolulu@noaa.gov

Acknowledgement

This lesson is one in a series exploring the geology, biology, oceanography, and ecology of the Pacific Marine National Monuments. It was developed for the NOAA Fisheries Pacific Islands Regional Office.

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All images are from NOAA, Laura Nelson or Mary Engels unless otherwise cited.

Thank you to all the reviewers for their feedback and assistance.

Sources

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Duke University David M. Rubenstein Rare Book & Manuscript Library
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Education Standards

Next Generation Science Standards	• **MS-ESS3-1**. Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes. • **MS-LS2-3.** Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem. • **MS-LS2-4**.Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. • **HS-ESS3-1**. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity • **HS-ESS3-2**. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios. • **HS-LS4-5**. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.
Ocean Literacy Principles	• **4C** - The ocean provided and continues to provide water, oxygen, and nutrients, and moderates the climate needed for life to exist on Earth (Essential Principles 1, 3, and 5). • **5D** - Ocean biology provides many unique examples of life cycles, adaptations, and important relationships among organisms (symbiosis, predator-prey dynamics, and energy transfer) that do not occur on land. • **6B** - From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security. • **6D** - Humans affect the ocean in a variety of ways. Laws, regulations, and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (point source, nonpoint source, and noise pollution), changes to ocean chemistry (ocean acidification), and physical modifications (changes to beaches, shores, and rivers). In addition, humans have removed most of the large vertebrates from the ocean. • **6G** - Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

NOAA Fisheries' Pacific Islands Regional Office & The Marine National Monuments Program

Pacific Islands Regional Office

NOAA Fisheries
Honolulu, Hawaii

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

Mission

The mission of PIRO is to provide stewardship of marine the living resources in the Western and Central Pacific for the benefit of the Nation, its citizens, and the island communities through science-based conservation and management and the promotion of the health of the environment.

Responsibilities include the maintenance of healthy fish stocks for commercial, recreational and subsistence fishing; the conservation and recovery of protected species; the preservation and restoration of marine habitat; and the coordination with international organizations to implement and monitor fishery agreements and treaties.

Marine National Monument Program (MNM)

- Papahānaumokuākea Marine National Monument
- Pacific Remote Islands Marine National Monument
- Rose Atoll Marine National Monument
- Mariana Trench Marine National Monument

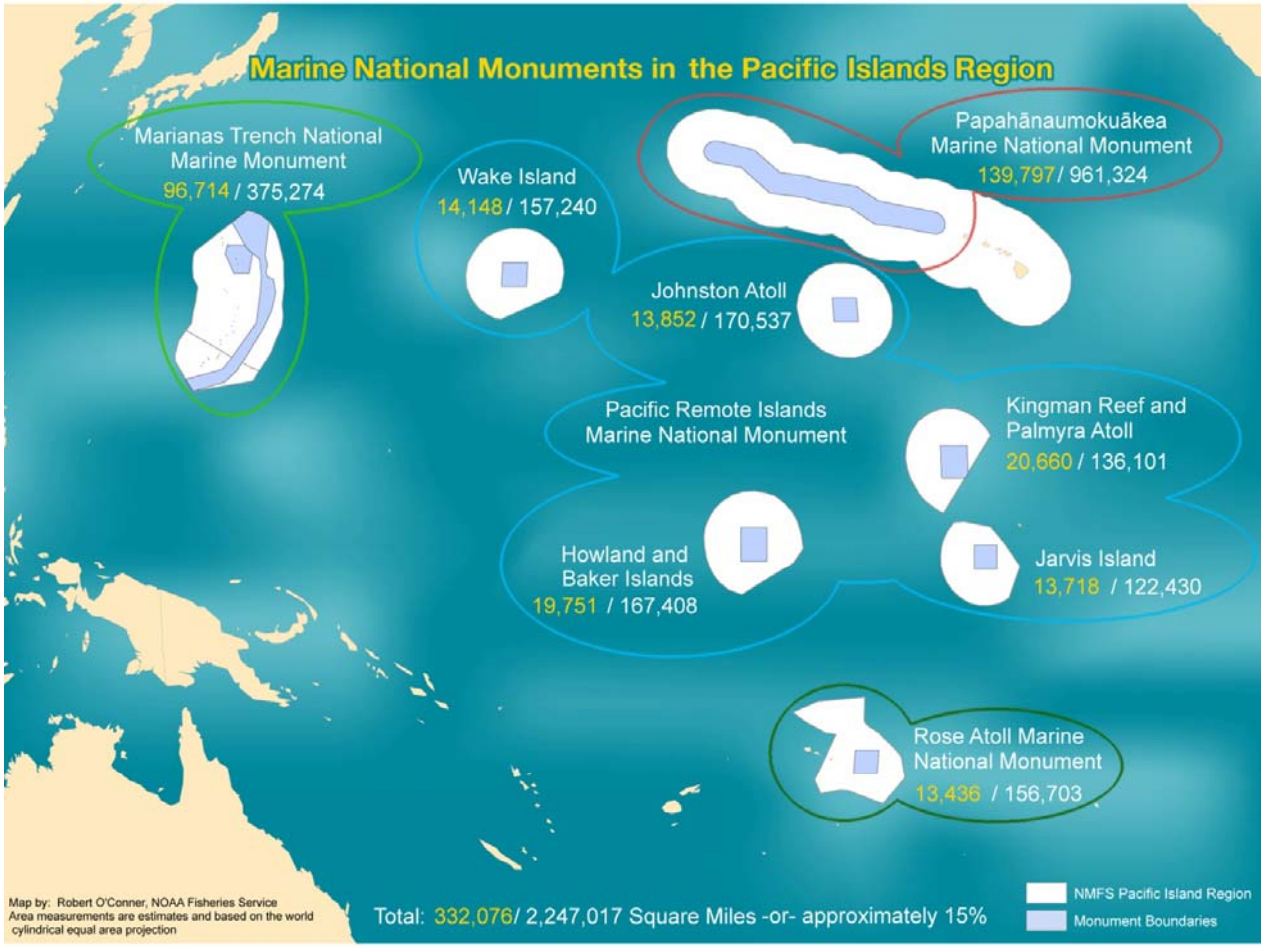
NOAA's Marine National Monument Program implements the Presidential Proclamations that created the four Pacific Marine National Monuments. These protected areas encompass approximately 332,000 square miles or 15% of the U.S. EEZ in the Pacific Islands.

Marine National Monument Program (MNM) (continued)

The Monuments are home to many rare and endangered species and unique geologic features. These near-pristine locations also provide opportunities to conduct climate change research, habitat studies and ocean exploration. Under NOAA's existing authorities and the Antiquities Act, the Marine National Monument Program coordinates with federal and regional partners, as well as stakeholders, to conserve and protect the marine resources in these protected areas.

For more information on the Monuments Program: www.fpir.noaa.gov/MNM/mnm_index.html

Marine National Monument Program (MNM) (continued)



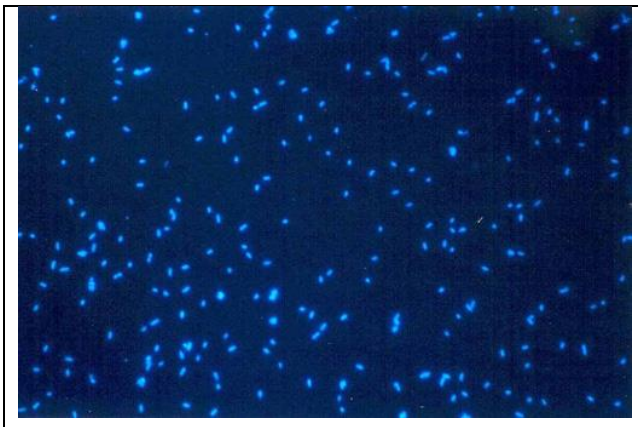
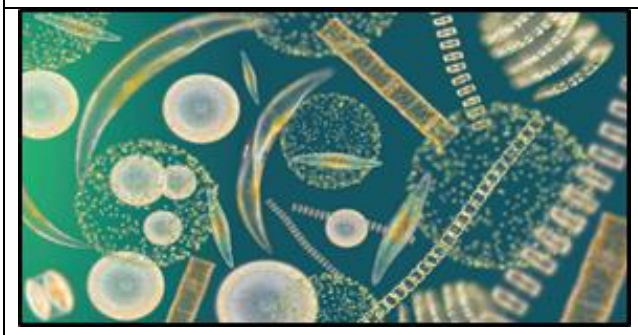
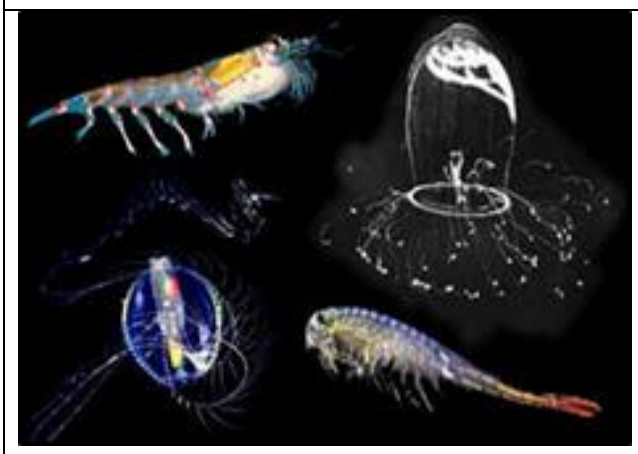
The Pacific Remote Island Areas Marine National Monument (PRIA's)

working to develop a management approach.

Management Partners:

- NOAA/NMFS
- USFWS/NWRS

Pacific Remote Islands Marine National Monument: Nutrient Web Cards

	**Marine Bacteria** **Nutrient Sources:** water and atmosphere **Efficiency:** Every time you collect 4 nutrients, recycle 3 back into the water.
	**Marine Phytoplankton** **Nutrient Sources:** water **Efficiency:** Every time you collect 4 nutrients, recycle 2 back into the water.
	**Marine Zooplankton** **Nutrient Sources:** phytoplankton **Efficiency:** Every time you collect 4 nutrients, recycle 2 back into the water.

	Squid **Nutrient Sources:** zooplankton **Efficiency:** Every time you collect 4 nutrients, recycle 2 back into the water.
	Anchovy **Nutrient Sources:** zooplankton **Efficiency:** Every time you collect 4 nutrients, recycle 2 back into the water.
	Sooty Tern **Nutrient Sources:** squid and anchovies **Efficiency:** Every time you collect 4 nutrients, recycle 2 back into the water. **Reproduction:** When you have 6 nutrients, give 3 to a chick on the island.

	Sooty Tern Chick **Nutrient Sources:** sooty tern parent **Efficiency:** Every time you collect 4 nutrients, recycle 2 onto the island.

Pacific Remote Islands Marine National Monument: Plotting Worksheet

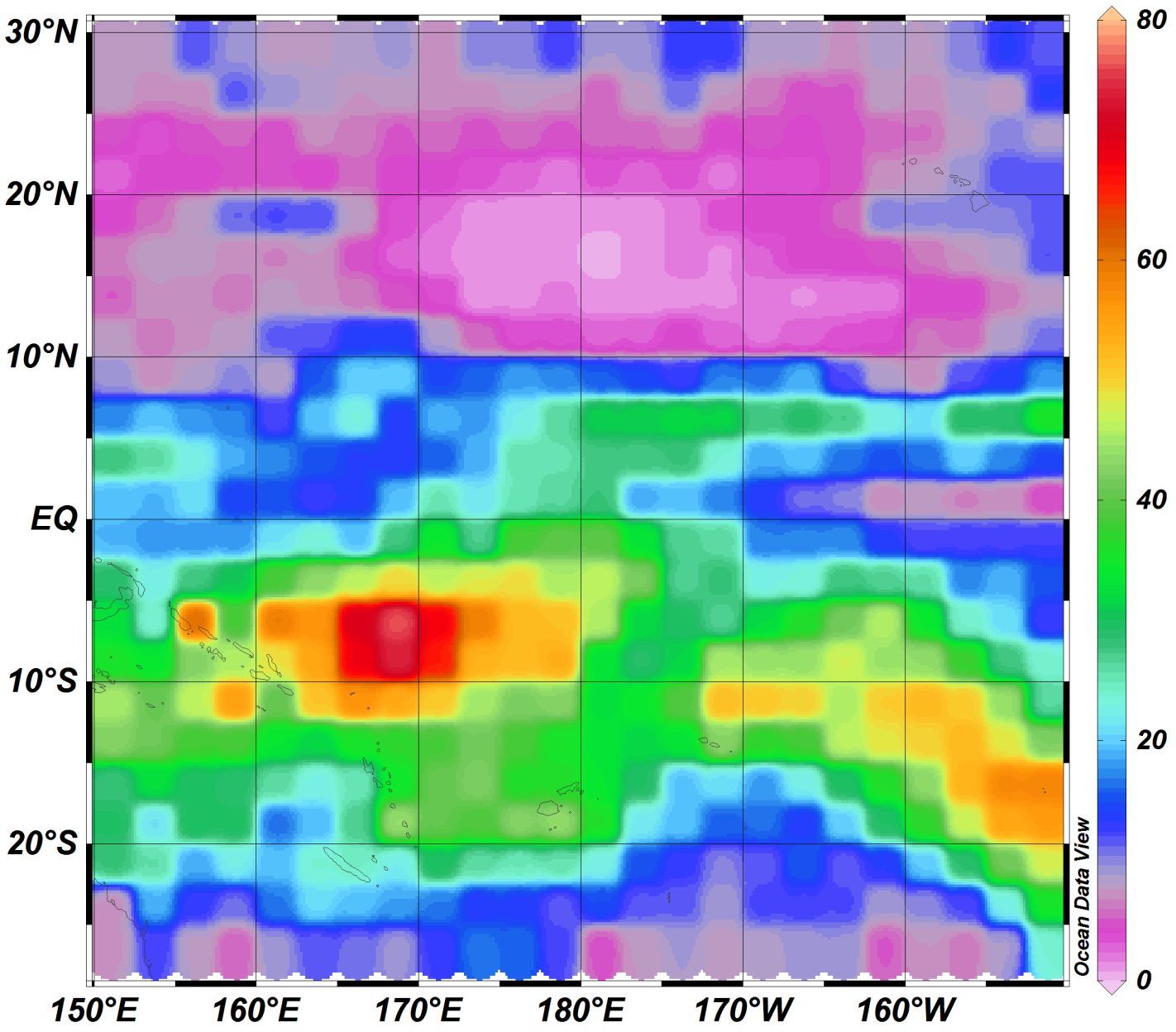


Figure 1: Monthly Average Precipitation [cm]

LOCATION	LATITUDE	LONGITUDE
1	0° 12’N	176° 29’W
2	0° 48’N	176° 37’W
3	0° 22’S	160° 01’W
4	16° 45’N	169° 31’W
5	6° 23’N	162° 25’W
6	5° 53’N	162° 05’W
7	19° 18’N	166° 38’W

Pacific Remote Islands Marine National Monument: Guano and Nutrient Cycling Worksheet ANSWER KEY

Name_____ Date_____

Part 1: Where are we?

1. With a partner, brainstorm what these latitude and longitude coordinates might represent. In general, where are these positions on the planet? What do these locations have in common?

   Answers will depend on students' familiarity with the concepts of latitude and longitude and world geography. They should be able to determine that all the lat/long coordinates are generally in the Pacific Ocean and that the sites are likely islands. As a helpful point of reference, you may want to let students know that Hawaii is located at approximately 21° 18'N x 157° 47'W.

2. Using the plotting sheet, actually plot these latitude and longitude coordinates. Pay careful attention to °N vs. ° S and ° W vs. ° E.

   A helpful way to remember latitude and longitude is to have the students think about a ladder. "Ladditude" would be the horizontal rungs of a ladder, that allow you to climb up and down, and the "Long"itude would be the long sides of the ladder that run vertically. It will also be helpful to give the students an overview of the plotting sheet before they begin plotting. Hawaii is drawn on the map as a point of reference, longitude is on the x-axis, latitude is on the y-axis, and the grid frame has two colors to help with plotting.

3. Based on your plotting, revise your answers from Question 1.

   All the islands are located in the central Pacific Ocean, west of Hawaii and east of the date line. All of the islands fall in the tropics and subtropics which generally indicates hot climates and limited seasons. Some students may also comment based on their plotting that a number of the islands are pretty dry and remote.

4. Why might these locations be important to protect?

   Answers will vary, but ideally students will come up with that these islands are home to many unique species. In particular, these islands are very important as seabird nesting habitat.

Part 2: Food Webs and Nutrient Flows

Directions: Answer the following questions.

1. What are primary producers in the marine environment? Where do they get their nutrients from?

   Primary producer in the marine environment are typically phytoplankton who can use photosynthesis for an energy source. Their productivity is limited by their access to nutrients in the water and the amount of sunlight they receive. The amount of nutrients in the water is controlled by the rate of N_2 fixation from the atmosphere (thanks to both heterotrophic and autotrophic bacteria species), upwelling from the deep ocean, inputs from land via rivers or wind, and nutrients released by the decomposition of organic matter by bacteria. The availability of nutrients in the upper ocean frequently limits the abundance of organisms in the upper oceans.

2. **Nutrient reservoirs** are places where nutrients are stored for a long period of time. In the simulation we just did, what would be the nutrient reservoir? What might control how long the nutrients remain in that reservoir? Explain your reasoning.

   *The island is a nutrient sink, or a **nutrient reservoir**, which traps and immobilizes the nutrients away from access by living organisms. The amount of precipitation will control how long nutrients remain in the island reservoir. If there is a lot of rain, nutrients will be washed back into the ocean, but if not, they tend to stay put. Large deposits of bird poop are known as guano.*

3. What is the role of bacteria in food webs and nutrient cycles?

   Bacteria are the decomposers in food webs. As they break down dead organisms and release many of the nutrients locked up in those cells back to the ocean through their waste. In addition, many bacteria are able to fix nitrogen from the atmosphere making it available to organisms that are not able to fix nitrogen on own.

4. How are food webs and nutrient cycles related?

   A food web describes how energy moves through the living (organic) part of any ecosystem. Nutrients are also moved in this way, however, nutrients can also be moved around by non-living (inorganic) processes such as the weathering of rocks, deposition of sediments by wind, and inorganic chemical reactions. The organic and inorganic movement of nutrients together makes up the nutrient cycle.

Part 3: Focus on Jarvis Island

Jarvis Island, located just south of the Equator in the central pacific (0° 22'S x 160° 01'W), is a US National Wildlife Refuge and part of the Pacific Remote Island Marine National Monument. This island is excellent seabird nesting habitat and currently there are 20 different seabird species that spend time on the island. The largest group is a colony of sooty terns (*Onychoprion fuscatus*) that numbers more than a million and is one of the largest sooty tern colonies anywhere in the world. It is thought that in the past their numbers might have been much greater.

Source: US Fish and Wildlife

Thanks to many generations of seabirds, parts of the island of Jarvis have been buried in thick layers of bird poop known as ***guano*** deposits. Since these deposits are very rich in ***bioavailable*** nitrogen and phosphate, this island (and others like it) became very valuable as a source of fertilizer during the late 1880's when ***synthetic fertilizers*** were not available. The guano resources of Jarvis were so valuable that the island was claimed for the United States under the US Guano Islands Act of 1856. In fact, all the islands in the Pacific Remote Island Marine National Monument (PRIMNM), with the exception of Wake Island, were claimed by the US for their guano resources, which gives indication of how important fertilizers were to the US agricultural industry. Heavily mined for guano from 1858 till 1879, guano transport ships such as the *White Swallow* removed a total of 300,000 tonnes (600,000,000 lbs) of guano from Jarvis. This is equivalent to filling 1200 Olympic sized swimming pools full of bird poop!!

Historical ownership is not the only legacy of guano mining on these islands. Rats and mice came to the islands aboard the guano ships and quickly adapted to a diet of seabird eggs and chicks. In addition, domesticated cats were introduced in the 1930s to control the rodent populations, but easily adapted to a bird-based diet once the rodents were exterminated. Ground nesting birds such as sooty terns were especially susceptible to predation by rats and cats and many seabird species were extirpated (localized extinction) altogether. Indeed by 1966 only three species of seabirds remained on Jarvis Island when the Pacific Ocean Biological Survey Program visited. The ecological devastation resulting from these invasive species remains a lasting legacy of the guano mining era and is one of the major challenges faced by the managers of the Monument today.

Part 4: Climate Mapping

Climate is one significat factor that will control where guano resources will develop. Use the data from your plotting exercise in Part 1 to determine the average montly and annual rainfall for each island and answer the following questions.

NAME	LATITUDE	LONGITUDE	MONTHLY RAINFALL (cm)	ANNUAL RAINFALL (cm)
Baker Island	0° 12'N	176° 29'W	*10*	*120*
Howland Island	0° 48'N	176° 37'W	*10*	*120*
Jarvis Island	0° 22'S	160° 01'W	*10*	*120*
Johnston Atoll	16° 45'N	169° 31'W	*2*	*24*
Kingman Reef	6° 23'N	162° 25'W	*25*	*300*
Palmyra Atoll	5° 53'N	162° 05'W	*25*	*300*
Wake Island	19° 18'N	166° 38'W	*8*	*96*

1. Which islands in the PRIMNM receive the most rainfall? Which island receives the least?

   Palmyra Atoll and Kingman reef receive the most rainfall of any of the islands. Johnston Atoll receives the least.

2. Which islands do you think historically had the least and best developed guano reserves and how do you think climate impacts the development of these reserves?

   While all the islands are great habitat for seabirds (good nesting habitat, few predators, and productive waters in which to feed due to upwelling around islands) guano only develops in regions that have limited precipitation. Significant rainfall prevents guano development at Palmyra Atoll and Kingman Reef because the bird poop is physically washed away or the nutrients are leached out of the soil before guano reserves can develop. Jarvis, Howland, Baker, Johnston Atoll and Wake Island all historically had well developed guano resources. Jarvis, Howland, and Baker islands were mined extensively during the 1800s, but Johnston Island was mined only sporadically and Wake Island was not mined for guano at all.

Part 5: Poop Calculations

In addition to climate, guano development depends on the number of birds pooping and how much each bird is pooping. Below are the bird counts for two different years from Howland, Baker and Jarvis Islands. If one bird poops on average ***0.6 lbs of poop a year***, how much guano would develop on those islands in each different year from all the birds? Show your work!

Table 2 Seabird counts at the time of cat eradication for Jarvis, Baker, and Howland Islands and subsequent seabird counts on each island several years after cat eradication. The numbers represent the largest count of birds documented on a single trip but not the total population, as birds nest throughout the year.

Scientific Name	Common Name	Jarvis 1982	Jarvis 2004	Baker 1965	Baker 2002	Howland 1986	Howland 2007
Phaethon rubricauda	Red-tailed tropicbird	2500	2500	15	72	122	496
Sula dactylatra	Masked booby	3000	7000	400	3134	2387	3763
Sula leucogaster	Brown booby	500	2000	10	375	15	275
Sula sula	Red-footed booby	550	1000	1	714	41	825
Fregata minor	Great frigatebird	50	2400	3	900	0	550
Fregata ariel	Lesser frigatebird	1500	4000	0	16,200	0	3850
Onychoprion fuscatus	Sooty tern	1,000,000	+1,000,000	6000	1,600,000	0	150,000
Onychoprion lunatus	Grey-backed tern	6	1100	25	2000	0	2000
Anous stolidus	Brown noddy	1	10,000	1000	3600	50	1000
Procelsterna cerulea	Blue noddy	1	650	0	26	0	11
Gygis alba	White tern	12	11	0	38	2	50
Nesofregetta fuliginosa	Polynesian storm-petrel	1*	3	0	0	1	0
Puffinus nativitatis	Christmas shearwater	0	20	0	0	0	0
Puffinus bailloni	Tropical shearwater	0	20	0	0	0	0
Puffinus pacificus	Wedge-tailed shearwater	100	41	0	10	0	1*

*Birds found dead
Sources: Clapp and Sibley 1965; Forsell and Berendzen 1986; Sibley and Clapp 1965; Skaggs 1994; US Fish and Wildlife Service 2007

Jarvis 1982 *1,008,220 birds x 0.6 lbs/bird/year = 604,932 lbs/year*	**Jarvis 2004** *1,030,745 birds x 0.6 lbs/bird/year = 618,447 lbs/year*
Baker 1965 *7,454 birds x 0.6 lbs/bird/year = 4,472 lbs/year*	**Baker 2002** *1,627,069 birds x 0.6 lbs/bird/year = 976,241 lbs/year*
Howland 1986 *2,618 birds x 0.6 lbs/bird/year = 1,571 lbs/year*	**Howland 2007** *162,820 birds x 0.6 lbs/bird/year= 97,692 lbs/year*

1. Which *year* and *island* had the greatest guano production?

   Baker Island in 2002 had the highest number of birds (1,627,069 birds) which means it also had the highest guano production rate.

2. Using the greatest guano production rate, how many *years* would it take to get 600,000,000 lbs of guano (the amount mined from Jarvis between 1858 and 1879)?

   600,000,000 lbs / 976,241 lbs/year = 615 years

3. How many years would it take to develop 600,000,000 lbs if you used the lowest guano production rate?

   600,000,000 lbs / 1,571 lbs/year = 381,971 years

4. Based on the numbers you just calculated, would you describe guano on these islands as a renewable resource? Why or why not?

   Generally speaking, no, this is not a very renewable resource. If the bird populations were much larger, or we mined much less guano, this might be a renewable resource, but at the rates of guano mining in the past, this is not a renewable resource.

Part 6: Summary

Directions: Based on what you have learned, answer the following questions:

1. Describe the process of seabird guano development on islands from source to reservoir. Be sure to include a discussion of climate.

   Bioavailable nutrients present in ocean water (the source) are used by phytoplankton in their growth and development. As primary producers, the phytoplankton are the base of a large marine food web. Nutrients, as well as energy, flow through the trophic level of the food web until they reach seabirds who transfer food and nutrients to their chicks. Since the chicks are flightless and the parents spend a lot of time nesting, their wastes accumulate on the islands instead of returning directly to the ocean to be recycled by bacteria and other decomposers. If the climate is dry enough, wastes will not be washed off the islands due to precipitation events and over long time scales a nutrient sink, or large guano reservoir, will develop.

2. What would be a sustainable amount of guano that could be harvested from these islands?

   A sustainable guano mining operation would not take more guano each year than is being produced. Based on our rough calculations about ~900,000 lbs of guano are produced on Baker Island each year. This is enough fertilizer for about 4500 acres of farmland, far less than 1% of all the farmland in the US. In short, the limited supply of guano and the ecological disturbances of guano mining mean that sustainable guano mining operations are not really possible today.

3. What are some of the environmental consequences of guano mining in the PRIMNM?

   The introduction of invasive species, disturbance of seabirds and destruction of seabird habitat are all consequences of guano mining.

4. Guano is not being mined from these islands today. What are some reasons, both economic and ecological that guano mining operations may have stopped?

   Guano is not being mined from the islands for many reason. First, development of synthetic fertilizers made guano mining mostly obsolete, though organic farming has renewed some interest. In addition, given that these islands are very remote, it would be hard to bring the guano to markets in a cost-effective way. Additionally many guano reserves were depleted during the late 1800s and have not been renewed. Finally, and most importantly, mining operations dramatically disturb the bird populations and expose them to threats from invasive species. Many of these bird species are currently threatened or endangered, and these remote islands are their only breeding grounds. Given that these islands are critical to the long term sustainability of these bird populations, protecting and restoring these island habitats is a huge part of the mission of the Marine National Monument Program.

Pacific Remote Islands Marine National Monument: Guano and Nutrient Cycling Worksheet

Name_____ Date_____

Part 1: Where are we?

1. With a partner, brainstorm what these latitude and longitude coordinates might represent. In general, where are these positions on the planet? What do these locations have in common?

2. Using the plotting sheet, actually plot these latitude and longitude coordinates. Pay careful attention to °N vs. ° S and ° W vs. ° E.
3. Based on your plotting, revise your answers from Question 1.

4. Why might these locations be important to protect?

Part 2: Food Webs and Nutrient Flows

Directions: Answer the following questions.

1. What are primary producers in the marine environment? Where do they get their nutrients from?

2. **Nutrient reservoirs** are places where nutrients are stored for a long period of time. In the simulation we just did, what would be the nutrient reservoir? What might control how long the nutrients remain in that reservoir? Explain your reasoning.

3. What is the role of bacteria in food webs and nutrient cycles?

4. How are food webs and nutrient cycles related?

Part 3: Focus on Jarvis Island

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Jarvis 1982	Jarvis 2004
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