Marine Science Lesson Plans about the Pacific Marine National Monuments: Options for Enhancing Ocean Literacy in the 7th through 12th Grade Classroom

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Abstract

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Abstract

The ocean is one of the Earth's defining features; it provides our world with variety of beneficial services like regulating climate, providing food, and is a source of wonder and inspiration. However, despite its size and powerful nature it is not immune to degradation. One of the greatest risks to our ocean is a general lack of understanding amongst the public of basic ocean processes and how an individual's actions contribute to environmental harm. In the United States, a low level of ocean-centered education in the K-12 classroom contributes to the lack of ocean literacy. This study presents a review of current levels of ocean literacy in the United States and highlights the benefits of increased levels of ocean science education. Barriers, challenges, and potential solutions for the increased implementation of ocean literacy in the classroom are identified. One of the barriers identified is lack of appropriate curricula available to teachers. In response, this study presents a newly developed suite of lesson plans that fit into a variety of scientific disciplines that draw upon the systems of the Pacific Marine National Monuments as examples. Several example lessons are discussed as well as the educational research that influenced their design and the lesson development methodology.

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Acronyms

COSEE – Centers for Ocean Science Education Excellence

EALR – Essential Academic Learning Requirements

MNM – Marine National Monument

NGSS – Next Generation Science Standards

NMEA – National Marine Educators Association

NOAA – National Oceanographic and Atmospheric Association

NRC – National Research Council

NWHI – Northwest Hawaiian Islands

OL – Ocean Literacy

OLEP – Ocean Literacy Essential Principles

OLFC – Ocean Literacy Fundamental Concepts

PMNM – Pacific Marine National Monuments

TNC – The Nature Conservancy

UWFWS – United States Fish and Wildlife Service

Introduction

The field of marine and environmental affairs is concerned with pressing issues in marine social-ecological systems. Topics addressed within the field include marine science and policy, specifically fishery management, marine recreation and tourism, marine debris, maritime commercial industries, coastal zone management, and education. While scientific research is crucial for our field, policy analysis and an understanding of the process of developing regulations are also important components. Now more than ever, there is a pressing need to not just regulate and create policy, but to effectively communicate ongoing scientific research and focus efforts on education. Developing a knowledgeable and engaged public is an important part of the ocean conservation and stewardship effort and being increasingly recognized by the community as a necessary part of the process. One of the champions of this cause, the Ocean Literacy Network, has a clearly defined goal of helping the general public become informed enough about the ocean to be able to make the connection between actions and their environmental consequences. This will hopefully inspire a culture of ocean literacy where positive behavioral change results due to increased knowledge, as opposed to change effected solely through regulation. The dissemination of ocean knowledge to a greater degree can be accomplished by increasing the amount of ocean science content taught in primary and secondary schools.

Increasingly ocean sciences are recognized viable content options for teaching science and environmental education. Ocean systems have been recognized as excellent examples for teaching the interconnectedness that exists in nature in traditionally taught sciences like biology, chemistry, and geology. Marine science education can happen in the field or in the classroom;

however it is not often used as an in-classroom option for teaching sciences. The extent to which ocean and aquatic sciences are being taught in the K-12 classroom is not sufficient to produce an ocean literate society. Barriers and challenges to increasing the frequency of marine science in the classroom have been identified in numerous studies. Meeting this challenge and increasing teaching of the subject requires collaboration between scientific and educational researchers and the development of more suitable curricula available for teachers.

Though perhaps not typically considered a major pillar of marine affairs, the campaign for increased marine education in the classroom features components that are hallmarks of the field: it addresses an issue relevant to both human and natural marine systems and requires an interdisciplinary approach involving science and social science. To that effect, the marine affairs community should embrace the dissemination of the ocean literacy principles as an important component in the quest for a future that contains healthy oceans and coasts.

Plan of the Thesis

This thesis is a review of the status of ocean literacy in the United States and presents newly designed lesson plans as an example of curricula appropriate for integrating ocean sciences into the secondary school classroom. The research seeks to gain a better understanding of the benefits to students of utilizing ocean specific examples and systems into traditional science, technology, engineering, and math (STEM) lessons. This study also provides a framework and examples of designing lesson plans that adhere to both Ocean Literacy Principles and the Next Generation Science Standards (NGSS).

Chapters 1 and 2 examine ocean literacy in the United States. Chapter 1 is an introduction to the concept of ocean literacy and why it is important. The formal development of the Ocean Literacy Fundamental Concepts and Essential Principles is also discussed. Chapter 2 is an examination of how those concepts and principles are being applied in the classroom. It gives an overview of barriers that prevent ocean sciences from being taught more frequently within primary and secondary schools and provides solutions to address those barriers.

The remainder of the thesis surrounds the development of a series of science lesson plans that address a variety of disciplines including oceanography, biology, chemistry, and technology. The lessons use the ecosystems of the islands and atolls that are part of Papahānaumokuākea, the Marianas Trench, the Pacific Remote Islands, and Rose Atoll Marine National Monuments to teach STEM subjects. Together, those four protected areas constitute the Pacific Marine National Monuments (PMNM). Chapter 3 provides background information on the MNM system and its management as well as information about each individual monument. Chapter 4 contains a pathway for a lesson development process in which the use the Ocean Literacy Principles and the scope and sequence frameworks are utilized as part of lesson design. It also discusses the educational pedagogy that supports the use of these types of lesson plans. Also part of this chapter is a summary of some of the lessons themselves featuring the systems from Papahānaumokuākea and the Pacific Remote Islands MNMs. Several complete lessons can be found in appendixes. The thesis concludes with recommendations and lessons learned from the research and development process. This work will benefit those in the field of education, both educators and policy makers, who seek to increase the frequency of ocean sciences taught in their classroom, school, or state. It will also benefit members of the marine affairs community who want to gain an understanding of the role of education in the field of marine affairs and in the bigger picture of ocean conservation.

1. Ocean Literacy in the United States

"The sea, once it casts its spell, holds one in its net of wonder forever."

- Jacques Cousteau

"Far and away, the greatest threat to the ocean, and thus ourselves, is ignorance. But we can do something about that."

- Dr. Sylvia Earle

1.1 How much do people really know about the ocean

The vastness of the ocean inspires wonder, sparks curiosity, and gives it an aura of power of invincibility. However, the ocean is not immune to degradation and the global ocean is in serious trouble. The most recent report by the Intergovernmental Panel on Climate Change identified and reemphasized melting ice, ocean acidification, sea level rise, and death of coral reefs as major issues that are affecting the ocean (IPCC, 2013). Marine debris and other forms of pollution are impacting water quality, coastal and open ocean ecosystems, and there has been unsustainable overexploitation of our marine resources (US Commission on Ocean Policy, 2004). Additional pressure is put on the oceans and coasts by the increasing global population; more than 1/3 of the world's population lives in coastal areas (UNEP, 2006). In the United States, 50% of the population lives within 50 miles of the shoreline despite the fact that it constitutes less than 25% of the country's land area (US Commission on Ocean Policy, 2004). Ocean degradation is not just a problem for the animal residents of the ocean or even humans that live on the coast. The global ocean covers roughly 70% of the Earth's surface and all life on Earth is dependent upon the services provided by the ocean. People specifically are dependent on the ocean and coastal systems for a variety of ecosystem services including food, water, carbon sequestration and climate regulation, tourism, and cultural and spiritual fulfillment (UNEP, 2006, Liquete et al., 2013).

Despite this inextricable tie between people and the ocean, the population of the United States in general has a poor understanding of this relationship and basic ocean processes (Steel, Lovrich, Lach, Fomenko, 2005(a); Plankis and Marrero, 2010; The Ocean Project, 2010). The public is concerned about the ocean yet possesses only superficial knowledge about it which renders them unable to connect their actions to negative impacts on ocean health (Steel, Smith, Opsommer, Curiel, Warner-Steel, 2005(b)). The lack of connection between an individual's actions and the environmental consequences is a huge hurdle for ocean conservation as the collective everyday actions of individuals are partially responsible for degradation of the marine environment (McKinley and Fletcher, 2010). In addition to the physical harm to the ocean caused by this lack of connection, garnering support for conservation initiatives and environmental policies to protect the ocean is hindered by the generally low level of knowledge.

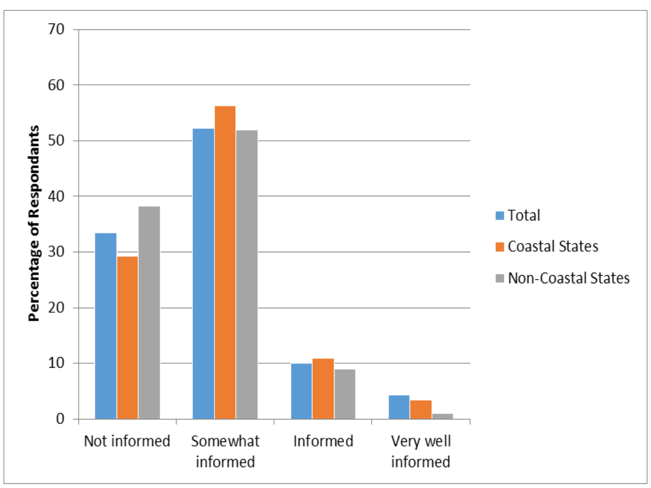

Figure 1. Results of survey asking how well informed people considered themselves to be concerning ocean and coastal issues. Original figure, data from Steel et al., 2005

Several national and regional surveys have highlighted this lack of understanding. A 2003 survey found that only 14.3% of Americans consider themselves to be informed or very well informed about ocean and coastal policy issues while the remained self-reported as somewhat informed or uninformed (Steel et. al, 2005(b), Figure 1). The same study contained two follow-up components: an additional survey where respondents answered if they "knew" a handful of scientific and ecological terms related to ocean science and management, and also a five question quiz to actually access knowledge. Out of 12 terms, people said they were familiar with an average of 5. Ecosystem was the most well-known term with 82.4% of people saying it was familiar, and the Magnuson-Stevens Fishery Conservation and Management Act was the lowest, only recognized by 5.1% of people. In the 5 question quiz the mean score was 2.23. For all three sections, respondents were grouped based upon where they lived into either the coastal state or non-coastal state group. While there was a statistically significant difference in the self-reported sections of the survey, there was no difference in the mean quiz scores between the two groups (Steel et. al., 2005(b)). A very similar study was conducted in 2002 of residents of Oregon and Washington and found analogous survey results (Steel et al., 2005(a)). Since 1999, the Ocean Project has conducted a series of national surveys focusing on public knowledge of a variety of ocean-related topics. A 2012 survey of the general public assessed their understanding of ocean acidification. Using a scale of 1 to 100 where 100 was complete agreement of a statement they found an average score for the general public of 14 in response to the statement "I have heard of ocean acidification" (The Ocean Project, 2012).

Further work by the Ocean Project reveals that people's feelings towards the ocean tend to fluctuate depending on current events. For all of the following responses the scale was set to 1 equaling strongly disagree and 100 equaling strongly agree. The mean response for 2009 to the statement "Protecting the Ocean should be a priority for the US government" was 52. However, in June 2010, shortly after the Deepwater Horizon oil spill the mean response jumped up to 72. The mean score for 2009 to the statement "I worry about the health of the world's ocean" was just 58, or slightly agree, and 68 for "My individual actions have little to no impact on the health of the ocean" (The Ocean Project, 2011). While the numbers seem slightly alarming by themselves, perhaps the piece of data with the biggest implications from The Ocean Project's series of surveys is evidence that suggests there has been no improvement in the public's awareness of major ocean issues since their initial report in 1999 (The Ocean Project, 2011).

1.2 The Connection between knowledge and environmental protection

The poor level of understanding of ocean processes and how they affect the earth has consequences. An engaged and educated public is necessary if there is to be real change to the current pattern of environmental degradation. It is impossible to understand the earth as a system and truly have an environmentally literate society without an understanding of ocean and aquatic concepts (Payne and Zimmerman, 2010). An environmentally literate, and specifically ocean literate public, is important when it comes to public participation in the ocean and coastal policy-making process. People cannot fully participate in their roles as citizens giving input into potential policy options if they lack the information and capacity to consider alternatives (Castle, Fletcher, and McKinley, 2010). In order to successful address the complex issues that threaten the ocean the U.S. Commission on Ocean Policy noted,

> …an interested, engaged public is essential. The public should be armed not only with the knowledge and skills needed to make informed choices, but also with a sense of excitement about the marine environment. Individuals should understand the importance of the ocean to their lives and should realize how individual actions affect the marine environment (p. 123, 2004).

In the previously referenced Ocean Project survey on ocean acidification, despite the initial lack of awareness of the issue, when people were prompted with a short explanation of the matter the score in response to “I am worried about ocean acidification,” increased dramatically compared to the unprompted answers. This and similar survey results with different questions suggest that it is a lack of knowledge rather than a lack of concern that is inhibiting an individual’s behavioral change with respect to their actions that affect the ocean. Evidence suggests the ocean has been allowed to slip to its current state not because people don’t care but because they don’t know (West, 2004/2005). Even amongst those who have a basic understanding of the issues, there remains a lack of urgency to take action. Though there is general support for ocean conservation the public feels little urgency about the issues the scientific community considers to be the most pressing (The Ocean Project, 2011).

If lack of knowledge concerning the ocean is contributing to its degradation, then one of the clear steps to improved ocean stewardship is education. Knowledge is crucial in developing an individual’s awareness of the ocean and the resources it provides (Steel et al., 2005(b)). There is a growing body of evidence supporting the importance of educating society if the goal is to change behaviors that negatively affect the ocean. Education is a necessary component to altering behavior which in turn affects the success and acceptance of environmental policy development and implementation (Castle et al., 2010). In addition to behavioral change associated with policy acceptance, increased knowledge about the marine environment is also linked to changes in behavioral patterns that benefit that environment (McKinley and Fletcher, 2010).

The scientific and policy-making communities are formally recognizing the role that education will play as they work to mitigate the negative anthropogenic effects on the ocean and increase ocean preservation. The US Commission on Ocean Policy (2004) considers education to be one of three essential actions that must be taken at a national policy level saying, “Formal and informal ocean education should be strengthened to better engage the general public, cultivate a broad stewardship ethic, and prepare a new generation of leaders to meet future ocean policy challenges” (p. 2). It also recognized that improved aquatic education is necessary for citizens to understand the impacts they have on oceans, coasts, and the Great Lakes and the role those bodies of water play in their lives. This improved knowledge base of everyday citizens is crucial and should be the first step taken on a national level in the work to protect the oceans (Steel et al., 2005(b)).

Though improving the level of knowledge for the entire population is important, emphasizing the importance of ocean and aquatic education in the K-12 system is especially crucial. If we are going to develop an ocean literate society our children must be included. While children in school today are not decision-makers in environmental management, they will soon be voting members of society. An escalation of marine environmental education would lead to higher levels of awareness and hopefully concern about the marine environment. This may eventually result in the formation of a sense of marine citizenship amongst youth (McKinley and Fletcher, 2010). The potential impact of educating teens on environmental issues goes beyond just their personal knowledge level as older relatives seek their advice on environmental issues. Of all the age groups surveyed, today’s teens have the highest level of confidence in their ability to make a difference in our environment (The Ocean Project, 2011). However, without more targeted ocean education programs or curriculum in our schools, the amount children and teens understand about the ocean is going to continue to be below the optimal level.

Not surprisingly, the few studies on ocean literacy in the classroom have shown that students that participate in classroom programs focused on ocean education see an increase in ocean literacy (Lambert, 2006; Plankis and Marrero, 2009). Though the increase is encouraging, the typical baseline level of understanding concerning ocean issues in these studies was low. The two schools in Marrero's study were located less than 10 miles from the nearest bay yet 35% of students responded to a survey question about how the ocean affects them saying either "it doesn't affect my life" or "I don't know." Across the different student populations that participated in their two studies, Plankis and Marrero identified 3 common themes: "1) initial interest but low knowledge levels about the ocean, 2) low awareness of the urgency of ocean issues, and 3) student-reported interest in behavior changes to protect the ocean" (p. 32, 2009). Perhaps most importantly, these studies suggest that the ocean literacy focused curriculum may lead to students modifying behaviors that could be harmful to the ocean.

Increased ocean education in schools does not only benefit the ocean. Many studies have shown the benefits to students of using ocean and other environmental examples when teaching science. Studies have shown a positive correlation between environmental education and student performance, and that using the environment as part of instruction led to better understanding of science content and processes, as well as improved problem solving abilities (Leidermann and Hoody, 1998; Parlo and Butler, 2007). Teaching scientific concepts as part of a system has been recognized in the educational community as a more effective way of teaching students compared to using stand-alone concepts (NRC, 1996). The ocean lends itself well to the systems approach as the disciplines of biology, geology, and chemistry can all be taught using ocean examples.

Ocean systems naturally provided coherence that, when used in science courses, can help students reach higher levels of scientific literacy and understand complex systems (Fortner, Coreny and Mayer, 2005; Lambert, 2006)

1.3 The Ocean Literacy Movement

Recognizing the need to improve understanding of the ocean and address the lack of ocean-related concepts in education standards and curriculum, a group of educators and scientists collaborated to define ocean literacy and outline what they believe a person needs to know in order to be ocean literate. Groups involved in this process included the National Geographic Society, Centers for Ocean Sciences Education Excellence (COSEE), the National Marine Educators Association (NMEA), and the National Oceanic and Atmospheric Association (NOAA). Through a two-week long workshop in 2004, they reached a consensus and defined ocean literacy as "an understanding of the ocean's influence on you—and your influence on the ocean" (Cava, Schoedinger, Strang, and Tuddenham, 2005). This same group also created the Essential Principles and Fundaments Concepts of Ocean Literacy. The goal of the ocean literacy campaign is to have people reach the point where they "understand the Essential Principles and Fundamental Concepts about the ocean; can communicate about the ocean in a meaningful way; and are able to make informed and responsible decisions regarding the ocean and its resources" (COSEE et al, 2013). Though there have been additions and updates to the Ocean Literacy materials, from the beginning Cava et al. (2005) have defined the Essential Principles as:

1. The Earth has one big ocean with many features.
2. The ocean and life in the ocean shape the features of the Earth.
3. The ocean is a major influence on weather and climate.
4. The ocean makes the Earth habitable.

5. The ocean supports a great diversity of life and ecosystems.
6. The ocean and humans are inextricably interconnected.
7. The ocean is largely unexplored.

Expounding upon these 7 Essential Principles are the 44 Fundamental Concepts that provide components that are crucial to the full understanding of each principle. These principles are a guide to give teachers an idea of what ocean topics they should be teaching and to also to help them understand how ocean science education can be used to meet state or national science standards. The establishment of these principles and an agreed upon definition of ocean literacy provided a solid foundation for the ocean literacy movement, but there will not be success in achieving the goal of an ocean literate society until ocean sciences are integrated into all types of educational components like standards, research, curricula, and assessments (Tran, Payne, and Whitley, 2010). The entire Ocean Literacy Guide can be found at http://oceanliteracy.wp2.coexploration.org/brochure/.

2. Ocean Literacy in the K-12 Classroom

> "School curricula, starting in kindergarten, should expose students to ocean issues, preparing the next generation of ocean scientists, managers, educators, and leaders through diverse educational opportunities."
>
> - U.S. Commission on Ocean Policy

2.1 Barriers to Ocean Education in the Classroom

Despite the demonstrated need and benefits of increased ocean education in the K-12 classroom, many barriers to its implementation or increased frequency in the classroom still exist. Ocean sciences have been shown to be poorly represented in national and state education frameworks and standards (Walker, 2000; Schoedinger, Cava, Strang, and Tuddenham, 2005; Hoffman and Barstow, 2007). Since these standards typically drive curriculum choices, the result is that ocean sciences are frequently overlooked as a vehicle to teach science in the classroom (Tran et al., 2010). If a subject is not already in the existing curricula it faces an uphill battle to be included. In an educational realm where results are increasingly based on metrics it is difficult to introduce new material, especially considering most teachers are already strapped for time (Boxall, 2013). While the scope and interdisciplinary nature of marine and coastal subjects allows it to be taught relatively easily to meet general standards, it means that the subjects can be easily disregarded as well (Castle et al., 2010).

In addition to being overlooked in science standards, a hurdle for ocean science in the classroom is that a large portion of science teachers lack knowledge of ocean and aquatic topics (Nowell, 2000; Parlo and Butler, 2007; Eidietis and Jewkes, 2011). Lack of time and resources hinders them from learning more once already established as classroom teachers. Studies suggest that these teachers feel they are not qualified or are not confident in teaching ocean content (Parlo and Butler, 2007). Though standards and administrators have input on what is taught, ultimately it is the teachers that are making the curriculum and content decisions for their classroom (Porter, 2002). In addition to content knowledge, teachers dispositions towards science and pedagogical knowledge of teaching environmental issues affect their decision to include ocean and aquatic science instruction in their classroom (Kim and Fortner, 2006; Eidietis and Jewkes, 2011). Eidietis and Jewkes (2011) found that teachers' feelings of preparedness to teach ocean literacy was significantly related to the frequency of which it was taught and that attitude toward ocean science had a marginally significant relationship with frequency (Figure 2).

	Statistic	Preparedness to teach ocean literacy	Attitude toward ocean science
Frequency of teaching ocean literacy[1]	n	79	80
	r	0.35	0.23
	p	0.001[2]	0.041[2]
Preparedness to teach ocean literacy[1]	n		83
	r		0.30
	p		0.006[2]

[1]Composite scores were square-root transformed.
[2]Statistical significance at the $p < 0.05$ level.

Figure 2. Statistical results of teachers' preparedness and attitude compared with frequency ocean literacy it taught. From Eidietis and Jewkes, 2011.

The fact that ocean sciences have historically been infrequently taught in the K – 12 classroom contributes to today's teachers, products of those classrooms, possessing low levels of ocean science knowledge and associated feelings of lack of preparedness to teach ocean content. However, studies suggest that it is also due to the fact that few who study ocean sciences at an undergraduate level go on to enter the educational field. A study comparing the employment field post-graduation between recipients of bachelor's degrees in physics and ocean sciences found that 10% of those who studied physics went on to teach at the high school level while less than 1% of those who studied oceanography went into teaching (Nowell, 2000). This may explain why more teachers do not bring pre-existing ocean science knowledge to their classrooms. However, if there was more ocean sciences taught in the K-12 classroom, this may help to give more future teachers some exposure to and a basic foundation in ocean sciences even if they do not pursue them at a university level. This could potentially help with a teacher's comfort level with the subject or make it seem more accessible as a potential teaching topic.

Kim and Fortner (2006) investigated how the level of pedagogical knowledge, in addition to attitude, affected the level of teaching environmental education. Environmental education has been defined as education dedicated to the fostering of knowledge of ecology, the environment, and environmental issues, the results of which produce an environmentally literate society motivated to solve environmental problems (Fortner, 2001; Parlo and Butler, 2007). Ocean literacy content and goals fit within the definition and field and environmental education, as well as being part of the general field of science. Respondents in Kim and Fortner's study (2006) said that they believed external issues and logistical barriers like lack of time and adherence to curriculum standards were greater hurdles than personal barriers like content and pedagogical knowledge. However, Kim and Fortner (2006) found that the level of pedagogical knowledge was more strongly correlated to the level of environmental education being taught than the external barriers identified by the teachers. It is realistic to believe that both of these issues contribute strongly to the challenges of teaching environmental education.

Another issue is communication between the research community and the educational community. There is a need to bridge current research results and K–12 appropriate interpretations of those data, a process complicated when teachers do not possess the background and training to feel confident interpreting the data themselves (Walker, Coble, and Larkin, 2000). That bridging process would be greatly helped by having scientists dedicated to distilling results for educational purposes. Other barriers to teaching marine science in the classroom have been identified as lack of hands-on scientific experiments and instructional materials, lack of time and resources, and unsupportive school management (Walker et al., 2000; Kim and Fortner, 2006; Castle, 2010). Time is an issue when teachers consider learning new content or developing new lessons but also because science instruction time is limited. A survey of U.S. K–8 teachers found that the average amount of science instruction per week was 98 minutes, or just about 20 minutes per day (Banilower, Heck, and Weiss, 2007).

2.2 Ocean Literacy and Education Standards

As our education system becomes increasingly focused on standards based teaching, the lack of ocean sciences in national and state science standards has become a larger challenge for implementing ocean sciences in the classroom. The literature frequently recognizes that ocean and aquatic sciences are overlooked in K-12 state and national science standards (Hoffman and Bartow, 2007; Castle, 2010) and that incorporation of ocean literacy concepts into standards that are being revised or newly developed should be a primary goal of those campaigning for ocean literacy (Cava et. al, 2005).

In an assessment of the earth science standards for all 50 states, Hoffman and Barstow (2007) examined how well standards addressed a variety of scientific topics and teaching methodologies including ocean literacy.[1] Hoffman and Barstow did a close reading of the science standard documents and ranked each standard as directly, indirectly, or failing to address each content category (Figure 3). The seven states with the highest level of recognition of ocean literacy concepts in their standards addressed 16 to 20 of the 35 concepts while 3 states did not address any. The national mean was 9.6 concepts addressed, however the majority of these recognitions were categorized as indirect. Only 11% of the standards classified as addressing ocean literacy principles were categorized as addressing them directly. They noted that their results, "…point to a disconnect between the pressing need for an Earth system literate society and the current K-12 education system that is responsible for developing this capacity" (Hoffman and Barstow, 2007 p. 6).

Grade	Indicator	Example Standards
Directly (D)	• Statements directly articulate or refer to two or more major components of the specific review criteria. • Direct statements span multiple grade levels. • Major concepts of review criteria progressively developed over the K-12 grade span	1) Describe how organisms on Earth contributed to the dramatic change in oxygen content of Earth's early atmosphere. (Ohio) 2) Describe the use and benefits of land based light telescopes, radio telescopes, spectrophotometers, satellites, manned exploration, probes, and robots to the study of Earth Space Science. (New Hampshire)
Indirectly (I)	• Statements can be interpreted to include one or more components of the specified review criteria, but do not directly mention the major components of the specific review criteria. • Statements span more than one grade level.	1) Describe how Earth's atmospheric composition has changed from the formation of the Earth through current time. (Mississippi) 2) Explore past, present, and future space technology. (Arkansas)
Fails (F)	• Statements addressing the review criteria are absent from standards or so generalized that review criteria cannot be assumed to be addressed by the standards. • Statements found only at one grade level.	

Figure 3. Grading rubric used by Hoffman and Barstow in their 2007 assessment of state science standards.

[1] Since the study was commissioned to examine the status of earth sciences, Ocean Literacy Essential Principle 5 – *the ocean supports a great diversity of life and ecosystems* – was not included in the assessment since it addresses only biological concepts.

2.2.1 Washington State Standards Assessment

Since the initial study by Hoffman and Barstow in 2007, the state of Washington has revised its state science standards. The current version, 1.2, was completed and released in 2010 and entitled “Washington State K-12 Science Learning Standards.” The science standards are organized by categories called Essential Academic Learning Requirements (EALRs). The four EALRs are Systems, Inquiry, Application, and the Domains of Science which is further broken down into Physical Science, Life Science, and Earth and Space Science. Other components included in each standard include a summary of the core content, content standards, and performance expectations (Appendix A). Using the methods established by Hoffman and Barstow (2007), the new Washington State science standards were assessed to account for recognition of ocean literacy principles into the standards design. The original study found that more recently revised standards addressed slightly more concepts on average compared to those that had not been revised recently, addressing an average of 10.7 and 8.8 respectively. It might be expected that Washington’s newer standards would reflect this trend. This assessment is valuable as a comparison to the established baseline and provides insight into the current representation of OL in the Washington standards.

Hoffman and Barstow note in their study that there is inherently some subjectivity to this methodology. Their previous grades and examples, available online, were used as guidelines in an attempt to stay as faithful to their ranking system as possible. The same grades were given to standards: directly, indirectly or fails. This study looked at all science standards and essential principles and will make it clear when comparing years if the numbers include all sciences or just earth sciences. In addition to the close reading of the standards and evaluation using Hoffman and Barstow's methods, this study conducted a key word search using the words "ocean," "local," and "environment." These keywords were selected in recognition that for many students in Washington studying the local ecosystems or environment would include the Pacific Ocean or Puget Sound and thus ocean issues may be addressed with those standards despite the fact that it does not otherwise reference ocean literacy principles.

Washington's previous earth science state standards, written in 2005, fell just below the national mean of 9.6, addressing 9 of the fundamental concepts of ocean literacy. When only the earth science standards were compared the 2010 standards did just slightly better than 2005 (Figure 4). Though only one more standard is addressed, there was a shift towards addressing the concepts more directly. When all the EALRs, as opposed to just earth science, were assessed 15 standards were found to directly or indirectly address OL fundamental concepts (Figure 5). Ocean literacy concepts were most well recognized in the earth science EALR and the ocean is explicitly mentioned as part of Earth Systems in an introductory breakdown of that EALR. There are a few Life Science standards that indirectly address OL concepts. Particularly with

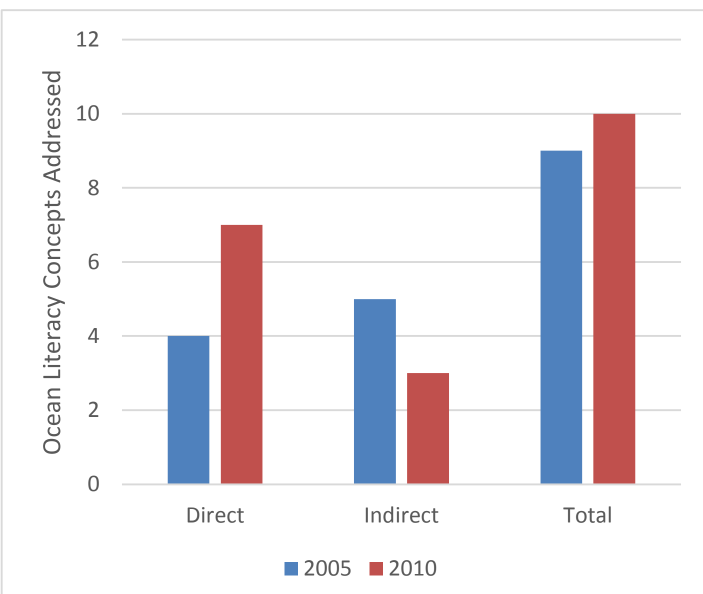

Figure 4. Comparison of Washington Earth Science Standards that address Ocean Literacy Concepts

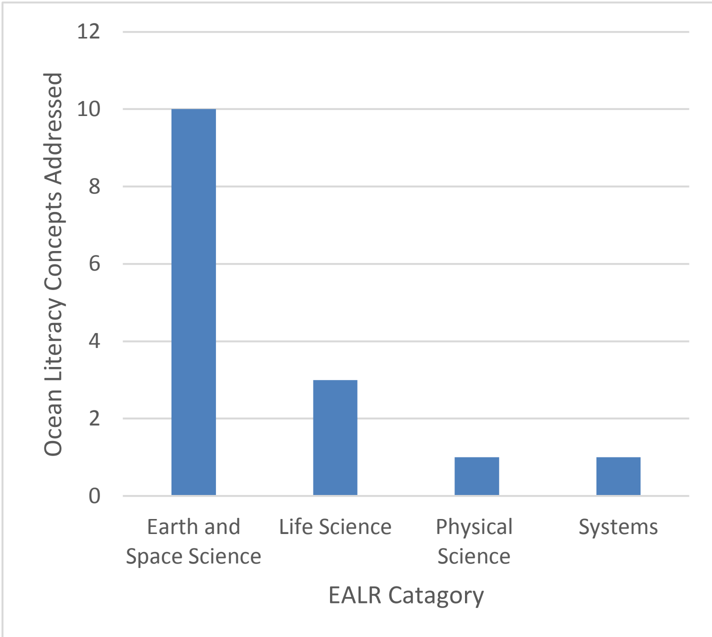

Figure 5. Breakdown of concepts addressed by EALR category.

the Life Science standards, ocean ecosystems examples would satisfy many standards but they are phrased in ways that do not distinguish ocean examples from any others. For example, one of the grade 9-11 Life Science Content Standards is,

> Carbon-containing compounds are the building blocks of life. Photosynthesis is the process that plant cells use to combine the energy of sunlight with molecules of carbon dioxide and water to produce energy-rich compounds that contain carbon (food) and release oxygen (LS1A, p. 98).

Phytoplankton's use of sunlight to undergo photosynthesis and how that contributes oxygen to the ocean environment would be an excellent context option to explain this subject. However, there are many terrestrial examples that are quite good as well. It is in these types of situations that ocean literacy awareness can be helpful so teachers at least consider ocean examples as opposed to only thinking of terrestrial ones. The second part of this assessment, the keyword search, found two additional standards where Washington teachers might be encouraged to use ocean examples based upon the word "local." Two 6-8 grade life science standards prompt the use of the local environment to analyze the flow of a food web or investigate an environmental issue. For the schools near the coast or Puget Sound this could easily include ocean and aquatic issues.

2.2.2 Ocean Literacy in the Next Generation Science Standards

The Next Generation Science Standards (NGSS) were recently developed in a collaborative process involving 26 states, the National Science Teachers Association, and Achieve, Inc. The foundation for the standards was a document created by The National Research Council (NRC) entitled, *A Framework for K-12 Education,* initially released for public comments in July 2010 and a final version published July 2011. The point of the framework was to identify the science that all K-12 students should understand and to use current science and education research as the base of this foundation. The NGSS were then developed with the goal of creating standards that would provide students a science education that would prepare them for college and make them internationally competitive. After the creation of the NGSS, they were reviewed by the NRC to ensure the standards remained faithful to the vision outlined in the framework.

The Ocean Literacy community was very active in the process of ocean sciences represented in the NGSS. The draft implementation plan for the *National Policy for the Stewardship of the Ocean, Our Coasts, and the Great Lakes* even includes the milestone, "Include ocean content in the Next Generation Science Standards" (National Ocean Council, 2012, p. 24). While the final implementation plan is not specific about its education goals, it does include the increasing of ocean and coastal literacy as a goal (National Ocean Council, 2013). The Centers for Ocean Science Education Excellence (COSEE) and the National Marine Educators Association (NMEA) contributed lengthy comments on the draft of NGSS and encouraged the inclusion of ocean sciences in the standards just as they had been recognized in the framework. It is important to note that the Ocean Literacy community is not seeking additional standards that recognize the ocean but as Craig Strang, NMEA president, wrote in an open letter to the state teams contributing to the final version, “The goal of this effort is to adjust the core disciplinary ideas in NGSS so that they reflect the true complexity of the natural world, including the tremendous influence of the ocean on living things, Earth systems and Earth processes” (2012).

The official Ocean Literacy Guide previously contained a matrix showing how the Essential Principles and Fundamental Concepts aligned with the National Science Education Standards. Since the release of NGSS that has been removed and an updated form showing connections between NGSS and the components of ocean literacy will be completed late spring to early summer 2014. The input of COSEE, NMEA, and the whole ocean literacy community is evident in the NGSS and they seem pleased with the results (NMEA webinar, 2014). The format of the standards themselves makes teaching ocean sciences easier as a systems approach and the interactions present in the natural world are recognized explicitly. The language used in NGSS is also similar to that used in the Ocean Literacy Guide (Figure 6). This recognition by no means solves the pervasive lack of ocean sciences in classrooms around the country, and the fact that they are included in the NGSS does not mean ocean sciences will suddenly increase in frequency in classroom lessons. However, it is a step in the right direction that will hopefully help to reduce one of the barriers to ocean and aquatic education.

Disciplinary Core Ideas

ESS2.A: Earth Materials and Systems

- Earth's major systems are the geosphere (solid and molten rock, soil, and sediments), the hydrosphere (water and ice), the atmosphere (air), and the biosphere (living things, including humans). These systems interact in multiple ways to affect Earth's surface materials and processes. The ocean supports a variety of ecosystems and organisms, shapes landforms, and influences climate. Winds and clouds in the atmosphere interact with the landforms to determine patterns of weather. (5-ESS2-1)

ESS2.C: The Roles of Water in Earth's Surface Processes

- Nearly all of Earth's available water is in the ocean. Most fresh water is in glaciers or underground; only a tiny fraction is in streams, lakes, wetlands, and the atmosphere. (5-ESS2-2)

Ocean Literacy Principles and Concepts

1E. Most of Earth's water (97%) is found in the ocean.
3. The ocean is a major influence on weather and climate.
2E. Tectonic activity, sea level change, and the force of the waves influence the physical structure and landforms of the coast.
5. The ocean supports a great diversity of life and ecosystems.

Figure 6. Disciplinary core ideas from NGSS 5th grade earth's systems standards and the ocean literacy principles and concepts touched upon. Disciplinary core ideas figure from NGSS, Achieve, Inc. 2013.

Yet, the adoption of NGSS will not be without controversy. Despite the fact that states were part of the development process Wyoming recently became the first state to reject the standards because the state legislature disagrees with the global warming components (Moen, 2014). Washington, on the other hand, has decided to adopt NGSS. The Office of the Superintendent of Public Instruction Teaching and Learning Science Program has published a transition plan for the elementary school levels that phases in NGSS over a four year period. Plans for the middle and high school levels are pending, but given the probable timeline, the current standards will continue to be the major influence on curricula for many more years.

2.3 Increasing Ocean Literacy in the K-12 Classroom

As the hurdles to increasing the teaching of ocean science in the classroom are better understood, the educational and scientific community can better address and respond to the challenges. In a webinar discussing the new standards, key members of the Ocean Literacy campaign commented that they felt the NGSS better recognize ocean literacy concepts than previous standards (13 March, 2014). However, their perspective is one of a group very familiar with the ocean literacy concepts. While people familiar with the OLEP and OLFC can read a standard and recognize the connection, a teacher just learning the new standards may not make that connection unaided. There needs to be some clear communication from the Ocean Literacy Network to the broader educational community about how ocean sciences can satisfy standards. It is clearly far easier to communicate how ocean sciences satisfy one set of standards rather than those of each state, though it will take time for the NGSS to be phased in and approved by states. Ultimately, the Ocean Literacy Network needs to be a positive force to influence a teacher's choice to teach ocean topics because there are many potential subjects that satisfy the new standards.

Outside of the issues related to standards, there are other actions that can be taken to increase ocean science education in the classroom (Table 1). Teachers' knowledge and comfort level with the subject needs to be improved. This can be accomplished by encouraging students who study oceanography to go into education and increasing the resources and learning opportunities for current teachers who want to increase their knowledge of the ocean. In addition to supporting learning opportunities for teachers, the existence of current resources needs to be better promoted. Though there are not as many resources as there should be, the awareness of the existing resources is low (Heimlich, Braus, Olivolo, McKeown-Ice, and Barringer-Smith, 2004). Specific content knowledge, in addition to training in environmental education pedagogy, is needed for teachers to feel adequately prepared to teach complex environmental issues (Kim and Fortner, 2006). That content knowledge cannot be attained without either a personal background in the subject or adequate resources. Without the appropriate content and pedagogical knowledge, teachers will be unlikely to engage their students in ocean and aquatic sciences and associated behaviors of environmental stewardship (Payne and Zimmerman, 2010).

Table 1. Summary of barriers and solutions for increasing the teaching of ocean sciences and ocean literacy principles in the K-12 classroom.

Barriers	Solutions
Ocean science is not recognized in education standards or formal assessments	• Advocate for adoption of Next Generation Science Standards • Push for integration into other science standards and assessments as updated • Make it clear to teachers how ocean science content satisfies existing standards
Teachers have a lack of knowledge or comfort with the subject matter or understanding of appropriate pedagogy	• Encourage more people who study ocean or aquatic sciences to go into teaching • Teacher workshops or other initiatives to expose existing teachers to ocean sciences • Communicate current research in formats that is already distilled for a K-12 audience and easier for teachers to use
Lack of ocean science curricula or hands on experiments	• Develop ocean science curricula that meets standards and clearly communicate how it satisfies them
Teachers have little understanding of the importance ocean literacy to their students so there is no motivation to teach the subject	• Continue to publicize the ocean literacy principles and their importance • Increase research about ocean literacy in classrooms • Make it clear how understanding ocean sciences is part of understanding overall earth systems

Resources for teachers need to go beyond learning opportunities. Scientists or educators who have a background in marine science need to produce suitable curricula that are available to teachers that contain explanations of how they meet educational standards. This helps address the issues of lack of time for teachers to develop lessons on new subjects and the need to teach to the established standards. The scientific community could also increase communication of available real-time oceanographic data for use in the classroom. The use of real-time data provides authenticity and connects the classroom to the outside world (Adams and Matsumoto, 2009).

Ultimately, the ocean literacy community needs to communicate to K-12 educators the importance of teaching ocean sciences and the positive benefits of an ocean literate society.

3. The Pacific Marine National Monuments

> "Where there's life there's hope, and so no place can inspire more hopefulness than the great, life-making sea, home to creatures of mystery and majesty, whose future now depends on human compassion and our next move."
>
> -Carl Safina

In order to address one of the identified challenges associated with increasing ocean science in the classroom, this study produced a series of marine science lesson plans that are focused on the environments of the Pacific Marine National Monuments. The Pacific Marine National Monuments provide an excellent platform for scientific research as well as for science education for younger students due to their biodiversity, high levels of endemism, unique geological features, and relatively pristine nature. The Pacific Marine National Monument system (PMNM) consists of four national marine monuments: Papahānaumokuākea Marine National Monument, the Marianas Trench, the Pacific Remote Islands, and Rose Atoll (Figure 7).

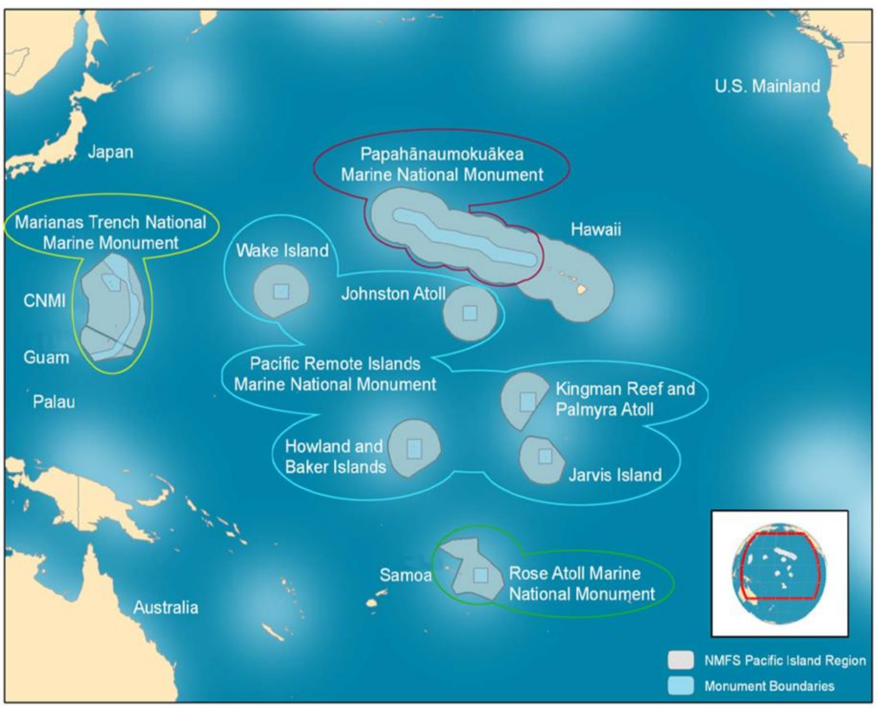

Figure 7. Map of the Pacific Marine National Monuments.
From http://www.fpir.noaa.gov/Library/MNM/eez_monument_4_6_2011.pdf

Papahānaumokuākea was established in 2006 and the rest were created in 2009, all the result of Presidential Proclamations. The simultaneous creation of the Marianas Trench, Pacific Remote Islands, and Rose Atoll MNMs was the largest act of marine conservation in history (NOAA).

A primary difference between the National Marine Monuments and the National Marine Sanctuaries is the law under which they were established. Two laws have been used to create marine reserves in the United States, the National Marine Sanctuaries Act of 1972 and the Antiquities Act of 1906. The National Marine Sanctuaries Act (NMSA) authorizes the Secretary of Commerce to "Identify and designate as national marine sanctuaries areas of the marine environment which are of special national significance and to manage these areas as the National Marine Sanctuary System" (NMSA, SEC. 301. [16 U.S.C. 1431]). The shipwreck of the Civil War vessel the USS Monitor was designated the first national marine sanctuary in 1975 and since then 12 additional marine sanctuaries have been established. The National Marine Sanctuary system is managed by the Office of National Marine Sanctuaries, a division of NOAA. The National Marine Monuments were created by President G.W. Bush under the Antiquities Act of 1906. The Antiquities Act gives the President the authority to,

> …declare by public proclamation historic landmarks, historic and prehistoric structures, and other objects of historic or scientific interest that are situated upon the lands owned or controlled by the Government of the United States to be national monuments, and may reserve as a part thereof parcels of land, the limits of which in all cases shall be confined to the smallest area compatible with proper care and management of the objects to be protected (16 USC 431-433).

There is an extensive process of engaging the public, stakeholders, and public review associated with the designation process under the NMSA, but the Antiquities Act has no public process requirement. Despite this difference the end goals, to protect and manage an area for conservation, are the same.

While each of the monuments and the atolls and islands that make up the monuments are unique, collectively they represent some of the most pristine coral reefs and tropical ecosystems remaining in the world. All together, the 4 monuments encompass 330,000 square miles of the Pacific which is more than all the national parks combined (NOAA). The Mission Statement for the Marine National Monument Program is,

> Understand and protect the unique natural and cultural resources within the Marine National Monuments through the advancement of scientific research, exploration, and public education (NOAA).

The MNMs are under a mixed management system; any emergent land and waters out to 12 miles are part of the National Wildlife Refuge System and 50 miles from shore constitutes the marine monument boundary. They are jointly managed by the U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration, and depending on the monument, additional state or territorial governmental agencies.

Just as the public's general level of knowledge of the ocean is fairly low, so is their knowledge of marine protected areas. Though the Ocean Project did not specifically ask about marine national monuments, only 16.7% of U.S. adults reported to having heard of national marine sanctuaries while 96.2% said they had heard of national parks (The Ocean Project, 2010). The marine sanctuaries and monuments would benefit from more exposure so people better understand the role of protected areas in marine conservation. The Marine National Monument Program explicitly lists, "Increasing stakeholder awareness, engagement, and support for the Marine National Monuments" as one of their goals (NOAA) and given the nod to education in the mission statement, well designed lesson plans can advance the NOAA's goals and increase ocean literacy.

3.1 Papahānaumokuākea MNM

Papahānaumokuākea Marine National Monument is the largest conservation area within the United States. The name comes from the names of two Hawaiian ancestors, Papahānaumoku and Wākea, whose union created the Hawaiian Islands and the Hawaiian peoples. It was established in 2006 and in addition to its national monument status it has also been declared a natural and cultural World Heritage Site by UNESCO. The establishment of the national monument combined several existing conservation areas into one entity and added additional waters. The monument encompasses 139,797 square miles and extends northwest for 1,200 nautical miles starting north of the island of Kaua'i. In addition to the agencies managing the MNMs, the state of Hawaii and the Office of Hawaiian Affairs are involved in the management of Papahānaumokuākea. The vision and mission for the monument includes protecting the ecosystem and natural systems as well as the cultural resources and Native Hawaiian culture connected to the islands.

Though the majority of the monument is open ocean and submerged reef, there are a handful of atolls and islands with emergent land. Its remote location and historically low level of human impact has left Papahānaumokuākea MNM in a relatively pristine condition providing excellent habitat for resident species and a unique environment for scientists to study and to better understand how humans are affecting coral reef ecosystems elsewhere. This monument is home to over 7,000 marine species and has a very high level of endemism with roughly ¼ of those species found only in the Hawaiian Archipelago (NOAA). Several endangered and threatened species reside in the waters of the monument including the Hawaiian monk seal, green sea turtle, and the Laysan duck. There are also Native Hawaiian cultural sites on the islands of Nihoa and Mokumanamana.

The NWHI have been the focus of lots of scientific research and the high levels of endemism are frequently noted (Friedlander et al., 2009; Fautin et al., 2010). Recent dive surveys report that 46% of reef fish in the NWHI are endemic. Endemism appears to vary with latitude as well, at the southern end of the islands there was 16% endemism ranging up to 92% at the northern extent of the chain (Kane, Kosaki, and Wagner, 2014). Another feature frequently noted is the apex predator dominated food web, a feature not seen in coral reefs in less pristine condition (Sandin et al. 2008; Friedlander et al., 2009).

3.2 Pacific Remote Islands MNM

The Pacific Remote Islands MNM (PRIMNM) consists of seven atolls and islands: Howland, Baker, and Jarvis Islands, Wake, Palmyra, and Johnston Atolls and Kingman Reef. These islands are farther from a population center than anywhere else in the United States (NOAA, 2014). Baker, Howland and Jarvis are low coral islands that were claimed by the United States in 1856 under the Guano Act (USFWS, 2012). These islands are characterized by localized upwelling due the Equatorial Undercurrent which supports high productivity, fish biomass, seabirds, and top predators. The recovery of the seabirds has been the subject of research following the removal of feral cats from each of the islands. Scientists have seen the return of several species of extirpated seabirds on all three islands in the years following cat eradication (Rauzon, Forsell, Flint, and Gove, 2011).

Johnston Atoll is the northernmost of the Line Islands and extremely isolated. The U.S. also claimed it under the Guano Act; however the atoll was also claimed by the Kingdom of Hawaii. It was actively used during WWII as a refueling base and was home to a U.S. Air Force base which was closed in 2004. Biologically, Johnston has been identified as a connection between the Hawaiian and Line Islands (Friedlander at al., 2009, Fautin et al., 2010). Wake Atoll is the northernmost atoll of the Marshall Islands and one of the oldest living atolls in the word. Wake also has a history of military activity and was actually taken over by the Japanese from 1941-1945.

Palmyra Atoll is the only one of the group that has any human presence besides the occasional research or management visit. Palmyra was also a military base in WWII; roughly 6,000 men were stationed there at one point. It eventually was sold by Hawaii to a private family which sold the atoll to The Nature Conservancy (TNC) in 2000. TNC then sold most of the island to the U.S. Fish and Wildlife Service and the atoll is now jointly managed between the two groups. TNC maintains a small research station on one of the islets that make up Palmyra. Because of that research station, the atoll, lagoon, and surrounding reef at Palmyra have been the subject of much scientific research. The spread of an invasive species of corallimorph in an area of reef has been investigated and traced to a shipwreck on the western shelf of the reef (Work, Aeby, and Maragos, 2008). This was the first time a perceived phase shift on a coral reef could be attributed to a human structure and recently led to the removal of the shipwreck.

Palmyra has one of the largest remaining stands of *Pisonia grandis,* a tropical tree, and is an important nesting and feeding ground for birds. It has some of the largest colonies in the world of red-footed boobies and black noddies (TNC, 2013). It is also home to the endangered coconut crab, the world's largest land invertebrate, manta rays, giant clams, and sea turtles. Kingman reef is located roughly 36 nautical miles northwest of Palmyra and is the most undisturbed coral reef in the U.S. Unlike the other islands and atolls in the group, Kingman is a mostly submerged reef with no permanent land and the small bits of emergent coral rubble and sand typically awash. It has a large population of giant clams and an extremely high number of apex predators. 85% of the fish biomass is composed up of apex predators like sharks and jacks (FWS, 2012).

3.3 Marianas Trench MNM

The Marianas Trench MNM is located in the waters of the Marianas Archipelago and is divided into three units: the islands, trench, and volcanic units. In addition to NOAA and the USFWS, the Department of Defense and Government of the Commonwealth of the Northern Marianas Islands also assist in the management of the monument. This monument is more geologically focused than the others and a slightly complicated management regime concentrates on the submerged lands rather than the waters. The Islands unit includes the water and submerged lands of the three northernmost Mariana Islands, the Volcanic Unit includes submerged lands within 1 mile of the designated volcanic sites, and the Trench Unit includes the submerged lands that extend from the northern boundary of the U.S. exclusive economic zone (EEZ) associated with the Marianas Islands to the southern boundary of the EEZ surrounding Guam (USFWS, 2012).

The Marianas Trench is the deepest ocean canyon on earth, deeper than Mount Everest is tall and five times longer than the Grand Canyon. Several features in the Volcanic Unit are extremely rare including the Champagne Vent, one of only two known sites on earth that produces almost pure liquid carbon dioxide. The Daikoku submarine volcano has a pool of liquid sulfur, the only other location this is known to exist is on one of the moons of Jupiter (USFWS, 2012). There are incredible diverse and fish and coral communities within the Islands Unit and the Maug crater is one of the few places recorded where photosynthetic and chemosynthetic communities coexist.

There are vents on the northeast side of the carter that spew acidic water; how the coral reefs nearby respond to this acidity is giving scientists insight into ocean acidification (USFWS, 2012). The entire monument is not yet well studied and has the potential to provide insight into many not yet well understood systems like hydrothermal vents.

3.4 Rose Atoll MNM

Rose Atoll is the easternmost Samoan Island and one of the smallest atolls in the world. Located 130 nautical miles ESE of Pago Pago, American Samoa, it is the southernmost land and associated waters controlled by the United States. The monument is co-managed by NOAA, USFWS, and the government of American Samoa. The reef is distinctive from the other islands in Samoa and dominated by crustose coralline algae that give the reef a pink hue. Similarly, the reef fish communities are distinct from the rest of Samoa with a high number of small, planktivorous species represented in the 270 identified fish species. Green and hawksbill sea turtles nest on the atoll and several species of cetacean, humpback whales, pilot whales, and dolphins, have been seen at the atoll as well (USFWS, 2012).

While all of the islands are natural laboratories, Rose Atoll has subject to monitoring and research not only of its natural systems, but how they respond to human disturbance. A 120-foot longline fishing vessel, F/V *Jin Shiang Fa*, ran around on the atoll in 1993 causing physical damage to the reef and spilling 100,000 gallons of diesel and 2500 pounds of ammonia. While some of the ship was removed soon after the grounding, the rest was removed between 2004 and 2007 and the US Fish and Wildlife Service will be monitoring the reef recovery until 2017 (USFWS, 2012).

4. Developing Curricula using Ocean Literacy Principles: Lesson plans from the systems within the Pacific Marine National Monuments

> Agencies will contribute to opportunities for systematic inclusion of ocean topics and concepts into mainstream K-12 and informal education systems. Agencies will also develop content that incorporates the latest ocean science for use in schools, aquariums, science centers, National Parks, and other institutions, and conduct demonstration projects that deliver ocean observing data for schools and other educational opportunities.
>
> - National Ocean Council, 2013

Author's note: This chapter is being submitted to the Journal of Geoscience Education as for the upcoming themed issue on Teaching STEM Principles through Oceanography Content. Any formatting changes and redundant information is due to this.

4.1 Introduction

The ocean dominates the earth system and supports life on earth. The study of the ocean requires an understanding of biology, chemistry, physics and geology, and the interactions between them. Human use of the ocean requires an understanding of both natural processes and engineering. The interdisciplinary nature of oceanography and the importance of the ocean to society combine to make the ocean and its systems excellent topics for teaching science in the K – 12 classroom. However, ocean sciences and examples are rarely employed to teach those disciplines at a primary or secondary school level. Given that the 75% of the earth is covered by the ocean and the importance of the ocean's impact on climate and other natural processes, students are not getting the education they need to understand the world around them if it does not include the ocean. Without an understanding of ocean and freshwater systems, we cannot have a truly scientific and environmentally literate society (Strang et al., 2007; Payne and Zimmerman, 2009).

Sylvia Earle has said the greatest threat facing the ocean is ignorance, stating “The oceans deserve our respect and care, but you have to know something before you can care about it” (2011). However the educational system in the United States has historically done a poor job of giving students even a basic level of understanding of the ocean. The low societal knowledge of ocean issues is at least partially attributed to limited marine education in schools (Steel et al., 2005(b); Lambert, 2006; Castle et al., 2010; Plankis and Marrero, 2010). Understanding ocean issues, one’s impact on the ocean, and responding with behavioral changes that reduce negative impacts upon the ocean are keys to being a marine citizen (McKinley and Fletcher, 2012). Yet all of those are made more difficult without appropriate amounts of ocean science in schools. To address this lack of ocean science education and the resulting dearth of marine citizenry, a group of scientists, educators, and education policy makers came together to develop the Ocean Literacy Essential Principles and Fundamental Concepts. The resulting products define an ocean literate person as one who understands the ocean’s influence on them and their influence on the ocean (The Ocean Literacy Network, 2013). An ocean literate person,

1. Understands the Essential Principles and Fundamental Concepts about the ocean;
2. Can communicate about the ocean in a meaningful way; and
3. Is able to make informed and responsible decisions regarding the ocean and its resources.

One of the most important steps in achieving a society filled with ocean literate individuals is to increase the amount of ocean science taught in the K–12 classroom.

While there are multitudes of ocean topics to choose from, many stewardship and educational goals can be met by teaching students about marine sanctuaries and national monuments in the United States. These areas have value for scientific research and wildlife protection, as tourism attractions and for their intrinsic existence. This study produced a series of lesson plans on the Pacific Marine National Monuments in an effort to provide educational material for the newly established monuments. The project also created a methodology of lesson development using the OL products and empirically-affirmed educational models that could be used by other educators looking to produce similar products (Figure 8). Lessons on the Marine National Monuments further the Ocean Literacy Network's goal of increasing ocean and aquatic science content in the classroom and support the Marine National Monument Program goal to "Increase stakeholder awareness, engagement, and support for the Marine National Monuments" (NOAA). Increasing stakeholder awareness is of particular importance given evidence that the Marine Monument and Sanctuary systems are not well known amongst the general public.

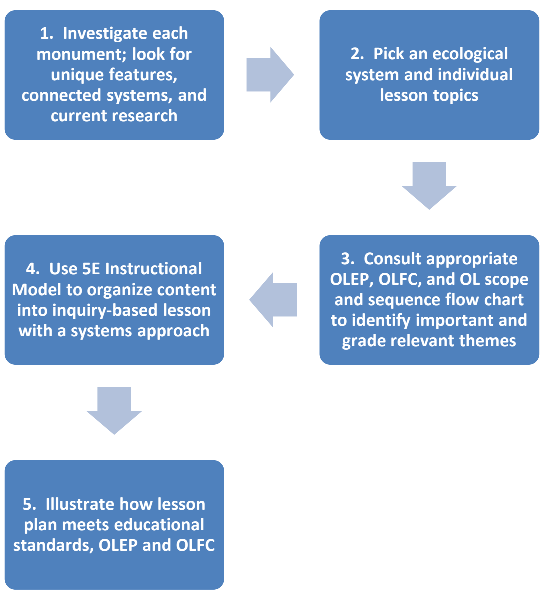

Figure 8. Ocean Literacy Pathway of lesson design.

4.2 Ocean Literacy Pathway

A 2010 survey, *America and the Ocean v 3.0*, completed by The Ocean Project, found that only 16.7% of U.S. adults had heard of National Marine Sanctuaries while 96.2% had heard of National Parks (Figure 9). People are even less likely to be aware of Marine National Monuments which are more recently established and more remote than most National Marine Sanctuaries. In an effort to increase knowledge of the Pacific Marine National Monuments and overall ocean literacy, a series of science lessons plans have been created featuring the monuments. The lessons use Ocean Literacy Essential Principles and Fundamental Concepts and current research on learning and teaching to guide their design. This curriculum is aimed at grades 7 through 12 and consists of twelve lessons (Table 2).

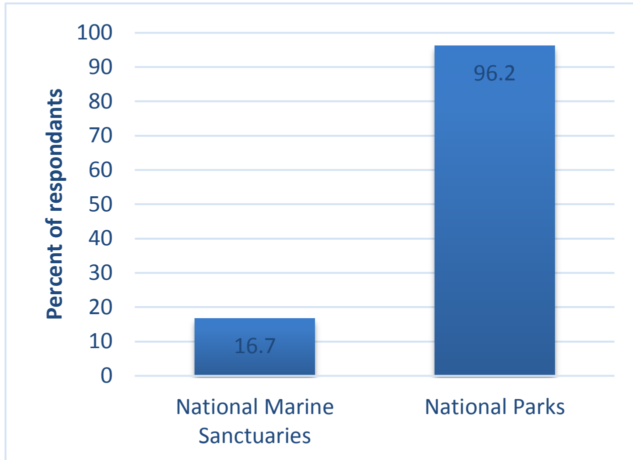

Figure 9. Percent of US Adults who responded yes to the question "Have you heard of..." for National Parks or National Marine Sanctuaries. Original figure created using data from The Ocean Project, 2010.

Three lessons were dedicated to each of the four Pacific Marine National Monuments: Papahānaumokuākea, the Marianas Trench, the Pacific Remote Islands, and Rose Atoll. Topics were chosen so that each lesson focuses on one part of a system within each monument. This arrangement allows each lesson to be taught alone or in combination with others. However, when the lessons are taught in sequence, students will benefit from expose to a more complete system, in turn facilitating the understanding of connections between individual processes. Systems thinking is widely recognized as an effective method to challenge students to higher level

Table 2. Overview of Lessons

	Lessons	Purpose
Pacific Remote Islands Marine National Monument	1. Seabird Biology	Students get an introduction to the PRIMNM, learn about the seabirds living there and how life history affects survival when there are disturbances.
	2. Guano Chemistry	Students learn about biogeochemical cycling, nutrient reservoirs, and develop a conceptual map of nutrient cycles around islands.
	3. Humans and the Ocean	Students explore how natural forces like wind and ocean currents affect human travel, use of resources, and local environments.
Papahānaumokuākea Marine National Monument	1. Marine Debris	Students are introduced to PMNM and learn what is being done to combat marine debris issues there. Contains an experiment to determine the fate of different types of plastic in the ocean.
	2. Biodiversity	Using the plants and animals of PMNM, students learn about biodiversity concepts and calculating diversity indexes.
	3. Science and Technology	Students learn about the variety of research methods, current projects, and technology used to learn about PMNM.
Marianas Trench Marine National Monument	1. Trench Unit	Students are introduced to deep sea trenches, geologic formations, and our limited explorations.
	2. Volcanic Unit	Students will explore the unique environment of undersea volcanoes, thermal vents and the unusual life associated with them.
	3. Island Unit	This lesson teaches students about Maug Crater, its rare features, and how it's helping scientists investigate ocean acidification.
Rose Atoll Marine National Monument	1. Sea Turtles	Students explore the unique life history of sea turtles and Rose Atoll's importance as a nesting ground.
	2. Coral Reefs	Students learn about the growth and development of coral reefs, how they form atolls and the dangers they face.
	3. Marine Protected Areas	This lesson teaches students the benefits of MPAs, how people interact with them, and how they are managed.

thinking and to help them make connections between components of a system they may not be able to make on their own (NRC, 1996; Tran et al., 2010). Furthermore, with regard to specifically marine systems, educational research has shown that curricula that use ocean and aquatic systems as large scale models can enhance understanding of complex systems (Fortner et al., 2005; Lambert, 2006). The goal of using a systems approach is to get students to understand that biological, physical, and human systems are all intertwined while simultaneously highlighting distinctive features of the individual marine monument.

Each lesson is organized using the BSCS 5E Instructional Learning Model. This instructional model is empirically supported, aimed at teaching scientific concepts, and consists of the following phases: engagement, exploration, explanation, elaboration, and evaluation (Bybee et al., 2006). Research has shown that the continued use of a research-based instructional model facilitates the learning of fundamental scientific concepts, as well as those in other disciplines (Donovan and Bransford, 2005). This instruction model facilitates inquiry-based learning to actively engage students, encourage them to ask questions, and think critically about the issues presented. Inquiry is a powerful way of learning and part of developing a students' understanding of the scientific process (NRC, 2000).

The Pacific Marine National Moments are full of unusual and visually stunning life that gets students excited like coral reefs, fish, and sharks. In addition to the incredible rich biology of the islands, the dynamic physical forces of the ocean are also well-represented in the monuments. The mix of islands and atolls demonstrate the evolving nature of oceanic islands and the undersea volcanos and vents of the Marianas Trench MNM showcase unique geological processes. The on-going scientific research provides a rich source of data for use in the classroom, as does having a specific environment as the context for the lessons. There is evidence from standardized tests scores indicating students of all ages understand and retain information better when the natural environment is used in the teaching process (Lieberman and Hoody, 1998). In addition to learning about the environment of the PMNM, the lessons encourage application of the newly gained scientific knowledge to place-based learning opportunities and investigations of the local environment. Place-based science instruction, or sense of place, can enhance a student's connection with their environment and enhance learning outcomes (Nehm, 2005). These lessons aim to assist students in making the connection between the ecosystem services provided by the monuments to those they receive from their local environment.

4.3 The Use of Ocean Literacy Products in Lesson Creation

The Ocean Literacy Network has created several products to assist with teaching and lesson plan design. The Ocean Literacy Scope and Sequence for Grades K-12 helps educators to understand the potential topics for instruction in each of a designated set of grade bands. For each Ocean Literacy Principle there is a separate conceptual flow diagram for each grade band, becoming increasingly complex in the older grades (Figure 10). Conceptual flow diagrams are provided as a visual reference of the progression of topical instruction and learning. The diagrams are meant not only to be used by teachers but also by individuals or groups developing curriculum or educational standards, textbook writers, and informal educators (Strang, DiRanna, and Topps, 2010). These diagrams were conceived and designed based upon research conducted on the components needed for successful inquiry, and are consistent with theories on learning and how a backward planning tool like conceptual flow diagrams can help teachers plan. In addition to assisting with lesson development, the flow diagrams describe what level of understanding is appropriate for each grade band and can help to devise a means of assessment (Strang et al., 2010). These flow diagrams, in addition to the Ocean Literacy Guide, were very helpful in the MNM lesson design process. Every lesson includes the relevant diagram to assist teachers in understanding the flow of concepts behind the lesson design and to provide support as they extend the ocean learning beyond from the pre-set lessons.

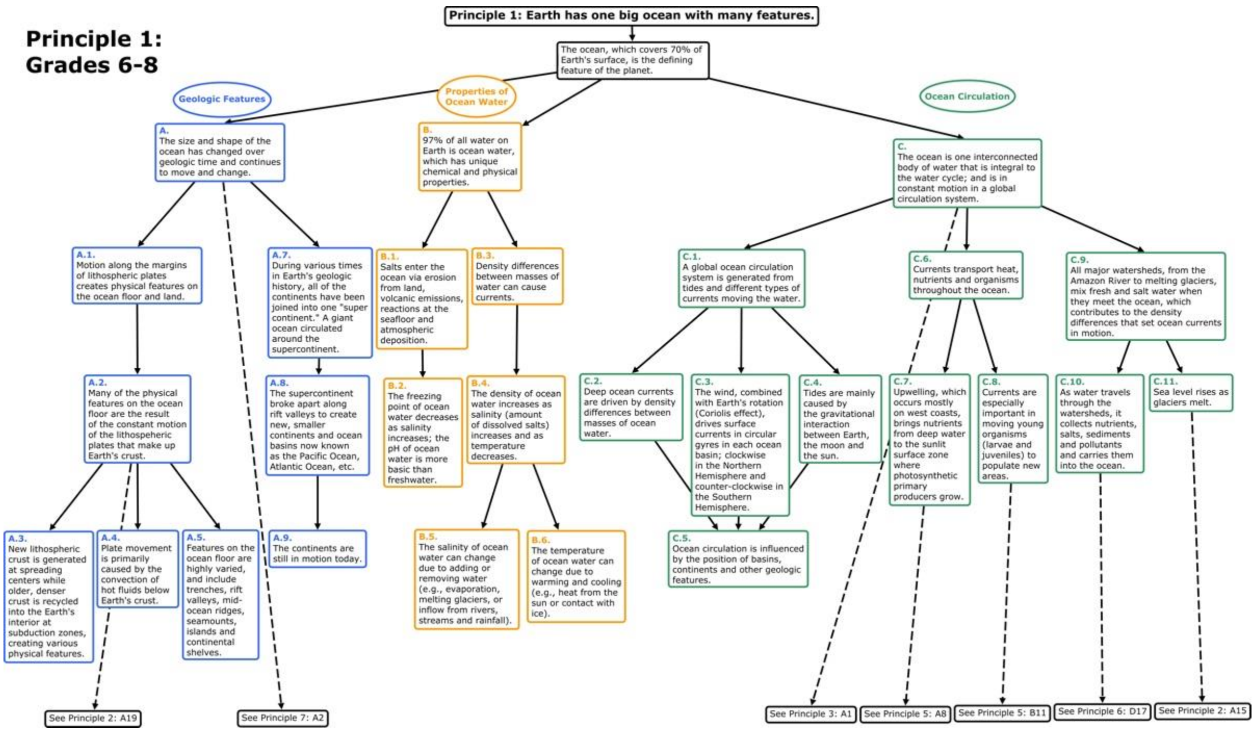

Figure 10. Conceptual flow diagram for Ocean Literacy Principle #1, grade band 6-8.Created by the Ocean Literacy Network, 2013. http://www.coexploration.org/oceanliteracy/CFDs/EP1/GB_6-8/cfd_1c.html

4.4 Lesson Plans

Six of the developed lessons are elaborated upon in this chapter; three each about Papahānaumokuākea and the Pacific Remote Islands MNMs. The lessons are presented in a range of detail, the location and type of information available for each is outlined below (Table 3).

Table 3. Road map of included lesson content.

Papahānaumokuākea MNM	1.	Seabird Biology	Description: section 4.4.1 Summary: Figure 9 Full Lesson: Appendix B NGSS and OL alignment: Table 3
	2.	Guano Chemistry	Description: section 4.4.1
	3.	Humans and the Ocean	Description: section 4.4.1 Full Lesson: Appendix C
Pacific Remote Islands MNM	1.	Marine Debris	Description: section 4.4.2
	2.	Biodiversity	Description: section 4.4.2 Summary: Figure 10 Full Lesson: Appendix D
	3.	Science and Technology	Description: section 4.4.2

4.4.1 Pacific Remote Islands Marine National Monument Lessons

The overall goals of these lessons are to introduce students to the MNM, the concept of marine protected areas, and to help them expand their appreciation and understanding of the ocean using scientific data being collected in these regions. The lessons from the ecosystem of the Pacific Remote Islands MNM explore the nutrient cycling system and its biological, chemical, and physical components. In this system, nitrates from bird guano first fertilize the soil, and then wash into the ocean or lagoon where they contribute to an increase in primary productivity. The resulting energy travels up the food chain eventually reaching high level consumers like the seabirds that produced the original nutrients. Some of the nutrients sink; at Baker, Howland and Jarvis Islands seabirds benefit from nutrients returned to the surface due to upwelling from the Equatorial Undercurrent (Rauzon, Forsell, Flint, and Gove, 2011).

At Palmyra Atoll, recent research has identified the key links in this nutrient chain, how the presence of native *Pisonia* trees influences bird distribution, and the resulting higher level of nitrates and phytoplankton growth near sections of the coastline with native trees (McCauley et al., 2012). Inspired by that research, the nutrient system was broken down into components to create three lessons: seabird biology, nitrate chemistry and cycling, and ocean currents and processes. The key idea is to get students to understand how the different parts of the system interact and also to understand a potential response if a link in the system is disrupted. The lessons also provide an introduction to the monument itself including the location of the islands and atolls and give students perspective on the relative size of these locations by comparing them to a local landmark (i.e. home state, city, etc.).

The first lesson, *Seabird Biology in the PRIMNM*, is about the life history of seabirds and how they have been affected by invasive species (Figure 11, complete lesson plan can be found in Appendix B). The lessons vary in content, but all contain background, in-class activities, and a worksheet or some other method of assessment. In this lesson, students will examine data on seabird populations and make predictions for other islands based upon those observations. Lesson two goes into details on nutrient cycling and how seabirds contribute nutrients to the ecosystem. In this lesson, students complete a hands-on activity to understand the process of nutrient distribution on these islands. Lesson three is an introduction to ocean currents and the physical processes involved in nutrient cycling. This introduction starts with student investigation of historical routes traveled by sailing vessels in the Pacific and an activity involving nautical charts. This activity introducing ocean currents leads to an examination of the process of upwelling and how it influences nutrient cycling. These lessons fit into OL Principles 5 – *the ocean supports a great diversity of life and ecosystems*, 2 – *the ocean and life in the ocean shape the features of Earth*, and 1 – *the earth has one big ocean with many features*, respectively.

Seabird Biology in the Pacific Remote Islands Marine National Monument

Objectives
- Learn about what islands and atolls are part of the PRIMNM
- Learn about the life history of seabirds
- Interpret data and make predictions about seabird populations

Key Concepts
- Life history traits
- K/R selected species
- Invasive species
- Recolonization

Materials
- Google earth
- Student worksheets and case studies

Engage
- Use google earth to look at both an overview of the PRIMNM and close ups of each island or atoll.
- How do the islands and atolls differ? What do you see?

Explore
- Discuss the wildlife that live on the islands. They are home to large seabird populations.
- How do seabirds differ from land birds? How are they adapted to life near or on the water?
- How do seabirds nest?
- What would happen do seabirds if their predators changed?
- Use data from Jarvis Island to explain the effect of an invasive species.

Explain
- Complete the seabird and rat interaction worksheet. Questions include:
- Predict 3 species of birds that would have difficulty coexisting with rats and list why.
- A group monitoring the recovery on Palmyra since the rat removal has found a 130% increase in native tree seedlings, which species of birds would you predict would benefit from this change in the environment?
- Chick translocation (humans moving seabird chicks) or using methods such as playing seabird sounds, can help speed up recolonization rates of seabirds. If you were the manager of a recovering island, would you use these techniques? Why or why not?

Elaborate
- Divide the class into three groups and give each group one of the case studies involving islands and invasive species.
- Have them give a short presentation on their case study.

Evaluate
- Presentation skills
- Use and interpretation of given data

Options for Extension
- Go birding in your local area and use http://ebird.org to record what you see
- Use data from the Audubon Society Christmas Bird Counts to investigate your local bird populations and practice making graphs.
- Investigate if/how invasive species have affected your area

Student Seabird Worksheet Information

Life History Traits and level of rat impact

Nesting Strategy	Impact
Burrowing	High
Crevice nesting	High
Branch	Low
Ground	Low

Family	Impact
Hydrobadidae	High
Diomedeidae	Low
Fregatidae	Low
Laridae	Medium
Alcidae	High
Sulidae	Low
Phaethontidae	Low
Procellariidae	High
Pelecanoididae	High

Adult Weight/size	Impact
Small (less than 300 g)	High
Medium (301-600 g)	Medium
Large (601-900 g)	Medium
Very Large (greater than 900 g)	Low

Seabirds of the Pacific Remote Islands Marine National Monument

Species	Family	Nesting	Size (g)
Audubon's Shearwater	Procellariidae	Burrows	170
Black Noddy	Sternidae	Branch	120
Blue Noddy	Laridae	Ground (rocky)	58
Brown Noddy	Laridae	Ground	200
Brown Booby	Sulidae	Ground	1270
Masked Booby	Sulidae	Ground	1855
Red-footed Booby	Sulidae	Arboreal	975
Great Frigatebird	Fregatidae	Branches	1185
Lesser Frigatebird	Fregatidae	Ground	750
Christmas Shearwater	Procellariidae	Ground under dense cover	350
Wedge-tailed Shearwater	Procellariidae	Burrows	455
Grey-backed Tern	Laridae	Ground	230
Sooty Tern	Laridae	Ground	180
White Tern	Laridae	Branches	110
Red-tailed Tropicbird	Phaethontidae	Ground	620
Bulwer's Petrel	Procellariidae	Crevices or burrows	95
Black-footed Albatross	Diomedeidae	Ground	3195
Laysan Albatross	Diomedeidae	Ground	2855

Figure 11. Summary of Seabird Biology in the PRIMNM lesson with associated student worksheet.

Included with each lesson is a list of the NGSS and Ocean Literacy Essential Principles and Fundamental Concepts represented in that lesson's content (Table 4).

Table 4. NGSS and Ocean Literacy Principles addressed in Seabirds of the PRIMNM. NGSS accessed at http://www.nextgenscience.org/search-standards-dci and OLEP and FC from The Ocean Literacy Guide, 2013.

Next Generation Science Standards	• **MS-LS2-2.** – Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems. • **MS-LS2-4.** – Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. • **HS-LS2-2.** – Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. • **HS-LS2-7.** – Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. • **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. • **HS-LS4-6.** – Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.
Ocean Literacy Essential Principles and Fundamental Concepts	• **5** – The ocean supports a great diversity of life and ecosystems. • **5D** – Ocean biology provides many unique examples of life cycles, adaptations, and important relationships among organisms (symbiosis, predator-prey dynamics, and every transfer) that do not occur on land. • **5F** – Ocean ecosystems are defined by environmental factors and the community of organisms living there. Ocean life is not evenly distributed through time or space due to differences in abiotic factors such as oxygen, salinity, temperature, pH, light, nutrients, pressure, substrate, and circulation. A few regions of the ocean support the most abundant life on Earth, while most of the ocean does not support much life. • **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.

4.4.2 Papahānaumokuākea Marine National Monument Lessons

Papahānaumokuākea MNM has the strongest historical human connection of all the MNMs and the lessons recognize and highlight pieces of the human/natural system of the Northwest Hawaiian Islands. The lessons examine marine debris, biodiversity, and the scientific research actively occurring in PMNM. Marine debris is defined by NOAA and the U.S. Coast Guard as any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes (33 USC 1951 et seq. as amended by Title VI of Public Law 112-213). Marine debris washing up on shore of the islands or getting stuck in coral reefs is one of the biggest management challenges of PMNM and the enormous size of the monument further complicates the issue.

Marine debris can cause entanglement issues for endangered Hawaiian monk seals and threatened green sea turtles and can be accidently ingested by a variety of marine life. Members of the marine debris team from NOAA's Pacific Island Fisheries Science Center Coral Reef Ecosystem Division removed 14 metric tons of marine debris from Midway Atoll in April, 2013 (NOAA PIFSC, 2013). The lesson on marine debris introduces students to the general concept and contains a hands-on experiment to demonstrate the densities of different types of plastic compared to seawater. This lesson addresses the OL Essential Principle 6 – *the ocean and humans and inextricably interconnected*. The idea is for students to "get to know" their plastic and understand what could happen to the plastic they use if it's not disposed of properly. They will also compare data on debris distribution to distributions of marine mammals to see how they overlap geographically.

The second lesson moves on from that introduction to marine mammals and other organisms that can be harmed by marine debris to a general discussion of biodiversity (Figure 12). The Hawaiian Islands archipelago is the most isolated island chain on earth and has a very high percentage of endemic species that are found nowhere else (Fautin et al., 2010) and is a great example of OL Essential Principle 5 – *the ocean supports a great diversity of life and ecosystems*. There is a latitudinal gradient reflected in the community composition across the NWHI. Temperate and subtropical fish species are found around the northern islands while tropical are found in the southern waters and shark species varied as well (Friedlander et al., 2009). One of the most unique features of the biology found in PMNM is the abundance of apex

Biodiversity in Papahānaumokuākea MNM

Objectives
- Learn about the different ecosystems of PMNM
- Understand the importance of biodiversity and how it varies in PMNM
- Learn and apply different methods of measuring biodiversity

Key Concepts
- Biodiversity or species richness
- Endemic
- Ecosystem importance of biodiversity

Materials
- Google earth
- Student computers (pairs or small groups)

Engage
- Use google earth to look the features of PMNM
- Using MPA layers, have the students try and find pictures and information for as many species as possible.
- Discuss the variety of geographic features (shoals, atolls, islands)

Explore
- Discuss the concepts of biodiversity and use the included power point to look at some features of biodiversity in PMNM
- Ask how many species students found earlier.
- How does biodiversity vary across the islands of PMNM?
- What are the challenges of studying animals in marine environment?

Explain
- Complete a short musical exercise that illustrates diversity.

Elaborate
- Complete the measuring biodiversity exercise to show students a few ways biodiversity if calculated quantitatively.
- Can the students think of other ways to measure biodiversity?
- Talk about the upside down biomass pyramid that can be found in the ecosystems of PMNM.

Evaluate
- Lead a class discussion to assess understanding of biodiversity concepts.

Options for Extension
- NOAA shiptracker: http://shiptracker.noaa.gov/Home/Map. This link allows you to see where the ships currently are and access data from previous cruises.
- Assign a chapter or short section of the Marine Biogeographic Assessment of the NWHI for reading. The whole report or individual chapters can be downloaded here: http://ccma.nos.noaa.gov/ecosystems/sanctuaries/nwhi/.

Biodiversity Student Worksheet

Species Investigation – done as homework
1. Pick one organism (plant or animal) and research some basic facts about that organism. Where does it live, how does it behave, and what does it need to survive.
2. What role does this organism play in the community? Is it a predator, prey, does it help or take advantage of any other animals? Write down at least 3 interactions between your species and others in the ecosystem.

Measuring and Comparing Biodiversity
Species richness is a measure of the number of species in a habitat, but it does not take into account how many of each species and how they are distributed. Diversity indexes, like the Shannon-Wiener Diversity Index, give scientists a metric to assess and compare different ecosystems. The value of the index gets higher as there are more species and the population of each is more balanced.

Use the Shannon-Weiner diversity index to calculate the diversity index of the following groups. What do the different index values mean? Walk through the Reef 1 calculation as a group, and then have the students do 2 and 3 as individuals or in pairs.

$$H' = -\sum_{i=1}^{R} p_i \log p_i$$

H' = diversity
∑ = sum of each individual
p_i = the proportion of individuals within the community

You do another survey of the three reefs and in addition to the fish listed above you find Tiger Sharks and Green Turtles living at Reef 1. What is the alpha of each reef and the beta richness when the reefs are compared?

	Reef 1	Reef 2	Reef 3
Parrotfish	30	14	18
Angelfish	4	12	0
Triggerfish	6	14	22

Figure 12. Summary of biodiversity lesson and associated worksheet. Full lesson in Appendix D.

predators. The lesson on biodiversity gives students an introduction to the basic concepts of biodiversity and provides a look at the unique biological make-up of PMNM. They will learn several methods of calculating biodiversity and do some calculations based upon actual population data from *A Marine Biogeographic Assessment of the Northwestern Hawaiian Islands*. As previously described, PMNM is a very unique ecosystem and lots of exciting scientific research is underway to better understand the biology, geology, and physical environments of the islands and atolls. The remote and sensitive environment has led to some creative developments in scientific sampling and is a chance to highlight the research being conducted and the instruments used to do the research. This lesson fits under the umbrella of OL Essential Principle 7 - *the ocean is largely unexplored*. Students will learn about the technology being used to understand PMNM and also understand just how much we still do not know about the monument.

4.5 Expected Benefits and Results

Multiple benefits are anticipated to result from this project. These lessons will improve the availability of ocean literacy based educational materials that promote higher order thinking and use the latest educational modalities. These lessons have been designed to be engaging and will hopefully infuse an excitement into the educational process that will be connected to the study of the oceans. They provide NOAA with educational materials aligned with the Next Generation Science Standards and Ocean Literacy Essential Principles and Fundamental Concepts and will constitute some of the first publically available lessons provided by NOAA on Rose Atoll MNM, the Pacific Remote Islands MNM, and the Marianas Trench MNM. Teachers and students will benefit from these educational materials that integrate cutting edge oceanographic research into the classroom learning process. Investigating actual environmental issues, like invasive species or marine debris, makes learning relevant to students lives and helps with skill like critical thinking and problem solving (Pennock and Bardwell, 1994). These, and similar lessons, will hopefully enhance recruitment of students to marine science and technology areas by highlighting a wide variety of exciting jobs and opportunities in the field. Lastly, these lessons will hopefully contribute to the larger goal of increasing ocean literacy in the United States, specifically in the secondary school-age population.

The nature of the PMNM is such that very few people will experience them in person so educational opportunities are a primary way to expose the public to their existence. These educational materials will increase public familiarity and appreciation for the PMNM by showcasing some of their captivating features. The sharing and learning process is mutually beneficial for students, their families, and monument mangers. Students are able to learn, experience, and share very special, remote places they might not otherwise experience in any capacity. This in turn benefits the MNM program as more people feel connected and become stakeholders in their continued preservation. The new lessons are also anticipated to result in increased use of NOAA research products and outreach resources by 7^{th} – 12^{th} grade students and teachers. Not only will students be increasingly exposed to NOAA's mission and research products, but the general public's exposure will also grow through interactions with the students' completion of projects, presentations, and homework material. This exposure of the general public to MNM will help convey the importance of these areas, the work that is being done to manage them, and how the average person can help in their protection.

4.6 Conclusion

The Ocean Literacy Network has done a lot of work to produce materials that aid in curriculum design and teaching. It is now up to scientists interested in education, educational organizations, and educators familiar with ocean science to create educational materials that are exciting for students and will help promote ocean literacy. Many teachers unfamiliar with the ocean are reluctant to teach about it because they are not confident to teach the subject given their knowledge level. Curricula that are clearly presented with sufficient background information, both on content and how lessons meet standards, can help increase the frequency that ocean and aquatic science are taught in the classroom. The design process described in this paper provides a pathway for incorporating Ocean Literacy Essential Principles and Fundamental Concepts and considering NGSS when creating lesson plans.

5. Conclusion

An investment in knowledge always pays the best interest.

-Ben Franklin

The fact that most of the public in the United States lacks a basic understanding of the ocean is one of the most serious threats the ocean faces. Fortunately, it is also probably one of the more approachable issues. Much of the ocean conservation outreach directed at the public in the United States concerns negative anthropogenic impacts. However, many people lack the knowledge concerning the ocean to both understand those negative impacts and how their behavior contributes to them. While it is important to spread awareness of those issues, it is also important to address why more people do not have an understanding of the physical processes of the ocean and how impactful the ocean is to their everyday lives. One does not need to live on the coast or earn a living from the sea for the health of the ocean to be relevant in their lives.

One way to address the gap in knowledge is to focus efforts on increasing ocean science education in primary and secondary schools. Examples from the ocean can be used to teach STEM topics, both increasing ocean literacy and providing real-world context for subjects like biology and earth science. This thesis identified several challenges associated with increasing the amount of ocean science content in the classroom and provided potential solutions. For some of the challenges, like education standards, recent developments could lead to ocean sciences being better addressed in the classroom. Others, like the level of teacher knowledge concerning ocean science content and appropriate pedagogy, are only being addressed intermittently when resources permit. No one solution is going to suddenly solve the greater problem, but if small progress is made tackling each challenge then the momentum will start going in the right direction. The Ocean Literacy Network has provided leadership in this effort, but it will take individual educators active in their community, creating curricula, and asserting the value of ocean science education to really effect progress.

The Ocean Literacy Pathway and lessons previously described are just one example of a product that could advance ocean literacy in the classroom. The pathway could be used to design other natural science lessons and also social science lessons with slight modifications. The examples provided in this study will be of use to educators, people working on curriculum design, and scientists concerned with education. The use of the Pacific Marine National Monuments helps to facilitate an increase in ocean literacy as well as increasing awareness of the monuments. Given that opportunities to teach ocean sciences will likely still be limited, when there is a chance to spread awareness of resources, like protected areas, while teaching about basic ocean topics the opportunity should be seized.

Increasing ocean stewardship through education is a major undertaking but one that must be recognized by the marine affairs, scientific, and educational communities as an important component of ocean policy and conservation. Some frequently addressed ocean issues, such as climate change and pollution, require a change in the action of individuals if there is to be any stemming of the tide of negative impacts. Though regulations are one method to control behavior, ideally teaching individuals about the ocean will allow them to make informed and responsible decisions regarding the ocean and its resources, one of the defined hallmarks of an ocean literate individual. Further research on the response of students to increased ocean science in the classroom is important to continue to aid in the refinement of teaching techniques and to understand and provide evidence of its benefits. As schools transition to the NGSS, marine science educators must use the opportunity to illustrate how well the ocean naturally lends itself to the teaching of interconnected systems. In order to have a future with a healthy ocean it is crucial that people, especially children and teens, are given the chance to experience the ocean through education.

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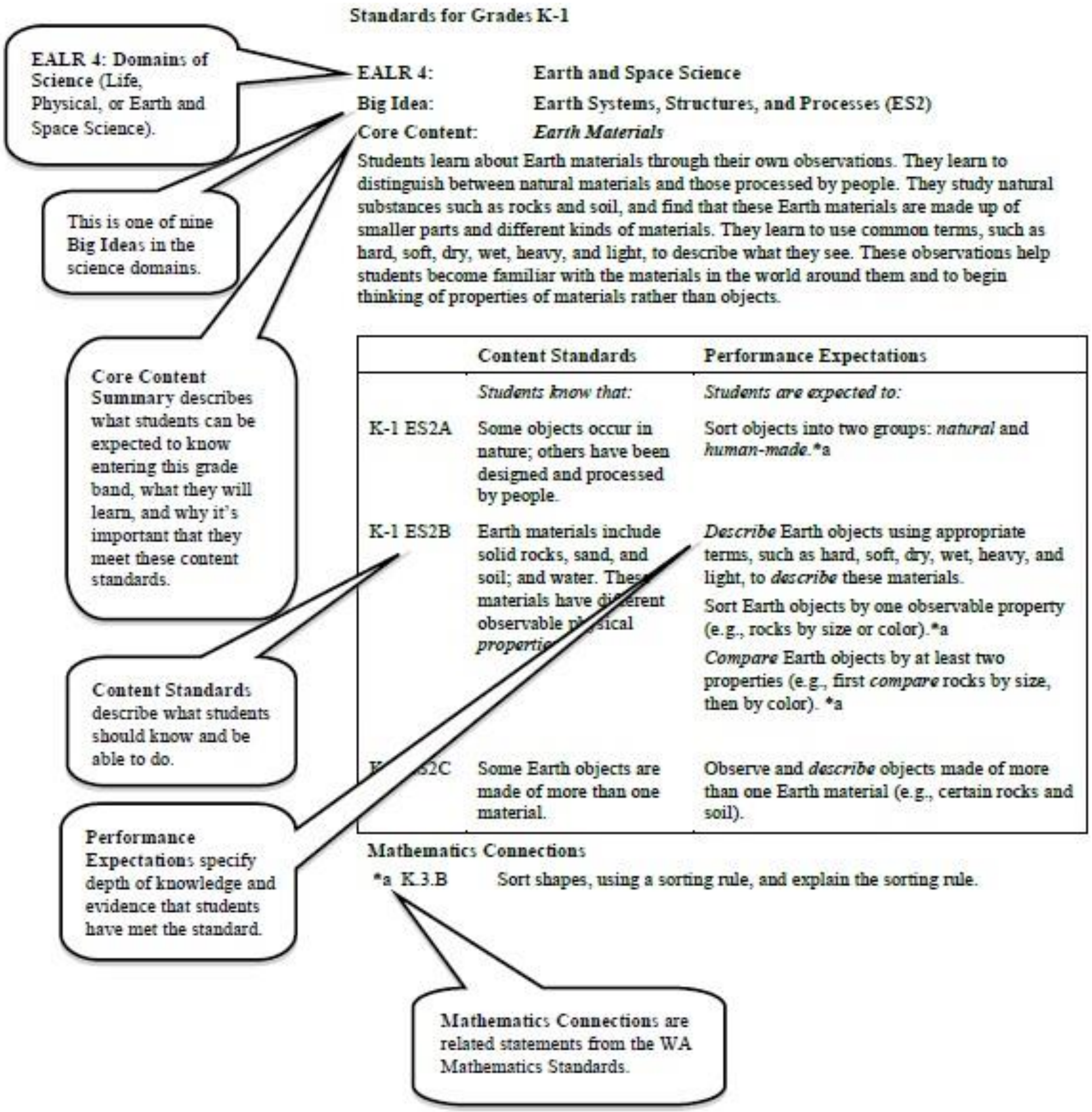
Appendix A: Components of a Washington State Science Standard



Standards for Grades K-1

EALR 4: **Earth and Space Science**
Big Idea: **Earth Systems, Structures, and Processes (ES2)**
Core Content: ***Earth Materials***

Students learn about Earth materials through their own observations. They learn to distinguish between natural materials and those processed by people. They study natural substances such as rocks and soil, and find that these Earth materials are made up of smaller parts and different kinds of materials. They learn to use common terms, such as hard, soft, dry, wet, heavy, and light, to describe what they see. These observations help students become familiar with the materials in the world around them and to begin thinking of properties of materials rather than objects.

	Content Standards	Performance Expectations
	Students know that:	*Students are expected to:*
K-1 ES2A	Some objects occur in nature; others have been designed and processed by people.	Sort objects into two groups: *natural* and *human-made*.*a
K-1 ES2B	Earth materials include solid rocks, sand, and soil; and water. These materials have different observable physical *properties*.	*Describe* Earth objects using appropriate terms, such as hard, soft, dry, wet, heavy, and light, to *describe* these materials. Sort Earth objects by one observable property (e.g., rocks by size or color).*a *Compare* Earth objects by at least two properties (e.g., first *compare* rocks by size, then by color). *a
K-1 ES2C	Some Earth objects are made of more than one material.	Observe and *describe* objects made of more than one Earth material (e.g., certain rocks and soil).

Mathematics Connections

*a K.3.B Sort shapes, using a sorting rule, and explain the sorting rule.

Appendix B: Pacific Remote Island Marine National Monument Lesson 1, Seabird Biology

Lesson Summary

In this lesson students will learn about the islands and atolls that are a part of the Pacific Remote Islands Marine National Monument. Then they will examine some of the wildlife of the islands, specifically seabirds, and learn the basic requirements for living and reproducing. They will make and/or analyze a graph from provided data, and learn to interpret data to make predictions about trends or anomalies. Last, data of seabird populations will demonstrate how invasive species have affected seabirds and case studies of conservation successes show how people are helping populations recover.

Learning Objectives

- Understand the size of the PRIMNM and relative ratios of land to water.
- Understand the basic requirements of seabirds and how the fill those needs.
- Learn about the impacts of introduced species and how some people are working to lessen that impact.
- Make predictions based up data from studies of islands recovering from invasive species.

Organization

- **Engage –** Introduction to Pacific Remote Island Marine National Monument
- **Explore** – Seabird nesting strategy discussion
- **Explain –** Seabird and rat interactions Palmyra Atoll
- **Elaborate-** Seabird and invasive species interaction case studies
- **Evaluate-** Presentation of case study

Grade Level

- 7-12 grade

Teaching Time

- Two 45-minute periods, one 90 minute period

Instructional Materials and Resources

- Computer with Google Earth and projector
- Student worksheets and case studies
- Fact sheet on the NOAA fisheries National Seabird program: http://alaskafisheries.noaa.gov/protectedresources/seabirds/seabird_factsheet.pdf
- Fish and Wildlife Service PRIMNM website - clicking on the links to individual islands or atolls on the left will give you information about all the birds found at each place. http://www.fws.gov/pacificremoteislandsmarinemonument/
- Fact sheet on the monument http://www.fws.gov/pacificremoteislandsmarinemonument/PRIMNM%20brief.pdf
- Slideshow of birds of Palmyra Atoll http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/hawaii/slideshow-birds-of-palmyra-atoll.xml
- You Tube videos
    - Kingman Reef: about 2 minutes, made by Environmental Defense Fund https://www.youtube.com/watch?v=I8m5_aeq4tQ&feature=player_embedded#at=52

Vocabulary and Key Concepts

- LIFE HISTORY TRAITS – major characteristics that affect the rate, timing, and other aspects of growth, reproduction, and resource gathering
- K SELECTED SPECIES – species that tend to have a lower number of offspring but invest more energy in individual offspring, mature more slowly and/or be older at the time of first reproduction, and have a longer lifespan
- R SELECTED SPECIES – species that tend to have a shorter life span, mature rapidly and reproduce early, they typically have lots of offspring but low levels of parental investment leading to high offspring mortality
- INVASIVE SPECIES – non-native species that negatively affect the environment, ecology, or economy of the area they invade
- RECOLONIZATAION – to colonize a region or habitat again

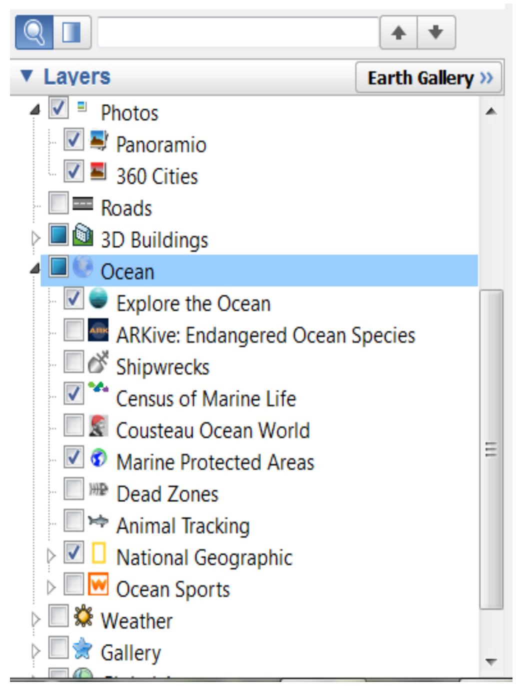
Background

An estimated 14 million seabirds from 21 species use the small area of emergent land in the PRIMNM for nesting (MCBI, 2010). Jarvis Island alone is home to an estimated 1 million sooty terns and Palmyra Atoll is home to the second largest red-footed booby breeding colony in the world with an estimated 6250 breeding pairs (TNC, 2013). These small areas of land are extremely important for seabirds foraging and breeding. While many species of seabirds spend large amounts of time at sea, nesting requires that they come ashore. Seabirds have several adaptations for life at sea. Their wings can be long for pelagic species that fly over great distances, shorter for those that are diving species, and most have webbed feet for better propulsion while on the surface or diving. Most seabirds also have salt glands that allow them to excrete excess salt that they consume by eating and drinking from a saline environment. Seabirds have three primary methods of feeding: Surface feeding, pursuit diving, and plunge diving. Some seabirds, such as frigatebirds, also get some of their food by stealing it from other birds. There is large a range of how far seabirds will forage from their nesting area. Blue Noddies forage close to shore typically staying within 1-2 km of their nesting site, whereas Masked and Red-footed Boobies will forage 100-200 km from their nesting sites and Red-tailed Tropicbirds have a range of 1500 km.

In addition to physiological adaptations for life at sea, the life history of seabirds also differs from their land relatives. Seabirds usually live longer than land birds and are K-selected species meaning they live longer, have fewer offspring and typically give more parental care than R-selected species which tend to be small, quickly reproducing organisms with short generation time. Most seabirds breed in colonies, leading to the incredible amounts of seabirds that gather on the islands and atolls of the PRIMNM. Palmyra Atoll is the only seabird nesting area in 450,000 square miles of ocean, so the protection offered by being part of the national monument system is crucial for the birds that nest there and on the other remote islands. Just as they feed in a variety of ways, seabirds also have different preferences for nesting. Some like to nest in trees, some on the ground in the open, and others will make burrows on the ground. White Terns are well known for laying eggs in precarious places like rocks, rock ledges, or bare branches. Information on all species found in the monument can be found at Fish and Wildlife website for the monument, address can be found in the internet resources section.

Though seabirds greatly benefit from the islands and atolls of the PRIMNM and their associated ecosystems, they also give benefits back to those ecosystems. Seabirds play important roles in tropical food webs and ecosystems. Seabirds consume an estimated 7% of ocean primary productivity and the guano they produce fertilizes terrestrial and tidal zones. It is critical that people recognize the importance of seabirds to these ecosystems because many seabird species are listed as threatened. There are 326 species of seabirds identified, 102 are threatened or endangered and 5 are considered extinct by the IUCN. (Jones, 2010). NOAA Fisheries has a National Seabird Program that monitors and tries to reduce seabird bycatch from fisheries. They also use seabirds as ecosystem indicators when conducting research.

Engage



Show students an overview of PRIMNM. Use google earth or google maps satellite view to show close ups of the individual islands and zoom out to show how far they are from your school or other major landmarks like Hawaii, or Australia. Talk about the differences that you can see between the islands and atolls. The islands (Jarvis, Howland, and Baker) do not have center lagoons while the atolls (Palmyra, Wake and Johnston) have center lagoons and are made up of small islets that surround the lagoon. On Johnston there are clear remnants of the air force base that closed in 2004 and there is also visible runways and development on Wake from military activity. The military presence both places dates back to pre-WWII. Kingman Reef has very little emergent land, but the reef can be seen. You can discuss what the different colors of water mean and the different depths are visible. After viewing the individual locations zoom out and look at the whole area.

- From each island or atoll, the water out to 50 nautical miles is part of the monument.
- Ask your students to estimate something equivalent to the size of the park. It's roughly 86,888 square miles or roughly the size of Minnesota (86,897 square miles).
- Have the students predict what percentage of the monument is exposed land. It is only 11.22 sq. miles or 0.013% of the area of the monument truly making this a marine preserved area as opposed to a terrestrial one. If you would like to compare your home state to the area of the monument, data on the area of every US state can be found here: http://en.wikipedia.org/wiki/List_of_U.S._states_and_territories_by_areathe

Explore

What kinds of wildlife can be found in the PRIMNM? Despite the relatively small amount of land, these islands and atolls are home to a very large seabird population. Seabirds and shorebirds have some of the same requirements for living, but their challenges can be different.

- Brainstorm with your students the need of seabirds, and how living primarily at sea requires different adaptations than living on land. They may come up with things like ability to swim (seen in different wing shape and webbed feet), and dealing with the fact that their primary source of water is saline. Steer the discussion towards nesting behavior; even though adult seabirds can spend extended time at sea they must nest on land.
- Lead a discussion with your students on the different types of nesting behaviors in seabirds (information in background section). Ask you students questions like:
    - How do you see birds where you live nest?
    - Why might the behaviors vary for the seabirds out on these islands?
    - What are the challenges for nesting?
    - Did you see many trees or foliage when looking at the images of the islands? What might that mean for where birds nest?
    - Why might nesting on the ground be hazardous?

As a visual to stimulate discussion show the table of numbers of seabirds on Jarvis. Even under good conditions there is a lot of variation in nesting numbers from year to year. Aim to have the students leave this discussion with the understanding that nesting on the ground is safe under natural conditions but if predators are introduced by humans it can lead to negative results for those species.

Table 1. Status of seabirds seen on Jarvis Island NWR, 01 – 05 April 2010 with comparisons to 2008, 2004, and 1996[1].

Species Name	Nesting Y/N	Number of Nesting Pairs[1]	Total number of birds seen 2010	Results From 2008 26-28 Mar	Results From 2004 26-27 Mar	Results From 1996[4] 20-23 Mar
Wedge-tailed Shearwater	?	25[2]	35	100	41[3]	0(8)
Christmas Shearwater	Y	1	8	20	20[3]	0(12)
Audubon's Shearwater	N	0	8	20	4[3]	1(20)
Red-tailed Tropicbird	Y	92	400	40[3]	150	13(110)
Masked Booby	Y	935	5,421	2,323[3]	5,000	333(2,515)
Brown Booby	Y	20	≈75	8[3]	200	51(86)
Red-footed Booby	Y	63	>100	17[3]	750	216
Great Frigatebird	Y	293	>500	95[3]	1,600	251
Lesser Frigatebird	Y	744	>900	0	4,000	809
Brown Noddy	Y	68	>600	250	10,000	1,238
Black Noddy	N	0	3	0	NA	0(1)
Species	N	0	95	25[3]	650	4(100)
White Tern	Y	1	6	0	NA	1(5)
Sooty Tern	Y	≥100,000	≈200,000	Na	150,000	117(TMTC)
Gray-backed Tern	N	0	76	300	1,100	90

[1]Yearly comparisons are not intended to express differences in population size but to demonstrate variability of nesting effort in the equatorial region of the Pacific.
[2]Number of nesting pairs resulted from direct counts except where noted.
[3]Number of active burrows encountered.
[4]Indicates actual nest counts, otherwise number of nesting pairs was estimated in 2008 and 2004.
[5]The 1996 results display number of nest sites and (total number of birds seen).

From Depkin, F.C. and Kim, J. (2010) USFWS Trip Report, Jarvis Island NWR.

Explain

Nesting on the ground isn't typically a problem because few of these islands have native ground-dwelling predators. When one is introduced it can be disastrous for native species without ways of defending themselves and their nests. Invasive species are a problem in a lot of ecosystems and the PRIMNM is no exception. Rats were probably introduced to Palmyra Atoll during WWII when it was a military base.

Complete the seabird and rat interaction worksheet. This has students interpret the data on Palmyra Atoll seabirds and rats interactions to order to answer the following questions:

1. Look at the list on the next page of life history traits of central Pacific seabirds and how that affects how they are impacted by rats. Predict 3 species of birds that would have difficulty coexisting with rats and list why.

Audubon's Shearwater, Christmas Shearwater, Wedge-tailed Shearwater, Bulwer's Petrel, Blue Noddy, Grey-backed Tern – Though no records exist from before rats were introduced, these birds are all believed to have been extirpated from Palmyra by rats based on best estimates from scientists. These species are all high risk in 2 or 3 of the categories. In addition to those species, the Phoenix Petrel and White-Throated Storm Petrel are also believed to have lived on Palmyra but are not found on other islands in the PRIMNM.

2. A group monitoring the recovery on Palmyra since the rat removal has found a 130% increase in native tree seedlings, which species of birds would you predict would benefit from this change in the environment?

The arboreal and branch dwelling species: Black Noddy, Red-Footed Booby, Great Frigatebird, and White Tern.

3. If seabirds that have been killed off by rats were going to recolonize Palmyra Atoll, where do you think they would come from?

Jarvis, Howland, Baker, and Kiritimati (Christmas Island) are the closest to Palmyra.

4. Chick translocation (humans moving seabird chicks) or using methods such as playing seabird sounds, using decoys and smells, or creating artificial burrows can help speed up

recolonization rates of seabirds. If you were the manager of a recovering island, would you use these techniques? Why or why not?

More of an opinion question but look for good reasoning to back up either a yes or no decision. Potential reasons include it would be better left to happen naturally, or less human interference, using those techniques would speed up recovery and help them get established rather than leaving it to chance. It's reasonable to say that they would use some of the less intrusive techniques like creating artificial burrows but that they might not go as far as physically moving seabird chicks.

Life History Traits and level of rat impact

Nesting Strategy	Impact
Burrowing	High
Crevice nesting	High
Branch	Low
Ground	Low

Family	Impact
Hydrobadidae	High
Diomedeidae	Low
Fregatidae	Low
Laridae	Medium
Alcidae	High
Sulidae	Low
Phaethontidae	Low
Procellariidae	High
Pelecanoididae	High

Adult Weight/size	Impact
Small (less than 300 g)	High
Medium (301-600 g)	Medium
Large (601-900 g)	Medium
Very Large (greater than 900 g)	Low

Seabirds of the Pacific Remote Islands Marine National Monument

Species	Family	Nesting	Size (g)
Audubon's Shearwater	Procellariidae	Burrows	170
Black Noddy	Sternidae	Branch	120
Blue Noddy	Laridae	Ground (rocky)	58
Brown Noddy	Laridae	Ground	200
Brown Booby	Sulidae	Ground	1270
Masked Booby	Sulidae	Ground	1855
Red-footed Booby	Sulidae	Arboreal	975
Great Frigatebird	Fregatidae	Branches	1185
Lesser Frigatebird	Fregatidae	Ground	750
Christmas Shearwater	Procellariidae	Ground under dense cover	350
Wedge-tailed Shearwater	Procellariidae	Burrows	455
Grey-backed Tern	Laridae	Ground	230
Sooty Tern	Laridae	Ground	180

White Tern	Laridae	Branches	110
Red-tailed Tropicbird	Phaethontidae	Ground	620
Bulwer's Petrel	Procellariidae	Crevices or burrows	95
Black-footed Albatross	Diomedeidae	Ground	3195
Laysan Albatross	Diomedeidae	Ground	2855

Elaborate

When the students have completed the worksheets, form the class into three groups and distribute the case studies. Have each group give a short presentation of the observed results and what they think those results mean for the future of Palmyra. Encourage them to include details in their predictions; which species will see the most benefit from the removal of rats or some sort of timeline for recovery. Provide them with either chalkboard/dry erase board space or a large piece of newsprint or paper so the groups can create a visual aid for their presentation.

Evaluate

Evaluate the presentations of your students and consider the following metrics:

- Presentation skills – eye contact, clear speaking, everyone contributing
- Effective visuals
- Use and interpretation of the data from the given case study
- Discussing similarities and differences with Palmyra and making informed predictions for the future of birds on the atoll

Extend

- Do some birding in your area either as part of class or encourage the class to do it after school on their own. If they're interested, students can use http://ebird.org/ebird/eBirdReports?cmd=Start to find good places for birding nearby and to record the birds they see.
- Use data from the Christmas Bird Count organized by the Audubon Society to practice making graphs and interpreting data trends. You can use data from your local area or

from Hawaii and the Northwest Hawaiian Islands if you'd like to continue to looks at some of the same species. Data sorted either by species or by location can be downloaded here: http://netapp.audubon.org/CBCObservation/#

- Investigate some cases of invasive species in your area and how they have affected native species.

Pacific Remote Island Marine National Monument Lesson 1: Seabird Biology Case Studies

Case Study #1 – Wake Atoll

Wake Atoll is a very isolated atoll and the farthest north and west atoll of the PRIMNM. Despite its remote location, Wake has a long history of human impact, mostly during WWII. Thousands of Japanese soldiers were under siege there during the war and over 2,000 American personnel lived on Wake in the 1970's. The military activity and predation from feral cats (originally pets brought by residents of the base) was very destructive to the seabird populations. Look at the table of bird numbers from Wake Atoll and prepare a brief, 5 minute presentation about how bird numbers have changed since observations have been made at Wake. Include at least 1 visual in your presentation, discuss similarities and differences with Palmyra, and make a prediction for the future of birds on Palmyra based on this data.

Important Facts for bird populations

- Cat control started in 1996 and all feral cats were moved away by 2004.
- It's estimated that 30,000 birds were killed annually by the feral cats.
- Typhoon Ioke hit Wake on August 31st, 2006 leading to damage of a shearwater colony at Peacock Point and the Grey-backed Tern colony on the north shore of Peale Island was abandoned.
- Ironwood Trees were introduced and began expanding in range after the 1970s. They create habitat for tree-nesting species but their needles smoother native vegetation.

Table 2. Wake Bird Population Counts

(Population count/number of nests)

BIRDS	1923	1939-40	1949-53	1967	1988-92	1993	Dec-96	Jul-98	Mar-99	Jul-03	Dec-03	Aug-04	2005	2006 IOKE	Jun-07	Jan-08
Laysan Albatross	0	?	0	0	5/1?	p/1	5/1n?	0 (1 n-'97)	2/(1n-'98)	0	2/n	Feb-00	2/1chick	p/0	2/failed nest	0/0
Black-footed Albatross	p/0?	3/0?	0	0		6/?	3/1n	6-'97/?	4/0n	0	3-6/1n?	0	p/0	p/0	1 Dead, p/0	p/0
Wedge-tailed Shearwater	100/n	100/n	0	6/?	0	0	0	?/50	0	?/70	?/n	176/105			81/90 burrows	24 active nests
Christmas Shearwater	2/?	+ in 1936	0	0	0	0	0	0	1/?	0	0	1/?			1/n?	
White-tailed Tropicbird		?	2	15/n?						2	4	5/2n?			3/courting	
Red-tailed Tropicbird	30/n	"many"/12	0	20/2		4/n	0	25/?	100/25	p/40	p/?	p/15			p/n	
Masked Booby	3/2n	?/"many"	0	0	?/2n	5/n	10/2n	21/5n	11/5n	25/7	75/18	70/18			60/25	p/31
Brown Booby	500/n	?/100	0	40/23	212/106n	111/56n	26/13n	400/107n	111/?	400/162	300/31	p/76			313/164	p/60
Red-footed Booby	5,000	2000+/++	p/n	p/18	p/41	p/35n	1,500/32n	2,200/5n	p/25n?	2500/20?	2500/76	3000/5			733/n	
Great Frigatebird	2,000/n	"very many"/25	"a few"/?	30/2n	274/0	225/0	500/0	100/0	400/n	150-300	150-300	150-300	Possible Nesting		Possible Nesting	Nesting/one red-headed juvenile
Sooty Tern	?/300n	p/500	"1000's"	p/230,000	p/143,000	p/300	10K/n	11K/75	200,000 87,000	p/n	p/0	p/0			Chick mass starvation	50,000 @Peale
Gray-backed Tern	100/n	400/?	0	21		8/?			4/0n	5/1?	0	60/9			75/n	
White Tern	2,500/n	p/14	p/n	p/n		6/n	p/1n	100/3	60/n	200	300	400/n			all isles nests	
Black Noddy	200/n	p/25	0	0		2/?	200/100n	300/100n	715/2n	1000/n	1500/n	2000/n			common/n	
Brown Noddy	6,000/n	"abundant"/ 4 nests	p/n	50/0		98/3n	Jun-00	100/50n	20/4n	200/n	500/n	1000/n			Tree&ground nesting	
Pacific Golden Plover	200	"abundant"	24	250		p	200	31	160	20	200	20			23	6
Bristle-thighed Curlew	3	4		p					4	0	1	1				
Wandering Tattler	2	26	2	10		p			30	5?	15	5			4	5
Ruddy Turnstone	2	25	1	20	p	1	4	2	1	5	12	5			3	
Pintail Duck				9	5		4	0	6	0	2	0			9	26 on 10/07

CHART KEY

p/n = number present/number of nests

/ ? = not known if nesting

"many" are quotes taken from papers

87K= 87,000

From Rauzon, et al., (2008) The Status of Birds of Wake Atoll.

Case Study #2 – Anacapa Island, California

Anacapa Island is one of the Channel Islands off southern California. Rats have been present on the island since at least the early 20th century and were eradicated in 2001 and 2002. Use the recovery facts and Xantu's Murrelets nesting numbers and prepare a brief, 5 minute presentation about how bird numbers have changed since the rat eradication. Include at least 1 visual in your presentation, discuss similarities and differences with Palmyra, and make a prediction for the future of birds on Palmyra based on this data.

Anacapa Seabird Recovery facts

- Ashy Storm-petrels recorded breeding on the island for the first time ever
- Cassin's auklets were not breeding on the island when rats lived there but have expanded their territories and began breeding on the island
- The number of Scripps murrelets nests has quadrupled, rats used to eat roughly 70% of their eggs
- The cliffs are home to the largest breeding colony of brown pelicans in California

TABLE 1
Breeding effort and success of Xantus's Murrelets in sea caves at Anacapa Island during 2000–2005

Nest site summary	Pre-eradication year				Post-eradication year			
	2000	2001	2002	2000–2002	2003	2004	2005	2003–2005
Tagged & monitored	13	15	16	16	24	25	28	28
Potential	28	28	28	28	28	28	28	28
Nesting attempts	9	11	11[a]	31	15	11	18[a]	44
Occupied	9	11	10[a]	—	15	11	17[a]	—
(occupied/potential)	32%	39%	36%	36%	54%	39%	61%	51%
Hatched	7	2	4	13	12	8	15	35
(hatched/nesting attempts)	78%	18%	36%	42%	80%	73%	83%	80%
Depredated	2	8	6	16	1	2	0	3
(depredated/nesting attempts)	22%	73%	55%	52%	7%	18%	0%	7%
Abandoned	0	1	1	2	2	1	3	6
(abandoned/nesting attempts)	0%	9%	9%	6%	13%	9%	17%	14%

[a] Two nesting attempts in one site treated as separate nesting attempts.

From Whitworth et al. (2005) Initial Recovery of Xantu's Murrelets Following Rat Eradication on Anacapa Island, California.

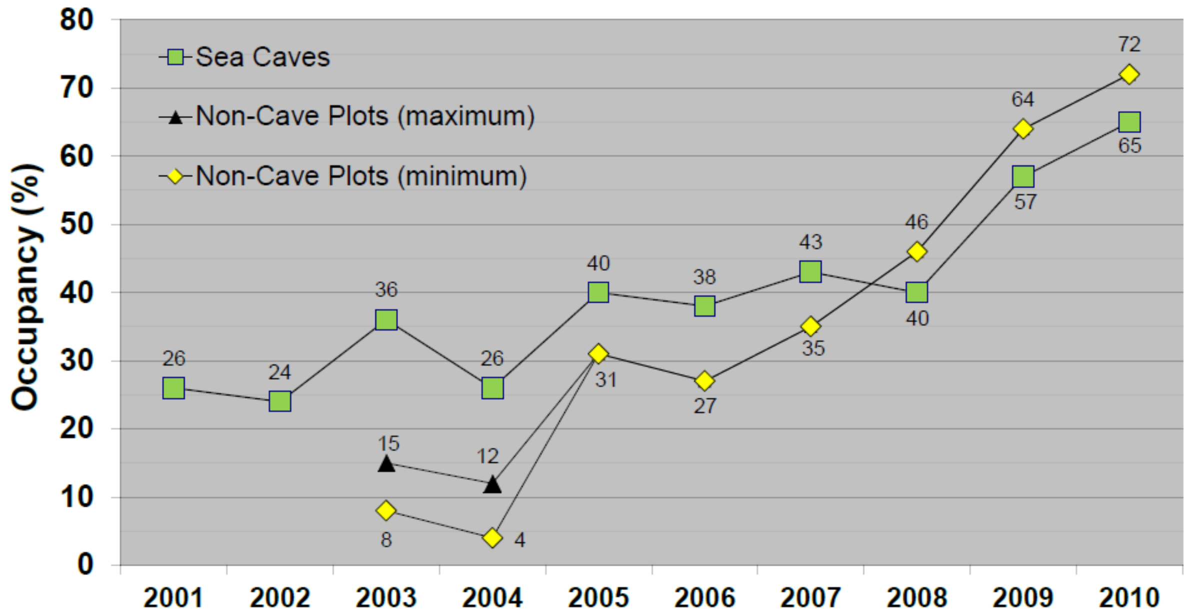


Figure 9. Annual site occupancy for Xantus's Murrelets in sea caves (2001-2010) and non-cave plots (2003-2010) at Anacapa Island, California. Minimum occupancy in non-cave plots assumed no occupied sites in Rockfall Cove plot in 2003-04, while maximum occupancy assumed two occupied nests found in 2005 were occupied in both 2003 and 2004 (*see Methods; Table 3*).

From Whitworth et al. (2012) Responses by Breeding Xantu's Murrelets Eight Years after Eradication of Black Rats from Anacapa Island, California.

Case Study #3 – Baker, Howland, and Jarvis Islands

Baker, Howland and Jarvis are the southernmost islands of the PRIMNM. Cats were introduced in the 1930s to control rat populations. While the cats got rid of the rats, they also killed off a number of small bird species including grey-backed terns, blue noddies, brown noddies, Christmas shearwaters, Tropical shearwaters, and Polynesian storm-petrels. They negatively affected the seabirds' populations that remained on the islands as well. Use the time table of events and the table of bird numbers from the three islands to prepare a brief, 5 minute presentation about how bird numbers have changed since cats have been removed. Include at least 1 visual in your presentation, discuss similarities and differences with Palmyra, and make a prediction for the future of birds on Palmyra based on this data.

Table 1 Historical timeline of introduction and eradication of predators, and selected human activities at Howland, Baker and Jarvis Islands.

Year	Howland	Baker	Jarvis
Pre-history	*Rattus exulans* introduced		
Early 1860s	Guano miners and whalers brought rodents. Species and islands not specified		
1858 - 1878	104,000 tons guano taken	300,000 tons guano taken	300,000 tons guano taken
1935	All three islands colonised, cats introduced		
		Norway rats named as present	
Post WW II	Cats probably exterminated Pacific rats	Cats probably exterminated Norway rats. Mice remain	
1963 -– 64	Cats removed from these two islands		211 cats killed (80% of popn)
1965	Cats allegedly introduced to these two islands by military		
1965		Mosquitoes introduced, island sprayed with DDT	
1982	Cats present	Cats died out naturally by now	118 cats killed (99% of popn)
1986	Final 17 cats killed		
1990			Last cat killed
2010	No introduced predators		Mice still present

From Rauzon et al. (2011) Howland, Baker, and Jarvis Islands 25 years after cat eradication: the recovery of birds in a biogeographical context.

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Appendix C: Pacific Remote Island Marine National Monument Lesson 3, Humans and the Oceans

Lesson Summary:

Understanding that the environment provides us with resources and how the resources that humans need have changed over time and that the need for resources is a big part of why islands of the PRIMNM are part of the United States. The historical resource use and the transportation will be used to give students an understanding of ocean currents and how latitude and longitude can be to measure distance or find a location. Comprehend the driving forces behind global wind patterns.

Learning Objectives:

- Get a basic understanding of wind patterns in the central Pacific and how that might affect travel decisions
- Understand that wind is a major component driving ocean currents
- Understand that the physical processes of the ocean can affect both biological and human systems

Organization:

- **Engage –** Discovery of the islands of PRIMNM
- **Explore** – Wind patterns of the central Pacific and historical sailing routes
- **Explain –** Visualization of global wind and ocean currents
- **Elaborate –** Upwelling demonstration
- **Evaluate –** Create a voyage plan based upon wind and ocean currents

Grade Level:

- 7-12 grade

Teaching Time:

- One 60 minute period

Instructional Materials and Resources:

- Pilot charts: 1 of the same month for North Pacific and South Pacific (1 per pair or small group) can be downloaded here: http://www.offshoreblue.com/navigation/pilot-charts.php

- Computer and projector
- Animation of global wind patterns and ocean currents: http://earth.nullschool.net/#current/wind/surface/level/orthographic=-158.83,3.97,608
- For upwelling demonstration:
    - Clear, rectangular container roughly 18” x 4” x 4” (large Tupperware or small fish tank would work)
    - Water, some warm or room temperature and enough to fill the bottom of the container with about 2” of water chilled with ice cubes
    - Food coloring
    - Wind source – a fan or hair dryer

Vocabulary:

- LATITUDE AND LONGITUDE – the lines that divide the globe and run parallel to the equator or prime meridian
- OCEAN CIRCULATION – the movement of ocean water around the globe due to wind forces and temperature differences between the equator and the poles.
- UPWELLING – the process by which deep ocean water returns to the surface

Background

Many of the islands of the Pacific Remote Islands MNM were visited by ancient Polynesian voyageurs, but none of the islands appear to have sustained long term colonization due to lack of available resources. However, one of the resources they do possess, guano, was of great interest in the mid-1800s. Crops like cotton and tobacco had left the land nutrient poor and guano was found to be a very good fertilizer. Farmers used the guano to fertilize their fields and improved the growing conditions; important and there was greater demand for agriculture because of the growing population of the United States. The ships that would travel to the islands to transport the guano back to the Americas were sailing ships. These square-rigged ships sailed best with the wind at their stern, pushing them along from behind. Sailing with, as opposed to against, a dominant ocean current also was in a ships advantage. Today, as ships plan their routes, the captains still consider wind and currents even though they have less significant effects upon large motor vessels. Navigators planning routes for private and commercial vessels use pilot charts same as the ones used in this lesson to plan the best route.

In addition to affecting how the sailors would travel to and from the islands, ocean currents have a great effect on the natural processes. Baker, Howland and Jarvis Islands are located within 50 nm of the equator in the central Pacific Ocean and this location puts the islands in the flow of the Equatorial Undercurrent (EUC). The EUC is a cold, nutrient rich subsurface current flowing from west to east, and when it comes into contact with the underwater volcanoes that form the base of the islands the water is deflected toward the surface of the ocean in a process known as upwelling. When the nutrient-rich waters come to the surface it fuels primary productivity, the energy from which travels up the food chain to zooplankton, fish, and seabirds, forming a productive hot-spot in a region that otherwise has very low productivity. These productivity hot-spots coupled with exposed land for nesting sites make ideal seabird breeding colonies and over the years, millions of seabirds have spent time rearing their young on these island. The legacy of these colonies are thick deposits of guano that brought these islands to the attention of the world during the mid-1800s.

Preparation

- Familiarize yourself with the Pacific Remote Islands on Google Earth.
- Print the pilot charts and understand how to read them. Directions for reading the charts are included with the chart.
- Make sure the ocean and wind circulation animation is working on your computer
- Practice the upwelling demonstration

Engage

Either using Google Earth or the map from the images file, show the Pacific with the islands of the PRIMNM. If you did not do Lesson 1 on seabirds, you may want to do the *Engage* part of that lesson to give your students some perspective on the size and locations of these islands.

- Give your students a few minutes to talk in small groups to brainstorm about the discovery of the islands and how they came to be part of the United States.
- Have the students share their ideas, make a list of reasons they might be part of the U.S.

Give your students a brief introduction to the fact that a unique feature of these islands (and a few other coastal areas in the world) is that guano accumulates which can then be mined by people and used for fertilizer in agricultural areas. ***You may skip or just do a very quick reminder if you completed the lesson on nutrient cycling.*** The United States passed a law called the Guano Islands Act on August 18, 1856 that enables U.S. citizens to claim islands containing guano for the United States as long as they are not previously occupied and not already owned by another government.

> *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 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.*
>
> *1. —first section of Guano Islands Act of 1856*

Over 100 islands were claimed at some point for the United States under this act, though only a few remain in the possession of the U.S. Of those, several are in the PRIMNM including Baker, Howland, Jarvis, Johnston, Kingman Reef, and Palmyra Atoll.

How were the islands discovered and claimed and how was the guano transported? Use the following questions to determine what students know about the reasons for exploration.

- Who was exploring and what were their motivations?

Many of the islands of the central Pacific had historically been used as stops for Polynesian voyageurs. Most of the first Europeans to discover the islands were on whaling ships. These ships departed from lots of locations on the mainland of the U.S. and frequently were from New England and occasionally came across new islands as they sailed around. Once the guano trade was established and the U.S. passed the Guano Act, some ships went out specifically looking for islands with guano resources.

- What was their method of traveling and what technologies did they have at their disposal?

Open ocean exploring was done in sailboats at that time. This meant explorers were at the mercy of the wind for how fast and where they could sail since you cannot sail into the direction that the wind is coming from. They navigated using instruments like sextants which helped them find their position using the sun stars.

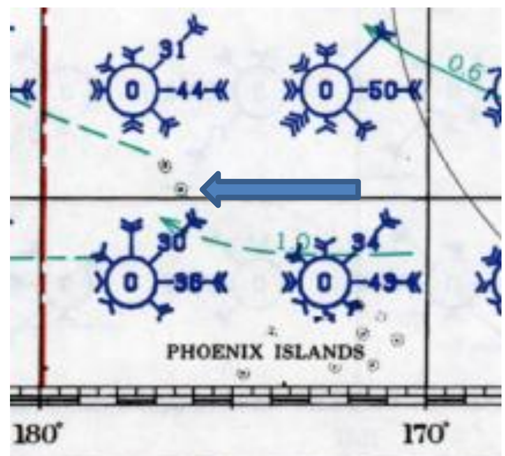
- How would current technology have changed the exploration process?

Modern day navigation has made much easier to find a ships location while out at sea. In addition, large ships powered by engines instead of the wind give ships more flexibility of how long they can be out at sea and what direction they travel since they do not rely on wind for propulsion.

Explore

> *When I'm playful I use the meridians of longitude and parallels of latitude for a seine, drag the Atlantic for whales.*
>
> *-Mark Twain, Life on the Mississippi*

Distribute the pilot charts and the Pacific Ocean charts and give a brief overview of how to read the pilot chart (instructions also on the chart itself). Show the students how to line up the north and south Pacific charts so they have a picture of the whole Pacific Ocean. Baker is located at 0°11'41" N x 176°28'46" W and is not labeled but there is a circle on the chart marking its location. Just northwest of the Phoenix Islands label there are two circles, Baker is the one to the south almost touching the equator line. Ask the students to predict a route in pencil on the pilot chart of where the ship that discovered Baker Island may have been traveling to and from. Remind them you cannot sail straight into the wind, draw on the board the diagram shown below to clarify in which directions a sailboat can sail relative to the wind.



From the North Pacific Pilot Chart. The blue arrow is pointed at Baker Island.

- Things you may stress for them to consider: wind, currents, proximity, destination, transportation infrastructure in the U.S. in the mid 1800's. Depending on time, you may want to remind them the Panama Canal did not yet exist, or give them a chance to predict the route and remind them second. The pilot charts do not show the eastern seaboard of the US. It may be useful to project or display a map that shows the Pacific as well as all of North and South America and have them verbalize the parts of the route they cannot draw.
- Give them the following information and ask them to refine their predictions.
  - The ship that discovered Baker Island was originally from Nantucket Island off the east coast of Massachusetts. It was in the Pacific to hunt whales.
  - The ship, called the Equator, was a sailing ship that worked best with the wind behind it. You could also think of it sailing best in the directions that the longest arrows on the pilot chart point towards.

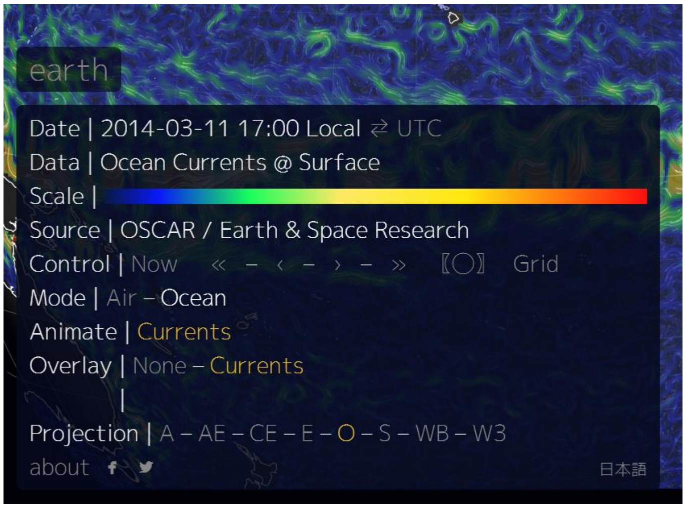
- Ask students to talk with the neighbors, share their predictions, and then give them final piece of information.
    - The Equator was in Hawaii in 1819, sometime after discovering Baker.
- Ask students to share their ideas with the class, and then explain that the Equator, and other whaling ships from New England, would have gone around Cape Horn and north along the coast of South America. Eventually they would sail offshore to go to Hawaii. Both the wind direction and ocean currents played a role in how they would travel because they did not have engines to move their ships. Show the image of typical whaling routes and currents. The Equator would have likely taken a route similar to the pink one.
- Tie this to modern times by explaining the ocean is still used for lots of global transportation. On the North Pacific Pilot chart, all of the arc that say great circle route and list two locations are routes taken by cargo ships today. They represent the shortest route between those two places.

Explain

Wind was crucial for the movement of the ships that discovered these islands and were used to transport guano back to the United States. Where does wind really come from?

- Show this animation of global wind and ocean currents: http://earth.nullschool.net/#current/wind/surface/level/orthographic=-158.83,3.97,608
- Reorient the globe so the Pacific is the focus so it's clear what's happening there. By clicking on the earth and moving the cursor you can move the image however you'd like.
- Earlier in the lesson students learned about how wind had an effect on how explorers traveled; ask what other global processes (natural and human) wind effects?
    - *Ocean currents, wind power, weather*

Show the animation again but this time switch it to show ocean currents.



- You can change to ocean currents by clicking on "earth" in the corner, then click "ocean" option under mode. Show the Atlantic and see if your students recognize the Gulf Stream along the eastern coast of the U.S.
- Switch back to the Pacific. What are some of the major currents in the Pacific Basin? Are the currents that we see on this animation the only currents in the ocean?
    - *These are just surface currents, subsurface currents exist as well.*

Elaborate

In the equatorial Pacific, there is a nutrient rich subsurface current called the Equatorial Undercurrent (EUC). When this moving water runs into the underwater volcanoes that Howland, Baker and Jarvis sit on top of, the nutrient rich water moves up to the surface in a process called upwelling. This is important because the nutrients brought to the surface by the upwelling are important for phytoplankton. More phytoplankton means more zooplankton which means more birds and all sorts of life.

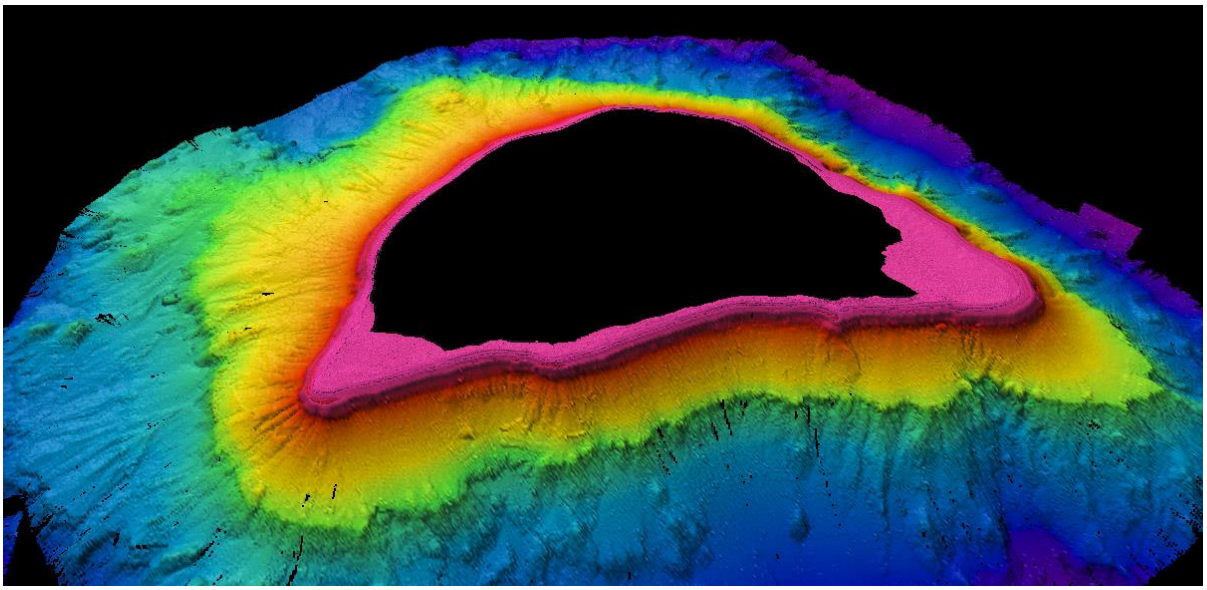
Upwelling Demonstration

1. Put a few drops of food coloring in the container with cold water, mix well and then pour into clear rectangular container.
2. Gently fill the rest of the container with warm or room temperature water and get the water level as close to the top of the container as possible.
3. Give your students a moment to observe the layers, then apply the wind source (a fan or hair dryer on a cool setting).
4. Put the wind source at the edge of the container and have it blowing the long way across the container.

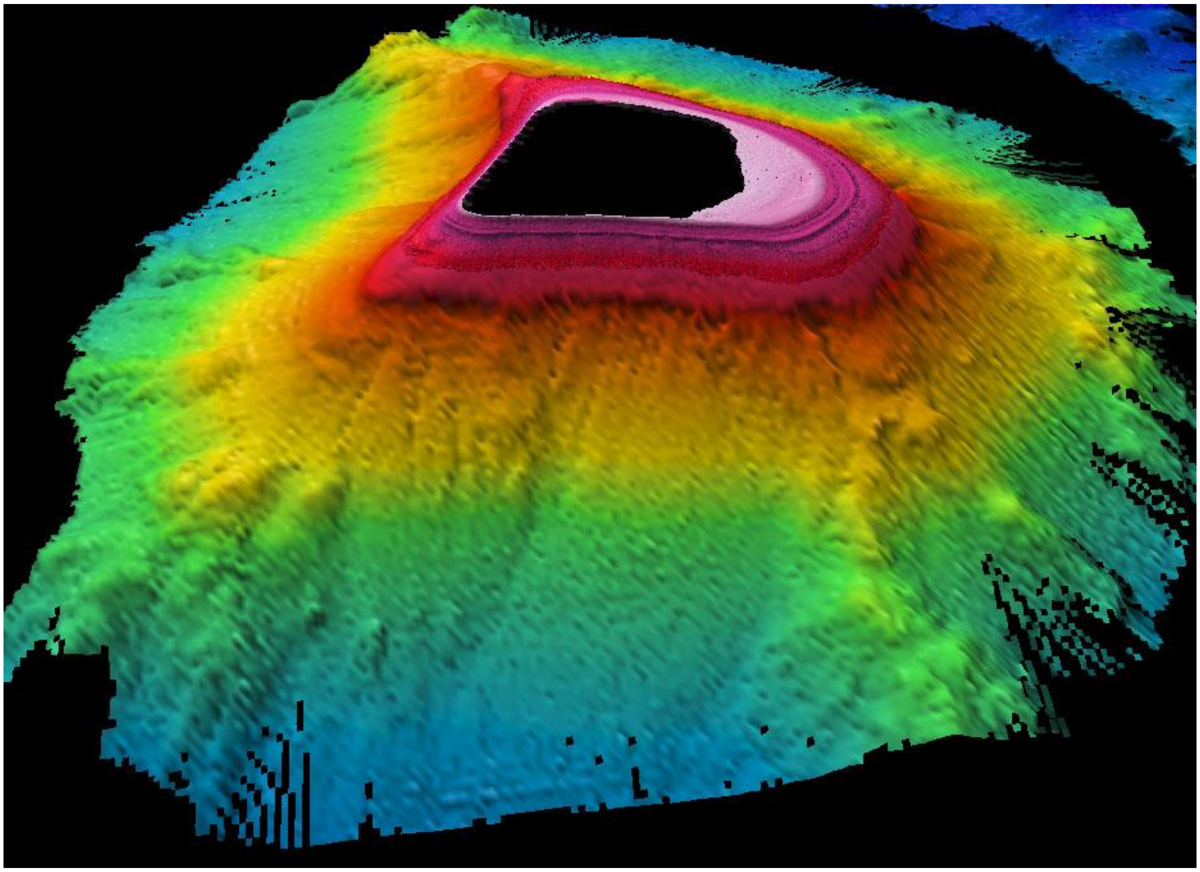
Explanation

The layers of water represent the water surface water and the cold, deep, nutrient rich water. The wind, in the Pacific it is the Northeast Trades, generates surface currents and also effects subsurface currents. When those subsurface currents hit an obstruction like the edge of the container or a submerged volcano, the water and nutrients rise to the surface. This demonstration is really showing wind driven upwelling, whereas the upwelling occurring at these islands is due to the EUC. However, the physical process of cold, nutrient rich water coming to the surface from depth is the same. Show the students the images below of the bathymetric images of Baker, Howland, and Jarvis and explain how the islands act like the edge of the container in the demonstration. All of the images are 3-D images of multibeam bathymetry from Pacific Benthic Habitat Mapping Center, part of the School of Earth Science and Technology at the University of Hawaii at Manoa. Purple/blue represents the deepest areas while red is the shallowest. The faster its transitions from cool to warm colors the steeper the landform.

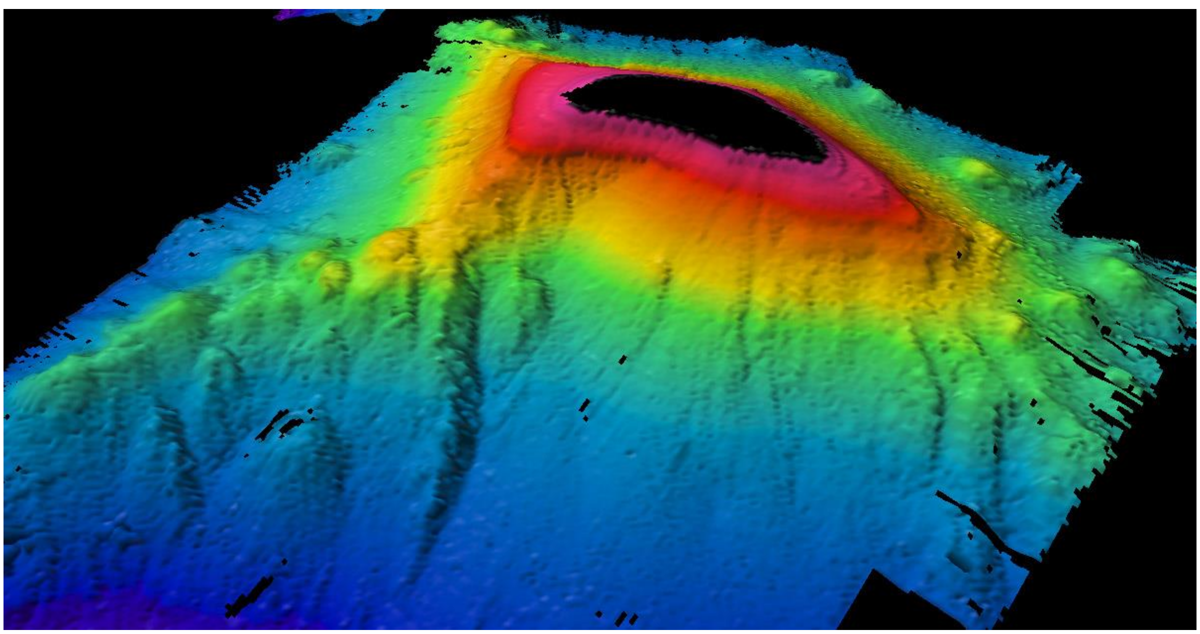
Johnston Atoll



Baker Island



Howland Island



Evaluate

Return to the Pilot Charts used at the beginning of the lesson. Have the students design a voyage based upon what they've learned about ocean currents and how sailboats work. You can give them a starting and finishing location or let them design the whole voyage themselves. Have them fill out the voyage plan worksheet, giving an explanation of why they would travel to those places, being explicit about how the currents and wind affect their directional choices. The worksheet prompts the students to use the pilot charts and teacher guidance to plan the voyage; feel free to provide as much or as little direction as you feel your students need. For example, you can give the students options of destinations, say they must include at least two continents, or let them decide entirely.

Extend

- Investigate one way we learn about ocean circulation. There is an international project called Argo and ships launch floats all over the global ocean. Float data and information can be found here: http://www.argo.net/index_flash.html and here http://www.argo.ucsd.edu/.
- Connect lessons learned to your local environment. If you are coastal, there may be some historical connection between the ships that were part of the guano trade, if not you can just discuss the major local ocean currents. If you are inland, discuss how major wind patterns that cause ocean currents also affect weather in your area.
- Based on the discussion of two different types of upwelling you discussed, have the students use the pilot charts and a world atlas to determine where they think upwelling regions of the world are likely to be. Use the following website http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MY1DMM_CHLORA that has a short animation of regions of high primary productivity to validate their investigations. A link at the bottom of that site will take you to http://neo.sci.gsfc.nasa.gov/view.php?datasetId=MY1DMM_CHLORA where you can see the currently monthly or weekly average. Ask them to speculate about what might be causing high productivity if it is not due to upwelling.

- *Land based sources of nutrients such as rivers, coastal runoff, or wind carrying dirt are also great sources of nutrients.*

Sources

Lesher, Pete. (2008). A Load of Guano: Baltimore and the Fertilizer Trade in the Nineteenth Century. *The Northern Mariner,* (3-4): 121-128.

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U.S. Fish and Wildlife Service. Baker Island National Wildlife Refuge. http://www.fws.gov/refuges/profiles/index.cfm?id=12511

Appendix D: Papahānaumokuākea Marine National Monument Lesson 2, Biodiversity Lesson Plan

Lesson Summary:

The objective of this lesson is for students to understand the importance of biodiversity and how changing biodiversity affects an ecosystem. Using ecosystems found in Papahānaumokuākea MNM, they will learn how to quantitatively measure biodiversity and compare different areas. They will also be introduced to some of the local flora and fauna of the Northwest Hawaiian Islands.

Learning Objectives:

- Learn about the importance of biodiversity in an ecosystem
- Learn details about biodiversity within Papahānaumokuākea MNM
- Practice and experience different methods of quantifying biodiversity

Organization:

- **Engage** – Digital exploration of Papahānaumokuākea MNM and its flora and fauna
- **Explore** – Introduction to biodiversity
- **Explain** – Experiencing diversity through music
- **Elaborate** – Calculate biodiversity several ways
- **Evaluate** – Class discussion on biodiversity

Grade Level:

- 7-12 grade

Teaching Time:

- Two 45-minute periods, one 90 minute period

Instructional Materials and Resources:

- Computers (exercise can also be done as a class or small groups/partners and modified with just calculators)
- Shannon-Wiener Diversity Index excel file
- Biodiversity PowerPoint
- Google Earth

- Links to pronunciation and explanation of the name Papahānaumokuākea MNM
  - **http://www.papahanaumokuakea.gov/about/pronounce.mp3**
  - **http://www.papahanaumokuakea.gov/about/meaning.mp3**
- Video of marine creatures of PMNM
  - **https://www.youtube.com/watch?v=Y_9lPax5_HI&feature=player_embedded#at=37**
- Video about Hawaiian Monk Seal
  - **https://www.youtube.com/watch?v=6eKlF66CEdQ&feature=player_embedded#at=46**
- Encyclopedia of the Sanctuary: Papahānaumokuākea MNM
  - **http://www8.nos.noaa.gov/onms/park/Parks/?pID=12**

Vocabulary and Key Concepts:

- BIODIVERSITY OR SPECIES RICHNESS – the number of species in an ecosystem
- ENDEMIC – a plant of animal species that has a highly localized or restricted geographic distribution
- Biodiversity can be measured in different ways. The population of individuals of a particular species, the percent of endemic species, and the number of unique species in one ecosystem as compared to another can all be used as metrics.
- Maintaining biodiversity has important ramifications to preserving food webs and ecosystem functions.

Background

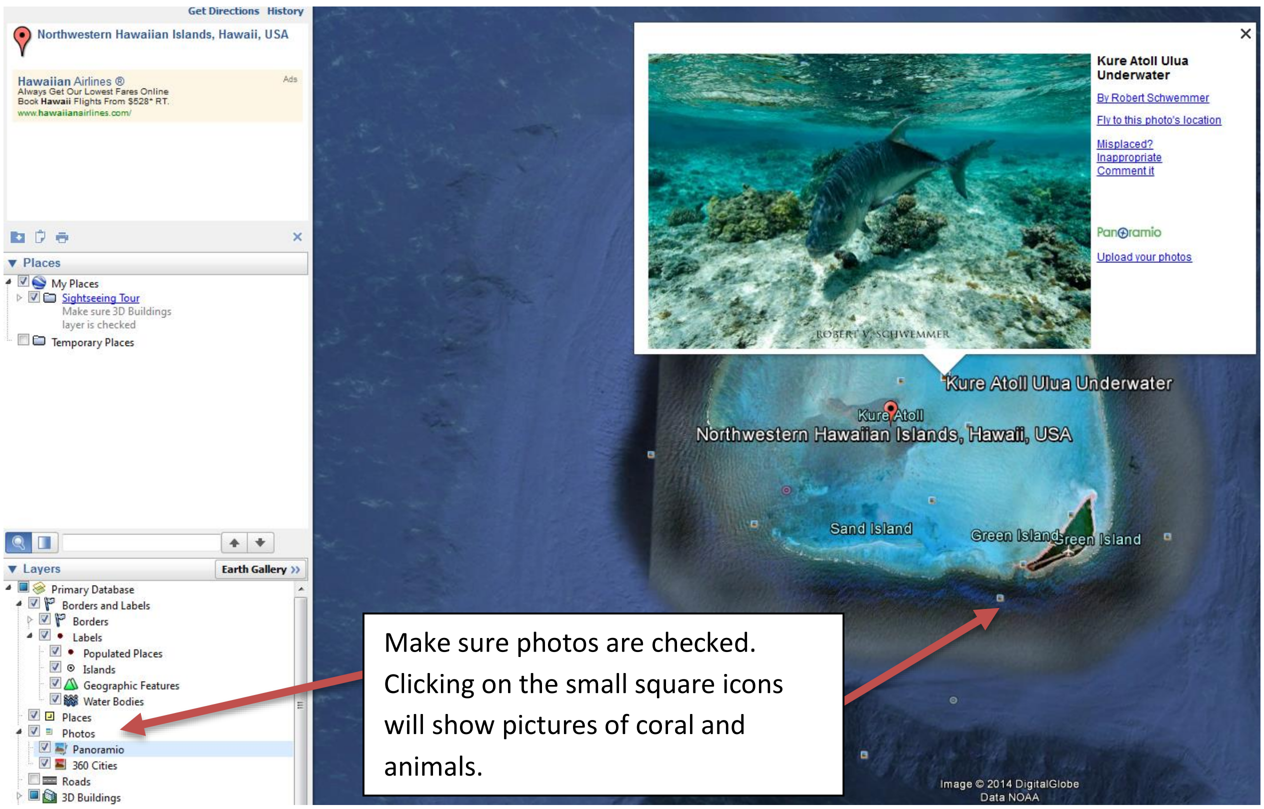
Papahānaumokuākea Marine National Monument is the largest conservation area within the United States. The name comes from the names of two Hawaiian ancestors, Papahānaumoku and Wākea, whose union, according to legend, created the Hawaiian Islands and the Hawaiian peoples. The monument was established in 2006 and in addition to its national monument status it has also been declared a natural and cultural World Heritage Site by UNESCO. The establishment of the national monument combined several existing conservation areas into one entity and added additional waters. The monument encompasses 139,797 square miles and extends northwest for 1,200 nautical miles starting north of the island of Kaua'i. In addition to the agencies managing the MNMs, the state of Hawaii and the Office of Hawaiian Affairs are involved in the management of Papahānaumokuākea. The vision and mission for the monument includes protecting the ecosystem and natural systems as well as the cultural resources and Native Hawaiian culture connected to the islands.

Though the majority of the monument is open ocean and submerged reef, there are a handful of atolls and islands with emergent land. Its remote location and historically low level of human impact has left Papahānaumokuākea MNM in a relatively pristine condition providing excellent habitat for resident species and a unique environment for scientists to study and to better understand how humans are affecting coral reef ecosystems elsewhere. This monument is home to over 7,000 marine species and has a very high level of endemism with roughly ¼ of those species found only in the Hawaiian Archipelago (NOAA). Several endangered and threatened species reside in the waters of the monument including the Hawaiian monk seal, green sea turtle, and the Laysan duck. There are also Native Hawaiian cultural sites on the islands of Nihoa and Mokumanamana.

The Papahānaumokuākea MNM have been the focus of lots of scientific research are a great model ecosystem for OL Essential Principle 5 – *the ocean supports a great diversity of life and ecosystems*. There is a latitudinal gradient reflected in the community composition across the Papahānaumokuākea MNM. Temperate and subtropical fish species are found around the northern islands while tropical are found in the southern waters and shark species varied as well (Friedlander et al., 20009) The Papahānaumokuākea MNM have high levels of endemism due to their isolation (Friedlander et al., 2009; Fautin et al., 2010). Recent dive surveys report that 46% of reef fish in the Papahānaumokuākea MNM are endemic. Endemism appears to vary with latitude as well, at the southern end of the islands there was 16% endemism ranging up to 92% at the northern extent of the chain (Kane, Kosaki, and Wagner, 2014). Another feature frequently noted is the apex predator dominated food web, a feature not seen in coral reefs in less pristine condition (Friedlander et al., 2009).

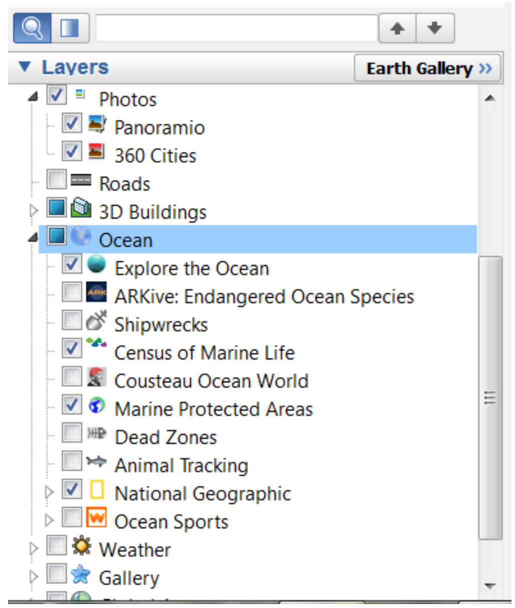
Preparation

- Familiarize yourself with Google Earth for Papahānaumokuākea and how you can find pictures of plants and animals by clicking on the icons.
    - Note – If you type Papahānaumokuākea into search on Google Earth many times it takes you to the visitor's center in Honolulu as opposed to the actual monument. Searching Northwest Hawaiian Islands or the name of any of the atolls will take you to the right area.



- Make sure the other internet and computer activities (the YouTube music and PowerPoint) are working.
- Familiarize yourself with the math in the *Elaborate* section where there are biodiversity calculations. Depending on your class's math skills level you may want to make it a group activity or only do the easier questions.

Engage



Give a short intro to Papahānaumokuākea MNM. Play the clips that explain the pronunciation and history behind the name. Move onto Google Earth showing show the islands are in relation to your location and Hawaii, then zoom in and investigate some of the individual islands. There are a few features of Google Earth that will help with the exploration. On the lower left portion of Google Earth, click on the Ocean option and expand that tab by clicking on the triangle at the left. Start with Explore the Ocean, Census of Marine Life, Marine Protected Areas, and National Geographic checked. As time allows you can have your students check out the features of the other layers. If your students have access to computers, let them explore, otherwise do it as a class using a projector. The Marine Protected Area layer outlines the monument and the others of the Pacific, making it easy to visualize the boundaries. Direct the student's exploration with the following questions:

- How many different species can they find in the pictures?
- How many different types of geographic features (atolls, islands, shoals, etc.) can they find?
- Do they know anything about the animals that they find? What they eat, how they live or interact with other species in the ecosystem?

Watch the videos on the marine creatures and Hawaiian Monk Seals if desired, they can be accessed from the above links or from the square icon labeled Northwestern Hawaiian Islands Marine National Monument on Google Earth.

Explore

What is biodiversity and why is it important? Use the biodiversity power point to explain the basic principles of biodiversity. Ask these questions as you start:

- What do they think of when they hear the term biodiversity?
- Is it important? Why?
- How many different species of animals and corals did they discover when looking at the google earth of the monument?
- What are the challenges of studying animals in a marine environment versus on land?

The power point notes direct you to get students predictions on species richness and endemism. When you get to the endemism slide, stop there for the day and discuss if the predictions were supported or refuted by the graphs and maps. Assign the Day 1 homework – Student Worksheet 1; use the Encyclopedia of the Sanctuary if needed to get ideas for students to choose organisms.

Explain

Start the lesson by asking students to share what they learned about the species they investigated. Stress the sharing of what role the organism plays in the ecosystem and links it has to other organisms. How would losing species affect those links and the overall ecosystem? To give your students perspectives on diversity complete the following musical exercise.

- Play two different versions of the 1812 Overture. First with violin and melodica. Start this clip at 5:23 so that each features the finale of the overture. https://www.youtube.com/watch?v=JmS7fKEE_nA
- Next play the version that features the full orchestra version: https://www.youtube.com/watch?v=u2W1Wi2U9sQ&feature=related
- Don't show the associated videos, just play the music and have students keep a tally on a piece of paper of how many instruments they can identify in each version. Then give them a few minutes to brainstorm answers the following questions.
  - Which version would you prefer to listen to? Why?
  - Can you draw any analogies between music and the concepts of biodiversity we talked about yesterday?
- Aim to have them come away with the understanding that the music with more diversity has a fuller sound just as an environment with more species is more complete.

Elaborate

The next step is to give the students some tools to measure biodiversity. Is just counting plants and animals, like you counted the instruments sufficient or are there other methods that seem like better options?

- Complete the Measuring Biodiversity exercise. Have the students work in pairs or small groups and do the first part of question 1 as a class so that everyone understands how to calculate the Shannon-Wiener Diversity Index. The Shannon-Wiener Diversity Index puts a numerical value on biodiversity by taking into account the number of species and also how evenly distributed the individuals are amongst the different species. Students will need calculators if not using computers.
- *If you do not have access to computers in class you have options for question 3 involving excel: do it together as a class via projector, assign for homework, or just ask them to make predictions on how the index would compare between the two areas based on what they've learned.*

1. Use the Shannon-Weiner diversity index to calculate the diversity index of the following groups. What do the different index values mean? **Walk through the Reef 1 calculation as a group, and then have the students do 2 and 3 as individuals or in pairs.**

$$H' = -\sum_{i=1}^{R} p_i \log p_i$$

H' = diversity
∑ = sum of each individual
p_i = the proportion of individuals within the community

	Reef 1	Reef 2	Reef 3
Parrotfish	30	14	18
Angelfish	4	12	0
Triggerfish	6	14	22

1. Find the total population for the community: 30 + 4 + 6 = 40
2. For the first species, find the p_i, what portion of the total population it equals: 30/40 = 0.75
3. Use that value to find $p_i \log p_i$: 0.75log(0.75) = -0.094
4. Repeat for the two other species: 4/40 = 0.10 6/40 = 0.15
0.10log(0.10) = -0.10 0.15log(0.15) = -0.124
5. Get the sum of those values and multiply by -1: -0.094 + -0.10 + -0.124 = -0.318(-1) = 0.318
Repeat for the 2 other reefs and compare the final values
Reef 1 = 0.318 Reef 2 = 0.465 Reef 3 = 0.299

Reef 2 has the highest value, it has populations of all 3 species and they have very similar population numbers (it's evenly distributed). Reef 3 is next, it has all 3 species but heavily favors the parrotfish in terms of population. Reef 3 has only 2 of the 3 species represented.

http://bumperscollege.uark.edu/west/3103/08diversityexercise.htm for additional numbers and explanation

2. You do another survey of the three reefs and in addition to the fish listed above you find Tiger Sharks and Green Turtles living at Reef 1. What is the alpha of each reef and the beta richness when the reefs are compared?

Alpha richness is the number of species.

Reef 1 = 5   Reef 2 = 3   Reef 3 = 2

Beta Richness is the number of unique species in a community when compared to another.

Reef 1: compared to Reef 2 = 2 (tiger sharks and green turtles found at 1 but not 2), Reef 1 compared to Reef 3 = 3 (tiger sharks, green turtles, and angelfish found at 1 but not 3)

Reef 2 compared to Reef 3 = 1 (angelfish found at 2 but not 3), no unique when compared to Reef 1

Reef 3 has no unique species when compared to the other reefs

3. Use the table of species populations in the NWHI and the excel sheet for the Shannon-Weiner Index to calculate diversity for each place. What is the diversity index for each, how do they compare, and why do they vary?

Table 6.1. Estimated abundance of 19 cetacean species in the MHI and outer Hawaiian Islands EEZ. Overall abundances, overall densities, and coefficients of variation (CV) are pooled from the MHI and outer EEZ estimates. Pooled abundance and density estimates are given for delphinids and beaked whales. Asterisk (*) indicates a more recent estimate of false killer whale abundance in offshore waters of the Hawaiian EEZ (484 individuals, CV=0.93) comes from Barlow and Rankin (2007). Source: Barlow, 2006.

SPECIES	MAIN ISLAND ABUNDANCE (n)	OUTER EEZ ABUNDANCE (n)	OVERALL ABUNDANCE (n)	OVERALL DENSITY PER 1,000 km² (D)	CV
Offshore spotted dolphin	4,283	4,695	8,978	3.66	0.48
Striped dolphin	660	12,483	13,143	5.36	0.46
Spinner dolphin	1,488	1,863	3,351	1.37	0.74
Rough-toothed dolphin	1,713	6,997	8,709	3.55	0.45
Bottlenose dolphin	465	2,750	3,215	1.31	0.59
Risso's dolphin	513	1,859	2,372	0.97	0.65
Fraser's dolphin	0	10,226	10,226	4.17	1.16
Melon-headed whale	0	2,950	2,950	1.20	1.17
Pygmy killer whale	956	0	956	0.39	0.83
False killer whale *	0	236	236	0.10	1.13
Short-finned pilot whale	3,190	5,680	8,870	3.62	0.38
Killer whale	0	349	349	0.14	0.98
Sperm whale	126	6,793	6,919	2.82	0.81
Pygmy sperm whale	0	7,138	7,138	2.91	1.12
Dwarf sperm whale	0	17,519	17,519	7.14	0.74
Blainville's beaked whale	0	2,872	2,872	1.17	1.25
Cuvier's beaked whale	0	15,242	15,242	6.21	1.43
Longman's beaked whale	0	1,007	1,007	0.41	1.26
Bryde's whale	0	469	469	0.19	0.45
Delphinids pooled	13,267	50,087	63,354	25.83	
Beaked whales pooled	371	19,121	19,492	7.95	

SW Index for main islands = 0.80
SW Index for outer EEZ = 1.08
The outer EEZ has populations of 10 species the main islands don't have, while the reverse is only true for 1 species.

Biodiversity is just one of a number of ways to measure biological activity in an area.

- Ask your students if they can think of other things we might measure to learn about biological interactions in an ecosystem. Eventually steer the discussion towards food webs and energy transfers between species and trophic levels if they don't get there without a hint.
- Return to the power point used earlier and explain the idea of biomass pyramids and how the upside down pyramid with high levels of apex predators is unique to PMNM and a few other pristine reefs of the Pacific.
- Summary option: watch the following roughly 20 minute Ted talk that discusses the difference between pristine coral reefs like Papahānaumokuākea MNM and degraded reefs and ecosystems, the importance of marine reserves, and how reserves can benefit society and the ocean.

Evaluate

Lead a wrap up discussion to assess understanding:

- What does biodiversity mean for an ecosystem?
- Why is it important to protect this area?
- What are threats to biodiversity and what can individuals do to lessen them?
- Besides good habitat for these plants and animals, how does it benefit us?
    - *Intrinsic value knowing that it exists even if we can't visit it, ability to protect endangered species, larval disbursement to non-protected areas leading to more fish and biomass in surrounding waters, potential biological resources that we do not know about yet (e.g. medicine, compounds, etc.)*
- If you could see one plant or animal you've learned about which one would it be?

Extend

- NOAA ship tracker: http://shiptracker.noaa.gov/Home/Map. Lots of the information on the biodiversity in PMNM came from surveys conducted from NOAA ships. This link allows you to see where the ships currently are and access data from previous cruises.
- For older students: assign a chapter of the Marine Biogeographic Assessment of the NWHI for reading. The whole report or individual chapters can be downloaded here: http://ccma.nos.noaa.gov/ecosystems/sanctuaries/nwhi/.
- Investigate biodiversity in a local ecosystem.

Sources

Fautin, D., Dalton, P., Incze, L.S., Leong, J-A.C., Pautzke, C., et al. (2010). An Overview of Marine Biodiversity in United States Waters. *PLoS ONE*, 5(8): e11914. doi:10.1371/journal.pone.0011914

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