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Building Marine Reserve Networks to Fit Multiple Needs: An Introduction to Marine Spatial Planning Using SeaSketch

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ABSTRACT
Marine spatial planning is growing in use as a tool to aid management efforts in coastal and ocean systems. In this exercise, we briefly review the history and rationale behind marine spatial planning and consider its relationship to and use in ecosystem-based management. We then outline an activity that introduces students to marine spatial planning through the use of SeaSketch (training-barbuda.seasketch.org). SeaSketch is a web-based program that allows users to create, analyze, and compare how marine protected areas and networks contribute to achieving conservation goals. Building on the use of SeaSketch to engage stakeholders in the creation of reserve networks off the island of Barbuda, students use a SeaSketch training environment to create networks of marine protected areas that meet habitat protection goals and consider how these networks impact local species and human fishing value. After creating and analyzing individual networks, students engage in small- and large-group discussions to consider and compare alternative plans and decide on final choices. At each of these levels, students can compare their chosen plans to the zoning regulations that were approved in Barbuda.

LEARNING OBJECTIVES
After completing this exercise, students will be able to:
1. Discuss the need for marine management strategies.
2. Define and compare various marine management strategies and tools, including marine spatial planning, ecosystem-based management, and geographic information systems.
3. Create reserves and networks in SeaSketch and analyze their contribution to habitat protection, species coverage, and impact on fishing value.
4. Use numerical outputs to justify design choices and compare multiple plans.
5. Contextualize analyses by deciding on best design choices and discussing necessary trade-offs in marine spatial planning.

INTRODUCTION
"I believe, then, that the cod fishery, the herring fishery, the pilchard fishery, the mackerel fishery, and probably all the great sea fisheries, are inexhaustible; that is to say, that nothing we do seriously affects the number of the fish. And any attempt to regulate these fisheries seems consequently, from the nature of the case, to be useless."
- Thomas Huxley, 1883 address to the International Fisheries Exhibition in London.

"I don't have a crystal ball and I don't know what the future will bring, but this is a clear trend. There is an end in sight, and it is within our lifetimes."
- Boris Worm, 2006 (Dean 2006), commenting on model predictions that the world fisheries might be exhausted by 2048 (Worm et al. 2006).

While neither of the above quotations may be totally correct in their perspectives on fisheries management, they clearly display how our view of managing ocean resources has changed over the past ~150 years. In addition to fisheries, marine systems also harbor other resources and provide various services that sustain life on earth. Managing those resources in a sustainable and optimal manner is an ongoing quest that, to succeed, generally involves scientists from various fields, resource managers, and key stakeholders[1] from both the business and public spheres. In this exercise we consider the evolution of these strategies and allow students to use marine spatial planning[2] tools to design networks[3] of marine protected areas (MPAs)[4] and consider their impact on ecological and human communities.

A Transition to Ecosystem Based Management and Marine Spatial Planning in Marine Systems

Humans rely on marine ecosystems for a variety of valuable resources. From artisanal efforts to industrial operations, wild-caught and aquaculture fisheries provide an important source of food, employment, and cultural heritage to millions worldwide. In 2015, global annual consumption of "fish" (including both finfish and shellfish) reached an average of greater than 20 kg/person, and fish accounted for ~17% of the protein humans consumed in 2015 (FAO 2018). More than 59 million people are directly engaged with fisheries through employment or subsistence-related activities (FAO 2018). Marine systems are also home to other valuable activities such as water-based recreation, tourism, and energy extraction. Offshore operations accounted for nearly 30% of global oil production in 2015 (United States Energy Information Administration 2016), and recent estimates suggest energy from off-shore wind projects could meet the power needs of the entire United States (United States Department of Energy & United States Department of the Interior 2016). Marine systems also provide a number of other invaluable (and sometimes unvalued) ecosystem services[5]. For example, coastal oyster reefs and salt marshes may aid in reducing the wave surge of storms and in removing nitrogen from coastal waters (Beck et al. 2011; Grabowski et al. 2012; Kellogg et al. 2013). As a whole, the world's oceans also play a key role in regulating global climate, having absorbed over 90% of the excess energy resulting from increases in the greenhouse effect and 30% of the excess CO_2 humans have released into the atmosphere (Hoegh-Guldberg et al. 2014).

Given the variety of services provided by marine communities and associated value, it is no surprise that many marine areas are heavily impacted by human activity (Halpern et al. 2015). Overfishing has been documented in all major marine areas; ~33% of fish stocks currently appear to be over-exploited, and almost another 60% of fish stocks are currently harvested at maximum sustainable yields (FAO 2018). Other activities such as energy extraction, shoreline development, and pollution may also lead to habitat damage and degradation that eventually lead to a loss of marine communities and the ecosystem services they provide (Halpern et al. 2008, 2015). On a global scale, the continued increase in atmospheric CO_2 and resulting absorption by ocean waters has led ocean pH to drop (Breitberg et al. 2015). This effect, known as ocean acidification, may result in calcifying species such as oysters and corals being unable to produce shells and skeletons (O'Donnell et al. 2010); acidification can also disrupt species interactions (Dixson et al. 2010). These combined effects have led to massive degradation and loss of marine systems (Halpern et al. 2008, 2015). Coastal communities have been some of the most heavily impacted, with the majority of oyster reefs (>80%) and mangroves (>50%) and large portions of coral reefs (20%) and seagrass habitats (>29%) lost worldwide (Grabowski et al. 2012).

In response to the loss of marine resources and habitats and the services they provide, regulations have been enacted to conserve and restore populations and areas. Over time these regulations have evolved in how they coordinate activity among various fisheries and other industries and in how they consider the ability of different areas to support various activities. Regulations historically focused on single fisheries or industries. For fisheries, these regulations were often set based on recent catch data and included limits on catch, gear, and season (Lear 1998; Lackey 2005). For example, size limits may have first been used for fisheries management in North America to manage the harvest of Canadian lobsters (Anderson 1998). When regulated, other industries such as off-shore drilling were managed by local or federal authorities through leases of submerged lands or licenses.

Unfortunately, isolated sets of regulations may miss interactions that occur among various fisheries and other non-harvest industries (e.g., energy extraction, tourism) and may themselves have unintended consequences for the rest of the marine community (Worm et al. 2009). Beyond impacts on targeted species, for example, fisheries may directly impact other species through bycatch, or incidental take (Dayton et al. 2003; Pikitch et al. 2004). In the United States, some bycatch rates have recently been estimated at 17% (National Marine Fisheries Service 2011), and past global estimates have ranged from 8% to 27% (Kelleher 2005). Harvest of one species may also lead to changes in the strength or intensity of species interactions or availability of resources for another species, which can in turn impact entire communities (Zabel et al. 2003; Lafferty 2004; Daskalov et al. 2007; Baum and Worm 2009; Madin et al. 2010; Loh et al. 2015). Habitat destruction and degradation may also result from fishing strategies such as trawling (Hiddink et al. 2006, 2017), and from infrastructure and activity related to both energy extraction (Holdway 2002) and tourism (Harriott et al. 1997; Davenport and Davenport 2006). These interactions may mean regulations focused on single fisheries or industries do not produce optimal productivity or sustainability outcomes.

Just as not accounting for interactions among groups could lead to sub-optimal regulations, failing to consider spatial differences in the ability of a region to support fisheries or other industries may lead to unnecessary conflict and mismanaged systems. Although early fisheries regulations were often established at a regional (e.g., state, country) level, they frequently did not account for differences among coastal habitats or populations. For example, harvested populations may differ in biological traits relevant to management across their range [e.g., urchins (Rogers-Bennett et al. 1995), abalone (Leaf et al. 2007), sheephead (Caselle et al. 2011), grass rockfish (Wilson et al. 2012)]. Not taking these differences into consideration may lead to over- or under-fishing a stock. Fishing and other industries may also be concentrated in specific habitat types; ignoring the distribution patterns of these habitats and activities may increase negative interactions among competing groups, resulting in adverse or at least undesirable outcomes.

For these reasons, management strategies that specifically considered spatial differences in harvest potential or other activities in addition to interactions among fisheries and other spatially-coinciding industries began to emerge. These new approaches included marine spatial planning strategies. Marine spatial planning allows managers to explore how various activities may be distributed to optimize use of resources (White et al. 2012). Early examples of this from fisheries management included closing specific geographical areas to certain types of gear in order to minimize conflicts among fisheries (Anderson 1998). As stock assessment efforts grew and matured, specific regulations were also varied across the range of a species (Ciannelli et al. 2008; Costello et al. 2010; Dunn et al. 2011).

Fisheries aside, marine spatial planning is also useful for coordinating multiple activities co-occurring in marine areas. For example, infrastructure for energy extraction may constrain movement of SCUBA diving and sightseeing operators (White et al. 2012), whereas shipping lane placement may negatively impact whale movements, health, and survivorship (Redfern et al. 2013). Recognizing and accounting for these interactions can lead to more effective management strategies by minimizing conflict and maximizing total productivity. For example, spatially-explicit models that integrate the value of each geographical or ecological portion of a coastal region to the various industries present have demonstrated that flounder fisheries, lobster fisheries, whale-watching activities, and off-shore energy farms may be optimally co-established in Northeast bays (White et al. 2012). Given the large number of parameters these models must consider, optimization algorithms are often used to fully consider all possible options and their trade-offs.

The integration and consideration of interactions among various industries is a form of ecosystem-based management (EBM)[6]. Overall, EBM seeks to ensure the optimal and sustainable use of the full range of resources and services in an ecosystem or among ecosystems. Successful outcomes of the EBM approach can include an improved understanding of how changes in fisheries practices for a single species might impact harvest of other fisheries or optimization of the sustainable use of diverse resources (Leslie and McLeod 2007; Levin and Lubchenco 2008; May et al. 2008). Due to differences in potential resource availability among different geographical areas, effective EBM necessitates a spatial component.

Marine Protected Areas in EBM and Marine Spatial Planning

One increasingly common marine spatial planning strategy for balancing resource use with protection of populations and habitats is the designation of marine protected areas (Hooker and Gerber 2004). MPAs are a geographically-specified area of the ocean where use regulations have been established, usually to provide protection for natural or cultural resources. These regulations may include restrictions on fishing, energy extraction, tourism, or other activities. Where all commercial fishing has been eliminated, MPAs are often known as no-take MPAs, marine reserves[7], or marine sanctuaries. By reducing fishing and other human pressures, these areas may allow locally harvested populations to increase, which as a consequence can have positive direct and indirect spill-over benefits for adjacent fisheries (Gaylord et al. 2005; Lester et al. 2009; Buxton et al. 2014; da Silva et al. 2015). Due to the dispersal and movement patterns of many marine species, multiple MPAs are often designated to form a network in a given area (Gaines et al. 2010). Increases in local fisheries populations may also lead to an increase in the recreational value of these areas (Sala et al. 2016; Viana et al. 2017). For these and other reasons, the designation of MPAs is a common tool in EBM.

Despite their clear benefits, the creation of MPAs is not always without controversy and may even be contentious (Klein et al. 2008). MPAs need to be placed in areas that can support strong populations of multiple species. Not surprisingly, these areas are often of high value to fishermen. Similar issues may arise if areas are designated as no- or limited-access for tourist operators. Successful conservation strategies must balance trade-offs among groups through compromise, as an imbalance of cost and regulation with biological benefits and gains can lead to a lack of short- and long-term community, economic, or political support for a management strategy (Bennett et al. 2019). Considering stakeholder input, information on spatial differences, and potential economic impacts can therefore be a valuable part of the MPA designation process, leading to stronger local awareness and support (Beddington et al. 2007; Klein et al. 2008; Costello et al. 2010). For example, efforts to reduce the effects of a marine reserve designation in Australia on a local lobster fishery led only to slight changes in reserve design while decreasing use impacts by a third (Stewart and Possingham 2005).

Geographic information systems (GIS)[8] that store spatially-explicit data and allow visual mapping play a key role in the creation and development of marine protected areas (McClintock 2013). GIS-based tools can also act as a critical link to unite scientists and other stakeholders (Brown and Weber 2013). Due to the proliferation of data, increases in computing power, and greater access to technology, new GIS-based tools can allow stakeholders to propose networks of marine reserves or regulations and actually compare their choices to those generated by multiple users. For example, various stakeholder groups can generate prospective marine reserve networks and compare how each protects various fishery stocks and habitats or how they displace fishing activity. The freedom to fully design and compare individual solutions is critical to promoting transparency regarding alternative management strategies and to enabling the public to better understand potential trade-offs. Trade-offs occur when an overall goal or goals of one stakeholder group cost another group or groups. Creation of a marine reserve in one area, for example, may increase habitat protections while reducing access to optimal fishing locations.

The process for involving multiple stakeholders in considering MPA placement has been well-documented for MPA designation and management in California (USA). Over the past 15 years, California has established some form of marine protected areas for ~16% of its shoreline. These regulations were determined based upon input from scientists; local, state, and federal agencies; the fishing community at-large; and the general public (Osmond et al. 2010). In later parts of the process, stakeholders were able to use MarineMap software (Merrifield et al. 2013) to design marine reserve networks and compare their impacts on fisheries and ability to meet stated conservation goals. In the following exercise, we will explore how GIS-based tools can increase stakeholder participation by using SeaSketch, the descendant and current iteration of MarineMap.

SeaSketch and the Blue Halo Initiative
SeaSketch is a web-based application that allows users to create, share, and compare spatially-based solutions to management questions. The software is based on the geodesign approach, wherein users are allowed to easily map various potential solutions on an interactive map and obtain relevant data on outcomes (McClintock 2013). The web-based implementation also makes involving and empowering stakeholders extremely easy, and SeaSketch is now currently used by almost 5000 users in over 200 active projects (map of current projects available at www.seasketch.org/projects).

SeaSketch was used to involve a large proportion of the island of Barbuda (population ~ 1800) in the development of new marine zoning policies (Pomeroy et al. 2014). Sponsored by the Waitt Institute, the Barbuda Blue Halo Initiative used SeaSketch to consider how well reserve plans developed by the local government, fishermen, and the general public met the goals of protecting the local marine resources while simultaneously supporting the livelihood of local fishermen and other industries. In less than two years, the project moved from initial surveys of the local habitat and recognition of stakeholder needs to an approved zoning plan. In this exercise, students will use a SeaSketch training environment to create their own plans to satisfy basic reserve requirements (e.g., preserving 10% of various habitats in no-fishing reserves) while attempting to minimize impacts on fishing activity.

EXERCISE OVERVIEW
The goals for the Blue Halo Initiative were based on protecting one-third of major habitat types around the island from fishing in large protected areas. Target levels for habitat protection are typically set by determining how much area is required to allow populations of key species to persist while also considering how habitat protection will influence other activities (e.g., lead to fishing displacement). Since conservation benefits of reserves increase with size while benefits to fisheries tend to asymptote or decrease at larger sizes, target levels represent a tradeoff among goals for MPAs (Airame et al. 2003; White et al. 2008). Large protected areas (as opposed to a greater number of smaller areas that cover the same percentage of habitat) are necessary so that sites have a clear "core" area where human impacts are minimized (Gaines et al. 2010). For this exercise, you will produce no-take marine protected areas, or reserves, that contain at least 10% of prime habitats; SeaSketch will offer feedback on the size of selected areas. The 10% protected habitat can be shared among a network of reserves.

After creating these networks, you will consider disparate impacts on key species in the island (conch, lobster, gray snapper) and overall impacts on fishing activity. After considering and justifying your own plans, you will engage in a larger class-based discussion where you will each present and compare plans before deciding on a final zoning design.

Background
The video of the presentation introducing SeaSketch to the larger GIS community at the 2012 ESRI User conference makes an excellent introduction to the program and its capabilities (available from youtu.be/d4z6m56pAIc). The Waitt Institute also has produced several videos on the Blue Halo Initiative in Barbuda:

- youtu.be/I0SUymbJi8U, ~ 2 min length;
- youtu.be/qoTTnSWZ1sk, ~ .5 min (shorter version of first video);
- youtu.be/ahRkXxhIPao, ~ 2.5. min length.

Note: These management efforts took place prior to the devastating impacts of Hurricane Irma on the island in September 2017.

Using SeaSketch

SeaSketch has created a sandbox environment focused on the Blue Halo Initiative where educators and students can use the software (available at training-barbuda.seasketch.org or from links found at www.seasketch.org/training/). A training manual has also been created (available at s3.amazonaws.com/SeaSketch/140822+SeaSketch+Training+Manual.pdf) that can be referenced as needed. Below we cover the basic steps involved in reserve and network creation and analysis. Throughout the exercise, make sure the top left of the page states Barbuda Training Project and not Blue Halo Barbuda (Figure 1), as the Blue Halo project page will not contain all layers required for the exercise. It is important to note that the training project contains an estimate of how MPA placement disrupts fishing patterns. This estimate was produced by aggregating data compiled by surveying Barbuda fishermen on the relative value of locations where they fished. The data are for educational purposes only and should not be redistributed.

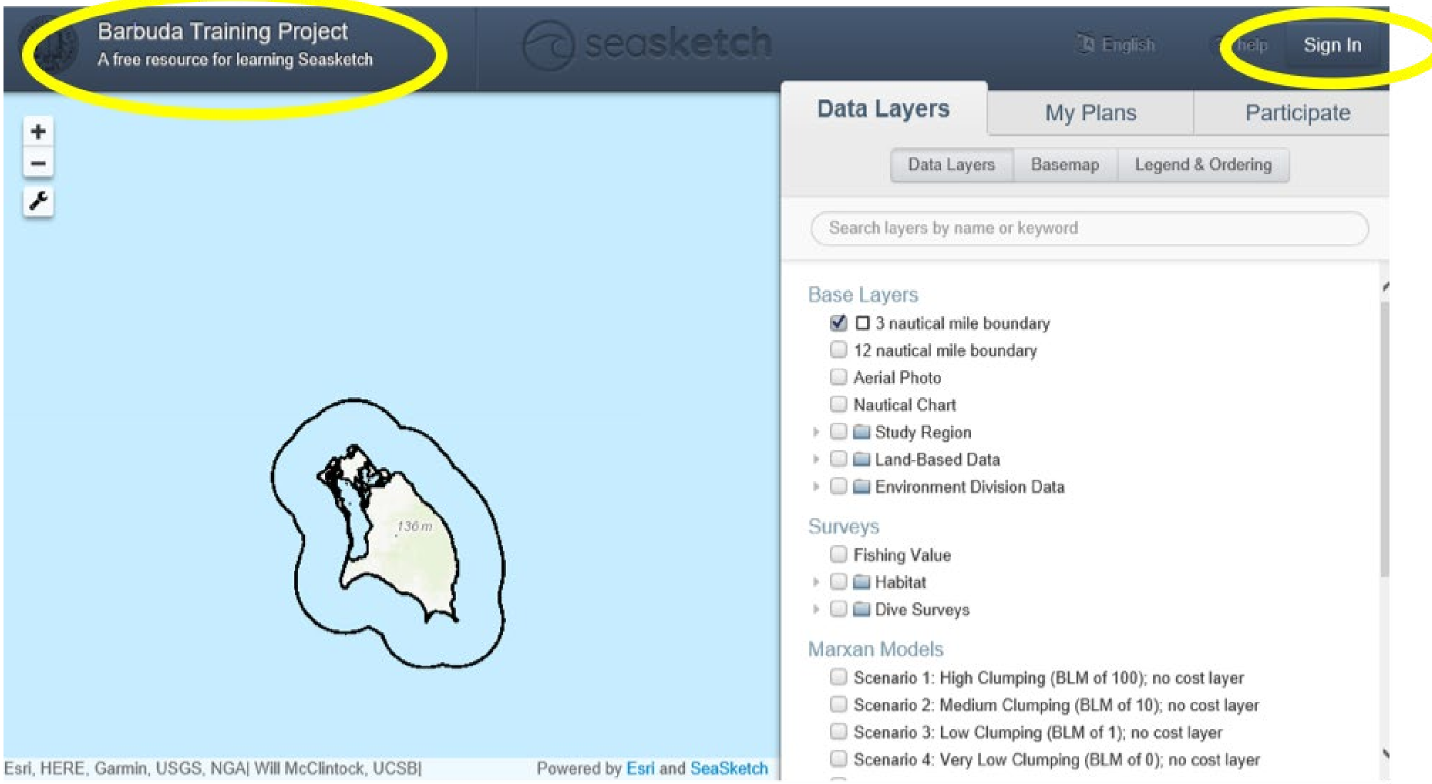

Figure 1: Selecting the "Sign In" button from the training site will allow a new user account to be created. Ensure you are working from the Barbuda Training Project maps for all exercise activities.

Account Creation and Naming Convention Notes

Actual projects that utilize SeaSketch allow users to share maps and plans with others via discussion boards or forums as shown in the video demonstrating SeaSketch. For the sake of simplicity, in this exercise you will all share one account created by your instructor.

SeaSketch Basics

Log-in to the training site (training-barbuda.seasketch.org) using the single account created by your instructor to aid in viewing and comparing class outcomes. If logged in to the main SeaSketch site, you can also navigate to the training tab and follow links to Barbuda training. Once logged in, you will be shown a base map of Barbuda (Figure 2).

You can visually display various data layers representing habitat and ecological data onto the map by selecting checkboxes; of key use to the exercise are Fishing Value layer, Habitat, and Dive Survey data. Before creating any sanctuaries or reserves, make sure you are comfortable moving around the map and adding multiple layers. Layer order and markings can be manipulated in the Legend and Ordering tab. Once you are comfortable working with the map you can create your first marine protected area. We recommend becoming familiar with the process before focusing on goals for habitat and fishing impact. In the Barbuda Blue Halo project, the MPAs where fishing regulations are in place are called sanctuaries[9]. For this training exercise, sanctuaries should be set to exclude all fishing (i.e., marine reserves). The option to only allow lobster and/or conch fishing is also present in the Barbuda Training Project. However, if groups differ in fishing restrictions, then comparison of "protected" habitat will be complicated.

To create a new sanctuary or network after logging in, select the My Plans tab. Next, select Create New › Sanctuary. A protected area can then be placed in island waters by clicking on the screen to create adjacent corners for the MPA; a double-click will close the resulting polygon. Any area outside a 3-mile nautical boundary will be removed, and if land was included in the polygon the final sanctuary will follow the coastline. Once created you can name the site and indicate if conch or lobster fishing is allowed (Figure 3). To make sure you do not overwrite existing plans, name areas and networks using your initials (e.g., JSGArea1, MLNetwork2).

Once the sanctuary is created, you can view how it meets habitat coverage and other goals by selecting the site and choosing View Attributes and Reports. Data on size, habitat coverage, and impact on fishing displacement are provided for the site (Figure 4). The minimum width of the sanctuary is also shown; the recommended minimum width is 2–3 miles. Smaller sanctuaries may increase edge effects in these systems and consequently not offer enough core area for species protection. Clicking on the "X" will allow you to select or create additional sanctuaries (Figure 4).

Multiple marine sanctuaries can be combined into networks and analyzed for total impact. Networks are created by selecting Create New › Collection. Once named, individual sanctuaries can be placed in a collection by right-clicking on the sanctuary and choosing Place in collection. Data on entire networks is also provided by selecting the collection and View Attributes and Reports (Figure 5). Specific sanctuaries can also be copied (right-click on chosen network › copy) and placed in multiple networks (right-click on chosen network › place in a collection).

EXERCISE

The goal of the exercise is to create reserves or networks that:

- preserve at least 10% of each of several important habitat types (continuous reef, patch reef, hard bottom, sand, seagrass) in sanctuaries within the 3-nautical mile boundary surrounding Barbuda. To view these, make sure that Habitat is selected within Data Layers; the habitat-type legend can then be viewed under Legend & Ordering.
- include protection for key ecological and economic species—queen conchs (*Lobatus [Strombus] gigas*), Caribbean spiny lobster (*Panulirus argus*), and gray snapper (*Lutjanus griseus*). You must ensure that the sanctuary you create includes areas where these species have been surveyed or exist (possible by layering Dive Survey and/or Habitat data over final network design).
- minimize impact on total fishing value.

After creating an individual plan, you will compare your design to those of your classmates. Throughout this exercise, you will prepare a short submission (numbered responses to questions) detailing your findings. Information that should be included in the submission and questions that should be answered are noted below in bullets and aggregated in Appendix 1.

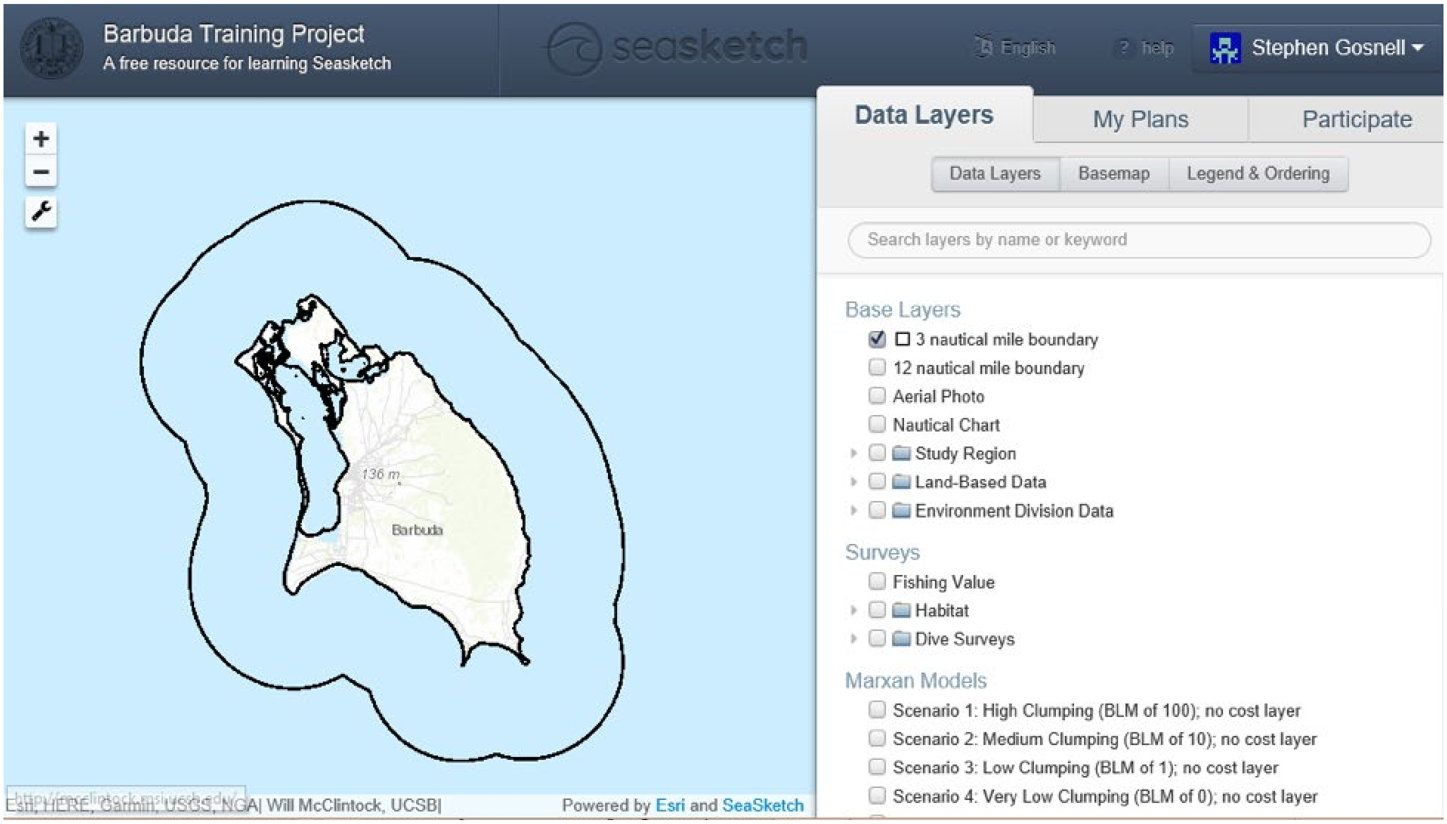

Figure 2: The base map of Barbuda is displayed when users login to SeaSketch. Data layers may be added by selecting checkboxes.

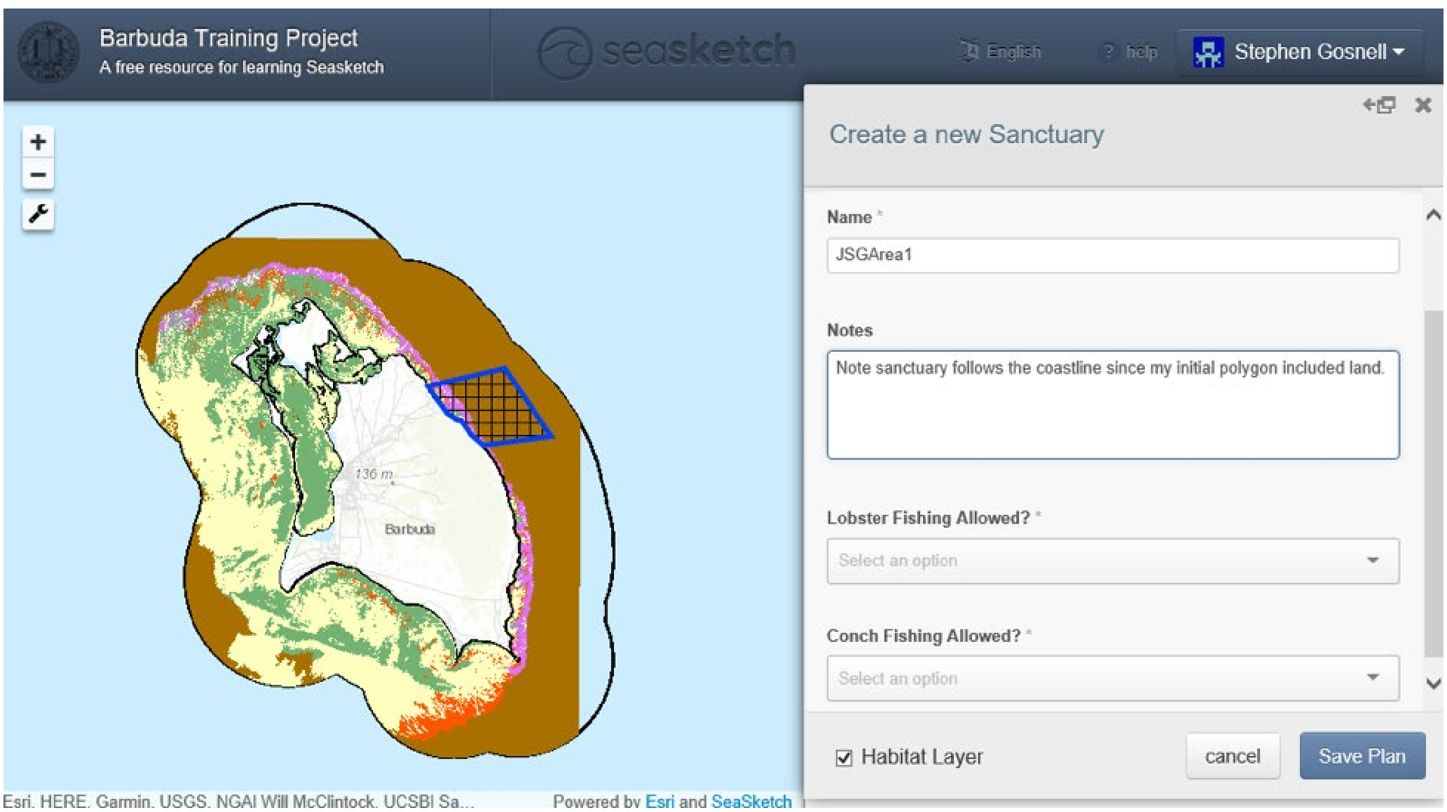

Figure 3: Once outlined, new sanctuaries can be named and saved.

Figure 4: Once saved, information on the size, coverage, and impact of a sanctuary on fishing are provided via the View Attributes and Reports tab. Clicking on the "X" will allow you to select or create additional sanctuaries.

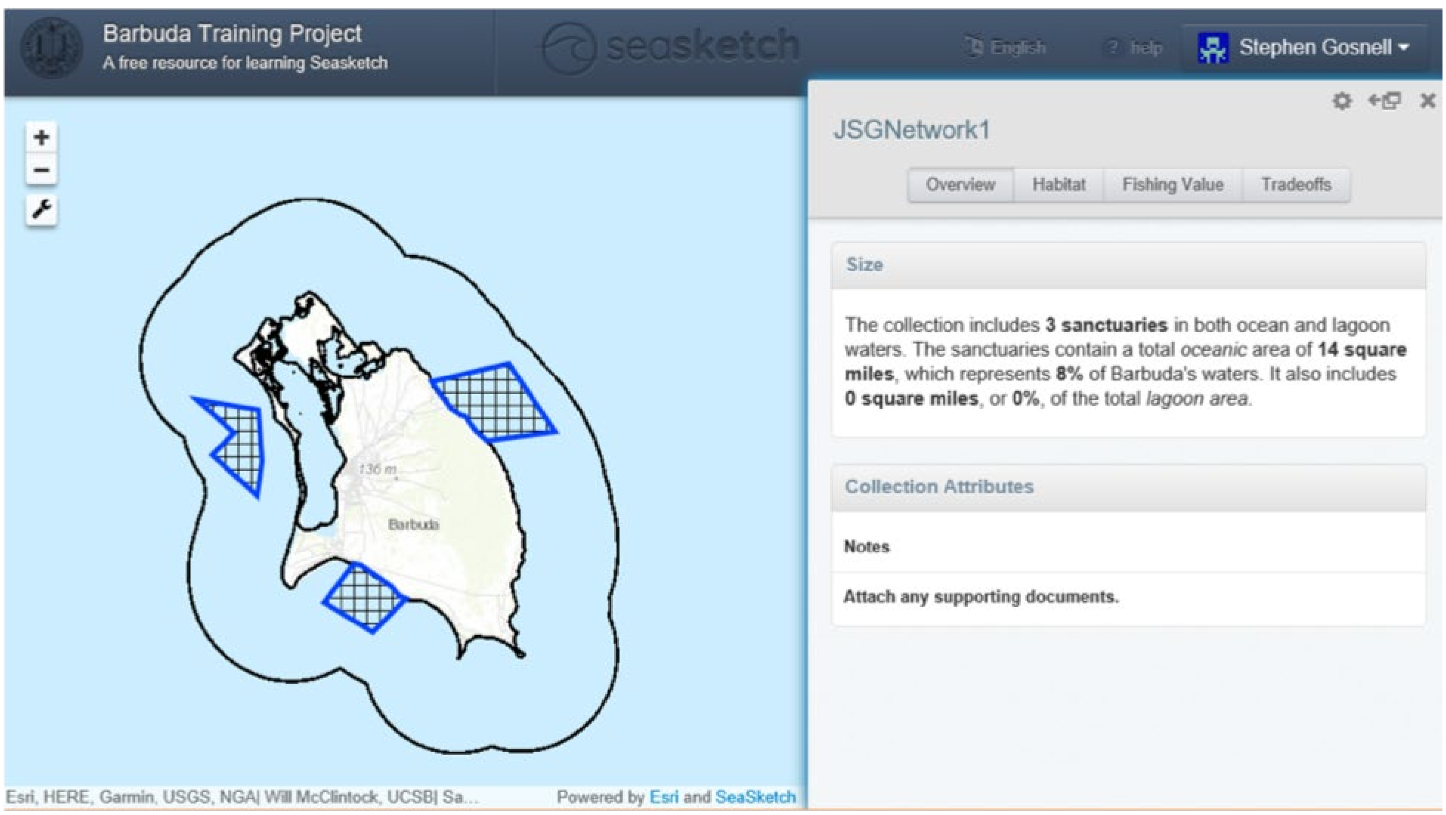

Figure 5: Collections can also be visualized by selecting the checkbox next to their name. Once selected, data is provided by the View Attributes and Reports tab.

Individual Plan Development
Create a network that meets these goals. If you are working in teams, you should each complete your own plan. Use your plans to respond to the numbered prompts and questions below.

1. To begin the exercise, create your initial network of sanctuaries. You can use the provided map layers, but do not use the assessment tools provided by SeaSketch. You should start your report by copying and pasting images of your network into a Word document (or a similar program). You should also justify your network design by writing about what made you choose these areas.

Next, analyze the sanctuaries or networks you have created to consider how they meet the conservation goals. Habitat coverage and impacts on fishing level are provided under the View Reports and Attributes tab. To consider the coverage for the specific species (gray snapper, lobster, and conch), ensure the sanctuary or collection of interest is selected under the My Plans tab and then return to the Data Layers tab. Select appropriate species under Diver Surveys to consider spatial overlap (Figure 6). Impacts on fishing displacement are also provided and may be visualized using the Fishing Value layer.

Using this information, revise your sanctuaries and networks to meet habitat coverage and species protection goals while reducing the impact on local fishermen. The shape and coverage of a specific sanctuary can be edited by right-clicking on the Sanctuary and selecing Edit under the My Plans tab. Edges of the sanctuary may then be moved as needed before the area is updated by saving.

2. Once designs are finalized, copy and paste resulting images of your revised network and associated report tables (to ensure minimum habitat protection has been met) into your Word document.
3. Explain why you selected each protected area.
4. Discuss the process you went through in reaching the final design. How many times did you have to update your initial plan before arriving at your final result, and what were the key factors driving your decision to change your plan?
5. Compare your plan to the final zoning proposal for Barbuda (adopted in August of 2014) (Figure 7), focusing on sanctuaries, and discuss how you see compromise occurring (or not). Additional information on the development of the zoning configuration and the specific sanctuaries that comprise the final approved plan is also available at seasket.ch/ywryFYjx2z. **Note**: the final Barbuda plan had more requirements than our exercise, such as the need to protect one third of many habitats.

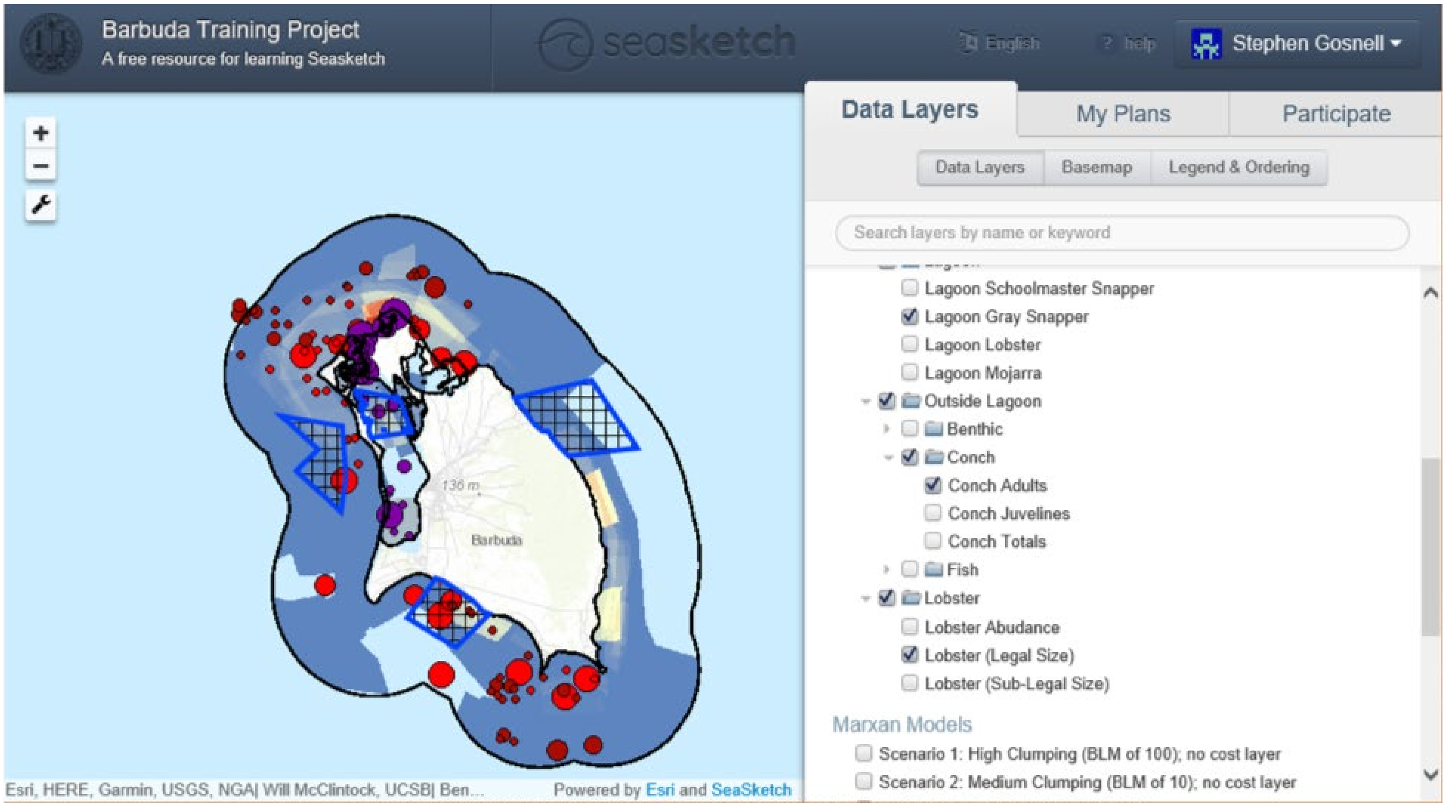

Figure 6: The ability of a protected area to protect certain species or impacts on fishing can be visually inspected by adding the respective sanctuary or network to the map and then adding species data or Fishing Value layers.

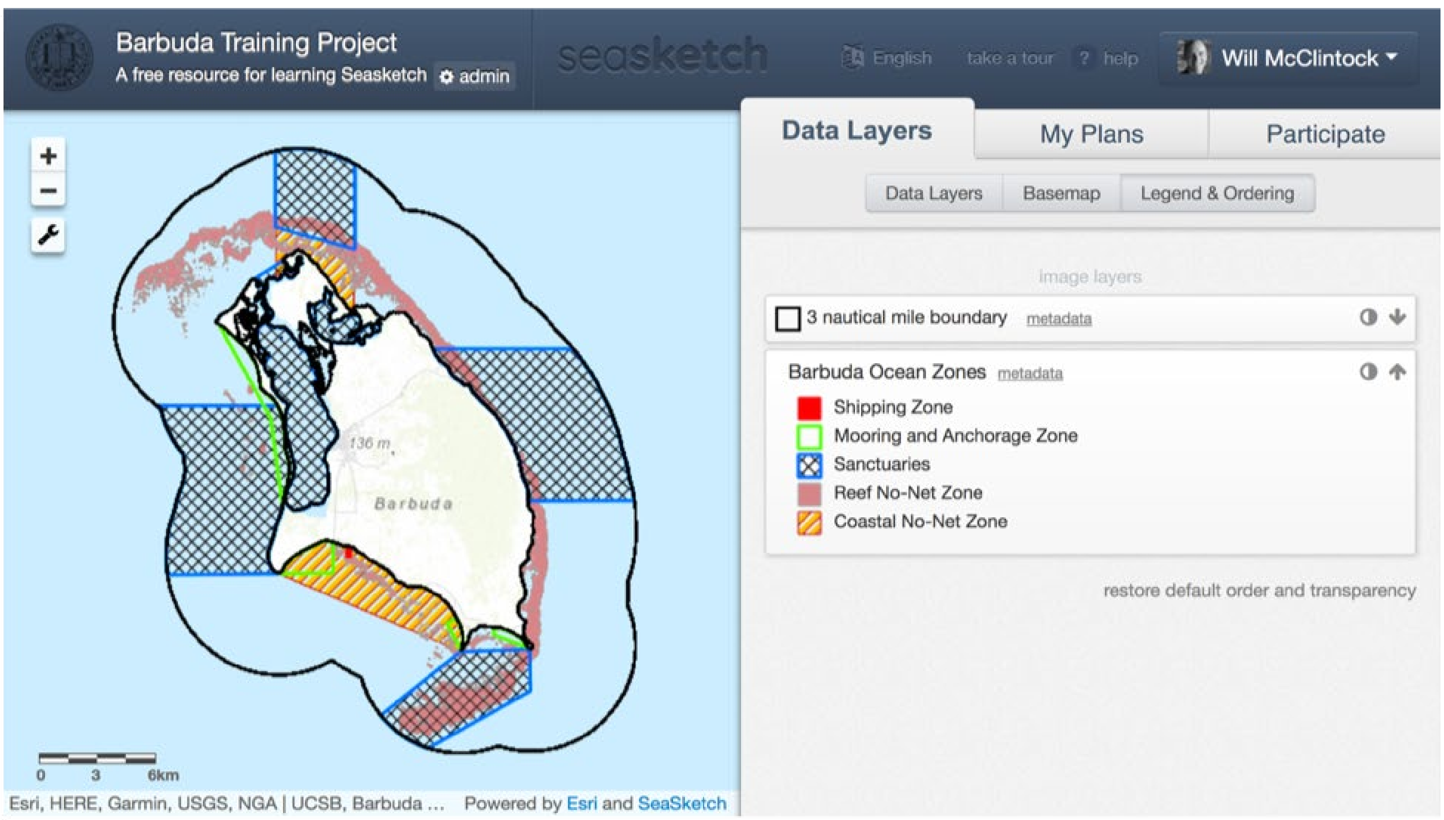

Figure 7: The final zoning proposal for Barbuda, which was adopted in August of 2014, can be viewed with the Barbuda Ocean Zones layer.

Small Group Discussion

After you have finalized your own plans, form small groups (3–4 students) to compare your decisions to those of classmates. Since you and your classmates all used one account, all plans should be available for viewing. Internet browsers may need to be refreshed to ensure all plans are loaded.

Discuss why you made specific decisions. If so desired, other layers and trade-off analysis may be employed here. For example, does your group note trade-offs between how much total habitat is conserved and how much fishing is displaced? The Tradeoffs tab under View Attribute and Fishing Reports offers a quantitative assessment of trade-offs regarding conch and lobster fishing (Figure 8). For example, whereas protecting areas where adult lobsters can be fished may reduce fishing value, protecting nursery areas may actually increase both fishing productivity and ecological value in an area.

6. List three trade-offs you observed between various plans presented by your group members. Were you surprised at the ways each person constructed their networks or in the multitude of ways goals could be met?
7. As a group, decide which plan was the best. Remember, you can view multiple plans simultaneously on a single screen by selecting the appropriate layers. In your submission, explain how the group decided on a best plan. Did everyone agree? What was different about the best overall design plan selected by the group and your own design?

In your small group, if your instructor is including a classroom discussion, prepare a short (2–3 minute) description of your final plan and how you arrived at it.

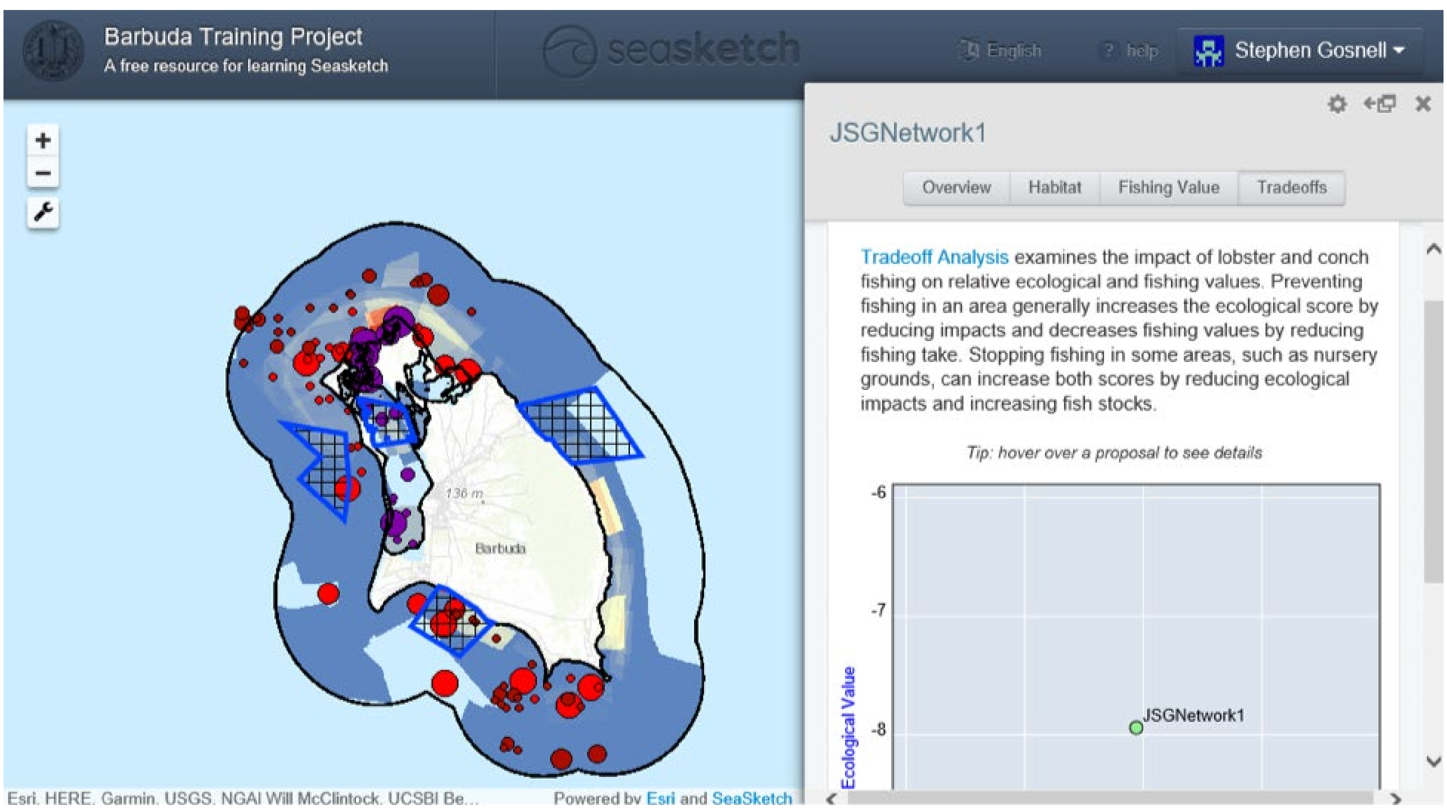

Figure 8: The Tradeoff Analysis tab considers how protecting conch and lobster in sanctuaries impacts fishing and ecological outcomes.

Classroom Discussion

Each group will present their "best" plan to the entire class. As a class, discuss differences among the plans and select an overall final design. Then answer the following questions.

8. What do you think about the final design chosen by the class? Do you think the final design was the best at meeting the stated goals?
9. How does the final class plan compare to the zoning regulations adopted in Barbuda (adopted in August of 2014) (Figure 7)? **Note**: the final Barbuda plan had more requirements than our exercise, such as the need to protect one third of many habitats.
10. Now that you have gone through this process, how would you start the sanctuary design process differently in the future? Comment on how you initially constructed your networks (e.g., based on habitat or species layer) and what approach you would use in the future based on your experience and discussions.
11. Given the parameters you had to consider, simply searching for placement options may not lead to the optimal outcome being found (and may be very time consuming). Algorithms can be used to find optimal solutions to these issues. Comment on why having people create their own designs may still be useful despite the existence of algorithms. How could you combine the two approaches?
12. Finally, comment on how you think geodesign tools such as SeaSketch will change the process of creating marine reserves and carrying out marine spatial planning. How do these tools impact stakeholder involvement and participatory design? Do you think that allowing stakeholders to be involved in actual sanctuary or reserve designation is a good thing? What might be some of the benefits and challenges?

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GLOSSARY

1. **Stakeholder:** People or groups who will be impacted by a conservation action or regulation.
2. **Marine spatial planning:** Management strategy that distributes activities or regulations across an area based on spatial differences in order to achieve better use of resources.
3. **Network:** A group of MPAs designed to work together to promote long-term persistence of populations.
4. **Marine protected area (MPA):** An area of the ocean where regulations have been put in place to provide protection for natural or cultural resources.
5. **Ecosystem services:** The benefits people obtain from ecosystems (Millennium Ecosystem Assessment).
6. **Ecosystem-based management (EBM):** Holistic management approach that considers how all ecosystem services provided by an area can be optimally managed (as opposed to single-species or single-sector management).

7. **Marine reserve:** A marine protected area where no take (fishing) is allowed.
8. **Geographic information systems (GIS):** A system that organizes data in a spatially-explicit manner so that it can be mapped (often in layers) and analyzed.
9. **Sanctuary:** Term used for marine protected area in SeaSketch software.

APPENDIX 1: EXAMPLE STUDENT WORKSHEET FOR SEASKETCH EXERCISE

Answer the following questions and/or provide requested images (also found in the text) as you work through the SeaSketch assignment. Submissions should include answers to numbered questions that include text and required images. Answers should be complete and concise (~1 paragraph for numbered questions that require text responses).

Individual Plan Development:

1. To begin the exercise, create your initial network of sanctuaries. You can use the provided map layers, but do not use the assessment tools provided by SeaSketch. You should start your report by copying and pasting images of your network into a Word document (or a similar program). You should also justify your network design by writing about what made you choose these areas.
2. Once designs are finalized, copy and paste resulting images of your revised network and associated report tables (to ensure minimum habitat protection has been met) into your Word document.
3. Explain why you selected each protected area.
4. Discuss the process you went through in reaching the final design. How many times did you have to update your initial plan before arriving at your final result, and what were the key factors driving your decision to change your plan?
5. Compare your plan to the final zoning proposal for Barbuda (adopted in August of 2014) (Figure 7), focusing on sanctuaries, and discuss how you see compromise occurring (or not). Additional information on the development of the zoning configuration and the specific sanctuaries that comprise the final approved plan is also available at seasket.ch/ywryFYjx2z. **Note**: the final Barbuda plan had more requirements than our exercise, such as the need to protect one third of many habitats.

Small-Group Discussion:

6. List three trade-offs you observed between various plans presented by your group members. Were you surprised at the ways each person constructed their networks or in the multitude of ways that goals could be met?
7. As a group, decide which plan was the best. Remember, you can view multiple plans simultaneously on a single screen by selecting the appropriate layers. In your submission, explain how the group decided on a best plan. Did everyone agree? What was different about the best overall design plan selected by the group and your own design? In your small group, prepare a short (2–3 minute) description of your final plan and how you arrived at it.

Classroom Discussion:

8. What do you think about the final design chosen by the class? Do you think the final design was the best at meeting the stated goals?
9. How does the final class plan compare to the zoning regulations adopted in Barbuda (adopted in August of 2014) (Figure 7)? **Note**: the final Barbuda plan had more requirements than our exercise, such as the need to protect one third of many habitats.
10. Now that you have gone through this process, how would you start the sanctuary design process differently in the future? Comment on how you initially constructed your networks (e.g., based on habitat or species layer) and what approach you would use in the future based on your experience and discussions.
11. Given the parameters you had to consider, simply searching for placement options may not lead to the optimal outcome being found (and may be very time consuming). Algorithms can be used to find optimal solutions to these issues. Comment on why having people create their own designs may still be useful despite the existence of algorithms. How could you combine the two approaches?
12. Finally, comment on how you think geodesign tools such as SeaSketch will change the process of creating marine reserves and carrying out marine spatial planning. How do these tools impact stakeholder involvement and participatory design? Do you think that allowing stakeholders to be involved in actual sanctuary or reserve designation is a good thing? What might be some of the benefits and challenges?