Eelgrass Restoration Support in the Santa Monica Bay

UCLA Environmental Science Practicum Project 2020-2021

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1. Abstract

This project focuses on the benefits that eelgrass and kelp provide to marine environments, methods to ensure transplanting success, and metrics to measure success after transplants are complete. We are helping The Bay Foundation (TBF), a non-profit group attempting to create a healthy environment in Santa Monica bay, to find ideal locations in the Santa Monica bay for eelgrass transplants and to effectively monitor these transplants. We have developed an interactive GIS map which indicates ideal locations for transplanting based on a set of criteria determined by TBF. We conducted a meta analysis on eelgrass and kelp and used the information we gathered to create a three star success monitoring system which we hope can be used by TBF's other groups to monitor the success of their marine vegetation transplants. We have created a 10 minute documentary which communicates what we have learned about the importance of kelp and eelgrass in ecosystems like Santa Monica bay. The Bay Foundation is planning on transplanting eelgrass into the Santa Monica bay this June and we hope that this transplanting project will be the first of many to use the resources that we have created over the course of this year.

2. Introduction

We are the 2021 UCLA practicum team working with The Bay Foundation. We have spent the past 8 months under the mentorship of Dr. Robert Eagle Tripati, learned about the benefits that eelgrass and kelp have on marine environments, and created tools to track and quantify these benefits. The increase of atmospheric carbon dioxide is the connecting thread between the variety of environmental issues this planet faces today: climate change, air pollution, rising sea levels, ocean acidification, and others. This excess atmospheric CO_2 seeps into the ocean and causes ocean acidification. We are interested in organisms like eelgrass and kelp which can help mitigate the negative effects of ocean acidification and promote the health and biodiversity of our coastal ecosystems. As we started talking with TBF about their eelgrass transplanting project we came to the conclusion that identifying priority zones for eelgrass transplanting, monitoring the success of these transplantes, and sharing these resources with a wider audience would be useful in advancing the field of marine vegetation transplanting. There are not many standardized methods for measuring success or identifying low risk zones for marine vegetation transplanting so we set out with the goal of making a model to pinpoint areas where eelgrass would thrive and an easy-to-use tool to evaluate the success of eelgrass transplants. Along with creating these tools, we wanted to share what we learned about coastal ecosystem health with anyone who was interested, so we created a 10 minute documentary that encapsulates what we learned throughout the course of this project.

3. Deliverables

3.1 Suitability Map of the Santa Monica Bay

Our aim with this deliverable was to make a map utilizing ArcMap to indicate suitable areas in the Santa Monica Bay (from Point Dume in the north and Palos Verdes Peninsula in the south) where eelgrass, specifically *Z. Pacifica* could be transplanted successfully. This map is unique and the first of its kind. By identifying priority zones for transplantation, our map will support TBF in their efforts to successfully carry out their planned eelgrass restoration projects.

In order to do this we had to first indicate important parameters that support optimal eelgrass growth through scientific papers, guidance by those conducting work in the field, and client input from employees at TBF. We added bathymetry of the bay, contour lines up to -15 meters, sewage output buffers, low wave exposure, Los Angeles drainage systems on land, nitrogen, photosynthetically active radiation (PAR), temperature, current kelp beds, buffers around kelp beds, and proposed TBF eelgrass bed layers to our map (see Appx 7.1.2).

A. *Physical Parameters/Stressors*

Suitable physical conditions are essential for *Zostera pacifica* establishment and growth. The team includes temperature, bathymetry and seafloor substrate in this study. Temperature ranges between 10 - 20 ℃ would be considered suitable for *Z. pacifica* (PMEP, 2018, p. 50). While bathymetry also works on a range, the team has decided to reclassify this parameter into 4 levels (0 - 3) after discussion with TBF. On the other hand, seafloor substrate functions on a binary basis. *Z. pacifica* requires sandy sediment on the seafloor for root establishment (Zhou et al., 2014), thus the team would classify all areas with rocky substrate to be unsuitable. Kelp beds are included as requested by TBF. One desired objective for transplant locations is to establish connection between existing kelp and newly developed eelgrass habitats, which could potentially provide an overall increase in vegtative coverage within the region. 2 sets of buffer zones around kelp are developed based on surveys from TBF. 50m buffers are considered to be unsuitable and 100m to be suitable. Observation on substrate composition near kelp indicates a shallow layer of soft sediments above rocky layers, making root establishment unfavorable; an approximation of 100m around kelp would provide sandy substrate deep enough for roots and maintain close proximity between two vegetation types. Wave exposure is another factor to be considered since excessive wave energy can be obstructive for root establishment and raises water turbidity (Bernstein et al., 2011; PMEP, 2018, p. 9). This factor can be further subcategorized into significant wave height and wave period.

B. *Biological Parameters/Stressors*

Nitrogen concentration and photosynthetically active radiation (PAR) would be considered in this study. The reason to focus on nitrogen is due to the transplanting location. Santa Monica Bay is a coastal upwelling region and several sewage outfalls can be found. High nutrient availability enhances phytoplankton and algae productivity at ocean surface, thus reducing light available for *Z. pacifica* (Benson et al., 2013). Due to limited data availability, only nitrate (NO_3) and ammonium (NH_4) are included in this study. Both nitrogen level and PAR can be used to estimate surface productivity. PAR is critical for photosynthesis and to prevent shoot loss (Benson et al., 2013). To account for potential high levels of nitrogen input, 2 buffer zones with radius 500 m are also established at the outfalls located at Marina del Rey and Malibu Lagoon.

Discussion

We were unable to collect our own data in the field due to the COVID-19 pandemic, so we were challenged with finding/ creating layers to display on ArcMap with pre-existing data online. We were able to get into contact with Paige Hoel, Ph.D. student in the Department of Atmospheric and Oceanic Sciences at UCLA and a member of the Ocean Biogeochemistry and Ecosystem group at UCLA. She works on a team that uses ROMS-BEC (see Appx 7.1.3) to analyze collected data and was able to provide us with NH4, NO3, PAR, and temperature values that we could manipulate to create ArcMap layers with. The data for these layers was collected monthly in the year 1999 and we were advised to focus on the months April, May, and July by Ben Grime, Marine Program Manager at TBF. These months are significant to TBF timeline of planning when to plant their restoration sites. Since 1999 there have been significant policy reforms regarding waste output in the SMB (DPW, 2015; Sutula et al., 2021) , creating the possibility that the nitrogen, PAR, and temperature layers on our map are not as accurate as more recent data would provide. However, we were unable to find any layers from recent years, so we went forward with the understanding that those variable's data are not up to date and therefore affect the accuracy of our final map.

Regarding data for seafloor substrate and wave information, we were also able to receive help from Seafloor Mapping Lab (SML) of California State University Monterey Bay and Coastal Data Information Program (CDIP) of University of California, San Diego. Existing kelp and eelgrass beds are available for public use from California Department of Fish and Wildlife (CDFW) (Miller, 2013) and Pacific Marine and Estuarine Fish Habitat Partnership (PMEP).

Client Use

After finalizing our map on ArcMap, we wanted to go one step further and create an interactive map using the same layers on ArcGIS Online that was user friendly and informative at the same time. The final product of this map is a tool that anyone can use to visually understand where in the Santa Monica Bay there are prime locations for eelgrass transplantations to take place, as well as a bigger picture layout of chemical and physical components that make up the bay. When opened by a user, our map shows default settings of selected layers of kelp, kelp buffers at 50m and 100m, sandy and rocky substrate, bathymetry, and contour lines (Figure 1).

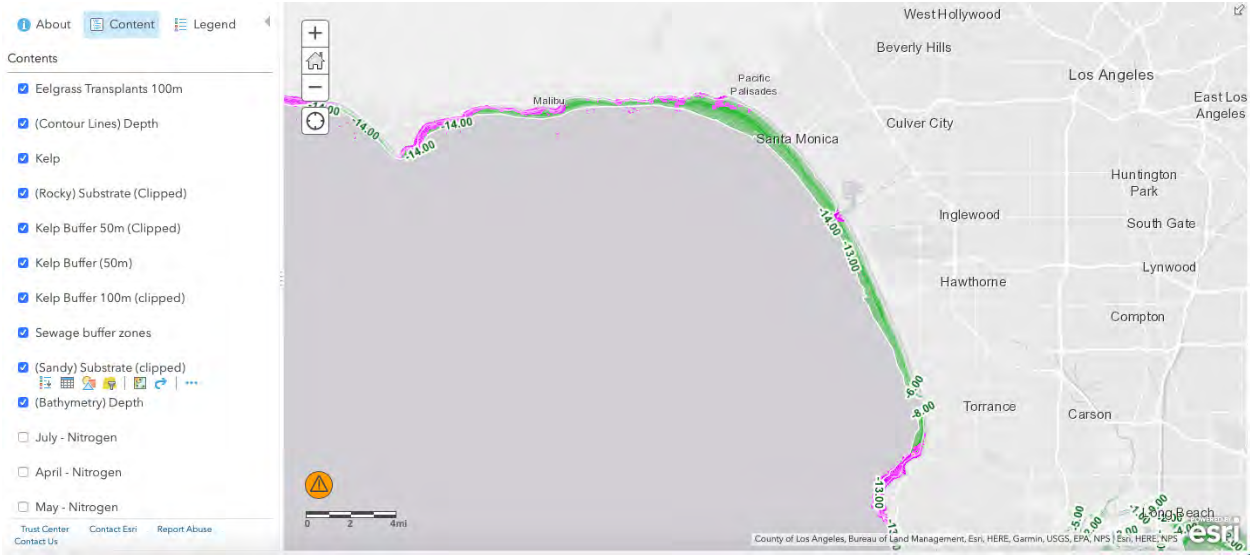


Figure 1. Default Suitability Map showing toggled "on" layers

Eelgrass cannot grow in the areas where kelp grows due to differing substrate needs (Neilson et al., 2018), but it can grow a certain distance from the kelp, hence a buffer. Eelgrass can also only grow where the substrate is sandy, and has a difficult time surviving at depths past 15 meters (Need a source). These are the default layers as they indicate the minimum required to have an area suitable to grow eelgrass.

In addition to these default layers, there are also PAR, temperature, and nitrogen values from 1999 in April, May, and July. We intentionally left these layers turned off for the default map for several reasons; one being that the data is from 1999 and therefore not an accurate portrayal for the actual current values in the bay. Secondly, the visuals provided by these layers are informative to TBF and their restoration projects, but they do not directly indicate suitability one way or another. The data does not quite reach up to the shoreline (Figure 2) where eelgrass can successfully live due to the limitations of the ROMS-BEC data, and therefore stands more as general information layers rather than direct suitable or unsuitable indicators for eelgrass transplantation.

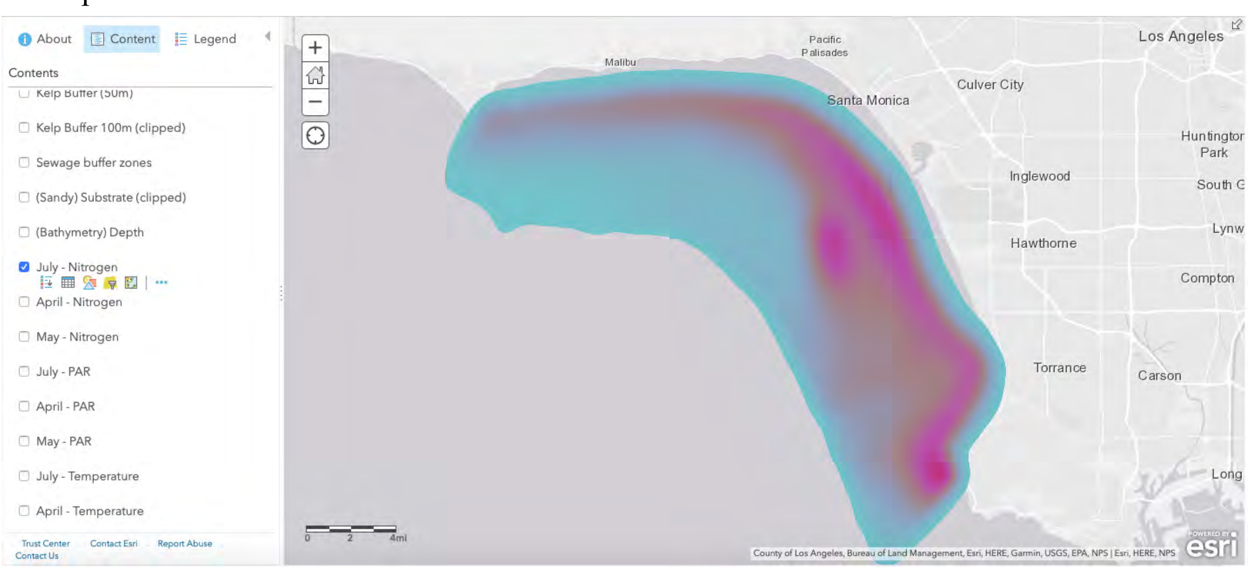


Figure 2. Representation of Nitrogen values from the month of July in 1999

Each layer on the ArcOnline map can be toggled on and off by the user, allowing for each variable to be looked at separately or in combination with any or all other variables. We visually weighted each variable with opacity levels in the greenness, so that when all the variables are selected "on" the darkest green colors on the map indicate that that area is most suitable for eelgrass to persist. If someone just wanted to look at levels of nitrogen in comparison to where there are sewage outputs into the bay, all they would have to do is select those variables and deselect the rest to have the map show nitrogen values and sewage output. For binary variables such as substrate, we used purple to indicate "not suitable" in rocky substrate regions and green for "suitable" in sandy substrate regions as there are no ranges to show with shades of green for suitability. This way the purple will dominate over any other colors indicating that the area is ultimately unsuitable despite the fact that there might be other suitable ranges of variables in that region.

See Appx 7.1.1 for Guide on how to use the Eelgrass Suitability Map.

Our map can be used to aid in locating suitable areas within the SMB for groups such as TBF, but it can also be utilized by anyone who wants to understand the layout of the bay, or even groups interested in eelgrass transplantation. The map is clear and user friendly, allowing it to be a tool for those both within and outside the scientific field.

3.2 Three star success monitoring system

To better understand the criteria typically used to evaluate the success of an eelgrass restoration site, and the measurements/values associated with those criteria, we conducted an in-depth meta-analysis of eelgrass restoration projects around the world. The focal species of eelgrass for our client was Zostera pacifica, however with only one recorded study on this species, The Bay Foundation pointed us toward a more common species, Zostera marina, whose characteristics are similar to Z. pacifica apart from ideal depth. To standardize our data search and collection, we used the 3 digital databases, GoogleScholar, PubMed, and ScienceDirect; we further used phrases with the key words "success", "Z. marina restoration" and "case-study" -- for example, one search phrase might be "successful Z. marina restoration" or "case-study on Z. marina restoration"; this phrase would then be entered into all 3 databases and relevant articles from across the first 5 pages of results were collected.

In reviewing the literature, we were able to extract three broad divisions ("Attributes") in which the majority of eelgrass restorations use to communicate the general health, functionality, and efficiency of the ecosystem: [(1)]Species Diversity and Composition, [(2)]Enhanced Vegetation, and [(3)]Physical Conditions. Each of these Attributes is only measurable when resolved to its smaller components ("sub-factors"). For symmetry and weighting purposes, each Attribute contained *three to four subfactors*, all of of which we selected as they provide the specific measurements necessary to evaluate each Attribute, and together can indicate a high-functioning eelgrass ecosystem: [1A]Abundance of Key Species, [1B]Abundance of Invasive / Undesirable Species, [1C]Genetic Diversity, [1D]Trophic Pyramid / Food Web Stabilization ; [2A]Survival Rate, 2BShoot Density, 2CCanopy Distance, 2DExpansion/Connectivity ; 3AWater Turbidity, 3BSediment Accretion, and 3CVital Nutrient (C_{org} + Nitrogen) Accumulation.

To record all of the relevant data for each restoration, we created a spreadsheet that included the basic information from each site such as location, depth, substrate, and species, as well as columns for the three main attributes. Each attribute had a Y/N column that visually signified the presence or absence within each restoration (rows), as well as a neighboring dropdown menu containing the respective three to four subfactors as a means to further specify which elements of the Attribute the restoration measured. We additionally listed the method used to measure the subfactor, and recorded each sub-factor's outcome.

Ranking System

Our 3-Star Method employs a Ranking System (i.e. 1-3 stars, 1=lowest, 3=highest) to reflect the degree of similarity between a restoration effort and its reference ecosystem (i.e. a natural ecosystem that characterizes the condition of the restoration area had it not been degraded). An accompanying 3-Star Ranking Chart contains descriptions of what observations / measurements constitute 1, 2, and 3 stars for each subfactor, and were used to determine a star ranking for each Attribute *(See Fig 3.).* The descriptions of each standard/classification is based on descriptions taken directly from our sources, and most ranges were created by combining the data from various projects with varied outcomes.

	*	**	***
	[Abundance of Key Species, Abundance of Invasive / Undesirable Species, Trophic Pyramid / Food Web Stabilization, Genetic Diversity]		
Species Diversity & Composition	• **Complete absence** or **minimal individual number** of key species present after mitigation (Note: species are dependent on the geographic location of the restoration site. Can include certain species of juvenile fish, oysters, fauna etc.) • **Invasive or undesirable competitors present until meadows are beyond natural self-repair (minimal sign on recovery)** • **Few signs** of stabilization within trophic levels (i.e. imbalance between predators and prey). • Habitat is in **decline** and low genetic diversity is measured	• **Moderate** individual numbers of key species are beginning to be seen (Note: specific number of individuals is dependent upon comparison between 1restoration site and 2reference site or 2initial number of individuals observed). • Evidence of **decreased** number of invasive or undesirable species • **Projection of stabilization** within trophic indicating **moderate** levels/food web maturity. • **Moderate** signs of genetic diversity was measured, early signs of recovery	• **Diverse** number of individuals can be very clearly observed with an array of diverse species ranging from fish, gastropods, oysters, fauna, etc • **Minimal** or **no** invasive or undesirable species identified. • Predator and prey interactions have reached stable state, indicating maturity of eelgrass bed. • **Elevated genetic diversity** has created an ecosystem that is resilient to temporary changes in community composition
	[Shoot Density, Canopy Distance, Expansion / Connectivity, Survival Rate]		
Enhanced Vegetation	• If shoot density was <20% of the shoot numbers in the preceding year after winter period, plots can be marked as unsuccessful • Canopy distance (area restored) of eelgrass restored shows **no substantial recruitment** of species to use the given area as an estuary or habitat. (Ha of eelgrass canopy **<30%** from the initial restoration.) • No clear evidence of expansion leading to new species exchange or facilitating gene flow • **%SurVival Metric (?)	• **>50%** of shoot density survived during at least *one* winter cycle, **indicating** resilience to disturbance • Canopy distance (area of eelgrass restored) shows moderate recruitment of species that utilize the habitat (Ha of eelgrass canopy is **>50%** from initial restoration) • Expansion / Connectivity of restoration area has allowed for the observance of new species exchanges • Percentage of transplant survival was **equal** or **moderately less** than reference site	• **>70%** shoot density show signs of survival after *one or more* winter cycles, proving **strong** resilience to disturbance • Canopy distance of the area restored shows significant recruitment of species that live and benefit from the habitat restored (Ha of eelgrass canopy is >70%) • If measurable, the increased levels of **new species exchange** (allowed for by connectivity) have stabilized (**Note:** if levels are not measurable, but evidence of new interaction is present, or if levels are measurable but they are not stable → 2 stars) • Percentage of transplant survival **match** or **exceed** that of the reference site (**>70%** of shoots survived during one or more critical winter cycle, demonstrating **strong resilience to disturbance**
	[Water Turbidity, Sediment Accretion, C_{org} + Nitrogen Stocks and Accumulation]		
Physical Conditions	• **No significant** change in water turbidity • **No significant** change in sediment accretion due to changes in water turbidity. • Organic Carbon (C_{org}) and Nitrogen accumulation rate and stocks remain **unchanged** in relation to bed maturity.	• **Moderate** influence in water flow (i.e. water turbidity) causing a shift from an erosional to a depositional environment (due to increase in seagrass density) • **Moderate increase** in sediment accretion (due to the decrease in water turbidity) • **Net positive** change in C_{org} stocks — evidence that C_{org} and Nitrogen accumulation are reaching levels similar or equal to the reference site. (**Note:** increase in Organic Carbon burial / C_{org} stocks is proportional to Carbon sequestration).	• **Significant** level of change in water turbidity has allowed for sediment categorization as depositional • **Significant** Evidence of ongoing growth and recruitment of new vegetation facilitated by the now-depositional sediment • C_{org} and Nitrogen accumulation have **reached** or **surpassed** that of the reference site alongside bed maturity and have shown signs of stabilization (i.e. 1-2x larger stocks than reference site)

Figure 3 : 3-Star Ranking Chart that contains criteria required to receive 1, 2, and 3 stars for each subfactor in its respective attribute.

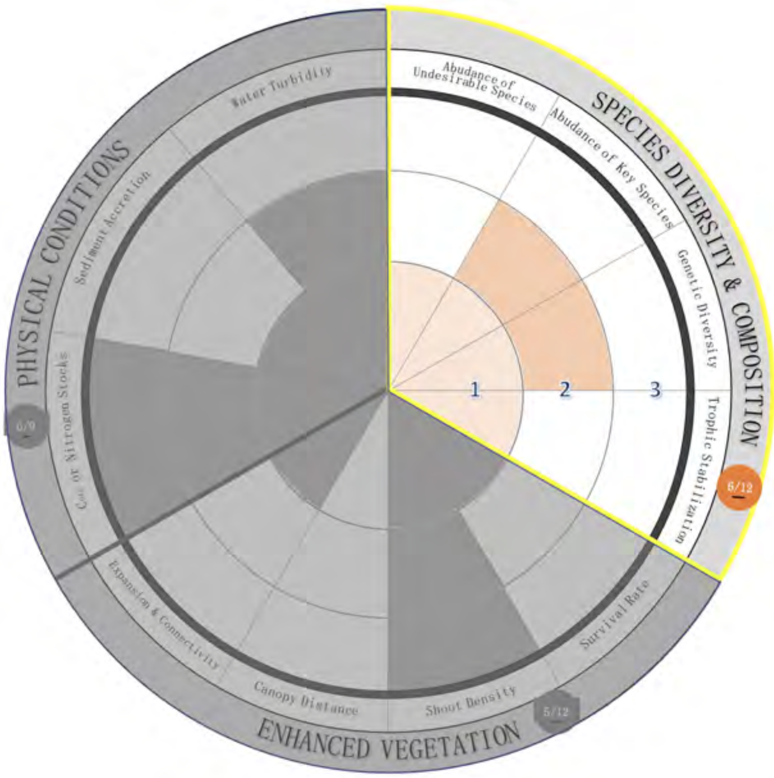


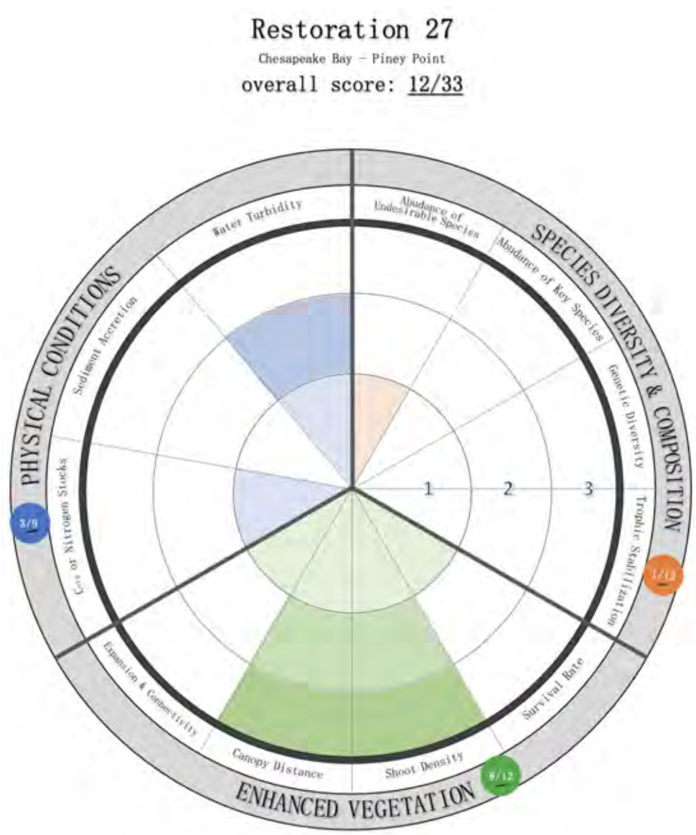
Figure 4: Species Diversity & Composition attribute ranking by sub-factor measurements at example restoration site

In order to systematically evaluate these metrics in each restoration, subfactors were individually ranked out of 3 stars and their scores were tallied to determine the ranking of their corresponding Attribute; for example if within Attribute 1 (Species Diversity) of Restoration Y, the data indicated that subfactors *genetic diversity* and *abundance of key species* received 2/3 stars each, and *abundance of undesirable species* and *trophic stabilization* received 1/3 stars each, then the Species Diversity Attribute scored an overall ranking of 6 stars out of a total 12 stars (*See Fig. 4)*. In addition to recording scores for the three Attributes, each restoration also received an overall score which was simply the total of all three Attributes combined.

Visual Representations

Each restoration has its own pinwheel visual representation which was designed to incorporate the rankings of individual subfactors (denoted by area shading) as well as the overall Attribute rankings (denoted as a fraction alongside the Attribute) into a single, multi-level Pie Chart (*See Fig 5.)*. For simplicity, the restorations were given a Numerical Title according to the order they appear in the GoogleSheet containing the rest of its more detailed information. The ranking of the restoration in its entirety is written under the Restoration label.

Using Restoration 27 as an example, for Attribute 1, Species Diversity and Composition, this restoration tracked only the presence and [1A]Abundance of Undesirable / Invasive Species; based on their results discussing that the decline of eelgrass at one of its two transplant location during the summer of 2006, as well as



the lack of recovery that followed, largely correlated to the heavy epiphyte loads. Thus, for Abundance of Undesirable / Invasive Species, Restoration 27 received 1/3 stars, as compared to the reference data description stating "Invasive or undesirable competitors present until meadows are beyond natural self-repair (minimal sign on recovery)," and as it was the only subfactor of Attribute 1, Attribute 1 received an overall score of 1/12. Moving to Attribute 2, Enhanced Vegetation, this restoration measured all four subfactors; for [2A]Survival Rate, Restoration 27 recorded that "survival of eelgrass planted in 2003 was 34% after 1 month, 26% after 6 months, and less than 10% after 1 year" – according to the reference Chart, "survival of transplant was below that of reference site or <35%" denotes a ranking of 1/3 stars; for [2B]Shoot Density, Restoration 27 recorded that maximum shoot densities were as high as 5,500 shoots/m2, which were similar or greater than peak densities reported for its reference site – according to the reference chart "more that 50% of peak densities > than those of the reference site denote 3/3 stars; for [2C]Canopy Distance and [2D]Expansion / Connectivity, the restoration recorded that "by June 2006, the initial transplants had vegetatively propagated (ramet formation) forming clumps that reached sizes approaching 1 m2" – since Canopy Distance reference "Canopy distance of the area restored (Ha of eelgrass canopy) is >70%", it received 3/3 stars, and with Expansion / Connectivity reference "No clear evidence of expansion leading to new species exchange or facilitating gene flow", it received 1/3 stars since it did expand however there is no measurements of species recruitment. Thus, Attribute 2 received an overall score of 8/12. Finally, for Attribute 3, Physical Conditions, this restoration measured [3A]C_{org} or Nitrogen (Vital Nutrient) Stocks, as well as [3C]Water Turbidity; for [3A]CO_2, the site recorded "organic content and nitrogen concentrations similar" to a reference eelgrass restoration, but "significantly lower than the natural eelgrass meadow" reference – since the nutrient reference data stated "Organic Carbon (Corg) and Nitrogen accumulation rate and stocks remain unchanged in relation to bed maturity", it received 1/3 stars; for [3C]Water Turbidity, the site recorded The planting site at PP had calculated wave heights (WHs) (max WH = 0.466 m, avg WH = 0.270 m) similar to the natural eelgrass meadow at DM, Virginia" – since the Water Turbidity reference states "Moderate influence in water flow (i.e. water turbidity) causing a shift from an erosional to a depositional environment (due to increase in seagrass density), similar or equal to that of the reference site" it received 2/3 stars. Thus, Attribute 3 received a score of 4/9, which brings the overall score of Restoration 27 in Chesapeake Bay to 12/33. Ultimately based on these results coupled with the visual, it is clear that the restoration might extrapolate that it should focus more of its efforts towards evaluating and bettering Attribute 1, Species Diversity and Composition.

In addition to individual graphics, we created a summary graphic of the three main Attributes (see Appx 6.3.2) We did this by categorizing the restorations by whether they recorded "y" (denoting that they *did* measure the attribute) or "n" (denoting that they *did not* measure the attribute, to produce a visual that identifies the *general* strengths & weaknesses of the restoration. If the majority of restoration efforts measured Attribute 1 (Species Diversity & Composition), but only a few measured Attribute 3 (Physical Conditions), this could indicate that future restorations should focus on the physical conditions as a way to maximize potential success.

Client Use

This tool is ultimately designed to summarise the most common metrics in eelgrass restoration and an analytical approach to gauging the status of an ongoing restoration effort or group of efforts. It is easily adaptable for our client's existing Z. marina restorations, as they only need to fill in their recovery outcome measurements in our Spreadsheet Template, and compare them to the 3-Star Standards Chart we have provided. If our client wanted to further visualize the efficacy of *all* their existing Z. marina restoration efforts, they can do so by simply substituting their own efforts in the meta-analysis template (in place of where we have analysed projects worldwide). This will allow them to produce individual visuals for each of their own projects, as well as an overview of what areas they are generally having desirable outcomes and where they might need to devote more effort. However, as The Bay Foundation is conducting pioneering research on Z. pacifica, their upcoming restoration may require slight modification of subfactors and/or standards reflect the change in species; that said, we intentionally created our Scheme based on Z. marina *because* many aspects are largely applicable and proportionate to Z. pacifica.

See Appx 7.2.2 for procedural steps on how to use the ranking system

3.2.1 Results and Discussion

Among all restorations that were analyzed in this report we found that the most commonly measured attribute was Enhanced Vegetation with roughly 85% of the sites measuring this attribute. Species Diversity and Composition was the second most measured attribute with roughly 58% of the sites measuring this attribute. The least assessed attribute was Physical Conditions, with only about 44% of the sites evaluating this as a measurement of success. These findings may indicate that a lot more monitoring may be needed in regards to the physical conditions of sites, if proper quantification of how successful an eelgrass restoration site is desired. The assessment of water turbidity, sediment accretion, and carbon & nitrogen stocks are critical components of quantifying the success of eelgrass restoration projects; its lack of measurement indicates strong urgency for increased monitoring and evaluations in these areas. Our findings also indicate that while Species Diversity and Composition was the most commonly used metric for indicating the success of eelgrass restorations it does not holistically represent the success of eelgrass as a whole.

Refer to *7.2.3 Summary Statistics,* for breakdown of statistics.

3.3 Science Communication Documentary

The purpose of our science communication documentary is to explain how seagrass and kelp ecosystems play a major role in supporting life as we know it, from the environment to the economy to society. With the rise of climate change along with the existing local anthropogenic impacts, marine vegetation ecosystems are and have been threatened. Yet, they are the very solutions to mitigating these problems we've created. One of the many services they provide is mitigating climate change through carbon sequestration and consequently creating local pH barriers from ocean acidification (Oreska et al, 2020; Xiao, et al 2021). We explain how people have had a significant impact on the degradation of these eelgrass and kelp ecosystems that are essential to our health. There are solutions to protect these ecosystems and the documentary highlights The Bay Foundations eelgrass and kelp restoration projects as one.

Through our research, we found many videos that focus just on kelp or just on eelgrass. Most were also created in a "news report" style that was not particularly engaging to those that do not care about the issue. Thus, our documentary aims to make scientific information on anthropogenic impacts on the environment and marine vegetation restoration more accessible to the public. We want to convey why people should care and how these seemingly disconnected ecosystems impact them. Several experts and professionals (Dr. Bianchi Daniele, Dr. Kyle Cavanaugh, Dr. Tonya Kane, Ben Grime and Rilee Sanders) were interviewed and asked to provide insight on these topics, which adds credibility and scientific knowledge to the film. To make complex information engaging, we use animations and a conversational narrative dialogue. The documentary also highlights the synergistic effect of having kelp forests and eelgrass beds close to each other, which is often not talked about.

We hope this science communication documentary will be an useful outreach and educational tool that The Bay Foundation can send to stakeholders, including the local community, policy makers, and coastal managers. It explains the importance and purpose of the kelp and eelgrass restoration projects in relation to people and garners support for such projects. It is also an educational tool for the public and local community. To reach a wide audience, we recommend the documentary to be spread on social media through The Bay Foundation and our practicum team's network. We also suggest that the video lives on the TBF's Youtube channel and/or their website so it is accessible years down the line.

4. Conclusion

Over the last academic year our team has worked to create these 3 deliverables with the intention to support TBF in their eelgrass restoration projects. The suitability map and the ranking system will act as tools for TBF to refer to when planning and carrying out their eelgrass restoration projects, and will hopefully be relevant to projects for years to come. Our documentary brings attention to the synergistic qualities of eelgrass as well as negative human impact on marine vegetation systems, both of which are vital to understand in order to maintain and protect coastal ecosystems.

5. Acknowledgements

Wave data was furnished by the Coastal Data Information Program (CDIP), Integrative Oceanography Division, operated by the Scripps Institution of Oceanography, under the sponsorship of the U.S. Army Corps of Engineers and the California Department of Parks and Recreation." https://doi.org/10.18437/C7WC72. ROMS-BEC data used with permission/ access of ROMS-BEC outputs courtesy of Dr. Daniele Bianchi/Paige Hoel, Department of Atmospheric and Oceanic Sciences, University of California Los Angeles. Seafloor substrate data used in this study were acquired, processed, archived, and distributed by the Seafloor Mapping Lab (SML) of California State University Monterey Bay. Drainage network data were obtained from the Department of Public Work, County of Los Angeles, and edited in this study for focussing on regions of interest.

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7. Appendix

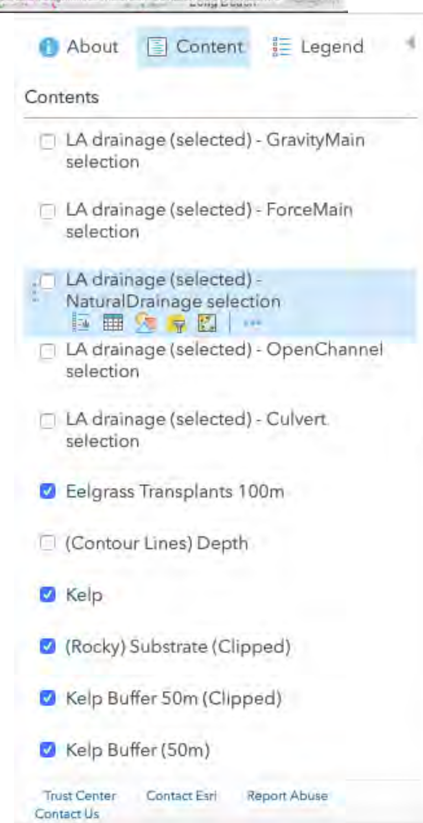
7.1 Suitability Map of the Santa Monica Bay

7.1.1 Guide on how to use the Eelgrass Suitability Map

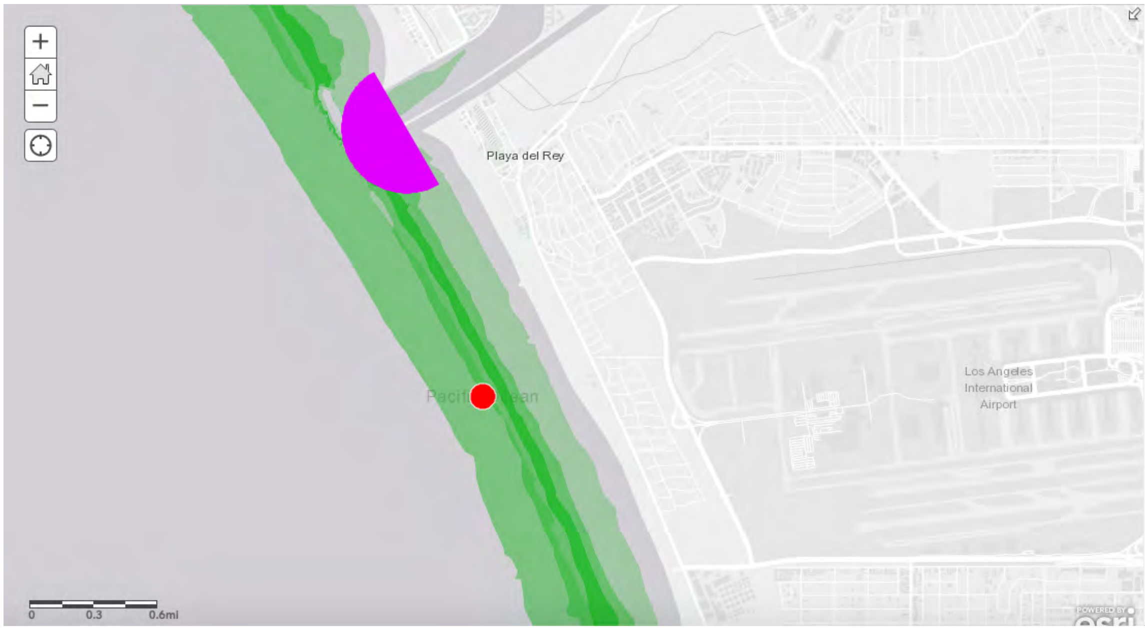
1. Open map (put link to website here)
   You will see a map with an extent showing the Santa Monica Bay from Point Dume to Palos Verdes Peninsula.
   The default selected layers include proposed eelgrass transplantation sites, current kelp locations, a 50m buffer and a 100m buffer around the kelp, sewage output buffers, rocky substrate, sandy substrate, bathymetry in the bay, and 4 Los Angeles drainage systems on land.

Default map with selected layers

2. On the left-hand side of the screen there are all of the layers we created, and to have them appear on the map or taken off one must just select or deselect the small box with a check mark next to the layer in question. This image shows the content with deselected layers of drainage systems and contour lines. They will not appear on the map if deselected.

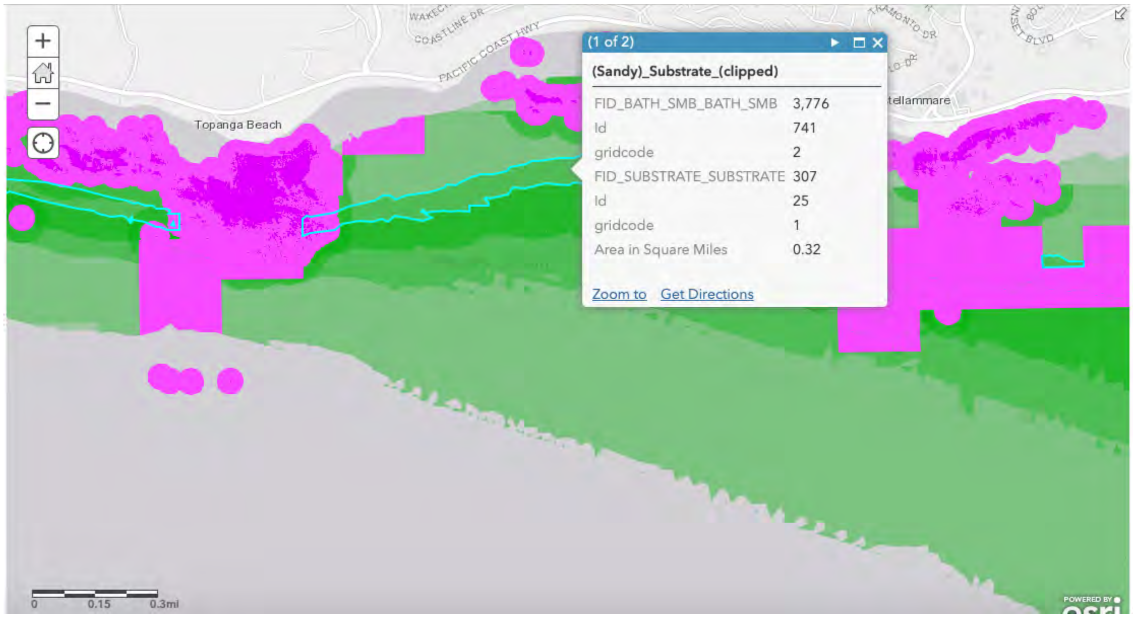


3. To find the places most suitable for eelgrass transplantations, it is ideal to have the default layers all selected. Areas in purple indicate that the region is not suitable, and green indicates that the area is suitable. You can zoom in and out on the map using the scrolling feature on a trackpad or mouse, or use the + and - in the upper left to zoom in and out. The greenness is scaled from light green to dark green, with dark green being the most suitable.

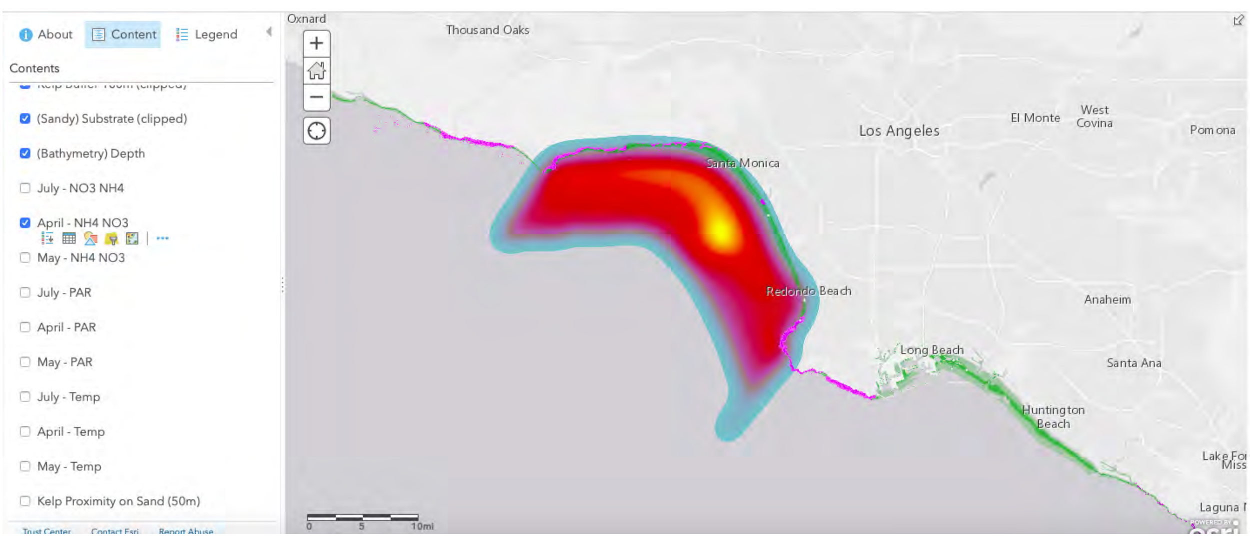


Above is a zoomed in clip of the default map, showing scales of green, a purple sewage output buffer, and a red proposed eelgrass site. As you can see, the red circle is in a medium green area, out of the unsuitable purple buffer, indicating that this proposed site is in an area that will be suitable for eelgrass to grow.

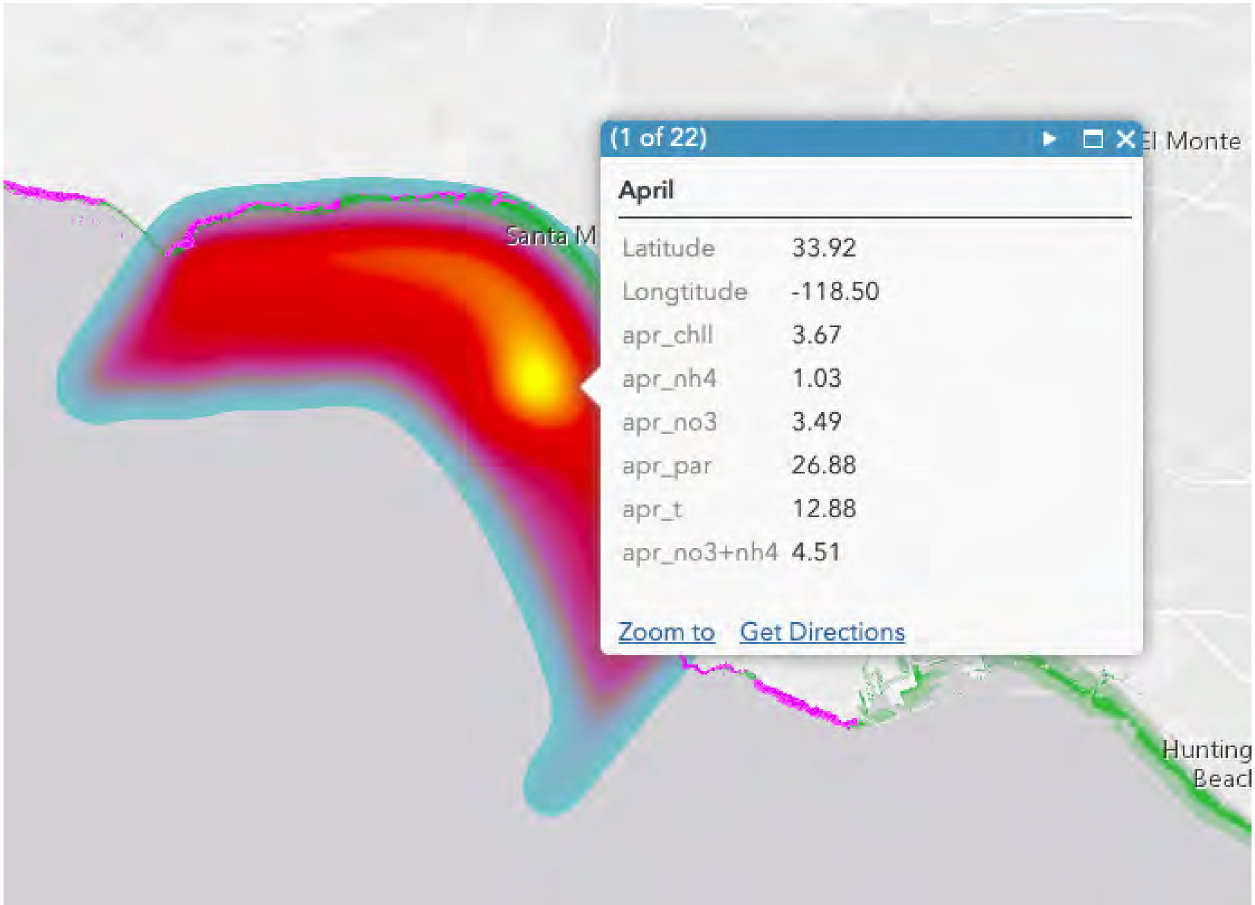
4. You can also select a region on the map itself and an information box will pop up with details about the layer in that particular location. Here a sandy substrate layer location was selected on the map and we can see a breakdown of that layer in the information box.



5. Beyond the default layers, we have also included data layers for nitrogen values, PAR values, and temperature values, from April, May, and July in 1999. You can select these layers and they will show a heat map display of the values. Here is an example of nitrogen values in April 1999, with yellow being the highest values in the range and blue being the lowest.



Much like the default layers, you can also click directly on the map and have an information box pop up with details about the certain selected location within the layer.



7.1.2 Layers for Suitability Analysis

Parameter	Type	Suitability Level	Value	Source	Reference
Bathymetry	Shapefile[1]	High (3)	-10.0 - -11.3m	NOAA[2]	TBF[3],PMEP, 2018
		Moderate (2)	-9.1 - -10.0m, -11.3 - -12.2m		
		Low (1)	-5 - -9.1m, -12.2 - -15m		
		Unsuitable (0)	>-5m, < -15m		
Substrate	Shapefile	Suitable (1)	Sandy	SML[4]	Zhou et al., 2014
		Unsuitable (0)	Rocky		
Temperature	csv	Suitable (1)	14.4 - 17.8℃	ROMS-BEC[5]	PMEP, TBF[3]
		Unsuitable (0)	<14.4℃, >17.8℃		
Nitrogen (NO_3+ NH_4)	csv	Suitable	<27.9 mmol $N \cdot m^{-3}$		Benson et al., 2013
PAR	csv	Suitable	Bottom light ⩾15.3 Wm^{-2}		
Significant wave height	Shapefile[1]	Suitable (1)	< 0.8 m	CDIP[6]	TBF[3]
		Unsuitable (0)	⩾ 0.8 m		
Wave period	Shapefile[1]	Suitable (1)	< 15 s		TBF[3]
		Unsuitable (0)	⩾ 15 s		
Sewage buffer zones	Shapefile	Unsuitable	Semicircle at outfall location, r =500m		TBF[2]
Kelp buffer zones	Shapefile	Unsuitable	50m around kelp bed		TBF
		Suitable	100m around kelp bed		
Additional layers					
Name	Type	Description		Source	Reference
Kelp beds	Shapefile	Current existing kelp locations		Miller et al., 2012	

LA Drainage	geodatabase	Network of drainage system in Los Angeles County	DPW[7]	
TBF Eelgrass Transplant	csv	Location of eelgrass donor and transplant sites	TBF	

[1] NetCDF is the original format available from the sources. Layers are first converted into raster for reclassification, followed by shapefiles for arcgis online.
[2] National Centers for Environmental Information, National Oceanic and Atmospheric Administration
[3] Due to limited research on *Z. pacifica*, values corresponding to suitability level are obtained based on preliminary data from The Bay Foundation.
Seafloor Mapping Lab of California State University Monterey Bay
[4] Seafloor Mapping Lab of California State University Monterey Bay
[5] ROMS-BEC data, see *7.1.3 ROMS-BEC Data* below
[6] Coastal Data Information Program, University of California San Diego
[7] Department of Public Work, County of Los Angeles

7.1.3 ROMS-BEC Data

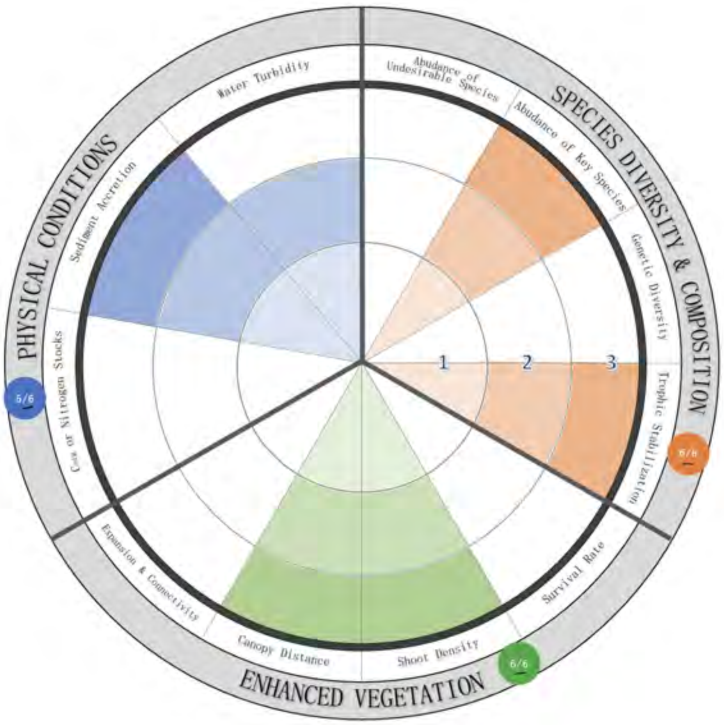
The ROMS-BEC data obtained for this study are generated from ROMS dynamically coupled to BEC. The Regional Oceanic Modeling System (ROMS) is an open-source code that was first developed by the Institute of Geophysics and Planetary Physics, University of California, Los Angeles (UCLA) in 2004 (Shchepetkin et al., 2005). The model incorporates time-stepping and mode-splitting algorithms in 3-D curvilinear coordinates to provide a spatial and temporal representation of physical processes in 300m resolution (Kessouri et al., 2021). On the other hand, the Biogeochemical Elemental Cycling (BEC) model is responsible for incorporating multi-element (C, N, P, O, Fe, Si) biogeochemical cycles and multiple plankton functional groups. The BEC model would be sufficient in estimating net primary production and tracking the movement of various nutrients across the ocean.

The version of the ROMS-BEC model used in this study is V2020 which has been reconfigured and validated for the California Current System (CCS) (Kessouri et al., 2021). Anthropogenic forcing (e.g. point source) is also included to make the data more realistic to the actual environment (Kessouri et al., 2020). The integration depth is 30 m which is the approximation of average mixed layer depth (Leinweber; Grubber, 2013). Nutrient data from 1999 is used due to limited availability. As suggested by Paige, the climatology of 1999 and 2021 are compared to assure the accuracy of data. La Niña lasted throughout the entire 1999 while the most recent La Niña ended in May 2021 (Becker, 2021; NWS). The Oceanic Niño Index (ONI) in 1999 is also more negative than in 2021, which indicates La Niña was stronger in 1999 (NWS). With differences in climatology, the ROMS-BEC data is used for additional information instead of direct suitability calculation.

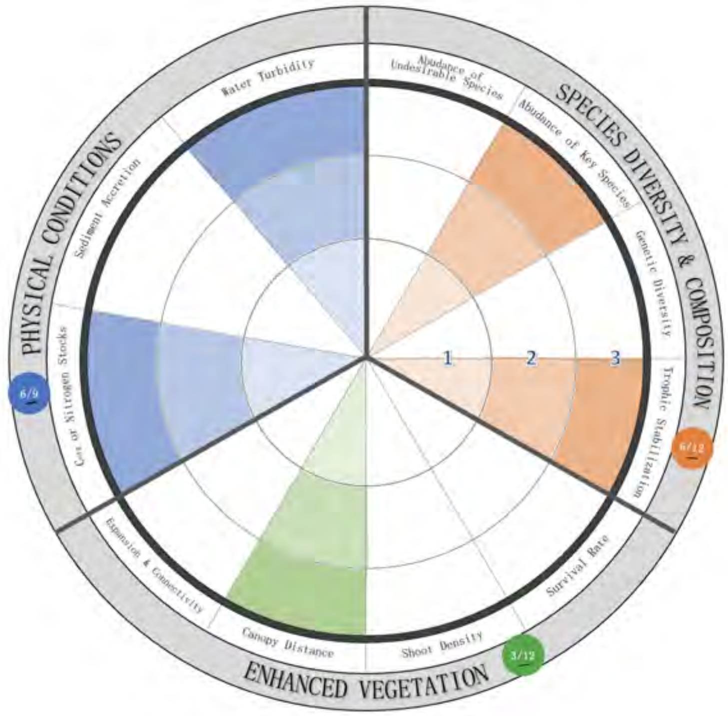
7.2 Success Quantification

7.2.1 Pie Charts

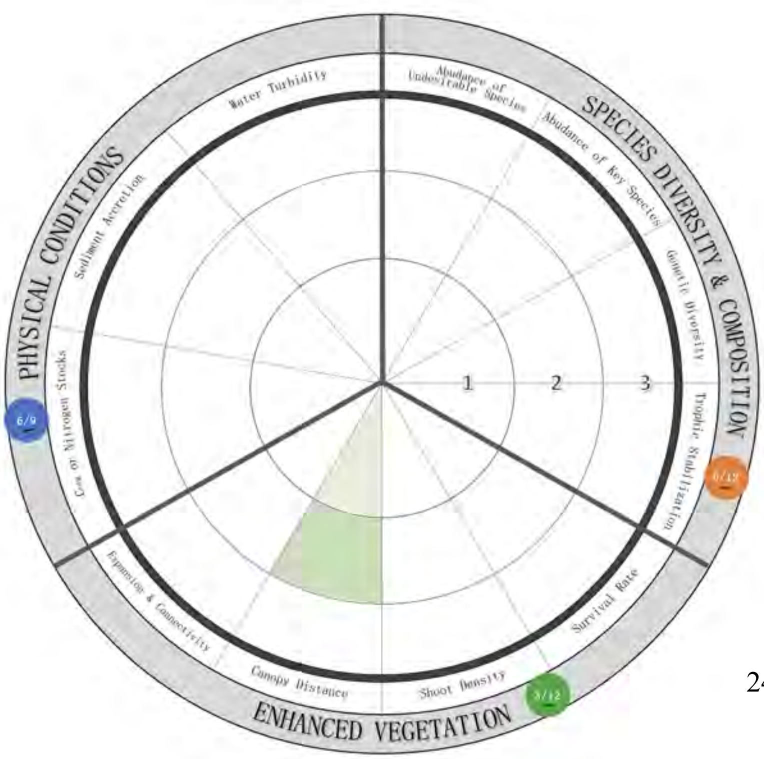
Restoration 1
Boston Harbor
overall score: 17/18



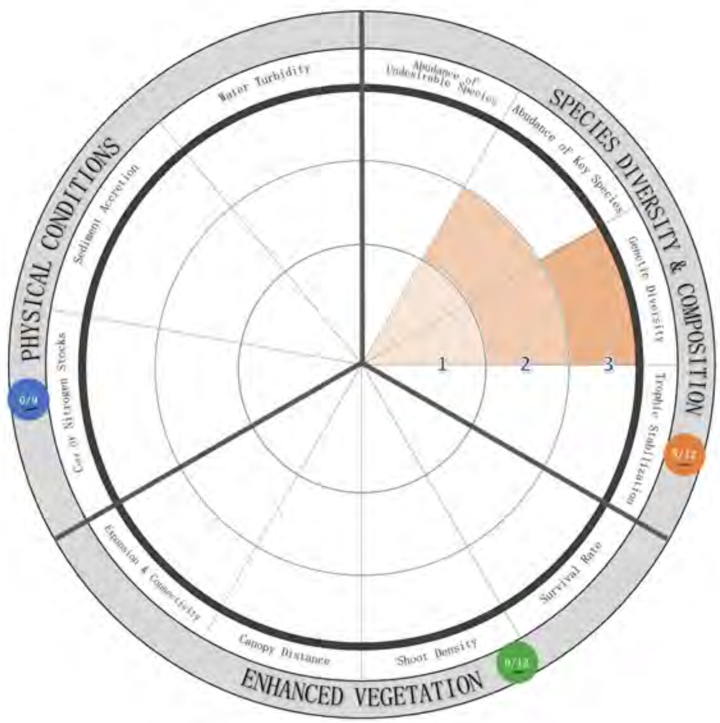
Restoration 2
US East Coast - Delmarva Peninsula
overall score: 15/33



Restoration 3
Maryland, US - Chesapeake Bay
overall score: 2/33



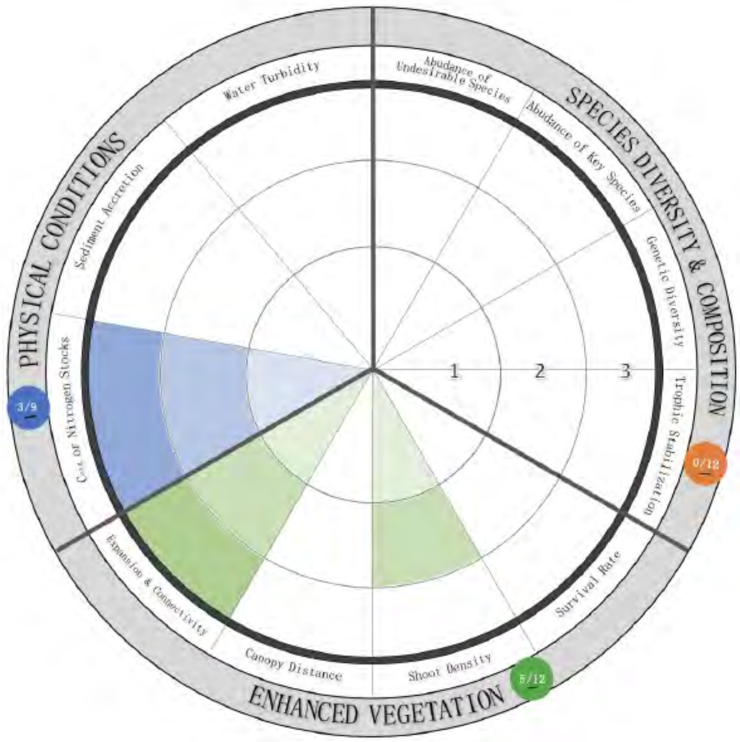
Restoration 4
Australia & New Zealand
overall score: 5/33



Restoration 5

Virginia, USA

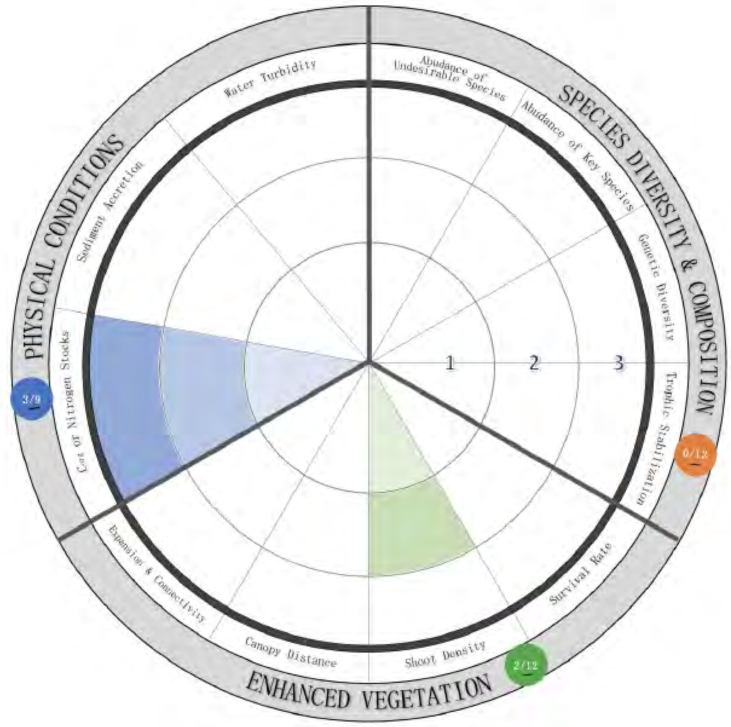
overall score: 8/33



Restoration 6

Finland & Denmark - Baltic Sea

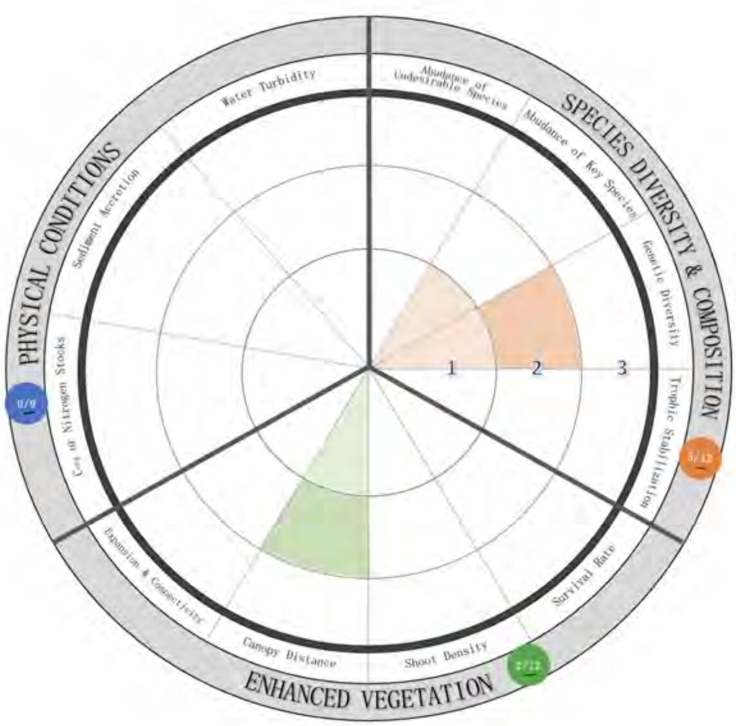
overall score: 5/33



Restoration 7

Florida

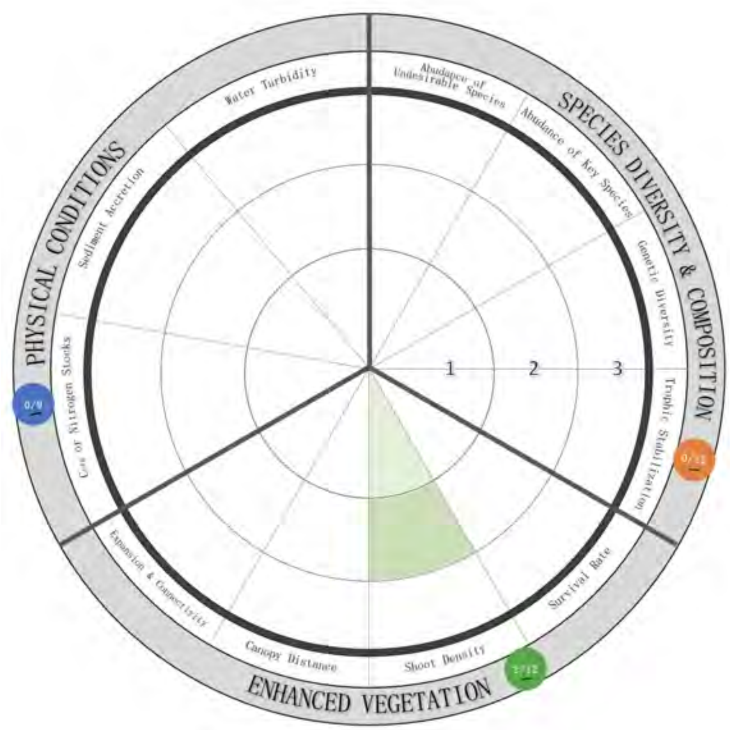
overall score: 5/33



Restoration 8

Shandong Peninsula, China - Swan Lake

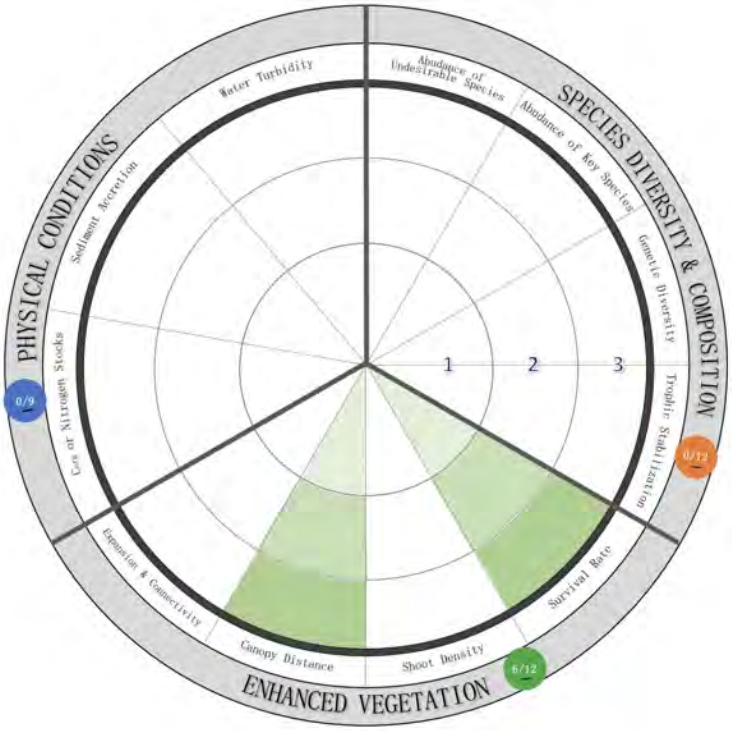
overall score: 2/33



Restoration 9

The Netherlands – Oossterschelde Delta

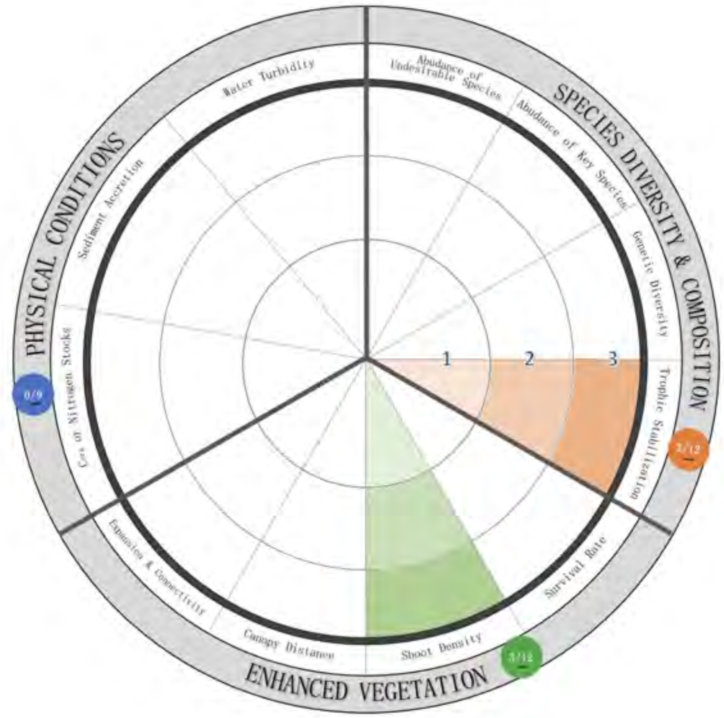
overall score: 6/33



Restoration 10

Port of New Hampshire

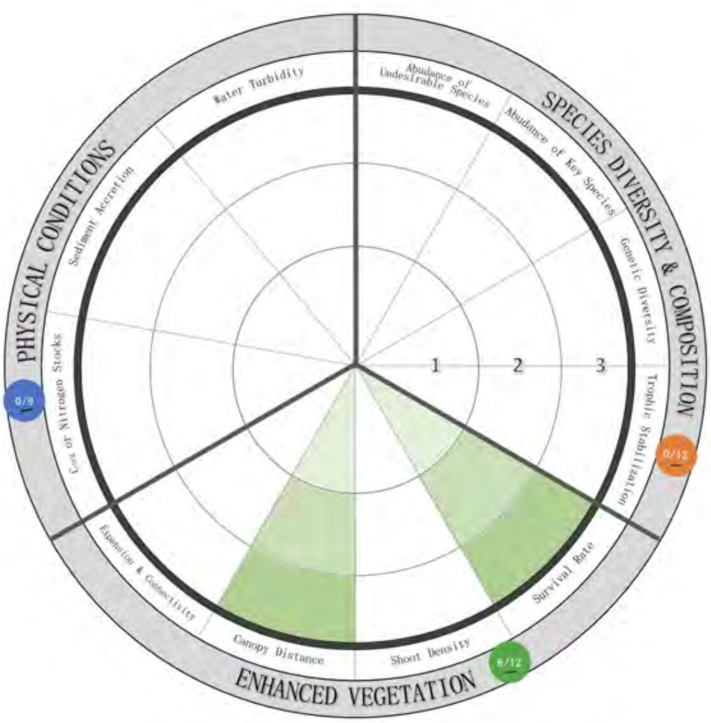
overall score: 6/33



Restoration 11

Tampa Bay, Florida – Great Bay Estuary

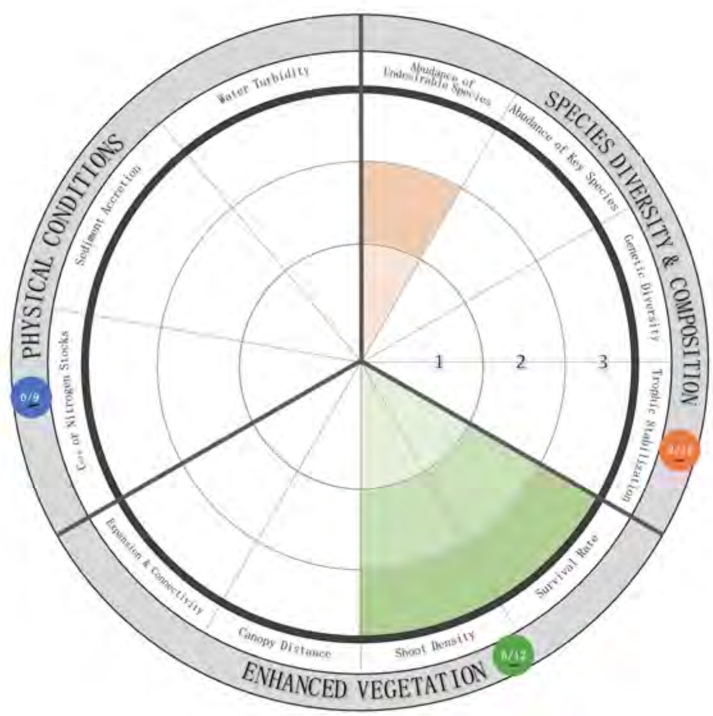
overall score: 6/33



Restoration 12

New Hampshire, USA – Great Bay Estuary

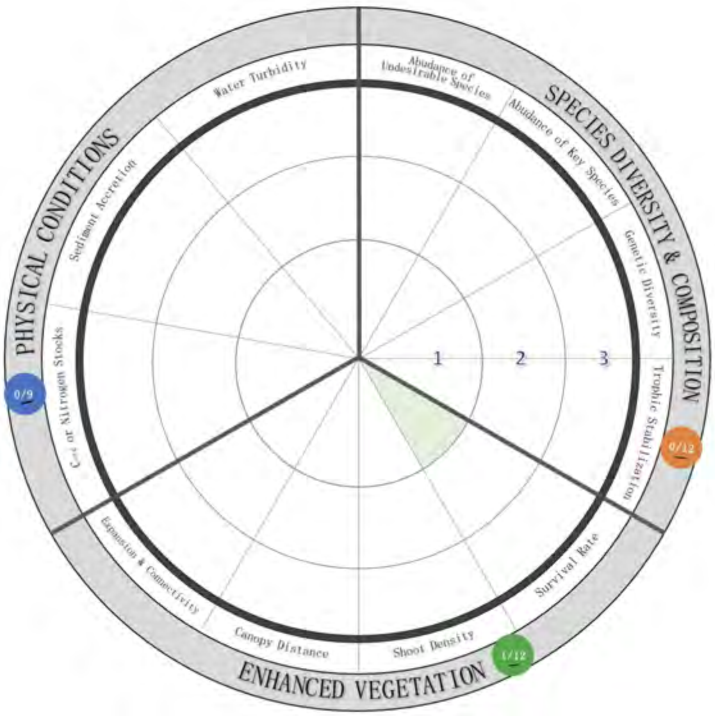
overall score: 8/33



Restoration 13

German Barrier Island Sylt

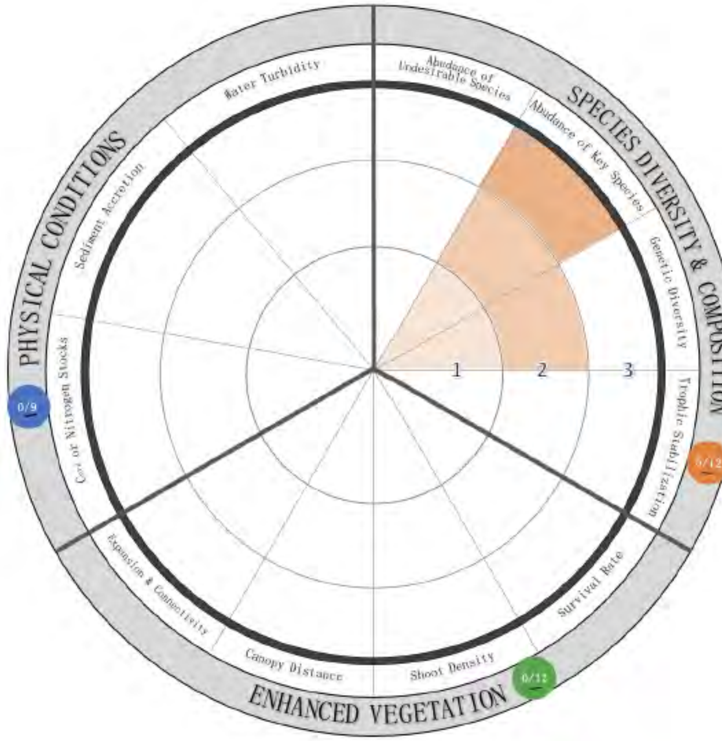
overall score: 1/33



Restoration 14

San Francisco Bay, USA - Romberg Tiburon Center

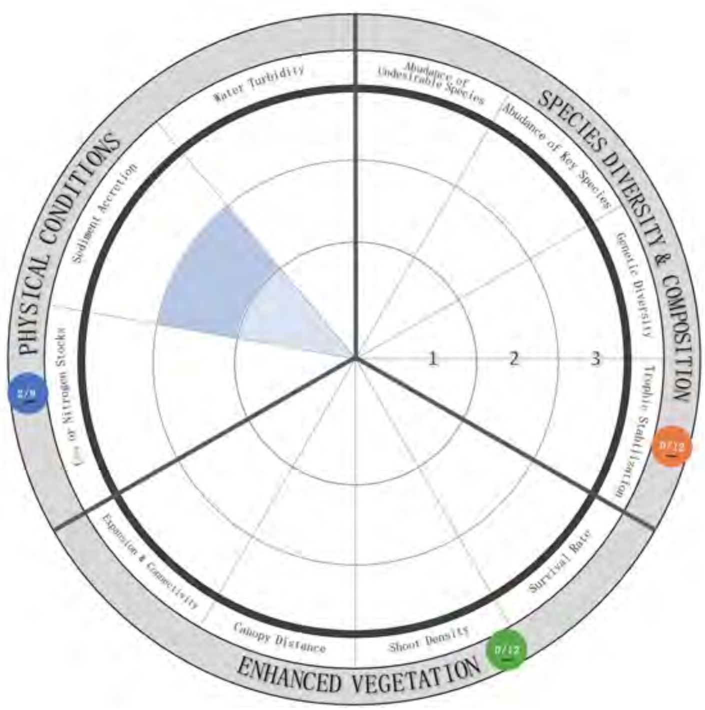
overall score: 5/33



Restoration 15

Korean Coast - Jaran Bay & Onsan Bay

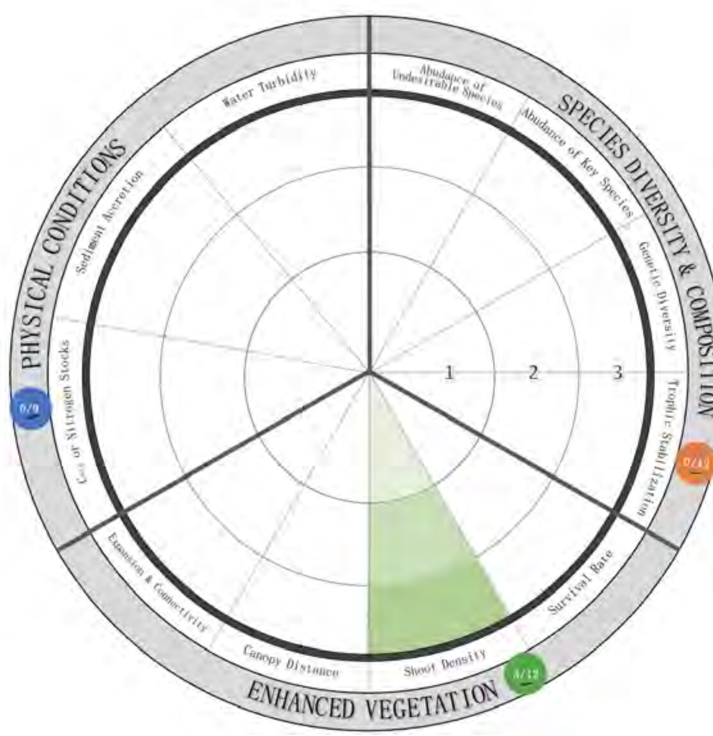
overall score: 2/33



Restoration 16

Yuehu, China - Swan Lake

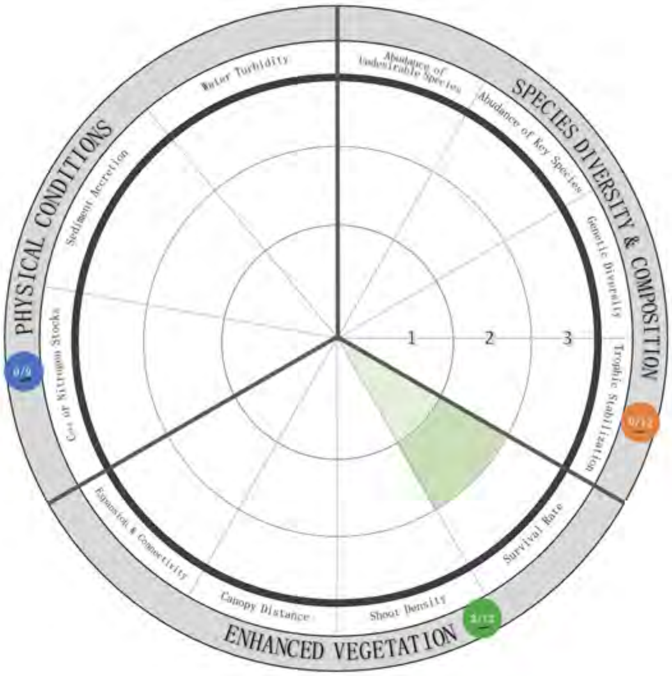
overall score: 3/33



Restoration 17

Yuehu, China (In-Lab) - Swan Lake

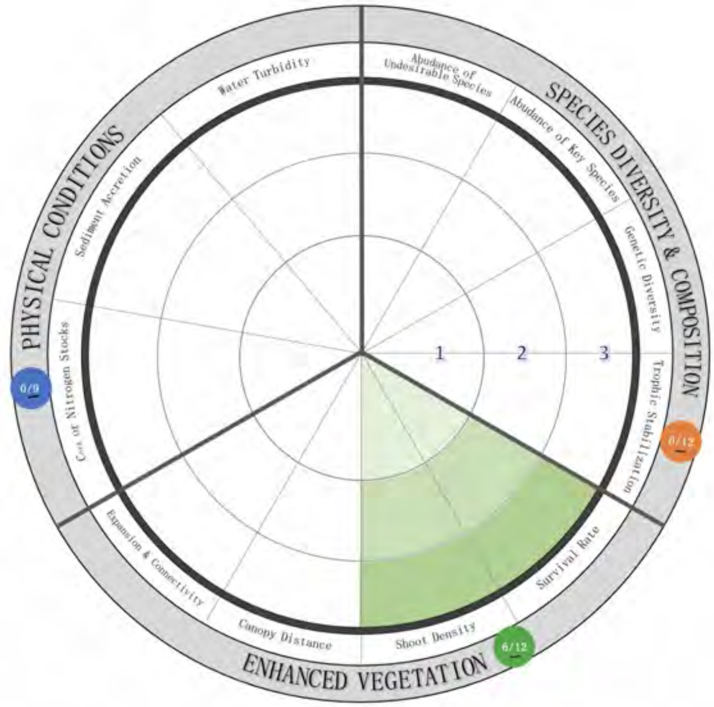
overall score: 2/33



Restoration 18

South Korea - Koje Bay

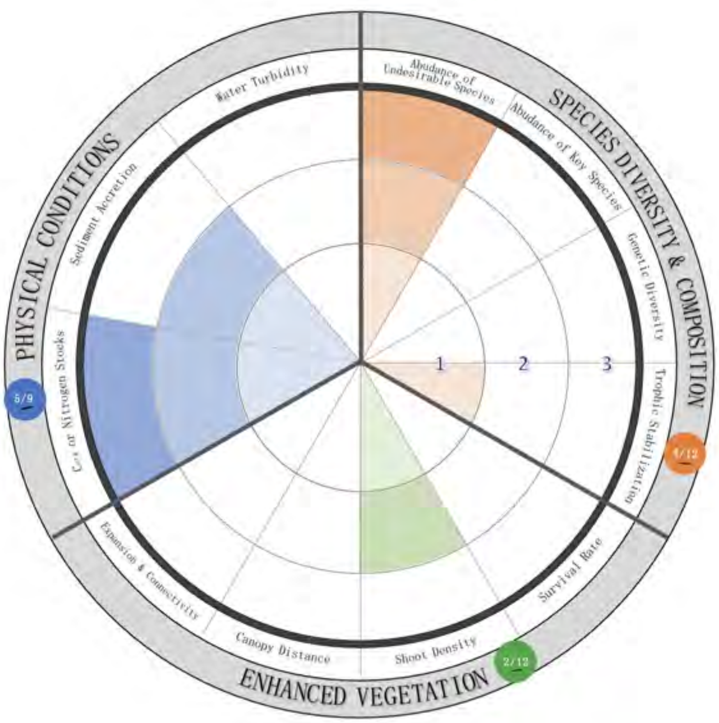
overall score: 6/33



Restoration 19

2021

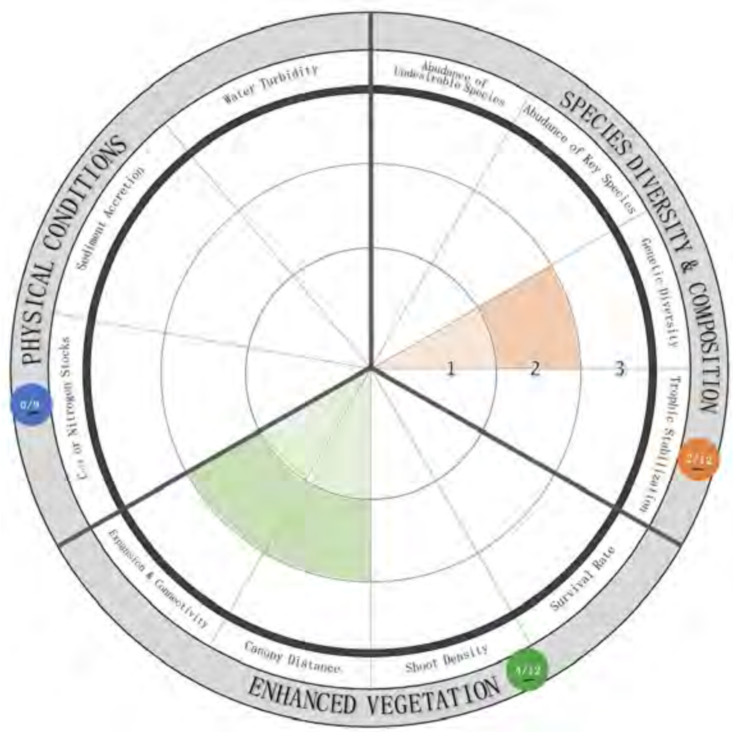
overall score: 11/33



Restoration 20

Swedish West Coast

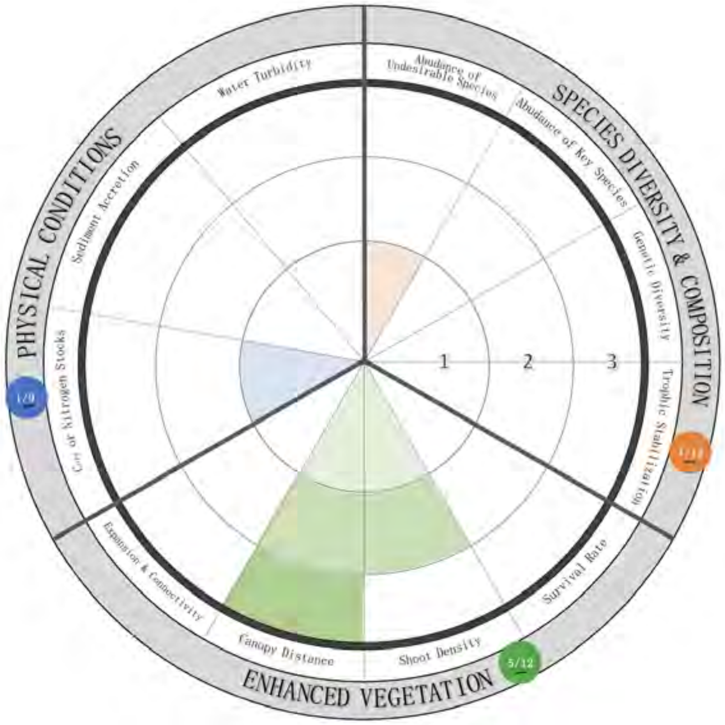
overall score: 6/33



Restoration 21

Cape Cod, Massachusetts

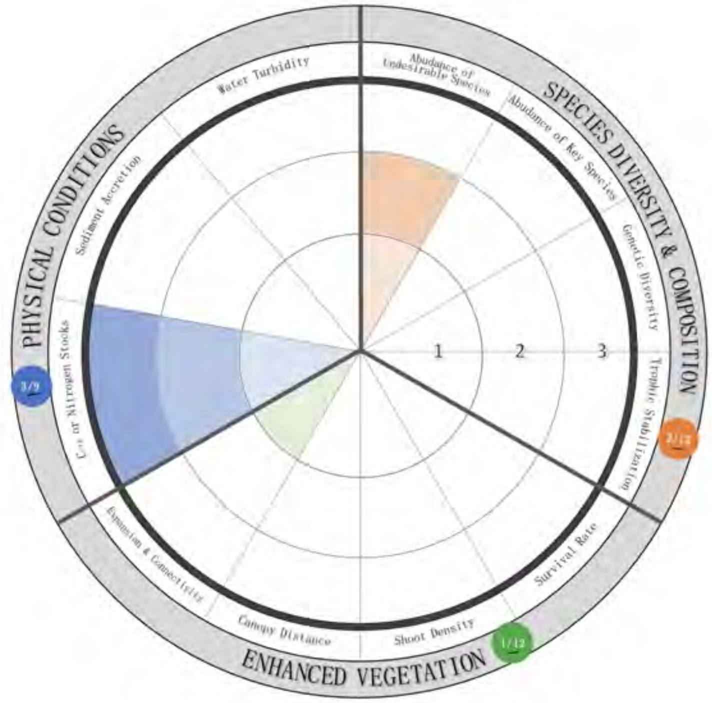
overall score: 7/33



Restoration 22

North Hiroshima Bay, Japan

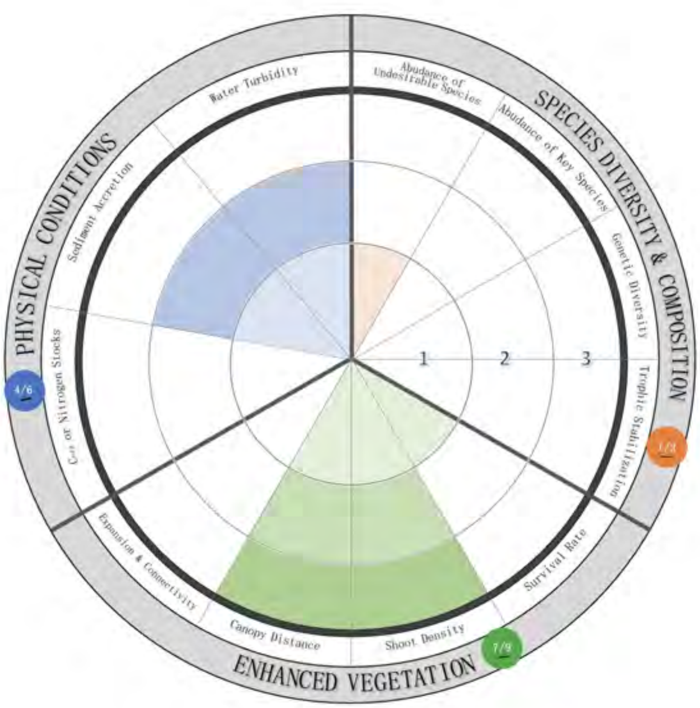
overall score: 6/33



Restoration 23

Washington State, USA - Grays Harbor & Eagle Harbor

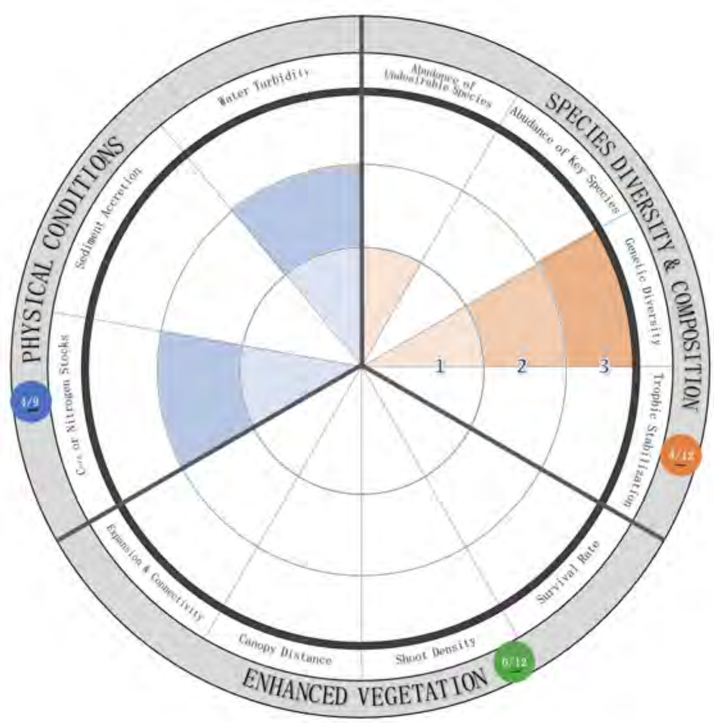
overall score: 12/33



Restoration 24

United States - Chesapeake Bay

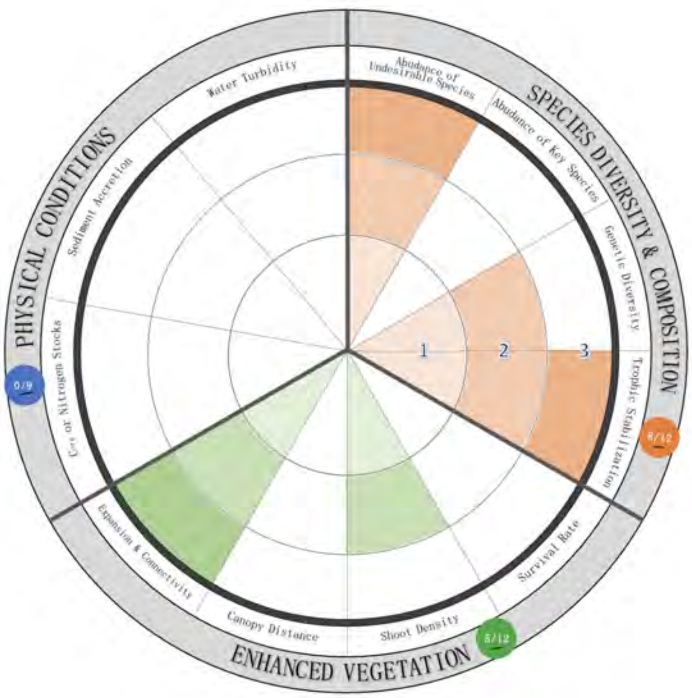
overall score: 8/33



Restoration 25

Southern California - Frenchy's Cove, Anacapa Island

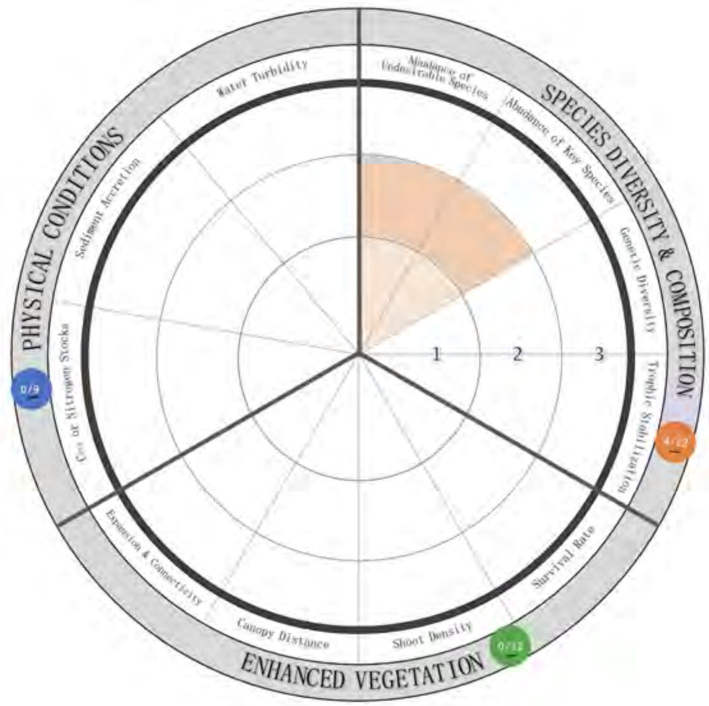
overall score: 13/33



Restoration 26

Southern Coast of Korea - Jindong Bay

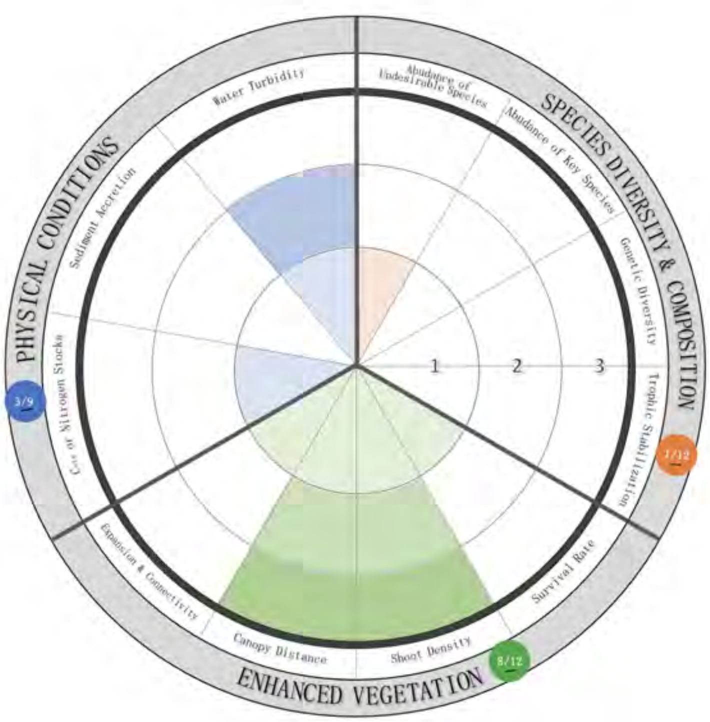
overall score: 4/33



Restoration 27

Chesapeake Bay - Piney Point

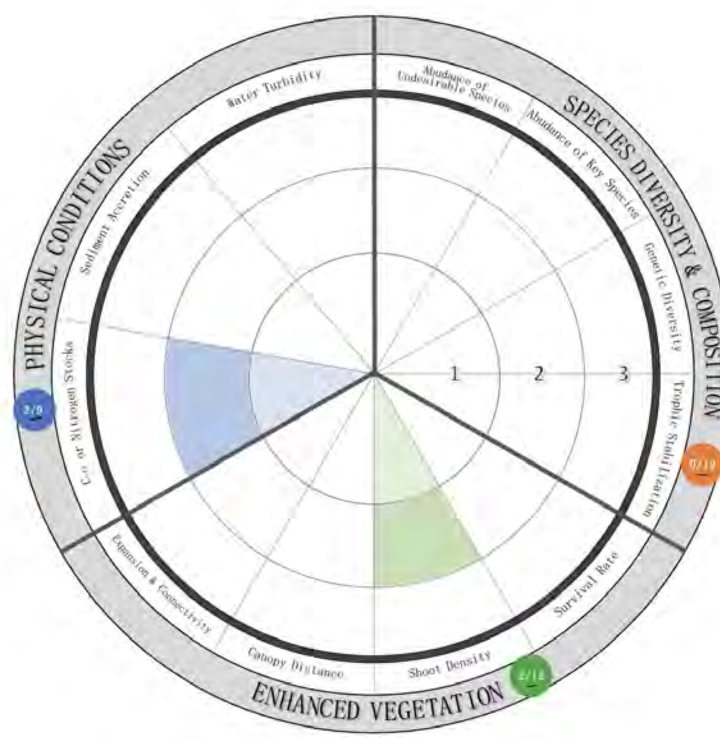
overall score: 12/33



Restoration 28

Northwest Coast of Sweden

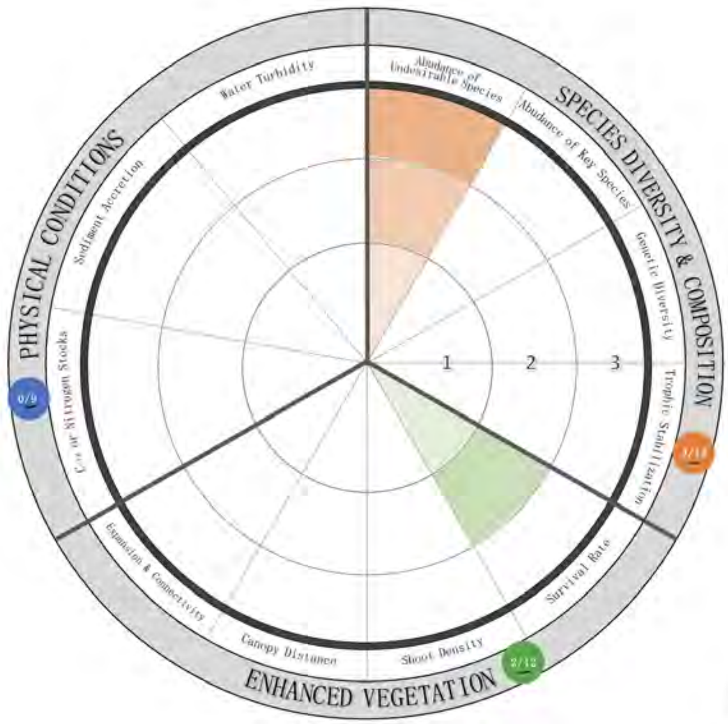
overall score: 4/33



Restoration 29

Global Analysis

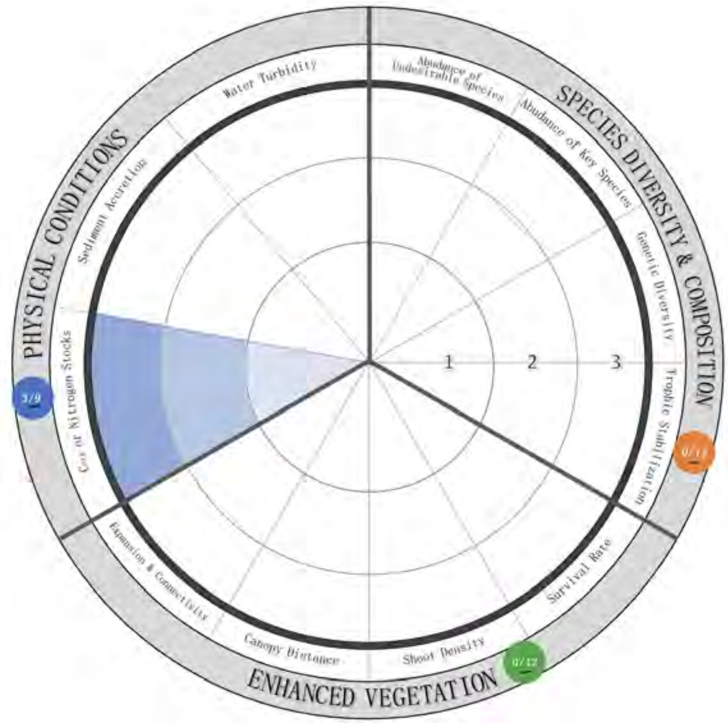
overall score: 5/33



Restoration 30

In-Lab Model

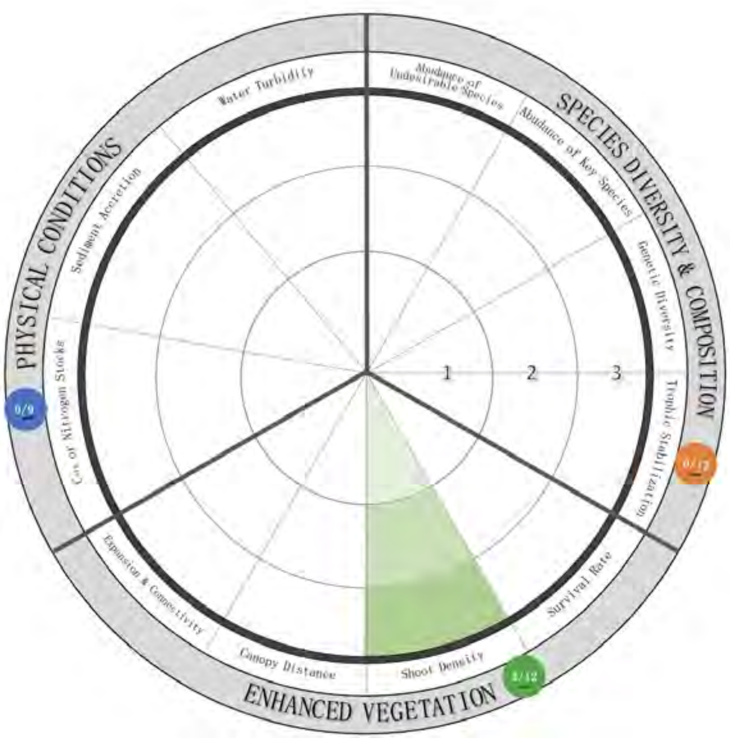
overall score: 3/33



Restoration 31

Shandong Peninsula, China - Swam Lake

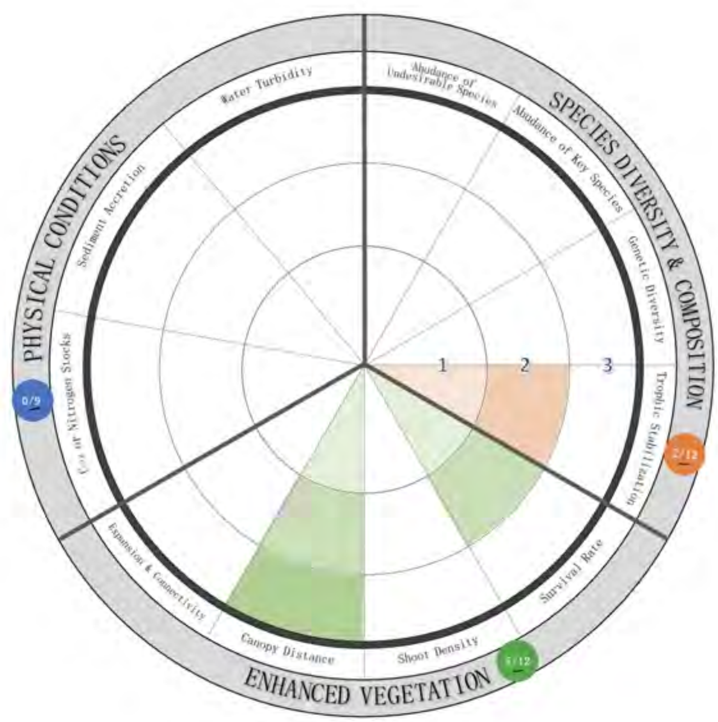
overall score: 3/33



Restoration 32

Portugal - Marine Park

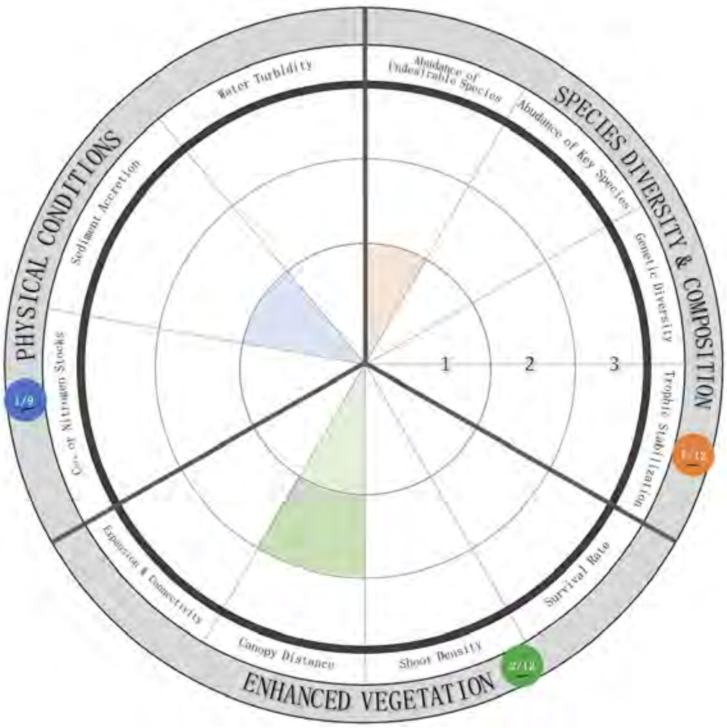
overall score: 7/33



Restoration 33

Delmarva Peninsula Coastal Bays, USA

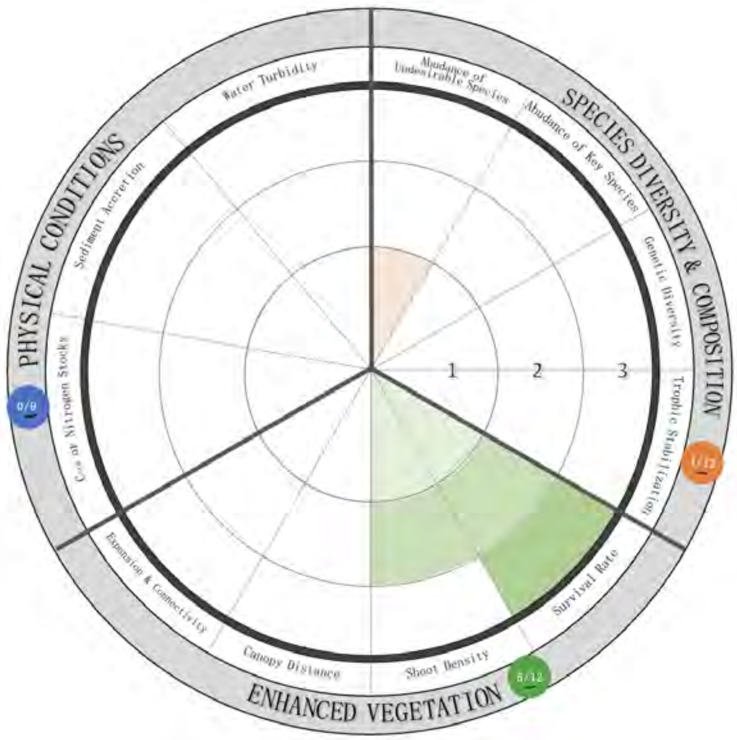
overall score: 4/33



Restoration 34

Shandong Province, China - Huiquan Bay Qingdao Bay

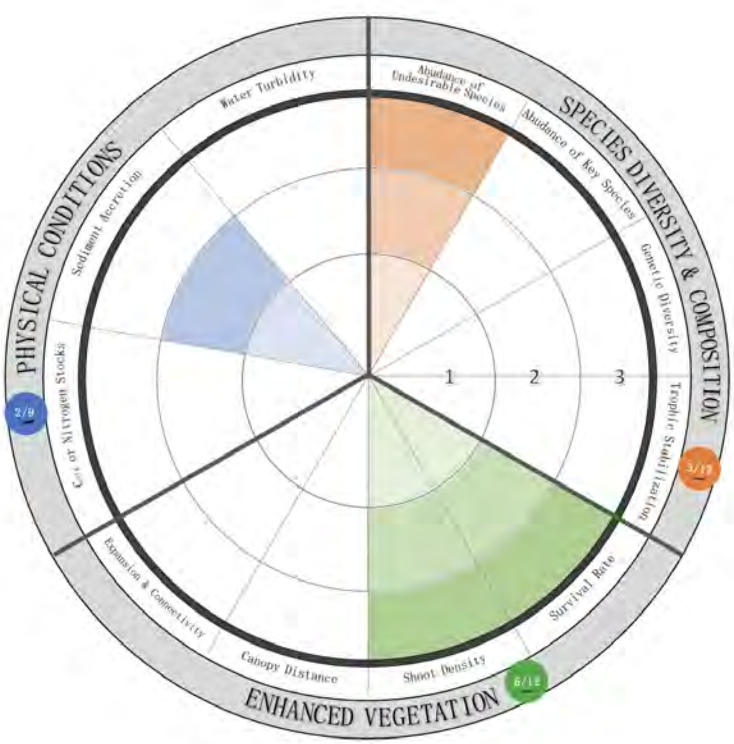
overall score: 6/33



Restoration 35

Eastern Coast of Shandong Peninsula, China

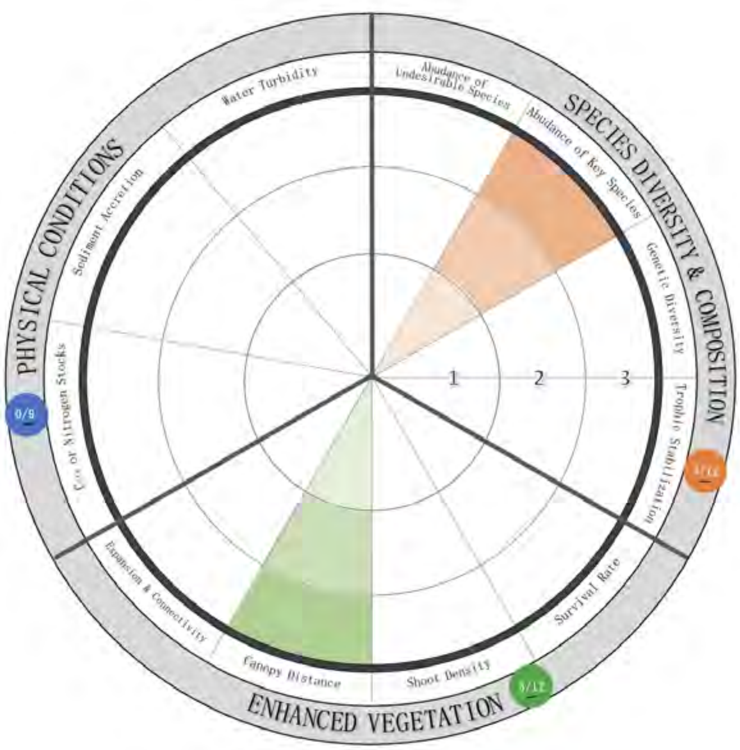
overall score: 11/33



Restoration 36

Newfoundland, Canada

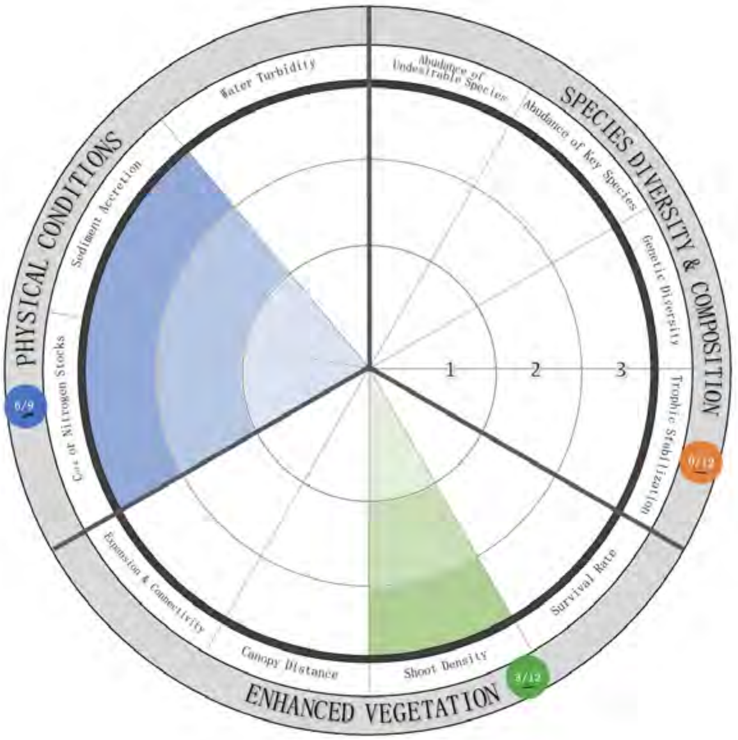
overall score: 6/33



Restoration 37

Virginia, USA - Hog Island Bay & South Bay

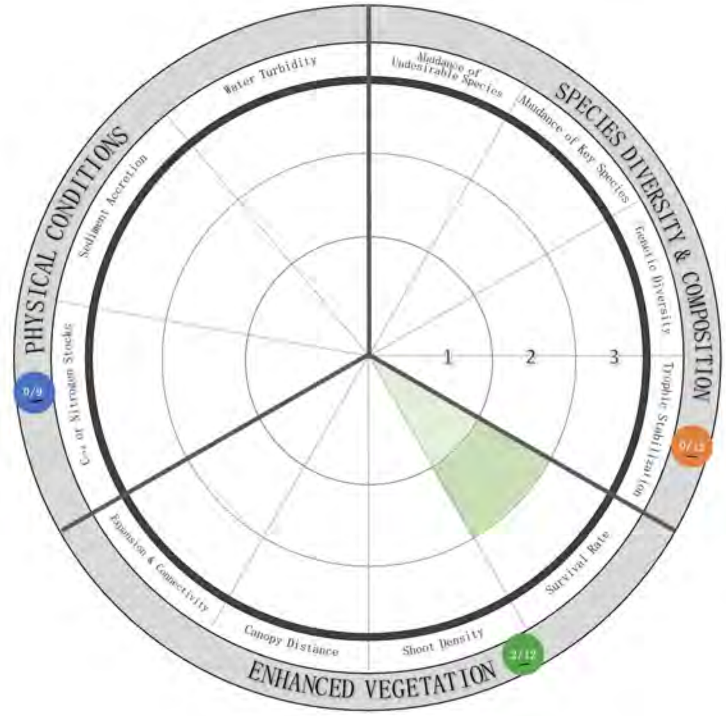
overall score: 9/33



Restoration 38

Virginia, USA - Hog Island Bay & South Bay

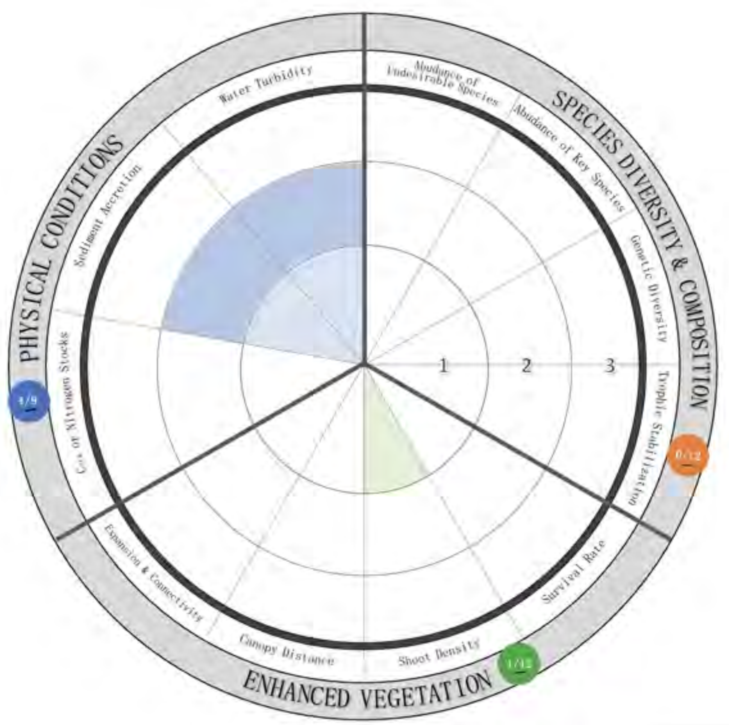
overall score: 2/33



Restoration 39

The Wadden Sea

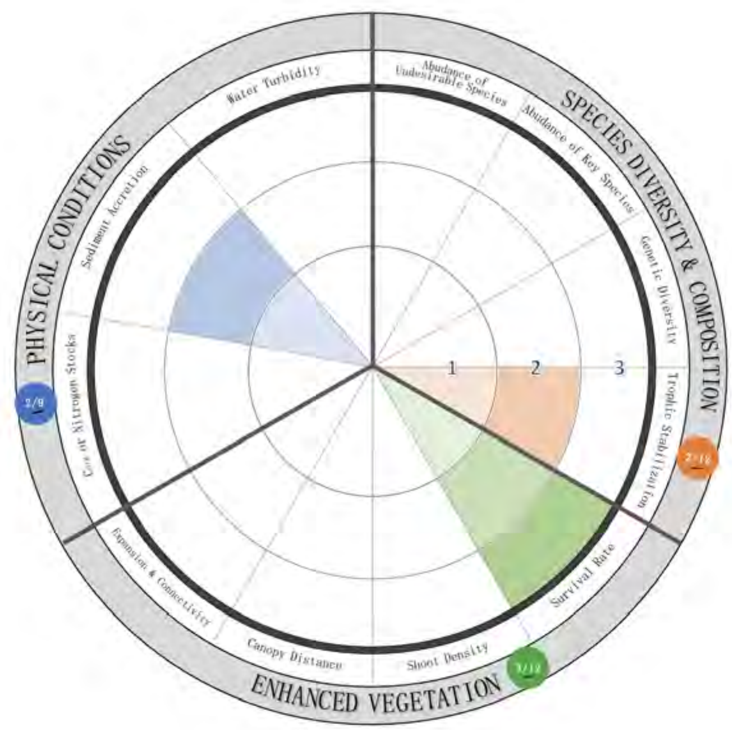
overall score: 5/33

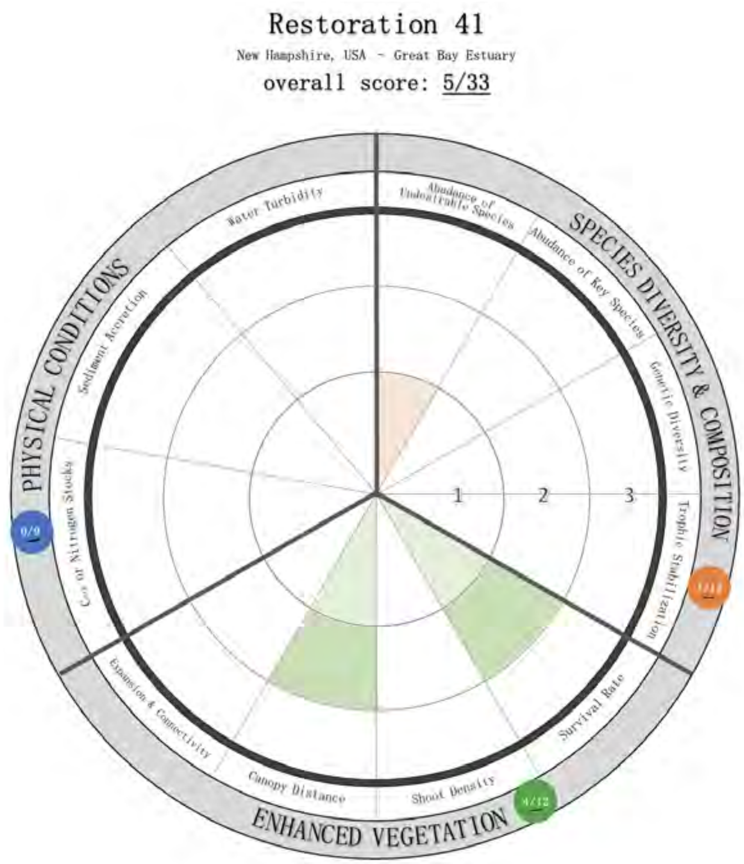


Restoration 40

Virginia Coastal Bays

overall score: 7/33





7.2.2 Procedural Steps:

(1) Within a restoration, different Attributes progress at different paces. You will rank each subfactor out of 3 stars in order to determine overall Attribute ranking for your restoration.

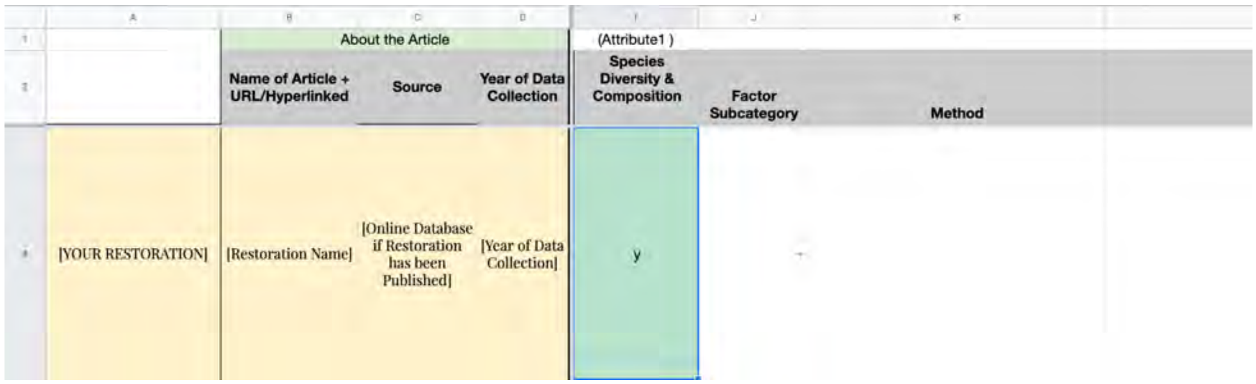
(2) Within the GoogleSheets Template provided, fill in the background information for your restoration.

A	B	D	E	F	G	H
						(Attribute 1)
Name of Article + URL/Hyperlinked	Source	Restoration Site Location	Type of Site (biome)	Species of Eelgrass	Depth of area restored (m)	Species Diversity & Composition
[YOUR RESTORATION]	[Restoration Name]	Example : Santa Monica Bay	Example : Sandy Substrate, Estuary, No neighboring Marine Vegetation	Z. Pacifica	Example : 2-3 metres	

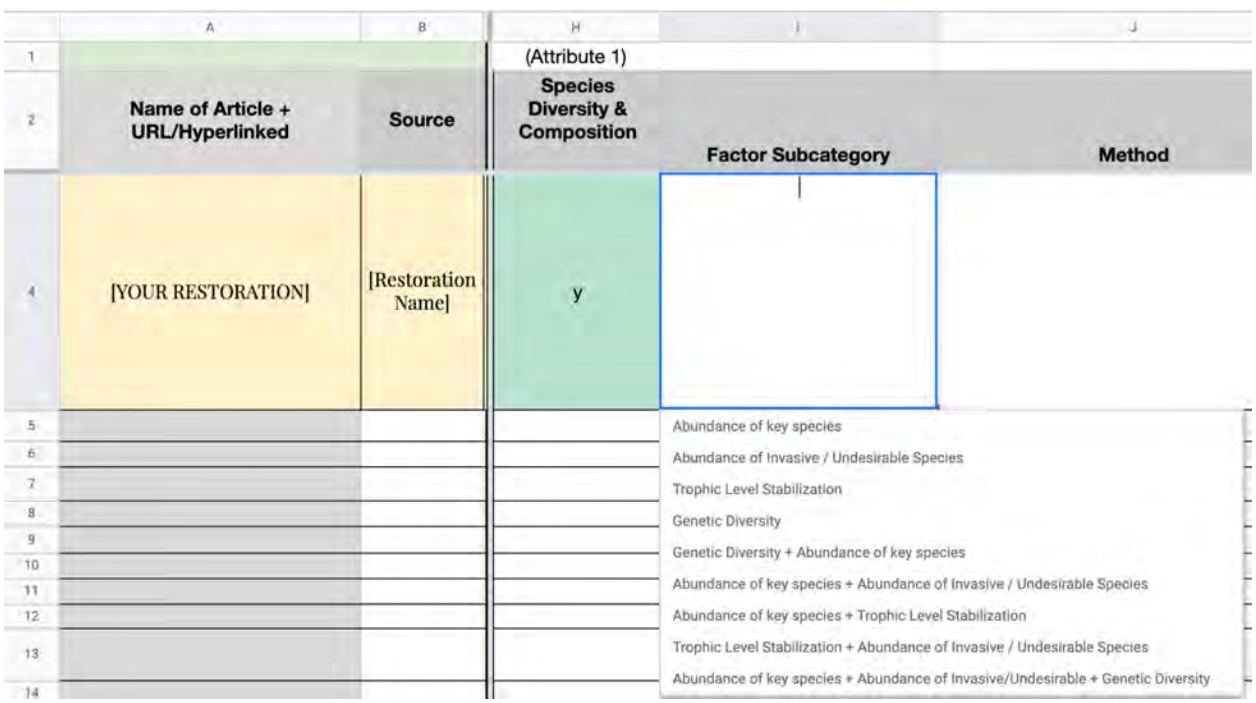
(a) Note: If you are aiming to assess how a restoration is progressing with regards to the existing meta-data, all of the information recorded in the following steps will input to the ***existing*** data collection tab labelled "3-Star MetaData"

(b) If you are wanting to perform your own meta-analysis comparing your restorations to one another, you will record the information referenced in the following steps to the tab labelled "Meta-Analysis Blank template"

(3) Working left-to-right across the row of the newly added restoration, the first column is labeled "Attribute 1: Species Diversity and Composition" - here you will note whether or not your restoration measures any of the Attribute 1's subfactors by typing "y" to indicate that at least one subfactor of Attribute 1 is measured, or "n" to indicate that no subfactor of Attribute 1 is measured



(a) **If you marked "y" for (3)**, use the neighboring drop-down menu to identify which of the Attribute subfactor(s) are addressed in the restoration, and record the method of assessment ("Method" column) and the outcome of the assessment ("Result" column) before moving to Attribute



	A	B	H	I	J	K
1			(Attribute 1)			
2	Name of Article + URL/Hyperlinked	Source	Species Diversity & Composition	Factor Subcategory	Method	Result
4	[YOUR RESTORATION]	[Restoration Name]	y	Abundance of key species + Trophic Level Stabilization	**Abundance of Key Species:** method method method **Trophic Stabilization:** method method method	**Abundance of Key Species:** resut resul **Trophic Stabilization:** resut result r

(b) **If you marked "n" for (3)**, leave the neighboring columns blank and continue to Attribute 2.

	A	B	C	D	I	J	K
1		About the Article			(Attribute1)		
2		Name of Article + URL/Hyperlinked	Source	Year of Data Collection	Species Diversity & Composition	Factor Subcategory	Method
4	[YOUR RESTORATION]	[Restoration Name]	[Online Database if Restoration has been Published]	[Year of Data Collection]	n		

(4) *Repeat step 3 for all Attributes.*

Once you complete the meta-analysis of your restoration, you can evaluate the success of your restoration to existing restorations

(1) First, determine a ranking for each subfactor by comparing its condition to the values presented in Figure X, and identifying which reference condition of each subfactor best reflects that of your own restoration. Record the score in the corresponding "3-Star Ranking Table" provided. *For the subfactors you input as "n", the ranking is NA / 0.*

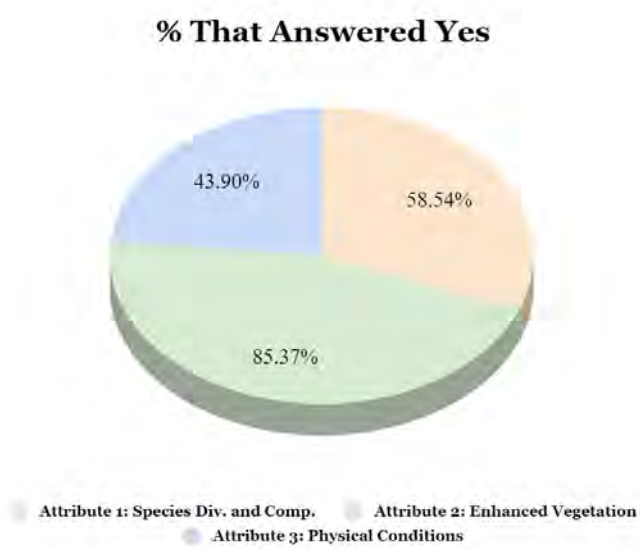
(a) Note: it may be helpful to evaluate subfactors from left-right, beginning with Attribute 1: Abundance of Key Species

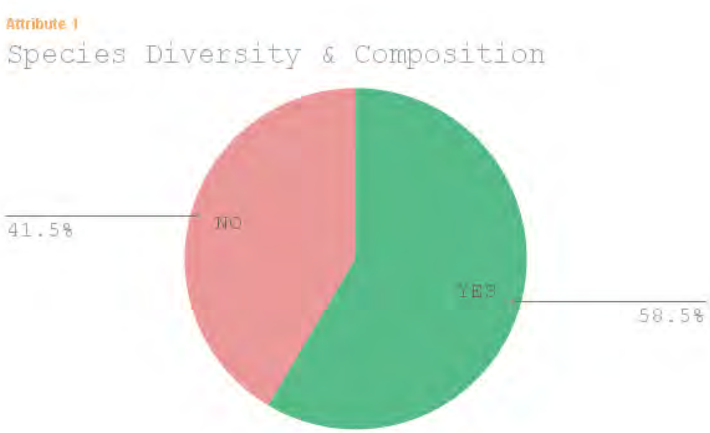
(2) Once you have recorded individual subfactor scores, you can determine an Summary score of each Attribute by tallying up their corresponding subfactors - this score is presented as a fraction with the Attribute score as the numerator, and the max potential as the denominator.

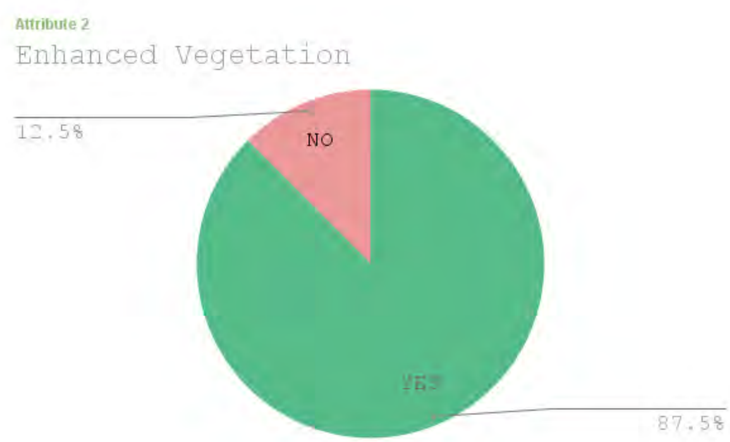
(3) You can now illustrate your results visually by transferring your values to the blank pinwheel template provided.

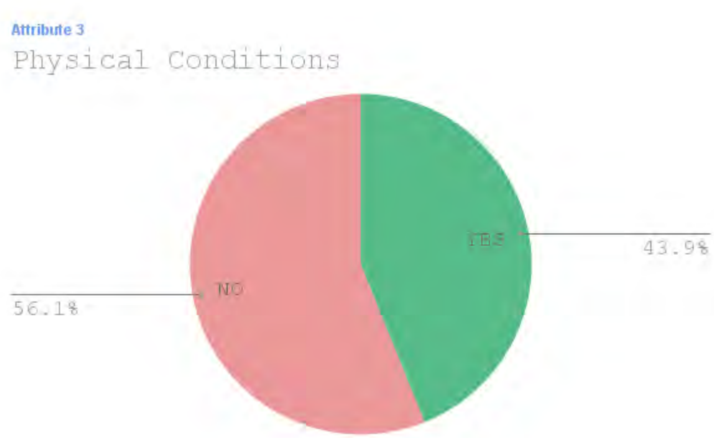
(a) 1 star corresponds to the innermost slice of the pie,
(b) 2 stars corresponds to the middle slice
(c) 3 stars correspond to the the outermost slice

7.2.3 Summary Statistics









7.3 Science Communication Documentary

The documentary was edited in Adobe Premiere Pro and animations in Adobe After Effects. The documentary would not be possible without the footage from The Bay Foundation, Paua Marine Research Group, Amanda Bird, Pixabay, Vice, World Economic Forum, *(include any other footage credits here)*. Thank you to Professor Sjoerd Oostrik for the valuable tips, guidance, and feedback for us first time filmmakers. Thank you to the following people for graciously offering your time and expertise for our interviews:

Daniele Bianchi is an assistant professor in UCLA's atmospheric and oceanic sciences department. His current research focuses on the anthropogenic nutrient inputs on primary production and eutrophication, oxygen loss, acidification, and changes in water clarity and other potential ecological consequences in the Santa Monica Bay.

Kyle Cavanaugh is an Assistant Professor at the UCLA Institute of the Environment and Sustainability and the UCLA Geography Department. He studies the drivers and consequences of changes in coastal foundation species such as giant kelp forests and mangroves.

Tonya Kane is a professor in UCLA's Ecology and Evolutionary biology department. Her work focused on nutrient dynamics in estuaries along the southern California coast, where she studied the microbial processes of nitrogen fixation and denitrification in estuarine sediments using field surveys and experimental approaches. She is especially interested in how human impacts can affect nutrient dynamics in coastal ecosystems.

Ben Grime joined The Bay Foundation in March 2016 as the Abalone Lab Technician. He received his B.A. in Marine Biology from Occidental College in 2013 and is currently working on his M.S. in Biology from Cal Poly Pomona. His graduate studies are focusing on green and red abalone aquaculture method development and wild population restoration.

Rilee Sanders joined The Bay Foundation in December 2019 as the Marine Programs Coordinator. He received his B.S. in Environmental Studies and Marine Biology from the University of Southern California in 2018. He remained at USC to complete his master's degree in 2019, which focused on the impacts of boat anchoring fragmentation on eelgrass habitats on Catalina Island.