QUBES
The Power of Biology × Math × Community

INSTRUCTOR VERSION

Water We Doing: A Deep Dive Into Sustainable Ocean Management & Blue Economies

Rachel Kline
Virginia Commonwealth University
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The purpose of this lesson is to explore the relationship between resource availability and enabling conditions in order to determine a country's capacity to establish a blue economy. Students will review, test, and visualize aggregate data on 6 ocean sectors and enabling conditions using a large, global data set. Students will be given the opportunity to use R and RStudio, a free, open-access statistical software, to consider how their analysis can inform global conservation efforts.

Learning Objectives & Prerequisites (30-45 min.)

At the end of this lesson, students should have a basic understanding of the following concepts. Students should have both R and RStudio installed, as well as a working knowledge of the software. A foundational knowledge of statistics is required, with a particular emphasis on understanding linear regression. Please also have students read 'Enabling conditions for an equitable and sustainable blue economy' Cisneros-Montemayor, 2021), attached to this lesson. This lesson is appropriate for upper-level high school students and collegiate undergraduate students.

Environmental Science Concepts	Statistical Analysis Concepts	Conservation Concepts
Components and importance of a blue economy	Assess a global data set to determine the most viable countries in which to establish a blue economy	The importance of holistic equitability
The interdisciplinarity of socio-politics, economics, and environmentalism	Perform a linear regression using RStudio	Explain how certain conservation practices are best fit for certain areas

What is a Blue Economy?

An Introduction to Sustainable Management of Our World's Most Abundant Resource

Have students read this section individually and then discuss what you learned as a class before moving on to the next section.

The future of the global ocean economy is currently envisioned as advancing towards a '**blue economy**' — socially equitable, environmentally sustainable, and economically viable ocean industries (Cisneros-Montemayor, 2021). In other words, a **blue economy** is a sustainable ocean and coastal economy, which emerges when economic activity is in balance with the long-term capacity of ocean and coastal ecosystems to support this activity and remain resilient and healthy. The **blue economy** is oftentimes extracted from the green economy, acting as a part of a whole. A green economy is a politically focused economy that focuses on sustainable development, low carbon emissions, resource efficiency, and social inclusivity (Wenhai, 2019).

As originally conceived by the Small Island Developing States of the United Nations, a **blue economy** intends to be economically viable, prosperous, and environmentally sustainable, while also being culturally appropriate and focused on social equity and well-being. This is reflected in research and policy publications that reference related terms such as 'blue growth' and a 'sustainable ocean economy'. However, recent plans from governments, trade associations, civil society and inter-governmental organizations tend to focus primarily on the resources necessary for industrial expansion and economic growth of multiple ocean sectors, instead of equitable outcomes from these sectors.

As you will see in the section entitled "Focal Paper", a territory's capacity for establishing a **blue economy** is assessed based on its resource availability and enabling conditions, discussed in the "Understanding the Data" subsection below.

Why Should We Care?

There is increasing global interest in the **blue economy** and BlueTech as humans rediscover the importance of the ocean. The importance of the **blue economy** is clear because of its positive implications in working towards the achievement of the United Nations Sustainable Development Goals (SDG), especially Goal 14: 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development' (UNEP, 2021). The UN Sustainable Development Goals "were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity" (UNDP, 2022).

"Tensions exist within sustainable development approaches, arising from differing perspectives framed around natural capital or social equity" (Cisneros-Montemayor, 2021). In order to circumvent these tensions, we need to identify the most viable territories in which to establish a

blue economy and start to work towards addressing Goal 14. In doing so, we can aim to address and respond to decades of damage inflicted not only on ocean health, but on the health of those vulnerable populations that rely on the ocean for survival and economic advancement.

We're All In The Same Boat

Ocean-linked sectors such as fishing, shipping and marine tourism are among the major arteries of the global economy, providing food, goods, and livelihoods to billions of people worldwide. These sectors are estimated to contribute $1.5 trillion USD in value-add to the economy, supporting around 31 million jobs. In fact, around two-thirds of all global economic activity is moderately or heavily dependent upon ocean resources, making the value of ocean ecosystem services extremely high.

However, due to declining ocean health, climate change and its accompanying social impacts, the ocean economy is at risk of faltering if it is not rapidly transitioned towards sustainability; towards one which is anchored in the intertwined principles of economic viability, environmental stewardship, and social wellbeing. Indeed, ocean industries should aspire to be both sustainable and equitable. To properly address the inequity gaps surrounding the current ocean economy, there needs to be a heavy emphasis on holistic equitability in future planning.

Women, indigenous groups, local communities, and youth are integral to ocean-linked sectors, providing much of the workforce, consumer base, land rights and local knowledge needed to power them. However, these groups are often overlooked in financial decision-making. Major power imbalances significantly underrepresent and marginalize them at decision-making levels, undervaluing their contribution and jeopardizing their rights and needs. This is a critical issue, exacerbating inequalities and driving ocean sectors ever further from being sustainable. To address these challenges, the transition of ocean-linked sectors to sustainability needs to be one based on the three pillars of social equity: stakeholders' full recognition, meaningful participation and fair distribution of costs and benefits (UNEP, 2022).

There will not be a one-size-fits-all solution for addressing the inequities and short comings of the existing ocean economy, and different conservation practices will be better fit for different territories. For example, a territory in which the economy is heavily dependent on marine fisheries would not require the same conservations tactics as a territory that specializes in marine permaculture or eco-tourism. By assessing the unique needs of all relevant territories, we can start to build healthy and plentiful **blue economies** around the world.

"If the ocean were a country, it would have the seventh largest economy in the world."

- *Reviewing the Ocean Economy* (2015)

The Focal Paper

Enabling conditions for an equitable and sustainable blue economy

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Received: 29 June 2020
Accepted: 4 February 2021

Andrés M. Cisneros-Montemayor[1]✉, Marcia Moreno-Báez[2], Gabriel Reygondeau[3], William W. L. Cheung[3], Katherine M. Crosman[4], Pedro C. González-Espinosa[5], Vicky W. Y. Lam[3], Muhammed A. Oyinlola[3], Gerald G. Singh[6], Wilf Swartz[7], Chong-wei Zheng[8] & Yoshitaka Ota[4]

This QUBES lesson is framed around the paper "Enabling conditions for an equitable and sustainable blue economy" by Cisneros-Montemayor et al. (2021). In this observational study, researchers seek to demonstrate that there exists stark differences in a territory's capacity to establishing a **blue economy** when considering social conditions, governance capacity, and resource availability (Cisneros-Montemayor, 2021).

Andrés Cisneros-Montemayor, the paper's primary author, is a resource economist specializing on ocean and coastal social-ecological systems. He is from the fishing port of Guaymas, Sonora, México, and has always been deeply involved with fisheries. His interests and his work focus on highlighting ocean equity within sustainable development strategies and include the first global estimates of the economic value of marine ecotourism, seafood consumption by coastal Indigenous Peoples, and capacity to establish an equitable and sustainable **blue economy**.

"Integrating field experience with theoretical work, my work contributes to research on global resource management issues that need high-level policy and local solutions. My primary areas of expertise are economics, ecosystem services and modelling, and real-world fishery dynamics."

- *Andrés Cisneros-Montemayor*

The Data

The data for this lesson comes from a study published by Cisneros-Montemayor et al. in 2021 titled "**Enabling conditions for an equitable and sustainable blue economy"**. In this study, the authors evaluated the capacity for different territories to establish a **blue economy** by analyzing a fuzzy logic model that integrated indicators from multiple disciplines, such as social conditions, governance capacity, and resource availability. Given the complexity of fuzzy logic models, we will not be seeking to recreate Cisneros-Montemayor's work, but instead utilize his identified variables to perform a linear regression. Knowledge gaps in the data "can be addressed by integrating historical natural and social science information on the drivers and outcomes of resource use and management, thus identifying equitable pathways to establishing or transforming ocean sectors" (Cisneros-Montemayor, 2021).

Territory	Resource.Availability	Enabling.Conditions	Blue.Economy	Development Category
Amsterdam and Saint Paul Island	40	81.3	71	NA
Samoa	31.8	65	56.7	High
Palau	35.2	63.8	56.6	High
Antigua and Barbuda	36.25	63.7	56.825	High
British Virgin Islands	37.325	78.9	68.45	High
Cook Islands	39.5	65.6	59.1	High
Tuvalu	39.5	59.6	54.6	High
Barbados	43	66	60.2	High
French Polynesia	44.2	80.3	71.3	High
Iceland	45.5	82.8	73.5	High
Tonga	45.8	58	55	High

A snapshot of our data set

Understanding the Data

If you would like to learn more about the terms introduced below, check out the TedEd YouTube channel for easily digestible videos on concepts such as bioprospecting and mariculture.

Please note that the data set we will be working with in this lesson has been obtained by specific request from the focal paper's author, and therefore will not match the data set referenced in the paper that is housed on Dryad. The data set we will be working with is a simplified version of the original, larger data set cited in the focal paper.

This data set contains values for resource availability, enabling conditions, blue economy capacity, and development status for 168 territories and countries. Let's break down what each of these data columns represents.

Resource Availability

Resource Availability considers criteria (n = 6) regarding the availability of natural resources that underpin ocean sectors. These six criterion are: 1) bioprospecting, 2) blue carbon, 3) ecotourism, 4) fisheries, 5) mariculture, and 6) ocean energy.

Enabling Conditions

Enabling Conditions considers criteria (n = 11) regarding the capacity to ensure that sectors are socially equitable, environmentally sustainable, and economically viable. These eleven criterion are: 1) corruption, 2) economic equality, 3) gender equality, 4) group equality, 5) human rights, 6) biodiversity, 7) habitat, 8) water quality, 9) infrastructure, 10) investment risk, and 11) national stability.

Blue Economy Capacity

Blue Economy Capacity comprises two over-arching dimensions: Resource Availability and Enabling Conditions (explained above). The criteria (n = 33) scores are informed by indicators based on a review of ocean sectors from the perspective of social, economic, and ecological dimensions of sustainable development. All indicator data sets were standardized and scores were aggregated to produce our working data set. See the figure below for the indicator criterion used to inform each data column score.

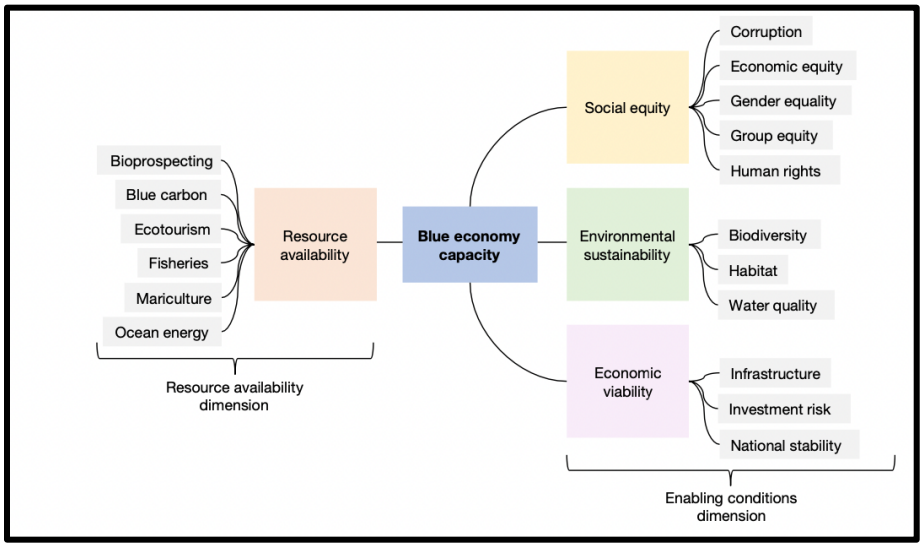


Fig. 1 | Dimensions and criteria used to evaluate the capacity to establish and equitable, sustainable, and viable blue economy ("blue economy capacity"). *The resource availability dimension here pertains to six specific ocean economy sectors. The enabling conditions dimension comprises three facets of development: social equity, environmental sustainability and economic viability, each with corresponding criteria (Cisneros-Montemayor, 2021, pg. 397).*

Quantitative Skills

In this lesson, students will walk through a simple linear regression using data from the study conducted by Cisneros-Montemayor et al. (2021). Students will run a linear regression to determine if there is a relationship between resource availability and enabling conditions in determining the capacity for a territory for establishing a **blue economy**. We will briefly discuss the definition and uses of linear regression, how to construct a linear regression in RStudio, and how to interpret the output of a linear regression.

As you may have noticed, the relationship we are going to examine is not the same as the statistics performed in the focal paper. Cisneros-Montemayor delves into the creation and interpretation of a fuzzy logic model, a complex model examining many-valued logics to evaluate indicators in terms of their contribution to heuristic categories representing capacity for corresponding criteria, dimensions, and **blue economy** scores ([0–100]). Given that this is a very complex and time-consuming process, we are going to go another route with our analysis.

Our Hypothesis

We will be aiming to create a figure similar to Figure 4a from the focal paper. In the focal paper this figure simply serves to demonstrate the span of our data and to highlight some territories on either end of the **blue economy** capacity spectrum. For our analysis, we will flip the axes according to our newly developed hypothesis and perform a linear regression to determine if a predictive relationship exists between these two variables.

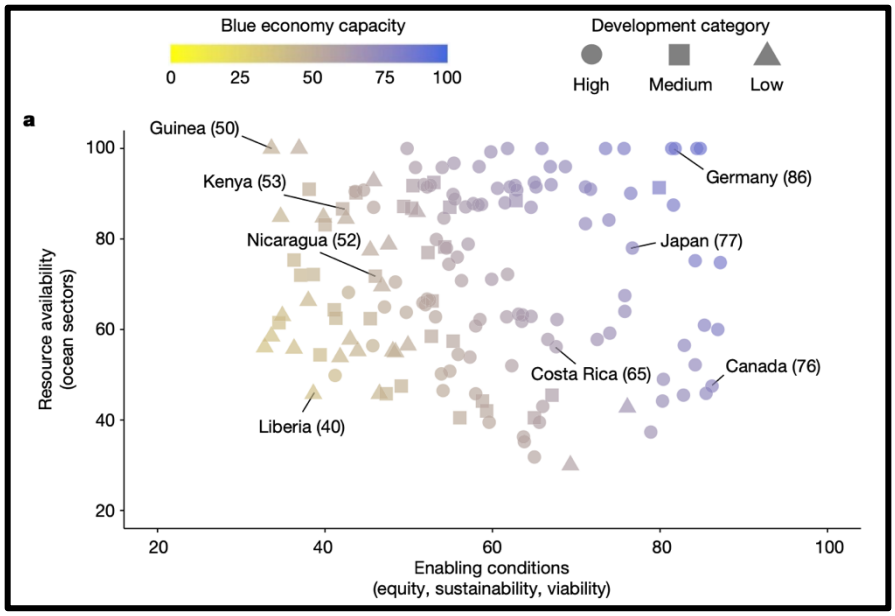


Fig. 4a | Resource availability and enabling conditions scores for coastal territories. *Symbol shapes indicate UN HDI development category: circle, high and very high; square, medium; triangle, low. Symbol colors indicate a*

higher or lower capacity to establish blue economy sectors that are equitable, sustainable and viable ('blue economy capacity'); some territories are labelled as examples. We note that scores do not reflect the current relative importance of oceans to particular territories and only consider the six sectors included in this study.

To perform a linear regression, we need to identify our two variables. In this lesson we will be using 'Resource Availability' as our independent variable, and 'Enabling Conditions' as our dependent variable. Given the destabilizing effects of water scarcity, 'Resource Availability' is our independent variable, as the lack of an adequate, healthy water supply would likely disrupt the reliability and stability of a territory's 'Enabling Conditions'. Vice versa, if resource availability increases, it seems safe to assume that enabling conditions (societal equitability, sustainability, etc.) would also increase. This brings us to our hypothesis: **If a territory has high resource availability and high enabling conditions, then, regardless of development status, that territory has a greater capacity for establishing a viable blue economy**.

Linear Regression

Linear regression models are relatively simple and provide an easy-to-interpret mathematical formula that can generate predictions. Linear regression analysis is used to predict the value of a variable based on the value of another variable. This form of analysis estimates the coefficients of the linear equation, involving one or more independent variables that best predict the value of the dependent variable. Our model will have one independent variable (resource availability).

Modeling Our Data

This is where our lesson in RStudio begins. To fully prepare, please open RStudio and the following documents attached to this lesson: Establishing_A_Blue_Economy_RAnalysis.Rmd, QUBES_Lesson_Ocean_Data.xlsx, and the Data Info Sheet. Proceed to the Rmd document to complete the lesson.

Lesson Outline

- Section I: Set Up
  - Document setup – loading in libraries, examining the data, and creating histograms
- Section II: Graphics
  - Working our way up from a simple baseplot to create a complex, visually appealing figure
- Section III: Statistics – Linear Regression
  - Perform a linear regression
  - Analyze the trendline
- Section IV: R Analysis Questions
  - Students will answer analysis questions to check their understanding of the entire lesson

Additional Resources

Run into any issues? **Here** is a comprehensive guide on all things R.

Remember: you can always use the Console panel for extra help. Try typing in **?ggplot** or **?legend** for help on specific libraries and graph characteristics.

Interested in learning more about fuzzy logic models? Check out **this** series for tips on understanding and teaching the concept.

Interested in learning how each criterion was evaluated? See Supplementary Information 1 section in the focal paper, linked **here**.

Check out this YouTube video for tips on understanding the dimensions of sustainable development.

If you want to change theme of your plots in R, check out this webpage for a rundown of all themes available in **ggplot2**.

Here's how to add titles, captions, and more in **ggplot2**!

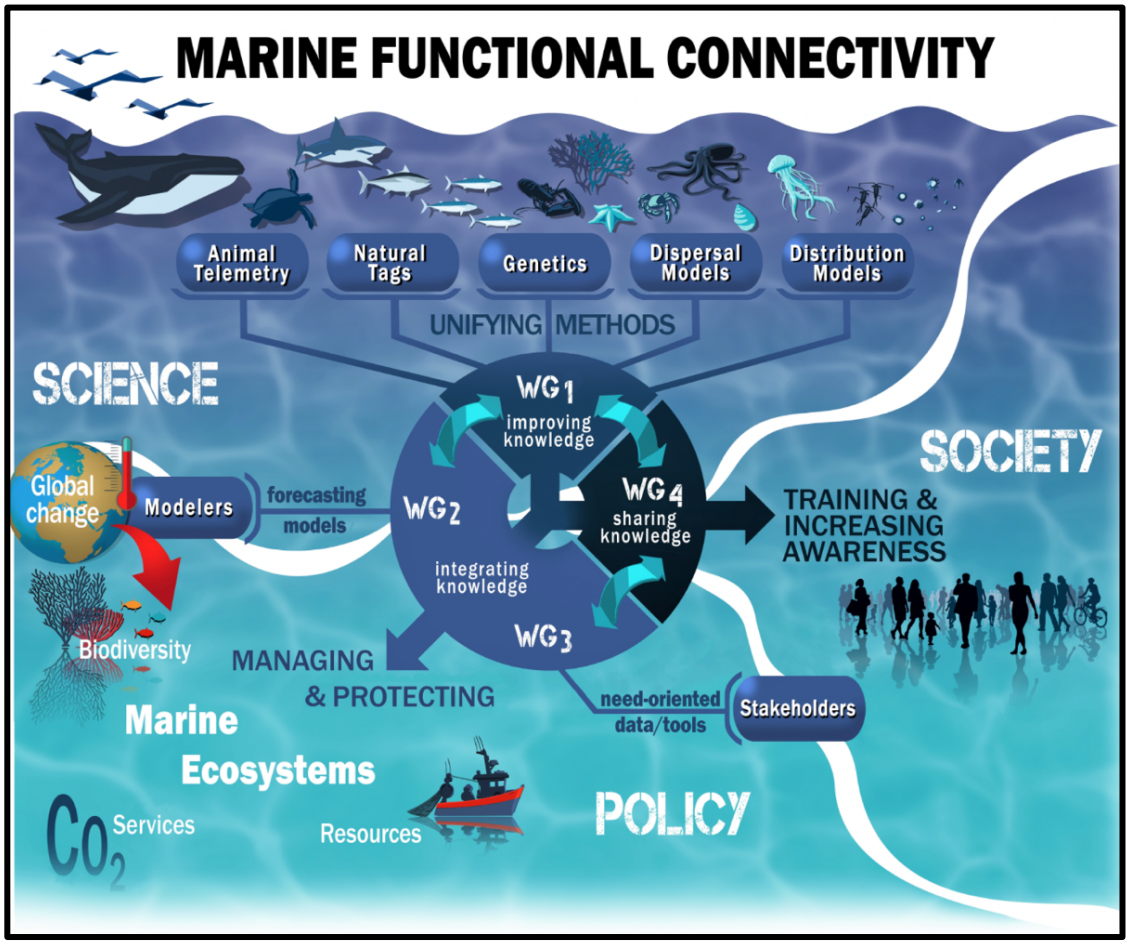
Lesson Summary

Key Takeaways

In this lesson, students have been introduced to the concept of a blue economy, its characteristics, its importance, and what it takes for a territory to establish their own **blue economy** successfully.

Students also received a refresher on basic statistics with the brief activity on creating histograms, as well as a tutorial on how to build graphics in RStudio using a combination of libraries.

Finally, we identified the conservation goals relevant to a **blue economy**, and highlighted prime geographic areas to begin implementation of **blue economies** today.



Answer Key – R Analysis Questions

Students should answer these questions in the Rmd file.

Q1. How would you describe the histogram for Resource Availability?
This histogram appears to be multimodal, with two distinct peaks. Students should note that the data does not appear to be normally distributed. The red trend line helps us visualize the flow of our data.

Suggested code for creating the Enabling Conditions Histogram:

```
ggplot( fig_dat, aes( x = Enabling.Conditions ) ) +
  geom_histogram( aes ( y = ..density.. ),
                  color = "black",
                  fill = "orange", bins = 20 ) +
  geom_density( color = "red", lwd = 1.5 ) +
  xlab( "Enabling Conditions" )
```

Guide to describing histograms.

Q2. How would you describe the histogram for Enabling Conditions?
This histogram appears to be, overall, more normally distributed than the Resource Availability histogram. Students should note that the right-most region of the histogram appears to be non-normally, or randomly distributed. Again, the red trend line just helps students to visualize the flow of the data.

Q3. Looking at the trendline you just added, how would you describe the relationship between Enabling Conditions and Resource Availability? Does it appear to be statistically significant? What does the gray shading around the line represent?
The relationship between Enabling Conditions and Resource Availability appears to have a slight negative relationship. Given the gradual grade of the trendline, the relationship does not appear to be statistically significant. The gray shaded band around the trendline represents a pointwise 95% confidence interval. Confidence intervals show the uncertainty inherent in the estimate of the true relationship between the response (Enabling Conditions) and predictor variable (Resource Availability).

Q4. What, if anything, stands out to you about this trendline? Given our two variables, Resource Availability and Enabling Conditions, does our final graph surprise you?
This is a free response question. Students should think critically about what our two variables represent, and how their relationship might be expected to behave.

Q5. Take a look at the R-squared value of this plot. Given this value, does our model appear to be statistically significant? Explain your answer.
Students should include the R-squared value in their response (0.015, or 1.5%). Our model does not appear to be statistically significant; our R-squared value tells us that the relationshp between these two variables is only explaining 1.5% of the variation we see in our plot.

Tips for describing R-squared values

Q6. Does the final Fig2 output support our original hypothesis? Why or why not? Original hypothesis: "If a territory has high resource availability and high enabling conditions, then, regardless of development status, that territory has a greater capacity for establishing a viable blue economy."
No. given the slight negative trend seen in Fig2, our original hypothesis is not supported. As mentioned in the Abstract of our focal paper, there are knowledge gaps that exist within the data set that could be contributing to the output we are seeing. Challenge your students to think of other reasons why the hypothesis is not supported.

Q7. Based on the final figure output, which countries appear to be the most capable of supporting a blue economy? What do these countries have in common (geographically, socially, financially, etc.)?
Students should be looking for dark blue-shaded territories in the top right corner of the final figure. Denmark and the Netherlands appear to be tied as the most capable territories for establishing a blue economy. These countries are both found in the northeast region of Europe, and are both classified as progressive countries with high social mobility. Students can mention any aspect of these countries' socio-economic, political, or geographic traits.

Q8. Given the statisical significance, or lack thereof, of our model, what other factors not accounted for in our model could be affecting a territory's ability to house a viable blue economy? Provide 3 examples.
As we stated in Q5, our model does not appear to be statistically significant. If students refer back to the focal paper attached to this lesson, we can see the author has highlighted possible factors not present in our model that may be affecting a territory's ability to establish a successful blue economy. Differences in national stability, corruption and infrastructure appear to be key to determining a territory's ability to establish a successful blue economy. (This answer can be found in the Abstract of the focal paper. Students are welcome to provide their own ideas on top of these 3 examples.)

Q9. What criteria underpin Resource Availability? Enabling Conditions?
Resource Availability considers criteria (n = 6) regarding the availability of natural resources that underpin ocean sectors. These six criterion are: 1) bioprospecting, 2) blue carbon, 3) ecotourism, 4) fisheries, 5) mariculture, and 6) ocean energy. Enabling Conditions considers criteria (n = 11) regarding the capacity to ensure that sectors are socially equitable, environmentally sustainable, and economically viable. These eleven criterion are: 1) corruption, 2) economic equality, 3) gender equality, 4) group equality, 5) human rights, 6) biodiversity, 7) habitat, 8) water quality, 9) infrastructure, 10) investment risk, and 11) national stability.

Q10. How can policymakers utilize this data to work towards establishing a blue economy in their home territory?
Again, students can refer to the focal paper to identify suggested strategies for conservation efforts and blue economy implementation tips. Answers that mention an interdisciplinary approach to conservation and economic standards necessary to establish

a blue economy are accepted, such as policymakers brining in researchers and stakeholders alike to promote collaborative planning on all fronts to in order to deliver on the goals of a blue economy.

Q11. Why is establishing a blue economy so important?

The ocean economy is a trillion dollar industry that supports two-thirds of global economic activity. Prioritizing equitability within this sector is incredibly important so that usually marginalized groups that already participate and drive this sector, women, indigenous groups, local communities, and youth, are compensated fairly, and can build more stable, prosperous futures for themselves and future generations. As the ocean is such a vital resource for global development and social welfare, preserving the remaining resources we do have while working to support those who support this economy is essential for a healthier, more sustainable future for all.

Want to follow our focal paper author's journey? Click here to view Andrés' social media and current career interests.

Check out this case study of a blue economy in Bangladesh.

Answer Key – R Output

This section contains images of proper output from the R analysis. If your students get stuck, check here to see how their output varies from the desired outputs below.

Section I: Set Up

Chunk - Examing our data

Running the head(fig_dat) line should produce this tibble:

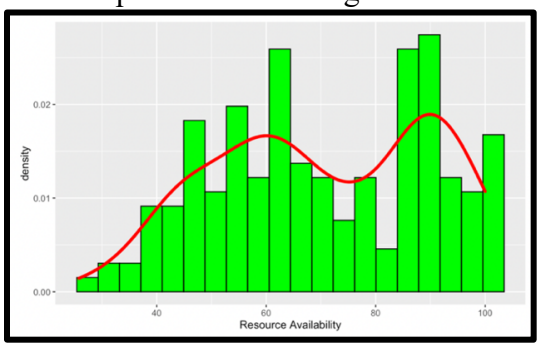
A tibble: 6 × 5

Territory <chr>	Resource.Availability <dbl>	Enabling.Conditions <dbl>	Blue.Economy <dbl>	Development_Category <chr>
Amsterdam and Saint Paul Island	40.000	81.3	71.000	NA
Samoa	31.800	65.0	56.700	High
Palau	35.200	63.8	56.600	High
Antigua and Barbuda	36.250	63.7	56.825	High
British Virgin Islands	37.325	78.9	68.450	High
Cook Islands	39.500	65.6	59.100	High

6 rows

Chunk - Histogram of Resource Availability

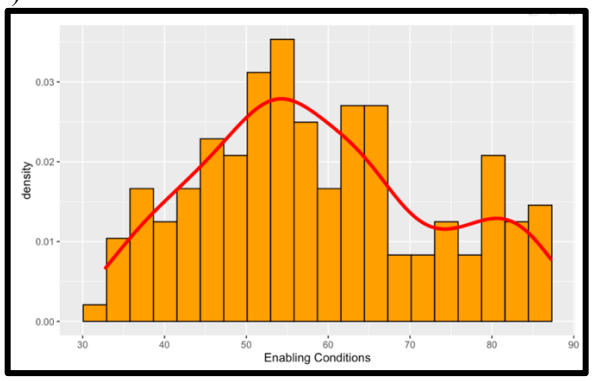
Running the ggplot(…) lines should produce this histogram and trendline:



Chunk - Histogram of Enabling Conditions

Suggested code for this chunk (also found in the 'Answering Key – R Analysis Questions' section:

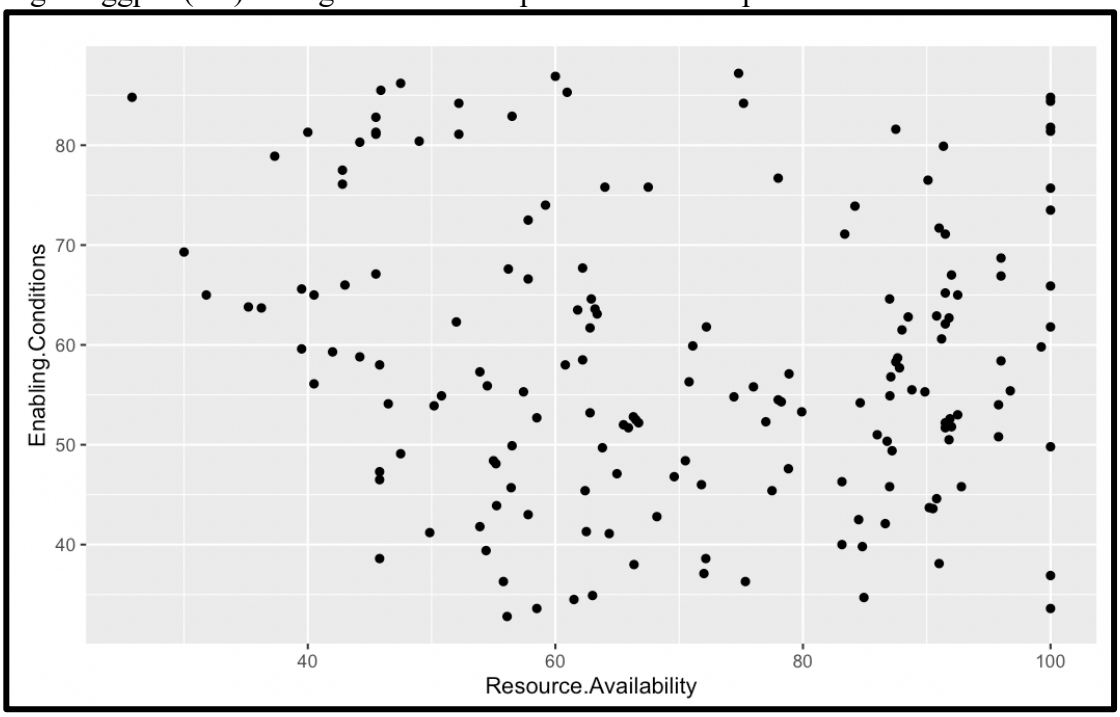
```
ggplot( fig_dat, aes( x = Enabling.Conditions ) ) +
  geom_histogram( aes ( y = ..density.. ),
                  color = "black",
                  fill = "green", bins = 20 ) +
  geom_density( color = "red", lwd = 1.5 ) +
  xlab( "Enabling Conditions" )
```



Section II: Statistics – Graphics

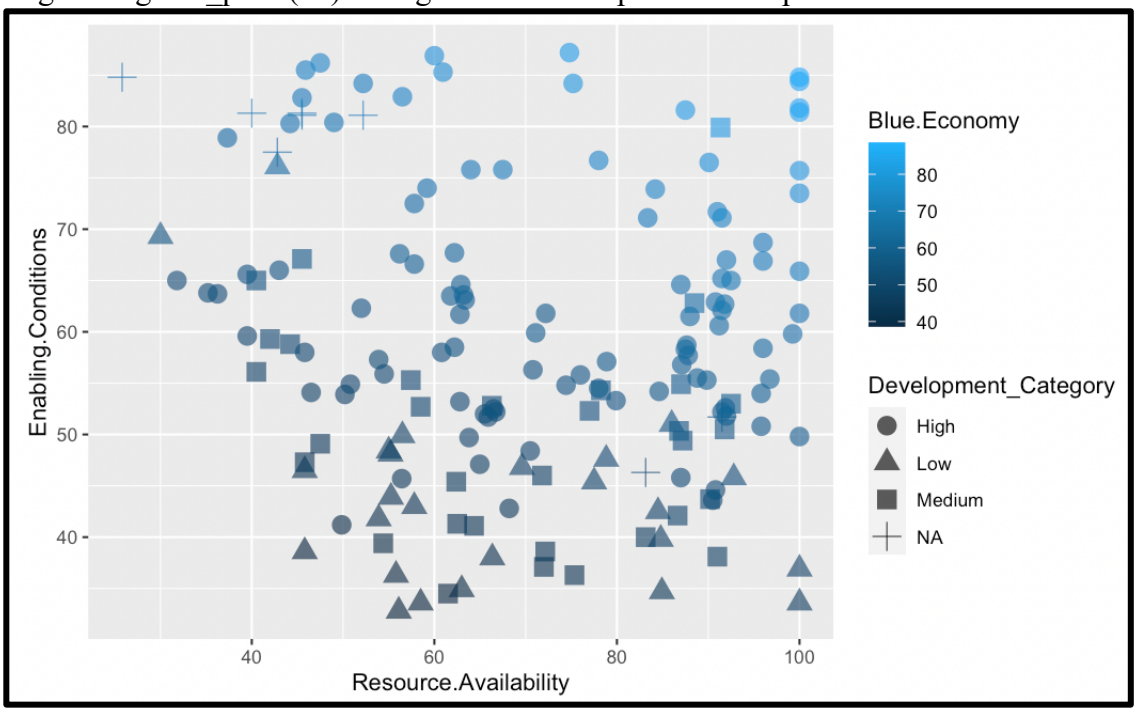
Chunk - Creating the Basic Plot

Running the ggplot(…) → Fig1 lines should produce this baseplot:



Chunk - Addition of Color Gradient and Data Point Shapes

Running the + geom_point(…) → Fig1 lines should produce this plot:

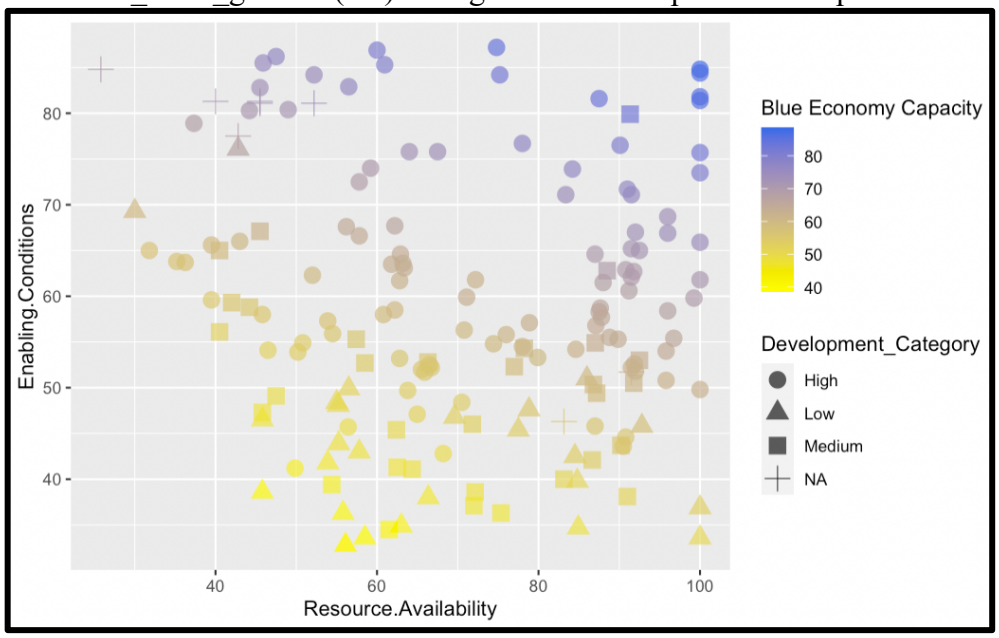


Depending on the layout of your students' screens, the upper right-hand corner of the Development Category legend may get cut off. In this case, you can remind students of the legend key:

- ● *Ciricle = High*
- ■ *Square = Medium*
- ▲ *Triangle = Low*
- ✚ *Plus sign = NA (no developmental category identified)*

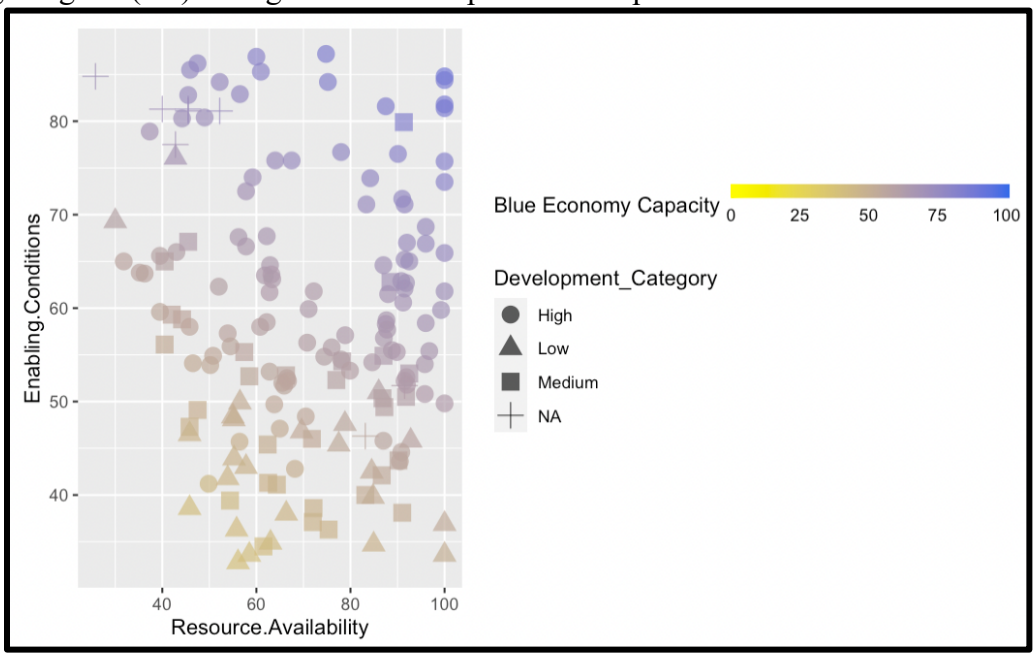
Chunk - Adjusting the Color Gradient

Running the + scale_color_gradient(…) → Fig1 lines should produce this plot:



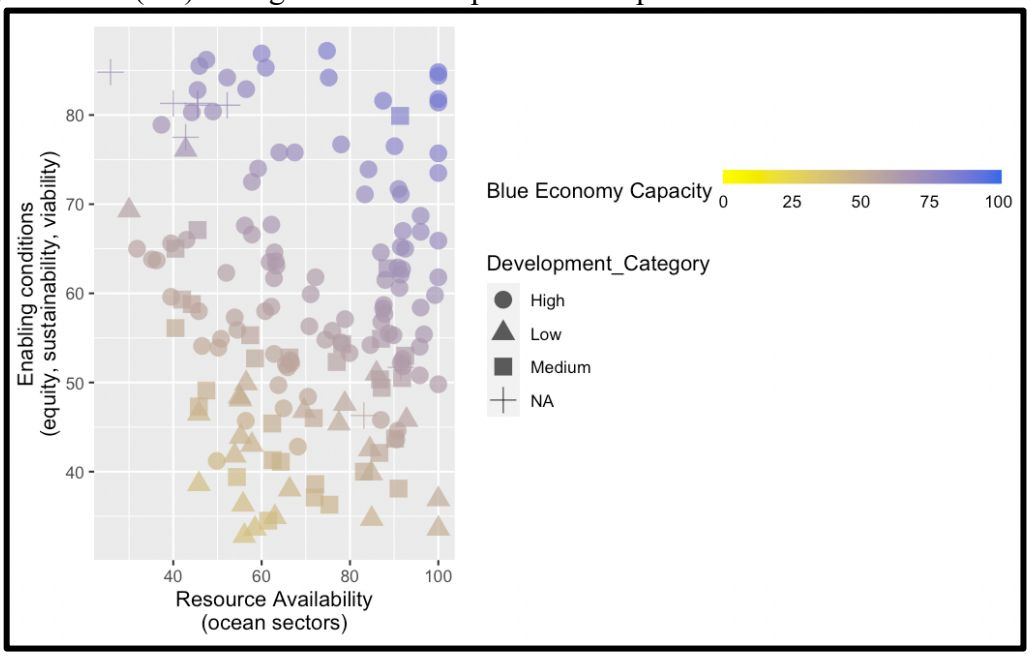
Chunk - Legend and Graph Limits

Running the guide(…) → Fig1 lines should produce this plot:



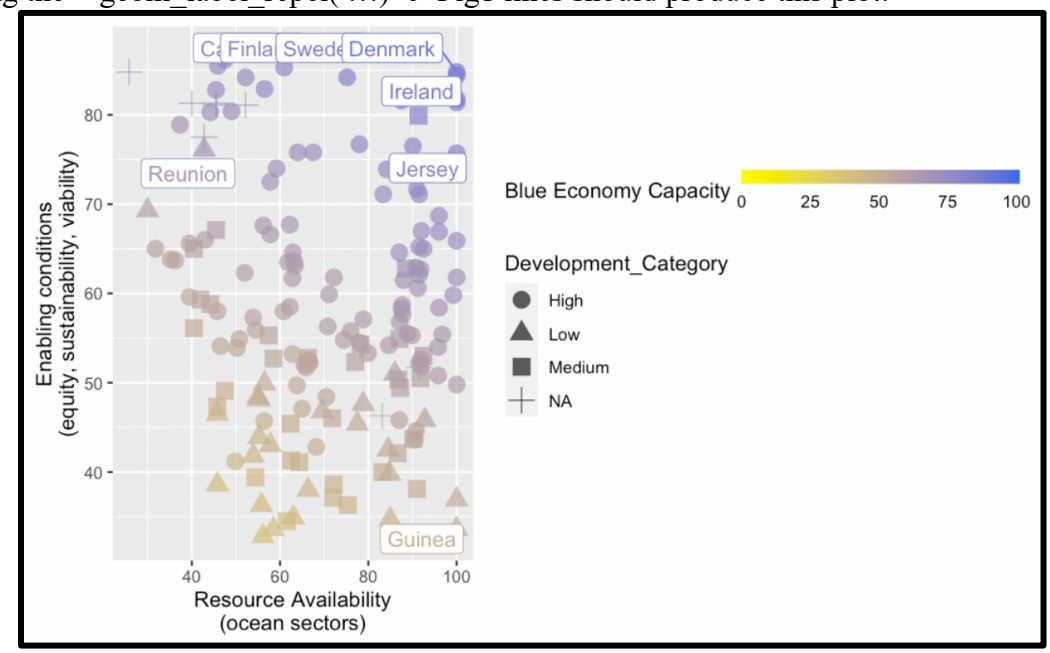
Chunk - Proper Axes Names

Running the + labs(…) → Fig1 lines should produce this plot:



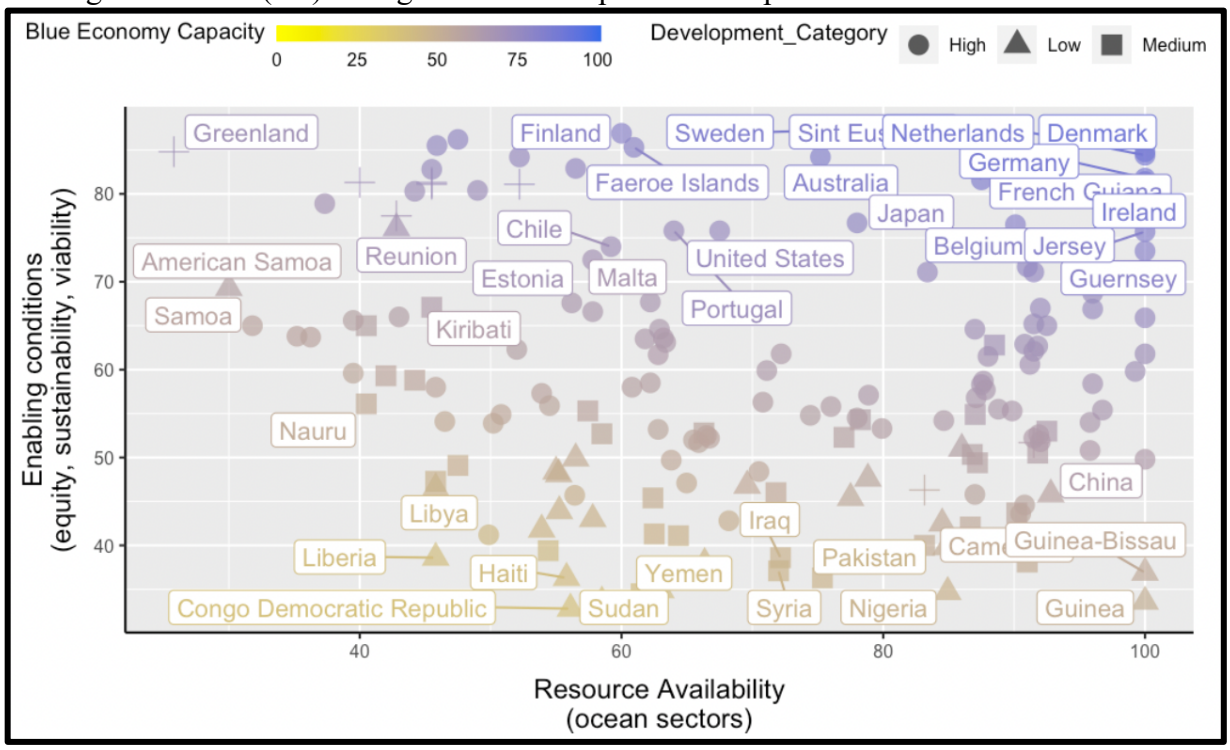
Chunk - Adding Territory Labels

Running the + geom_label_repel(…) → Fig1 lines should produce this plot:

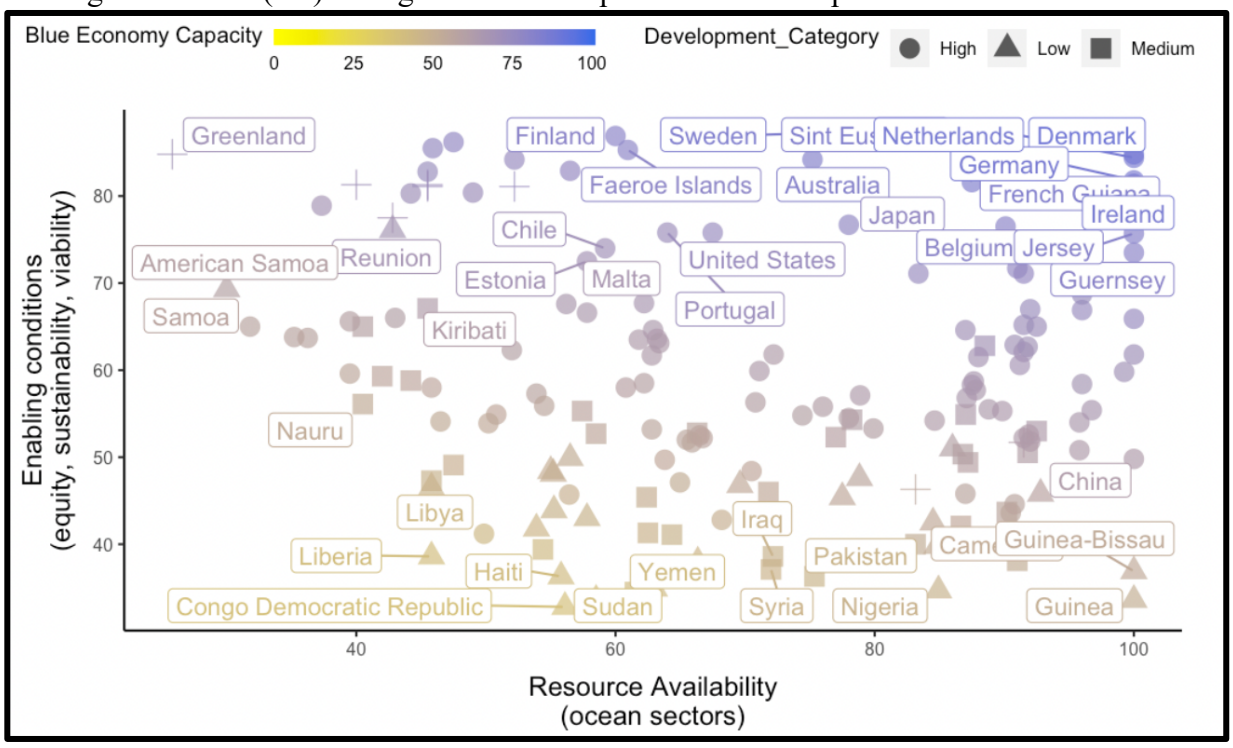


Students may receive the following warning message: Warning: ggrepel: 141 unlabeled data points (too many overlaps). Consider ## increasing max.overlaps. This error message is not a deterant to the success of the code, it is simply stating that there are too many data points to apply labels to every point, so R has selected a few points to label, mainly on the outskirts of the figure, so as to not overcrowd the figure space.

Chunk - Theme: Element Positions and Axes Properties
Running the + theme(…) → Fig1 lines should produce this plot:



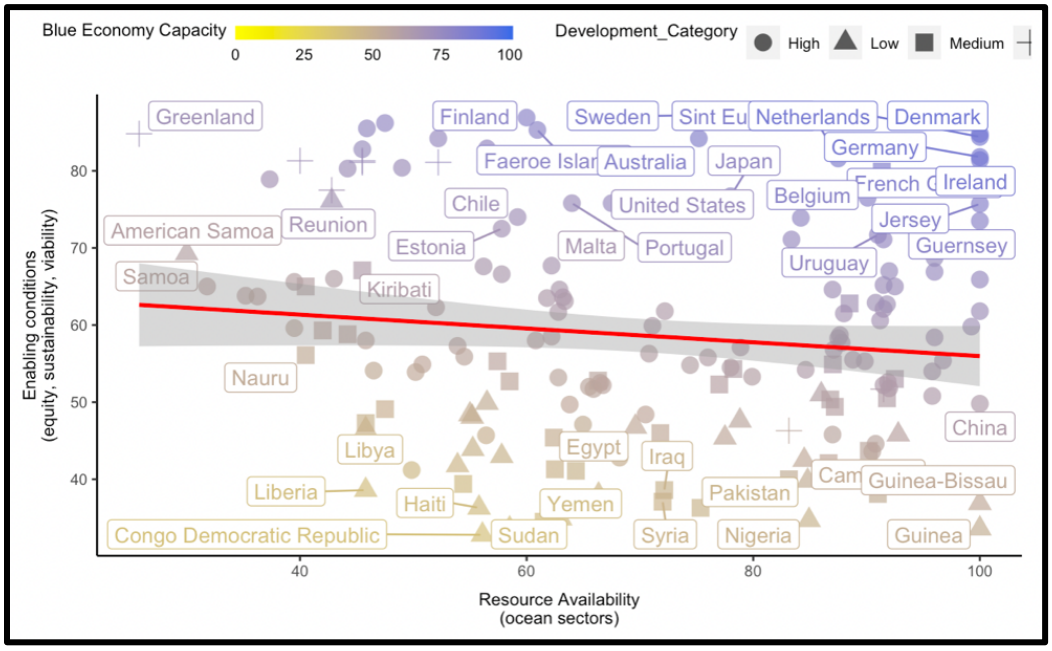
Chunk - Theme: Background Removal
Running the + theme(…) → Fig1 lines should produce this final plot:



Section III: Statistics – Linear Regression

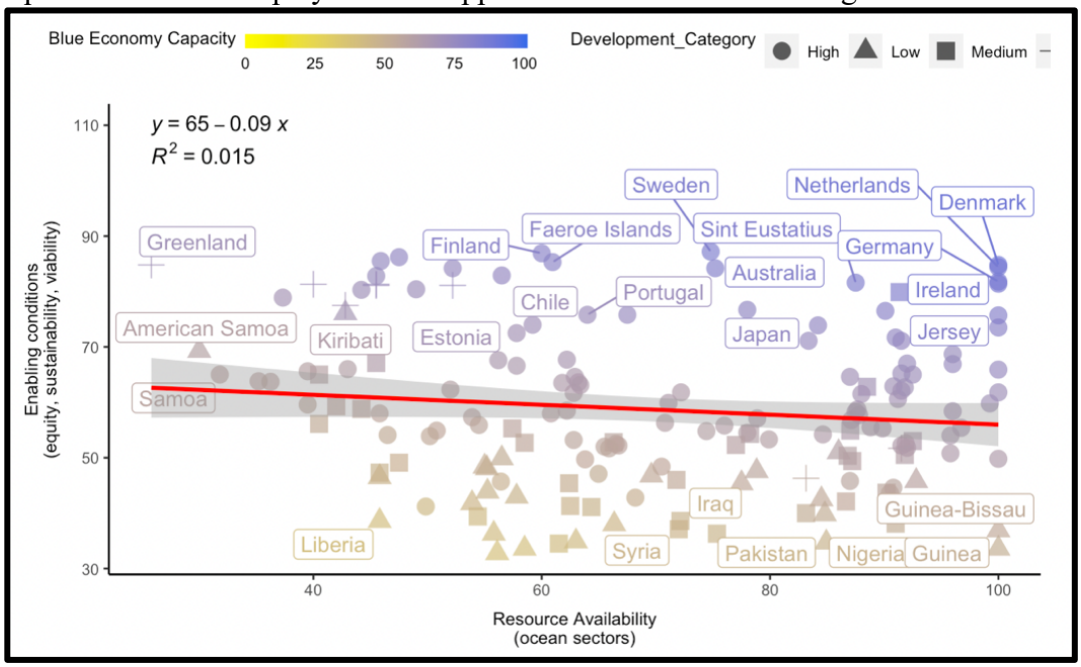
Chunk - Beginning Linear Regression

Running the Fig1 → Fig2 lines should produce this plot. In this step we have added in the linear regression line and confidence interval:



Chunk - Display Regression Equation

Running the Fig2 + stat_regline_equation(…) produces this plot, where the regression equation and R-squared value are displayed in the upper left-hand corner of the figure:



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