Tuna Economics and its Sustainability

by Yi-Hsin Chien and Harit Achanapornkul

Motivation:

Harit and I are both tuna lovers and enjoy the taste of tuna sashimi. However, we noticed more consumers are falling in love with tuna just like us in recent years, making us concerned about the tuna supply and raising questions about its sustainability. Thus, the nature of our project is to get the big picture of tuna economics and identify what factors might be correlated to the tuna caught volume and who are the major stakeholders in the tuna market, allowing us to anticipate the future of the tuna species.

Background[1,2]:

Tuna demand is highly related to two significant markets: the canned tuna market and the sushi and sashimi market. The wild fishery solely supplies the canned tuna industry; meanwhile, the sushi and sashimi market is provided by the modern tuna aquaculture and wild fishery. However, tuna aquaculture requires wild catches of seed stock and is mainly focused on the Bluefin tuna due to its higher market price than other tuna species. Therefore, the wild fishery is still the main source of tuna supply, and the major ocean areas for wild fishery are as follows (with % of total catch):

1) WCPO: Western and Central Pacific Ocean (54%)
2) EPO: Eastern Pacific Ocean (14%)
3) Atlantic Ocean (10%)
4) Indian Ocean (22%)

We understand our proposal is a big topic that requires much effort and time, and we cannot analyze it this time due to constraints. So, we will focus on the Atlantic Ocean, the small proportion of the tuna supply, to get familiar with the tuna species and the possible factors that might impact tuna sustainability. The datasets we used will mainly be from the International Commission for the Conservation of Atlantic Tunas (ICCAT)

Goal:

Our goal is to answer the following questions:

Tuna species:

- The changes in the number of tuna species caught throughout these years.
- Where do different tuna species live?
- Are there any tuna species that suffer from overfishing?

Commercial activities:

- What countries have caught most of the tuna?
- What countries import and export more tuna than others?
- How does the price of tuna fish affect overfishing?

Once compiling insights, we would like to go deeper into the tuna topics and hope one day we can present our findings to offshore fisheries and attract their attention to the sustainability of tuna because current regulations are limited on a national level and have less impact on the fishery companies. We hope the tuna fishery can be sustainable and everyone can enjoy the taste of tuna sashimi.

Reference:

1. Fernandez Polanco, Jose & Llorente, Ignacio. (2016). Tuna Economics and Markets. 10.1016/B978-0-12-411459-3.00014-X.
2. *WCPFC Tuna Fishery Yearbook - annual catch estimates*. WCPFC. (n.d.). Retrieved October 13, 2022, from https://www.wcpfc.int/statistical-bulletins

Data Source

Name	Description	Key Features	Details
raw	Nominal annual catch by species, region, gear, flag	Species, YearC, FlagName, Qty_t	Source: https://www.iccat.int/Data/t1nc_20220131.7z Method/ Format: Download/ xlsx Size : 10.3MB | Shape: 89265 rows x 37 columns | Time periods: 1950-2020
sizemap	Catch data raised to total landings (5x5 degree squares, quarter, gear)	Species, YearC, yLat5ctoid, xLon5ctoid, Catch_t	Source: https://www.iccat.int/Data/Catdis/cdis5020_all.7z Method/Format: Download/ xlsx Size : 53MB | Shape: 605346 rows x 18 columns | Time periods: 1950-2020
avg_catch_size	Size and size class by flag, species class = size (cm)/weight (kg)	FlagName, YearC, SpeciesCode, MinClass, MaxClass, MeanSize, NrFish	Source: https://www.iccat.int/Data/t2size/T2SZ-CS_detailedCatalogue.xlsx Method/Format: Download/ xlsx Size : 4.6 MB | Shape: 26754 rows x 27 columns | Time periods: 1915-2020
trade	International trade of fisheries commodities	Country, Commodity, Flow, Year, Value	Source: https://stats.oecd.org/Index.aspx?DataSetCode=FISH_TRADE# Path: Agriculture and Fisheries > Fisheries and Aquaculture statistics > International trade of fisheries commodities Method/Format: Download/ xlsx Size : 28.3 MB | Shape: 198088 rows x 17 columns | Time periods: 2010-2020
GDP_oecd	Gross domestic product (GDP) : GDP per head, US $, current prices, current PPPs	Country, Year, Value	Source: https://stats.oecd.org/# Path: National Accounts > Annual National Accounts > Main Aggregates Method/Format: Download/ xlsx Size : 106.8 KB | Shape: 589 rows x 17 columns| Time periods: 2010-2020
EU_price	Tuna price and volume by country, year, and flow type	Country, Year, Species, exp_EUR, exp_KG, imp_EUR, imp_KG	Source: https://www.eumofa.eu/en/ad-hoc-queries1 Path: New Ad Hoc View > columns(Flow, EUR, Kg) > rows (country, year, species) > filter species with tuna Method/Format: Download/ xlsx Size : 40.7 KB | Shape: 799 rows x 9 columns | Time periods: 2004-2022
country_code	Country name and three letter country code	Country, Country Code	Source: https://www.iban.com/country-codes Method/Format: Webscraping (Selenium)/ csv Size : 4.4 KB | Shape: 249 rows x 4 columns | Time periods: NA

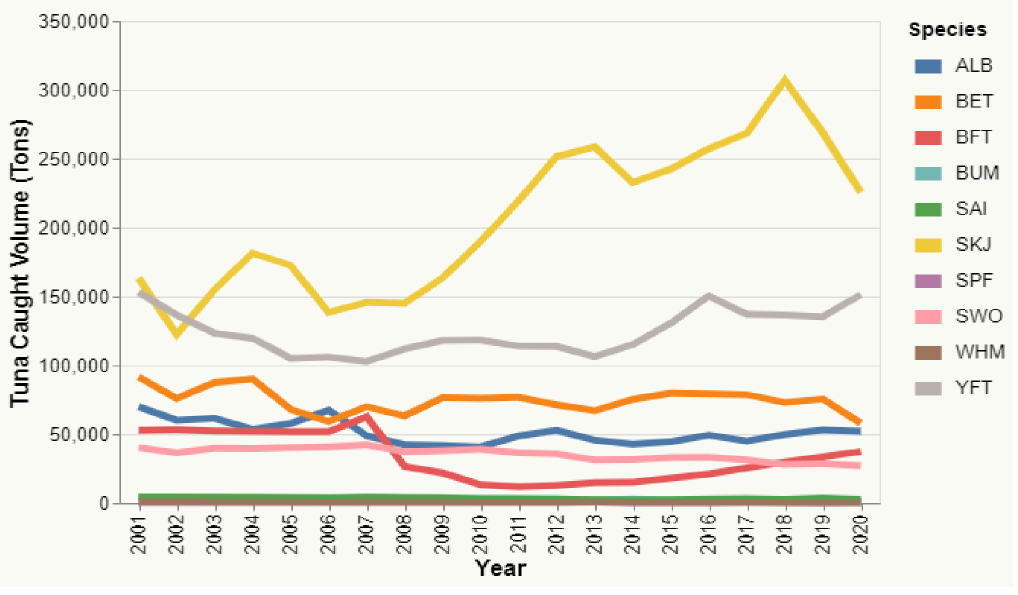
Exploratory Data Analysis on Tuna Caught Dataset (raw.xlsx)

Identify key tuna species and major countries involved to guide analysis

Key Tuna Species:

According to the ICCAT tuna caught dataset, there are ten tuna species regarded as major tuna species. We have identified six major species worth further analysis through the annual caught volume trend (Figure 1). However, SWO is not considered the true tuna3, so we remove it from our focus, leaving **ALB, BET, BFT, SKJ, and YFT** as our primary focus for this project.

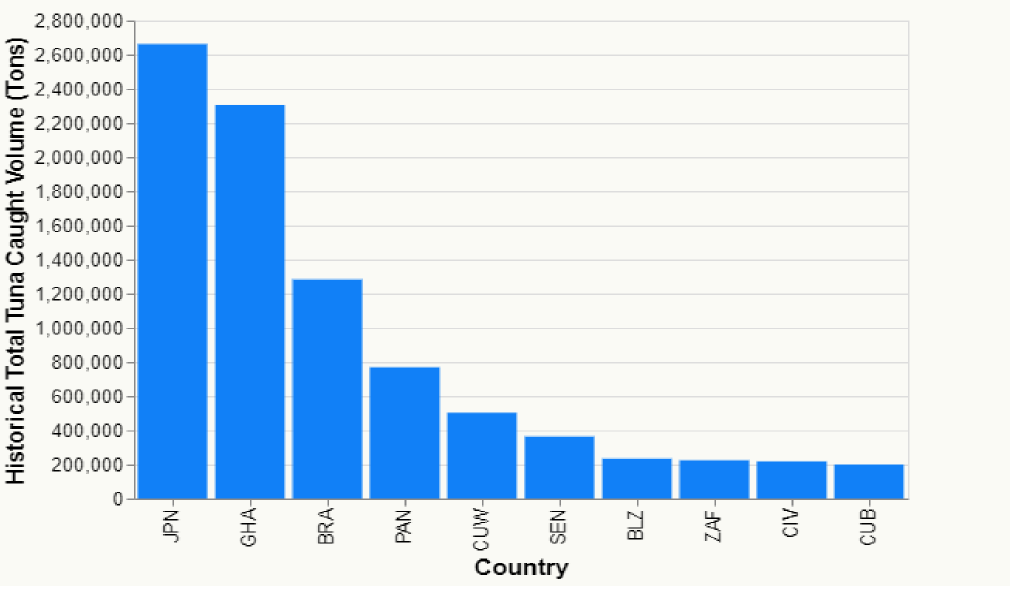
Figure 1. Tuna Caught Volume for Each Species by Year in Tons



Major Countries Involved :

Indonesia, Vietnam, and South Korea catch tuna the most in the Pacific Ocean4; however, the major countries involved in the ICCAT tuna caught are different from that in the Pacific Ocean. The bar chart below shows the major countries that catch tuna the most in the Atlantic Ocean and a **long tail distribution** (Figure 2). **The countries with the highest tuna caught volume are Spain, France, and Japan.**

Figure 2. Historical Total Tuna Caught Volume by Country: Top 20



Reference:

3. Wikimedia Foundation. (2022, August 4). Tuna. Wikipedia. Retrieved October 15, 2022, from https://en.wikipedia.org/wiki/Tuna
4. *Tuna global exports and top exporters 2022*. Tridge. (n.d.). Retrieved October 15, 2022, from https://www.tridge.com/intelligences/atlantic-bluefin-tuna/export

Abbreviation: SWO, swordfish; ALB, Albacore tuna; BET, Bigeye tuna; BFT, Bluefin tuna; SKJ, Skipjack tuna; YFT, Yellowfin tuna

Data Manipulation Methods (1/2)

Raw Dataset:

Due to this dataset containing three tables in one sheet, we will only select relevant columns: Species, SpeciesGrp, YearC, FlagName, Qty_t. After that, filter out unwanted species groups (SpeciesGrp) by only choosing those containing (1-Tuna). This dataset will then be used in 2 analyses.

First, we grouped the data by Species and YearC with the sum of caught quantity as an aggregation. Then we only select data from the year 2000 or after to observe the trend of the tuna fishery.

For the second one, we grouped the data as Species, YearC, and Flagname with the sum of caught quantity (Qty_t) as an aggregation. This will then be merged with the aggregate catch size dataset later on Flagname, YearC, and Species, to observe the relationship between weighted average caught tuna size and tuna caught volume.

Sizemap Dataset:

For this dataset, we will only select relevant columns: SpeciesCode, YearC, FlagName, yLat5ctoid, xLon5ctoid, and Catch_t. After that, filter out unwanted species (SpeciesCode) by selecting only SKJ, BET, YFT, ALB, or BFT.

This dataset will be used to observe the change in fishing between 2000 and 2020. To do so, first, we need to sum up the caught quantity in each location, defined by latitude(yLat5ctoid) and longitude (xLon5ctoid), and year (YearC). We use the unstack function to make selecting data from those two years easier. After we remove all the unwanted years, we create a new column (difference), which is the caught quantity in 2020 minus the amount caught in 2000.

Average Catch Size Dataset:

For this dataset, we only select the following columns: FlagName, YearC, SpeciesCode, SpeciesGrp, MinClass, MaxClass, MeanSize, NrRecs, and NrFish. After that, filter out unwanted species (SpeciesCode) by selecting only SKJ, BET, YFT, ALB, or BFT. Lastly, remove unwanted species groups (SpeciesGrp) by selecting only those containing (1-Tuna). After removing all unnecessary columns and rows, rename SpeciesCode to Species for future merging purposes. Before merging, we need to create a new column, WA_MeanSize, which is the product of the column MeanSize and NrRecs. Lastly, the resulting dataframe is grouped by Flagname, YearC, and Species with the following aggregation for each feature, summation for WA_MeanSize, NrRecs, and NrFish, minimum for MinClass, and maximum for MaxClass. This final data frame is called the aggregate catch size dataset, which we will use to merge part of the raw dataset to observe the relationship between the weighted average caught tuna size and tuna caught volume.

Trade Dataset:

For this dataset, we will only select relevant columns, which are COUNTRY, Country, Commodity, Flow, YearC, and Value. After that, filter out unwanted Commodity (Commodity) by only selecting those containing (tuna), but since python is case sensitive, we need to make sure that the Commodity column only contains a lowercase letter by applying the .lower() function. We also need to rename the COUNTRY column to Country Code for merging purposes. The column Flow contains essential information we want to work on, Export, Import, and Re-Export. So, first, we grouped this dataset by Country Code, Species, Year C, and Flow. Using unstack, we created three new columns, Export, Import, and Re-Export.

Data Manipulation Methods (2/2)

Trade Dataset (Continue):

Two more columns are introduced to this dataframe: net_imp_flow and total_market_value. Net import flow (net_imp_flow) is the difference between Imports and the summation of Exports and Re-Exports. Total market value (total_market_value) is the summation of Imports, Exports, and Re-Exports.

This dataframe will then be merged with the foc_maj_merge dataframe, which combines country, raw, and GDP OECD datasets. The result dataframe will be used in two analyses.

The first one is the net import flow, and tuna caught analysis; for this analysis, we only select data from the year 2020 and divide both net_imp_flow and total_market_value by a million for ease of visibility.The second analysis is GDP per capita VS Tuna Import Value. For this one, we merge the resulting dataframe with the GDP dataset.

GDP OECD Dataset:

For this dataset, we will only select relevant columns: LOCATION, Country, Year, and Value. After that, filter area data, leaving only data for the country. Renaming column, Year to YearC, and Value to GDP per capita for merging purposes.

This dataframe is then merged with the country dataset and raw dataset to form the foc_maj_merge dataframe, which will be used to observe the relationship between tuna caught volume and GDP per capita of OECD countries.

EU Price Dataset:

For this dataset, we only select the following columns: COUNTRY, YEAR, MAIN COMMERCIAL SPECIES, and VALUE (EUR).1, VOLUME (KG).1, VALUE (EUR).2 and VOLUME (KG).2. Then, we rename all columns as Country, YearC, Species, Exp_EUR, Exp_Kg, Imp_EUR, and Imp_Kg respectively. This is for ease of use and understanding. We then fill NAN between values by using the function .ffill(). Since the Species column value in this dataset is not in the format we used, we use the replace function to replace it with the species abbreviation. After that, filter out unwanted species (species) by selecting only SKJ, BET, YFT, ALB, or BFT. Lastly, this dataset is used to create a new dataframe by groupby function, which we grouped by Species and YearC with summation performed on all other columns. This new dataframe was named agg_eup. In this dataframe 5 more columns are introduced namely: total_EUR, total_Kg, Exp_EUR_per_Kg, Imp_EUR_per_Kg and EUR_per_Kg. total_EUR and total_Kg are the sums of import and export of euro and kilograms, respectively. At the same time, the Exp_EUR_per_Kg and Imp_EUR_per_Kg are the ratio between the monetary value and weight of exports and imports, respectively. The final EUR_per_Kg is the ratio between total_EUR and total_Kg. This dataframe will then be merged with the raw dataset to observe the relationship between tuna price and caught volume.

Country Dataset:

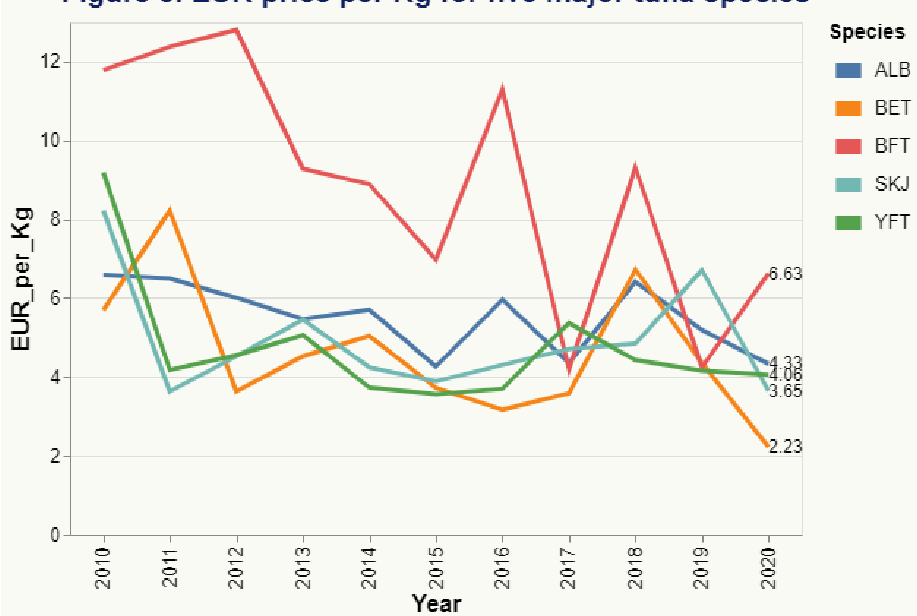
For this dataset, we will only select relevant columns: Country and Alpha-3 code. After that, we rename the Alpha-3 code column Country Code for future merging.

Analysis (1/4) – The correlation between tuna caught volume and price of tuna is moderate negative, instead of positive.

Tuna Price Issue:

Among the five major tuna species, the bluefin tuna is the most valuable (Figure 3). It might be mainly due to the rapid growth of the sushi and sashimi industry, which cause the huge decline in the bluefin tuna population. For example, Japan consumes nearly 80% of the world's bluefin tuna, prompting it to exceed fishing quotas, along with Mexico, the United States, and Korea5. Thus, we are curious about how the price of tuna affects the tuna caught volume.

Figure 3. EUR price per Kg for five major tuna species



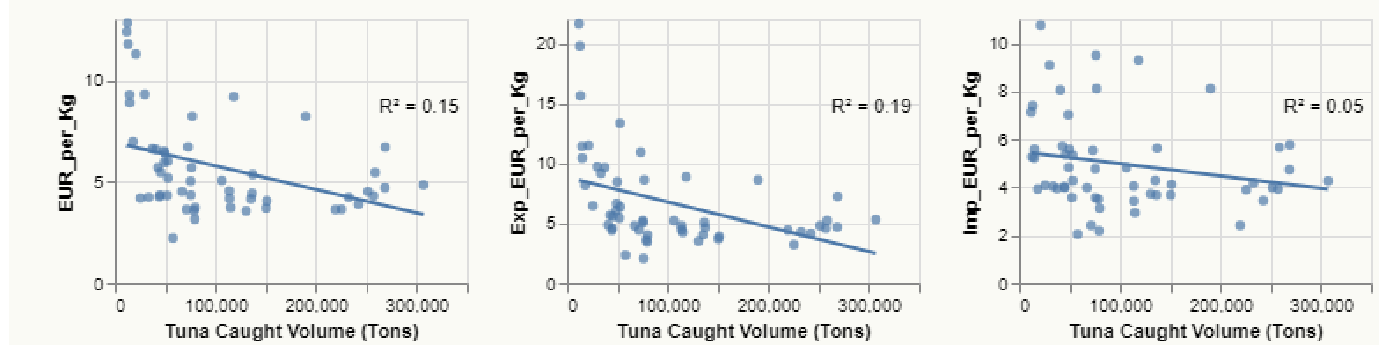
Supply Tuna Volume more than demand:

Typically, if the tuna price is higher, the supplier gets more incentives to catch more tuna. However, we find that tuna caught volume and price of tuna show a moderate negative correlation (Table 1, Figure 4). From our analysis, we conjecture that the tuna fisheries might supply more tuna volume than the demand in the EU countries, so **suppliers might lower the price of tuna to stimulate the demand that initially did not exist.** In this case, there would be a sweet spot for supply and demand, meaning the supplier can earn money with less caught volume.

Table 1.

	EUR_per_Kg	Exp_EUR_per_Kg	Imp_EUR_per_Kg	Qty_t
EUR_per_Kg	1.000000	0.880000	0.740000	-0.390000
Exp_EUR_per_Kg	0.880000	1.000000	0.450000	-0.430000
Imp_EUR_per_Kg	0.740000	0.450000	1.000000	-0.220000
Qty_t	-0.390000	-0.430000	-0.220000	1.000000

Figure 4. Tuna Caught Volume vs EUR per Kg (Different Flow Type)



Reference:

5. Paris, F. (2019, January 5). Threatened bluefin tuna sells for $3 million in Tokyo market. NPR. Retrieved October 15, 2022, from https://www.npr.org/2019/01/05/682526465/threatened-bluefin-tuna-sells-for-5-000-per-pound-in-tokyo-market

Analysis (2/4) - Tuna caught volume and OECD GDP per capita barely show a correlation, but correlation can be seen in selected countries.

Higher GDP per capita, more tuna caught?

Consumers with more income are more likely to spend money on more expensive food, such as sushi and sashimi. So, we wonder whether the increase in GDP per capita would relate to higher demand for Tuna, boosting the Tuna caught volume. However, we find almost zero correlation between Tuna caught volume and OECD GDP per capita based on our linear regression and coefficient analysis (Figure 5, Table 2).

Focused Countries show correlation:

From our EDA analysis, the tuna caught volume showed a long tail distribution, meaning few countries are responsible for nearly 80% of the tuna caught volume. Therefore, in this part of the analysis, we also conducted a focused group, including Spain, France, and Japan. We found a moderate negative correlation between tuna caught volume and GDP per capita (Figure 6, Table 3).

Figure 5. Tuna Caught Volume vs GDP per capita: OECD Countries

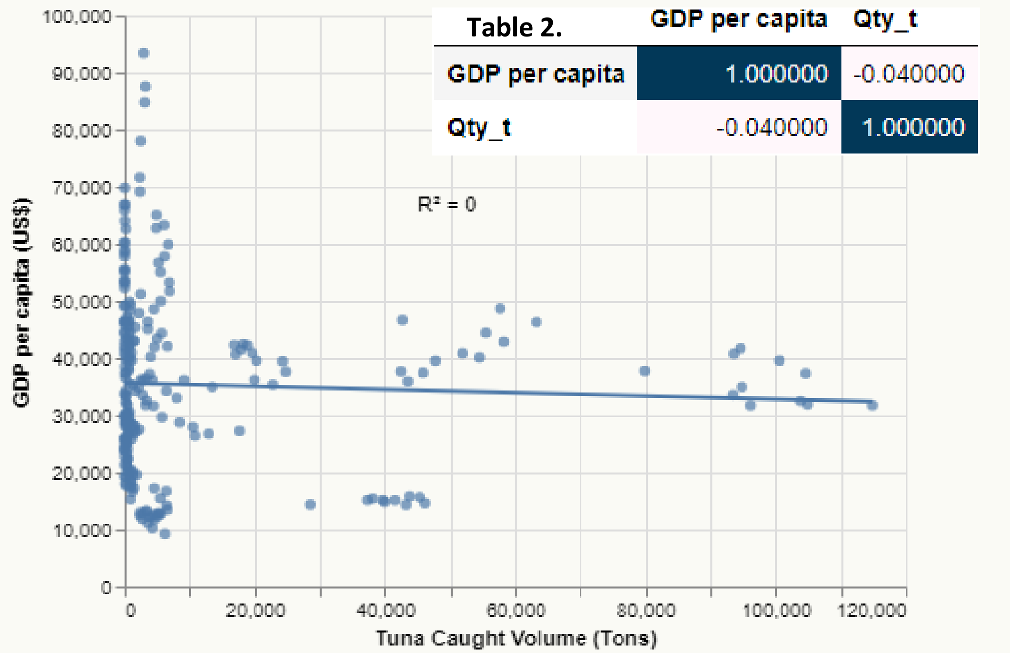


Table 2.

	GDP per capita	Qty_t
GDP per capita	1.000000	-0.040000
Qty_t	-0.040000	1.000000

Figure 6. Tuna Caught Volume vs GDP per capita: Spain, France, and Japan

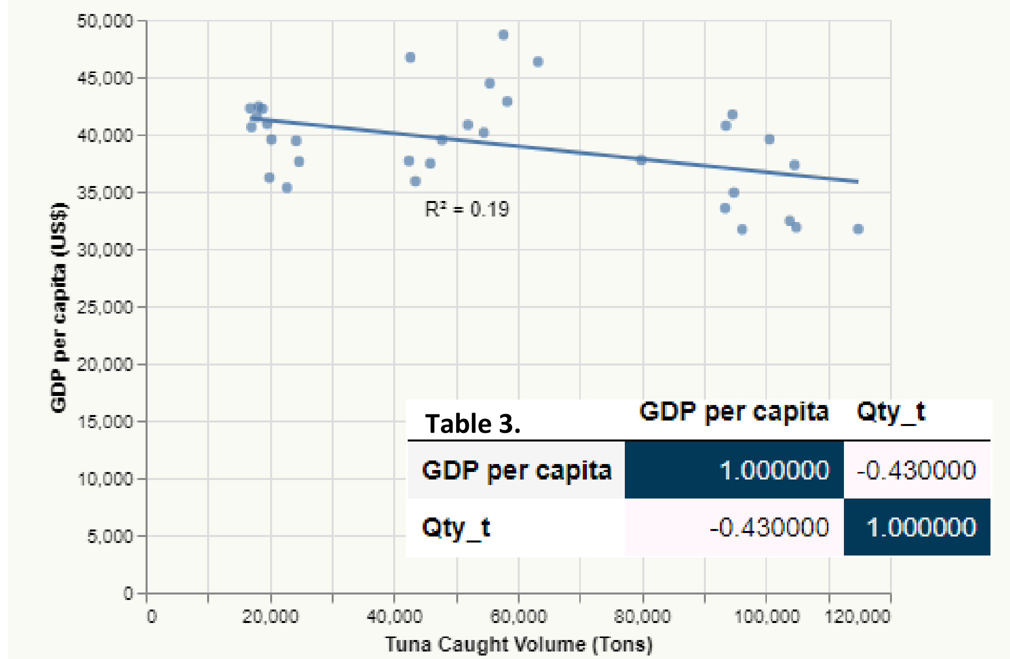


Table 3.

	GDP per capita	Qty_t
GDP per capita	1.000000	-0.430000
Qty_t	-0.430000	1.000000

Analysis (3/4) – GDP per capita and net import value of tuna show a strong correlation in our focused countries.

Major tuna markets influenced by GDP per capita:

In the previous analysis, we understand that there is a moderate correlation between GDP per capita and tuna caught volume in our focused countries. Here, we want to analyze the role of focused countries in the tuna market. Based on Figures 7 & 8, we can identify Japan as the biggest tuna market, followed by USA and Spain. However, their flow types are different. For example, most of the tuna is imported into Japan and USA, while Spain exports tuna to other countries. To interpret this result carefully, we assume the demand for tuna in Japan would be the major key factor that impacts the global tuna caught volume and affect the effectiveness of tuna protection. For further analysis of our topic, we would like to dive deep into the tuna caught volume in the Pacific Ocean, the most productive area that provides nearly 50% of the tuna caught volume. And this approach will help us understand the role of Japan in tuna economics and sustainability.

Figure 7. Top 5 Tuna Markets: Net Import Flow and Tuna Caught Volume

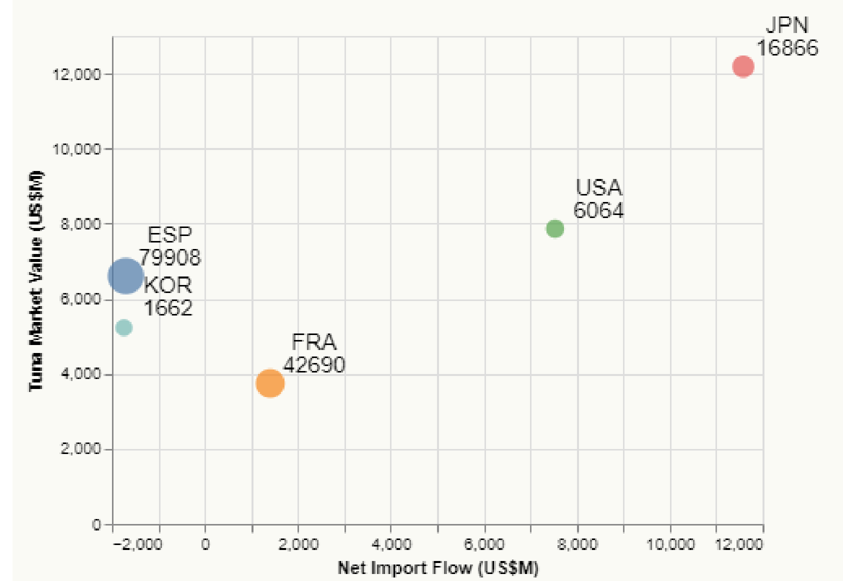
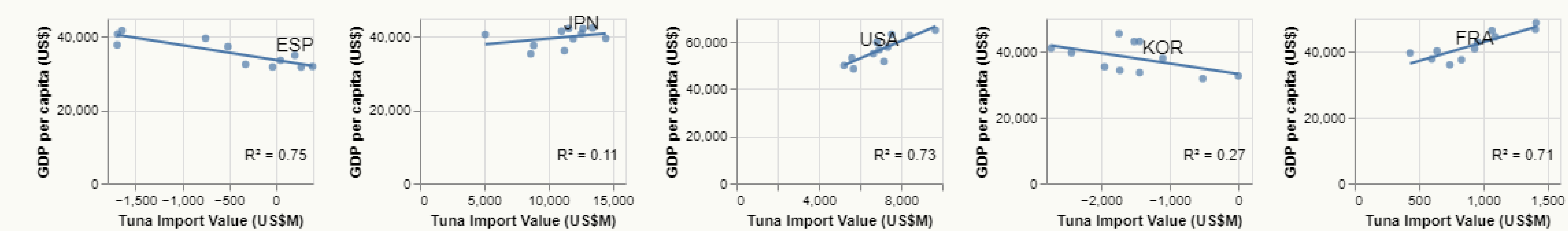


Figure 8. GDP per capita vs Tuna Import Value



	net_imp_flow	GDP per capita
net_imp_flow	1.000000	-0.870000
GDP per capita	-0.870000	1.000000

	net_imp_flow	GDP per capita
net_imp_flow	1.000000	0.340000
GDP per capita	0.340000	1.000000

	net_imp_flow	GDP per capita
net_imp_flow	1.000000	0.850000
GDP per capita	0.850000	1.000000

	net_imp_flow	GDP per capita
net_imp_flow	1.000000	-0.520000
GDP per capita	-0.520000	1.000000

	net_imp_flow	GDP per capita
net_imp_flow	1.000000	0.840000
GDP per capita	0.840000	1.000000

Analysis (4/4) – Overfishing seems to have negative impact on weighted average tuna size.

Overfishing and Tuna Size Reduction:

We compare the tuna caught volumes of five significant species at the same location between 2020 and 2000 and find more tuna have been caught at nearly all locations, indicating overfishing problem is getting more serious in the Atlantic Ocean (Figure 9). Furthermore, we analyze the combined caught volume and tuna size datasets and find the negative correlation (-0.65, Table 4) and moderate R-square value (0.42, Figure 10), showing that overfishing seems to be moderately related to a reduction in the size of tuna.

Negative Impact:

Since the bigger tuna are more likely to be caught due to the economic value, overfishing hinders tuna species from growing to maturity. According to researcher Barneche's study6, the reproductive output of fish is not a linear function. For example, the reproductive output of a 30 Kg cod is equivalent to ~ 37 two Kg cods, representing a 2.5-fold increase in biomass. Hence, **overfishing depletes mature tuna and decreases the reproductive output of tuna species.**

Table 4.

	MinClass	MaxClass	Weighted_Average_Size	Qty_t
MinClass	1.000000	-0.220000	0.030000	-0.280000
MaxClass	-0.220000	1.000000	0.460000	-0.240000
Weighted_Average_Size	0.030000	0.460000	1.000000	-0.650000
Qty_t	-0.280000	-0.240000	-0.650000	1.000000

Figure 9. Tuna Caught Volume at Same Location

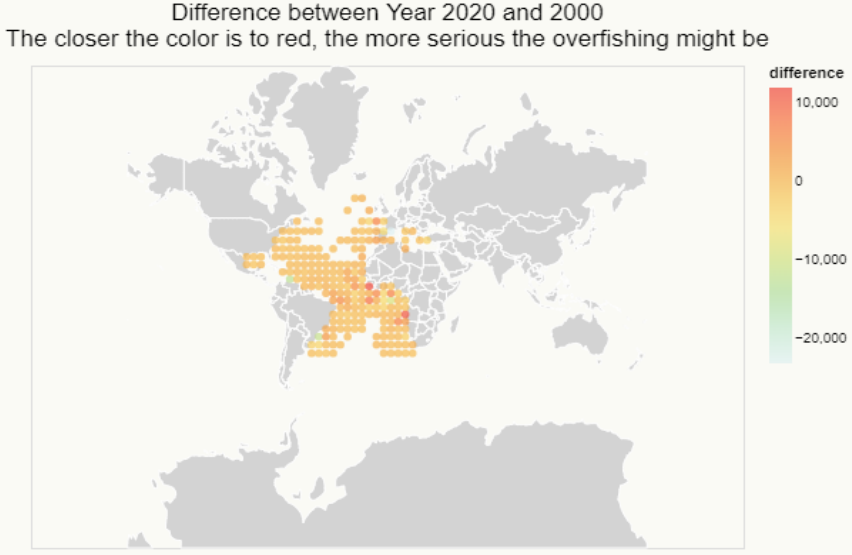
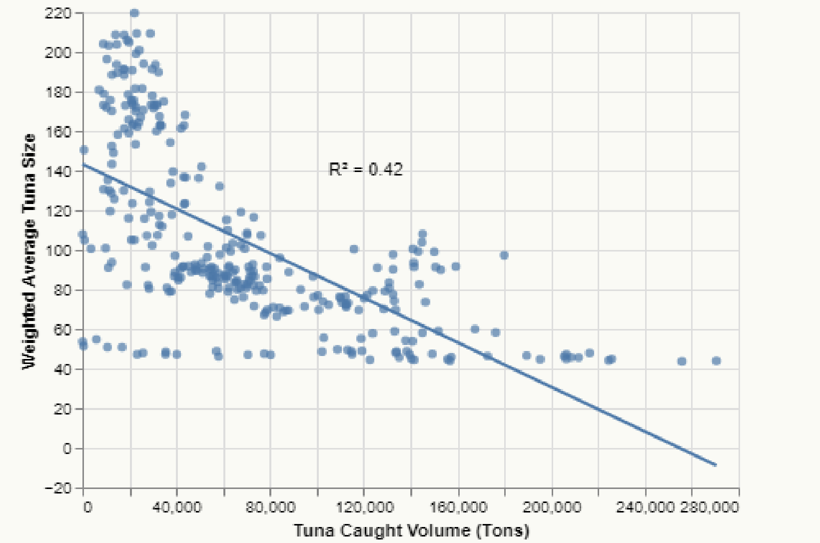


Figure 10. Tuna Caught Volume vs Weighted Average Tuna Size



Reference:

6. Barneche, D. R., Robertson, D. R., White, C. R., & Marshall, D. J. (2018). Fish reproductive-energy output increases disproportionately with body size. Science, 360(6389), 642–645. https://doi.org/10.1126/science.aao6868

Summary – Tuna sustainability is affected by overfishing and several key countries would be the main stakeholders for tuna protection.

Discussion:

From our work, we find out that tuna price and caught volume negatively correlate in the EU countries. We anticipate the reason because EU countries typically are not used to having sushi and sashimi like Asian countries. Moreover, when consumers become richer, there is no sign of an increase in tuna demand in the Atlantic Ocean area. However, we identify that consumers in countries like France and Spain show an increase in tuna demand when the GDP per capita increases. Subsequently, we evaluate the tuna trade data of OECD countries to identify the major tuna markets and the import/export flow types. From the analysis, we understand that Japan, the USA, and Spain are the major tuna markets but with different flow types. For example, Japan is the biggest tuna market globally, requiring tons of imported tuna to meet its demand.

On the other hand, Spain is the third major tuna market, and it catches enough tuna from the Atlantic Ocean and export some of the caught volumes. The result helps us distinguish the role of different countries in the tuna market and figure out what countries should be watched to protect tuna species. Furthermore, overfishing is serious in the Atlantic Ocean area, and it will harm the tuna species' reproductive output. To cope with the overfishing problem and preserve the reproductive output of tuna species, we should pay attention to tuna fisheries' method of catching tuna and put a strict tuna quota on the major countries. So, we preliminarily propose three recommendations:

Preliminary Recommendations:

1. Ask neutral parties like researchers or institutes to review the tuna quotas for each organization; since the current tuna quotas might be decided by countries with huge tuna demand and stakes in the tuna market, thus a fair review should be implemented.
2. Change the catching approach and updates the knowledge of tuna reproduction. The current catch approach is to remove the bigger tuna from the tuna population; however, big mamas matter for tuna because they provide higher reproductive output. Hence, eating small tuna is an excellent method to protect the tuna population.
3. Tuna fisheries should faithfully record their tuna caught volume and invite economists or consultants to help them identify the suitable captured volume to meet the market demand. In this way, tuna fisheries can still earn handsome money with adequate tuna volume without lowering the price of the overfishing supply.

Further Plans:

To move forward with our project, we will need to analyze the data from other Oceans, such as the Pacific Ocean and the Indian Ocean, to understand the whole picture of tuna fisheries and the tuna markets. Moreover, global warming hurts the tuna population size. We want to collect datasets from the National Oceanic and Atmospheric Administration (NOAA), which provides ocean temperature and the nutrient of the seawater. We hope we can find more exciting insights and contribute to protecting tuna.

Statement of Work and References

Collaboration – Meetings:

1. Sep-02: Kick-off meeting
2. Sep-05: Confirmed project topic
3. Sep-11: Proposal writing
4. Oct-04: Report: split works
5. Oct-08 & 09: Progress follow-up
6. Oct-12: Visualizations reviewed by prof
7. Oct-15 & 16: Report and notebook writing
8. Oct-17: Finalizing report and notebook

Statement of Work	Yi-Hsin Chien	Harit Achanapornkul
Topic, Proposal, and Motivation	60%	40%
Data Sources & Research	50%	50%
Exploratory Data Analysis	60%	40%
Data Manipulation Method	40%	60%
Analysis and Visualization	50%	50%
Summary and Recommendations	50%	50%
Jupyter Notebook	40%	60%
Average, %	50%	50%

References:

1. Fernandez Polanco, Jose & Llorente, Ignacio. (2016). Tuna Economics and Markets. 10.1016/B978-0-12-411459-3.00014-X.
2. *WCPFC Tuna Fishery Yearbook - annual catch estimates*. WCPFC. (n.d.). Retrieved October 13, 2022, from https://www.wcpfc.int/statistical-bulletins
3. Wikimedia Foundation. (2022, August 4). Tuna. Wikipedia. Retrieved October 15, 2022, from https://en.wikipedia.org/wiki/Tuna
4. *Tuna global exports and top exporters 2022*. Tridge. (n.d.). Retrieved October 15, 2022, from https://www.tridge.com/intelligences/atlantic-bluefin-tuna/export
5. Paris, F. (2019, January 5). Threatened bluefin tuna sells for $3 million in Tokyo market. NPR. Retrieved October 15, 2022, from https://www.npr.org/2019/01/05/682526465/threatened-bluefin-tuna-sells-for-5-000-per-pound-in-tokyo-market
6. Barneche, D. R., Robertson, D. R., White, C. R., & Marshall, D. J. (2018). Fish reproductive-energy output increases disproportionately with body size. Science, 360(6389), 642–645. https://doi.org/10.1126/science.aao6868