Transactions on Environment, Energy and Earth Sciences
ISSN: 2960-1924, eISSN: 2960-2300 | Volume 3
GRET 2024

Fukushima Wastewater Release and its Profound Impact on the Fishing Industry

Daniel Liu *

Episcopal High School, Virginia, U.S

* Corresponding Author Email: daliu25@163.com

Abstract. This research delves into the significant effects of releasing Fukushima wastewater in August 2023 on the fishing industry, using linear and multivariate regression models for a thorough analysis computed by SPSS. Post-Fukushima, the introduction of radioactive wastewater into the marine environment has raised alarm, particularly regarding the repercussions for marine biodiversity and the crucial fishing sector in the Northern Pacific. Analyzing data from the North Pacific Anadromous Fish Commission and Japan's fishery exports, with the aid of a Tsinghua University simulation, this study evaluates the impact of radioactive discharge on marine ecosystems and fishing economies. Findings indicate a clear negative impact on fisheries, affecting not just Japan but also other Northern Pacific regions. Statistical models confirm substantial environmental and economic detriments to the fishing sector stemming from contamination. This work not only highlights the immediate fallout from the Fukushima incident but also provides foresight into enduring effects for Japan and other involved countries. Results accentuate the urgent need for robust disaster management and strategies to maintain ecological and industry health, vital for sustaining community economies).

Keywords: Fukushima; Fishing Industry; Economy.

1. Introduction

Since 1956, the global focus on energy production has shifted from traditional energy sources to more environmentally friendly nuclear energy [1]. In the 1960s, there were merely 17 nuclear power plants in operation. By 2023, there will be 440 nuclear power stations under operation. The number increased by 26-fold over the past 63 years [2]. Very optimistic sentiments have derived from the early success of nuclear power in energy production. It is a clean and convenient source of energy with the utmost potential. However, the continuous accidents and catastrophic consequences such as Chernobyl and Three Mile Island accidents have served as a warning call to the rest of the world that nuclear energy still needs to be proficiently employed.

The 2011 Japan earthquake led Fukushima's reactors to overheat due to a cooling system failure. Seawater cooling created 1.3 million tons of nuclear wastewater over 12 years. Japan started discharging this into the ocean in 2023, a process lasting decade. While most radionuclides meet regulatory limits, tritium and Cesium-137 persist as concerns. Research by Robert Richmond suggests Pacific dispersion, with Fukushima fallout found off California [3] [4].

The direct release of treated water into the ocean impacts marine life, economy, and human health. Seafood, a significant global commodity constituting over 30% of production value, faces risks post-release, influencing consumer choices and health concerns. Public opinion affects seafood choices post-Fukushima, with McKendree et al. (2013) finding 30% decreased consumption and over 50% worried about health risks from Asian seafood due to the nuclear disaster [4]. Additionally, consuming goods exposed to radionuclides endangers human health. These substances concentrate up the food chain, particularly affecting organisms like plankton. Since plankton forms the base of the food chain, higher trophic levels face contamination [5].

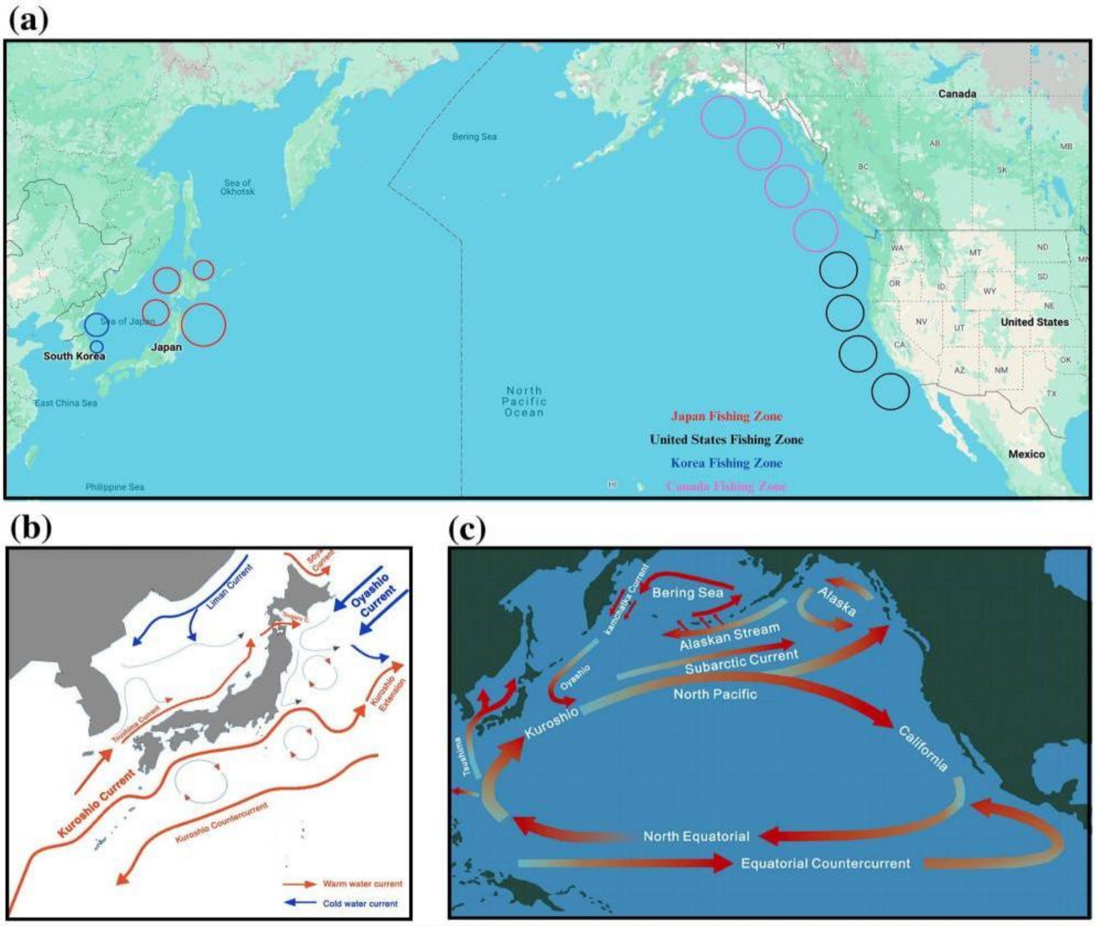
Numerous studies explore nuclear wastewater's effects post-Fukushima, including its impact on seafood trading, diffusion simulation, and marine radioactivity [5] [6]. Recent research probes long-term ecological consequences [7]. However, there's a gap in understanding the fishery industry's enduring impact from Japan's wastewater release. This research will investigate how Japan's choice to release treated nuclear wastewater over three decades affects the fishing industry. The study will use a simulation model to analyze how the nuclear wastewater spreads and settles. In addition, the study will employ linear and multiple regression. The study will assess the consequences in four specific places along the North Pacific Coast: Japan, Canada, the United States, and Korea.

2. Data and Materials

2.1. Research Area

Japan primarily emphasizes the fishing industry in the Sea of Japan and its exclusive economic zone southeast of its coastline [9]. Korea has a close ocean border with Japan, engaging in fishing activities in the Sea of Japan and the Yellow Sea. Despite their location-based differences in fisheries, both countries are immediately affected by the widespread impact of discharging nuclear wastewater. This occurrence can be attributed to the characteristics of Japan's ocean currents and the North Pacific Ocean currents.

The Kuroshio Current, also known as the "Black Current," is a major oceanic force in Japan's maritime environment. It originates from the Pacific North Equatorial Current, flows northeast past the Philippines and along Japan's eastern shores, transporting warm, saline water. With varying speeds between 0.5 to 3 meters per second, the Kuroshio is part of a dynamic array of currents detailed in Figure b, impacting not just Japan but extending influence as far as Korean waters [12].



(a) The illustration of North Pacific Fishing Zone

(b) The Japan ocean currents [10] (c) The North Pacific Ocean Current [11]

Figure 1. Research Area of the Study

Across the Pacific, the cooler, slower Alaska and California currents shape the marine climate of North America, with velocities ranging from 0.03 to 0.1 meters per second (Figure c). These currents are components of the larger North Pacific Gyre, which is driven by prevailing winds and circulates water in a clockwise motion from the east to the west of the Pacific. This gyre moves warm water towards higher latitudes at a pace of 0.03 to 0.06 meters per second. When compared, the Kuroshio and Gulf Stream are more rapid, flowing at speeds up to 1.2 meters per second, whereas the California Current is more sedate, at 0.03 to 0.07 meters per second [13].

2.2. Data Collection and Sources

The study examines fisheries trends spanning 40 to 60 years across Japan, South Korea, the United States, and Canada, utilizing data from the North Pacific Anadromous Fish Commission (1960–2022) [14]. It also analyzes Japan's fishery export data (1983–2023) from Trading Economies [15], offering insights into annual exports and their rate of change. The study also incorporates a dataset for multivariate regression analysis, which includes variables such as fishery exports, Gross Domestic Product (GDP), and population figures of Japan, enabling a nuanced multivariate analysis. Furthermore, a linear regression model was utilized, which includes data from a dispersion wastewater simulation combined with Japan's fishery exports data. This model aids in assessing correlations, determining the strength of these relationships, and formulating future projections. The complete datasets mentioned in the study are accessible via the provided digital object identifier that is published at zenodo (10.5281/zenodo.10674545).

2.3. Model

The diffusion model from Tsinghua University[16] breaks down the spread of wastewater in the North Pacific into Macro and Micro scales, with this study focusing on Macro scale analysis. It uses a grid system to track how pollutant concentrations change over time and simulates this iteratively to pinpoint concentration levels at different times. The model considers three sub-processes: migration with currents, dispersion across concentration gradients, and attenuation through breakdown or decay.

The dispersion process involves pollutants' concentration change proportional to the gradient. Described by Fick's law:

$$J = -D\frac{\partial c}{\partial x} \tag{1}$$

Where D is the dispersion coefficient, $\frac{\partial c}{\partial x}$ is the concentration gradient, and J is the diffusion flux denoting the total amount of pollutants passing through a unit area in unit time.

Another equation that is crucial to the modeling of the dispersion section is:

$$\frac{\Delta C}{C_d} = k = D\frac{\Delta t}{(\Delta x)^2} \tag{2}$$

The equation above denotes D to be an unchanged coefficient, and the value k represents the simulation speed of the dispersion process, its significance can be understood through the following process. For any two adjacent grids, the difference in pollutant concentration at the center points is C_d.

The migration process tracks pollutant movement via ocean currents. Pollutant concentrations are recorded at each square's center, with the fluid element advancing according to the flow field . For a two-dimensional migration problem, the flow field speed at the square center is denoted as V with components V_x and V_y along orthogonal directions. After a time Δt, the fluid element at the center moves by $V_x\Delta t$ and $V_y\Delta t$ along x and y directions. Concentration at the new location equals that at the center before migration. The moving distance is set as an integral multiple to maintain grid division Δx. The number of squares advanced is recorded as $< V_x \frac{\Delta t}{\Delta x} >$ and $< V_y \frac{\Delta t}{\Delta x} >$ along the x and y directions, respectively.

The attenuation process in nuclear pollution is primarily governed by the decay of radioactive elements, expressed by the equation

$$\frac{dc}{dt} = -\lambda c \tag{3}$$

C is the concentration and λ is the decay constant. The concentration decreases exponentially over time, $e^{-\lambda \Delta t}$ representing the reduction after an arbitrary time Δt. The decay constant λ, is related to the half-life ($T_{\frac{1}{2}}$) through the equation:

$$\lambda = \frac{ln2}{T_{\frac{1}{2}}} \tag{4}$$

For a single pollutant discharge, concentrations are multiplied by $e^{-\lambda \Delta t}$ during attenuation. In dispersion, only relative concentration matters, while migration involves ocean current data. The attenuation process within each period is unnecessary; only the time difference (t) and $e^{-\lambda t}$ are relevant for the diffusion process.

2.4. Analytical methods

2.4.1. Pearson Correlation Analysis.

The Pearson Correlation Analysis is a statistical technique used to measure the strength and direction of the linear relationship between two quantitative variables. The Pearson correlation coefficient, denoted as r, is calculated using the formula:

$$R \quad = \frac{\Sigma(x_i - \underline{x})(y_i - \underline{y})}{\sqrt{\Sigma(x_i - \underline{x})^2 \Sigma(y_i - \underline{y})^2}} \tag{5}$$

Within this equation x_i and y_i are the value of the two variables, and the $\underline{x}$ and $\underline{y}$ are the means of the respective variables, and the summation runs over all data pairs (x_i , y_i).

2.4.2. Linear Regression Model.

$$y = \beta_0 + \beta_1 x + \epsilon \tag{6}$$

Where the y is the dependent variable. It is the variable being predicted or explained. x is the Independent variable. It's the variable used to predict the value of y. β_0 Intercept. It represents the value of y when x is 0. β_1 is the slope coefficient. It quantifies the change in y for a one-unit change in x. ϵ Error term. It accounts for the variability y that cannot be explained x.

To quantifies the variance in the dependent variable explained by the independent variables, the coefficient of determination is adapted by the following formula:

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \tag{7}$$

Where the R^2 is Proportion of the variance in the dependent variable is predictable from the independent variables. SS_{res} is the Sum of the squares of the differences between the observed and predicted values of y. SS_{tot} is the sum of the squares of the differences between the observed values of y and the average of y.

2.4.3. Multivariate Modeling.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \epsilon \tag{8}$$

Where the y is the dependent variable. It is the variable being predicted or explained. $x_1, x_2 \ \ldots, x_n$ is the independent variable. It's the variable used to predict the value of y. β_0 Intercept. It represents the value of y when x is 0. $\beta_1, \beta_2 \ldots, \beta_n$ is the slope coefficient. It quantifies the change in y for a one-unit change in x. ϵ Error term. It accounts for the variability y that cannot be explained x.

To quantifies the variance in the dependent variable explained by the independent variables for multiple regression, the adjusted R^2 is adapted by the following formula:

$$R^2 = 1 - \frac{(1-R^2)(n-1)}{n-p-1} \tag{9}$$

Within the aforementioned formula, R^2 accounts for the number of predictors in the model. It adjusts R^2 to reflect the number of variables and the size of the sample. n is the number of observations in the data, and p is the number of independent variables.

3. Results and Discussion

3.1. Simulation of Fukushima Wastewater in the North Pacific

This section employs the macroscopic diffusion model from Section 2.3 to simulate the spread of Fukushima's treated nuclear wastewater in the North Pacific. It offers essential insights into tritium dispersion and projects the impact timelines on Japan, Canada, the U.S., and Korea.

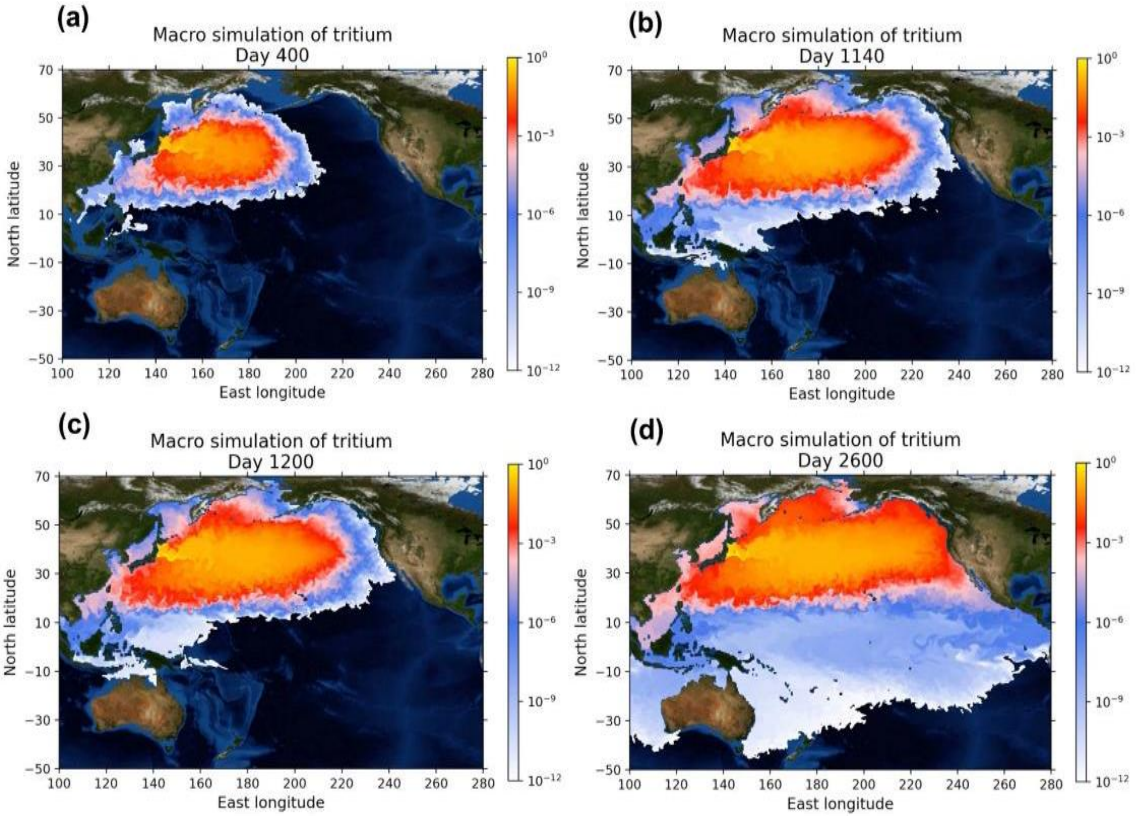


Figure 2. Macro simulation of tritium diffusing over the Northern Pacific Ocean [14]

Figure 2 presents four simulations of tritium dispersal post-release. Simulations a and b depict the tritium concentration reaching South Korea's fishing zone at $10^{-12}\ Bq/M^3$ in 400 days and escalating to $10^{-3}\ Bq/M^3$ by day 1140. Simulations c and d show the tritium impact on the Pacific's eastern side, affecting the U.S. and Canada with initial concentrations of $10^{-9}\ Bq/M^3$ within 1200 days, rising to $10^{-3}\ Bq/M^3$ by day 1400. These simulations indicate significant oceanic chemical changes, with implications for ecosystems and fisheries.

The nuclear wastewater release accelerates the Northern Pacific's dominant ocean current, causing the wastewater to cluster and circulate within this region.

3.2. The Impacts of Fukushima Wastewater on Fishing Industry in Japan

3.2.1. Overview of Fishing Industry in Japan.

In 2023, Japan began releasing 1.3 million tons of treated Fukushima wastewater into the ocean, posing significant risks to the fishing industry, a keystone of its economy, already impacted since the 2011 nuclear disaster.

The North Pacific Anadromous Fish Commission's data, as shown in Figure 3, clarifies the situation by presenting the Japan NPAFC Salmonid Catch Statistics from 1960 to 2022. These figures confirm the downward trend in Japan's fishery yields. Stable catches are recorded from the 1960s up to the early 2000s, but there is a sharp drop in 2010—a fall from 70,573 thousand to 54,205 thousand, aligning with the Fukushima nuclear disaster, highlighting its significant effect on the industry.

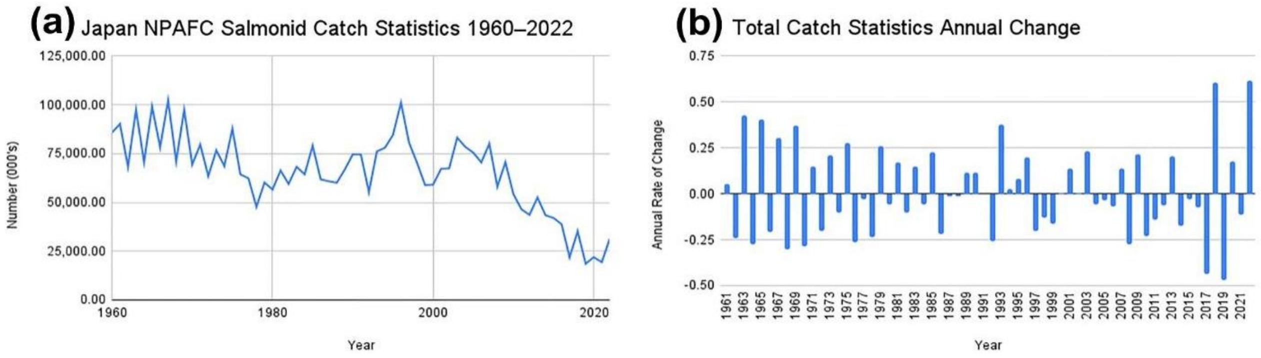


Figure 3. Japan NAFC Catch Total Statistics and Annual Change

Complementing this analysis, the right side of Figure 3, diagram b presents the annual change in Japan's total fish catch, revealing a notable decline in 2011. This decrease aligns with the Fukushima nuclear incident and indicates a diminished demand for fish, consequently impacting the fishing industry. This trend of a prolonged period of negative annual growth, interspersed with occasional years of positive change, is evident in the data.

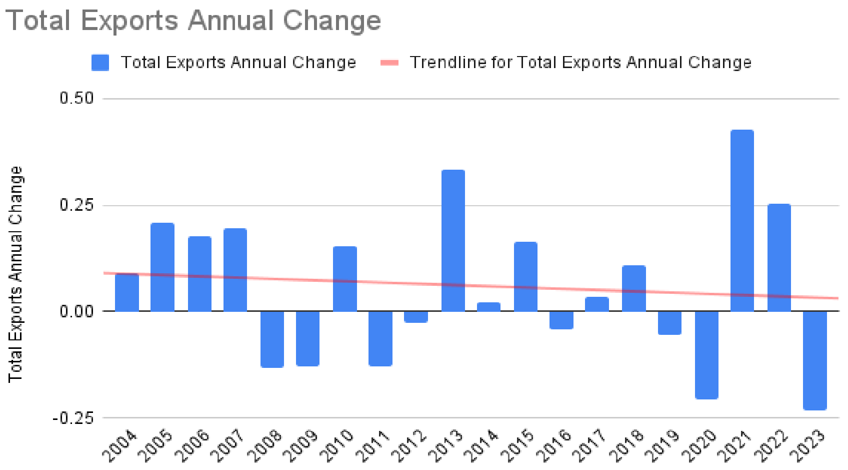


Figure 4. Total Japan Fishery Exports Annual Change

The Fukushima nuclear accident has long affected Japan's fishing industry. Figure 5 displays the yearly fluctuation of Japan's total fishery exports from 2004 to 2023, mirroring the data in Figure 4, which aligns the export changes with catch statistics. This has resulted in a consistent negative growth trend in the fishery market, driven by multiple factors.

During 2008 and 2009, Japan's economy reeled under the global financial crisis, mirroring a downturn in fisheries growth [17]. The situation worsened with the 2011 Fukushima nuclear disaster, dealing a direct blow to the fishing sector. Although there was a partial recovery, another setback occurred with the 2016 Fukushima earthquake, which had a depth of 11.4 km and registered a maximum of VII on the Mercalli scale [18]. The fishing industry faced further challenges in 2019 and 2020 due to the Covid-19 pandemic, with Japan's GDP plummeting by 4.7% in 2020 as the virus disrupted international markets [19][20]. A rebound in fishery exports was seen in the subsequent years. However, in 2023, Japan's decision to discharge stored Fukushima nuclear wastewater had a pronounced effect on fisheries' export rates.

3.2.2. Modeling recent impact of Fukushima Wastewater Release on Fishery Exports.

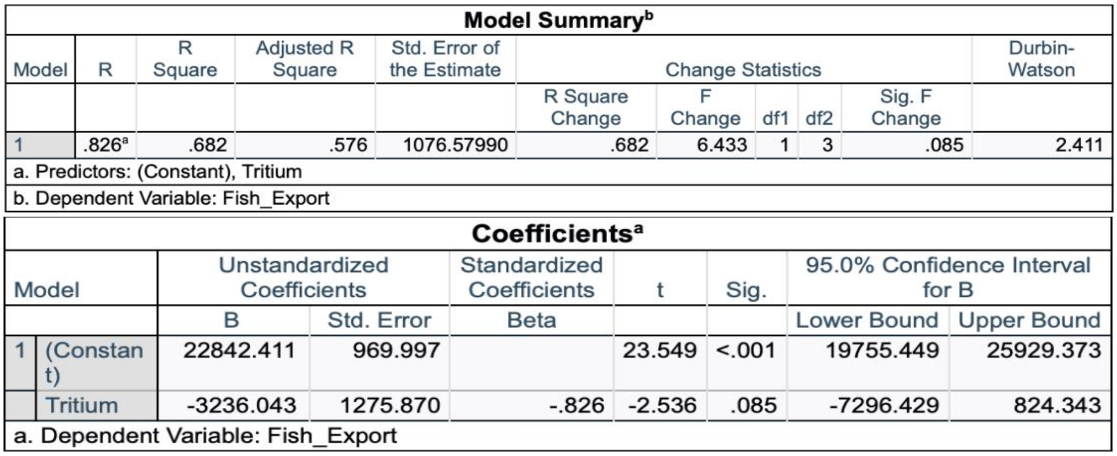
Using the Data of tritium concentration [14] by month and the monthly Japan fishery export data which is shown in Table 1. With the two datasets, the study is able to produce a single variable linear regression model that analyzes the correlation between the two variables and the strength.

Table 1. The Dispersion Concentration data after the Fukushima Dischargement of Nuclear waste and the according monthly fishery export data.

Date	Tritium Concentration (Bq/m^3)	Months	Fishery Exports
8.24	0	August	22529.195
9.13	1	September	20451.018
10.3	1	October	19125.405
10.23	0.8	November	22302.09
11.12	0.5		

Despite the limited amount of data available for this analysis, the resulting model revealed a strong and statistically significant correlation between Tritium concentration and Fishery Exports. The model summary, as depicted in Table 2, indicates an R-square value of 0.682. This value, a measure of the proportion of variability in the dependent variable that is predictable from the independent variable, suggests that approximately 68.2% of the variance in Fishery Exports can be accounted for by the Tritium concentration in this model.

Table 2. Modeling Summary of the Single Variable Model



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.826[a]	.682	.576	1076.57990	.682	6.433	1	3	.085	2.411

a. Predictors: (Constant), Tritium

b. Dependent Variable: Fish_Export

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	22842.411	969.997		23.549	<.001	19755.449	25929.373
	Tritium	-3236.043	1275.870	-.826	-2.536	.085	-7296.429	824.343

a. Dependent Variable: Fish_Export

The Durbin-Watson statistic of 2.411 indicates that the errors in the regression model are independent, as the value is within the acceptable range, showing no significant autocorrelation. Autocorrelation can compromise a model's validity by violating the independence of residuals. Additionally, the regression coefficients show a strong negative relationship between Tritium concentration and Fishery Exports, with a Beta of -0.826, indicating that higher Tritium levels correspond to lower Fishery Exports. Lastly, the 95% confidence interval for the Tritium coefficient, between -7296.429 and 824.343, does not include zero. This confirms the negative correlation is statistically significant and not by chance, highlighting the potentially substantial impact of the Fukushima incident on the economic performance of fisheries.

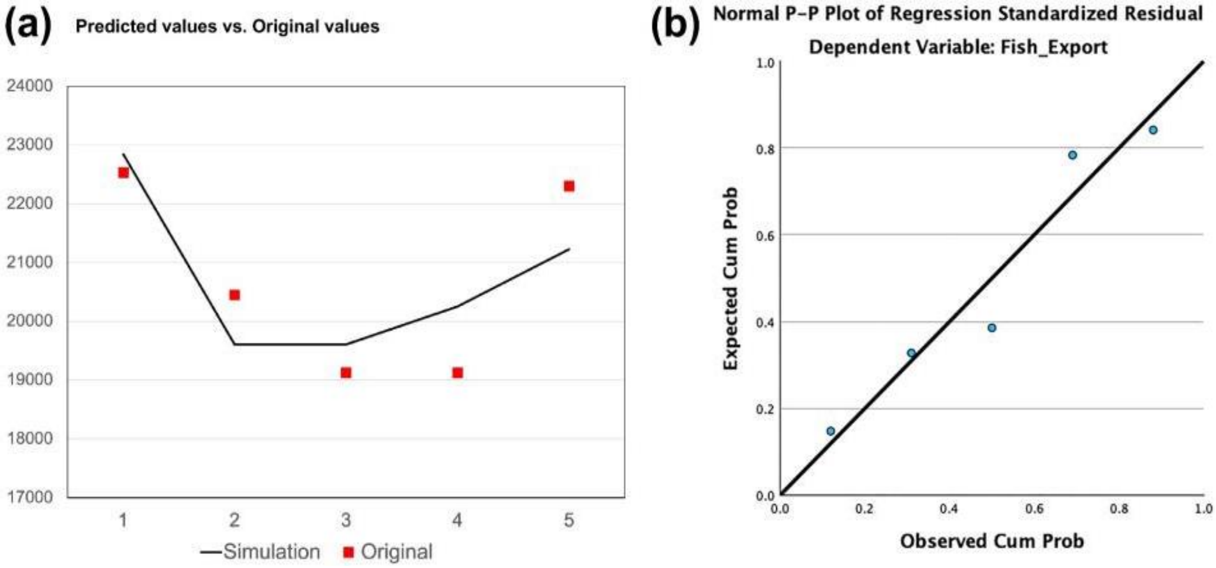


Figure 5. (a) Single Variable Model Predicted values vs. Original values (b) SingleVariable Normal P-P Plot of Regression Standardized Residual Dependent Variable: Fish Export

In Figure 5, the graph comparing Predicted and Original values illustrates the effectiveness of our regression model. The line reflects the model's predictions, and the red squares indicate the actual data. The deviation of these squares from the line visually quantifies the model's precision in forecasting Fishery Exports. Lesser distance between the squares and the line would imply greater accuracy. However, the present gaps indicate that the model, despite its predictive capabilities, misses some variation, possibly due to limited data or omitted variables. Adjacent to this, the Normal P-P Plot of Regression Standardized Residual evaluates the distribution of residuals, a key consideration in linear regression. Ideally, data points would align with the 45-degree reference line, indicating normal distribution. The minor straying of points in the plot suggests that our residuals mostly conform to normality, reinforcing the reliability of our regression coefficient hypothesis tests.

3.2.3. Modeling long-term impact of Fukushima Wastewater Release on Fishery Exports.

Table 3. Pearson’s Linear Correlation Analysis

	Fish Catch	GDP	Population	Fish Export	Cs137
Fish Catch	1	-0.2604524152	-0.1693586487	-0.6588827061	-0.5071538238
GDP	-0.2604524152	1	0.8619101383	-0.03672966436	0.295652711
Population	-0.1693586487	0.8619101383	1	-0.0840249825	0.2472230072
Fish Export	-0.6588827061	-0.03672966436	-0.0840249825	1	0.4225994083
Cs137	-0.5071538238	0.295652711	0.2472230072	0.4225994083	1

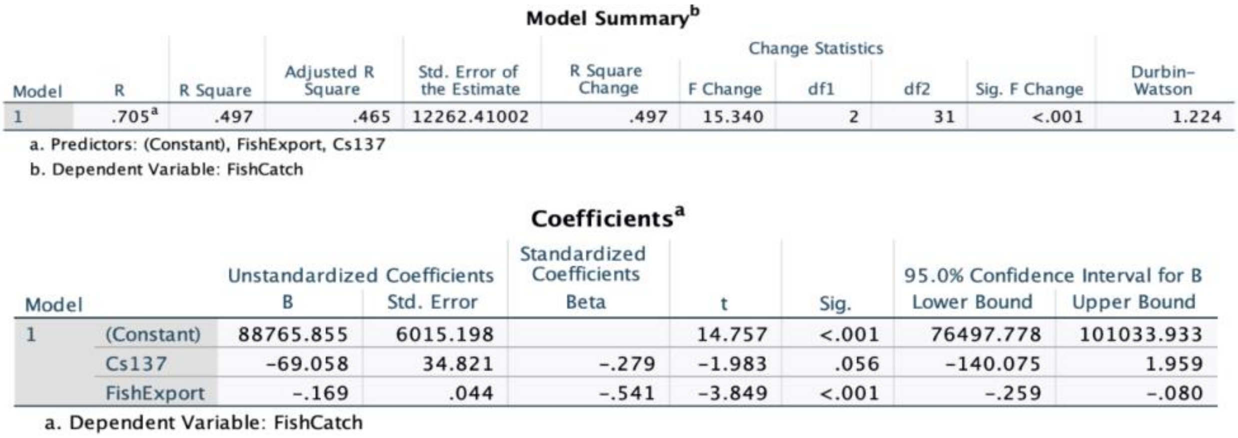
To examine the long-term impact of Fukushima's wastewater on Fishery Exports, we incorporated diverse factors such as Fish Catch, Gross Domestic Product (GDP), Population, Fish Export volumes, and Cesium-137 (Cs-137) levels—a byproduct of the nuclear incident. The study's correlation matrix (Table 3) unveils key relationships. There's a pronounced negative correlation between Fish Exports and Fish Catch (-0.6588827061), suggesting that abundant local catches might decrease export needs.

Intriguingly, a positive correlation exists between Fish Exports and Cs-137 (0.4225994083), an unexpected trend that calls for further exploration. GDP and Population, however, show weaker connections to Fish Export volumes, indicating less influence on exports.

Based on Pearson's Linear Correlation Analysis, Population and GDP were excluded from multivariate regression due to their weak correlation with Fish Export. This suggests they may not be significant predictors for long-term impact of radioactive waste on Fishery Exports. The model prioritizes more strongly correlated variables to capture significant effects.

Consequently, the multivariate model was constructed using Fish Export and Cs-137 as the independent variables to predict Fish Catch volumes.

Table 4. Modeling Summary of the Multivariate Model



Model Summary[b]

					Change Statistics					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.705[a]	.497	.465	12262.41002	.497	15.340	2	31	<.001	1.224

a. Predictors: (Constant), FishExport, Cs137

b. Dependent Variable: FishCatch

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
Model		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	88765.855	6015.198		14.757	<.001	76497.778	101033.933
	Cs137	-69.058	34.821	-.279	-1.983	.056	-140.075	1.959
	FishExport	-.169	.044	-.541	-3.849	<.001	-.259	-.080

a. Dependent Variable: FishCatch

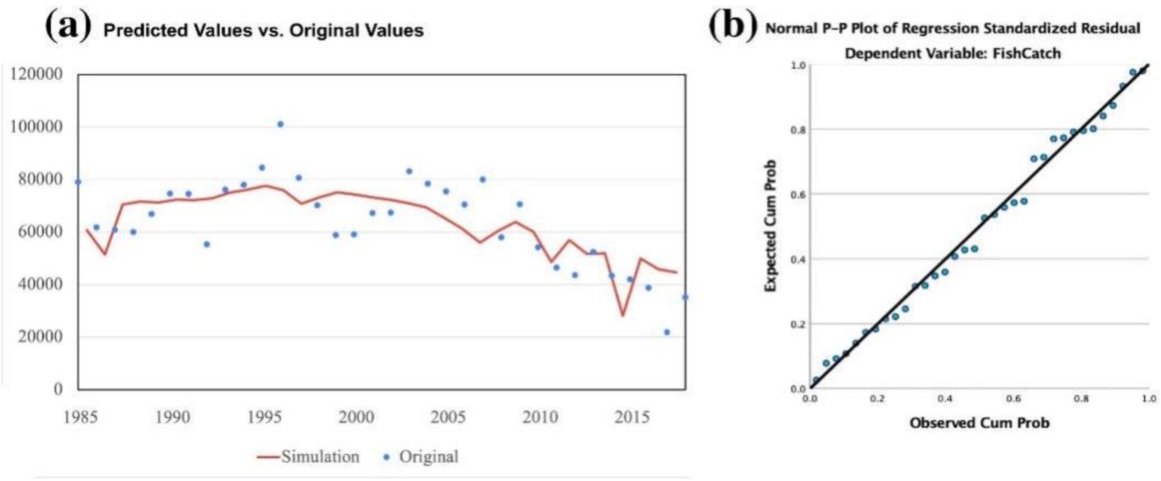


Figure 6. (a) Multivariate Model Predicted values vs. Original values (b) Multivariate Normal P-P Plot of Regression Standardized Residual Dependent Variable: Fish Catch

Table 4 depicts multivariate analysis results. An R-squared value of 0.497 shows 49.7% of fishery export variability is explained by Cs137 levels and fish export volume, indicating a strong correlation. The Durbin-Watson statistic (1.224) suggests slight positive autocorrelation in residuals, potentially affecting coefficient reliability. The regression coefficients provide insight into the impact of Cs137 and Fish Export on Fish Catch. A negative correlation is evident for Cs137 (-0.279), indicating that as Cs137 levels increase, Fish Catch decreases. This implies potential harm to fish populations from wastewater contamination. Similarly, Fish Export's coefficient of -0.541 suggests decreased catches with rising exports, possibly due to overfishing for exports, affecting fish stocks. The 95% confidence intervals for Cs137 (-140.075 to 1.959) and Fish Export (-2.59 to -0.080) confirm statistical significance, aligning with negative beta coefficients and rejecting randomness.

Graph (a) illustrates predicted versus original Fish Catch values over time, showing the simulation's attempt to mimic the data trend. Discrepancies, notably in the early 2000s, imply the model may miss certain fluctuations due to unaccounted factors like environmental changes. Graph (b), the Normal P-P Plot of Regression Standardized Residual, confirms residual normality, a key assumption for linear regression. The closely aligned data points with the diagonal line indicate a normally distributed residual pattern, suggesting randomness and minimizing omitted variable bias. This reinforces the model's reliability and regression coefficients' robustness.

3.3. Will Fukushima wastewater affect the fishing industry in Korea, Canada, and the U.S?

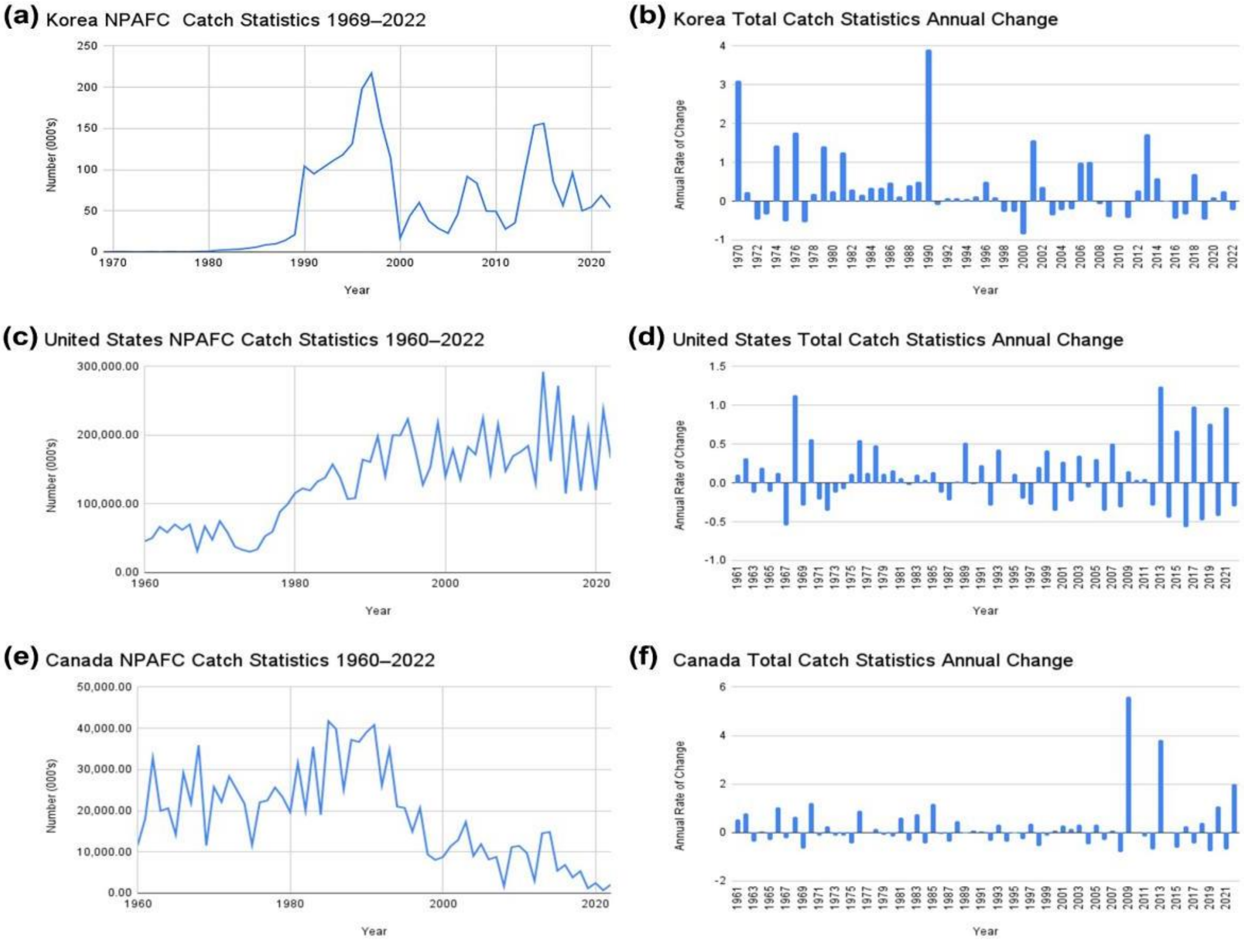


Figure 7. Modeling Summary of the Single Variable Simulation

In South Korea's graphs (a) and (b), spanning 1969-2022, (a) depicts fishery catch trends, and (b) shows annual changes. Pre-2011, catch rates fluctuated but generally grew. Post-2011, a notable decline reflects Fukushima's impact. Annual changes affirm this downturn, indicating a lasting effect on Korea's fisheries.

Figures (c) and (d) display U.S. fishery data. Total catch from 1960 to 2022 gradually rises, with increased variability recently. Unlike Korea, no immediate decline post-2011 is evident. Annual change fluctuates positively and negatively, indicating resilience post-Fukushima, with no significant persistent decline observed.

For Canada, Figures (e) and (f) show a stable fishery catch trend until the early 1990s, followed by increased fluctuation. Post-2011, no abrupt decrease is observed, with variability continuing. Annual change data indicates some years of higher variability, but no discernible long-term negative trend after 2011, similar to the U.S.

Considering the macroscopic diffusion model simulations discussed in section 3.1, the outlook for fisheries in South Korea, the United States, and Canada is concerning. The simulations predict significant impacts on marine environments due to the dispersion of tritium from Fukushima's treated nuclear wastewater. South Korea's fisheries could face challenges within 400 days, given their proximity to Japan, while the United States and Canada may experience effects within 1200 days, with tritium concentrations increasing over time. This diffusion, combined with accelerated ocean currents, suggests impending negative impacts on North Pacific fisheries, particularly for South Korea. To address this, proactive measures may be necessary to mitigate the changing chemical composition of the ocean and its effects on fisheries in these nations.

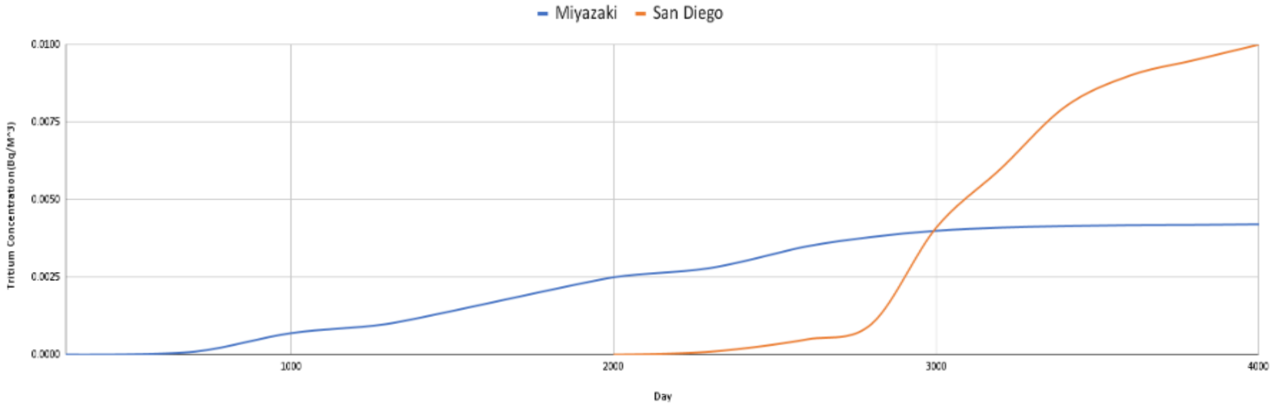


Figure 8. Miyazaki and San Diego Tritium Concentration Overtime after Fukushima Decision to Release Nuclear Wastewater

Figure 8 highlights the spread of nuclear wastewater's impact from Japan to the United States by comparing Tritium levels in Miyazaki, Japan, and San Diego, United States. Initially, Tritium concentrations are low in both locations. A notable uptick occurs around 2000 days post-discharge, with San Diego's levels eventually surpassing those of Miyazaki. By day 3000, San Diego experiences a tenfold increase in Tritium, peaking at 0.0100 Bq/m³, indicating trans-Pacific dispersion of nuclear contaminants.

The graph reveals rising Tritium levels in San Diego surpassing those in Miyazaki, indicating wider impacts on Pacific fishing sectors. Continuous monitoring and global cooperation are imperative to address risks to marine ecosystems and reliant fishing economies. The alarming trend underscores nuclear wastewater's significant influence globally.

4. Conclusion

In summary, the decision by Japan to release treated nuclear wastewater from the Fukushima disaster into the ocean has been shown to have a profound and far-reaching impact on the fishing industry, not just within Japan but extending to other countries such as South Korea, Canada, and the United States. This paper, through meticulous analysis utilizing linear and multivariate regression models, supported by the simulation model from Tsinghua University, indicates a discernible negative correlation between the discharge of nuclear wastewater and the health of the fishing industry. This correlation is not localized to Japan; it spans across the Northern Pacific to countries such as Korea, Canada, and the United States.

The study's findings reveal a significant ecological disruption and economic losses within the fishing sector due to increasing levels of radioactive substances such as Tritium and Cesium-137 in marine ecosystems. The intricate ocean currents play a critical role in this transboundary pollution, as demonstrated by the marked increase in Tritium concentration in San Diego's waters, which eventually surpasses that of Miyazaki, Japan. This underlines the long-term environmental and economic challenges that lie ahead for the fishing industry in these regions.

The implications of this study emphasize the need for rigorous international regulatory measures and the adoption of sustainable fishery management practices to mitigate the long-term effects of nuclear contamination. It also highlights the importance of collaboration among nations to monitor and address the spread of radioactive materials across the oceans, ensuring the protection of marine biodiversity and the safety of seafood consumption.

References

[1] Outline History of Nuclear Energy. (n.d.). World Nuclear Association. https://world-nuclear.org/information-library/current-and-future-generation/outline-history-of-nuclear-energy.aspx.

[2] Char, N. L., & Csik, B. J. (n.d.). Nuclear power development: History and outlook. The IAEA. Retrieved December 22, 2023, from https: //www.iaea.org/sites/default/files/publications/magazines/bulletin/bull29-3/29304781925.pdf.

[3] Blume, L. M. (n.d.). Japan releases nuclear wastewater into the Pacific. How worried should we be? National Geographic. Retrieved December 22, 2023,from https: //www.nationalgeographic.com/premium/article/fukushima-japan-nuclear-wastewater-pacific-ocean.

[4] Nogrady, B. (n.d.). *Is Fukushima wastewater release safe? What the science says*. Nature. Retrieved December 22, 2023, from https://www.nature.com/articles/d41586-023-02057-y 1/5.

[5] Wang, M., Tan, Z., Liu, J., & Chen, J. (2022). Analyzing the impact of fukushima nuclear wastewater discharge on seafood trade with gravity model. *Ocean & Coastal Management, 230,* 106302. https: //doi.org/10.1016/j.ocecoaman.2022.106302.

[6] Buesseler, K., Aoyama, M., & Fukasawa, M. (n.d.). Impacts of the Fukushima Nuclear Power Plants on Marine Radioactivity. Retrieved December 22, 2023,from https: //pubs.acs.org/doi/10.1021/es202816c.

[7] Lu, Y., Yuan, J., Du, D., Sun, B., & Yi, X. (2021). Monitoring long-term ecological impacts from release of fukushima radiation water into ocean. *Geography and Sustainability*, *2* (2), 95 - 98. https: //doi.org/10.1016/ j.geosus.2021.04.002.

[8] *The amazingly wide variety of seafood species in each season*. (n.d.). Japan Aquatic Product Export Council. https://japan-aquatic-products-export-council.jp/eng/values/variety.

[9] *An overview of the 8 major currents affecting the Japanese archipelago* [Photograph]. (n.d.). Blue Japan. https: //bluejapan.org/geography/currents-of-japan/.

[10] *Speed of Ocean Current*. (n.d.). The Physics FactBook. Retrieved December 22, 2023, from https: //hypertextbook.com/facts/2002/EugeneStatnikov.

[11] Kuroshio. (n.d.). Britannica. Retrieved December 22, 2023, from https: //www.britannica.com/place/Kuroshio.

[12] Zhang, Q. (n.d.). [Fig 1]. ResearchGate. https://www.researchgate.net/figure/ North-Pacific-Subtropical-Convergence-Zone-and-the-ocean-currents-involved-in-the-North_fig1_259166112.

[13] Statistics NPAFC. (n.d.). https://www.npafc.org/statistics/.

[14] Japan Exports of Fish & Fish Preparations (1983-2021 Data) 2022-2023 Forecast. (n.d.). Tradingeconomics.com. https: //tradingeconomics.com/japan/exports-of-fish-fish-preparations

[15] Liu, Y., Guo, X.-Q., Li, S.-W., Zhang, J.-M., & Hu, Z.-Z. (2021). Discharge of treated fukushima nuclear accident contaminated water: Macroscopic and microscopic simulations. *National Science Review*, *9* (1). https: //doi.org/ 10.1093/nsr/nwab209.

[16] Kawai, M. (2009, October). *Why was Japan Hit So Hard by the Global Financial Crisis?* (S. Takagi, Ed.) [Review of *Why was Japan Hit So Hard by the Global Financial Crisis?*]. ADBInstitute; Asian Development Bank Institute.

[17] 2016 Fukushima earthquake.(2024, January 27). Wikipedia. https: //en.wikipedia.org/wiki/2016_Fukushima_earthquake.

[18] Center on Budget and Policy Priorities. (2024, January). Tracking the Recovery from the Pandemic Recession. https: //www.cbpp.org/research/economy/tracking-the-recovery-from-the-pandemic-recession.

[19] Dyomina, Y. V., & Mazitova, M. G. (2021). The COVID-19 pandemic and its impact on the Japanese economy. Japanese Studies in Russia, (3), 57-75. https: //pesquisa.bvsalud.org/global-literature-on-novel-coronavirus-2019-ncov/resource/pt/covidwho.