Illuminating Fishery Drivers in the South China Sea

Analyzing Spatial Non-Stationarity of Fishing Activity

Michael W. Andrews

University of California, San Diego

December 2019

Abstract:

The South China Sea is a hotbed of conflicting territorial claims, particularly based around regions vital to the regional fishing industry. Contemporary rhetoric claims that fishing activity in the South China Sea disputed areas are greater than justified by the ecological conditions. This paper aims to contribute to this topic of study by analyzing macro-scale ecological drivers of fishing activity in the region and evaluate the spatial non-stationarity of the relationship. A geographically weighted regression shows that biological productivity is a decent driver of fishing activity and that this relationship is indeed spatially non-stationary. The results of this paper beg further questions regarding other potential explanatory variables.

Introduction

Comprising 71 percent of the earth's surface, the oceans play a vital role in providing for human society. Oceanic resources are bountiful, contributing to the global food system, natural and strategic resource regimes, and the transportation industry.

As a contributor to the global food system, fish (both capture and aquacultural) supply approximately 16 percent of total global protein consumption, even more so amongst developing nations.[1] For example, in 2010, 30 nations were dependent on fisheries for one-third of total protein consumption and amongst these 30 nations, 22 were considered low-income countries.[2] Typically, sources of protein in low-income countries are going to be consumed based on available supply rather than preference amongst animal proteins.[3] This indicates that a potential shock to fishery production could prove disastrous for dependent nations, making fisheries a matter of food security.

However, the economic value of fisheries must also be stressed. The fishing industry acts as a major employer, especially in Asia, providing about 56.6 million jobs in 2014 amongst capture fisheries alone.[4] A portion of the production from this industry is then exported as a commodity, accounting for $148 million in exports in 2014.[5]

Beyond fishing activity, the ocean space is also valuable as a source of strategic resources. These resources include oil, natural gas, and minerals. In fact, the ocean space itself may also be counted amongst these strategic resources. This space is the most cost-efficient domain to transport large amounts of goods. As a result, maritime trade accounts for about 90 percent of global trade.[6] If one is a subscriber to Mahan's theory of sea power, then the importance of ocean space is bolstered beyond food security and economic security as a matter of power projection and national security.[7]

These examples are provided with the intent to highlight the immense value of ocean space. Indeed, troves of literature exist examining and theorizing on the importance of ocean space well beyond what has been discussed here. However, the provided considerations of oceanic value are vital in understanding that this value acts as a threat-multiplier in disputed ocean regions. In particular, this paper will focus on the case study of fishing activity in the South China Sea (SCS).

The South China Sea

The SCS has become central to the discussion of the use of ocean space and the question of its division amongst sovereign states in recent decades. Split between several bordering littoral states (China, Taiwan, Vietnam, Brunei, Malaysia, Indonesia, and the Philippines) the SCS is perhaps the most disputed contemporary maritime space.

The primary driver behind this dispute is still debated. Some argue that control over the region is vital for projection of power, others argue natural resources, and some will even argue matters of nationalism and historical rights. The SCS contributes to about 12 percent of global fishery catch production[8], contains an estimated 11 billion barrels of oil and 190 trillion cubic feet of

[1] MarineBio, "Ocean Resources."
[2] Béné et al., "Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction."
[3] FAO, *The State of World Fisheries and Aquaculture: Contributing to Food Security and Nutrition for All*.
[4] FAO
[5] FAO
[6] "ICS | Shipping Facts."
[7] Mahan, *The Influence of Sea Power upon History, 1660-1783*.
[8] Fridtjof Nansen Institute (FNI), "Fish, Not Oil, at the Heart of the South China Sea Conflict"

natural gas[9] and carrying an estimated one-third of global shipping.[10] The true source of conflict is likely some amalgam of the aforementioned drivers.

Hypothesis

This paper is particularly concerned with how the disputing nations attempt to control this region rather than the core drivers of the conflict. How this may be occurring places the regions fishing industry at the forefront. Recent studies and news media present the notion that fishing fleets are being used as militias to assert control over the region disguised as fishing effort.[11] Strategically, this would allow involved states to assert territorial claims without a blatant military presence while also securing the extraction of the resource, albeit likely unsustainably. The claim is dependent on higher rates of fishing activity in disputed areas than justified by the presence of fish stocks. This would indicate that non-ecological factors are explaining fishing activity in the SCS.

Studies on the socioeconomic drivers of illegal fishing and overfishing are quite prevalent. However, the examination of spatial drivers of general fishing effort are less so. This paper aims to spatially analyze the ecological drivers of fishing effort in the SCS. A spatial analysis allows for examination of non-stationarity. If the relationship between fishing effort and potential ecological drivers does not hold throughout the study region, then there are likely other variables driving fishing activity than the fish stocks themselves.

Literature Review

Spatial analysis of fishing effort is a relatively new pursuit primarily due to the technological demand on data collection and the extensive size of the data necessary for a comprehensive study. However, recent studies and efforts on behalf of NGO's and national governments has begun breaking these barriers.

Global Fishing Watch (GFW) has been at the forefront of this pursuit. In 2012, GFW began collecting georeferenced fishing effort at the 10th degree and 100th degree resolution by remotely collecting shipboard Automatic Identification System (AIS) information.[12] This provided the first macro-scale georeferenced dataset of fishing effort. After five years of collection, in 2016 Kroodsma et al. published an analysis of this data and its correlation with several environmental drivers.[13] However, this dataset suffers from the nature of AIS technology, which can be deactivated by operators when a vessel wishes to be hidden. In the case of the SCS, where vessels operate in disputed areas or cannot afford this technology, the problem is pervasive.

In 2015, Elvidge et al., published a system for automatic detection of fishing vessels utilizing night light data collected from Visible Infrared Imaging Radiometer Suite (VIIRS) also known as VIIRS Vessel Boat Detection (VBD).[14] This system was adopted by the National Oceanographic and Atmospheric Administration (NOAA) to provide nightly, monthly, and annual nighttime fishing vessel detections. This publicly available data has greater resolution than the AIS data and is not subject to the same issues in disputed regions. However,

9 AMTI, "South China Sea Energy Exploration and Development."
10 ChinaPower, "How Much Trade Transits the South China Sea?"
11 Hongzhou, "Beijing Has a Maritime Militia in the South China Sea. Sound Fishy?"
12 Kroodsma et al., "Tracking the Global Footprint of Fisheries."
13 Kroodsma et al.
14 Elvidge et al., "Automatic Boat Identification System for VIIRS Low Light Imaging Data."

the system is incapable of distinguishing vessel information such as flag-type, gear-type, or effort hours. Rather this data provides only a count of vessel detections available at a very high resolution.

Analysis of the relationship of the VIIRS data to environmental drivers is limited. This paper aims to perform a cursory study of this relationship, contributing to the study of drivers of fishing effort and alternative motives for fishing effort in disputed areas.

Methods and Analysis

Data Sources and Preparation

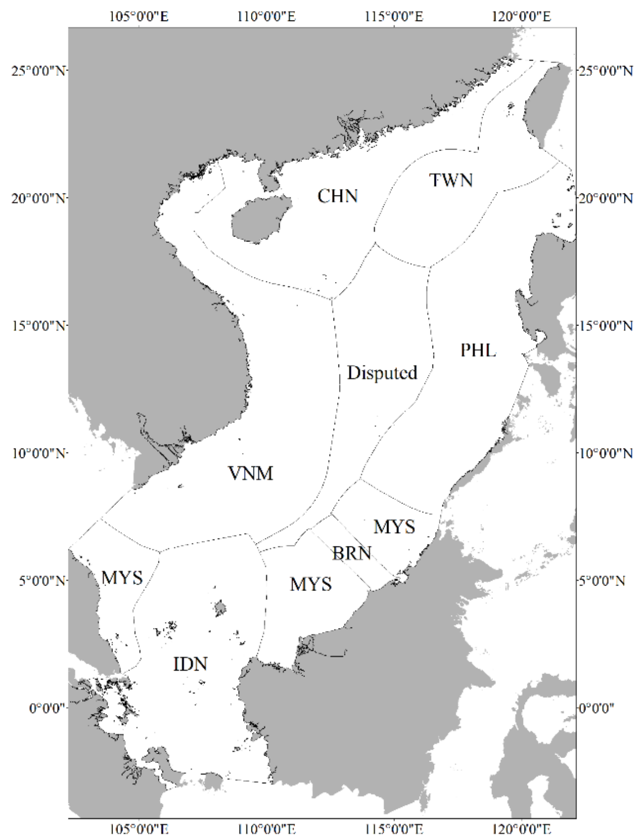
The spatial analysis within this paper will be entirely carried out using Esri's ArcGIS 10.7.1 program. The analysis of this paper is limited to the SCS study region. This region was selected because of the prevalence of reported territorial disputes. In analyzing the question of spatial non-stationarity in fishing activity as a result of non-ecological drivers, the SCS disputes provides the proper conditions for analysis.

The SCS region is defined by the International Hydrological Organization (IHO) as south of China, north of Borneo, east of Vietnam and the Malay Peninsula and west of the Philippines.[15] The exact extent is publicly available online at marineregions.org as a part of the larger IHO marine regions shapefile.[16] This site also provides an Exclusive Economic Zone (EEZ) shapefile, including a disputed region within the SCS.

In order to form the study region, the SCS was selected and extracted from the global marine regions' shapefile. The EEZ shapefile was then clipped to the SCS study region to provide a visual breakdown of the study region by sovereign control. The resulting study region is provided in **Fig 1.**

In order to prepare for analysis, a buffer of the SCS was created to 4.26 arcminutes. A buffer at this size was created because the unit of analysis for this paper will be 6 arcseconds despite higher resolution availability of some of the variables. This unit of analysis was selected based on availability of processing power. Note that buffers and distance measures would typically be calculated as a distance rather than an arcminute/degrees, however, the raster data is available in decimal degree

Fig 1. South China Sea Study Region



[15] "Limits of Oceans and Seas, 3rd edition" (PDF). International Hydrographic Organization. 1953. § 49. Retrieved 13 December 2019.

[16] "Marine Regions"

cell sizes and distance calculations are accounted for using geodesic calculations. Following the buffer, a polygon fishnet shapefile (including a matching label point shapefile) was created at 6 arcseconds within the extent of the SCS buffer. Both the fishnet and the label point features were clipped to the SCS buffer. The fishnet polygon will be used to convert the rasterized variables to the proper 6 arcsecond cell size. Meanwhile, the label point feature, here on referred to as the “analysis points”, will be used to store the cell values of the rasterized variables for spatial analysis.

In order to analyze the relationship between fishing activity and potential environmental drivers this paper utilizes publicly available macro-scale variables. The primary variable of concern is fishing activity. Supporting variables utilized are primary productivity and distance to ports.

Fishing activity is the dependent variable in this paper’s analysis. This analysis utilizes NOAA’s VBD annual data for 2018.[17] However, a single file is not available for the study region, thus, annual measures for China, Vietnam, The Philippines, Malaysia, and Indonesia were separately downloaded as raster files. Once imported in ArcGIS, the raster datasets were then mosaiced together to form a singular raster. ArcGIS’s Zonal Statistics tool was then used to aggregate the resulting dataset into the 6 arcsecond bins of the fishnet layer, providing.

Primary productivity is a common geographic environmental driver of fish stock biomass. Chlorophyll *a* can be used as a proxy for this primary productivity and is easily measured as a blue-green band using remote sensing. NASA publicly provides this blue-green band at 8 day and monthly averages.[18] Monthly averages for January-December 2019 at 6 arcminutes were imported to ArcGIS. Raster Calculator was then utilized to average these monthly values and then masked the resulting raster to the SCS buffer.

Distance to major ports may affect the prevalence of fishing activity as a greater distance increases costs of the activity itself, which is highly undesirable when fishing for sustenance or commerce. A .csv table of

Fig 2. Spatial Visualization of Dependent and Independent Variables

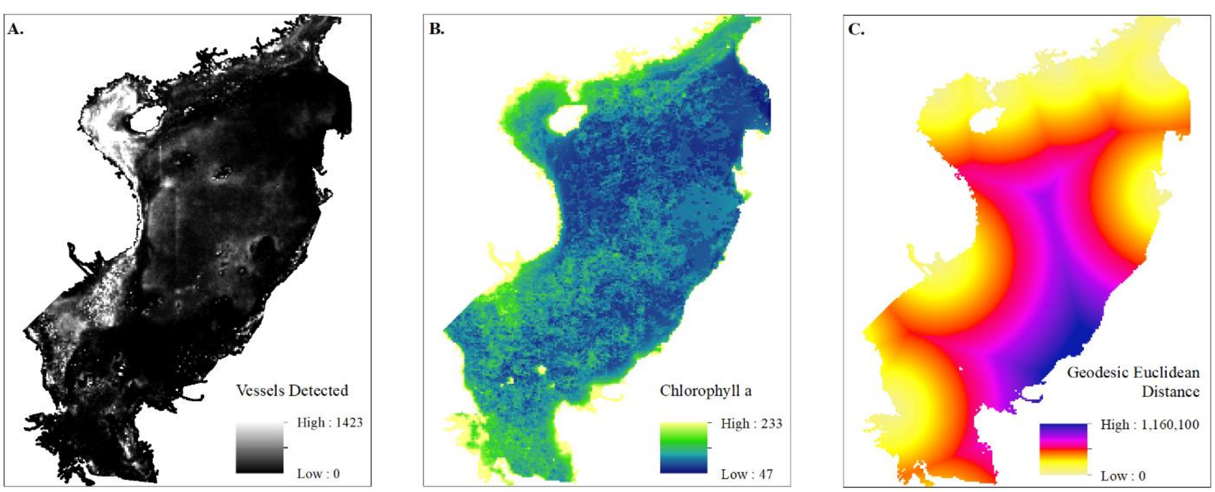


Fig 2) The figures above visualize the dependent and independent variables utilized in this analysis. (A.) The vessel activity in the SCS study region as measured by number of VIIRS nighttime vessel detections in 2018. (B) Primary productivity in the SCS study region as measured by average chlorophyll a concentration index in 2018. (C) Distance to major ports measured as logged geodisic euclidean distnce to major regional ports.

17 “Earth Observation Group - Defense Meteorological Satellite Progam.”

18 “Chlorophyll Concentration (1 Month - Aqua/MODIS) | NASA.”

georeferenced major ports was provided by Dr. Gordon McCord for use with this project. This table was imported to ArcGIS and the xy data was added and extracted as a separate point feature. The major ports were limited to those relevant to the study region (i.e. those within the littoral states that border the study region). Geodesic Euclidean Distance was then calculated at 6 arcseconds within the buffered study regions extent, providing distance to nearest port at the appropriate cell size. Using Raster Calculator, the resulting raster was masked to the SCS buffer.

The three resulting variables are visualized in **Fig 2.** In order to prep for spatial analysis, the three raster values were extracted to the analysis points feature, creating a georeferenced dataset of the three variables. Distance to ports was then log transformed for future analysis.

OLS Regression

A basic initial exploration of the relationship between fishing activity and environmental drivers can be done with an Ordinary Least Squares (OLS) regression analysis. Such an analysis can be performed in ArcGIS to determine a global relationship. However, the value of an analysis of this sort in ArcGIS is that the resulting regression can produce local residuals that can be used to diagnose certain aspects of the model.

Using the OLS tool in ArcGIS, the fishing activity variable in the analysis points feature was regressed on the biological productivity measure and logged distance to major ports. **Fig 3** provides the results from the OLS regression.

Fig 3. OLS Regression of Fishing Activity and Environmental Factors

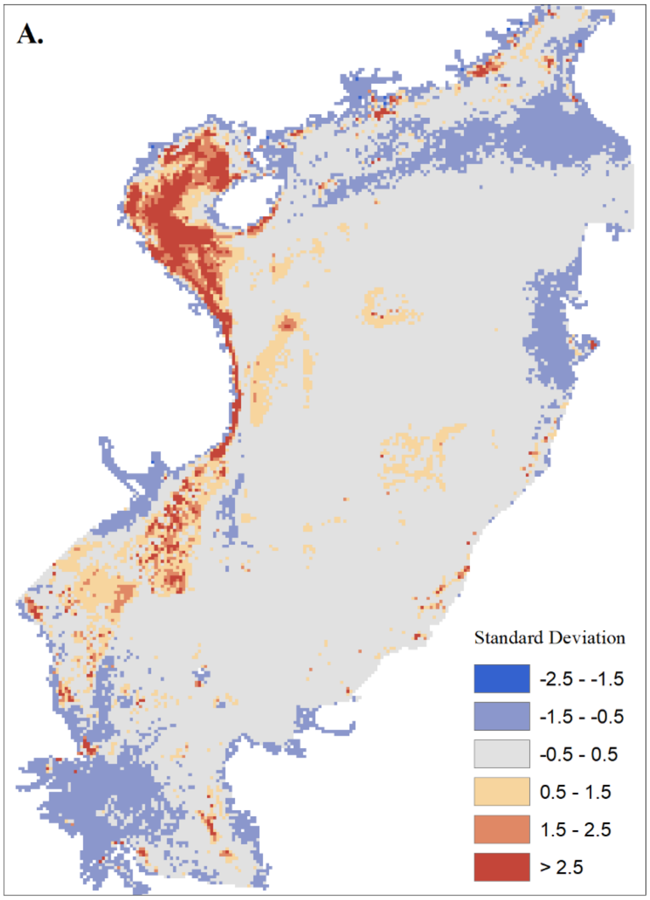
VARIABLES	Fishing Activity
Chlorophyll *a*	0.089***
t-statistic	6.894
	(0.013)
Port Distance (log)	-11.597***
t-statistic	-16.829
	(0.689)
Constant	181.212***
t-statistic	18.954
	(9.561)
Observations	29,650
Adjusted R-squared	0.018

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Both primary productivity and distance to port shows a statistically significant relationship to fishing activity. The Chlorophyll *a* measure provides a positive relationship while port distance provides a negative relationship, as expected. However, the effect of the ecological variable, chlorophyll *a*, is relatively weak and the model shows an overall weak fit to the data, observing the very low adjusted R-squared.

The model is diagnosed for autocorrelation based on the standardized residuals. **Fig 4** provides the local standardized residuals for the OLS regression which show a clear spatial relationship indicating clustering

Fig 4. OLS Model Autocorrelation Diagnostic



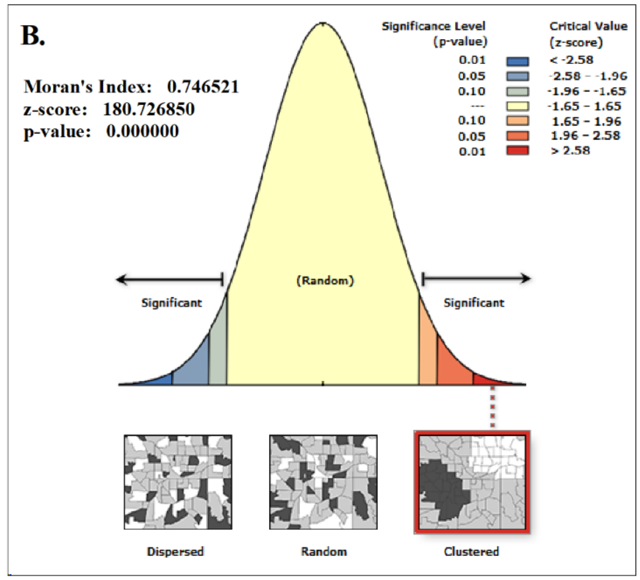


Fig 4. This figure shows the results of an autocorrelation diagnostic of the OLS model regressing fishing activity on ecological and geographic factors. (A) The mapped local standardized residuals shows a clear, non-random pattern in the residuals, indicating spatial autocorrelation. (B) The Moran's I statistic results confirm spatial autocorrelation clustering in the standard errors at 99% confidence. These two diagnostics indicate clear autocorrelation issues in the OLS model.

autocorrelation in the model. The figure also provides a Moran's I statistical analysis of the dependent variable, fishing activity. The resulting statistical diagnostic supports the visual results of the standardized error. Thus, an OLS model shows clear autocorrelation issues.

Geographically Weighted Regression

Spatial analysis provides the unique ability to comprehensively address gross autocorrelation in a regression model. A geographically weighted regression (GWR) penalizes the model based on potential autocorrelation, allowing a regression model that is valid amongst potential spatial autocorrelation.

In addition, a GWR is a powerful mapping tool as it allows the analysis to map localized coefficients. Doing so can be used to analyze the spatial stationarity of a causal relationship. In the case of this case study, such an analysis can be used to address the hypothesis that a relationship based on ecological drivers does not hold in the disputed areas of the SCS study region.

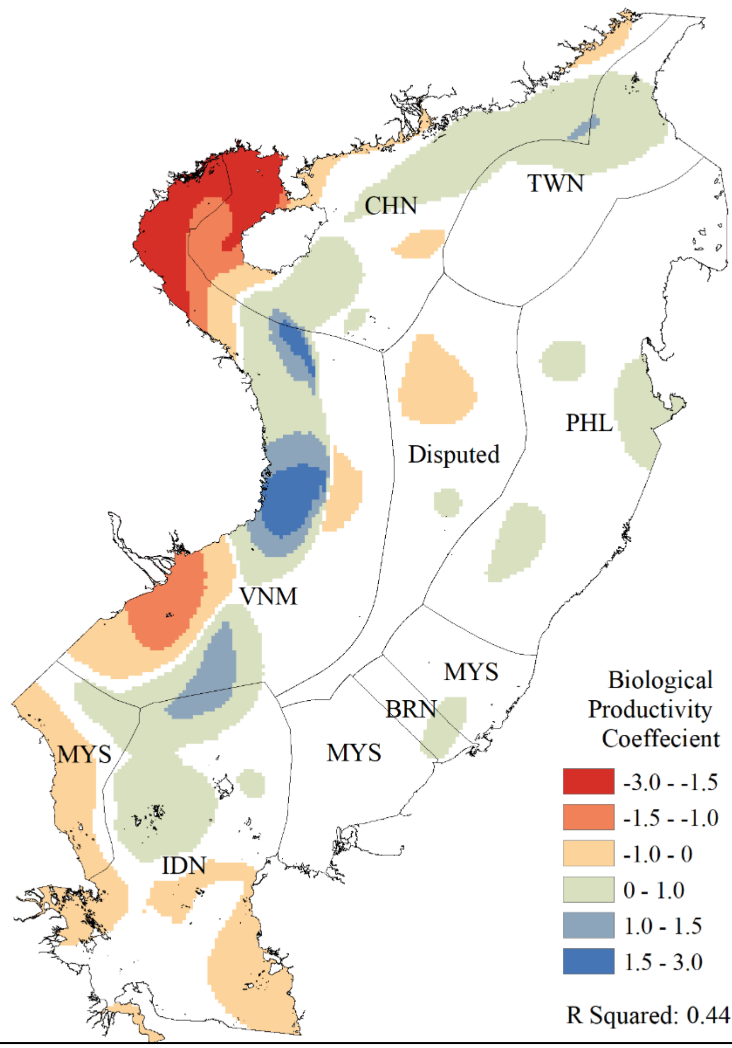
However, GWR regression tools have been known to fail when certain explanatory variables are too highly spatially autocorrelated. The artificial construction of the distance to major ports variable falls victim to this issue and is thus excluded from the GWR model.

In order to address clustering error in the OLS model and to evaluate spatial non-stationarity, fishing activity is regressed on biological productivity within ArcGIS's GWR tool. This regression produces a series of points corresponding with the analysis points with the various regression statistics included, such as local coefficients and standard errors. A T-statistic field is calculated for the chlorophyll coefficient as follows:

$$t = \frac{\beta_{Chlorophyll}}{\sigma_{chlorophyll}}$$

All points with a t-statistic not between 1.96 and -1.96 were selected and extracted into a separate shapefile representing local coefficients with 95% confidence. **Fig 5** provides visualized results of the GWR analysis. The model returns an R-squared of 0.44, indicating a strong fit with the data.

Fig 5. Geographically Weighted Regression Analysis of Environmental Drivers of Fishing Activity



Biological productivity shows negative causal effects in some areas of the study region and positive in others. The negative relationship is likely caused by a high constant in the model. This varying relationship indicates spatial non-stationarity in the effects of ecological drivers of fishing activity, particularly in the heavily disputed eastern region.

Discussion and Conclusions

The results of the GWR indicate that the causal effects of environmental drivers on fishing activity are spatially non-stationary. The relationship also appears to fail in the heavily disputed regions of the SCS study region.

This project supports the notion that there are environmental drivers for fishing activity. However, it also supports the notion that factors outside of this relationship, potentially political in nature, are driving fishing activity levels in the disputed regions of the SCS.

Nonetheless, there are a host of shortfalls with this analysis that provide the opportunity for further spatial analysis research into the relationship between geographic and institutional drivers of fishing activity in disputed regions. Primarily, improved AIS compliance could provide a more comprehensive analysis of fishing effort.

Additionally, the exploration of environmental drivers aside from biological productivity could provide a better assessment of the ecological relationship. Ultimately, as spatial data resolution improves, new understandings of the environmental and non-environmental drivers of oceanic conflict will become possible.

Data Sources

Chlorophyll Concentration (1 month - Aqua/MODIS) | NASA. "Chlorophyll Concentration (1 Month - Aqua/MODIS) | NASA." Text.Article, December 13, 2019. https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MY1DMM_CHLORA.

"Earth Observation Group - Defense Meteorological Satellite Progam." Accessed December 13, 2019. https://www.ngdc.noaa.gov/eog/viirs/download_boat.html.

"Marine Regions." Accessed December 13, 2019. http://www.marineregions.org/eezsearch.php.

Bibliography

AMTI. "South China Sea Energy Exploration and Development." Asia Maritime Transparency Initiative. Accessed December 13, 2019. https://amti.csis.org/south-china-sea-energy-exploration-and-development/.

Béné, Christophe, Robert Arthur, Hannah Norbury, Edward H. Allison, Malcolm Beveridge, Simon Bush, Liam Campling, et al. "Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction: Assessing the Current Evidence." *World Development* 79, no. Supplement C (March 1, 2016): 177–96. https://doi.org/10.1016/j.worlddev.2015.11.007.

ChinaPower. "How Much Trade Transits the South China Sea?" *ChinaPower Project* (blog), August 2, 2017. https://chinapower.csis.org/much-trade-transits-south-china-sea/.

Elvidge, Christopher D., Mikhail Zhizhin, Kimberly Baugh, and Feng-Chi Hsu. "Automatic Boat Identification System for VIIRS Low Light Imaging Data." *Remote Sensing* 7, no. 3 (March 2015): 3020–36. https://doi.org/10.3390/rs70303020.

FAO, ed. *The State of World Fisheries and Aquaculture: Contributing to Food Security and Nutrition for All*. The State of World Fisheries and Aquaculture 2016. Rome, 2016.

Fridtjof Nansen Institute (FNI). "Fish, Not Oil, at the Heart of the South China Sea Conflict - Fni," 2017. https://www.fni.no/news/fish-not-oil-at-the-heart-of-the-south-china-sea-conflict-article1556-330.html.

Hongzhou, Zhang. "Beijing Has a Maritime Militia in the South China Sea. Sound Fishy?" South China Morning Post, March 3, 2019. https://www.scmp.com/week-asia/geopolitics/article/2188193/beijing-has-maritime-militia-south-china-sea-sound-fishy.

"ICS | Shipping Facts." Accessed December 12, 2019. http://www.ics-shipping.org/shipping-facts/shipping-facts.

"Limits of Oceans and Seas, 3rd edition" (PDF). International Hydrographic Organization. 1953. § 49. Retrieved 13 December 2019.

Kroodsma, David A., Juan Mayorga, Timothy Hochberg, Nathan A. Miller, Kristina Boerder, Francesco Ferretti, Alex Wilson, et al. "Tracking the Global Footprint of Fisheries." *Science* 359, no. 6378 (February 23, 2018): 904–8. https://doi.org/10.1126/science.aao5646.

Mahan, A. T. *The Influence of Sea Power upon History, 1660-1783*. New York: Dover Publications, 1987.

MarineBio. "Ocean Resources." Accessed December 12, 2019. https://marinebio.org/conservation/ocean-dumping/ocean-resources/.