Biological Conservation 225 (2018) 31–41

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

A micro-spatial analysis of opportunities for IUU fishing in 23 Western African countries

Gohar A. Petrossian

John Jay College of Criminal Justice, Department of Criminal Justice, 524 West 59th Street, Haaren Hall - 63107, New York, NY, 10019, The United States of America

1. Introduction

Illegal, unreported and unregulated (IUU) fishing is one of the biggest and most serious environmental crimes. Global fisheries lose an estimated 11–26 million tons, or roughly one-quarter of the world catch of fish to IUU fishing every year, making the annual economic loss about $11–24 billion (Agnew et al., 2009). This means 108,000 pounds (approximately 49 metric tons) of wild-caught fish are lost *every minute* to IUU fishing (Pew Charitable Trusts, 2013). Approximately three billion people depend on fish as a source of food and nutrition (FAO, 2016), and fish are the main source of protein for approximately one billion people worldwide (OECD, 2014). IUU fishing not only significantly impedes the development and sustainable management of the fisheries around the world, but it also severely undermines the global efforts to reduce malnutrition and hunger in developing countries. Considering that globally 94% of commercial fish are harvested within exclusive economic zones (EEZs) of coastal countries (SAUP, 2014), these economic losses directly impact these countries.

The Western African coast hosts some of the most fertile fishing grounds in the world (Ighobor, 2017). It encompasses the Canary and Benguela upwelling systems - the two ecosystems that maintain one of the world's most productive tuna fishing grounds (Daniels et al., 2016). This region is also among the regions in the world most affected by illegal fishing (Doumbouya et al., 2017): nearly 40% - the highest level worldwide, of all the fish caught in this region is illegal (Doumbouya et al., 2017; Agnew et al., 2009). In the European Union Strategy on the Gulf of Guinea, IUU fishing tops human, narcotics and arms trafficking, as one of the top threats in the region, having dominated EU's West Africa agenda since 2014 (Lewerenz and Vorrath, 2015).

By all measures, IUU fishing is a serious crime, however, criminological research on the topic remains relatively scarce. The criminological literature that does exist uses the framework of environmental criminology to empirically test the driving factors of IUU fishing. Petrossian (2015), in her study of 53 countries, found that IUU fishing within the EEZs of these countries is driven by the availability of highly commercial species, and the countries' relative proximity to known ports of convenience. Other studies examined the CRAVED[1] characteristics of commercial fish and crustacean species, and their vulnerability to IUU fishing (Petrossian and Clarke, 2014; Petrossian et al., 2015a), and found that the easily 'concealable', 'removable', 'abundant', as well as 'valuable' and 'enjoyable' species were significantly more likely to be targeted by IUU fishers than their matched controls. Lastly, two criminological studies specifically examined that ports of convenience facilitated IUU fishing by allowing 'concealability' of illegally caught fish that are laundered through these ports (Petrossian et al., 2015b; Marteache et al., 2015). None of these past studies, however, examined the driving factors and opportunity structures for IUU fishing in a micro-spatial context, which is the aim of the current study. Guided by the theoretical assumptions of environmental criminology, this research examines the relevance of micro-spatial predictors of IUU fishing in the exclusive economic zones of 23 Western African countries, and expects that the attributes of these locations, when combined in prescribed ways, create contexts in which certain outcomes are made more likely, and, as such, can predict the spatial preferences of likely motivated offenders.

1.1. Guiding theory: environmental criminology

In their seminal work, "Opportunity Makes the Thief", Felson and Clarke (1998) argued that crime opportunities are a necessary condition for a crime to occur, in other words, crime is largely a product of opportunity. They then laid out ten principles that formed the foundation for three 'opportunity' theories in criminology: the routine activity approach, the crime pattern theory, and the rational choice perspective, all of which belong to the family of theories known as environmental criminology. *The routine activity approach* suggests that for a crime to occur, there must be a convergence in time and space of three elements: a motivated offender, a suitable target, and the absence of a capable guardian (Cohen and Felson, 1979).

The crime pattern theory (Brantingham and Brantingham, 1993) considers how people move about in space and time. Movement from one area, or node, to another, creates an activity space for the offenders. According to the theory, crime happens when the activity space of a victim or target intersects with the activity space of an offender.

E-mail address: gpetrossian@jjay.cuny.edu.

[1] The CRAVED acronym was proposed by Clarke (1999) to explain the characteristics of products that make them attractive to thieves. The products that are easily concealable, removable, available, valuable, enjoyable and disposable are more likely to be stolen, according to this theft model.

https://doi.org/10.1016/j.biocon.2018.06.011
Received 16 January 2018; Received in revised form 18 May 2018; Accepted 11 June 2018

Importantly, they suggest that the journey to crime is typically very short - offenders generally don't travel far from these nodes and paths to commit crimes (also see Rossmo, 2000, for a discussion of the literature on this).

Lastly, *the rational choice approach* (Cornish and Clarke, 1987) assumes that offenders make rational decisions structured by the social, environmental and situational variables. Offenders prefer to commit crime in environments that provide high rewards, as well as minimal risk and effort.

It is important to note that the above-mentioned theories focus on explaining the *crime events* in the context of the immediate environment in which these events unfold (Wortley and Townsley, 2016). These theories focus on explaining the interaction between the motivated offender and the opportunities for crime commission created by the environment. As such, these theories focus on crime problems, rather than offenders' criminal dispositions that may lead them to commit a crime.

Environmental criminological theories have the following important five premises: (1) crime is always a choice; (2) opportunity plays a significant role in crime; (3) crime is highly concentrated (in time and space, among offenders and victims) where the opportunities are greatest; (4) all crime can be reduced if measures that reduce crime focus on reducing the opportunities for crime; (5) to be successful, any prevention measure should be tailored toward highly specific forms of crime and take into consideration the unique opportunity structures and facilitating conditions that assist the crime commission.

Consistent with the expectations outlined by these theories, we would expect to find significant concentrations of IUU fishing activities around the micro-environmental opportunity structures that not only reward such activity, but also facilitate easy removal and inconspicuous getaway, lowering the risk of apprehension and the consequent costs of engaging in such activity (Sumaila et al., 2006).

2. Materials and methods

2.1. Study area and units of analysis

This research examines IUU fishing activity within the exclusive economic zones of 23 countries in the Western African coast. The data available on the variables were at the ½ ° × ½ ° latitude and longitude grid cell level, therefore, the units of analysis in this study included a total of 2342 grid cells that were clipped to the exclusive economic zones of these 23 countries.

2.2. Data sources

This study uses a range of geographic and species-specific variables from various sources. This section provides an overview of these data sources and the variables they measure.

Source 1. Aquamaps.org provides data on the natural occurrences of known marine species around the world (Aquamaps, 2017). Using different algorithms and data sources, the species distribution data provided by Aquamaps.org take into consideration such environmental factors as temperature, salinity, water depth, and primary productivity, among others, to estimate the probabilities of a given species occurrence at a ½ ° × ½ ° latitude and longitude grid cell level. The data can be downloaded in a spreadsheet format and converted into an ArcGIS-compatible shapefile format to display the species-specific information on a map. This research uses Aquamaps.org species distributions data for 2016 for all the species used in the models (to be discussed later).

Source 2. The Sea Around Us Project (SAUP) is a scientific research initiative housed at the University of British Columbia. The goal of the project is to provide assessments on fisheries around the world, and their impact on the global marine ecosystems (SAUP, 2017). This research uses EEZ-specific data to identify the commercially harvested species within the EEZs of the 23 countries examined, and the commercial status of these species as of 2016 (which is listed as “commercial for local use”, “commercial for use elsewhere”, “highly commercial for local use”, etc.…). According to Petrossian (2015), countries are most vulnerable to IUU fishing if they have species that are highly commercial internationally. Upon a closer look at the species found within the EEZs of these 23 countries, this research identified a total of 22 such species that were not only commercially harvested species within individual countries in West Africa, but also “highly commercial for use elsewhere” (SAUP, 2017). These species were extracted for analyses in this study (see Appendix A for a list).

Source 3. In their study, Petrossian and Clarke (2014) used multiple data sources to identify species that were most frequently targeted by IUU fishers ($N = 58$) (henceforth, CRAVED species). They also used multiple sources to create risk scores for these CRAVED species. These species were significantly more likely to be caught illegally than their matched controls due to their CRAVED characteristics. The current research extracted a total of 20 species from this list that are commercially harvested in the 23 West African countries examined (not replicating the already identified 22 highly commercial species mentioned above). Some of these species were not highly commercial, however, they were included in the analyses, as it was their overall CRAVED status that distinguished these species from the other 22 highly commercial species identified earlier. Conversely, the highly commercial species initially identified that were also CRAVED species were treated as CRAVED species, as more information could have been obtained about these species (i.e. CRAVED information). Appendix B provides a list of these species, their risk scores, as well as the countries where they are commercially harvested.

Source 4. The Pew Environmental Group (2010) conducted a study examining the worldwide movements of blacklisted fishing vessels from January 2004 through December 2009. During the study period, the research recorded a total of 509 different movements, and these included 425 visits to 140 ports in 71 countries. Data on the number of IUU visits to the ports that are in Western Africa were extracted from the Pew (2010) study. In addition to the 19 Western African ports identified, this research uses two additional ports (Las Palmas de Gran Canaria and Santa Cruz de Tenerif), considering the relative importance of these ports in the region as hubs for transporting fish from Western Africa into Europe. According to past research (Petrossian, 2015; Petrossian et al., 2015b; Marteache et al., 2015), ports of convenience are significant magnets for carrying out and inconspicuously offloading illegal catch, therefore, data on these ports were collected for use in this study.

Source 5. National Geospatial Intelligence Agency (2017) provides data on over 3700 ports around the world. The data are available in a shapefile format and can be downloaded and displayed in ArcGIS. Port location information was obtained from this data source to map out the locations of the 21 ports of convenience (19 West African and 2 Spanish).

Source 6. Global Fishing Watch (GFW), an initiative sponsored by Google, Oceana and SkyTruth, uses open technologies to publicly broadcast Automatic Identification Signals (AIS), a tool that tracks vessel locations via satellites and ground-station receivers from fishing vessels around the world (Global Fishing Watch, 2016). The GFW uses a convolutional neutral network analysis method to extract fishing effort (by number of hours) by gear type and flag country, among other vital information to ensure transparency of the activities of the global fishing industry. The data are available at different resolutions. This research uses the 2016 fishing effort data provided at the ½ ° × ½ ° latitude and longitude grid cell level, as data on species distributions and their probabilities from Aquamaps.org were available at that level of resolution only. Data on the locations of global transshipment activities in 2016, were also provided by Global Fishing Watch (for more information on transshipment data, as well as the methodology of data collection, see Kroodsma et al., 2018).

Source 7. International Transport Workers' Federation is an international federation that represents over 16 million transport workers from 150 countries (ITF, 2017). The federation has created a list of Flags of Convenience (FOCs) countries for IUU fishing. The use of FOCs has been largely reported in the literature as one of the principal facilitators of IUU fishing that allows the vessel owners to elude fisheries management regulations and fish illegally without the fear of serious repercussions. The list of the FOC countries currently provided by the ITWF was used in the current study to extract information on the vessels flagged to these specific countries. Vessels flagged to a total of 12 FOC countries were identified to have fished in the 23 West African EEZs in 2016.[2]

2.3. Variables

Each of the variables in the current study was built using a specific method and weighted using different criteria. The methods of variable calculations are discussed below.

2.3.1. Independent variables

Proximity to a Viable Landing Point. Using the "NEAR" tool in ArcGIS, we calculated the distance of each of the 2342 grid cells to the nearest port of convenience (see Appendix C for a map of the 21 ports). This tool calculates the distance from each feature, in this case the centroid of each of the study grid cells to the nearest feature (i.e. the location of the port of convenience). The distance is calculated from Point A to Point B as shown in Fig. 1.

Once ArcGIS has identified the nearest port for each of the 2342 grid cells, we then assigned the number of times the port was visited by blacklisted vessels as identified in the Pew (2010) study to these grid cells as a weighting measure of risk. For example, if Port Tema (Ghana) was identified as the nearest port of convenience for grid cell X, the grid cell will be assigned a score of "11", which is the number of IUU visits that were recorded at Port Tema by the Pew (2010) study. Therefore, the higher this score for the grid cells, the higher the risk of this grid cell to IUU fishing, when keeping all other factors constant. This is because the grid cell's relative proximity to the IUU port affords 'concealability' (Petrossian et al., 2015b) to the catches made within that grid cell, which can potentially be offloaded at this nearest "viable landing point".

Proximity to a Viable Exit Point. Using the "NEAR" tool in ArcGIS, the distance from each of the 2342 grid cells and the locations of the nearest transshipment activity (in 2016) was calculated to measure the variable "proximity to a viable exit point". It is assumed that the shorter this distance, the more IUU activity is likely to happen in that grid cell, because, based on the theoretical assumptions of the crime pattern theory, offenders are likely to travel short distances to carry out their illegal activities.

Presence of 'Suitable Targets'. To measure this variable, we first began by identifying the CRAVED species (Petrossian and Clarke, 2014) that are harvested commercially in the EEZs of the 23 West African countries. We then used the SAUP website to ensure that the selected species were actually harvested commercially in each of the 23 countries. We identified a total of 20 CRAVED species. We repeated the same procedure to identify species that are highly commercial internationally. With this step, we identified additional 22 species. Once these 42 species were identified, we downloaded the species distribution data from Aquamaps.org and geocoded the data for each species to be displayed in a shapefile format in ArcGIS. To measure the variable "presence of suitable targets", we calculated the total number of each of these species within each of the 2342 grid cells.

Abundance and Value of 'Suitable Targets'. This variable was measured by creating three different measures.

[2] Belize, Cambodia, Comoros, Cyprus, Malta, Marshall Islands, Mauritius, Panama, St Vincent & the Grenadines, Vanuatu, Faroe Islands, Korea.

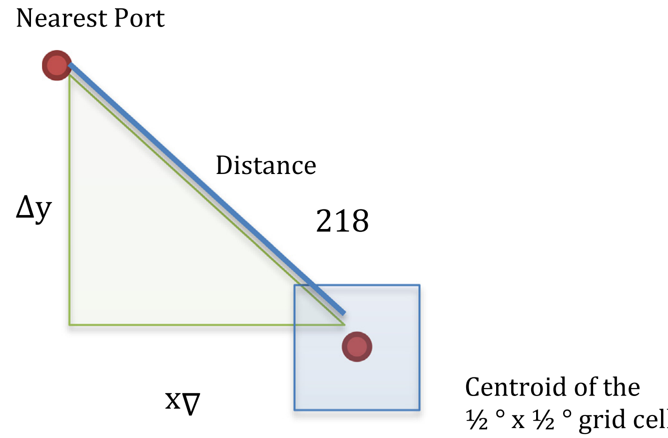


Fig. 1. Calculation of the distance between two features.

a. For each of the 20 CRAVED species, we examined the risk scores assigned by Petrossian and Clarke (2014), as well as the probability of occurrence of these species within the grid cells. We then weighted the grid cells for these CRAVED species by their risk score and the probability of occurrence. For example, Petrossian and Clarke (2014) assigned a risk score of "9" to Yellowfin tuna (*Thunnus albacares*). If in grid cell *X* the probability of occurrence of the species was 0.50, then the assigned weighted score for that grid cell (pertaining to this particular species) was 4.5 ($9 * 0.50$). Similarly, if in grid cell *Y* the species probability was 0.75, the assigned weighted score was 6.75. Once these weighted probabilities were calculated for all 20 CRAVED species, we created a cumulative weighted score to represent the overall risk of the grid cell to IUU fishing based on the (weighted) presence of these CRAVED species within it.
b. For each of the 22 highly commercial species, the probabilities of occurrence were used to weigh the cells. The cumulative score was then calculated for each of the grid cells using the weighted probabilities. These two measures above were used to operationalize the *abundance* of the 'suitable targets'.
c. The median length of all the combined CRAVED and highly commercial species found within each cell was also calculated to measure the *value* of the 'suitable targets' (similar to Petrossian and Clarke (2014)).

2.3.2. Dependent variable

IUU Fishing. This research examined the total fishing hours spent within the EEZs of the 23 Western African countries by vessels flagged to FOC states. A total of 12 FOC-flagged vessel countries were identified to have recorded fishing activity in 2016. We used the data on the total fishing hours by these FOC states spent within each of the 2342 grid cells to measure the dependent variable "IUU fishing".

2.4. Hypotheses

Table 1 summarizes the list of hypotheses, how the variables in each hypothesis were measured, and the justification for inclusion of each of these variables in the models.

2.5. Pre-analysis diagnostics

Preliminary analyses revealed three potential problems that needed to be addressed before building the final models. These included the following:

1. The variables measuring abundance and value of 'suitable targets' were highly correlated (correlations were above .70 and significant at $p < .01$).

Table 1
Hypotheses and variables used in final models.

What creates the opportunity to offend?	How is it measured?	Hypotheses
Proximity to a viable exit point	Distance to nearest transshipment activity	Grid cells closest to transshipment activity are more likely to have IUU fishing activity
Proximity to a viable landing point	Distance to nearest illegal fish landing port (weighted by the visits to the port by illegal fishing vessels to account for 'risk')	Grid cells closest to illegal fish landing ports are more likely to have IUU fishing activity
Presence and abundance of valuable 'suitable targets'	Presence and abundance of (1) CRAVED fish (2) highly commercial species	Highest concentrations of IUU fishing activity are likely to be in grid cells where there is a greater presence and more abundance of valuable 'suitable targets'

2. A Moran's I test revealed statistically significant spatial autocorrelation for the dependent variable (Moran's $I = 0.11$, $z = 8.9$, $p < .01$).

To address these problems:

1. The highly correlated independent variables were factored into a new variable (see Appendix D for factor analysis results).
2. A spatial lag variable was created in GeoDa for the dependent variable and used in the model as a control. The variable was computed using the K-nearest neighbor method as the distance weight.

3. Results

3.1. Examining concentrations of environmental opportunity structures and IUU fishing activity

This research constructed a composite IUU risk score for each grid cell that derives from the combinations of all the independent variables that were constructed using a total of 44 shapefile layers (42 species weighted layers, one layer indicating weights for distance to known ports of convenience, and one layer indicating the weighted distance to known transshipping locations). The composite risk score was calculated by adding the scores for the independent variables "proximity to a viable landing port", "presence of 'suitable targets'", "abundance and value of 'suitable targets'", and subtracting the score "proximity to a viable exit point" (assumptions for the latter is an inverse relationships: the shorter the distance to these locations the higher the risk of the grid cell). Fig. 2 shows the distributions of the composite IUU risk score in the 2342 grid cells that fall within the EEZs of the 23 Western African countries.

The map shows grid cells with high and low concentrations of the risk to IUU fishing. A large proportion of the EEZs of Morocco, Cape Verde, Senegal, Gambia, Guinea Bissau and Guinea, in the north, and Nigeria, Angola and South Africa, in the south, are at the highest risk to IUU fishing due to not only the presence, as well as abundance and value of highly commercial and known CRAVED fish species within their waters, but also their relative proximity to known ports of convenience and transshipment locations (see Appendix E for a map of transshipment activity carried out in 2016). To further examine whether fishing activity in 2016 clustered around these high-risk areas, we built Fig. 3.

A total of 1343 grid cells (57.3%) recorded fishing activity by FOC-flagged vessels in 2016, and these vessels collectively spent a total of 585,502 h within the EEZs of the 23 Western African countries. About 96% of the total fishing hours were spent in 367 grid cells, which account for 27.3% of all the grid cells that had fishing activity recorded. This reveals significant concentrations of IUU fishing activity within the region.

3.2. Predicting concentrations of IUU fishing activity

To examine whether the significant concentrations of IUU fishing activity are driven by the environmental opportunity structures, we built a Poisson Regression model.[3] The results are shown in Table 2.

The results of the regression analysis revealed interesting patterns. IUU fishing activity was concentrated in areas where the valuable 'suitable targets' are both present and abundant, and near known ports of convenience. The presence of known CRAVED and highly commercial fish within the grid cell increased the likelihood of IUU fishing activity by 61%, while the grid cells with more abundant and valuable fish species had 26% higher chance of IUU fishing activity, when holding all other variables constant. Additionally, the grid cells that are in close proximity to known ports of convenience (i.e. viable landing points) were 3.45 times more likely to have IUU fishing than those farther away, while holding all other predictors constant. Lastly, the significant spatial lag indicates that IUU fishing activity in grid cells is significantly clustered and happens near grid cells with other IUU fishing activity, statistically substantiating the descriptive results discussed earlier. The proximity of grid cells to recorded transshipping activity in 2016 did not have a significant impact, albeit, the beta score revealed the relationship in the expected direction. The overall model predicts 16% of the variance in the dependent variable.

4. Discussion

4.1. Summary of findings

This research examined the spatial preferences of motivated offenders for IUU fishing. Drawing from three theories of environmental criminology, namely the routine activity, rational choice and crime pattern theories, this study aimed at empirically testing the importance of micro-spatial opportunity structures within the environment, and understanding how these opportunities shape offender decisions to engage in IUU fishing.

The findings in this study endorse the relevance and importance of drawing upon environmental criminological theories to study IUU fishing, and have conclusions similar to past empirical reach that used the same theories as a guiding framework. This research found that illegal fish landing ports and the presence, as well as the abundance of commercially significant and CRAVED fish, were important micro-spatial risk factors that attract IUU fishing. These facilitating conditions collectively increase the likely offenders' perceptions of potential reward, and reduce their fear of being caught. The decision about the location where their illegal catch can be offloaded is consistent with the assumptions of previous criminological research that has found that criminals don't travel far to fence or handle stolen goods (e.g. LaVigne

[3] This model was deemed most appropriate given the characteristics of the dependent variable: 42.7% of the grid cells had no fishing activity by FOC-flagged vessels recorded in 2016. Additionally, considering the dependent variable is a 'count' variable (i.e. measures the number of hours spent within the grid cell), it is necessary to run a generalized linear model.

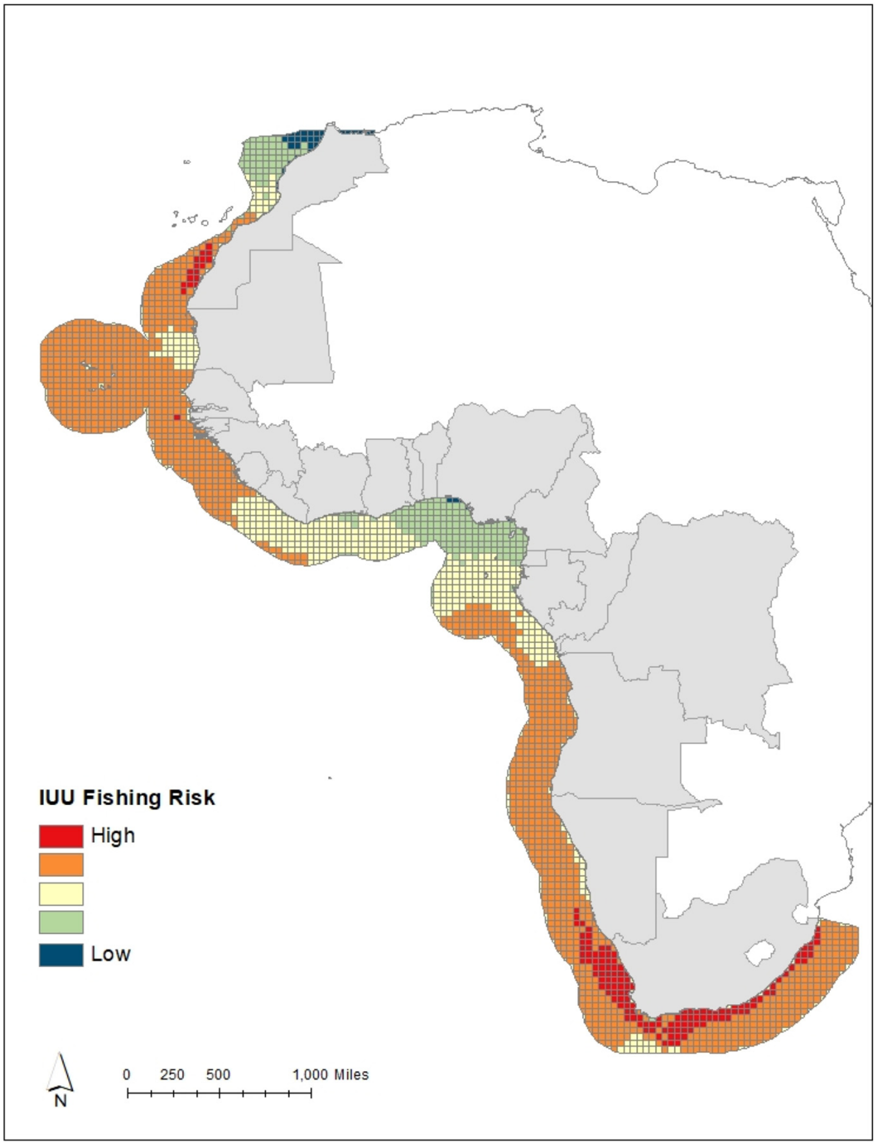


Fig. 2. Composite risk of grid cells to IUU fishing.

et al., 2000; Lu, 2003). With these predictors influencing illegal fishers' decisions, one can assume that they, like other offenders, seem to operate in accordance with the least effort principle: they go where opportunity is (i.e. where the likelihood of finding the valuable 'suitable targets' is highest), and where they can easily offload their catch without the fear of being caught. These findings not only confirm earlier empirical work on the role of the places that supply motivated illegal fishers with criminal opportunities to fish (Petrossian, 2015), and to offload their illegal catches (Petrossian et al., 2015a; Marteache et al., 2015), but also do so in a micro-spatial context, thus filling a significant gap in the literature on the topic. It is important to note that the environmental attributes proposed in this research do not create crime, but rather point to locations where, if the conditions are right, the risk of IUU fishing is much higher. In other words, conditions for criminal behavior in these places are better than in others, and, importantly, as discovered in this study, these conditions are not randomly dispersed, but rather significantly concentrated in specific environments.

4.2. Study limitations

Like many studies, this research has limitations, and, the most important of these being the measure of "IUU fishing". There is significant lack of information on the activities of actual locations of IUU fishing vessels around the world. While different estimates have been used in the past to calculate these activities (e.g. Agnew et al., 2009; Watson, 2017), the data cannot, with any degree of certainty, point to the actual micro-spatial locations of such activity. In fact, it is almost impossible to get reliable data on IUU fishing activity per se. This can be due to many factors, among which are the lack of a unified database on IUU fishing, and the likelihood of gross under-estimation of the scale of the problem even if such data were available (due to detection and spatial variation errors (Lemieux et al. (2014)), to name a few reasons. This research, therefore operationalized the variable "IUU fishing" by using the fishing activity of the vessels flagged to known flags of convenience countries as a proxy measure, assuming, that if a vessel is flagged to such a country, it has already shown a disposition to infringe upon international regulations (Gianni and Simpson, 2005), including the willingness to not comply with fisheries regulations of the 23 Western African countries examined. Literature suggests that using FOCs is a common practice among IUU fishing vessel owners. Operating under a FOC allows these vessels to maintain anonymity of ownership (Liddick, 2014), while openly flaunting labor, ship maintenance, environmental and other regulations (Hamad, 2015; Gianni, 2008), as

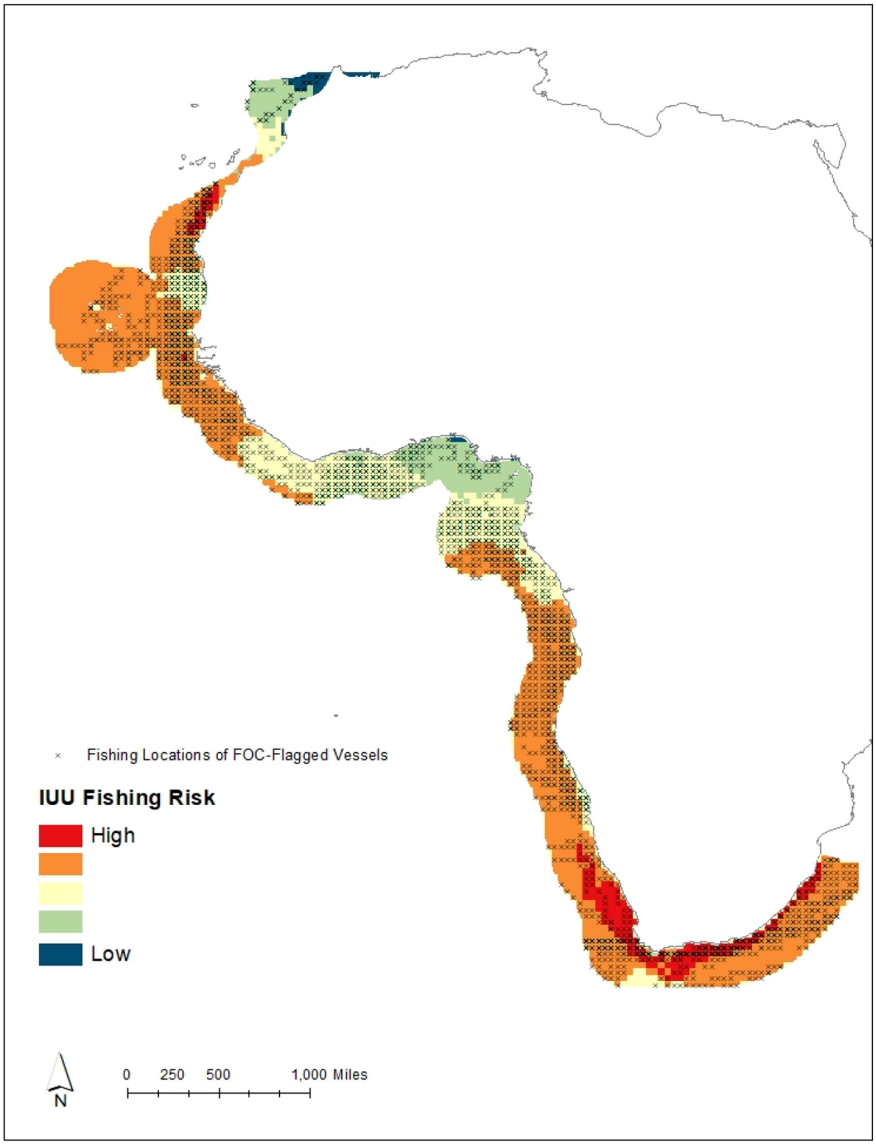


Fig. 3. Fishing activity by FOC-flagged vessels in 2016.

Table 2
Poisson regression results on the activity of FOC-flagged vessels in the EEZs of 23 west African countries.

	B	(SE)	Sig.	IRR	95% CI	
Proximity to a viable exit point	−0.000	0.000	*ns*	0.999	−0.000	0.000
Resource presence	0.051	0.001	0.000	1.05	0.051	0.052
Resource abundance and value	0.268	0.001	0.000	1.308	0.267	0.270
Proximity to a viable landing point	0.052	0.003	0.000	1.053	0.051	0.052
Spatial lag	0.002	0.000	0.000	1.000	0.000	0.000
Constant	4.257	0.005	0.000			
Pseudo R^2	0.161					
N	2342					

well as engaging in other types of maritime crimes, including maritime terrorism and weapons-trafficking (Hamad, 2015).

Another limitation is the somewhat dated information on illegal fish landing ports (Pew Environment Group, 2010) and CRAVED species (Petrossian and Clarke, 2014). However, the significant findings on the impact of these variables on the decision of illegal fishers speak to the relevance of these ports and these species today, regardless of the dates these ports and species were originally ‘discovered’.

It is likely that some of the data pertaining to fishing activity, transshipments and port visits by illegal fishing vessels are missing the actual number of such activities, with one reason being the vessels' common practice of turning off AIS transmitters to avoid detection of their movements (Hayes, 2015). The fishing and transshipment data, however, were based on the analysis of billions of AIS positions (Kroodsma et al., 2018). However, while it is likely that the information that has been captured through the Global Fishing database is representative of the general patterns of such activities, systematic errors in the data cannot be excluded.

Lastly, we used the ArcGIS ‘Near’ tool to calculate a point-to-point distance between the centroids of a grid cell and the ports. The actual distances might likely be slightly different from what ArcGIS produces, especially if a coast is convoluted. However, the purpose of the calculation was to identify the ports nearest to the given centroid, and given the ports are distributed relatively far from each other, it is unlikely that ArcGIS identified the wrong ‘near’ ports because of this likely minor margin of error in its calculation of the distance. Additionally, this variable was used to identify the location of each of these grid cells relative to the nearby ports, and not necessarily pinpoint the actual routes a vessel is likely to take to go from anywhere within that grid cell to the nearest port.

4.3. Policy implications

Resources are limited, inspectors can't inspect everything all the time, and police cannot patrol everywhere. It is, therefore, important to use the available resources as effectively as possible. To achieve maximum return for effort made, to maximize the probability of catching illegal fishers in action, as well as to discourage future illegal fishing activity, the following prevention strategies are proposed, all of which derive from the techniques of situational crime prevention (Clarke, 1980), and take into account the distribution of risk for IUU fishing within the study area. The techniques of situational crime prevention, which fall under five headings (increase the risk, increase the effort, reduce the reward, reduce the provocations, remove excuses) are grounded in the assumptions of the environmental criminological theories discussed earlier, and offer problem-solving tools to deal with any given crime. These strategies have undergone empirical testing in over 250 criminological studies, and systematically prove to be effective crime reduction methods. Thus, the following situational crime prevention strategies are proposed to deal with IUU fishing in Western Africa:

- Increase the effort by:
  - *Hardening targets* via the implementation of more stringent licensing, import/export requirements on known CRAVED and highly commercial species ($N = 42$) found in the waters of the 23 Western African countries. Not all of these species are found within the EEZs of each of the countries examined, therefore, these requirements can be implemented by each of these countries based on the presence, as well as the risk scores of the known CRAVED species found within their waters.
  - *Screening the known ports of convenience* ($N = 21$) by increasing the rigor of inspections at these ports. Not all Western African countries have such ports, and of those that do, the risk of offloading IUU catches at these ports is variable. With limited resources, regional efforts could, therefore, be placed on assisting the countries with highest risk ports with their efforts in improving inspections of landings made at these ports.
- Increase the risk by:
  - *Increasing inspections in the specific areas* known to have high concentrations of known CRAVED and highly commercial species, i.e. hot spots of 'suitable targets'. Each of the Western African countries can take a closer look at how many of these species are found within their waters, where the highest concentrations of these species are found, and, consequently, make decisions on where they should deploy their limited patrol efforts.

4.4. Considerations on displacement and diffusion of crime control benefits

While it is suggested that strengthening surveillance capacity in the identified high-crime risk areas will likely result in significant reductions of illegal fishing activities, one may argue that offenders will resort to spatial displacement by carrying out their illegal operations elsewhere. Moreover, placing stringent licensing requirements on the identified highly commercial and CRAVED species may lead to these species being replaced by others, and increasing inspections at known ports of convenience would lead to the emergence of new such ports. While displacement cannot be completely ruled out and should, in fact, be evaluated for any situational intervention program designed to address illegal fishing, a large body of criminological research suggests that the chances for this to happen are relatively low (see Guerette and Bowers, 2009, for their evaluation of displacement in 102 situationally-focused crime-prevention initiatives). Therefore, with some degree of confidence we can assert that it is less likely for geographic displacement to take place, because the opportunities afforded to the illegal fishers in the identified high crime-risk areas are significantly lower in other areas, and it will simply be less beneficial to fish in places that will yield significantly lower returns for the effort made. Similarly, target displacement is not likely to happen, as it is highly unlikely that these highly commercial and CRAVED species are easily *replaceable* by less valuable species that are less desirable in international markets. Also, vessel operators will have to make significant modifications to the gear and vessels used, as the fish are generally caught with specific gear and vessels. Lastly, imposing strong controls on known ports of convenience would not necessarily lead to the emergence of new ports of convenience. There is a reason why these ports attract illegal fish landings, and these reasons have been empirically revealed by Petrossian et al. (2015b) and Marteache et al. (2015), with 'concealability' and 'lax regulations and controls' being among some important predictors.

In fact, increasing patrol surveillance in these high-risk areas, controls over highly commercial species, as well as inspection of known ports of convenience, is likely to result in diffusion of crime control benefits (Clarke and Weisburd, 1994; Guerette and Bowers, 2009). For example, instances of human trafficking and migrant smuggling by using fishing vessels are widespread across the globe. These have been well-recorded by a study conducted by the United Nations Office on Drugs and Crime (de Coning, 2011), which found that while fishers may not be directly engaged in organized trafficking or smuggling activities, they accept bribes for smuggling migrants from developing countries to Europe and the United States. Additionally, the same study found that the use of fishing vessels in the illicit traffic of cocaine, heroin, cannabis, and amphetamine-type stimulants, is also widespread. Consequently, increasing patrol surveillance will not only deter the fishing vessel operators from engaging in IUU fishing, but it will also discourage them from engaging in other illegal activities. Lastly, strengthening port controls and security will have beneficial impacts on reducing the smuggling of illegal products transported via sea.

5. Conclusion

Illegal fishing is a significant global problem, affecting the marine ecosystem and disrupting the livelihoods of millions of people who depend on fishing for survival. This problem is especially pronounced in Western Africa, often referred to as the hotbed of illegal fishing. Opportunity plays a key role in fishing vessels' decisions to engage in illegal fishing. These vessels are likely to visit areas that facilitate easy entry into the fishing grounds and an inconspicuous exit into a port that allows easy disposal of the catch and lower chances of detection. Thinking about the problem of illegal fishing through criminological lens will allow us to better understand the issue, devise theoretically relevant and empirically sound research, and offer policy-relevant crime prevention interventions. Criminologists are trained to "think thief" (Ekblom, 2005), therefore, applying criminological thinking to the problem of IUU fishing, conducting rigorous, data-driven research will lead to devising useful response strategies that ensure prevention and protection of marine resources.

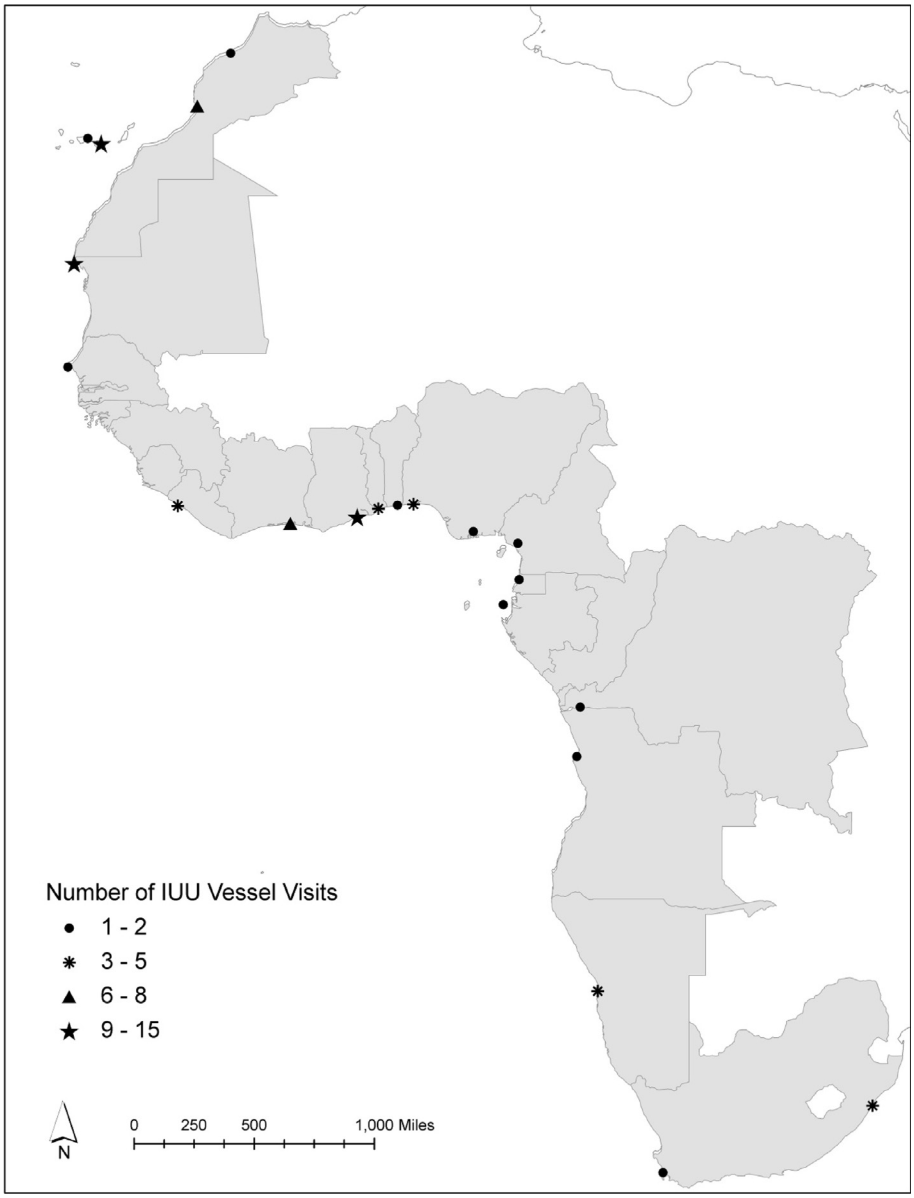
Appendix A. List of 22 commercially harvested species found in the exclusive economic zones of 23 Western African countries and are highly commercial for use elsewhere

Common name	Latin name	Country where species is commercially harvested
European anchovy	*Engraulis encrasicolus*	Ghana, Morocco, Namibia, Togo
Bogue	*Boops boops*	Mauritania, Morocco
South American pilchard	*Sardinops sagax*	Namibia, South Africa
Whitehead's round herring	*Etrumeus whiteheadi*	Namibia, South Africa
Bigeye grunt	*Brachydeuterus auritus*	Cote D'Ivoire, Mauritania, Senegal
Bonga shad	*Ethmalosa fimbriata*	Benin, Cameroon, Cote D'Ivoire, Gabon, Gambia, Ghana, Guinea, Nigeria, Senegal, Sierra Leone
Royal threadfin	*Pentanemus quinquarius*	Cameroon, Guinea, Sierra Leone
Round sardinella	*Sardinella aurita*	Angola, Cote D'Ivoire, Senegal, Sierra Leone
Madeiran sardinella	*Sardinella maderensis*	Benin, Cote D'Ivoire, Senegal, Sierra Leone
Cape horse mackerel	*Trachurus capensis*	Namibia, South Africa
Common sole	*Solea solea*	Morocco
Cunene horse mackerel	*Trachurus trecae*	Angola
Bullet tuna	*Auxis rochei*	Mauritania, South Africa
Flathead grey mullet	*Mugil cephalus*	Angola, South Africa
Atlantic bonito	*Sarda sarda*	Morocco
Frigate tuna	*Auxis thazard*	Mauritania, South Africa
Deep-water Cape hake	*Merluccius paradoxus*	Namibia, South Africa
Bluefish	*Pomatomus saltatrix*	Senegal, South Africa
Snoek	*Thyrsites atun*	Namibia, South Africa
Largehead hairtail	*Trichiurus lepturus*	Morocco
Dusky grouper	*Epinephelus marginatus*	South Africa
Tope shark	*Galeorhinus galeus*	South Africa

Appendix B. List and risk scores of 20 CRAVED fish found in the exclusive economic zones of 23 Western African countries

Common name	Latin name	Risk score	Country where species is commercially harvested
Orange roughy	*Hoplostethus atlanticus*	11	All
Atlantic bluefin tuna	*Thunnus thynnus*	11	All
Swordfish	*Xiphias gladius*	10	All
Albacore tuna	*Thunnus alalunga*	9	All
Yellowfin tuna	*Thunnus albacares*	9	All
Bigeye tuna	*Thunnus obesus*	9	All
Skipjack tuna	*Katsuwonus pelamis*	6	All
Southern bluefin tuna	*Thunnus maccoyii*	6	Namibia, South Africa
Anglerfish	*Lophius piscatorius*	5	Morocco
Piked dogfish	*Squalus acanthias*	5	All
Striped marlin	*Tetrapturus audax*	5	South Africa
Common dolphinfish	*Coryphaena hippurus*	4	All
Striped marlin	*Makaira nigricans*	3	All, except South Africa
European hake	*Merluccius merluccius*	3	Morocco, Mauritania
Shortbill spearfish	*Tetrapturus angustirostris*	3	South Africa
Porbeagle shark	*Lamna nasus*	2	Morocco, Mauritania, Angola, Namibia, South Africa
Silver scabbardfish	*Lepidopus caudatus*	2	Morocco, Mauritania, Angola, Namibia, South Africa
Black marlin	*Makaira indica*	2	South Africa
Cape hake	*Merliccius capensis*	2	Namibia, South Africa
European pilchard	*Sardina pilchardus*	2	Morocco, Mauritania, Cape Verde, Senegal

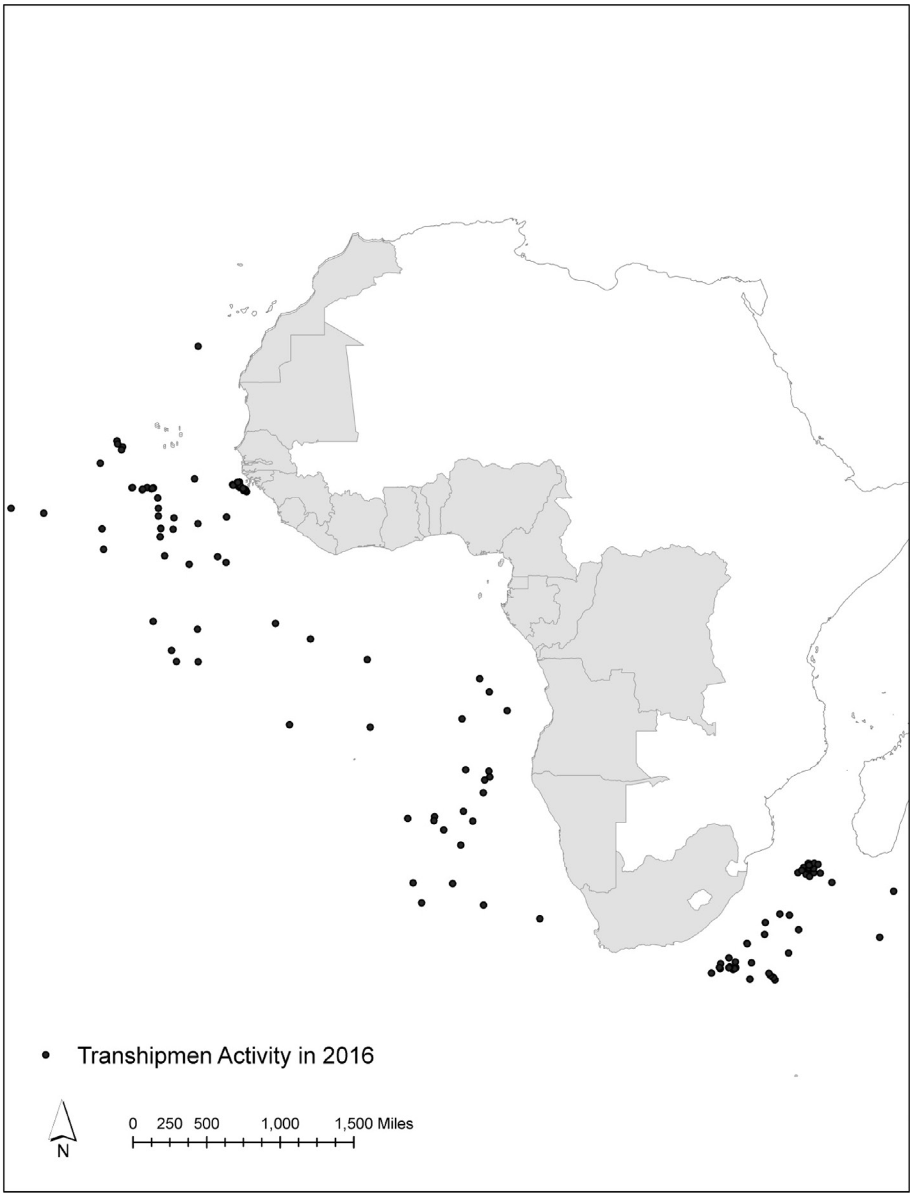
Appendix C. The location of ports of convenience and the number of visits by blacklisted vessels to these ports during 2004–2009



Appendix D. Principal components analysis

Factor	Items	Factor loadings	Communality
Resource abundance and value	Cum_Wrisk_iuu	0.36	0.13
	Avg_Lngth	0.95	0.91
	Cum_HG_Wgh	0.96	0.93
	Kaiser-Meyer-Olkin = 0.51		
	Bartlett's test = 3963.63, p < .01		
	Eigenvalue = 1.97% Variance = 65.53		

Appendix E. The locations of transshipment activity in 2016 near the 23 Western African countries



References

Agnew, D.J., Pearce, J., Pramod, G., Peatman, T., Watson, R., Beddington, J.R., Pitcher, T.J., 2009. Estimating the worldwide extent of illegal fishing. PlosOne 4 (2), e4570.

Aquamaps.org, 2017. About. Available at. http://aquamaps.org/main/FB_Book_KReyes_AquaMaps_JG_CG_22Feb16_KR_online.pdf#page=1.

Brantingham, P.L., Brantingham, P.L., 1993. Environment, routine and situation: toward a pattern theory of crime. Adv. Criminol. Theory 5 (2), 259–294.

Clarke, R.V.G., 1980. Situational crime prevention. Theory and practice. Br. J. Criminol. 20 (2), 136–147.

Clarke, R.V.G., 1999. Hot Products: Understanding, Anticipating and Reducing Demand for Stolen Goods. Police Research Series (Paper 112: Home Office).

Clarke, R.V., Weisburd, D., 1994. Diffusion of crime control benefits: observations on the reverse of displacement. Crime Prevention Studies 2, 165–184.

Cohen, L.E., Felson, M., 1979. Social change and crime rate trends: a routine activity approach. Am. Sociol. Rev. 588–608.

Cornish, D.B., Clarke, R.V., 1987. Understanding crime displacement: an application of rational choice theory. Criminology 25 (4), 933–948.

Daniels, A., Gutiérrez, M., Ganjul, G., Guereña, A., Matheson, I., Watkins, K., 2016. Western Africa's missing fish: the impacts of illegal, unreported and unregulated fishing and under-reporting catches by foreign fleets. In: Overseas Development Institute, Available at. https://www.odi.org/sites/odi.org.uk/files/resource-documents/10665.pdf.

de Coning, E., 2011. Transnational Organized Crime in the Fishing Industry: Focus On: Trafficking in Persons, Smuggling of Migrants, Illicit Drugs Trafficking. United Nations Office on Drugs and Crime (UNODC).

Doumbouya, A., Camara, O.T., Mamie, J., Intchama, J.F., Jarra, A., Ceesay, S., Guèye, A., Ndiaye, D., Beibou, E., Padilla, A., Belhabib, D., 2017. Assessing the effectiveness of monitoring, control and surveillance of illegal fishing: the case of West Africa. Front. Mar. Sci. 4, 1–10.

Ekblom, P., 2005. How to police the future: scanning for scientific and technological innovations which generate potential threats and opportunities in crime, policing and crime reduction. In: Crime Science: New Approaches to Preventing and Detecting Crime. Willan Publishing Ltd., pp. 27–55.

FAO, 2016. The State of the World Fisheries and Aquaculture. FAO, Rome.

Felson, M., Clarke, R.V., 1998. Opportunity Makes the Thief. Police Research Series, Paper, 98.
Gianni, M., 2008. Real and present danger: flag state failure and maritime security and safety. Available at. http://assets.panda.org/downloads/flag_state_performance.pdf.
Gianni, M., Simpson, W., 2005. The Changing Nature of High Seas Fishing: How Flags of Convenience Provide Cover for Illegal, Unreported and Unregulated Fishing.
Global Fishing Watch, 2016. About us. Available at. http://globalfishingwatch.org.
Guerette, R.T., Bowers, K.J., 2009. Assessing the extent of crime displacement and diffusion of benefits: a review of situational crime prevention evaluations. Criminology 47 (4), 1331–1368.
Hamad, H.B., 2015. Corporate social responsibility (CSR) in the shipping industry: a disturbing mechanism between maritime security needs and seafarers' welfare. In: Studies of Organisational Management & Sustainability. 3(1). pp. 1–13.
Hayes, G., 2015. Manipulating AIS, part 2. Mar. Electron. J Available at. https://www.marineelectronicsjournal.com/content/newsm/news.asp?show=VIEW&a=120.
Ighobor, K., 2017. African waters are powerful magnets for illegal and unregulated foreign fishing operations. In: Africa Renewal Online, Available at. http://www.un.org/africarenewal/magazine/may-july-2017/overfishing-destroying-livelihoods.
International Transport Workers' Federation, 2017. About ITF. Available at. http://www.itfglobal.org/en/about-itf/.
Kroodsma, D., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A., Bergman, B., White, T.D., Block, B.A., Woods, P., Sullivan, B., Costello, C., Worm, B., 2018. Tracking the global footprint of fisheries. Science 359, 904–908.
LaVigne, N., Fleury, J., Szakas, K., 2000. Auto theft and detecting chop shop locations. In: Turnbull, L.S., Hendix, E.H., Dent, B.D. (Eds.), Atlas of Crime: Mapping the Criminal Landscape. Oryx, Phoenix, AZ, pp. 60–67.
Lemieux, A.M., Bernasco, W., Rwetsiba, A., Guma, N., Driciru, M., Kulu Kirya, H., 2014. Tracking poachers in Uganda. In: Lemieux, A. (Ed.), Situational Prevention of Poaching. Routledge, London, pp. 102–119.
Lewerenz, C., Vorrath, J., 2015. Illegal fishing and maritime security: toward a land- and sea-based response to threats in West Africa. In: SWC Comments. German Institute for International and Security Affairs January, 2015. Available at. https://www.swp-berlin.org/fileadmin/contents/products/comments/2015C02_LewerenzVrr.pdf.
Liddick, D., 2014. The dimensions of a transnational crime problem: the case of IUU fishing. In: Trends in Organized Crime. 17(4). pp. 290–312.
Lu, Y., 2003. Getting was with the stolen vehicle: an investigation of journey-after-crime. Prof. Geogr. 55, 422–433.
Marteache, N., Viollaz, J., Petrossian, G.A., 2015. Factors influencing the choice of a safe haven for offloading illegally caught fish: a comparative analysis of developed and developing economies. Crim. Sci. 4 (1), 32.
National Geospatial Intelligence Agency, 2017. About NGA. Available at. https://www.nga.mil/About/Pages/Default.aspx.
OECD, 2014. Fishing for development: background paper for session 4. The challenge of combatting illegal, unreported and unregulated (IUU) fishing. Available at. https://www.oecd.org/tad/events/Fishing-for-development-2014-Session-4-IUU.pdf.
Petrossian, G.A., 2015. Preventing illegal, unreported and unregulated (IUU) fishing: a situational approach. Biol. Conserv. 189, 39–48.
Petrossian, G.A., Clarke, R.V., 2014. Explaining and controlling illegal commercial fishing: an application of the CRAVED theft model. Br. J. Criminol. 54 (1), 73–90.
Petrossian, G., Weis, J.S., Pires, S.F., 2015a. Factors affecting crab and lobster species subject to IUU fishing. Ocean Coast. Manag. 106, 29–34.
Petrossian, G.A., Marteache, N., Viollaz, J., 2015b. Where do "undocumented" fish land? An empirical assessment of port characteristics for IUU fishing. Eur. J. Crim. Pol. Res. 21 (3), 337–351.
Pew Charitable Trusts, 2013. How to End Illegal Fishing. PEW December 10, 2013. Available at. http://pewenvironment.org/news-room/reports/how-to-end-illegal-fishing-85899522612.
Pew Environment Group, The, 2010. Port state performance report: Putting illegal, unreported and unregulated fishing on the radar. Available at. http://www.pewtrusts.org/~/media/post-launch-images/2015/04/2015_april_pew_port-state-performance–putting-iuu-on-radar(1).pdf.
Rossmo, K., 2000. Geographic Profiling. CRC Press, Boca Raton, FL.
SAUP, 2014. Catches by taxon in the global ocean: percent of catch in EEZs vs high seas. Available at. http://www.seaaroundus.org/data/#/global?chart=catch-chart&dimension=taxon&measure=tonnage&limit=10.
SAUP, 2017. About. The sea around us project. Available at. http://www.seaaroundus.org.
Sumaila, U.R., Alder, J., Keith, H., 2006. Global scope and economics of illegal fishing. Mar. Policy 30, 696–703.
Watson, R.A., 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. Sci. Data 4.
Wortley, R.K., Townsley, M. (Eds.), 2016. Environmental Criminology and Crime Analysis. Vol. 18 Taylor & Francis.