Tuna and transshipment: a global analysis to explore the links between tuna diversity and transshipment vessel location

By

Claire Christie

Submitted in partial fulfillment of the requirements

for the degree of

Environmental Science and Environmental Sustainability and Society

At

Dalhousie University

Halifax, Nova Scotia

DALHOUSIE UNIVERSITY

AUTHOR: Claire Christie DATE: April 17th, 2017

TITLE: Tuna and transshipment: a global analysis to explore the links between tuna diversity and transshipment vessel location

DEPARTMENT OR SCHOOL: College of Sustainability

DEGREE: Bachelor of Arts Convocation: May, 2018

Environmental Science and Environment, Sustainability and Society

Claire Christie ________ Signature of Author

Abstract

Transshipment at sea is a practice where refrigerated cargo vessels, also known as reefers, meet with fishing boats to exchange catch, fresh water, food and crew. Transshipment makes economic sense as it greatly extends the time a vessel can spend at sea fishing. However, it compromises the transparency pertaining to environmental and social sustainability within the seafood industry as catch, both legal and illegal, from several fishing vessels are mixed onboard the reefer. Hence, transshipment often participates and services illegal, unregulated and unreported (IUU) fishing, which is detrimental to the sustainability of globally traded fish stocks, such as tuna. Currently six out of the seven main tuna species stocks are fully fished or overfished, making tuna more vulnerable to IUU fishing activities. This study aims to connect transshipment vessels and distribution patterns of seven tuna species by correlating tuna distribution and spawning grounds with reefer activity. Satellite-based Automatic Identification System (S-AIS) data was used to track transshipment vessels, and published data on the distribution of tuna was used to map tuna presence, spawning areas, and diversity. Tuna and reefer patterns were tested for correlations on a global scale. No correlation between tuna diversity and reefer presence was found, however reefer presence was higher in regions with high levels of documented IUU fishing. Lack of transparency due to transshipment effects the monitoring process of stocks, which are already under high fishing pressure and could result in a collapse of fish populations without proper management. Improved traceability of fish processed by reefer vessels would be an important step toward increased sustainability.

Table of Contents

Chapter 1: Introduction 6
1.1 Statement of the Problem 6
1.2 Research Question and Purpose 8
Chapter 2: Literature Review 9
2.1 Tuna Distribution and Migration 9
2.2 Flags of Convenience 12
2.3 Tuna Fishing Vessels 13
2.4 Regional Fisheries Management Organizations 14
Chapter 3: Methodology 16
3.1 Data 16
3.2 Consolidation of Data 18
3.3 Characterizing Vessel Activities 19
3.4 Training of the Algorithm 20
3.5 Data Analysis 21
Chapter 4: Results 22
4.1 Reefer Activity and Tuna Diversity Distribution 22
4.2 Tuna Value within EEZs 28
Chapter 5: Discussion 32
5.1 Limitations of this study 37
Chapter 6: Conclusion 39
6.1 Recommendations 39
6.2 Acknowledgements: 40
References 41

List of Figures and Tables

Figure 1: Larval and adult habitat for Atlantic, Pacific and Southern bluefin tuna.
Figure 2: Larval and adult habitat for skipjack and yellowfin tuna.
Figure 3: Larval and adult habitat for bigeye and albacore tuna.
Figure 4: Global reefer track with magnification of transshipment activity events.
Figure 5: Global pattern of reefer activity.
Figure 6: Global pattern of reefer encounters.
Figure 7: Diversity of global tuna distribution.
Figure 8: Tuna diversity within spawning habitat.
Figure 9: Correlations of tuna spawning diversity and reefer encounters.
Figure 10: Correlations of tuna spawning diversity and reefer drifting.
Figure 11: Correlations of tuna species diversity distribution and reefer drifting.
Figure 12: Correlations of tuna species diversity distribution and reefer encounters.
Figure 13: Total unreported and reported tones of tuna catch.
Figure 14: Total landing value of unreported and reported tuna catch.
Figure 15: Total landed value of tuna species globally.
Figure 16: Total catch of tuna species globally.
Figure 17: Regional percentage of global IUU fishing.

Table 1: Tuna species and their global habitat range
Table 2: Percentage of overlap of reefer activity and tuna habitat.

Chapter 1: Introduction

1.1 Statement of the Problem

Reefers or transshipment vessels are refrigerated cargo ships that deep-freeze fish to preserve quality and freshness before they are brought to international markets (Gianni & Simpson, 2005). The act of transshipment is defined as two vessels meeting and exchanging goods, which can include both fish and supplies and can occur at port or in the high seas (INTERPOL, 2014). Transshipment vessels have been known to store both legally caught fish and illegal, unreported or unregulated (IUU) fish while out at sea (Gianni & Simpson, 2005). Mixing legally and illegally caught fish decreases the transparency of the fishing industry and aids in the prevalence of IUU fishing (Gianni & Simpson, 2005). Both IUU fishing and transshipment are influenced by economic drivers and each practice benefits the other (Schmidt, 2005). Furthermore, reefers increase the fishing capacity of fishing vessels by enabling fish and workers to be offloaded while food and fuel can stay replenished (INTERPOL, 2014). These transactions extend the time a fishing vessel can be out at sea and the distances they can travel (Gianni & Simpson, 2005). Transshipment allows fishing vessels to remove more fish from the ocean and potentially contribute to overfishing. To regulate transshipment, different regional fisheries management organizations (RFMOs) have either banned or increased monitoring of transshipment exchanges that do not occur at port (INTERPOL, 2014). Other regulation strategies include, hiring observers on transshipment vessels or ensuring the ship returns to port when the vessel monitoring system (VMS) has a technical problem (INTERPOL, 2014). However, even with monitoring procedures in place, regulating transshipment in the high seas is extremely difficult because a lot of transshipment encounters take place in the high seas and away from authorities (INTERPOL, 2014). Transshipment vessels also often operate under flags of convenience (FOCs) to avoid strict regulations, which often leads to an increase in IUU fishing (EJF, 2013). A group of target species that is frequently part of the reefer trade is tuna (INTERPOL, 2014).

Tuna is an extremely important and high priced fish in the global market and plays a large role in the seafood trade (Galland, Rogers & Nickson, 2016). Tuna are a large pelagic fish known for their speed and power. The major species of tuna sold on international markets include, southern bluefin (*Thunnus maccoyii)*, Atlantic bluefin (*Thunnus thynnus)*, Pacific bluefin (*Thunnus orientalis*), albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*), yellowfin (*Thunnus albacares)* and skipjack (*Katsuwonus pelamis)* tuna (Arrizabalaga et al., 2015). All these species are heavily fished (Collette et al., 2011) due to advancing fishing techniques and their high market value (ICCAT, 2015). As a result, global stocks are declining and some species have been placed on the ICUN Red List. Southern bluefin is listed as critically engendered, Atlantic bluefin is endangered and bigeye is listed as vulnerable by the ICUN (Collette et al., 2011). A major market for tuna is the sashimi market in Japan where tuna is sold both fresh and frozen (ICCAT, 2012). Within the United States and Europe, canned tuna is of larger demand (Leadbitter & Benguerel, 2014).

Tuna have an extremely broad range in habitat, reaching the Atlantic, Indian and Pacific oceans (Arrizabalaga et al., 2015). Tuna habitat is often determined through a variety of environmental variables such as temperature, salinity, oxygen levels and prey distribution (Arrizabalaga et al., 2015). Most tuna species migrate long distances to get the ideal environmental and geographic conditions necessary for successful reproduction (Reglero, Ciannelli, Balbín, & Alemany, 2014). Due to the large geographic range, tuna play a large role in people's diet around the world (Galland et al., 2016). In 2014, the tuna industry's revenue globally, was approximately US$40 billion (Galland et al., 2016). However, when compared with historic data, the price of tuna has been increasing due to the low catch rates that the industry is experiencing (FAOa, 2016).

Tuna species are affected by reefer activity because reefers provide increased fishing capacity, which potentially places additional stress on the stocks. By extending the capacity of fishing vessels, tuna stocks that are farther off shore or in more remote places can be exploited. Transshipment also aids in IUU fishing, which mainly targets bluefin, yellowfin, albacore and bigeye tuna (Gianni & Simpson, 2005). The need for conservation and management tools for tuna is apparent and fisheries regulations, which are often compromised by transshipment, are vital in ensuring proper monitoring and sustainability of global fisheries.

1.2 Research Question and Purpose

This research aims to explore where the most common areas of transshipment vessel activity are located and if hotspots of transshipment correlate with areas of high tuna diversity. Fish are a highly traded and transported resource within the global market (FAOb, 2016). Fish will often be caught by one country, processed in another and consumed in a third (FAOb, 2016). Due to their large movements, ensuring traceability allows for accurate management, sustainable fishing and ultimately, sustainable fish consumption. However, transshipment limits transparency within the fishing industry and can be linked to IUU fishing (INTERPOL, 2014). By analyzing the connection and possible correlation of transshipment vessels and tuna stocks as well as identifying ‘hot spots’ of transshipment activity, the importance of limiting transshipment in sustainable fisheries management will be highlighted.

Chapter 2: Literature Review

To connect tuna diversity with transshipment vessel locations, the following information needs to be considered and understood. Focusing on tuna distribution, flags of convenience, tuna fishing vessel types and regional fisheries management organizations, this review considers important factors which play a role within the tuna and transshipment industry.

2.1 Tuna Distribution and Migration

Tuna are a highly migratory species, occupying waters in every ocean ranging from 0-55 degrees latitude (Table 1) (Reglero et al., 2014). Abundance and migration patterns have been documented for many years, mainly through fishing log books (Myers & Worm, 2003) and the use of tagging (Block et al., 2005). Analyzing historic fishing documents, provides the researcher with an understanding of past diversity, population size and ecosystem complexity, which often is lost once overfishing begins (Alexander et al., 2009). Tagging is also an effective tool to use when studying large, highly migratory species, such as tuna (Block et al., 2015). Through tagging, migratory routes and destinations can be observed and variation from the expected routes can be noted (Block et al., 2015).

The various tuna species have different preferences regarding migration times, routes and habitats. Species that prefer warmer waters include skipjack, bigeye, and yellowfin tuna, while the bluefin species prefers cooler waters (Reglero et al., 2014). Spawning for tuna species varies largely based upon sea surface temperature (SST) and eddy kinetic energy (EKE) (Reglero et al., 2014). EKE is defined as the horizontal mixing of the water column within the ocean (Gaspar, Gregoris & Lefevre, 1990). Spawning typically occurs around the $24°C$ isotherms and in intermediate levels of EKE, which aids in the dispersion of larvae for all species except southern bluefin (Reglero et al., 2014). Preferred spawning locations based upon various environmental conditions results in species-specific distribution and migrations (Figures 1- 3).

Table 1: List of tuna species and their habitat ranges and oceans where their habitats are located (Reglero et al., 2014).

SPECIES	LATITUDINAL RANGE	LONGITUDINAL RANGE	OCEANS
ATLANTIC BLUEFIN TUNA	65° N- 30° N	0 °- 70° W	Atlantic
PACIFIC BLUEFIN TUNA	50°N to 40° S	100° E- 140 ° W	Pacific
SOUTHERN BLUEFIN TUNA	$30° S - 50°S$	60° W- 180° E	Southern
SKIPJACK TUNA	50°N to 30°S	180°W to 180° E	All
YELLOW FIN TUNA	50 °N to 40 ° S	180° W to 180 ° E	All
BIGEYE TUNA	50 °N to 40 ° S	180° W to 180 ° E	All
ALBACORE TUNA	50 °N to 40 ° S	180° W to 180 ° E	All

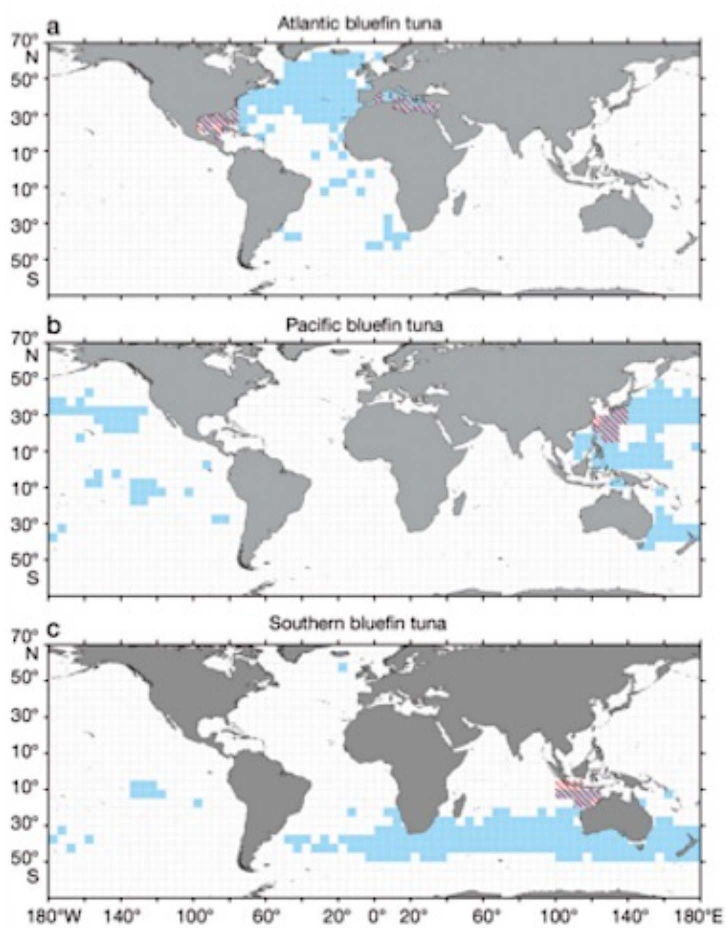

Figure 1: Larval (red hatching) and adult habitat (blue squares) for a) Atlantic bluefin, b) Pacifc bluefin and c) southern bluefin tuna (from: Reglero et al., 2014)

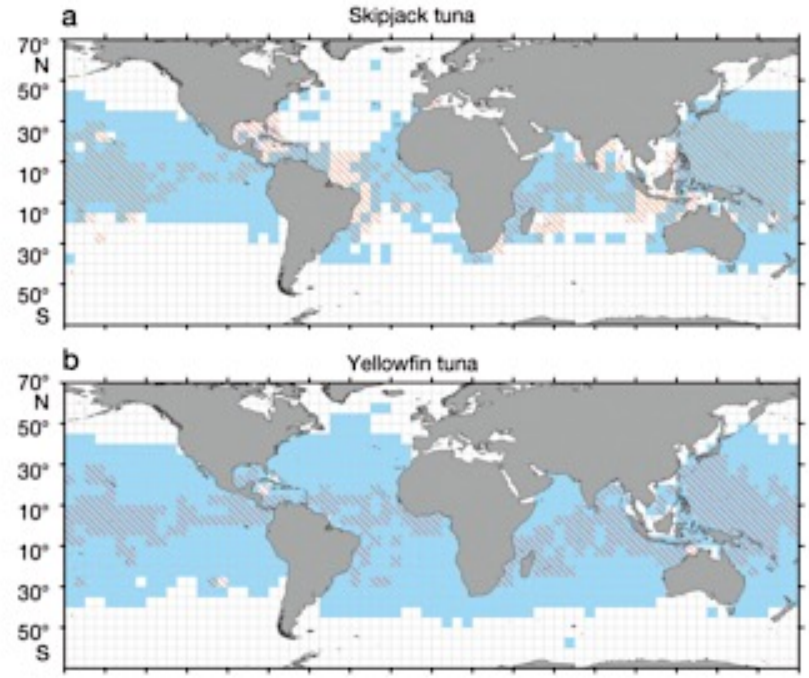

Figure 2: Larval (red hatching) and adult (blue square) habitats of a) skipjack and b) yellowfin tuna (from: Reglero et al. 2014).

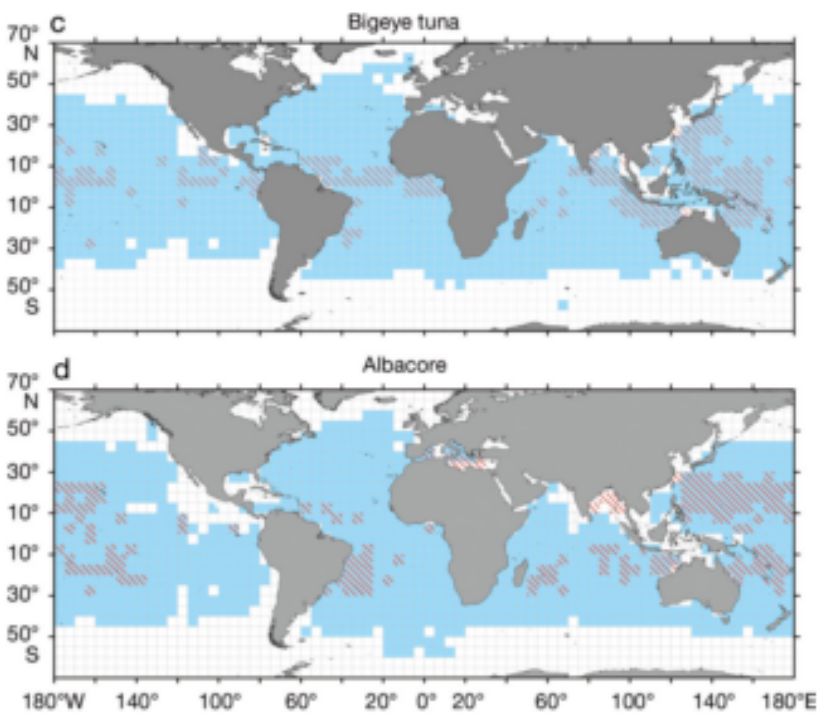

Figure 3: Larval (red hatching) and adult (blue square) habitat for c) bigeye and d) albacore tuna (from: Reglero et al., 2014).

2.2 Flags of Convenience

The use of flags of convenience (FOC), allows states to open ship registration of their nation's flag to foreign vessels (DeSombre, 2005). This is a common practice for fishing vessels and reefers (INTERPOL, 2014). Most vessels that sail under a FOC are flagged to developing nations but the vessel often is owned by companies operating out of developed nations (Agnew et al., 2009). A lot of large European Union (EU) fishing vessels fly a FOC, with Spain owning the majority (Gianni & Simpson, 2005). When a ship is registered to a specific nation they must follow the domestic and international regulations that the state has agreed to (Bache, 2002). Vessels must abide by the agreements made by the flag state, outside of that nations EEZ and within the high seas (Bache, 2002). However, with open registration, any vessel can buy the nations flag and therefore operate under that nations laws (DeSombre, 2005). Nations which have open registration often avoid international regulations and strict national fishing policies (DeSombre, 2005). It is often developing countries that will sell their flags, allowing other vessels to fish under their relaxed regulations (Agnew et al., 2009). Nations open their ship registration as a way to increase income from registration fees (DeSombre, 2005). Obtaining a FOC is also made easy with the price of vessels changing their flags costing around a $1000 and no requirement to return to port (DeSombre, 2005). The number of vessels with FOCs have been increasing (DeSombre, 2005) and globally, 48% of reefers are flying a FOC (Cutlip, 2017). The main four FOC countries are Belize, Panama, Hondouras and St. Vincent and the Grenadines while other very common FOC countries include Georgia, Cambodia, Vanuatu and Bolivia (Gianni & Simpson, 2005).

The practice of reflagging to a FOC potentially harms management and monitoring efforts of fish stocks because FOCs provide a loophole for vessels to not abide by the policies and legislation developed to conserve species (Gianni & Simpson, 2005). Determining the connection between large-scale, industrial fishing vessels with FOCs who sell catch in international markets, and transshipment vessels, will highlight how this transaction further decreases transparency within the fishing industry and allows IUU fishing to prevail (Gianni & Simpson, 2005).

2.3 Tuna Fishing Vessels

Purse seiners and longline fishing vessels are the most common fishing vessel types used in industrialized tuna fishing (Joseph, 2003). Other smaller vessels such as handlines, trollers and smaller longliners are often used in smaller scale tuna fishing (Joseph, 2003). The main target species for both purse seiners and industrial longliners are tuna and tuna- like species such as swordfish and bonitos (Joseph, 2003). Tuna purse seiners fish in areas where species are swimming and feeding, which is often surface and sub-surface waters, above and around the thermocline (Majkowski, 2003). Purse seiners use nets to surround and remove large schools of fish (Majkowski, 2003). Most purse seiners rely on freezing the fish right after they are caught to preserve freshness (Majkowski, 2003). Industrial longliners deploy long fishing lines which can be up to 100 km long and can carrying up to 3,500 baited hooks (Gilman, Brothers, McPherson, & Dalzell, 2007) at selected depths of 100- 300m (FAO, 2003). These vessels can stay out at sea for months and often have on board freezing capacities around -40 °C to -60°C (FAO, 2003). It is common for tuna fishing vessels to meet with transshipment vessels to offload their catch (FAO, 2003). Identifying and understanding various fishing techniques used to catch tuna, will provide insight onto fishing methods that often require or would benefit from transshipment.

2.4 Regional Fisheries Management Organizations

FOCs and transshipment pose a real threat to the conservation and management of the oceans and many Regional Fisheries Management Organizations (RFMOs) have created policies and regulations to deal with FOCs and transshipment (DeSombre, 2005). The International Commission for the Conservation of Atlantic Tunas (ICCAT) estimates that fishing vessels engaged in IUU fishing take 10% of the total catch in the Atlantic, and most of them are flying a FOC (DeSombre, 2005). In order to manage the global fishing stocks within their jurisdiction, RFMOs have created lists of vessels that have permission to fish within their convention area (Gianni & Simpson, 2004). Various methods have been implemented through different RFMOs and some strategies include market and trade-related measures to protect and monitor fishing activities (NOAA, 2015). ICCAT created a regulation which restricts market and trade access to include only fish that have the required fish catch documentation (DeSombre, 2005). ICCAT will also “identify” nations based upon destructive fishing activities in an attempt to encourage them to amend their fishing behaviours (NOAA, 2015). Another way ICCAT regulates tuna fisheries specifically, is through the Bluefin Tuna Statistical Document Program (BTSD), which prevents tuna from being sold without having BTSD documentation (DeSombre, 2005). A catch documentation scheme (CDS) has also been used by the Inter-American Tropical Tuna Commission (IATTC), the Western and Central Pacific Fisheries Commission (WCPFC) and Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (NOAA, 2015). ICCAT along with the Convention for Conservation of Southern Bluefin Tuna (CCSBT), and the Northwest Atlantic Fisheries Organization (NAFO) have implemented trade-based measures to conserve and monitor fish stocks (Bache, 2002). The trade measures used by these RFMOs are restrictions created at a multilateral level, to regulate the harvesting of species which are under threat and in need of conservation within the RFMO (Bache, 2002). Other RFMOs such as the Indian Ocean Tuna Commission (IOTC), CCAMLR and CCSBT have created a 'black list' and a 'white list' as a strategy to protect their stocks from over exploitation (DeSombre, 2005). If ships are "black-listed" they are not allowed to fish within the regulation areas (DeSombre, 2005). If ships are on the 'white list' then they are allowed to fish within countries exclusive economic zones (EEZ) (DeSombre, 2005).

The United Nations Fish Stocks Agreement (UNFSA) suggests that transshipment vessels flying under FOCs should be under supervision while transshipping on the high seas, in order to ensure the conservation and management of global fish stocks (McTee, 2011). Different RFMOs have different regulations surrounding transshipment. IATTC, ICCAT and IOTC require transshipment to occur at ports, while WCPFC prohibits any high sea transshipment with purse seiners in their convention (McTee, 2011). While, RFMOs play a vital role in protecting and conserving global fishing stocks (Aranda, Murua, & de Bruyn, 2012), they are not as efficient as they could be (Cullis-Suzuki & Pauly, 2010). Cullis-Suzuki and Pauly (2010) determined that 67% of high seas fishing grounds, which are under RFMO regulation, are overfished. This suggests that RFMOs are not enforcing regulations or protecting fish stocks effectively (Cullis-Suzuki & Pauly, 2010). RFMOs must place more efforts on conservation and move away from narrow, species-specific management techniques to a broader, ecosystem based approach (Cullis-Suzuki & Pauly, 2010).

Chapter 3: Methodology

This study uses the software programs ArcGIS 10.3.1, R Studio 1.0.136 and Excel 15.32 to conduct a comparative analysis of four data sets to determine the statistical significance of the correlation on the locations of transshipment activity, and the overlap with tuna diversity and habitat.

3.1 Data

Data from six main sources was used in this study. Data on transshipment vessels and their activity was obtained from a global dataset of Automatic Identification System (AIS). AIS is a tool used for maritime safety and tracks vessel locations throughout the global ocean through satellites or ground-station receivers (Global Fishing Watch, 2016). AIS data used in this study was provided by Global Fishing Watch[1] and originated from the commercial provider Orbcomm (Kroodsma, Miller & Roan, 2017). Global Fishing Watch is an initiative by Oceana[2], Sky Truth[3] and Google, providing a free online platform to help make the global fishing industry more transparent (Global Fishing Watch, 2016). The AIS data included thousands of refrigerated cargo vessels and fishing vessels and provided information on location, date, time, speed, gear type, vessel size as well as International Marine Organization (IMO) and Maritime Mobile Service Identity (MMSI) numbers. An IMO number is the identification number for vessels registered with the International Marine Organization. A MMSI number is a nine-digit number unique to each vessel and is read on a radio frequency channel to identify vessels out at sea (Government of Canada, 2015). The AIS data supplied by Global Fishing Watch was used in two main ways; analyzing tracks of transshipment activities which were meeting with another

[1] http://globalfishingwatch.org
[2] http://oceana.org
[3] https://skytruth.org

fishing vessel ('encounters dataset') and, where no fishing vessel tracks were available, but reefers were showing transshipment-like behaviour ('drifting datasets').

3.11 Transshipment Data

The data for transshipment movements contained information on where and when various transshipment activities occurred between 2012 and 2016. The transshipment data was made up of two different data sets: encounters and drifting data. The two data sets were compiled through the use of algorithms to identify encounters and drifting characteristics within various vessel tracks. The encounters algorithm was developed to identify two or more vessels that were within a 500m radius of each other for more than 3 hours and travelling at speeds less than 2 knots (personal communication Nate Miller, 2017). The encounters dataset contained information regarding other vessels that were meeting with reefers to participate in transshipment. This data set provided information on the reefer and the other vessel's identification number, gear type, nationality, speed and location. The second data set used was the drifting data set. The main difference here was that no other vessels were included in the identification of a transshipment event. This might have been less precise than the encounters data set but it included more data, as the fishing vessels meeting with a reefer do not often carry AIS (personal communication Nate Miller, 2017). The algorithm used to analyze drifting data and select data when the reefer was moving at a speed less than 2 knots and had been at this speed for more than eight hours (personal communication Nate Miller, 2017). The drifting data set provided information including: the latitude and longitude of the drifting, the duration the drifting happened for, the speed and the vessel's MMSI number.

3.12 Tuna Distribution Data

Tuna data was collected from the papers of Reglero et al. (2014) and Boyce, Tittensor &Worm (2008) to analyze tuna distribution, adult habitat and spawning areas. This data provided the latitude and longitude as well as presence for seven tuna species. Presence was recorded as either a zero (no presence) or a one (presence). Boyce et al. (2008) collected their data from, "primary sources of fisheries data, satellite tracking, acoustic tracking, ultrasonic telemetry, aerial surveys and captive studies" (Boyce et al., 2008). This data provided a general distribution of a variety of tuna and billfish species from over 190 publications. Adult habitat and spawning zones were taken from a study done by Reglero et al. (2014). The authors consolidated 92 reports that referenced spawning grounds and extracted the locations from each (Reglero et al., 2014).

3.13 Tuna Value

To understand the level of IUU tuna fishing occurring within the global oceans, data on total catch and landed value of tuna was obtained from the Sea Around Us Project (SAUP)[4] to estimate the amount of unreported and reported tuna caught each year within various country's EEZs (Zeller & Pauly, 2016). The unreported statistics are estimated based on detailed expert reports and investigations from individual countries (Zeller & Pauly, 2016).

3.2 Consolidation of Data

Sky Truth provided a list of 1,258 potential transshipment vessels from IOTC Consolidate List of Authorized Vessels (CLAV)[5]. From this list, each vessel was compared to the Western and Central Pacific Fisheries Commission[6] (WCPFC) vessel registry database. Additional sources such as national fleet databases Marine Traffic[7], and Fleetmon[8] as well as the

[4] http://www.seaaroundus.org
[5] http://clav.iotc.org/browser/search/#.WOZLnRgZNsM
[6] https://www.wcpfc.int/record-fishing-vessel-database
[7] http://www.marinetraffic.com/en/ais/home/centerx:-12/centery:25/zoom:4

search engine Google were used when the vessel was not listed in WCPFC. These databases were used to check and validate the MMSI identification number, the IMO number, vessel name, flag, crew nationality and company. Within the list of 1,258 vessels, those that were duplicates, no longer existing or mismarked as reefers, were removed and the list was refined to approximately 597 vessels.

3.3 Characterizing Vessel Activities

After initial research into transshipment activity, which included literature research and statistical analyses of movement patterns of known transshipment, a set of general characteristics were determined (Kroodsma et al., 2017)

Characteristics of transshipment defined during and for this study included: a distance of more than 20 nautical miles from shore, speeds under 2 knots and a zigzag movement pattern, usually interrupted by straight lines at high speeds (steaming) and a sharp turn into a new zigzag pattern (Figure 4) (Kroodsman et al., 2017) Based on these general characteristics, the Global Fishing Watch team developed an algorithm to detect and identify transshipment events within the entire reefer database.

---

[8] https://www.fleetmon.com

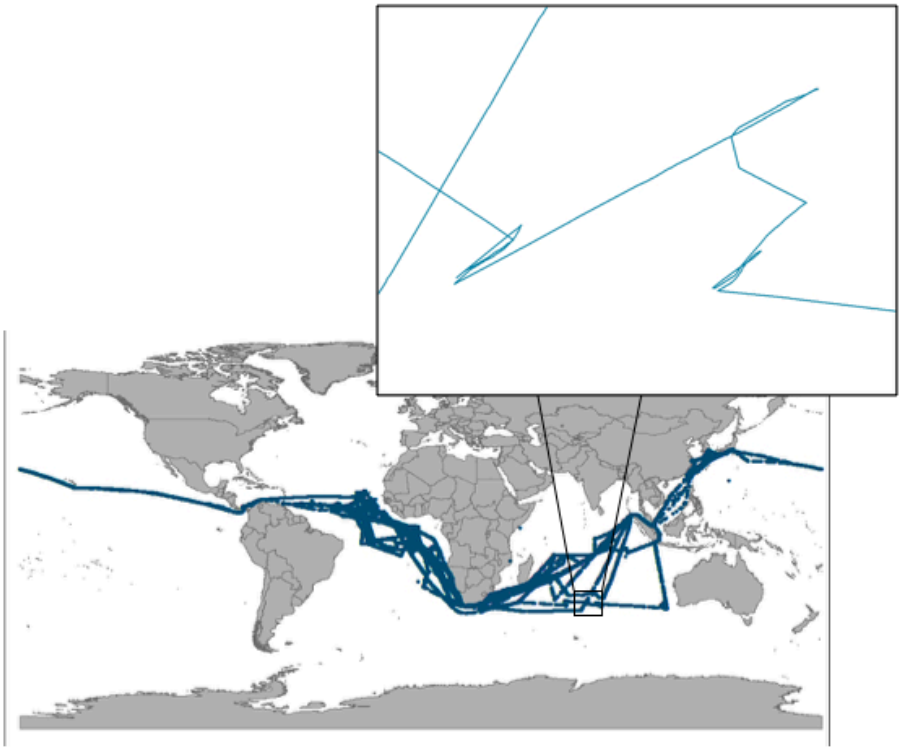

Figure 4 Reefer track circumnavigating the globe. Dots are individual AIS detections. Insert: close-up of multiple transshipment events within the southern Indian ocean (circled) (data from Global Fishing Watch, 2016).

3.4 Training of the Algorithm

The algorithm was used to detect an encounter within reefer tracks based upon the speed and movement patterns listed above. To refine the algorithm, 300 transshipment events, which were detected by the algorithm, were visually reviewed and classified as encounters or otherwise. Labeling the data was used to check for false positive or negative events and ‘label’ a true encounter with the classification of a transshipment event (personal communication Nate Miller, 2017). Based on the manual classification, the algorithm could distinguish corresponding patterns in the data and label unknown data as an encounter or not an encounter (personal communication Nate Miller, 2017).

3.5 Data Analysis

Using the mapping software ArcGIS 10.3.1, both reefer data and tuna distribution data was displayed and visually analyzed. The data was aggregated in 5 x 5 degree cells corresponding to the aggregation format of the tuna data. Overlap of the extent of tuna presence and reefer activity was calculated and mapped. Each data set was refined to exclude areas that were covered by land using a tool called clip and erase within ArcGIS. Mapping out the overall distribution of both tuna habitat and reefer locations aided in identifying possible hotspots throughout the global ocean.

To test for correlation between tuna and reefer activity, the two reefer sets, made up of encounters and drifting data were paired to the two tuna sets, spawning and overall distribution. Once the data was paired, all the grid cells which contained a tuna presence of zero were removed to focus on reefers which were located within tuna habitat. After the data was trimmed, a simple linear regression model was performed in Excel 15.32, to estimate The Pearson's correlation coefficient and to decide if further analysis was needed.

In order to analyze the impact IUU fishing may have tuna value and tonnage, SAUP data from 2003 to 2013 was displayed based upon its reporting status, using Microsoft Excel 15.32. Using SAUP data from 2008 to 2014, the total landing value and tonnage of tuna in various EEZs was mapped using ArcGIS 10.3.1. Two maps were created to show regional difference of catch tonnes and landing value for both unreported and reported tuna catch.

Chapter 4: Results

4.1 Reefer Activity

747 reefer vessels were included in the drifting data and 53,831 drifting events were identified. There were 361 reefers engaging in an encounter with 1038 different fishing vessels. Russia had the most flagged reefers engaging in encounters, followed by Panama. Russian flagged fishing vessels were also the most common vessel to perform an encounter with a reefer, while China was the second most common flagged fishing vessel to engage in transshipment.

A reefer was considered drifting if it was travelling at speeds less than 2 knots for more than 8 hours. Drifting hotspots were detected along the coasts of Russia, west Africa, and the north-west coast of South America, especially around Colombia, Chile, Ecuador and Peru (Figure 5). Another large hot spot is around the Falkland Islands and Argentina. There was less drifting activity around Indonesia and within the central Pacific as well as in the Indian ocean around North America, Oceana and the southern Pacific.

To be considered an encounter, there had to be two or more vessels that were within a 500m radius of each other for more than 3 hours and travelling at speeds less than 2 knots (personal communication, Nate Miller, 2017). Due to the strict classification requirements of encounters, this data set is more precise and sparse than the drifting data set. Hotspots of reefer encounters occurred along the coasts of Russia, west Africa, the north-west coast of South America, Falkland Islands and Argentina (Figure 6).

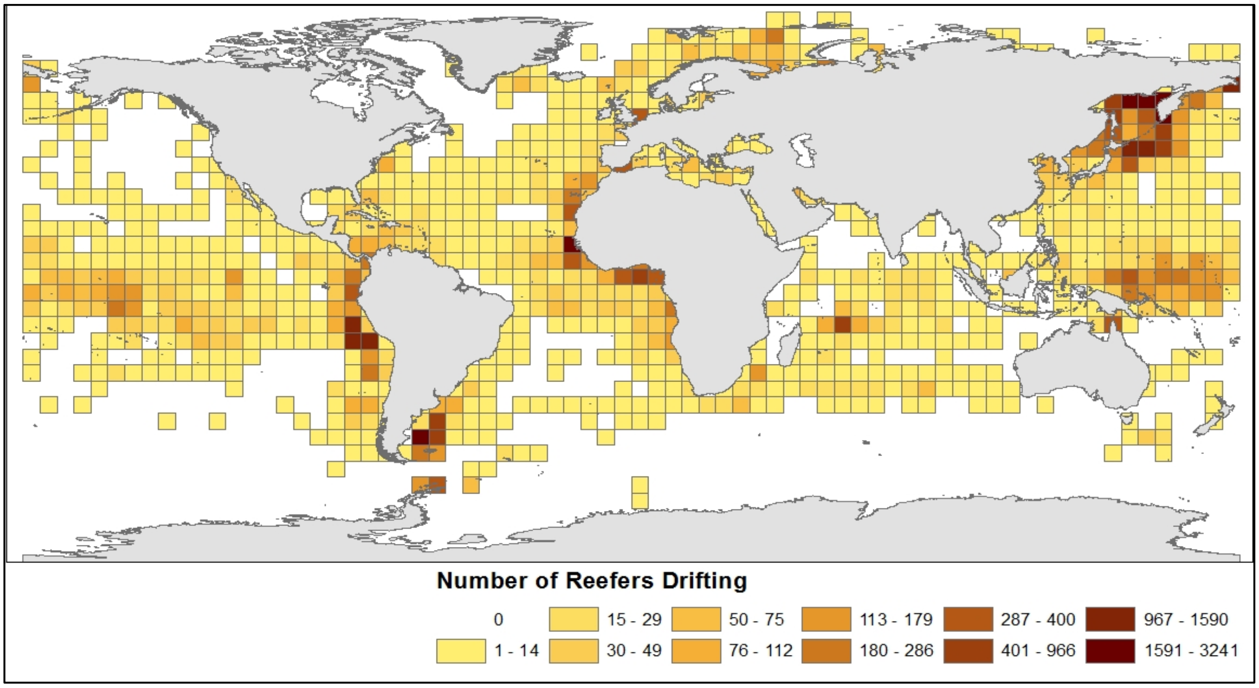

Figure 5. Global pattern of reefer activity. Count of reefers participating within an encounter with another vessel within 5x5 degree grid cell between January 1st, 2012 and January 1st, 2016. Drifting is defined as a reefer travelling at speeds lower than 2 knots for more than 8 hours. Data provided by Global Fishing Watch.

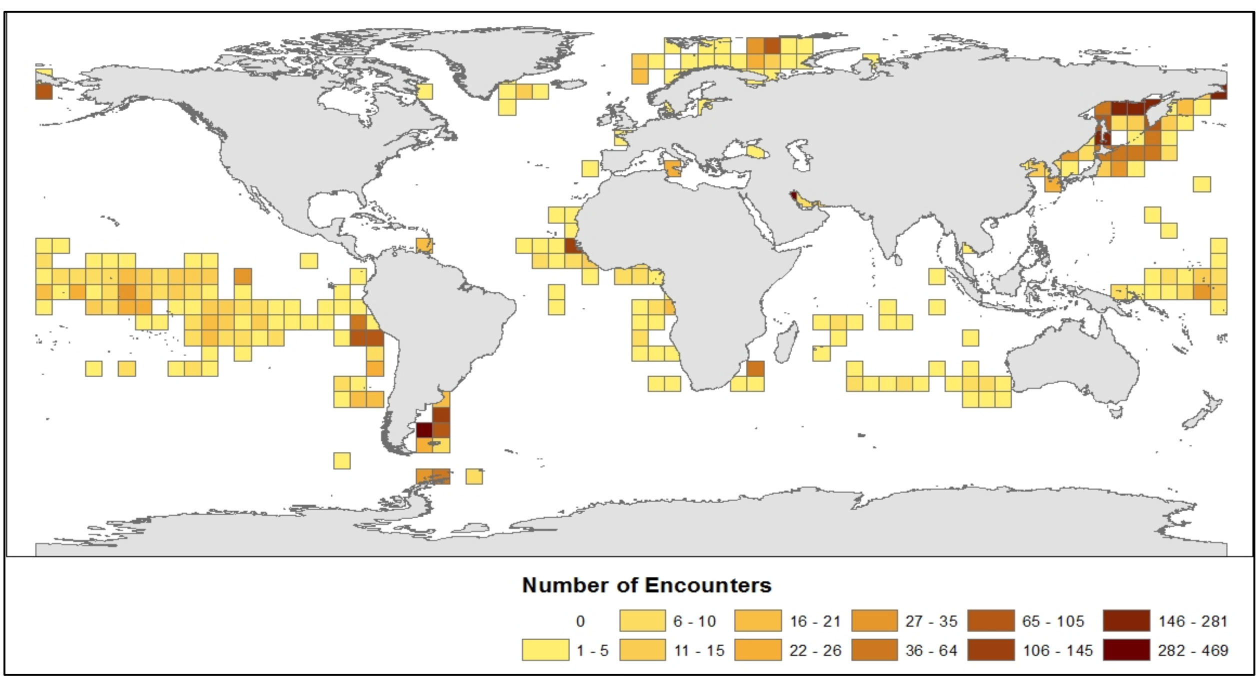

Figure 6. Global Pattern of reefer encounters. Count of the number of reefers meeting with another vessel within 5x5 degree grid cell between January 1st, 2012 and January 1st, 2016. Encounter is defined as a reefer being within a 500m radius of another vessel, going less than 2 knots an hour for more than 3 hours. Data provided by Global Fishing Watch.

The highest level of tuna diversity was a total of 5 different tuna species spawning within the same 5x5 degree grid cell. Highest species diversity is found around the southern tip of Africa, off the east coast of Australia and in the high seas of the Pacific (Figure 7). Diversity is lower in the Mediterranean, surrounding Mexico and within the Southern Ocean.

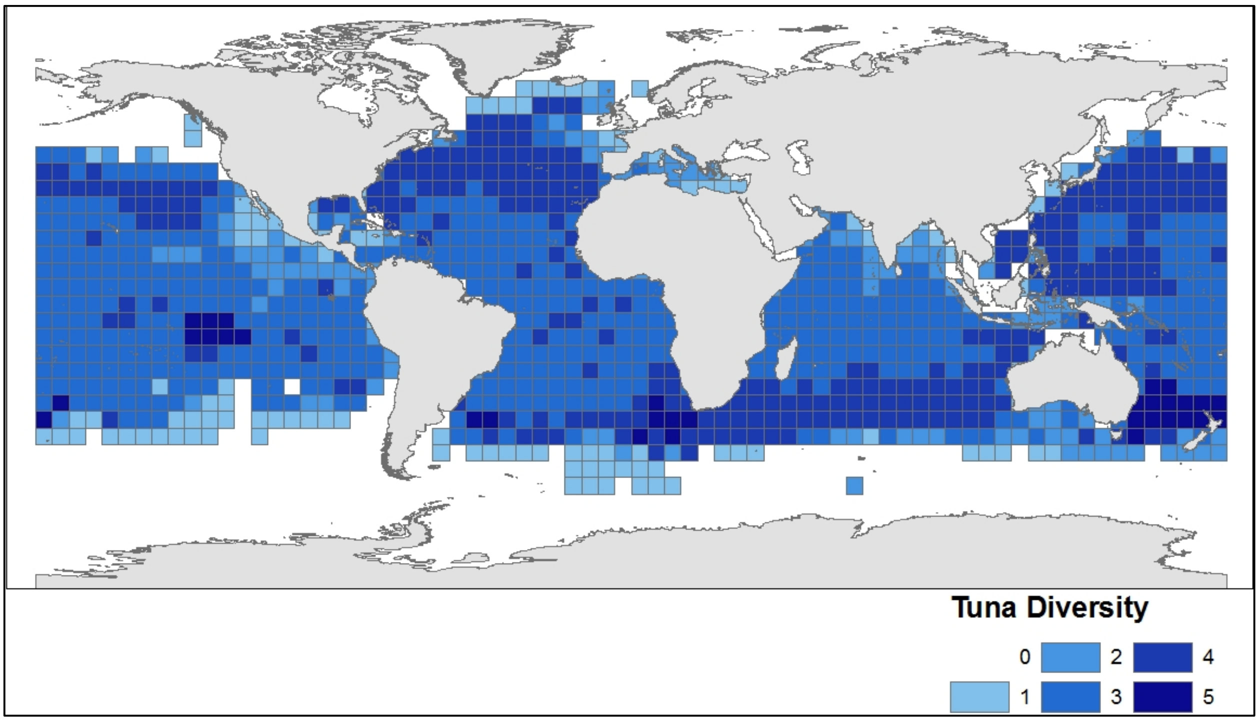

Figure 7. Diversity of global tuna distribution. Overlapping tuna distribution of bigeye, skipjack, Pacific bluefin, Atlantic bluefin, southern bluefin, yellowfin and albacore tuna. Data from Boyce et al. (2008).

Spawning hot spots are located within the Gulf of Mexico, Indonesia, northwest Australia and off the coast of China (Figure 8). Most of the spawning habitat is concentrated along the equator with the exception of some spawning activity within the Mediterranean (Figure 8).

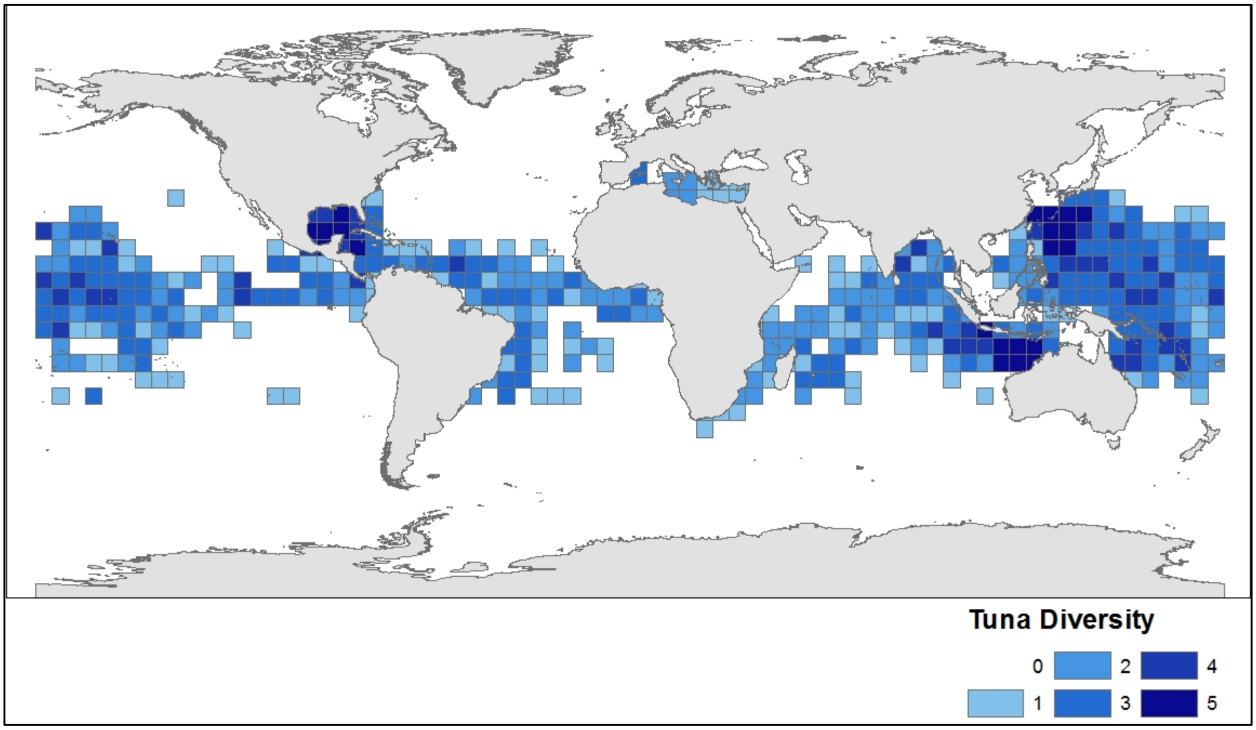

Figure 8. Tuna diversity within spawning habitats. Overlapping spawning habitats of bigeye, skipjack, Pacific bluefin, Atlantic bluefin, southern bluefin, yellowfin and albacore tuna. Data from Reglero et al. (2014).

The data was divided into correlation pairs which included spawning distribution and reefer encounters, spawning distribution and drifting reefers, overall tuna distribution and reefer encounters and overall tuna distribution and drifting reefers. No significant correlation (All $p > 0.1$) was found between tuna diversity and reefer activity, spawning grounds and encounters sites (R^2=0.0000095), spawning and drifting (R^2= 0.00077), tuna distribution and encounters (R^2=0.00061) and tuna distribution and drifting (R^2= 0.00049). There was also no correlations found for log-transformed data (Figure 9-12).

Figure 9. Correlations of tuna spawning diversity and reefer encounters within each 5x5 grid cell across global oceans. Reefer encounters were LOG+1 transformed and a linear line of best fit and the coefficient of determination was calculated.

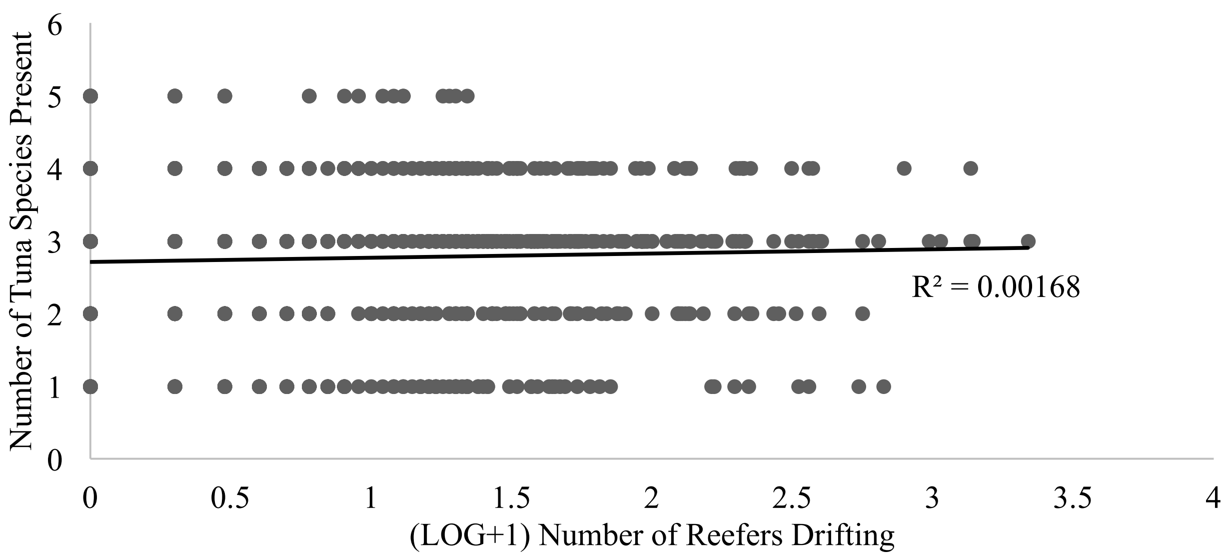

Figure 10. Correlation of tuna spawning diversity and reefers drifting within each of 5x5 grid cell across global oceans. Reefers drifting were LOG+1 transformed and a linear line of best fit and the coefficient of determination were calculated.

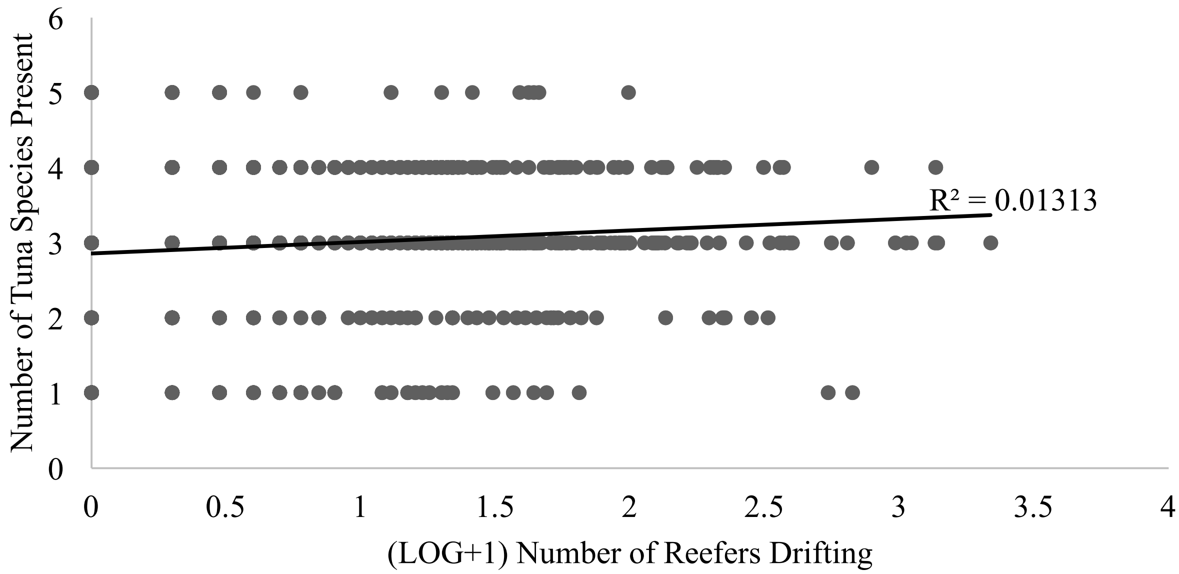

Figure 11. Correlations of tuna species diversity distribution and reefers drifting within a 5x5 grid cell across global oceans. Reefers drifting were LOG+1 transformed and a linear line of best fit and the coefficient of determination were calculated.

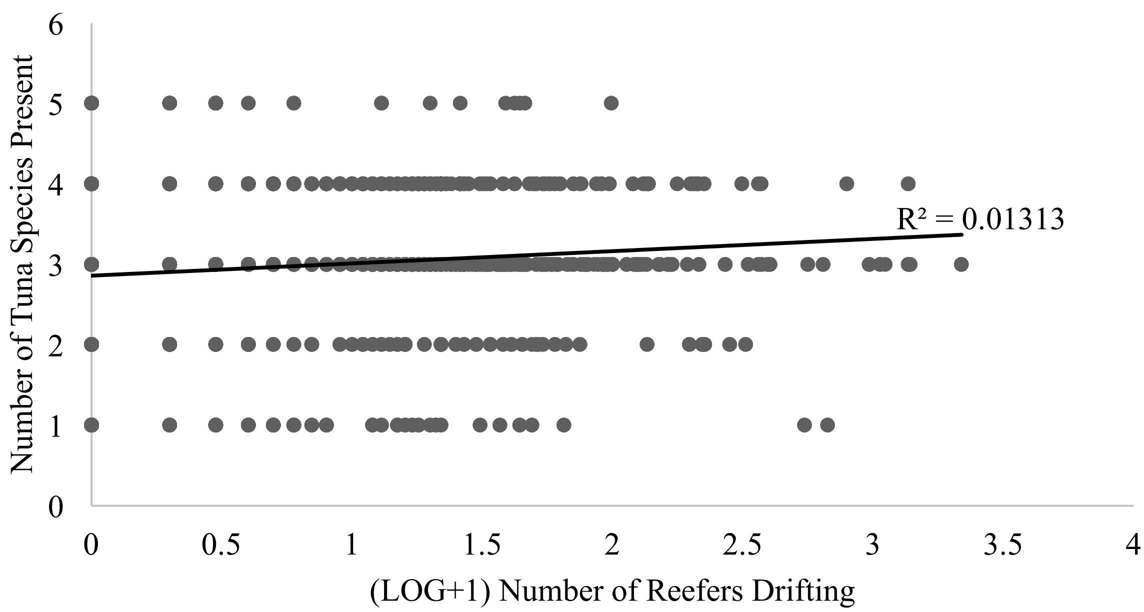

Figure 12. Correlations of tuna species diversity distribution and reefer encounters within a 5x5 grid cell across global oceans. Reefers drifting were LOG+1 transformed and a linear line of best fit and the coefficient of determination were calculated.

While there was no significant correlation at a global scale, there was some regional overlap between diverse tuna hotspots and hotspots of reefer activity (Table 2). Between all pairs the highest overlap was between tuna spawning habitat and drifting activity, at 73% of tuna spawning grounds having some reefer drifting activity. The lowest amount of overlap was between overall tuna habitat and reefers performing encounters at 17% overlap.

Table 2. Percentage of overlap of reefer activity and tuna habitat. Values were determined by removing all cells without tuna presence or reefer activity for each reefer-tuna pairing.

GROUPING	NUMBER CELLS WITH TUNA ACTIVITY	NUMBER WITH REEFER ACTIVITY WITHIN TUNA HABITAT	PERCENTAGE OF TUNA HABITAT WITH REEFER PRESENCE
DRIFTING AND SPAWNING	1,089	803	73%
DRIFTING AND TUNA	1,727	1180	68%
ENCOUNTERS AND SPAWNING	770	143	18%
ENCOUNTERS AND TUNA	1,727	295	17%

4.2 Tuna Value within EEZs

SAUP provided yearly data catch tonnage and landing values for reported and unreported tuna catch. Based on this data, 90 million tonnes of tuna catch went unreported and 82 million tonnes of tuna were caught and reported over ten years, from 2003 to 2013. During the same time frame the value of reported tuna catch landed was US$159 million, while the landing value of unreported tuna was US$170 million (Zeller & Pauly, 2016). In total more tonnes of tuna caught went unreported than what was reported, but the total landing value of reported tuna was higher than the unreported value (Figure 13-14).

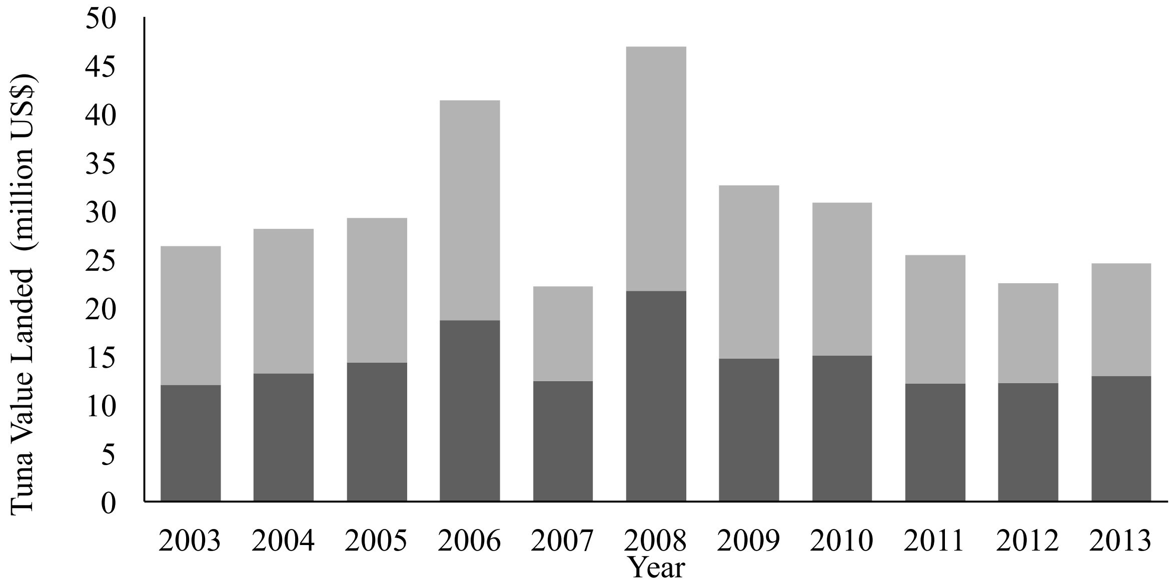

Figure 13. Total of unreported (dark grey) and reported (light grey) tonnes tuna catch of multiple EEZs between the years 2003 and 2013. Unreported tuna catch was estimated by Zeller and Pauly (2016) and reported catch was obtained from the Sea Around Us Project.

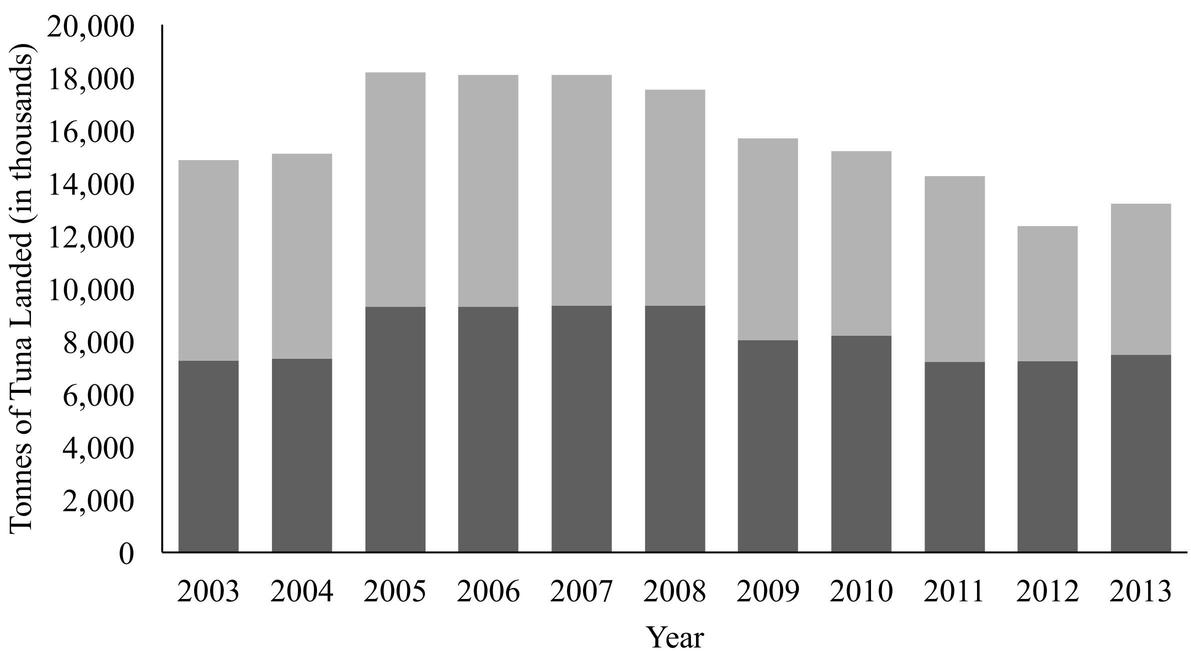

Figure 14. Total landing value of unreported (dark grey) and reported (light grey) tuna of multiple EEZs between 2003 and 2013. Unreported tuna value was estimated by Zeller and Pauly (2016) and reported tuna value was obtained from the Sea Around Us Project.

The SAUP data was categorized by EEZ and the EEZs with the largest total landed value of tuna between 2008 and 2014 were, Greece, Italy, Malaysia and Brazil (Figure 15). Madagascar, Guinea Bissau and Kenya had the most total catch of both reported and unreported tuna between 2008 and 2014 (Figure 16).

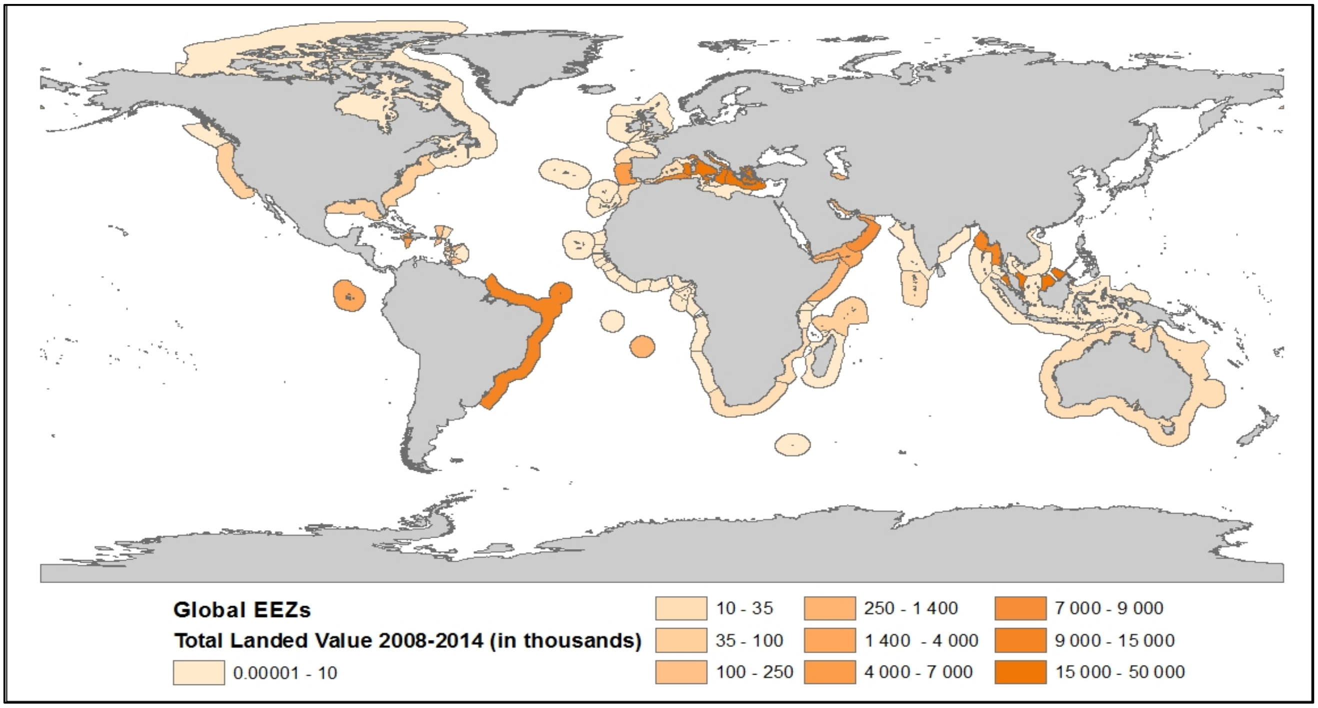

Figure 15. Total landed value of tuna species globally. Darker orange represents higher value (in 1000s) of USD landed. This data includes various tuna fishing techniques and accounts for both unreported and reported tuna landings by EEZ between 2008-2014. EEZs without colours reflect missing data.

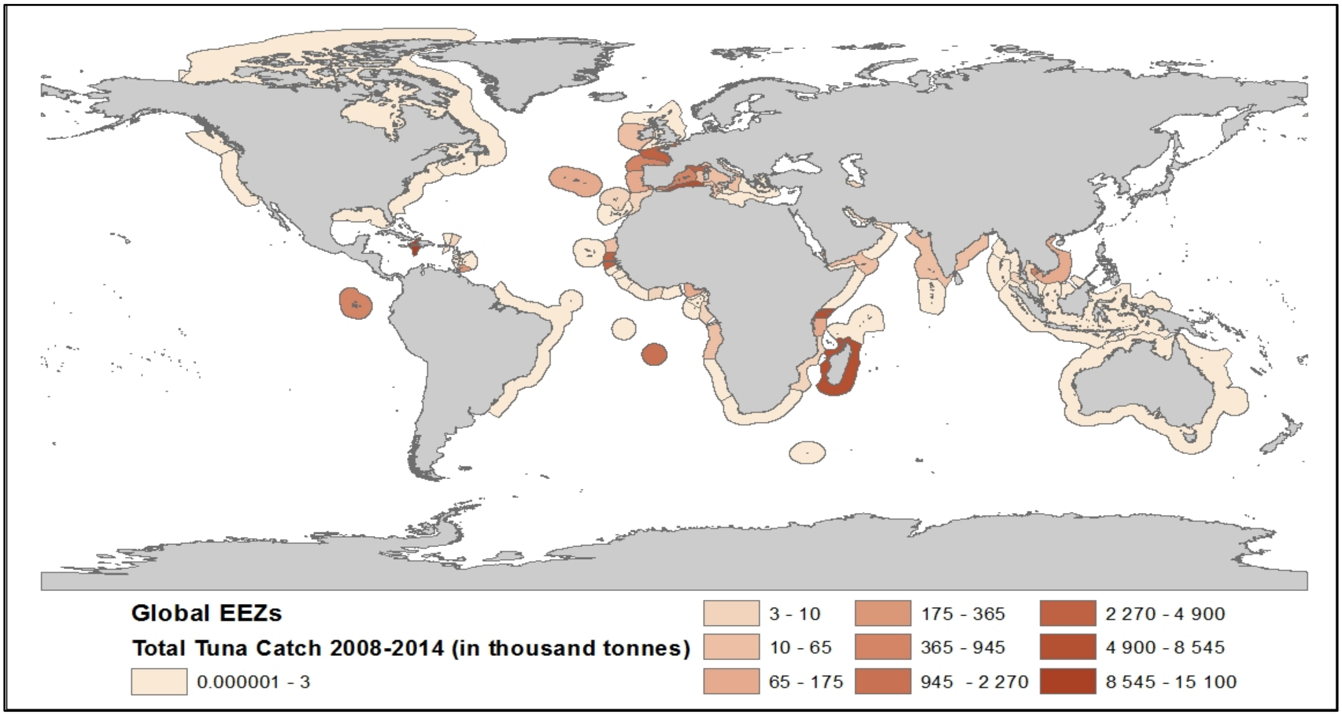

Figure 16. Total catch of tuna species globally. Darker red represents more tuna catch. This data includes various tuna fishing techniques and accounts or both unreported and reported tuna landings. By EEZ between 2008-014. EEZs with no colour reflects missing data.

Chapter 5: Discussion

The aim of this research was to determine spatial patterns of global reefer activity and the correlation to tuna ranges, habitat and diversity. Tuna is an extremely high valued and highly traded commodity (Paquotte, 2003). Globally, fresh and frozen exports account for 30% of the tuna caught, however of that, 90% is exported frozen (Paquotte, 2003). Reefers play a large role in the transportation of tuna caught by purse seine and longline fishing vessels (McCoy, 2012). However, no correlation between hotspots of reefer activity and tuna diversity or habitat was found. This raises the subsequent question, what might drive patterns of reefer activity instead?

While no correlation between tuna habitat and diversity and reefers activity was found, clear hotspots of reefer presence emerged. These hotspots appear to be located in areas where large commercial fleets operate, such as the Northwest and Southeast Pacific, the Western Central Pacific and the Northeast Atlantic (Figure 5) (FAOb, 2016). Therefore, it can be inferred that reefers are not targeting a specific species and instead may be servicing a range of different fishing fleets in popular fishing grounds like in the waters off China, Peru and Indonesia (FAOb, 2016). The largest hotspot of reefer activity was present around Russia and China, both of whom are major fishing nations globally (FAOb, 2016). This hotspot also could be a result of the large presence reefers have in Russia, because they are commonly used within Russian fishing fleets (Kroodsma et al., 2017).

A link between transshipment of fish at sea and IUU fishing has been documented and observed before this study (Kroodsma et al., 2017). The patterns of reefer activity found in this study overlap with known IUU hotspots, in areas such as the Southeast Pacific, Southwest Atlantic, East Central Atlantic, the Northwest Pacific and the West Central Pacific (Figure 17) (Agnew et al., 2009; Miyake et al., 2010; FAOb, 2016). A large hotspot of both transshipment activity and the highest reported level of IUU fishing (37%), occurred off the coast of west Africa (Figure 5&17). High levels of IUU fishing, transshipment and FOCs have been observed within these waters (EJF, 2013). Reefers are often associated with IUU fishing because fishing vessels do not need to return to port to offload their catch (Kroodsma et al., 2017). Transshipment vessels engaging with vessels flying a FOC, are also linked to the transportation of IUU caught fish due to the limited regulations of FOCs (EJF, 2013). FOC transshipment vessels decrease the transparency of catch, further aiding the ability for IUU caught fish to be sold on global markets (Gilman & Lundin, 2010). RFMOs attempt to create, and enforce documentation programs to limit IUU fishing, but illegal at-sea transshipment severely compromises the ability for these laws to be enforced (Gilman & Lundin, 2010). Furthermore, RFMOs with weak regulations surrounding transshipment often don't require reefers to verify catch while out at sea (Malarky & Lowell, 2017). Thus, transshipment often mixes legally and illegally caught fish together (Malarky & Lowell, 2017). The mixing of legally and illegally caught fish limits sustainability because regulators, processors, or consumers cannot trace where and how the fish product was caught (Malarky & Lowell, 2017).

There are some differences between IUU fishing (Figure 17) and reefer hotspots. There is a large amount of IUU fishing within the Eastern Indian Ocean (Figure 17), however it appears that reefers are not present at high densities within this location (Figure 5&6). This scarcity of reefer tracks within the Eastern Indian ocean, an area with high tuna diversity, could be a result of the limited coverage of satellites by data provider Orbcomm within that region of the world (Kroodsma et al., 2017). By being able to identify the link between a reefer activity hotspot (Figure 5) and the highest rate of IUU fishing (Figure 17) suggests that FOCs and low regulations are a driving factor behind the location of transshipment vessels.

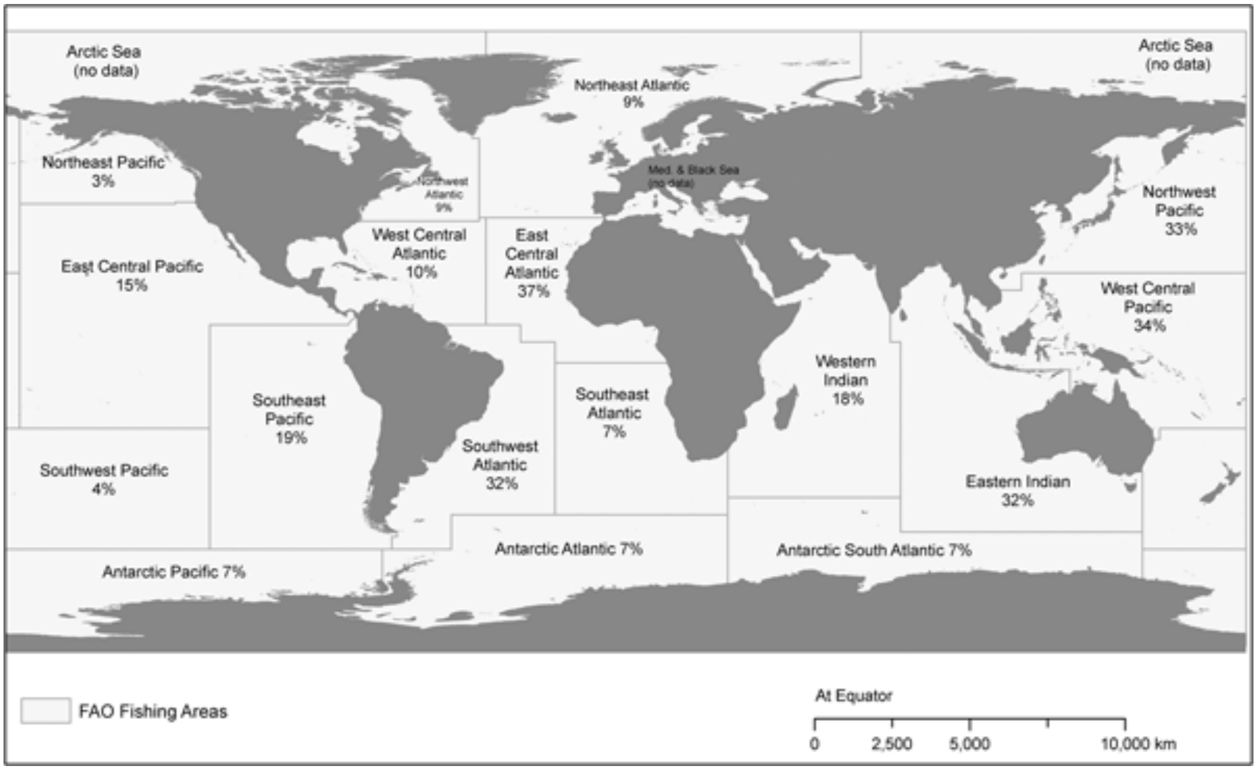

Figure 17. The world's largest fishing grounds and the corresponding percentage of global IUU fishing (from Agnew et al., 2009).

There was no statistical correlation between reefer activity and tuna diversity, however there was some visual overlap between these ranges. The largest overlap of reefers and tuna was between reefers drifting and spawning tuna distribution, with 73% of cells within tuna spawning habitat having reefers drifting. Drifting reefer data had a much larger overlap within tuna habitats, however, this is likely to be a result of the large distribution reefers have across the global oceans. It was interesting that the limited distribution of spawning habitat had more overlap with drifting activity compared to the extensive global distribution of tuna. This difference in overlap could be caused by reefer activity not being as concentrated on the high seas compared to the large hotspots along coastlines, which tuna spawning zones straddle.

It seems that tuna presence and density is not an indicator for reefer activity, despite most of the frozen tuna on the market being transported through transshipment (Miyake et al., 2010).

Tuna is an extremely high priced and high valued species within the global fishing market (Galland et al., 2016). There is a large discrepancy between unreported tuna being caught and the amount of revenue being made within the IUU markets (Figure 13 and 14). Approximately 8 million tonnes more tuna was caught by using IUU techniques (Figure 13 and 14). However, IUU caught tuna accounts for approximately 10 million dollars less than the reported tuna landings (Figures 13 and 14). The reason for this discrepancy could be a result of market regulations and practices throughout the global economy (Miller, Bush & Mol, 2014). While fish stocks become more depleted, countries and RFMOs have begun to regulate and restrict transshipment of fish before exporting to global markets (Gallic & Cox, 2006).

Processing plants of tuna exist all over the world including but not limited to, Thailand, Philippines, Indonesia, Fiji, Ecuador, Madagascar, Spain, Italy and France (Jimenez-Toribio et al., 2010). In 2015, the United States and Japan were the largest importers of fresh and frozen tuna while the US, Spain, Italy, France, the UK and Egypt were the largest importers of canned tuna (FAOa, 2015). Being some of the largest consumers of seafood and specifically canned tuna, The EU has a major influence on tuna stocks globally (Miller et al., 2014). With overall fish stocks declining, the EU has decided to take action in protecting tuna through the market. Some of the strategies being implemented are targeting what fish will be accepted into the EU markets based upon certain standards (Miller et al., 2014). These standards have taken the form of trade agreements such as catch certifications to ensure the tuna was caught legally and transshipped on land (Miller et al., 2014). Through these trade agreements, the EU has been successful at regulating other countries' fishing behaviours, specifically Pacific Islands states (Miller et al., 2014).

The EU is not the only major party using markets to protect seafood and tuna stocks. Various RFMOs including, ICCAT and CCAMLR certify catch to raise the price of legally caught species, as a way to reduce the incentive to sell fish through illegal markets (Gallic & Cox, 2006). By creating IUU limitations in the global fishing industry and some specifically for tuna species, the power of the fishing market is demonstrated and can be used as a tool to influence and reduce IUU fishing. These market regulations may also explain the price and catch discrepancy within unreported stocks (Figure 13 and 14).

Similarly to tuna distribution, there seems to be little correlation between landed tuna value, amount of catch landed and reefer density. Some countries that are large fishing nations and are known to have large reefer fleets were not part of the SAUP data set such as China and Russia (Kroodsma et al., 2017), which potentially could have skewed the results. However, the SAUP data appears to accurately depict European countries such as Spain and Italy, who have large landing values within the SAUP data set, which could supply their large capacity for canned tuna processing (Jimenez-Toribio et al., 2010). The EU has a large demand for canned tuna (Miller et al., 2014), which allows countries such as Spain and Italy to process and sell the tuna product domestically, increasing the demand for tuna (Jimenez-Toribio et al., 2010). In figure 16, West Africa data was available, suggesting the total amount of tuna catch within this region is very low. This is an interesting result, because West Africa is an area of high reefer density (Figure 5). The lack of correlation between reefer presence and high tuna catch further proves that tuna fisheries are not the major driving factor behind global transshipment patterns. Countries within the Northwest Pacific, such as Russia, Japan and China, have the largest total fish capture globally, with small pelagic species making up the largest category (FAOb, 2016). The Northwest Pacific has very little tuna activity but is a hotspot for reefer activity. This hotspot suggests that it is likely that transshipment prioritizes large multiple species fisheries and areas of limited regulations.

5.1 Limitations of this study

A limitation that needs to be considered when analyzing the data is that while AIS is very common within large vessels, not all fishing and reefer vessels have AIS (Kroodsma et al., 2017). AIS data can also be altered if crews tamper with the AIS transponder to transmit false Global Position System (GPS) locations (Hayes, 2015). Another more common way to influence AIS data is by simply turning off the AIS transmitter (Hayes, 2015). By turning off the transmitter, vessels may enter marine protected areas or engage with vessels that are fishing illegally. Evidence of turning off AIS can be identified within the data through large gaps in the vessel's track, however, while this may indicate there was interference with the data, the vessel's activities remain unknown.

Furthermore, data coverage for reefer activities may be incomplete due to limited satellite coverage (Kroodsma et al., 2017). Orbcomm does not have enough satellites within orbit to have full coverage of the global oceans at all times of the day (Kroodsma et al., 2017). As a result, there may be gaps within coverage for several hours in certain locations, causing transshipment activity to remain undetected (Kroodsma et al., 2017).

The main assumption made here is that the specific movements identified by the algorithms are in fact transshipment activities. Each vessel has had extensive background research to determine if it is a transshipment vessel, allowing for a high degree of confidence. This is based on previous research on characteristics of different vessel movements, as well as vessel type information available from sources such as fleet registries and vessel tracking databases. Therefore, while it cannot be confirmed that the movement patterns are indeed transshipment activities, it can be assumed with confidence.

Another limitation within this study is the result of incomplete data sets. The Sea Around Us Project data was missing certain countries of interest in the context of this study such as, China and Russia, and the unreported data was based upon estimated unreported tuna catch (Zeller & Pauly, 2016). China and Russia play a large role in both transshipment activity and global fish catch and consumption, and the absence of data from these countries could be skewing the picture. The Sea Around Us Project's unreported data was created through estimations based upon archives and non-fishery sources such as household nutritional surveys (Zeller & Pauly, 2016). While these estimations of unreported tuna are very reliable, it should be recognized that they are still estimations and may contain errors.

Chapter 6: Conclusion

This study focused on transshipment vessel activity and tuna habitat and diversity throughout the global oceans. The aim of the study was to identify common areas of transshipment vessel activity and if hotspots of transshipment correlated with areas of high tuna diversity. Both visual and statistical analyses suggested that there was no correlation between hotspots of reefer activities and areas of high tuna diversity. However, it was found that reefers were present in a large majority of tuna spawning habitats, and concentrated in areas of known IUU fishing. Areas with large fishing grounds such as the small pelagic fish industry off the coast of Russia and China are also hotspots of transshipment activity. There are many factors and drivers behind transshipment due to the complexity of the global fishing industry and the limited transparency in certain ports and the high seas.

6.1 Recommendations

Moving forward, more research needs to be done to determine the main drivers of transshipment and identify if specific species are being targeted. Considering country specific fish import and exports could be an interesting way to identify specific species targeted for transshipment. By identifying nations which rely heavily on transshipment and comparing with species that are highly traded, a link could be provided between the sea and the consumer. A comprehensive analysis of transshipment regulations within countries EEZs and specific RFMOs will also provide a clear picture into the location of transshipment activities. As well, creating universal transshipment regulations across all RFMOs could help to prevent transshipment vessels from finding loopholes and continuing to participate in IUU fishing (McTee, 2011). A follow up study could be done once Orbcomm satellite range increases to re-evaluate reefer activity hotspots and see if there is a shift to other locations, indicating other drivers of transshipment.

6.2 Acknowledgements:

I would like to thank Global Fishing Watch for allowing me to have access to their transshipment data. Thank you to Nate Miller and Aaron Roan at GFW for their knowledge and patience when dealing with the technical aspects of this project. Thank you to my supervisors Boris Worm and Kristina Boerder for their immense knowledge, dedication and continued support throughout this entire process, I could not have done it without them. As well, thank you to Sidney Rotchin- Black, a fellow Dalhousie honours student who also contributed countless hours to the tedious process of identifying transshipment vessels.

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. *PLoS ONE 4*(2). doi:10.1371/journal.pone.0004570

Alexander, K. E., Leavenworth, W.B., Cournane, J., Cooper, A.B., Claesson. S., Brennan, S., …Rosenberg, A.A. (2009). Gulf of Main cod in 1861: historical analysis of fishery logbooks, with ecosystem implications. *Fish and Fisheries, 10*(4), 428-229. Doi:10.1111/j.1467-2979.2009.00334.x

Aranda, M., Murua, H., & de Bruyn, P. (2012). Managing fishing capacity in tuna regional fisheries management organisations (RFMOs): Development and state of the art. *Marine Policy, 36,* 986-992. Doi: 10.1016/j.marpol.2012.01.006

Arrizabalaga, H., Dufour, F., Kell, L., Merino, G., Ibaibarriaga, L., Chust, G., … Bonhomeau, S. (2015). Global habitat preferences of commercially vulnerable tuna. *Deep Sea Research Part II: Tropical Studies in Oceanography*, *113*, 102-112. http://dx.doi.org/10.1016/j.dsr2.2014.07.001

Bache, S. (2002). Turtles, Tuna and Treaties: Strengthening the links between International Fisheries Management and Marine Species Conservation. *Journal of International Wildlife Law & Policy*, *5*(1-2), 49-64. 10.1080/13880290209353998

Block, B., Teo, S.L.H., Walli, A., Boustany, A., Stokesbury, M.J.W., Farwell, C.J., … Williams, T.D. (2005). Electronic tagging and population structure of Atlantic bluefin tuna. *Nature*, *434,* 1121- 1127.

Boyce, D., Tittensor, D., & Worm, B. (2008). Effects of temperature on global patterns of tuna and billfish richness. *Mar Ecol Prog Ser, 355*, 267-276.

Collette, B.B., Carpenter, K.E., Polidoro, B.A., Juan-Jorda, M.J., Boustany, A., Die, D.J., … Yanez, E. (2011). High Value and Long Life- Double Jeopardy for Tunas and Billfishes. *Science,333*(6040), 291-292. Doi: 10.1125/science.1208730.

Cullis-Suzuki, S., Pauly, D. (2010). Failing the high seas: A global evaluation of regional fisheries management organizations. *Marine Policy*, *34,* 1036-1042. Doi: 10.1016/j.marpol.2010.03.002

Cutlip, K. (2017). Flag of Convenience or Clock of Malfeasance? *Global Fishing Watch.* Retrieved from http://blog.globalfishingwatch.org/2017/02/flag-of-convenience-or-cloak-of-malfeasance/

Department of Fisheries and Oceans (DFO). (2014). At-Sea Observers and Electronic Monitoring. *Government of Canada*. Retrieved from http://www.dfo-mpo.gc.ca/fm-gp/sdc-cps/eng-comm/faq/obs-eng.htm#enforce

DeSombre, E. R. (2005). Fishing under Flags of Convenience: Using Market Power to Increase Participation in International Regulation. *Global Environmental Politics*, *5*(4), 73–94. http://doi.org/10.1162/152638005774785507

Environmental Justice Foundation (EJF). (2013). Transshipment at Sea. The need for a ban in west African waters. Retrieved from http://ejfoundation.org/sites/default/files/public/ejf_transhipments_at_sea_web_0.pdf

FAO (2003). Fishing Techniques: Industrial tuna longlining- Technology Fact Sheets. *Fisheries and Aquaculture Department.* Rome. Retrieved from http://www.fao.org/fishery/fishtech/1010/en

FAOa. (2016). GLOBEFISH- Analysis and information on world fish trade; Tuna- December 2015. Retrieved from http://www.fao.org/in-action/globefish/market-reports/resource-detail/en/c/358022/

FAOb. (2016).*The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all.*Rome. Retrieved form http://www.fao.org/3/a-i5555e.pdf

Gallic, B.L., & Cox. A. (2006). An economic analysis of illegal, unreported and unregulated (IUU) fishing: Key drivers and possible solutions. *Marine Policy*, *30,* 689-695. https://doi.org/10.1016/j.marpol.2005.09.008

Gaspar, P., Gregoris, Y., & Lefevre, J.M. (1990). A simple eddy kinetic energy model for simulations of the oceanic vertical mixing: Tests at station Pap and long-term upper ocean study site. *Journal of Geophysical Research, 95*(C9), 16179-16193. Doi: 10.1029/JC095iC09p16179

Gilman, E.L., Brothers, N., McPherson, G., Dalzell, P. (2006). A review of cetacean interactions with longline gear. *J. CETACEAN RES. MANAGE, 8*(2), 215-223.

Gilman, E.L., & Lundin, C.G. (2010). Minimizing Bycatch of Sensitive Species Groups in Marine Cpature Fisheries: Less from Tuna Fisheries. *Handbook of Marine Fisheries Conservation and Management.* Retrieved from https://books.google.ca/books?id=rZACECFPe1AC&printsec=frontcover&dq=Handbook+of+Marine+Fisheries+Conservation+and+Management&hl=en&sa=X&ved=0ahUKEwjH2trR3P7SAhUhh1QKHZNxDJAQ6AEIHzAA#v=onepage&q=Handbook%20of%20Marine%20Fisheries%20Conservation%20and%20Management&f=false

Gianni, M., & Simpson, W. (2005). How flags of convenience provide cover for illegal, unreported and unregulated fishing. Retrieved from http://www.wwf.org.uk/filelibrary/pdf/flagsofconvenience.pdf

Global Fishing Watch. (2016). Retrieved from http://globalfishingwatch.org

Government of Canada, Innovation, Science and Economic Development Canada. (2015). *MMSI Application Forms (Annexes*). Retrieved from http://www.ic.gc.ca/eic/site/sd-sd.nsf/eng/00009.html

Hayes, G. (2015). Manipulating AIS, part *2. Marine Electronics Journal*. Retrieved from http://www.marineelectronicsjournal.com/content/newsm/news.asp?show=VIEW&a=1

ICCAT. (2012). ICCAT Regional Observer Programme Manual. Retrieved from https://www.iccat.int/Documents/ROP/ICCAT_Observer_Manual.pdf

ICCAT. (2015). Panel 1. Retrieved from http://www.iccat.int/Documents/SCRS/Presentation/2015/Panel1-2015.pdf

INTERPOL. (2014). Study on fisheries crime in the West African coastal region. Retrieved from http://www.interpol.int/content/download/27590/369574/version/3/file/WACS%20EN.pdf

IUCN. (2011). Increased protection urgently needed for tunas. Retrieved from http://www.iucn.org/knowledge/news/?7820

Jimenez-Toribio, R., Guillotreau, P., & Mongruel, R. (2010). Global integration of European tuna markets. *Progress in Oceanography*, *86,* 166-175. Doi:10.1016/j.pocean.2010.04.022

Joseph, J. (2003) Managing fishing capacity of the world tuna fleet. FAO Fisheries Circular, *982,* 22-24. Retrieved from http://www.fao.org/3/a-y4499e.pdf

Joseph, J., Klawe, W., & Murphy, P. (1988). Tuna and Billfish- fish without a country. La Jolla, California: Inter-American Tropical Tuna Commission.

Kroodsma. D., Miller. N., & Roan. A. (2017). The Global View of Transshipment: Preliminary Findings. *Global Fishing Watch and Skytruth*. Retrieved from http://globalfishingwatch.org

Leadbitter, D., & Benguerel, R. (2014). Sustainable Tuna- Can the Marketplace Improve Fishery Management? *Business Strategy and the Environment*, *23*, 417-432. doi:10.1002/bse.1794

Majkowski, J. (2003). Fishing Techniques: Tuna purse seining- Technology Fact Sheets. FAO Fisheries and Aquaculture Department. Retrieved from: http://www.fao.org/fishery/fishtech/40/en

Malarky, L., & Lowell, B. (2017). No More Hiding at Sea: Transshipping Exposed. *OCEANA*. Retrieved from http://usa.oceana.org/TransshippingExposed

McCoy, M.A. (2012). A Survey of Tuna Transshipment in Pacific Island Countries: Opportunities for Increasing Benefits and Improving Monitoring. *Pacific Islands Forum*

Fisheries Agency. Retrieved from https://www.ffa.int/system/files/Transshipment%202012%20Report.pdf

McTee, S. (2011). Transshipment in Tuna-RFMOs and Mechanisms to Support Best Practices in Tuna Fisheries. *ISSF Technical Report 2011-09*. Retrieved from http://files.ctctcdn.com/03a79b0c001/29b28e67-743c-4941-b077-57e792d9db89.pdf

Miller. A.M.M., Bush. S.R., & Mol. A.P.J. (2014). Power Europe: EU and the illegal, unreported and unregulated tuna fisheries regulation in the West and Central Pacific Ocean. *Marine Policy*, *45*, 138-145. Doi:10.1016/j.marpol.2013.12.009

Miyake. M.P., Guillotreau. P., Sun. C.H., & Ishimura. G. (2010). Recent developments in the tuna industry: Stock, fisheries, management, processing, trade and markets. *FAO Fisheries and Aquaculture Technical Paper 543.* Retrieved from http://www.fao.org/3/a-i1705e.pdf

Myers, R. A., & Worm, B. (2003). Rapid worldwide depletion of predatory fish communities. *Nature,* 423(May), 280–283.

Paquotte, P. (2003). Tuna in the International market for seafood. In: Bridges. C.R. (Eds.), Garcia. A. (Eds.), Gordin, H. (ed.), *Domestication of the Bluefin tuna Thunnus thynnus thynuss. Zaragoza: CHIEAM* (159- 163). Cahiers Options Mediterraneennes.

Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., … Sainsbury, K.J. (2004). *Science, 305*(5682), 346-347. Doi: 10.1126/science.1098222

NOAA Fisheries. (2015). Improving International Fisheries Management February 2015 Report to Congress. Retrieved from http://www.fisheries.noaa.gov/ia/iuu/msra_page/2015noaareptcongress.pdf

Galland, G., Rogers, A., & Nickson, A. (2016). Netting Billions: A Global Valuation of Tuna. Retrieved from http://www.pewtrusts.org/en/research-and-analysis/reports/2016/05/netting-billions-a-global-valuation-of-tuna.

Reglero, P., Ciannelli, L., Balbín, R., & Alemany, F. (2012). Geographically and environmentally driven spawning distributions of tuna species in the western Mediterranean Sea, *Mar Ecol Prog Ser, 463*, 273–284. http://doi.org/10.3354/meps09800

Schmidt, C.C. (2005). Economic Drivers of Illegal, Unreported and Unregulated (IUU) Fishing. *International Journal of Marine and Coastal Law, 20*(3-4).

Zeller, D., & Pauly., D. (2016). Reconstructing marine fisheries catch data. Sea Around Us. Retrieved from http://www.seaaroundus.org

WWF. (2016). Bigeye Tuna. Retrieved from http://www.worldwildlife.org/species/bigeye-tuna