Mapping 21st Century Maritime Silk Road and its Impact to Marine Ecosystems

by

Hanyu Wang
Dr. Patrick N. Halpin, Advisor
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Abstract

Belt and Road Initiative (BRI), a controversial strategy with the goal to promote global trading, involves various risks from diverse aspects, including geopolitical, financial, and environmental perspectives. This study focuses on demonstrating the environmental impact to Large Marine Ecosystems (LME) under the influence of expanding 21st Century Maritime Silk Road (2013-2018), a key component of BRI involving maritime transshipment across continents. A total of 22,877 trips between 63 selected BRI ports in 6 years were examined. The result shows that ports around the North Sea, represented by Rotterdam port at Netherland, and ports around South Asia, represented by Laem Chabang port at Thailand, carried the most frequent shipping connections to China from 2013 to 2018. Two LMEs, South China Sea and North Sea, were most vulnerable from bio-invasion threat because they were connected to the highest variety of destinations and external LMEs.

Acknowledgement

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Executive Summary

Ballast water release, a mean to transmit invasive species across long distance via shipping, poses significant threat to healthy marine ecosystems by introducing novel pathogens and bringing the bio-invasion problem. As an environmental stressor caused from shipping, its impact should be incorporated into the goal of sustainable marine transportation so that ecosystems already suffered from higher risk of bio-invasion issue can take strict and necessary actions to protect themselves. In order to take account of shipping's environmental footprint, a geospatial analysis of recent global shipping network would be necessary, especially under the effect of a mega-size trading and transportation network proposed by and centered at China, which is the Belt and Road Initiative with a marine component called 21st Century Maritime Silk Road.

This study analyzes and maps out shipping dynamics from 2013 to 2018 under the effect of Belt and Road Initiative in order to identify the locations of most threatened marine ecosystems after acknowledging the importance of negative environmental impact from shipping activities.

The Introduction section of this paper explains the significance, origin, and background of 21st Century Maritime Silk Road, being as a marine component of Belt and Road Initiative (BRI) and involving controversies from political, financial, and environmental perspectives. The section provides some data and literature review to emphasize the expansive influence and substantial trading amount associated with Maritime Silk Road which is made up of vast shipping network. Also, Large Marine Ecosystems (LMEs) are introduced to be the unit of analysis for this study and their already vulnerable situations under rising human pressure are illustrated because industries like fishery, tourism and energy are active in LMEs due to their proximity to the coast and rich biological productivity. The bio-invasion issue brought from shipping is depicted while some past studies that used spatial modeling to assess regional risks are presented.

The Methods section is composed of data collection and data processing parts. The data collection started from world ports selection based on their involvement with BRI and a total of 63 world ports were identified as BRI ports for this study. Then, 6-year-shipping data from 2013 to 2018 between these 63 ports were obtained from the *Global Fishing Watch* database. LME shapefile was retrieved from the *LMEs of the World* website. Maritime Mobile Service Identities (MMSI) were used to filter our unidentifiable ships in the raw shipping dataset. For the data processing part, Microsoft Excel and Python were adopted to extract, organize, and filter data in order to map out shipping dynamic in certain years and around China, as a center of the network. ArcGIS Pro was used for the final data visualization to show a variety of shipping networks and the gradient of risks for LMEs across the global ocean.

The Results section showcases the 21st Century Maritime Silkroad with selected 63 ports. It includes shipping framework in both the global scale and shipping networks centered around China from 2013 to 2018. This section also presents two maps showing the degree of riskiness from bio-invasion threat for 22 LMEs that are associated with all the BRI ports. After analyzing 22,877 trips in 6 years, the North Sea, represented by Rotterdam port at Netherland, and ports around South Asia, represented by Laem Chabang port at Thailand, carried the most frequent shipping connections to China from 2013 to 2018. Two LMEs including South China Sea and

North Sea were likely to be exposed to most novel pathogens since they had the highest variety of connecting destinations and external LMEs.

This study mainly provides a baseline for future analysis on how shipping would be affected under the influence of BRI, consequently creating more expansive environmental footprint to our marine ecosystems. Future studies can include an ecological and human health risk assessment to capture local community’s risk from invasive species so that both the marine and coastal regimes can be taken account into when designing for sustainable maritime transportation.

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I. Introduction

1.1 Background and risks with Belt and Road Initiative (BRI)

Belt and Road Initiative (BRI), an ambitious global trading network proposed by People's Republic of China since 2013, has involved over 130 countries, 60% of world population, and generated roughly 6 trillion dollars of trading value till 2019 (World Bank Group, 2019; China Power Team, 2017; "From Initiative to Reality: Moments in Developing the Belt and Road Initiative."). The foundation for such a transcontinental-scale economic collaboration to occur is the building of transportation corridors for the exchange of goods. Six international economic corridors are meant to construct in order to connect China with Central Asia, Russia and Europe, contributing to the Silk Road Economic Belt which is the land portion of BRI (World Bank Group, 2019; The World Bank, 2018; OECD, 2018). For the marine portion of BRI, China is building 21st Century Maritime Silk Road to facilitate maritime transportation between China, Southeast Asia, Africa, and Europe (Koboević et al. 2018). Both the terrestrial and marine corridors require large amount of investment (~26 trillion dollars) and infrastructure expansion in participating countries, such as the building of railways, roads, bridges, tunnels, and ports (Watkins et al. 2018; China Power Team, 2017). Alongside with China's excitement in discovering more opportunity for the world, BRI's mega-size geographic influence, trillions of dollars of investment, and massive engineering projects have attracted worldwide attention and critiques from different perspectives (China Power Team, 2017; World Bank Group, 2019).

Controversies were raised over China's political intention behind BRI, the financing method supporting BRI projects, and environmental risks associated with massive infrastructure implementations along with transportation surge (Cai, 2017; CFR, 2020; OECD, 2018; World Bank Group, 2019; Losos et al. 2019). Firstly, the global scale of BRI manifests a super proactive or even aggressive profile of China's foreign policy, which is the opposite of the passive figure adopted during the 1980s (Yu, 2016). Such proactivity is fueled by the rising national pride and echoed with the "Chinese Dreams" promoted by President Xi in 2012, which can be comprehended as the "great revival of Chinese nation" (Yu, 2016; BBC, 2012). Historically, the Silk Road was adopted during Han Dynasty (206 BCE–220 CE) when China initiated a westward trading route to exchange goods with Central Asia and Europe regions (CRF, 2020). On the sea, the Maritime Silk Road could trace back to Ming dynasty (early 15th century) when marine expeditions extended up to African continent (Yu, 2016). BRI, the signature project of "Chinese Dreams", has been viewed not only as a revival of historical cultural communication pathway but also as a leverage for China to expand its geopolitical power over the great Asia area (Yu, 2016). Thus, BRI's historical background and China's political attitude really evoked global concerns over the geopolitical outcome that BRI would have to the world, especially to those third-world countries in Asia and Africa.

Beside the concerns from geostrategic intention of BRI, the geoeconomic influence on the globe through China's establishment of Asian Infrastructure Investment Bank (AIIB), as a financing engine for BRI projects in Asia, was perceived as a risk to the current international financial system constructed after World War II by the U.S. (Yu, 2016; OECD, 2018; Cai, 2017). As a growing number of U.S-allied-countries have joined AIIB, including U.K. Germany and other European countries, AIIB will not simply be a regional investment organization but will have a global impact (Yu, 2016). With more involved countries, more attention and concerns are drawn to the high risks associated with those loans that set up for projects based at weak economies and shaky political regimes, such as in Pakistan (Cai, 2017). Such instability exacerbates the high-cost-low-return scenarios many BRI projects are prone to fall into, especially in the third-world countries (OECD, 2018; Cai, 2017).

Other than the above risks to international politics and economies, BRI still bear a great challenge, which is to maintain environmental sustainability while developing mega-size infrastructure projects both on land and on the sea (Ascensão et al. 2018). On terrestrial regime, World Bank Group (WBG) and World Wildlife Fund (WWF) both conducted assessment on presenting the environmental risks associated with 6 land based BRI corridors (Losos et al. 2019; WWF, 2017). Losos et al. pointed out direct effects brought from the expansion of roads and railways, including modifications to physical environment, generation of air, water and noise pollution, destructions of ecosystem services, and the intervention to wildlife behavior (Losos et al. 2019). They also demonstrated deforestation and greenhouse gas (GHG) emissions as indirect effects (Losos et al. 2019). WWF's spatial analysis report mapped out different levels of risks that BRI corridors would bring to various biodiversity hotspots, key habitats, protected areas etc. (WWF, 2017). Marine transport component of BRI is also a source of environmental risks due to vessels' immense air emissions, improper ballast water disposal and noise pollution (WWF) but has not been well studied.

1.2 Background with 21st Century Maritime Silk Road

21st Century Maritime Silk Road (or Maritime Silk Road), carrying China's marine strategy, which is the development of blue economy and the facilitation of blue partnership, adheres to the pursuit of green development, ocean-based prosperity, maritime security, innovation, and co-governance (BBC, 2017). One important significance of this paper resonates with the call for a green development of Maritime Silk Road because the stewardship of marine ecological services requires BRI policy makers to understand where and how the current marine anthropogenic activities have been affecting our marine ecosystems.

Maritime Silk Road specifically expands a deep-sea trading between Southeast Asia, Africa, and Europe, involving major port constructions, new maritime connection development, and enhanced ocean co-governance with participating countries (BBC, 2017; Koboević, 2018). The westward advancement of the road already bares crucial economic significance for China, as 80% of oil and half of the gas import passes the Maritime Silk Road (Wang, 2017). The import amount of these raw materials to China will tend to increase, as there is a high potential for trading with countries such as Association of Southeast Asian Nations (ASEAN) and Persian Gulf countries (Wang, 2017). Between China and ASEAN countries, there was already a growth rate of 23.94% for trade volume in 2013, an increase of 10.26% for 2015, and an average growth rate of 10.45% from 2000 to 2015 (Wang, 2017). The trade volume China had with both the ASEAN and Persian Gulf countries increased over 26% from 2000 to 2015 (Wang, 2017). Thus, with a steady historic growth of trading, China's expanding manufacturing industry, and the rich resources available from South Asia and Persian Gulf, the economic potential for Maritime Silk Road will be huge (Wang, 2017).

1.3 Human impact on Large Marine Ecosystems (LME)

Managing our great ocean with unbelievably diverse species that occupies 70% of our planet is an undoubtedly challenging task so the proposed approaches for an efficient marine management would then involve various perspectives, including focuses on specific species, on particular geographic areas, or on certain habitats (Alexander, 1993). In order to take account into the important interactions between species and their living habitats, and to acknowledge countries' managerial limit of ocean waters, the idea of ecosystem-based management was proposed and the concept of Large Marine Ecosystems (LME) was raised in 1980s (Alexander, 1993; Halpern et al. 2008). There are 66 LMEs in world's ocean and they lie along continental margins, covering 200,000 square kilometers that extend from estuaries to the ocean beyond (IUCN, 2018). LMEs produce 90% of global fish catch, manifesting its high biodiversity, productivity, and important economic value with an estimated worth of 3 trillion dollars of ecosystem service provided (IUCN, 2018; Hoagland and Jin, 2008).

On the same time, attracted by LMEs' high biological productivity and their adjacency to the continent, various fishing, recreational, shipping and energy industries will leave their footprint at LMEs, creating pollution to the water body and disturbances to marine habitats, eventually leading to destructions of vulnerable habitats (Hoagland and Jin, 2008). Halpern et al.'s study constructed a spatial model to show the spatial distribution of various human impacts to 20 LMEs and found out that highest impacted areas were in continental shelf and slopes, including North and Norwegian seas, South and East China seas, Eastern Caribbean, North American eastern seaboard etc. (Halpern et al. 2008). In order to better manage LMEs by properly distributing limited financial resources for the establishment of sustainable programs, Hoagland and Jin developed an index approach to incorporate socioeconomic development and the level of marine activities in various LMEs (Hoagland and Jin, 2008). According to their index, LME regions with low socioeconomic development but with high marine industrial activities involved are identified to be prioritized for potential financial support from international sources because they are unable to fund themselves for a sustainable coastal development (Hoagland and Jin, 2008).

1.4 Environmental impact from ships' ballast water disposal

Among all the various human activities on marine ecosystems, the shipping footprint is never a negligible factor. Due to the disposal of ballast water when loading and unloading, the issue of invasive species and the introduction of pathogens would create threat to local LME ("Ballast Water Management"). Ballast water is a vast amount of seawater sucked up or discharged by ships before sailing, taking up 30% to 50% of the total cargo weight, with a capacity up to ten thousand tons or more ("Breaking down the Ballast Water Problem"; WHO, 2011). The intake and disposal of the ballast water is a measure for ships to balance weight so that they can maintain a steady navigation (WHO, 2011). As ships travel thousands of miles away, massive amount of the ballast water carrying thousands of marine species including algae, planktons, plants and animals will also transferred and get disposed to a coastal region with completely different ecology ("Ballast Water: How to Avoid the Resulting Threat in the Oceans"). Thus, the large number of indigenous species contained in the ballast water would become a biological threat to the local coastal community where ships make stops at.

There have been several past studies looking at the environmental risk of ballast water disposal using the spatial modeling approach but none of them examined the influence of BRI on the ballast water issues in either global or regional scale. Lim et al. (2016) conducted a regional risk assessment for non-indigenous marine species (NIMS) faced by Singapore based on the vessel movement records with two factors, ships' residence time and location of vessels' last port stop (Lim et al., 2016). Another regional study on ballast water discharge on Australia was implemented by Cope et al. (2015). The study predicted the ballast water discharge scale and ranked the associated risks of various invasive species into Australia with shipping model and vessels data from 1999 to 2012 (Cope et al., 2015). Azmi et al. (2014) also examined the risk of secondary transfer of newly introduced marine species by building a hub and spoke network (Azmi et al., 2014).

II. Methods

2.1 Data collection

In order to map 21st Century Maritime Silk Road and to conduct spatial analysis of six-year-shipping activities, determination of port locations would be the first step, which are also the nodes of our network construction. First, ports locations were determined by filtering out selected BRI-participating ports from the world port data called World Port Index, 26th edition, 2017, obtained from *National Geospatial-Intelligence Agency* in Springfield, Virginia. The selection of 15 BRI-participating ports along China's coastline was based on the official document released by *National Development and Reform Commission of the People's Republic of China*, called "Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road" (2015). Also, the selection of remaining BRI-participating ports across the globe was based on the BRI map produced by Mercator Institute for China Studies in May 2018, called "The Belt and Road Initiative creates a global infrastructure network" (2018). A total of 63 BRI ports were identified and their GPS locations were extracted from the Google Satellite map.

The six-year (2013-2018) shipping record was obtained from *Global Fishing Watch* (GFW) database, containing trips with only a starting port location and an ending port location, and both are from those 63 selected ports. Before acquiring data from GFW, each of the port was designated with respective buffer radius, which is a distance to accompany a single GPS location so that a port coverage can be retrieved. All the respective buffer radius was extracted from examining Google Satellite image by identifying the periphery of port infrastructure. The buffer radiuses range from 2 km to 23 km, depending on different sizes of ports.

The retrieved six-year shipping record contained many unrecognized trips with false IDs. Thus, trips with unrecognized national codes according to Maritime Mobile Service Identities (MMSI) were removed from the dataset. The Python code for clearing shipping record can be shown in Appendix 2.6. The final shipping record for six years to use, from 2013 to 2018, contains 22,877 trips.

Other than shipping record, geographic information on 66 Large Marine Ecosystems (LMEs) is essential to the study. The shapefile was downloaded from *Large Marine Ecosystems of the World*, containing their shape areas, names, and locations ("Digital Data").

2.2 Data processing

Three data processing software were used, including Microsoft Excel, Python and ArcGIS pro. Excel and Python were used to filter, summarize, and distill raw shipping record data. A variety of Python packages were used during the data filtering and extraction process, such as Pandas, Geopandas, and Numpy. The plotly and folium packages were utilized to visualize data on Python. Join function was used to attach ports' GPS locations to all the departing and arriving ports on shipping record dataset. Unique function was used to find unique shipping connections, the variety of unique connections that each LME had been associated with, and the count of each unique line. Masks were made on Python script to parse out different time periods.

After data was cleaned, ArcGIS pro was used to visualize and showcase various shipping network. "XY to Line" was used to generate curved lines between two GPS locations of connected ports. Figure 2 was created using this tool after the data was parsed out in six years and the internal Chinese trips were removed using Python codes. “Find Identical” command was used to remove identical connections. The symbology for shipping framework was changed to proportional symbols so that the thickness of lines can manifest the frequency of trips.

In order to construct a China-centric shipping network, ports connected to any of the 15 Chinese BRI ports were identified and their frequencies of attached trips were calculated using Python codes shown in Appendix 2.5. Then, the degree of riskiness from bio-invasion issue was shown in a color ramp from green to red for 22 LMEs after the number of shipping connections and the variety of connected LMEs were calculated with codes shown in Appendix 2.4 and 2.7.

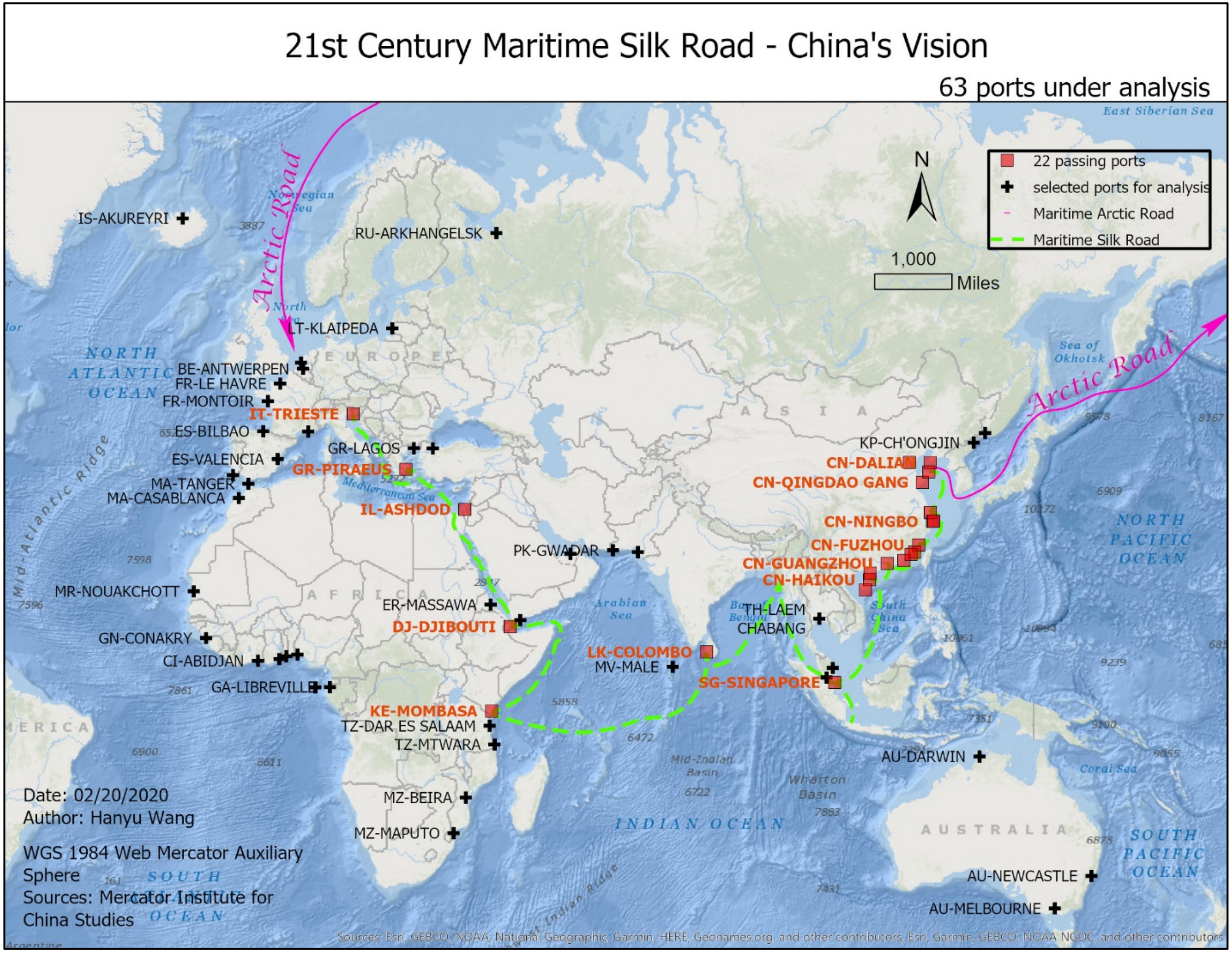
III. Results

The analysis constitutes four components which overall visualizes the global shipping dynamics from 2013 to 2018 and identifies key LMEs with highest risks due to shipping. The first section depicts the 21st Century Maritime Silk Road along with the involved BRI ports. Then, a sequence of global shipping framework was established with trips’ frequencies incorporated in network. The popular importing and exporting locations and annual gross tonnage associated with Chinese ports were identified and calculated. Lastly, South China Sea and North Sea, two LMEs, are most vulnerable ecosystems from shipping intervention.

3.1 21st Century Maritime Silk Road and ports identification

Sixty-three world ports were examined and considered as existing BRI harbors for the analysis of this paper while it is necessary to acknowledge that BRI is a growing and expanding projects with no official list of seaport sites yet. 25 of the ports are Asian, 3 of them at Australia, 18 of them in Africa, the rest 17 ports are in Europe and Middle East (Figure 1). As Figure 1 demonstrates, among these 63, only 22 of them are close to the actual major Silk Road route (Eder, 2018). The others are still considered to be BRI related because they are likely to connect with terrestrial infrastructure such as railways and highways as part of Silk Road Economic Belt.

Figure 1. Map showing China's vision for 21st Century Maritime Silk Road including 63 selected ports for analysis. Both the major Silk Road and the proposed Arctic Road are shown.



The Maritime Silk Road delineated on Figure 1 is a rough representation of how China envisioned for the Road, to facilitate marine connections between Eurasia continent, Africa and Oceania. The green dashed line does not represent an actual navigation route. However, this route reveals a few potential main regions or ports for BRI marine transportation, including Mediterranean Sea (Trieste port and Piraeus port), Gulf of Aden (Djibouti port), Mombasa port, Colombo port and Singapore port.

3.2 Global shipping framework

Based on the data set, a global shipping framework comprised of shipping connections between 63 BRI ports are presented in figure 2. Each line represents a trip from a port to another while the actual shipping track is not as manifested in the line. From 2013 to 2018, the unique global connections ranged from 200 to 300 with no consistent increase or decrease. The connections between internal Chinese ports were eliminated from these maps because domestic transshipment is not a focus of BRI project. The thickness of each line represents the number of trips documented in that year between two connected ports. Due to the limitation of the dataset, the trips associated with those 15 Chinese ports were underestimated.

Across six years, the overall frameworks do not carry significant differences between each other. From 2014 to 2015, more connections were established between African ports and Chinese ports (Figure 2). In 2018, connections emerged between western African ports and Newcastle port at Australia.

Looking at the thickness and aggregates of lines, the busiest trip in six years are between Piraeus port, Greece and Ambarli port, Turkey (around 200 trips per year). There have always been plenty of internal trips within Europe, especially between Le Havre port, France and

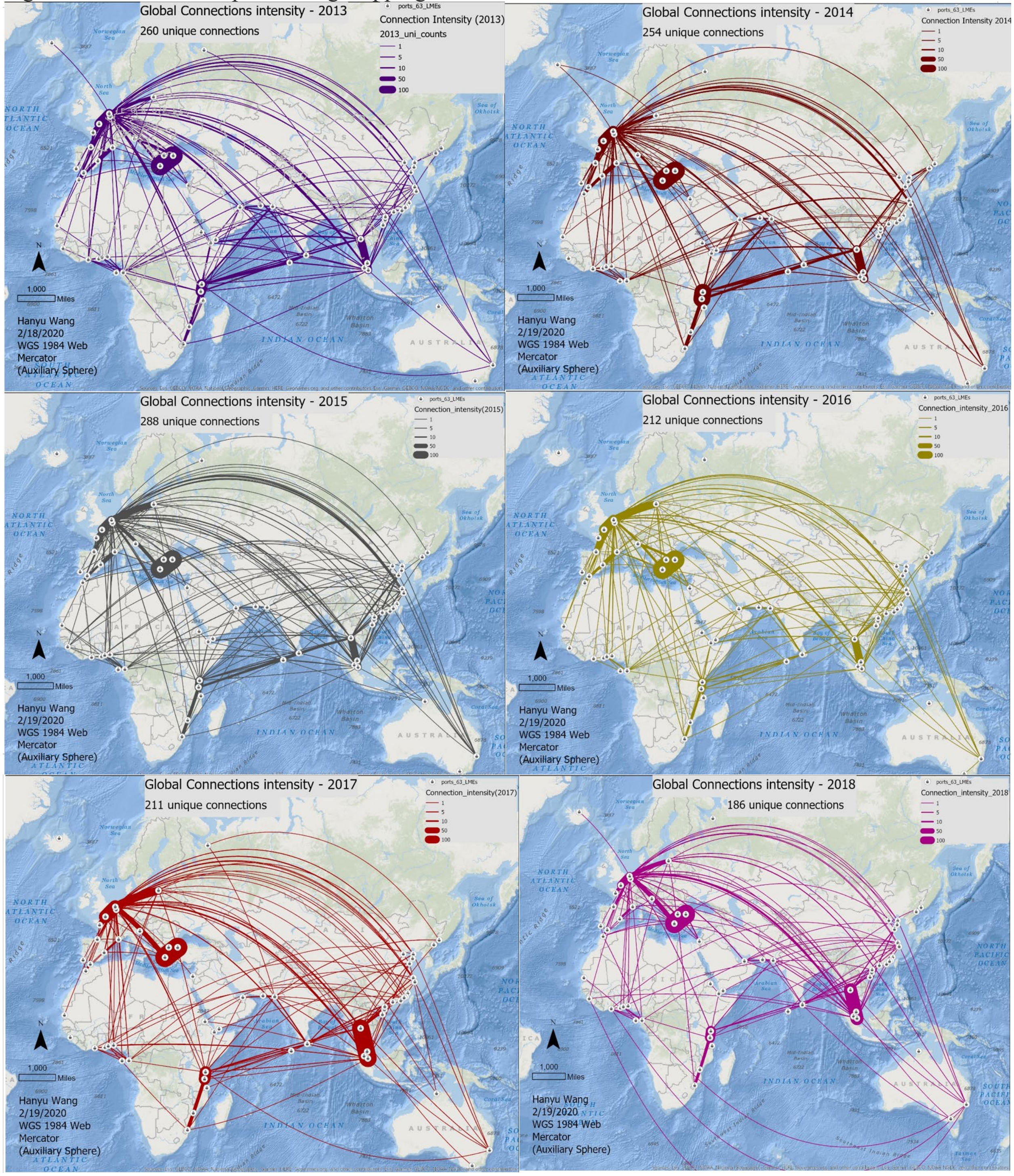
Rotterdam port, Netherlands (about 100 trips per year). In 2017 and 2018, the transshipment between Laem Chabang, Thailand and Singapore intensified, with 135 to 150 trips per year (Table 1).

Table 1. below lists out the frequencies of trips for top five selected connections. None of them are inter-continental but these ports are all along the Maritime Silk Road route as shown in Figure 1. They could be important stops for ships coming from Europe to reach south Asia.

Table 1. Counts of trips from 2013 to 2018 for top five connections

	Five connections- trips per year	2013	2014	2015	2016	2017	2018
1	GR-PIRAEUS-TR-AMBARLI	225	199	229	201	172	193
2	KE-MOMBASA-TZ-DAR ES SALAAM	120	174	97	87	102	102
3	TZ-DAR ES SALAAM-KE-MOMBASA	113	130	76	48	60	54
4	FR-LE HAVRE-NL-ROTTERDAM	109	114	102	107	114	79
5	SG-SINGAPORE-TH-LAEM CHABANG	89	88	86	76	154	135

Figure 2. A series of maps showing shipping connections and intensities from 2013 to 2018



3.3 China-centric shipping network

BRI was proposed and initiated by China and has been regarded as a central strategy for the nation. Thus, China is anticipated to be the geographic center of the whole BRI infrastructure framework. In order to capture where all the Chinse BRI ports have shipping connections with, table 2 lists out top five ports where vessels from China visited to, during 2013 to 2018. Figure 3 highlighted all the 25 international BRI ports that received vessels coming from Chinese ports.

Rotterdam, located at an endpoint of Maritime Silk Road, received the highest amount of ships from China. Laem Chabang port, located in South Asia, had the second highest number of ships from China. Figure 3 shows that China is connected to a pretty spread out number of international BRI ports.

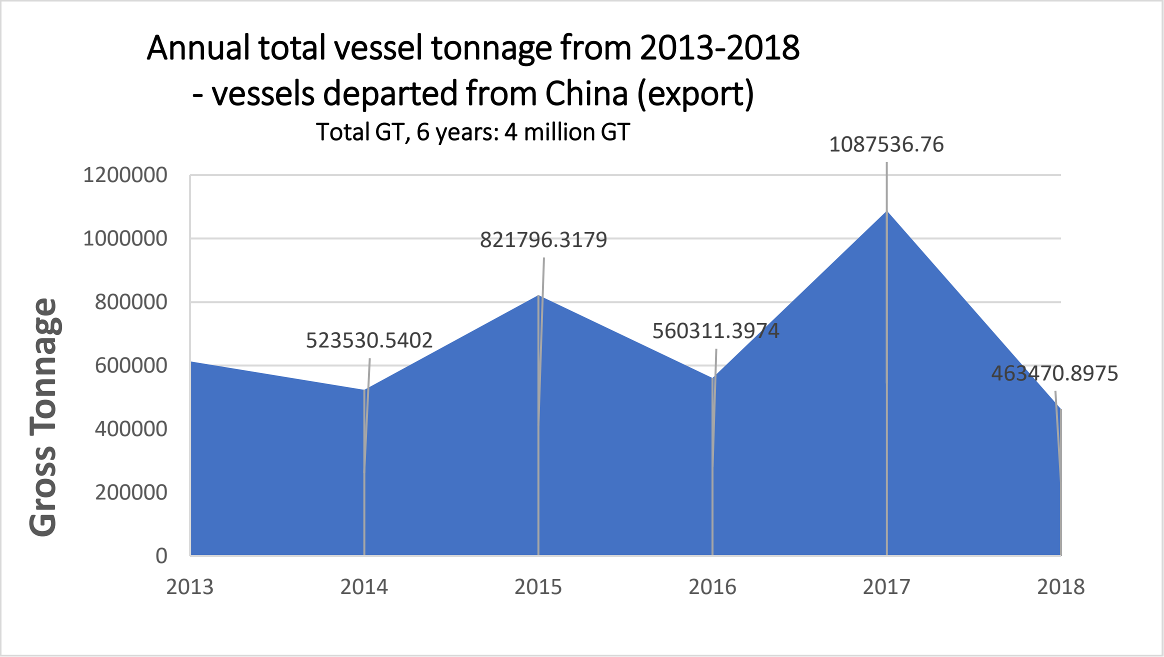
The annual total vessel tonnage in the unit of gross tonnage (Figure 4) represents a cumulative cargo volume for all ships departed from China in that year, excluding those domestic transshipment within China. From 2014 to 2017, there had been an increasing trend of annual total tonnage with a peak at 2017.

Table 2. The total vessel counts of most visited destinations (excluding domestic destinations) for ships departed from Chinese ports (2013-2018)

Top 5 ports	vessel count (6 years)
NL-ROTTERDAM	39
TH-LAEM CHABANG	34
BE-ANTWERPEN	18
AU-NEWCASTLE	14
LK-COLOMBO	12

Figure 3. Twenty-five BRI Ports labeled in red received vessels leaving from China during 2013 to 2018. The circled ports are top 4 most visited port destinations.

Figure 4.



In order to visualize a China centric network, foreign vessels arriving at Chinese ports would also be an important part of the analysis. Figure 3 took account of all the 167 documented trips from the dataset that departed China and made a stop at foreign BRI ports (2013-2018). Meanwhile, figure 5 shows that there had been 300 trips that arrived at Chinese ports but also previously made stops at other international BRI ports (2013-2018). From these two sets of data, it seemed that China had more import than export in maritime industry.

Table 3. shows that there is a dominant number of vessels coming from Laem Chabang port and Singapore port to China, both from the South Asia region. According to figure 1, ports in South Asia should be the last few stops of Maritime Silk Road, before arriving in China.

Rotterdam port became one of the top five port origins for ships arrived at China and it is also a top port destination for ships coming from China, making it an important harbor in Maritime Silk Road (table 3, 2).

Figure 6 depicts the trend of annual total vessel tonnage change from 2013 to 2018, for foreign ships arriving at China, which could be considered as import. The cumulative 6-year gross tonnage for the import to China was twice of the export volume as shown in figure 4.

Figure 6 does not illustrate an increasing or decreasing trend of total tonnage but reveals a peak in gross tonnage at year of 2015 with 2 million of gross tonnage record.

Table 3. The total vessel counts for top 5 ports that had sent out the most vessels to China (2013-2018)

Top 5 ports	Vessel count (6 years)
TH-LAEM CHABANG	85
SG-SINGAPORE	46
NL-ROTTERDAM	41
GA-LIBREVILLE	24
LK-COLOMBO	22

Figure 5. Twenty-five BRI Ports labeled in red sent out vessels that would make stop(s) at Chinse ports during 2013 to 2018. The circled ports are top 5 port origins.

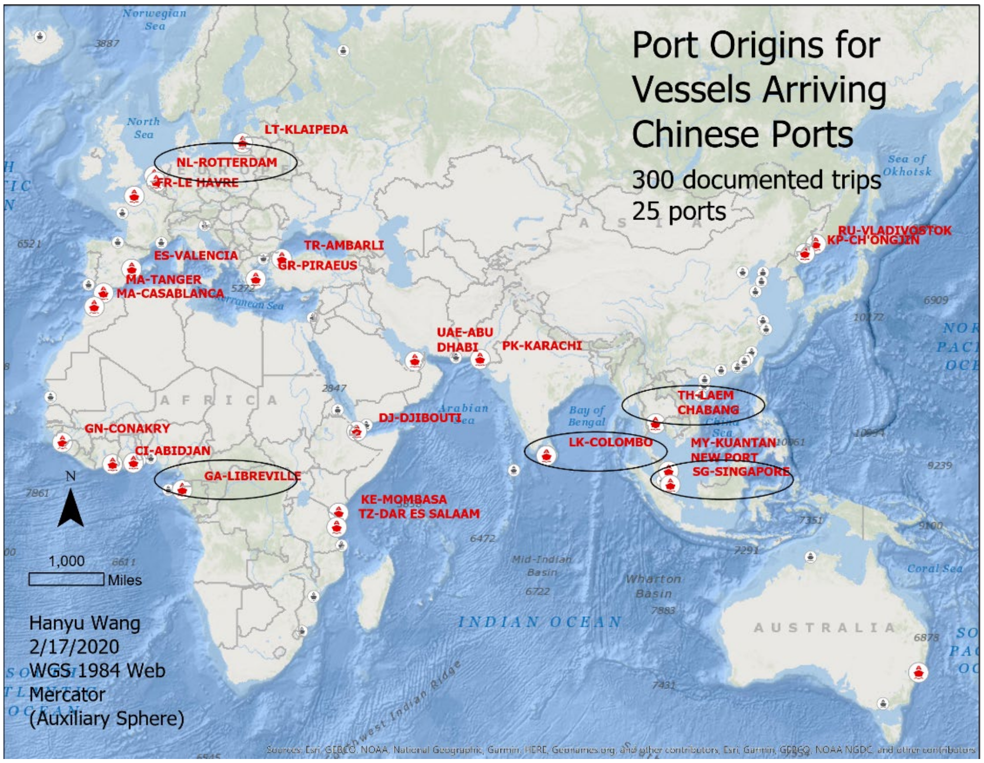
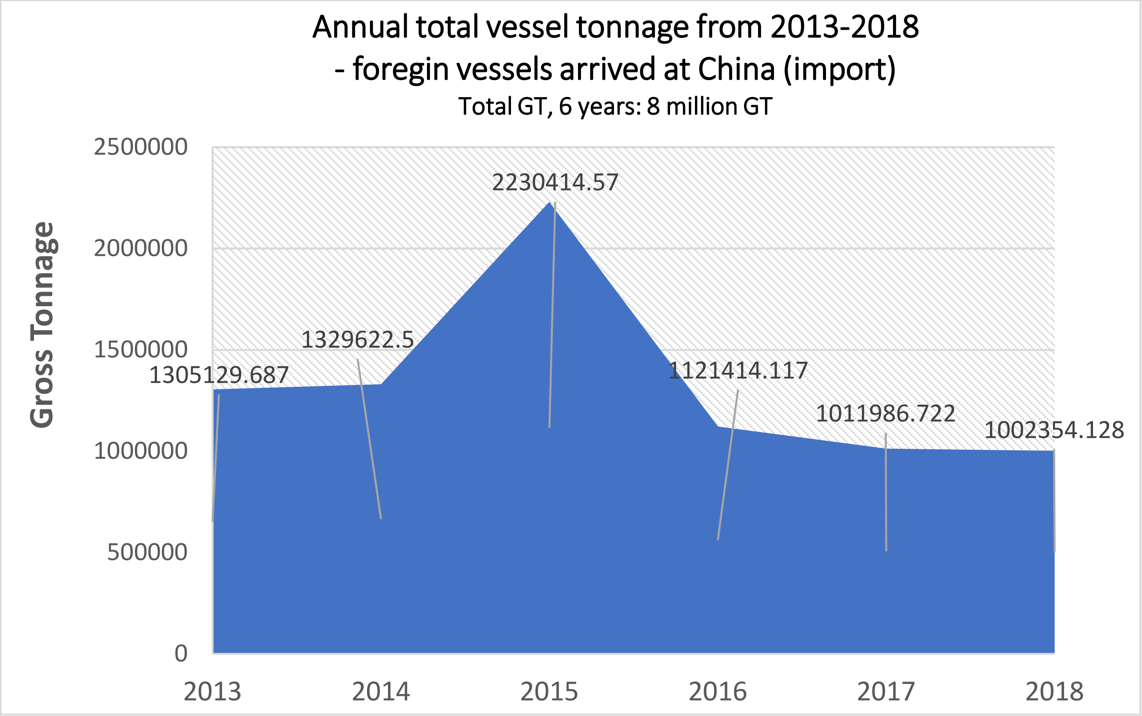


Figure 6.



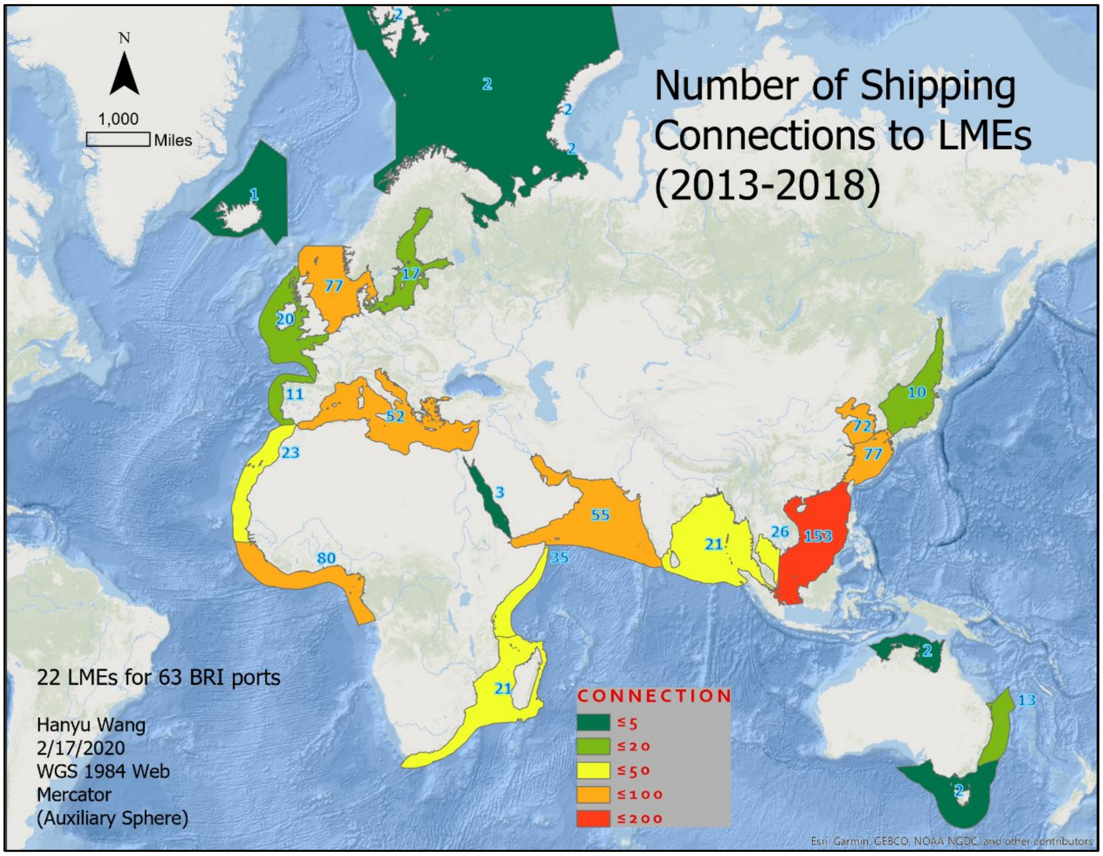
3.4 Impact on Large Marine Ecosystems (LME)

Among 66 LMEs across the world's ocean, 22 of them are correlated with 63 BRI ports and these areas are highlighted in Figure 7. As mentioned before, long distance and cross-habitat shipping activities would invoke invasive species problem due to ballast water release and biofouling. Thus, marine ecosystems with more diverse external shipping connections would have higher risk of be exposed to invasive species and associated water pollution issues.

As Figure 7. illustrates, the LME with the most variety of shipping connection (153 in six years) would be South China Sea, the only LME carrying over 100 shipping lines. It can be easily distinguished from other LMEs due to such high environmental risk. 7 out of 15 Chinese ports sit right on South China Sea coastline (Figure 1 and Figure 7).

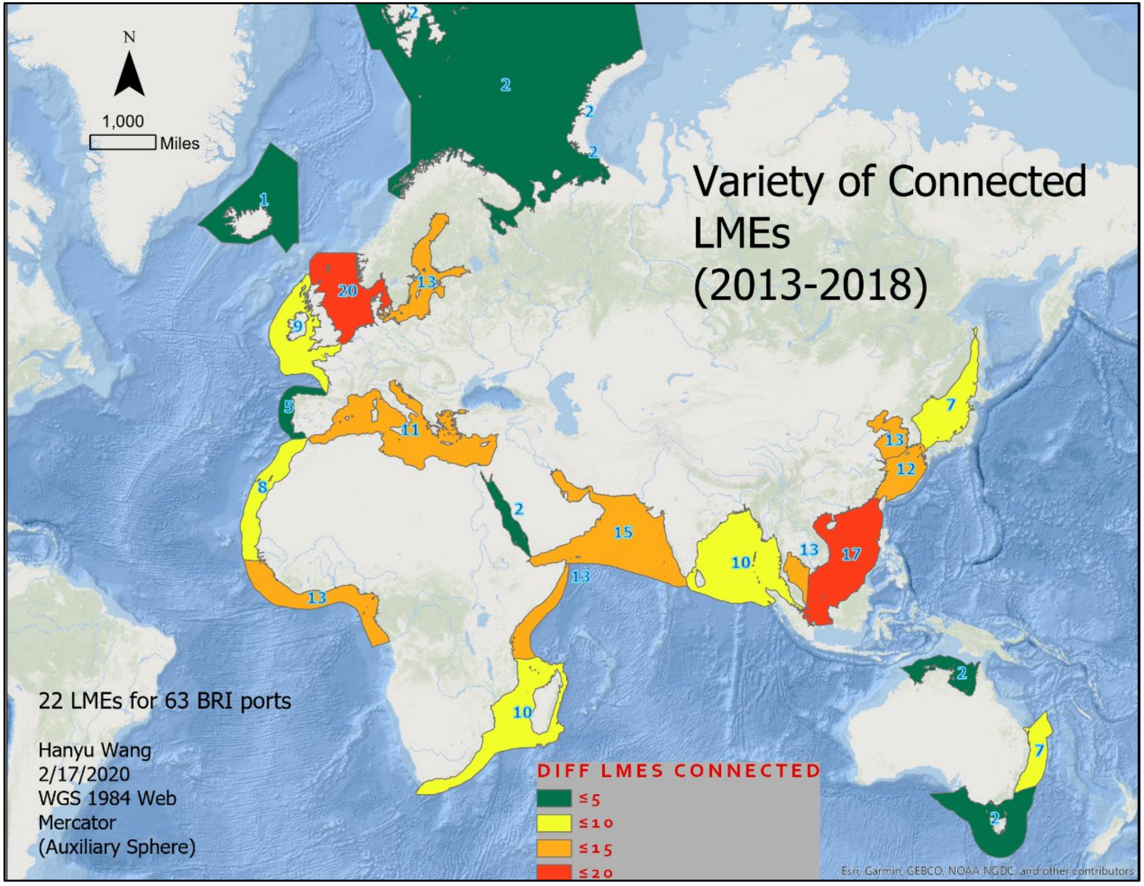
The next tier of LMEs with shipping connections ranging between 50 and 100 include Guinea Current (80 lines), North Sea (77 lines), East China Sea (77 lines), Yellow Sea (72 lines) Arabian Sea (55 lines) and Mediterranean Sea (52 lines). The East China Sea and Yellow Sea both have four Chinese ports by the coast. Among seven of the LMEs, including South China Sea, five of them are along the Maritime Silk Road route (Figure 1).

Figure 7. Map showing number of unique shipping connections associated with each LME as labeled on top. The color gradient of the LMEs is a manifestation of shipping intensity.



Other than the amount of unique connections carried by each LME, the variety of external LMEs could also be a great proxy to show the degree of environmental risks bared by marine ecosystems. Comparing Figure 7 with Figure 8, region with the highest variety of connecting LMEs is North Sea (20 LMEs), while South China Sea has the second most variety (17 LMEs). Thus, even though North Sea only has half of the distinct shipping lines as of South China Sea, the vessels stopped at North Sea came from 20 other LMEs (Figure 8). North Sea has been exposed to biological invasion from 20 different ecosystems.

Figure 8. Map showing number of different LMEs connected to each respective LME



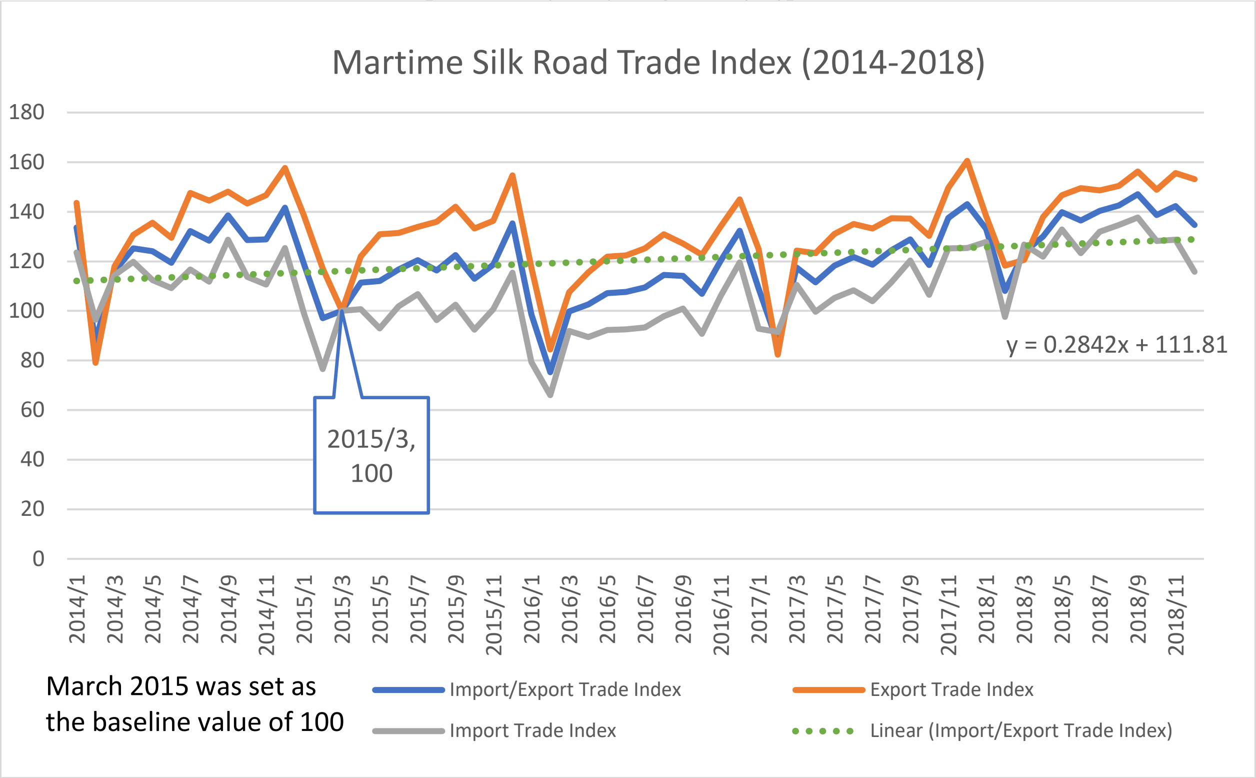
IV. Discussions

The objective of this project is to construct a global shipping network for maritime transportation under the effect of 21st Century Maritime Silk Road (2013-2018) and to identify which were the most vulnerable LMEs due to shipping. In order to build the network and to weigh the risks for different LMEs, shipping connections between 63 BRI ports in these six years were analyzed, global shipping framework was constructed, China-centric shipping network was presented, and the variety of connected LMEs was calculated as a proxy.

All the shipping networks presented in this study serve as a baseline for the future assessment of Belt and Road Initiative's impact to the global transshipment dynamic because BRI is still expanding while incorporating more countries and associating with bigger transportation infrastructures. The shipping frameworks in these six years can not readily manifest the emerging investment from BRI but provide very important fundamental information on global marine transportation condition.

The trading development in the past few years can be shown in figure 9 which was obtained from the official Belt and Road Portal, depicting the fluctuations of Maritime Silk Road Trade Index (STI) from 2014 to 2018, created by Ningbo Shipping Exchange ("Index Analysis"). The STI is calculated based on the values of exported and imported goods at the customs in a monthly routine and the base point of 100 was set based on trading values on March 2015 ("Index Analysis"). Figure 9 shows a consistent pattern within a year and an increasing trend from 2014 to 2018. By the end of 2018, the export trade index was 153.18, the import trade index was 115.8 and the import/export trade index was 134.66 ("Index Analysis").

Figure 9. Figure showing the Maritime Silk Road Trade Index from 2014 to 2018 obtained from official Belt and Road Portal in Chinese (https://www.yidaiyilu.gov.cn/jcsjpc.htm)



There are various limitations associated with the shipping dataset, including the incomprehensive trips documented, lack of stopping ports during the trip, and insufficient shipping data for most of Chinese ports. During the six years, there were only 22,877 trips between all the 63 ports according to the dataset. Among them, only 467 trips were associated with Chinese ports, which would likely be underestimated. Such incomprehensiveness could be derived from deviation in estimating buffer radius for each port. Also, each trip record only has origin and destination locations without the stopping locations during the trip, making the impact to LMEs along the shipping route not traceable.

Improvement can be made to the quality and scope of the data for a better representation of recent maritime activities and for an extended LME impact review. In acquiring the actual shipping track, the environmental footprint of each vessel can then be visualized. LMEs along each shipping route could be identified and be incorporated into environmental risks assessment.

Another limitation is related to the geospatial analysis of LMEs when accounting for their risks from bio-invasion as the differences in ecologies between LMEs were not incorporated. All the 22 LMEs represented by 63 ports were considered to be distinct to each other equally while not taking into account of the various levels of distances between them. Thus, to advance the geospatial analysis for LMEs, an ecological model demonstrating the degrees of differences between LMEs should be adopted, integrating oceanographic variables and interval-distances between each LMEs.

For future work in capturing the environmental impact from 21st Century Maritime Silk Road, the arising ecological and human health issues in coastal communities that are close to vulnerable LMEs can be examined. The transfer of invasive species and potential pathogens resulted from the ballast water displacement and biofouling could be diagnosed after necessary sampling. Then, concerning the specific groups of species or pathogens, the potential adverse effect, exposure routes and dose-response profiles will be developed for an assessment of risks to local ecological and human community. The spatial analysis of shipping activities and the environmental risk assessment of ballast water disposal in the future, together can thoroughly demonstrate the impact from Maritime Silk Road.

This study is significant as it established the baseline for global shipping dynamics, allowing predictions to make on how BRI will further influence the marine ecosystem. Decision makers for BRI that strive to construct a green and sustainable Silk Road would find this study useful as it fills the research gap in assessing environmental impact on the marine regime from BRI.

V. Appendix

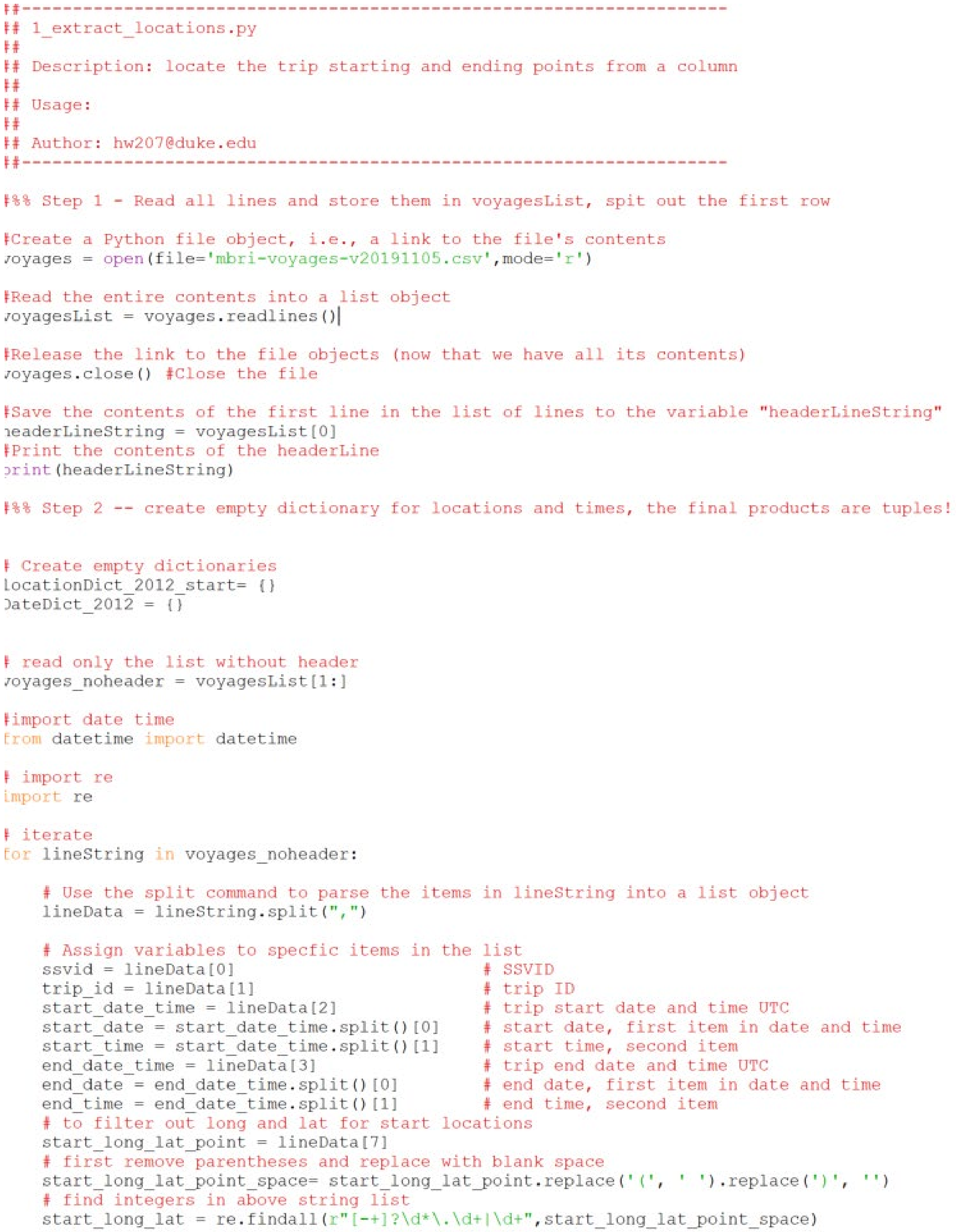
1. A list of 63 ports

NO.	Port City	Country	Buffer distance (km)	Large Marine Ecosystems	Longitude	Latitude
1	AU-DARWIN	Australia	10	North Australian Shelf	130.849795	-12.462281
2	AU-MELBOURNE	Australia	5	Southeast Australian Shelf	144.909002	-37.841860
3	AU-NEWCASTLE	Australia	5	East Central Australian Shelf	151.767180	-32.900751
4	BE-ANTWERPEN	Belgium	16	North Sea	4.407283	51.241231
5	CI-ABIDJAN	Ivory Coast	7	Guinea Current	-4.023366	5.304378
6	CN-DALIAN	China	23	Yellow Sea	121.653047	38.931204
7	CN-FUZHOU	China	15	East China Sea	119.474919	26.006438
8	CN-GUANGZHOU	China	20	South China Sea	113.575830	22.866419
9	CN-HAIKOU	China	10	South China Sea	110.283881	20.033985
10	CN-NINGBO	China	15	East China Sea	122.045613	29.883562
11	CN-QINGDAO GANG	China	15	Yellow Sea	120.201960	36.014168
12	CN-QUANZHOU	China	7	South China Sea	118.722503	24.813590
13	CN-SANYA	China	4	South China Sea	109.497537	18.236384
14	CN-SHAN T OU	China	7	South China Sea	116.726051	23.351102
15	CN-SHANGHAI	China	13	East China Sea	121.656262	31.322896
16	CN-TIANJIN XIN GANG	China	15	Yellow Sea	117.741242	38.985768
17	CN-XIAMEN	China	10	South China Sea	118.059036	24.408998
18	CN-YANTAI	China	8	Yellow Sea	121.379970	37.576021
19	CN-ZHANJIANG	China	15	South China Sea	110.400587	21.165339
20	CN-ZHOUSHAN	China	20	East China Sea	122.277228	29.941782
21	DJ-DJIBOUTI	Djibouti	5	Arabian Sea	43.142428	11.608738
22	ER-MASSAWA	Eritrea	3	Red Sea	39.466745	15.608199
23	ES-BILBAO	Spain	7	Iberian Coastal	-3.040589	43.343775
24	ES-VALENCIA	Spain	5	Mediterranean Sea	-0.329244	39.449560
25	FR-LE HAVRE	France	5	Celtic-Biscay Shelf	0.148577	49.472603
26	FR-MARSEILLE	France	9	Mediterranean Sea	5.365056	43.295418
27	FR-MONTOIR	France	13	Celtic-Biscay Shelf	-2.157867	47.297380
28	GA-LIBREVILLE	Gabon	17	Guinea Current	9.433728	0.400490
29	GH-TEMA	Ghana	4	Guinea Current	0.005692	5.626542
30	GN-CONAKRY	Guinea	3	Guinea Current	-13.718893	9.514547
31	GR-LAGOS	Greece	2	Mediterranean Sea	25.118888	41.004715
32	GR-PIRAEUS	Greece	3	Mediterranean Sea	23.640709	37.945587
33	IL-ASHDOD	Israel	5	Mediterranean Sea	34.645448	31.828921

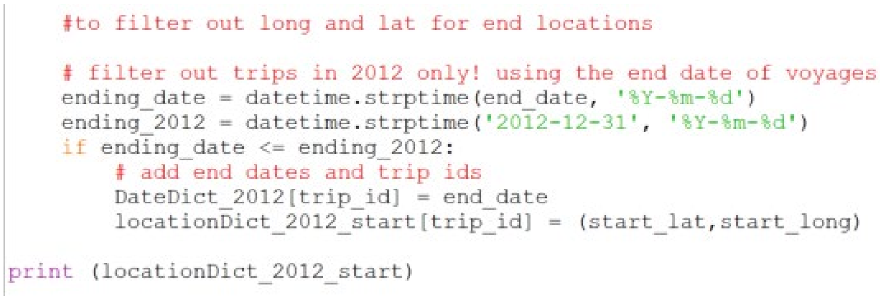
34	IS-AKUREYRI	Iceland	3	Iceland Shelf and Sea	-18.077322	65.685893
35	IT-TRIESTE	Italy	6	Mediterranean Sea	13.766667	45.650000
36	KE-MOMBASA	Kenya	7	Somali Coastal Current	39.664510	-4.072781
37	KP-CH'ONGJIN	North Korea	6	Sea of Japan	129.759703	41.759903
38	LK-COLOMBO	Sri Lanka	6	Bay of Bengal	79.826701	6.945397
39	LT-KLAIPEDA	Lithuania	10	Baltic Sea	21.093654	55.727224
40	MA-CASABLANCA	Morocco	10	Canary Current	-7.597159	33.603968
41	MA-TANGER	Morocco	10	Canary Current	-5.804507	35.789170
42	MR-NOUAKCHOTT	Mauritania	3	Canary Current	-16.023656	17.992421
43	MV-MALE	Maldives	3	Arabian Sea	73.506301	4.179758
44	MY-KUANTAN NEW PORT	Malaysia	5	Gulf of Thailand	103.424297	3.977168
45	MY-MALACCA	Malaysia	3	Bay of Bengal	102.244628	2.190884
46	MZ-BEIRA	Mozambique	4	Agulhas Current	34.835591	-19.818505
47	MZ-MAPUTO	Mozambique	17	Agulhas Current	32.545385	-25.960354
48	NG-LAGOS	Nigeria	6	Guinea Current	3.370747	6.457109
49	NL-ROTTERDAM	Netherlands	15	North Sea	4.037779	51.952309
50	PK-GWADAR	Pakistan	5	Arabian Sea	62.341525	25.110586
51	PK-KARACHI	Pakistan	14	Arabian Sea	66.983221	24.806904
52	PT-LAGOS	Portugal	3	Iberian Coastal	-8.671473	37.103939
53	RU-ARKHANGELSK	Russia	5	Barents Sea	40.541116	64.528352
54	RU-VLADIVOSTOK	Russia	5	Sea of Japan	131.882035	43.092992
55	SG-SINGAPORE	Singapore	10	South China Sea	103.773657	1.283154
56	ST-SAO TOME	Saint Thomas and Prince	3	Guinea Current	6.737119	0.346664
57	TG-LOME	Togo	8	Guinea Current	1.277344	6.141120
58	TH-LAEM CHABANG	Thailand	14	Gulf of Thailand	100.891801	13.058096
59	TR-AMBARLI	Turkey	7	Mediterranean Sea	28.678945	40.970488
60	TZ-DAR ES SALAAM	Tanzania	10	Somali Coastal Current	39.286484	-6.821678
61	TZ-MTWARA	Tanzania	5	Agulhas Current	40.198124	-10.267938
62	UAE-ABU DHABI	United Arab Emirates	5	Arabian Sea	54.382486	24.514640
63	YE-ADEN	Yemen	4	Arabian Sea	45.007914	12.795001

2. Codes for python

2.1 Python code to extract and locate points from raw dataset



```
##---------------------------------------------------------------------
## 1_extract_locations.py
##
## Description: locate the trip starting and ending points from a column
##
## Usage:
##
## Author: hw207@duke.edu
##---------------------------------------------------------------------

#%% Step 1 - Read all lines and store them in voyagesList, spit out the first row

#Create a Python file object, i.e., a link to the file's contents
voyages = open(file='mbri-voyages-v20191105.csv',mode='r')

#Read the entire contents into a list object
voyagesList = voyages.readlines()

#Release the link to the file objects (now that we have all its contents)
voyages.close() #Close the file

#Save the contents of the first line in the list of lines to the variable "headerLineString"
headerLineString = voyagesList[0]
#Print the contents of the headerLine
print(headerLineString)

#%% Step 2 -- create empty dictionary for locations and times, the final products are tuples!


# Create empty dictionaries
LocationDict_2012_start= {}
DateDict_2012 = {}


# read only the list without header
voyages_noheader = voyagesList[1:]

#import date time
from datetime import datetime

# import re
import re

# iterate
for lineString in voyages_noheader:

    # Use the split command to parse the items in lineString into a list object
    lineData = lineString.split(",")

    # Assign variables to specfic items in the list
    ssvid = lineData[0]                        # SSVID
    trip_id = lineData[1]                      # trip ID
    start_date_time = lineData[2]              # trip start date and time UTC
    start_date = start_date_time.split()[0]    # start date, first item in date and time
    start_time = start_date_time.split()[1]    # start time, second item
    end_date_time = lineData[3]                # trip end date and time UTC
    end_date = end_date_time.split()[0]        # end date, first item in date and time
    end_time = end_date_time.split()[1]        # end time, second item
    # to filter out long and lat for start locations
    start_long_lat_point = lineData[7]
    # first remove parentheses and replace with blank space
    start_long_lat_point_space= start_long_lat_point.replace('(', ' ').replace(')', '')
    # find integers in above string list
    start_long_lat = re.findall(r"[-+]?\d*\.\d+|\d+",start_long_lat_point_space)
```

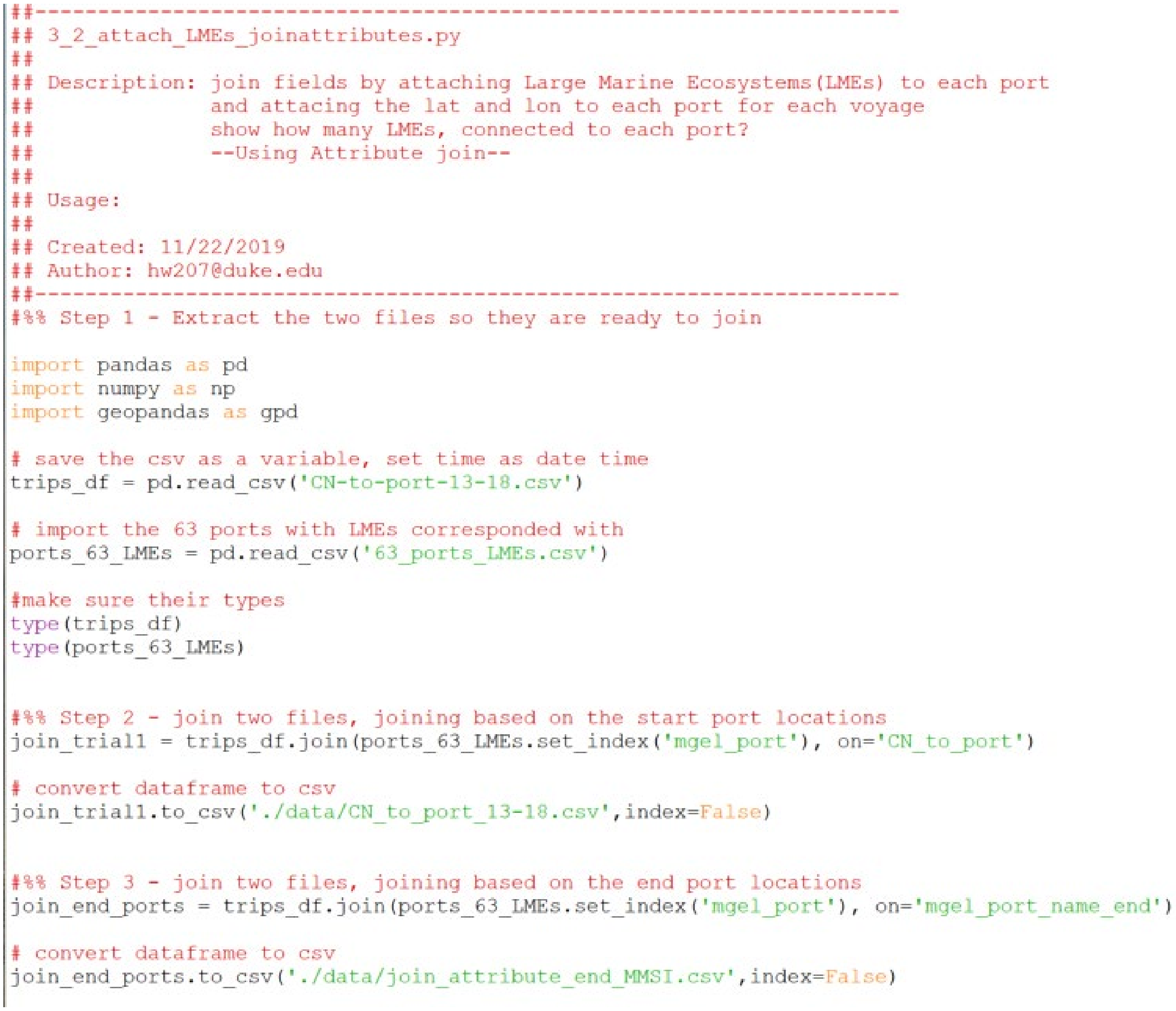


```
    #to filter out long and lat for end locations

    # filter out trips in 2012 only! using the end date of voyages
    ending_date = datetime.strptime(end_date, '%Y-%m-%d')
    ending_2012 = datetime.strptime('2012-12-31', '%Y-%m-%d')
    if ending_date <= ending_2012:
        # add end dates and trip ids
        DateDict_2012[trip_id] = end_date
        locationDict_2012_start[trip_id] = (start_lat,start_long)

print (locationDict_2012_start)
```

2.2 Show connections on map using python folium package

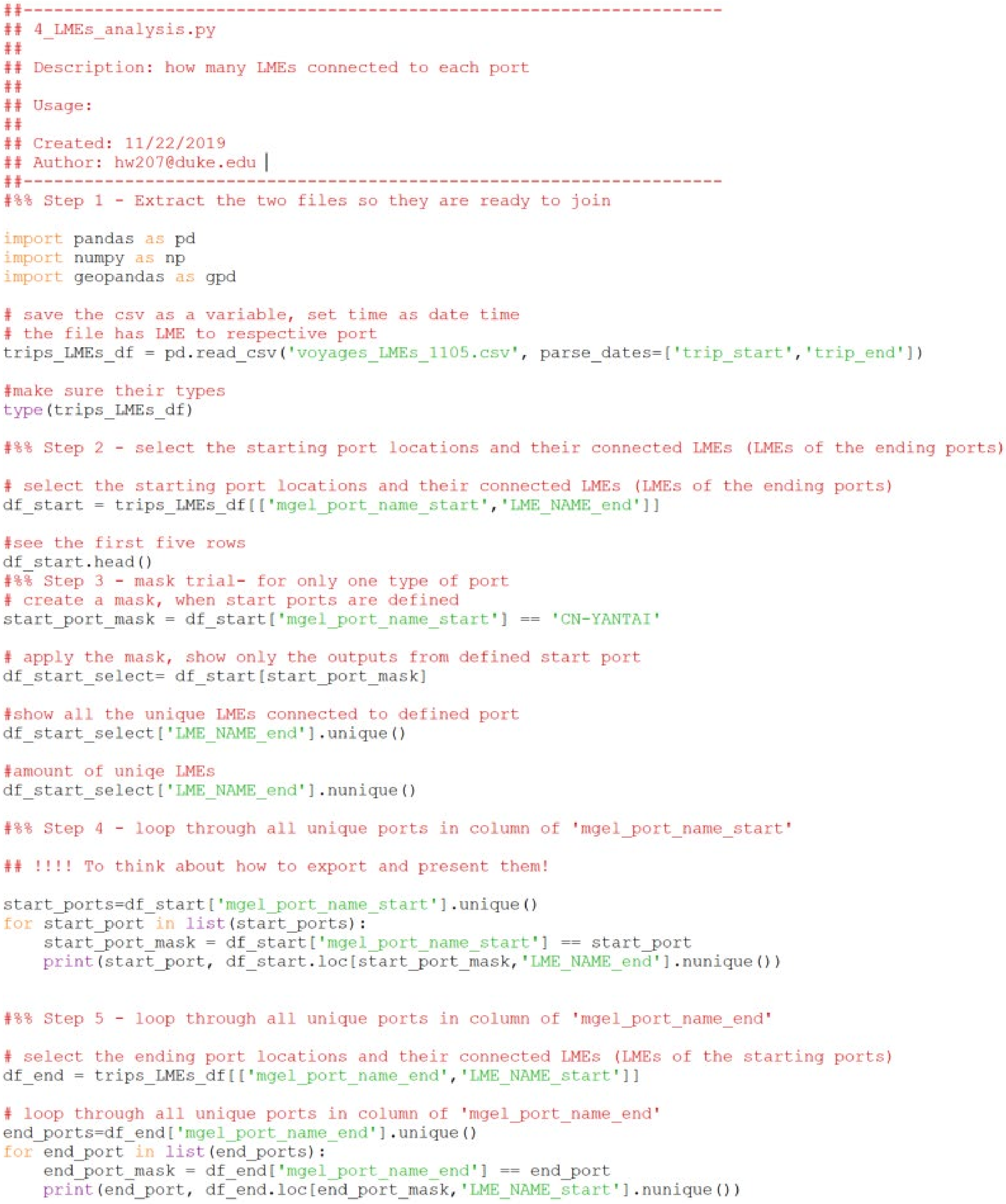
```
##--------------------------------------------------------------------
## 2_points_to_line.py
##
## Description: To show voyages by putting lines into the map based on starting and ending locations for year 2012
##
##
## Author: hw207@duke.edu (for MP)
##--------------------------------------------------------------------

#%% Step 1 - Select rows in year 2012 only (basically the same idea as Task 1 but using pandas masks)
import pandas as pd
# import numpy
import numpy as np

# save the csv as a variable, set time as date time
trips_df = pd.read_csv("../voyages_LMEs_1105.csv", parse_dates=['trip_start','trip_end'])

#Create date objects for the start and end dates for 2012
#set the datetime to UTC which is consistent with trip_end
startDate = pd.to_datetime('2012-01-01').tz_localize('UTC')
endDate = pd.to_datetime('2013-01-01').tz_localize('UTC')

#Create the date masks
startMask = (trips_df['trip_end'] >= startDate)
endMask = (trips_df['trip_end'] < endDate)

#Apply the masks, using the bitwise '&' to return rows where all masks are true
trips_2012 = trips_df[startMask & endMask]

#%% Step 2 -- install folium

pip install folium


#%% Step 3 -- Plot lines, using geopandas, folium
#import folium packages
import folium
import numpy as np

#determine the median lat/lon
medianLat = trips_2012['lat_start'].median()
medianLng = trips_2012['lon_start'].median()

#construct the map
map = folium.Map(location=[medianLat,medianLng], zoom_start=1.5)

#show port locations to map as markers
trips_2012.apply(lambda row:folium.CircleMarker(location=[row["lat_start"], row["lon_start"]],
                                              radius=5, color="blue")
                                             .add_to(map), axis=1)

#show voyages on map by connecting start and end locations
trips_2012.apply(lambda row:folium.PolyLine(locations=[[row["lat_start"], row["lon_start"]],[row["lat_end"], row["lon_end"]]],
                                              radius=5,weight=1, color ="red")
                                             .add_to(map), axis=1)

#%% Step 4 - Save map and please go to data folder to access html link for map
map.save("./data/voyages_2012.html")
print("please open data folder to acces the html link for interactive map and please feel free to zoom in and out! Thanks!")
```

2.3 Join two csv files together based on one column of information using Attribute join.



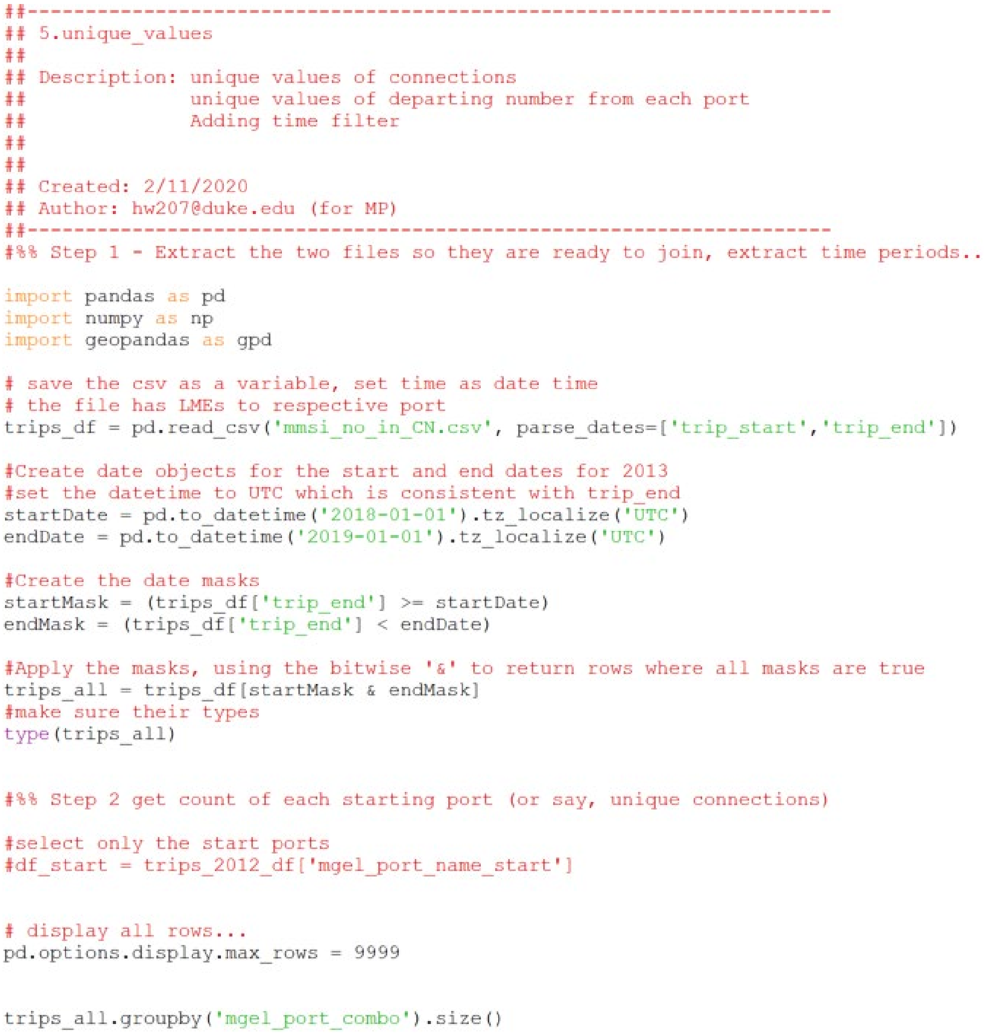
```
##---------------------------------------------------------------------
## 3_2_attach_LMEs_joinattributes.py
##
## Description: join fields by attaching Large Marine Ecosystems(LMEs) to each port
##              and attacing the lat and lon to each port for each voyage
##              show how many LMEs, connected to each port?
##              --Using Attribute join--
##
## Usage:
##
## Created: 11/22/2019
## Author: hw207@duke.edu
##---------------------------------------------------------------------
#%% Step 1 - Extract the two files so they are ready to join

import pandas as pd
import numpy as np
import geopandas as gpd

# save the csv as a variable, set time as date time
trips_df = pd.read_csv('CN-to-port-13-18.csv')

# import the 63 ports with LMEs corresponded with
ports_63_LMEs = pd.read_csv('63_ports_LMEs.csv')

#make sure their types
type(trips_df)
type(ports_63_LMEs)


#%% Step 2 - join two files, joining based on the start port locations
join_trial1 = trips_df.join(ports_63_LMEs.set_index('mgel_port'), on='CN_to_port')

# convert dataframe to csv
join_trial1.to_csv('./data/CN_to_port_13-18.csv',index=False)


#%% Step 3 - join two files, joining based on the end port locations
join_end_ports = trips_df.join(ports_63_LMEs.set_index('mgel_port'), on='mgel_port_name_end')

# convert dataframe to csv
join_end_ports.to_csv('./data/join_attribute_end_MMSI.csv',index=False)
```

2.4 Identify the number of different LMEs connected to each port



```
##-------------------------------------------------------------------
## 4_LMEs_analysis.py
##
## Description: how many LMEs connected to each port
##
## Usage:
##
## Created: 11/22/2019
## Author: hw207@duke.edu
##-------------------------------------------------------------------
#%% Step 1 - Extract the two files so they are ready to join

import pandas as pd
import numpy as np
import geopandas as gpd

# save the csv as a variable, set time as date time
# the file has LME to respective port
trips_LMEs_df = pd.read_csv('voyages_LMEs_1105.csv', parse_dates=['trip_start','trip_end'])

#make sure their types
type(trips_LMEs_df)

#%% Step 2 - select the starting port locations and their connected LMEs (LMEs of the ending ports)

# select the starting port locations and their connected LMEs (LMEs of the ending ports)
df_start = trips_LMEs_df[['mgel_port_name_start','LME_NAME_end']]

#see the first five rows
df_start.head()
#%% Step 3 - mask trial- for only one type of port
# create a mask, when start ports are defined
start_port_mask = df_start['mgel_port_name_start'] == 'CN-YANTAI'

# apply the mask, show only the outputs from defined start port
df_start_select= df_start[start_port_mask]

#show all the unique LMEs connected to defined port
df_start_select['LME_NAME_end'].unique()

#amount of uniqe LMEs
df_start_select['LME_NAME_end'].nunique()

#%% Step 4 - loop through all unique ports in column of 'mgel_port_name_start'

## !!!! To think about how to export and present them!

start_ports=df_start['mgel_port_name_start'].unique()
for start_port in list(start_ports):
    start_port_mask = df_start['mgel_port_name_start'] == start_port
    print(start_port, df_start.loc[start_port_mask,'LME_NAME_end'].nunique())


#%% Step 5 - loop through all unique ports in column of 'mgel_port_name_end'

# select the ending port locations and their connected LMEs (LMEs of the starting ports)
df_end = trips_LMEs_df[['mgel_port_name_end','LME_NAME_start']]

# loop through all unique ports in column of 'mgel_port_name_end'
end_ports=df_end['mgel_port_name_end'].unique()
for end_port in list(end_ports):
    end_port_mask = df_end['mgel_port_name_end'] == end_port
    print(end_port, df_end.loc[end_port_mask,'LME_NAME_start'].nunique())
```

2.5 Extracting unique connections and getting counts for each unique line

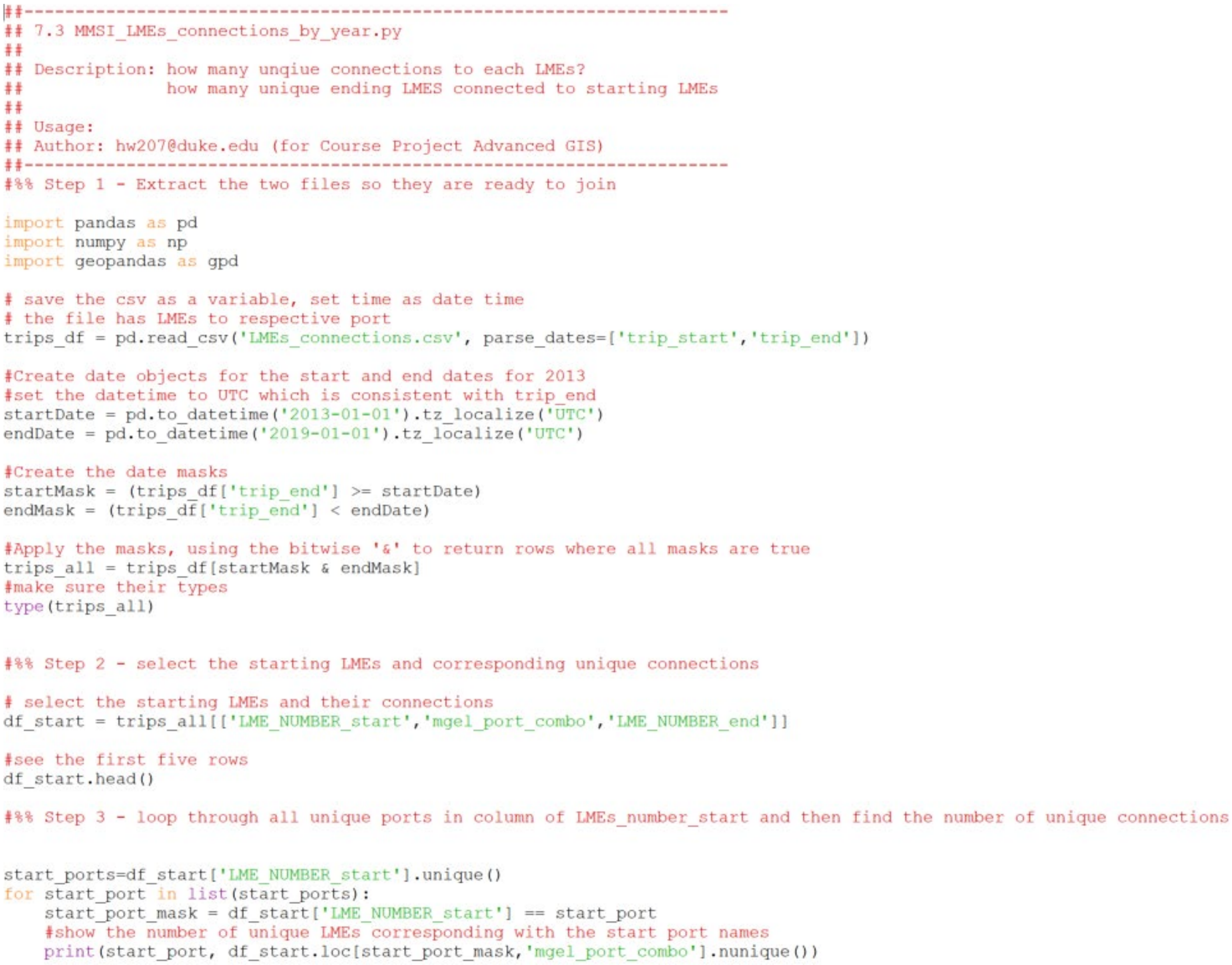


```
##---------------------------------------------------------------------
## 5.unique_values
##
## Description: unique values of connections
##              unique values of departing number from each port
##              Adding time filter
##
##
## Created: 2/11/2020
## Author: hw207@duke.edu (for MP)
##---------------------------------------------------------------------
#%% Step 1 - Extract the two files so they are ready to join, extract time periods..

import pandas as pd
import numpy as np
import geopandas as gpd

# save the csv as a variable, set time as date time
# the file has LMEs to respective port
trips_df = pd.read_csv('mmsi_no_in_CN.csv', parse_dates=['trip_start','trip_end'])

#Create date objects for the start and end dates for 2013
#set the datetime to UTC which is consistent with trip_end
startDate = pd.to_datetime('2018-01-01').tz_localize('UTC')
endDate = pd.to_datetime('2019-01-01').tz_localize('UTC')

#Create the date masks
startMask = (trips_df['trip_end'] >= startDate)
endMask = (trips_df['trip_end'] < endDate)

#Apply the masks, using the bitwise '&' to return rows where all masks are true
trips_all = trips_df[startMask & endMask]
#make sure their types
type(trips_all)


#%% Step 2 get count of each starting port (or say, unique connections)

#select only the start ports
#df_start = trips_2012_df['mgel_port_name_start']


# display all rows...
pd.options.display.max_rows = 9999


trips_all.groupby('mgel_port_combo').size()
```

2.6 Filter out trips with unidentifiable SSVID using known MMSI country codes

```
##---------------------------------------------------------------------
## 7_MMSI_filter.py
##
## Description: Filter out ssvid that do not start with correct MMSI country codes
##              join the file (code-country) with just the code file
##
## Author: hw207@duke.edu (for MP 2020)
##---------------------------------------------------------------------
#%% Step 1 - Select ships with correct MMSI country codes

import pandas as pd
import numpy as np

#load original data
trips_country_df = pd.read_csv('MMSI_country_code_display.csv', parse_dates=['trip_start','trip_end'])

#import code-country file
code_country_df = pd.read_csv('MMSI_Country_Codes.csv',encoding='latin-1')

type(trips_country_df)
type(code_country_df)

#%% Step 2 - join two files, joining based on the start port locations
join_trial1 = trips_country_df.join(code_country_df.set_index('Country_Codes'), on='country_code_mmsi')

# convert dataframe to csv
join_trial1.to_csv('./data/MMSI_country_join.csv',index=False)
```

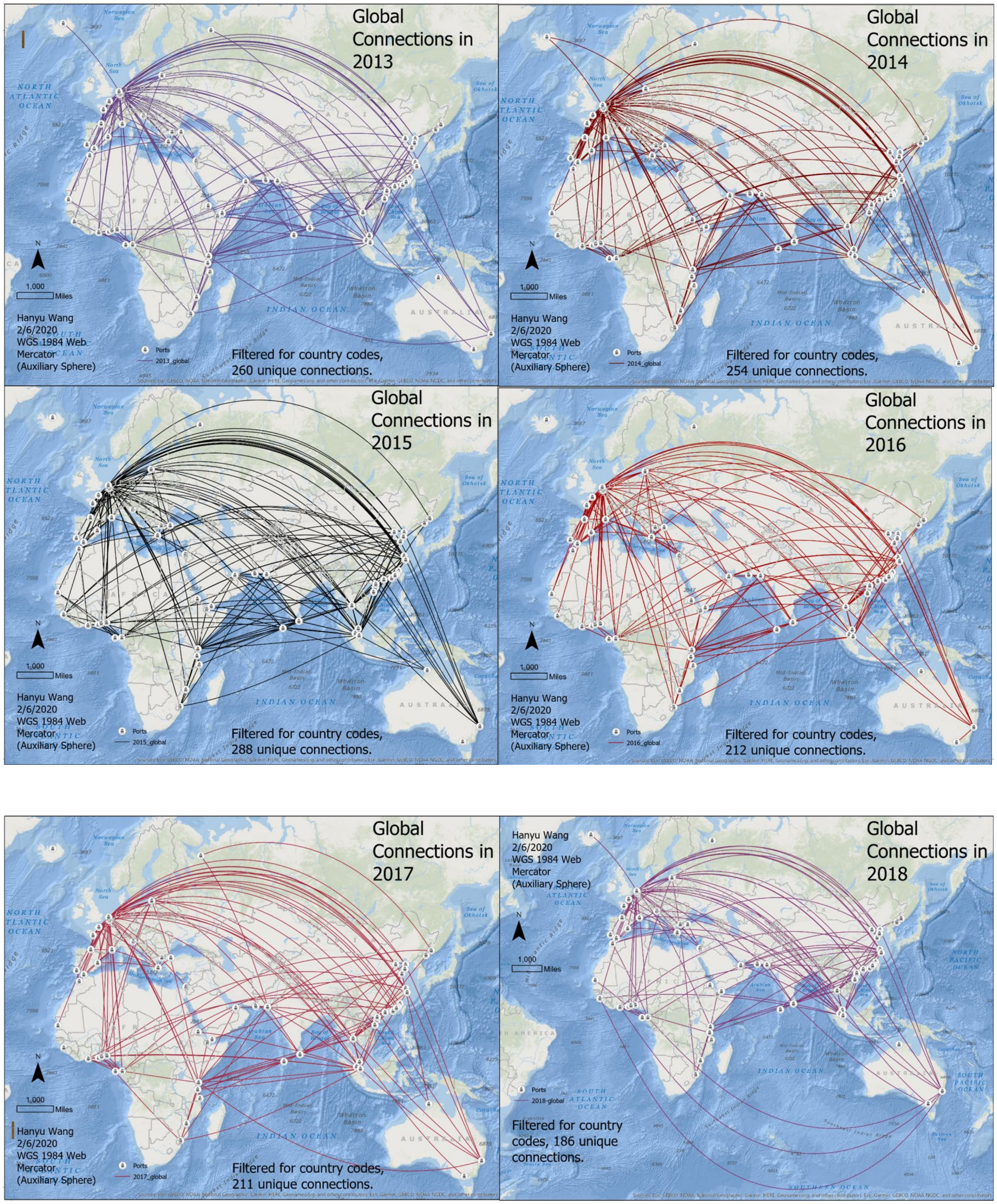
2.7 Find unique connections and different LMEs associated with each LME



```
##---------------------------------------------------------------------
## 7.3 MMSI_LMEs_connections_by_year.py
##
## Description: how many unqiue connections to each LMEs?
##              how many unique ending LMES connected to starting LMEs
##
## Usage:
## Author: hw207@duke.edu (for Course Project Advanced GIS)
##---------------------------------------------------------------------
#%% Step 1 - Extract the two files so they are ready to join

import pandas as pd
import numpy as np
import geopandas as gpd

# save the csv as a variable, set time as date time
# the file has LMEs to respective port
trips_df = pd.read_csv('LMEs_connections.csv', parse_dates=['trip_start','trip_end'])

#Create date objects for the start and end dates for 2013
#set the datetime to UTC which is consistent with trip_end
startDate = pd.to_datetime('2013-01-01').tz_localize('UTC')
endDate = pd.to_datetime('2019-01-01').tz_localize('UTC')

#Create the date masks
startMask = (trips_df['trip_end'] >= startDate)
endMask = (trips_df['trip_end'] < endDate)

#Apply the masks, using the bitwise '&' to return rows where all masks are true
trips_all = trips_df[startMask & endMask]
#make sure their types
type(trips_all)


#%% Step 2 - select the starting LMEs and corresponding unique connections

# select the starting LMEs and their connections
df_start = trips_all[['LME_NUMBER_start','mgel_port_combo','LME_NUMBER_end']]

#see the first five rows
df_start.head()

#%% Step 3 - loop through all unique ports in column of LMEs_number_start and then find the number of unique connections


start_ports=df_start['LME_NUMBER_start'].unique()
for start_port in list(start_ports):
    start_port_mask = df_start['LME_NUMBER_start'] == start_port
    #show the number of unique LMEs corresponding with the start port names
    print(start_port, df_start.loc[start_port_mask,'mgel_port_combo'].nunique())
```

3. Other maps

Figure 9. Global shipping network from 2013 to 2018 with unique connections but without trip frequencies



VI. References

"Action Plan on the Belt and Road Initiative." The State Council, People's Republic of China, 30 Mar. 2015, english.gov.cn/archive/publications/2015/03/30/content_281475080249035.htm.

"Ballast Water Management." International Maritime Organization, www.imo.org/en/OurWork/Environment/BallastWaterManagement/Pages/Default.aspx.

"Ballast Water: How to Avoid the Resulting Threat in the Oceans." International Atomic Energy Agency.

"Belt and Road Economics: Opportunities and Risks of Transport Corridors." *World Bank Group*, 2019, doi:10.1596/978-1-4648-1392-4.

"Belt and Road Initiative." *The World Bank*, 29 Mar. 2018, www.worldbank.org/en/topic/regional-integration/brief/belt-and-road-initiative.

"China's Future: Xi Jinping and the Chinese dream." *The Economist*, 4 May 2013, accessed 20 February 2014, http://www.economist.com/news/leaders/21577070-vision-chinas-new-president-should-serve-his-people-not-nationalist-state-xi-jinping.

"Digital Data." *Large Marine Ecosystems of the World*, lme.edc.uri.edu/index.php/digital-data.

"From Initiative to Reality: Moments in Developing the Belt and Road Initiative." *The State Council, People's Republic of China*, 23 Apr. 2015, english.gov.cn/policies/infographics/2015/04/23/content_281475094425039.htm.

"Full Text: China's New Party Chief Xi Jinping's Speech." BBC News, *BBC*, 15 Nov. 2012, www.bbc.com/news/world-asia-china-20338586.

"Greening the Belt and Road Initiative – WWF's Recommendations for the Finance Sector". *WWF*.

"Index Analysis" Belt and Road Portal, *State Information Center*, https://www.yidaiyilu.gov.cn/jcsjpc.htm

"LME Initiatives." *IUCN*, 8 June 2018, www.iucn.org/theme/marine-and-polar/our-work/international-ocean-governance/large-marine-ecosystems/lme-initiatives.

"MMSI MID Codes." VT Explorer, www.vtexplorer.com/mmsi-mid-codes-en/.

"The Belt and Road Initiative-WWF Recommendations and Spatial Analysis." *WWF*, May 2017.

"Vision and Actions on Jointly Building Silk Road Economic Belt and 21st Century Maritime Silk Road." National Development and Reform Commission, Ministry of Foreign

Affairs, and Ministry of Commerce of the People's Republic of China, Mar. 2015, https://reconasia-production.s3.amazonaws.com/media/filer_public/e0/22/e0228017-7463-46fc-9094-0465a6f1ca23/vision_and_actions_on_jointly_building_silk_road_economic_belt_and_21st-century_maritime_silk_road.pdf

“WORLD PORT INDEX.” Maritime Safety Information, NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY, msi.nga.mil/Publications/WPI.

Alexander, Lewis M. “Large Marine Ecosystems - A New Focus for Marine Resources Management.” *Marine Policy*, May 1993, pp. 186–198.

Ascensão, Fernando, et al. “Environmental Challenges for the Belt and Road Initiative.” *Nature Sustainability*, vol. 1, no. 5, 2018, pp. 206–209., doi:10.1038/s41893-018-0059-3.

Azmi, Fauziah, et al. “A hub and spoke network model to analyse the secondary dispersal of introduced marine species in Indonesia.” *ICES Journal of Marine Science: Journal Du Conseil*, vol. 72, no. 3, 2014, pp. 1069–77.

BBC. “China releases maritime plan document.” *BBC Monitoring Asia Pacific*, London, 21 June 2017.

Cai, Peter. “Understanding China’s Belt and Road Initiative.” *Lowy Institute for International Policy*, Mar. 2017.

CFR. “China's Massive Belt and Road Initiative.” *Council on Foreign Relations*, 28 Jan. 2020, www.cfr.org/backgrounder/chinas-massive-belt-and-road-initiative.

China Power Team. "How will the Belt and Road Initiative advance China’s interests*?" China Power*. May 8, 2017. Updated October 18, 2019. Accessed February 16, 2020. https://chinapower.csis.org/china-belt-and-road-initiative/

Cope, Robert C., et al. “Temporal Modelling of Ballast Water Discharge and Ship-Mediated Invasion Risk to Australia.” *Royal Society Open Science*, 2015, doi:10.1098/rsos.150039.

Eder, Thomas S. “Mapping the Belt and Road Initiative: This Is Where We Stand.” The Mercator Institute for China Studies (MERICS), 6 July 2018, www.merics.org/en/bri-tracker/mapping-the-belt-and-road-initiative.

Guide to Ship Sanitation. 3rd edition. Geneva: World Health Organization; 2011. 5, Ballast water. Available from: https://www.ncbi.nlm.nih.gov/books/NBK310820/

Halpern, Benjamin S., et al. “A Global Map of Human Impact on Marine Ecosystems.” *Science*, vol. 319, no. 5865, 2008, pp. 948–952., doi:10.1126/science.1149345.

Hoagland, Porter, and Di Jin. “Accounting for Marine Economic Activities in Large Marine Ecosystems.” *Ocean & Coastal Management*, vol. 51, no. 3, 2008, pp. 246–258., doi:10.1016/j.ocecoaman.2007.09.007.

Koboević, Žarko, et al. “The Maritime Silk Road and China’s Belt and Road Initiative.” *Naše More*, vol. 65, no. 2, 2018, pp. 113–122., doi:10.17818/nm/2018/2.7.

Lim, Chin Sing, et al. “Managing the Risk of Non-Indigenous Marine Species Transfer in Singapore Using a Study of Vessel Movement.” *Marine Pollution Bulletin*, vol. 115, no. 1–2, Elsevier Ltd, 2017, pp. 332–44, doi: 10.1016/j.marpolbul.2016.12.009.

Losos et al. "Reducing Environmental Risks from Belt and Road Initiative Investments in Transportation Infrastructure." *World Bank Group*, January 2019.

Ma, Alexandra. “Inside 'Belt and Road,' China's Mega-Project That Is Linking 70 Countries across Asia, Europe, and Africa.” *Business Insider*, 31 Jan. 2018.

OECD, "The Belt and Road Initiative in the global trade, investment and finance landscape", in OECD Business and Finance Outlook 2018, *OECD Publishing*, Paris, 2018, https://doi.org/10.1787/bus_fin_out-2018-6-en.

Wang, Jiaying. “Problem of New Marine Silk Road Construction in China.” *2016 National Convention on Sports Science of China*, 2017, doi:10.1051/ncssc/201701053.

Watkins, Derek, et al. “The World, Built by China.” *The New York Times*, 18 Nov. 2018, www.nytimes.com/interactive/2018/11/18/world/asia/world-built-by-china.html.

Yu, Hong. “Motivation behind China’s ‘One Belt, One Road’ Initiatives and Establishment of the Asian Infrastructure Investment Bank.” *Journal of Contemporary China*, vol. 26, no. 105, 2016, pp. 353–368., doi:10.1080/10670564.2016.1245894.