Effects of a Melting Arctic on Risk of Invasive Species' Spread

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Abstract

This paper examines the risk for nonindigenous species spread from key trade partners in East Asia to the U.S. due to the potential opening of Arctic shipping lanes in the near future. Changes in risk primarily originate from expected increases in trade flows from Asian-Pacific countries since the Arctic shipping routes would reduce the sailing distances between East-Asian countries and the U.S. east coast compared to the current route via the Panama Canal. The changes in risk for species spread is assessed based on two components: the risk of species introduction, which correlated with changes in imports into the U.S., and the risk of species establishment, which is based on the levels of the climate similarity between the U.S. east coast and countries in East Asia. We find that the greatest increases in risk of invasion to the U.S. are from Japan, due to the high levels of climate matching between the U.S. east coast and Japan, as well as expected increases in U.S. imports from Japan resulting from

decreased transportation and trade costs when the Arctic shipping routes are used. The increase in risk of invasion from China is also potentially high because of expected large quantities of imports into the U.S. and relatively high climate similarities between the two countries. On the other hand, there is negligible expected risk of invasion from Hong Kong and the Philippines. Relatively small changes in expected U.S. imports in tandem with very low climate similarity between the U.S. and both partners, leads to minimal potential for species introduction or establishment.

Keywords: Risk of species introduction; risk of species establishment; risk of species invasion; the United States; trade model; climate matching.

JEL codes: F18; Q54; Q57

1. Introduction

Roughly 90 percent of the world's cargo is transported via ships since boats provide many advantages over other means of transportation (International Chamber of Shipping, 2015). Other than air, ocean shipping is the only way to transport goods from Asia to North America, but even between North American coasts, ocean shipping often offers cost advantages over other methods like rail and trucking because large quantities of goods can be carried in more convenient ways. Other advantages include: (1) sailing passages are readily available, while rail and road transportation often require new construction. The construction costs would be very high when connecting many countries and crossing over mountainous and deserted areas. (2) Ocean shipping avoids unnecessary border procedures compared to land transports. (3) Ships can carry larger and heavier cargoes than other means of transportation.

These advantages have led mankind, throughout history, to explore new shipping routes. Where suitable waterways have not been provided by nature, massive engineering projects have been undertaken to create them. Dating back to about 1874 B.C., Egypt became the first country to dig a waterway across its land for the purpose of trade with a canal connecting the Mediterranean and Red seas. This canal persists today (it silted and reopened several times throughout history) as the Suez Canal, which opened for navigation in its modern form in 1869.[1] Prior to its opening, goods had to be shipped overland, where traders faced arduous terrain and hostile armies, or by ship around the southern tip of Africa, where traders faced unpredictable weather, strong currents, and massive waves. Similar advantages led to the opening of the Panama Canal in 1914 (somewhat adjacent to the already existent Panama Railway) and the St. Lawrence Seaway in 1959.

The exploitation of these shipping routes has brought unintended environmental consequences, including pathways for nonnative species to spread between countries, oceans, and continents due to both natural dispersal and ship-mediated transport (Gollasch et al., 2006; Miller & Ruiz, 2014). Aquatic species naturally travel by way of waterway connections between seas or oceans, but under limited conditions. For example, species often move from the Red Sea to the Mediterranean Sea, but rarely in the other direction as the salinity levels in the Red Sea are much higher than levels in the Mediterranean Sea. In addition, the Red Sea on average contains a lower level of nutrients in saltwater relative to nutrient components in the Mediterranean Sea (Zakaria, 2015). Most ocean species are also unable to travel naturally between the Pacific Ocean and the Atlantic Ocean through the waterways via the Panama Canal because the canal contains freshwater lakes. The water in these lakes also causes certain osmotic stress and mortality for many marine bio-fouling organisms, which cling to the hulls of ships sailing through the canal (Miller & Ruiz, 2014). Natural dispersal due to the

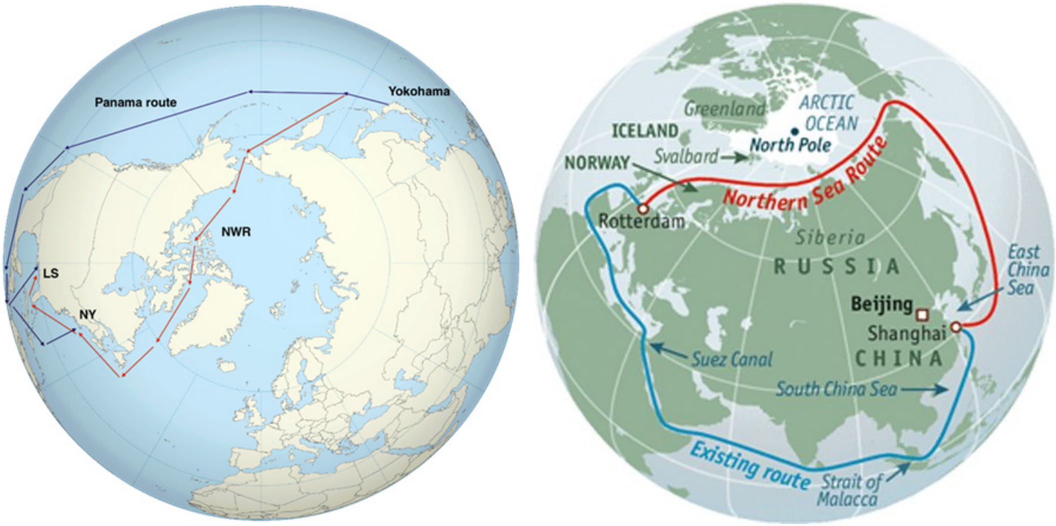
[1] https://www.suezcanal.gov.eg , accessed February 1, 2017

operation of canals is most likely to occur for fishes and in short distances. Ship-mediated transport through bio-fouling and ballast water, on the other hand, helps many aquatic species to travel between countries and continents.[2] Also, ships transport thousands of nonnative terrestrial species between regions because ships often carry large quantities of animals and plants, which consist of numerous species (Hulme, 2009).

The next major wave of changes in global shipping routes are not likely to be created by man, but by the melting of ice due to climate change. Rapid increases in global temperature, particularly in the Arctic, have caused sea ice to melt quickly. Soon, sea ice is expected to shrink enough to allow shipping to be diverted away from the Suez and Panama Canals through the Arctic. Borgerson (2008) concluded that further exploration of the Arctic sea routes is only a matter of time. The most likely Arctic sea routes are the North Sea Route and the Northwest Passage.[3] Figure 1(a) shows the Northern Sea Route, Northwest Passage, and existing routes via the Suez and Panama Canals. Figure 1 (b) shows the Northern Sea Route and Northwest Passage in the Arctic Ocean. The Northwest Passage is a route passing through Canadian archipelago, while the Northern Sea Route is close to Russia's mainland. The Northern Sea Route could be an alternative for the route via the Suez Canal, as it reduces the marine distance between North-west Europe and North-east Asia by 40% (Liu & Kronbak, 2010; Schøyen & Bråthen, 2011). Similarly, the Northwest Passage could become a viable shipping lane for cargo transportation from North-east Asia to the east coast of the U.S. instead of the route via the Panama Canal because it reduces the marine distance, for example, from China to Newark, New Jersey (U.S.) by 22.6% (Countryman et al., 2016).

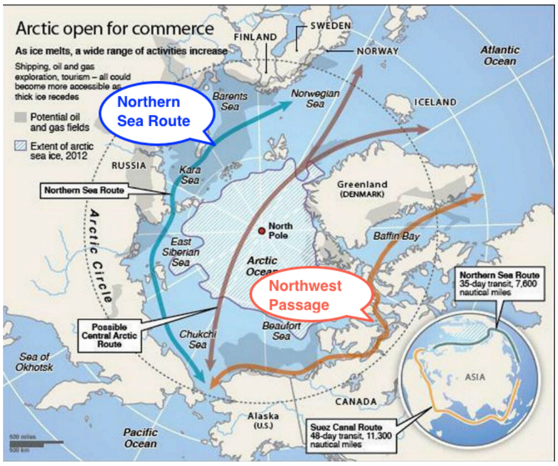
[2] Ships will load and discharge ballast water, which contains species, at ports depending on the levels of cargo in order to keep the ships balance.
[3] The Northern Sea Route links the ports in North-east Asia and North-western Europe, whereas Northwest Passage connects North-east Asia and the east coast of the United States.

Figure 1 (a): Two new routes via the Arctic Ocean (red lines) and the existing routes via the Suez Canal and Panama Canal (blue lines).



Source: Countryman et al. (2016) and Christyn (2015).

(b) The Northern Sea Route and the Northwest Passage shipping routes



Source: Farcuhar (2014).

This paper looks at the effects of the opening of the shipping routes through the Arctic, likely in the near future due to climate change, will have on the risk of invasions of NIS in the

United States (U.S.). We divide risk of an invasion into two components, the risk of introduction and the risk of establishment. We assume that the risk of introduction is directly tied to the volume of trade and that the risk of establishment is directly tied to similarities between the climate in a species' natural range and the climate in the location in which it is introduced. Changes in trade are projected using the Global Trade Analysis Project (GTAP) model, and climate similarities are calculated using the Euclidean distances between projected climate data.

The rest of the paper is organized as follows. Section 2 provides the background on the melting of the Arctic sea ice, impacts of such melting on trade, and invasive species spread via trade. Section 3 describes the methods used to measure the change in risk of species invasion. Section 4 provides the results and discussions, while Section 5 concludes the paper.

2. Background

The average global temperature has increased by 0.8^{o} Celsius since the pre-industrial period with an accelerated pace of 0.15^{o} – 0.2^{o} Celsius per decade since 1975 (National Aeronautics and Space Administration (NASA), 2016). These temperature increases are not uniform across the globe. Polar latitudes have seen the greatest increases, with the Arctic warming at twice the rate of the global average – faster than anywhere else on the planet (Council on Foreign Relations, 2013). Arctic temperatures are expected to increase by another 8^{o} Celsius by the end of the 21st Century (Weather Underground, 2016).

Such global warming, particularly in the Arctic, has broken down the stability and circulation of sea ice that has formed over thousands of years. Older thicker ice has declined and been replaced with younger thinner ice (Council on Foreign Relations, 2013), and the melting season has become longer (United States Environmental Protection Agency, 2016). As a result, Arctic sea ice extent has declined by 12% per decade since the late 1970s (Weather Underground, 2016). These trends are not likely to reverse soon (Comiso, 2012; Kerr, 2012; Kinnard et al., 2011; Shepherd et al., 2012; Stroeve et al., 2012), despite the Paris Agreement commitment to limit the global temperature increase to an additional 1.5^{o} Celsius (United Nation Framework Convention on Climate Change, 2016). Most models agree that the Arctic will be ice free in the not so distant future (Wang & Overland, 2012).

To date, the Northern Sea Route has mainly been exploited for transportation of oil products between July and November, with an increasing number of cargo vessels having sailed over recent years (Northern Sea Route Information Office, 2016). Transport companies have also used the Northwest Passage during summer, including 30 vessels in 2012, 17 in 2014, and one notable bulk carrier in 2013 (Canadian Department of Environment and Natural Resources, 2015). Full commercial exploitation of the routes through the Arctic ocean is, however, still limited due to icebreaking costs (Council on Foreign Relations, 2013) but will be a boon to shipping should icebreaking become unnecessary (King, 2015).

Because the Northern Sea Route is likely to open before the Northwest Passage, most studies on the opening of the Arctic routes focus on the comparison between the Northern Sea Route and the route via the Suez Canal (Borgerson, 2008; Kerr, 2002). Verny and Grigentin (2009) estimate the costs of transporting one container between Shanghai and Hamburg through various commercial networks under current Arctic ice conditions. They found that although the operational costs of the Northern Sea Route are relatively high, it is not cost prohibitive. They found that the Northern Sea Route could be a viable alternative to the Suez Canal route for container transport. Currently, shipping through the Suez Canal is by far the least expensive option; however, the Northern Sea Route and Trans-Siberian Railway appear to be good equivalent second-tier alternatives that would become more attractive with further melting of sea ice and corresponding decreased transportation costs. Similar studies on the operation of the Northern Sea Route solely can also be found in Liu and Kronbak (2010), Schøyen and Bråthen (2011), and Faury and Cariou (2016).

There have been some studies that consider the potential impacts of both the Northern Sea Route and Northwest Passage on trade. Kerr (2002) found that the Arctic routes could have major effects on trade since it could reduce the sailing distance between Europe and Asia by 11,000 km compared to the Panama Canal route. In addition, megaships, which cannot pass through the Panama Canal, could sail through the Arctic routes with a distance reduction of 19,000 km compared with sailing around Cape Horn. Borgerson (2008) suggested that the shortcuts of the Arctic routes could reduce transportation costs by 20% for a single voyage. The cost savings could be greater for supertankers that are not able to pass through the Suez and Panama Canals and currently sail around the Cape of Good Hope and Cape Horn. As a result, the new routes could save billions of dollars for shipping costs annually. Hong (2012) conducted a study to examine the opportunities for China due to the possible opening of the Northwest Passage and Northern Sea Route. Hong concluded that these routes would save Chinese transporters thousands of miles in travel and allow commercial and military vessels to avoid the politically unstable Middle Eastern regions and pirate infested waters. Countryman et al. (2016) found that if the Northern Sea Route and Northwest Passage are fully available for year-round sailing by 2030, international shipping will increase by 0.71% and the volume of global trade will increase by 0.76%.

These changes in shipping will have a direct effect on the spread of NIS due to changes in the conditions and sources of ballast water contained and released by cargo ships, the spread of species on the hulls of ships (bio-fouling), and the movement of species attached to trade goods and packaging material. Species spread via ballast tanks and ship hulls has been studied in Drake and Lodge (2007), Sylvester and MacIsaac (2010), and Keller et al. (2011). Westphal et al. (2008) concluded that the spreading rate of NIS has a positive relationship with the growth rate of international trade. Other studies reached a similar conclusion that the volume of commodity imports is an important determinant of the number of NIS spread (Desprez-Loustau, 2009; Roques et al., 2009). Galil et al. (2008) demonstrated that more than half of the established nonindigenous macrozoobenthic species found in inland waters in Germany came through international waterways, again highlighting the important relationship between ship traffic and NIS spread.

Regarding pathways for NIS, Keller et al. (2011) found that marine shipping is the main pathway for NIS to spread along the European Atlantic coast and the Baltic Sea. According to the study conducted by Horan and Lupi (2005), 60% of NIS recorded in the Great Lakes is sourced from commercial shipping. Keller et al. (2011) indicated similar findings. The Great Lakes has received NIS from most major ports around the world because ships often visit the Great Lakes soon after transiting other ports. In addition, the aforementioned authors also found that 50-60% of the NIS in the Great Lakes comes from Europe and/or the Ponto-Caspian Basin since the opening of the St. Lawrence Seaway in 1959. Similar studies on the relationship between trade or marine shipping and invasive species can be found in Padilla and Williams (2004), Olson (2006), Cook and Fraser (2008), and Perrings et al. (2010).

3. Methods

We assume the risk of introduction into the U.S. is the product of two independent events: introduction and establishment conditional on being introduced (Seebens et al., 2013). Introduction from a given location depends on trade volume with that country. Establishment depends on climate similarities between the U.S. and the country of origin.

This relationship between risk of introduction and international trade captures the idea of propagule pressure, which suggests risk of invasion increases due to both the number of individuals released during a single event and the number of discrete release events. This approach is consistent with Drake and Lodge (2007), Sylvester and MacIsaac (2010), and Keller et al. (2011). As others have shown, nonnative species already present in the U.S. largely reflect historic trade partnerships (Aukema et al., 2010; Brawley et al., 2009).

Let ΔT_{ij} denote the percentage change in imports of commodity i to the U.S. from country j. Let C_j denote the similarity of the climate in country j with the climate in the U.S. Our measure of relative risk is described by equation (1).

$$R_{ij} = \Delta T_{ij} \times C_j \quad (1)$$

We describe each component in turn.

3.1. Risk of species introduction

We assume the probability of introduction from any given trading partner is a function of trade volume, which implies that likelihood of a species being introduced increases over time. As more and more species are introduced, the number of potentially new invaders from a trading partner, therefore, decreases with time (Aukema et al., 2010). The pool of potential invaders can only expand if trade takes place with new partners or for new commodities.

Expected changes in trade are taken from Countryman et al. (2016), who employed a GTAP-class CGE model that allows monopolistic competition and increasing returns to scale in tandem with the GTAP database Version 8. The database is aggregated into 39 countries/regions and 23 industrial sectors. Following the climate change literature, the authors assumed that the Arctic routes are fully operational by 2030; accordingly, they updated the database from 2007 to 2030 by using the macroeconomic projections (O'Neill et al., 2012). Consequently, the expected changes in trade patterns resulting from opening the Arctic routes are compared to the 2030 projected economies without use of the Arctic routes.

The results from Countryman et al. (2016) are utilized for two reasons. First, they applied a novel method to measure the distances between countries or ports, hence obtaining the distance and cost differences between the new routes and the traditional routes. By employing data for actual shipping distances rather than using the traditional Great Circle Formula, greater accuracy is achieved for measuring the actual marine distances[4]. Second, their results particularly suit our purpose as they incorporated both the distance and transportation cost reductions from using the new routes into a global computable general equilibrium (CGE) model, to generate changes in trade for many countries. This modeling framework is appropriate for this task because it not only represents transportation margins used to transport goods but also provides a global model to alter the transportation costs between countries.

This modeling approach has also been one of the best methods for analysis of the effects of multilateral and regional trade related policies and facilitation (Dennis, 2006; Hertel, 1997, 2013). Such a model, for example, has been applied in Gehlhar (1997), Hertel et al. (2001), Cororaton and Cockburn (2006), Fischer and Fox (2007), Hertel et al. (2007), Andrew and Peters (2013), Beckman et al. (2015), and Siriwardana (2015).

Countryman et al. (2016) provide details of their model, which follows the general structure of the standard GTAP model and is extended to allow for monopolistic competition and

[4] Another feature in the method provided by Countryman et al. (2016) is the application of the weighted shipping distance method. Since the Northwest Passage mainly provides the shortcuts for marine shipping between the Asia-Pacific countries and the east coast of the U.S., Countryman et al. (2016) divided the destination/departure in the U.S. into three ports: Newark (New Jersey), New Orleans (Louisiana) and Long Beach (California). They measured the marine distances and trade values between the Asia-Pacific countries and these three ports, then applied the weighted shipping distance between the U.S. and the Asia-Pacific countries for the distance reductions between trading partners.

increasing returns to scale. In this global CGE model, every agent in each economy interacts with each other where producers minimize costs and households and governments maximize utility. As a result, prices adjust until demand and supply are equal in every market. Such mechanisms work through a set of market clearing equations in the model, which include behavioral parameters, coefficients, exogenous variables, and endogenous variables. When there is a change in the model (i.e. a change in an exogenous variable), the model determines the new equilibrium values for endogenous variables in every market. The model also provides detailed results at the country and industry levels, as well as resulting changes in emissions levels.

The expected changes in trade generated from the extended GTAP framework are results from multiple stages. First, the distance reduction estimates were calculated for trade partners by comparing the traditional route (Suez or Panama Canal route) versus the Arctic route (Northern Sea Route or Northwest Passage) between countries/ports. In the case of the U.S., Countryman et al. (2016) applied the weighted shipping distance method[5] to calculate the shipping distances between the Asia-Pacific countries and the U.S. via the Northwest Passage and Panama Canal. The weighted method was used because the Northwest Passage may only reduce shipping distances between the U.S. ports in the Atlantic Ocean and the Asia-Pacific countries compared to the Panama Canal route. The U.S's ports in the Pacific Ocean are not affected by the operation of the Northwest Passage. In the next stage, Countryman et al. (2016) employed an augmented gravity model of trade, following Francois et al. (2016), to estimate the changes in total transportation costs associated with the Arctic routes. This allows the cost reductions to be divided into two types; the distance reductions used for the transport margin sector as well as the iceberg trade cost reductions that result from the

[5] The method was applied by using the shipping distances and export values from the Asia-Pacific countries to the US at three ports: Newark (New Jersey), New Orleans (Louisiana) and Long Beach (California).

decreased distance[6]. Finally, both transportation cost reductions (i.e. distance and iceberg trade cost reductions) are used in a CGE model simulation to estimate the changes in expected trade flows and other economic factors resulting from opening both Arctic routes.

3.2. Modeling climate matching for risk of establishment assessments

The probability of species establishment relies on the environmental similarities between regions. We calculate environmental similarities using the Euclidean distance between several climate variables (Crombie et al., 2008). The distance, called the climate matching score, is calculated as follows

$$d_j = floor\left\{\left[1 - \min_{i \in sites}\left(\sqrt{\frac{1}{k}\sum_k \frac{(y_{ik} - y_{jk})^2}{\sigma_k^2}}\right)\right] * 10\right\}$$

where i and j are the stations in source and destination regions, y_{ik} and y_{jk} are the k^{th} climate variable for the i^{th} and j^{th} stations. This method is based on principal component analysis, for which climatic distance is converted into Euclidean distance by establishing a metric similar to Euclidean distance across the climatic variables between the input sites (e.g. meteorological stations in each Asia-Pacific country and Chinese east coast) and each target site (e.g. each meteorological station in the U.S. east coast). The closest metric between the input location and a given target location determines the level of match class or matching score, which is expressed in a scale from zero to ten (for more detail of this approach see Elmore and Richman (2001)). Our final measure of climate similarity, C_j, for the terrestrial and marine analyses is the percentage of meteorological stations or ports in the United States with a climate score of eight or higher. A climate score or eight was chosen as a cut-off because it has been associated with moderate to high nonindigenous species risk in other

[6] Iceberg trade costs refer to the residual costs related to international trade that occur as a result of the distance reductions, such as time, coordination and other non-shipping service.

analyses (e.g. Bomford et al., 2009) and because it resulted in a larger range of C_j among sources countries (0-0.547) allowing for better discrimination.

Rather than mapping distance into a probability function, we use the distance level to indicate relative potentials for establishment. Such climate matching has been widely used to examine potential habitats for NIS (Bomford et al., 2009; Britton et al., 2010; Kalous et al., 2015; Kopecký et al., 2013). We focus on climate matching between trade partners and the U.S. east coast because more ships associated with ship-borne species will be arriving to the east coast due to the reduction of the sailing distance between this region and the Asia-Pacific countries via the Northwest Passage. That is, the changes in risk of invasion in the U.S. environment by 2030 are measured according to the changes in risk of introduction, due to the changes in U.S. imports, and the risk of establishment both by 2030.

Our approach is similar to that used in the *Climatch* tool (Australian Department of Agriculture, 2008; Bradie et al., 2015; Cunderlik & Burn, 2006; Tatem & Hay, 2007). *Climatch*, however, is only based on current climate observations. Because we are interested in potential impacts of climate change, we calculate similarities across future climate scenarios extended out to 2030 to reflect the time period the Arctic routes will be available year-round for cargo transportation.

Analysis is done in R (R Core Team, 2014) using data for meteorological stations in each of the Asia-Pacific regions and stations in the U.S. east coast. We use 16 climatic variables commonly used in climate matching models (Table 1) (Australian Department of Agriculture, 2008). Such R codes include the uses of the online packages regarding the database raster and maps of countries. Our Euclidean algorithm closely follows that used in the *Climatch* matching tool (Crombie et al., 2008), though *Climatch* only calculates matches for current climate. We use climate projections for 2030 from the downscaled IPCC5 (or CMIP5[7]) data at 10 minutes resolution[8] associated with the GISS-E2-R model following the 'representative concentration pathway 4.5' (RCP45) (these are available on the website of the World Climate (2008)). Although there are multiple models developed by different institutes in order to use such a database to project the world climate in the future, we select the GISS-E2-R model, which was developed by the NASA (2016). Also, though four different RCPs result in great differences in greenhouse gas concentrations by 2100, the projected concentrations under all four RCPs are very similar by 2030 (Collins et al., 2013); hence, we select the medium concentration pathway 4.5, which peaks by 2040 and reduces thereafter (Meinshausen et al., 2011).

Table 1: Bioclimatic variables.

1. Annual Mean Temperature	9. Mean annual rainfall
2. Temp - coldest month	10. Rainfall - wettest month
3. Temp - warmest month	11. Rainfall - driest month
4. Annual temperature range	12. Coefficient of variation - rain
5. Temp - coldest quarter	13. Rainfall - wettest quarter
6. Temp - warmest quarter	14. Rainfall - driest quarter
7. Temp - wettest quarter	15. Rainfall - coolest quarter
8. Temp - driest quarter	16. Rainfall - warmest quarter

Source: Australian Department of Agriculture (2008).

4. Results and discussion

We first provide the analysis of the changes in risk of NIS introduction in the U.S. from the

[7] IPCC5 refers to Intergovernmental Panel on Climate Change fifth Assessment and CMIP5 refers to Coupled Model Intercomparison Project Phase 5.
[8] Resolution is expressed as minutes of a degree of longitude and latitude.

changes in imports into the U.S. from the six Asia-Pacific countries. We also provide such an analysis, which is linked with the changes in imports of main commodities to the U.S. In the next stage, we estimate the risk of establishment in the U.S. environments based on the similarities of climates between regions. The final stage is to estimate the changes in risk of invasion according to the changes in risk of introduction and the risk of establishment.

4.1. Risk of introduction from changes in U.S. imports

We have focused on the results for changes in U.S. imports disaggregated by sectors and sources to identify the potential changes in risk of introduction. Use of the Northwest Passage mainly reduces transportation costs between the U.S. and the Asia-Pacific countries; hence, U.S. imports from these countries are likely to increase considerably. Countryman et al. (2016) showed that real U.S. imports from South Korea, Japan, China, Taiwan, Hong Kong and the Philippines increase considerably in comparison with the imports from other regions[9]. Table 2, for example, shows the main commodities imported by the U.S. from these Asia-Pacific countries by 2030. The average real U.S's imports for all commodities from South Korea, Japan, Taiwan and Hong Kong would respectively increase by 7.4%, 6.9%, 4.5% and 2.4%, whereas an increase in imports of 5.5% would be likely from both China and the Philippines. Of these, the U.S. would considerably increase imports of agricultural products, mining and mineral commodities from all these countries. The U.S. also greatly increases its imports of fisheries products from Japan, South Korea, Taiwan and the Philippines, while imports of Chinese motor vehicles, clothing and transport equipment[10] (not shown in Table 2) will considerably increase in the U.S. market due to the reductions in transportation costs from the operation of the Northern Sea Route and Northwest Passage.

[9] The national import increases are mainly due to increases in imports in the east coast regions of the U.S. because the Northwest Passage only affects the transportation in the east coast.
[10] These real imports to the U.S. market from China would respectively increase by 7.7%, 5.5% and 8.9%.

Table 2: Percentage changes in main commodities imported by the U.S. from the Asia-Pacific countries by 2030 (%).

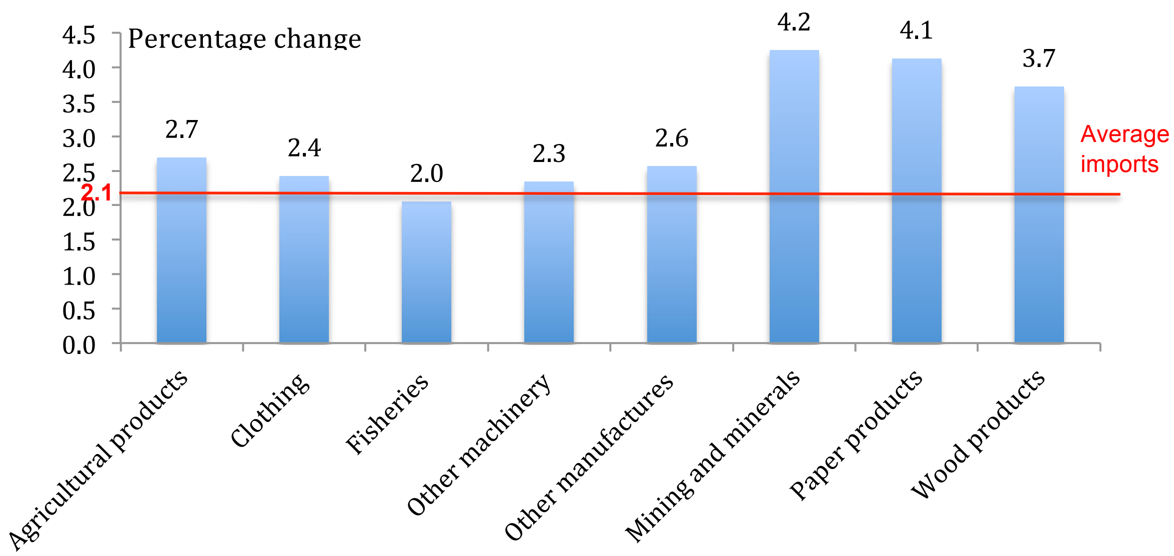
Commodities \ Regions	**China**	**Hong Kong**	**Japan**	**South Korea**	**Philippines**	**Taiwan**
Agricultural products	6.9	10.0	14.6	12.1	9.1	9.0
Beverages and tobacco	7.5	5.2	9.9	9.9	7.5	6.3
Chemicals	6.7	4.0	7.0	5.2	6.4	3.4
Plant products	5.7	6.3	11.9	8.8	6.9	6.2
Fisheries	0.0	4.0	14.0	7.4	16.9	10.4
Processed foods	6.4	5.5	10.2	9.4	7.0	6.1
Forestry	4.9	2.4	15.5	11.7	6.4	4.6
Metals	6.4	3.9	7.9	7.7	5.9	5.1
Petrochemicals and gas	7.8	0.7	9.2	8.0	7.7	5.8
Mining and extraction	23.9	8.2	21.4	48.3	12.7	17.7
Paper products and publishing	8.0	4.3	8.5	9.0	8.3	5.1
Wood products	7.6	0.7	5.9	6.6	10.7	5.4
Average (all commodities)	**5.5**	**2.4**	**6.9**	**7.4**	**5.5**	**7.1**

Source: Countryman et al. (2016).

Figure 3 shows the percentage changes in real imports of the selected commodities to the U.S. from the world markets by 2030. The operation of the Northern Sea Route and Northwest Passage would increase real imports of the U.S. by 2.1%. Imports of some commodities, however, would increase at much higher rates than the average rate of increase. The U.S., for example, would significantly increase its imports for mining and mineral products (4.2%), paper products (4.1%) and wood products (3.7%). The U.S. market would also enhance its demand for international agricultural products (2.7%), other manufactures (2.6%), other machinery (2.3%), clothing (2.4%) and fisheries (2.0%). Commodities absorb different effects since demands by the U.S. from various countries/regions are different. Such different demands consequently lead to different reductions in transportation costs for each commodity into the U.S. market.

It is worth noting that the risks only change in the east coast resulting from the operation of the Arctic routes mainly on the transportation to the east coast. As the imports to the west coast are unlikely to change, the imports to the east coast would increase more than 2.1% in order to produce a national average increase in imports of 2.1%. The changes in risk of introduction in the east coast are therefore multifold than those shown in the model.

Figure 3: Main commodities imported by the U.S. by 2030.

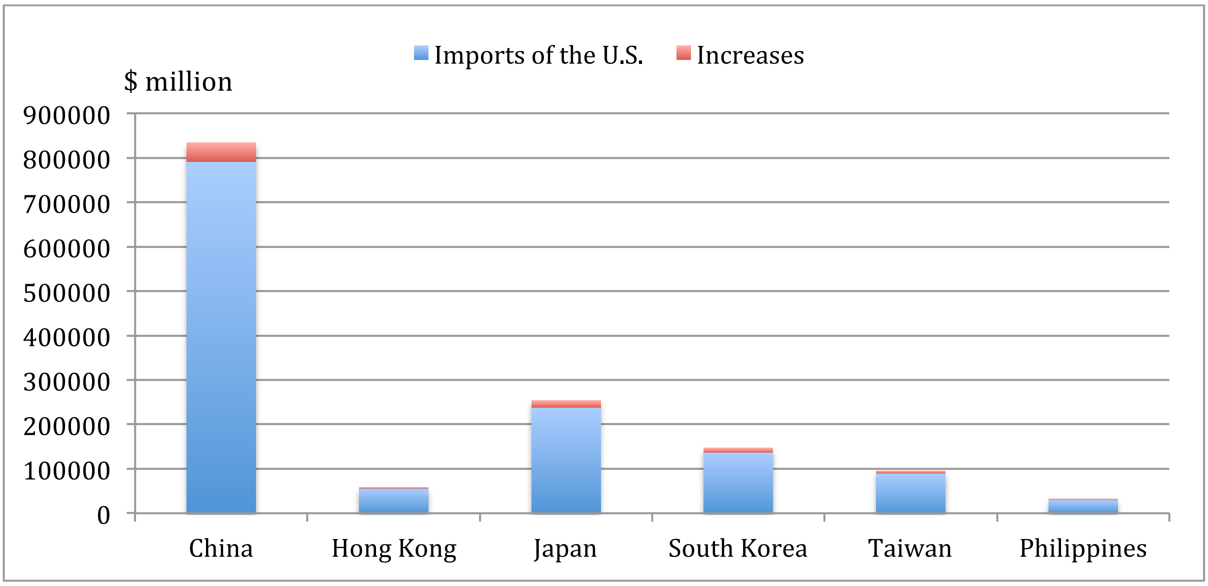


Source: Countryman et al. (2016).

The operation of the Arctic routes by 2030 is likely to cause the introduction of NIS to the U.S. to increase because the average imports in the U.S. will increase (see Figure 3). However, the increases in risk of introduction to the U.S. from six Asia-Pacific countries are diverse, which are associated with different average changes in imports from these countries. From Table 2, changes in U.S. imports from South Korea and Taiwan are greatest at increases of 7.4% and 7.1% respectively. These two countries, however, will not cause the greatest changes in risk of introduction to the U.S. because U.S. imports from these two countries are not as large as imports from China and Japan. In the database by 2030, U.S. imports from China and Japan are $791,020 million and $237,708 million (cif prices); hence, small percentage changes in U.S. imports from these two countries also indicate large changes in the quantity. The number of ships from these two countries to the U.S. will therefore change considerably, consequently altering the number of NIS contained in their ballast water and hulls. For example, U.S. imports from China were estimated at $791,020 million in the baseline for 2030 and it would increases by 5.5% from such a baseline due to the operation of the Arctic routes (see Table 2). The U.S. import increases from China are therefore $43,506 million, which is much higher than the U.S. import increases from South Korea of $10,109 million (equals product of imports of $136,606 million and an increase of 7.4%).

Figure 4 provides an illustration of changes in risk of introduction derived from the six Asia-Pacific countries, which are positively linked with changes in U.S. imports from these countries. China will cause the greatest increase in risk of introduction to the U.S., followed by Japan and South Korea, because increases in U.S. imports from China are greatest. The increases in risk of introduction from Taiwan, Hong Kong and the Philippines are relatively small since U.S. imports from these countries are small, thereby small percentage increases in imports from these countries will not greatly change the risk of introduction to the U.S. environments.

Figure 4: Import increases to the U.S. from six Asia-Pacific countries.



Source: Countryman et al. (2016).

Changes in risks of introduction contained in each commodity are also considered in the similar approach. Table 3 shows the changes of the selected U.S's imported commodities from the Asia-Pacific countries by 2030. Such fluctuations in imports indicate the changes in risk of introduction to the U.S. environment. Several commodities from particular countries especially increase the risk of introduction to the U.S. relative to other commodities. Chemical products from China and Japan, for example, increase the greatest risk to the U.S. compared to such imports of the commodity from the other countries because the changes in U.S. imports from these two countries are greatest. Metals, paper products and publishing, and wood products commodities from China; Petrochemicals and gas, and mining and extraction commodities both from China and South Korea also considerably increase risks of introduction to the U.S. due to great increases in U.S. imports from these countries.

Table 3: Changes of main commodities imported by the U.S. from the Asia-Pacific countries by 2030 (US$ millions).

	China	Hong Kong	Japan	South Korea	Philippines	Taiwan
Agricultural products	82	0	6	1	0	12
Beverages and tobacco	30	2	17	25	2	3
Chemicals	6,037	8	1,350	144	39	114
Plant products	30	0	13	4	1	11
Fisheries	0	0	95	24	23	37
Processed foods	688	6	140	61	108	41
Forestry	1	0	1	2	0	0
Metals	1,550	1	297	294	8	453
Petrochemicals and gas	789	0	642	1,017	16	92
Mining and extraction	15,366	1	72	1,051	0	13
Paper products and publishing	2,777	16	118	150	6	29
Wood products	4,395	0	28	17	74	94

Source: Countryman et al. (2016).

4.2. Risk of establishment from climate matching

Since the Northern Sea Route and Northwest Passage only reduce distances and therefore the transportation costs between the Asia-Pacific countries and the east coast of the U.S., the trade between these countries and the east coast of the U.S. will be affected. On the other hand, more ships will come to the east coast carrying large amounts of invasive species, while activities on the west coast of the U.S. will be relatively constant. Hence, we only examine the climatic similarities between the east coast of the U.S. and concerned Asia-Pacific countries.

Table 4 shows the number of the U.S's meteorological stations in the east coast matching the anticipated climate by 2030 with the stations in each of the six Asia-Pacific countries according to grades ranked from zero to ten. The last row of the table indicates the percentage of the number of the U.S's stations in the east coast matching climate with these countries with grades from eight. The number of stations in each grade indicates the levels of climatic similarities between two countries (i.e. the east coast of the U.S. and another country/region in this case). The high levels of climatic similarities indicated by the great number of stations with high grades arise for the following reasons. First, two regions are located in similar latitudes (degrees north). Second, two regions have similar terrain and altitudes, for example, they both have coastal and mountainous areas.

Table 4: The number of meteorological stations in the U.S. east coast matching anticipated climate by 2030 with the stations in the selected Asia-Pacific countries in each grade.

Grade \ Country	China (East coast)	Hong Kong	Japan	South Korea	Taiwan	Philippines
0	0	1329	0	0	0	0
1	0	1291	0	0	0	0
2	0	821	0	0	0	0
3	0	306	0	0	0	0
4	0	222	0	2	117	100
5	1	113	0	848	1115	2092
6	293	4	0	2175	1082	1261
7	2091	0	550	714	953	626
8	1363	0	3091	434	903	93
9	425	0	532	0	3	1
10	0	0	0	0	0	0
Percentage matching (>=8) or risk of establishment	**43%**	**0%**	**87%**	**10%**	**22%**	**2%**

Table 4 shows that the climate on the east coast of the U.S. is quite closely matched with the climate in Japan with 87% of the stations in the east coast of the U.S. matching with climates of stations in Japan with grades from eight. Such similarities are due to the locations of the two regions within similar latitudes and these two regions have similar altitudes and terrain. Although South Korea is located close to Japan, it shows low levels of climate matching with the east coast of the U.S. because the U.S. east coast has a wider range of the latitudes, which is similar to the range of latitudes of Japan, while the range of South Korean latitudes is far less. Consequently, only 10% of the U.S. stations on the east coast match with the climates in South Korea with grades from eight and above. In comparison with South Korea, Taiwan is located at much lower latitudes but the U.S. east coast still has higher levels of climate matching with Taiwan (22%). This issue arises because some areas in the Southeast coast of the U.S. are wide within a short range of latitudes and Taiwan is located within this range. In particular, there are many meteorological stations in Florida and the Southeast coast close to Mexico, which are located within similar latitudes with Taiwan. South Korea, on the other hand, is only located within the same latitudes with fewer stations in the east coast of the U.S. The higher latitudes of the U.S. east coast have the fewer stations located within a short range of latitudes compared to the farthest Southeast coast.

The U.S. east coast has low levels of climate matching with the climates in the Chinese east coast compared to those for Japan because the latitudinal range of the Chinese east coast does not particularly fit the latitudinal range of the U.S. east coast. For example, stations in Maine in the U.S. east coast are located at much higher latitudes compared to the farthest northern stations in Liaoning in the Chinese east coast; and the stations in Hainan in the farthest Southeast coast of China is located at much lower latitudes relative to the farthest southern stations in Florida in the U.S. east coast. The U.S. east coast, however, still shows higher levels of climate matching with the Chinese east coast (i.e. 43%) compared to such matching levels for the other countries, with the exception of Japan, because the Chinese east coast has a wider similar latitudinal range with the east coast of the U.S. Consequently, more stations on the east coast of the U.S. and China are located in the same latitudes relative to those from other countries such as South Korea.

The U.S. east coast has very low levels of climatic similarities with Hong Kong and the Philippines. Hong Kong is a very small region while the U.S. east coast is a very large region, which is located within a wide range of latitudes. Hong Kong is also located at a lower latitudinal level compared to the farthest Southeast stations in the U.S. As a result, the U.S. east coast only has matching climates with Hong Kong at low grades in Table 4. The U.S. east coast obviously has low levels of climate matching with the Philippines, a tropical country, because it is located in much warmer area compared to the locations of the U.S. east coast.

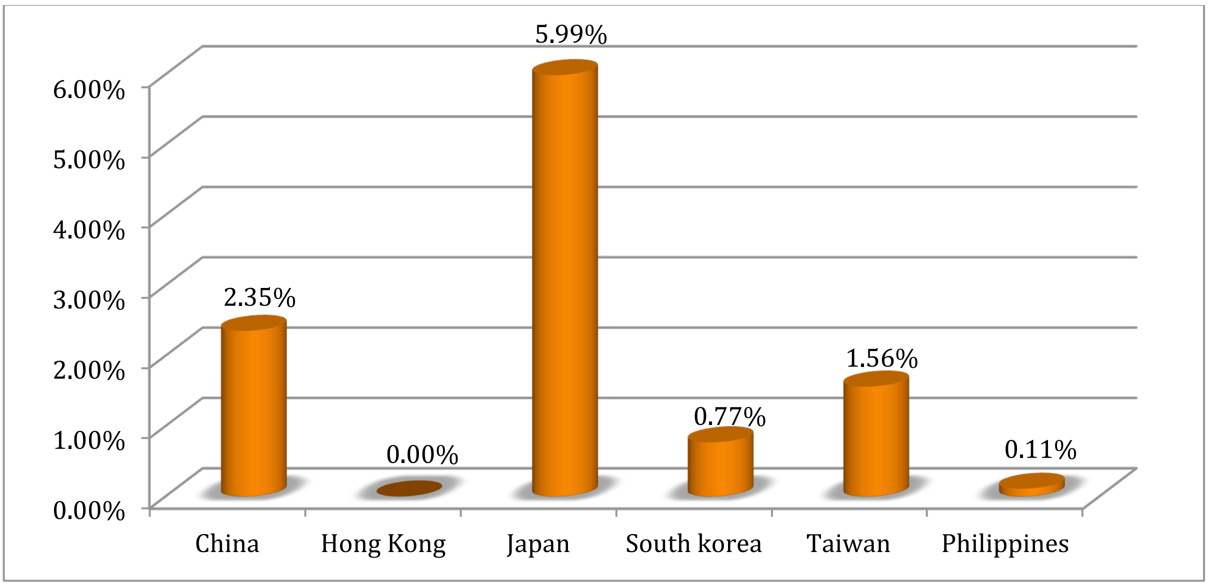
The evidence above shows that Japan is the highest source of risk of species establishment to the U.S. environments, followed by China and Taiwan. Such high climatic similarities are recognized as dangerous to the U.S. east coast environments because species from these regions readily experience similar environments in the U.S., thereby easily surviving translocation and spreading. It becomes more important and concerning because the U.S. has been an important importer for Japan and China's commodities. The more transportation between the U.S. and these regions, the higher are the risks the U.S. will suffer from invasive species originated from these regions.

South Korea, the Philippines and Hong Kong present very low risks of species establishment in the U.S. east coast environments due to their low levels of climatic similarities with the U.S. This indicates that many native species that come from these regions cannot survive and multiply in the U.S. environments, especially species originated in Hong Kong. More details that show the grades by color of the climate matching of meteorological stations in the east coast of the U.S. and stations in each of six Asia-Pacific regions are provided in Figure A1 in the Appendix.

4.3. Risk of species invasion

Figure 5 shows the changes in risk of invasion to the U.S. from six Asia-Pacific countries. Our measurements indicate that the increase in risk of invasion from Japan is highest due to its significant matching in climates with the U.S. Hong Kong and the Philippines indicates very little to low risk of invasion to the U.S. because the species from these regions cannot survive in the U.S environment due to the differences in climates. As a result, even if species introduction from Hong Kong and the Philippines increase because of increases in U.S. imports from these two regions, these species would not have a high chance to survive. China and Taiwan are the second and third greatest sources, which probably increase the risk of invasion to the U.S., while South Korea only increases small risk of invasion to the U.S. due to its low levels of climate matching with the U.S.

Figure 5: Changes in risk of species invasion in the U.S. from the Asia-Pacific countries.



Since Figure 5 shows Japan is the source, which increase the risk at the highest rate among the six Asia-Pacific countries for species invasion to the U.S. due to its high levels of climate matching with the climates in the U.S. east coast, Table 4 also indicates that the increases in risk of species invasion contained by each commodity from Japan is consistently high rates. As Hong Kong indicates no risk of species invasion to the U.S. in general, each commodity imported by the U.S. from Hong Kong also contains no risk of species invasion. For commodities imported by the U.S. from China, Table 4 indicates a second order by rank for sources that possibly increase the risk of species invasion to the U.S, while Taiwan and South Korea are in the third rank because these countries have lower levels of climate matching with the U.S. It is worth noting that U.S. imports from China are relatively high; hence, though the risk of species establishment from China in the U.S. is not high, a small increase in its imports by the U.S. also creates a substantial risk to the U.S. environment. On the other hand, many species originating from China will probably die but numerous species could survive and spread in the U.S. environment due to huge amounts of species, which will accompany the large volumes of imports by the U.S. from China.

Table 4: Changes in risk of species invasion to the U.S. from selected commodities and countries (percentage change).

Region / Country	**China**	**Hong Kong**	**Japan**	**South Korea**	**Philippines**	**Taiwan**
Agricultural products	2.95	0	12.67	1.26	0.18	1.98
Beverages and tobacco	3.21	0	8.59	1.03	0.15	1.39
Chemicals	2.87	0	6.08	0.54	0.13	0.75
Plant products	2.44	0	10.33	0.92	0.14	1.36
Fisheries	0.00	0	12.15	0.77	0.34	2.29
Processed foods	2.74	0	8.85	0.98	0.14	1.34
Forestry	2.10	0	13.45	1.22	0.13	1.01
Metals	2.74	0	6.86	0.80	0.12	1.12
Petrochemicals and gas	3.34	0	7.99	0.83	0.15	1.28
Mining and extraction	10.23	0	18.58	5.02	0.25	3.89
Paper products and publishing	3.42	0	7.38	0.94	0.17	1.12
Wood products	3.25	0	5.12	0.69	0.21	1.19

Sources: Authors' own calculations.

5. Conclusion

With the current increasing temperature rates of the world's atmosphere over decades, many scientists forecast that the Arctic sea ice will melt to a level that enables the use of Arctic shipping lanes in the near future and probably by 2030. This study takes this phenomenon into account to examine the effects of using Arctic shipping routes on the risk of NIS spread in the U.S., particularly focusing on the environment of the east coast. Since Arctic shipping lanes would reduce the sailing distances between Asia-Pacific countries and the east coast of the U.S. in comparison with the current route through the Panama Canal, this research mainly examines the changes in the risk of NIS invasion to the U.S from six countries/regions.

The study assesses the changes in risk of species introduction and risk of species establishment in the U.S. east coast. These assessments are combined to determine the changes in the risk of species invasion in the U.S. The changes in risk of introduction are determined by the expected changes in U.S. imports resulting from reduced transportation and trade costs when the Arctic routes become viable in 2030 from estimates provided by Countryman et al. (2016). The risk of establishment is assessed according to the levels of climatic similarities between the U.S. east coast and each of the six Asia-Pacific countries considered. We use the 'Closest Euclidean Match' method to assess the levels of climatic similarities between regions in 2030.

This work highlights three key findings. First, the U.S. east coast has relatively high climate matches with Japan; hence, there is potential for NIS from Japan to survive along the U.S. east coast, if introduced. Furthermore, imports from Japan are expected to increase if the Arctic shipping lanes are employed. This presents the greatest risk for the potential for NIS spread to the U.S. Second, although the east coast of China has moderate levels of climatic matching with the U.S. east coast, changes in imports into the U.S. from China are expected to be large. Consequently the risk of species spread to the U.S. originating from China is substantial and important. Third, Hong Kong and the Philippines present very little to no risk of species invasion to the U.S. due to low levels of climate matching with the U.S. east coast and relatively small expected changes in U.S. imports from both regions.

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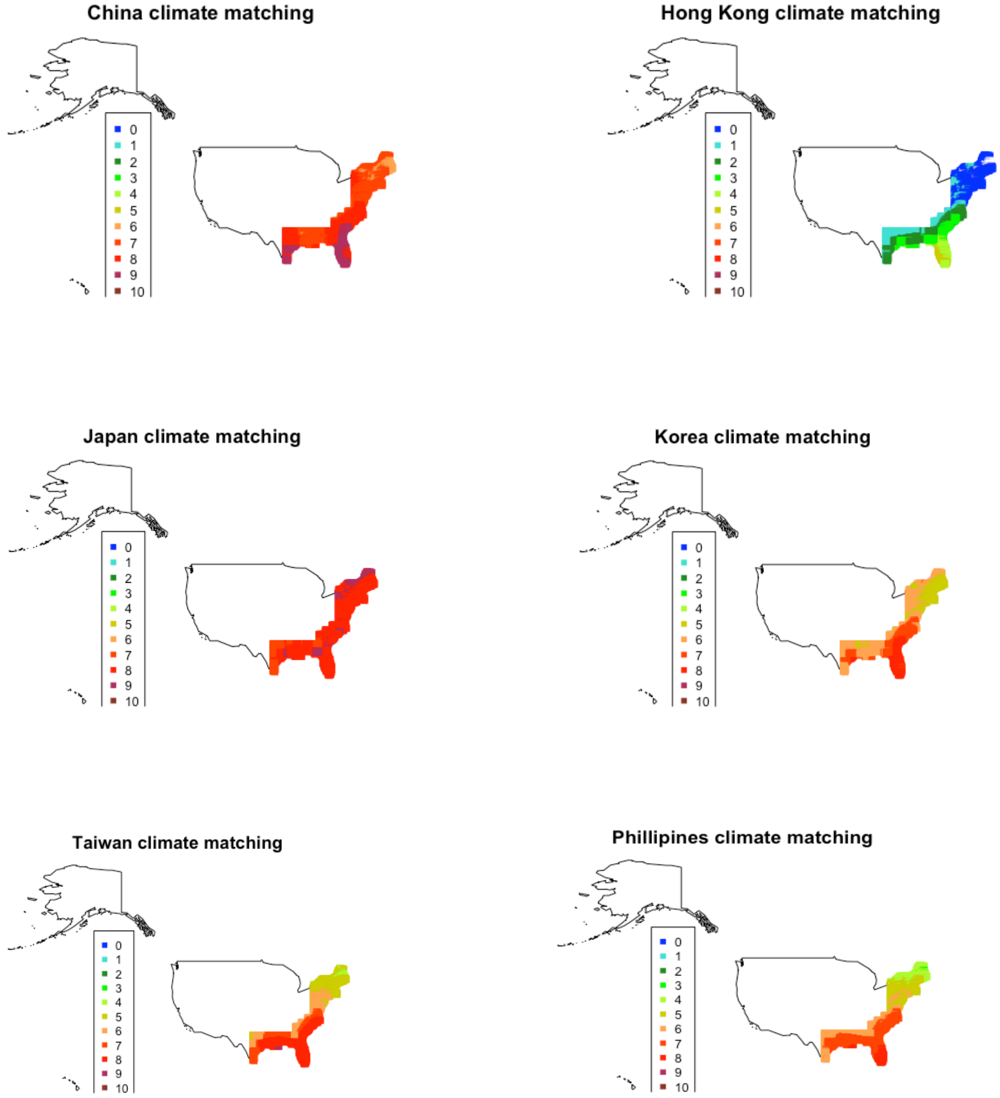
Appendix

Figure A1: Climate matching between the selected Asia-Pacific countries and the U.S. east coast by 2030



Source: Author's own calculations based on R programming.