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Original article

Structural changes in the cruise network by ship size in Northeast Asia

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A B S T R A C T

Several ports want cruise ships to call at their ports for economic benefits. However, the main cause of concern is the complexity of port selection behavior for cruise lines. Tracking cruise ship movement data may help them understand the port selection behavior of cruise lines. This study aimed to examine the structural changes in the cruise network by ship size in Northeast Asia from 2014 to 2019 using network science methods with automatic identification system data. We identified five key findings. First, the number of nodes and edges in the mega- and small-size ship networks was growing rapidly. Second, the small-size network was growing with unique characteristics of low density and average clustering coefficient, and high average shortest path length and diameter. Third, the hub ports of Shanghai in the mega- and Hiroshima and Kobe in the small-size had gained more degrees over time. Fourth, owing to the deployment of new mega-ships in Shanghai, existing large- and mid-ships were shifting to different ports. Finally, modularity of all sizes increased over time, and the community structure became clearer.

1. Introduction

The cruise industry has proliferated since the 1990s. The world cruise population increased from 3.8 million in 1990–29.7 million in 2019 (Cruise Lines International Association [CLIA], 2011, 2019). The average annual growth rate for the last 30 years is 7.37%. Furthermore, the global cruise industry has created huge economic benefits. The cruise industry generated $72.0 billion in total direct expenditures and $154.5 billion in total output contributions worldwide over the year 2019. A vast number of employment opportunities were also created, with a total income contribution of $50.5 billion and a total employment contribution of 1.16 million people, making it a huge industry (CLIA, 2020). Expecting these economic benefits, many port authorities are eager to have cruise ships call at their ports. Hence, they need to understand the cruise lines' port selection behavior.

The port selection behavior of cruise lines may be influenced by various factors such as the preferences of their target customers, quality of service, and size of their ships. The quality of a cruise line's service is classified into "cruise segments." Cruise segment classifications differ among evaluation agencies, and there are no uniform standards. Bjornsen (2003) provided examples of the differences in cruise duration, ticket price, and ship size for different segments. "Contemporary" includes 3–7 days, 100–200 USD per day per person, and operates mega- and large-size ships. "Premium" includes 7–14 days, 150–500 USD per day per person, and operates large- and mid-size ships. "Luxury" includes seven days and more, 600–3000 USD per day per person, and operates mid- and small-size ships (Gibson, 2012). In particular, the size of the cruise ship may be a limiting factor in port selection. In practical terms, the first step in developing a cruise port is to determine the size of the cruise ships to be anchored. In the case of mega-size ships, there are many restrictions. For example, they need to be based at a turnaround port that can handle large volumes of passengers quickly and efficiently. Additionally, they require ports that can physically handle such large ships and where there are no impediments to berthing (Henry, 2012).

A network diagram can be depicted by tracking the movement of cruise ships as they navigate between ports. The network describes the number and location of ports (nodes) that make up the cruise network and their connections (edges) due to cruise ship movements. Network structures can be measured using various network science methods, which is a powerful way to understand the structure of various networks of different types, such as technological, information, social, and biological networks (Newman, 2018).

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Barabási (2015) revealed that the architectures of networks that emerge in different domains of science, nature, and technology are similar and are based on the same organizational principles. If so, network science methods may be able to analyze the structure of cruise networks to understand their port selection behavior.

This study aims to investigate the structural changes in the cruise network by ship size because we recognize that it is essential for network science to understand the evolutionary process of cruise networks at both the system level (the network as a whole) and the individual node level. In particular, structural changes in the cruise network structure are measured using density, average clustering coefficient, network distance (average shortest path length, diameter), degree centrality, degree centralization, and modularity optimization (number of communities, modularity). We use the automatic identification system (AIS) data (https://maritime.ihs.com) to track the movement of cruise ships by size.

The rest of this paper is organized as follows. Section 2 presents the literature review. Section 3 outlines the significance of cruise network analysis using network science techniques. Section 4 presents the results of the study, which are discussed in Section 5. Finally, we provide the conclusions of the study in Section 6.

2. Literature review

Several previous studies have focused on cruise lines' port selection behavior. Marti (1990) suggested that the geographic concepts of "site" and "situation" can contribute to a greater understanding of the cruise-ship port selection process. "Site," a physical factor, holds great significance in the origin and evolution of cruise ports. "Situation" is a notion that can comprise either physical or cultural qualities. Manning (2006) explained that the main influencing factors for port selection include the key natural and cultural assets of the port, port facilities, location access to other destinations and the homeport, security, infrastructure, provisioning, port costs, and marketing. Gui and Russo (2011) showed that cruise lines' requirements include a wide range of dedicated infrastructure and services, as well as port area infrastructure, airports, taxi fleets, coach services, shore excursions, and shopping areas. Wang et al. (2014) analyzed the factors that affect cruise lines' port selections using the fuzzy-AHP method. The results showed that "tourism attractions" were the most significant issue taken into consideration when a cruise ship is selecting a port of call location. Castillo-Manzano et al. (2014) concluded that the likelihood of having cruise traffic was linked to ports located in populous areas and closer to large airports.

Few studies have analyzed cruise ship networks using network science techniques. Tsiotas et al. (2018) showed the double role of the cruise network, which is composed of the profit-driven strategies of cruise companies and port authorities, using data from the 2013 itineraries of Costa Cruises and Mediterranean Shipping Company (MSC) Cruises in the Mediterranean cruise market. Jeon et al. (2019) investigated the centrality of cruise ports in the Asian cruise shipping market while proposing the hub and authority centrality metric as a directional synthesis of the hub centrality and authority centrality to explore cyclical and directional features of centrality in the cruise shipping network. In a recent cruise network study, Kanrak and Nguyen (2021) revealed that the cruise shipping network is scale-free using itinerary data from Asian and Australian cruise network websites. Lopez Rodriguez et al. (2021) suggested that Caribbean ports are the most important with respect to hub and authority centrality, using 2018 itineraries for each cruise line from the sites of 902 ports in the Caribbean and Northern Europe. To the best of our knowledge, there are no cases of structural changes in cruise networks using network science methods.

Moreover, few studies have used AIS data for analysis in cruise shipping. Tichavska and Tovar (2015) used AIS data to measure the pollution status of exhaust gas from cruise ships calling at the Las Palmas Port in the Canary Islands. Vicente-Cera et al. (2019), (2020) arranged the cruise ship's operating hours, repair times, and berthing times, estimated seawater pollution status by cruise ships and assessed environmental pressures related to global cruise traffic along their paths based on AIS data. Vicente-Cera et al. (2020) used AIS data to aggregate cruise ship calling patterns at European ports and evaluated the diversity of cruise ship calls at each port. Ito et al. (2020) organized the port call patterns before and after the suspension of cruise ship operations owing to the coronavirus disease 2019 pandemic and analyzed the relationship between cruise ship operations and the spread of infection at the port of call using AIS data. However, there are no studies of network analysis focusing on the structural changes of cruise networks using AIS data for cruise ships for a longer period.

3. Methodology

3.1. Data

We selected the Northeast Asian cruise area as a case study because it has expanded rapidly in recent years. The CLIA officially began collecting data on the Northeast Asian cruise population in 2012. The cruise population in Northeast Asia in 2012 was approximately 450,000, reaching 2.84 million by 2019 (Asia Cruise Lines International Association, 2013, 2020). China is a source of demand for the fast-growing Northeast Asian cruise market. In 2006, the first year of the Chinese cruise market, the cruise population was 20,000 (Wang, 2017). In 2016, the number reached 2.1 million, and China became the world's second-largest cruise market, following the United States (CLIA, 2016).

We used data from international cruise itineraries (excluding domestic cruise itineraries) calling at ports in Northeast Asian countries (Japan, China, Hong Kong, Taiwan, and South Korea) from 2014 to 2019. Since some ports are not equipped with AIS data receivers and itineraries for which AIS data cannot be obtained, we supplemented it with brochures and other information from each cruise line. The division by the size of the cruise ship followed the classification criteria of CLIA Asia (2019). The classification criteria are as follows. Information on cruise operators, based on ship size, is provided in Appendix 1.

- Mega-size: Lower berth capacity of 3500 or more OR GRT over 150,000
- Large-size: Lower berth capacity of 2000 to 3500 AND GRT over 75,000
- Mid-size: Lower berth capacity of 750–2000 passengers
- Small-size: Lower berth capacity under 750 passengers (*including Expedition ships)

The locations of the ports targeted in this study are shown in Fig. 1.

3.2. Measurements of network structure

The cruise passengers depart from the generating region, stop at each port of call to look around, and finally arrive at the destination region, which can be the same as the generating region. In the case of these looped routes, whether the order of port calls is clockwise or counterclockwise is of little significance. Kanrak and Nguyen (2021) reported that the degree distributions for in-degree and out-degree were similar observations. Therefore, we analyzed the network in an undirected graph. In addition, since this study aims to understand port selection behavior, it focuses on the connections between ports rather than the number of port calls, so it is analyzed in an

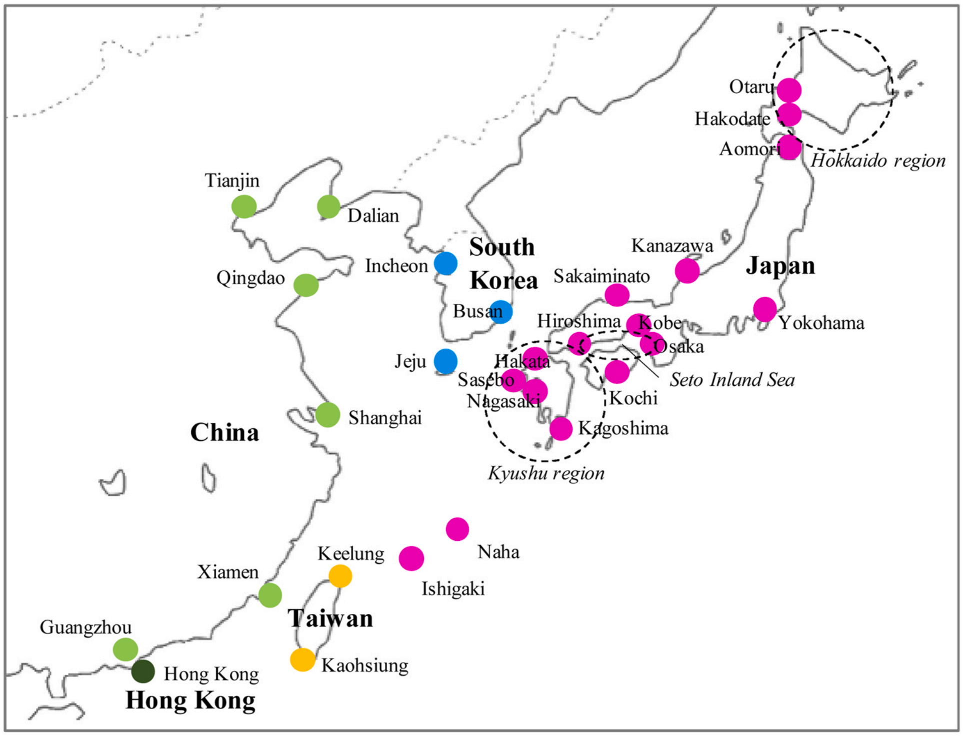

Fig. 1. Location of ports.

unweighted graph. Network analysis and visualization were conducted using Gephi (the open graph Viz platform).

The density is the ratio of the actual number of edges to the number of all possible edges in a graph. It is used to analyze the network's connectivity level. If the number of nodes is n and the number of edges is m, the network density d is given as follows:

$$d = \frac{2m}{n(n-1)} \tag{1}$$

The clustering coefficient of a node is the fraction of pairs of neighbors of the node connected. The clustering coefficient C_i of node i is defined as follows: $\tau(i)$ is the number of triangles involved in i. The maximum possible number of triangles for i is the number of pairs formed by its k_i neighbors. C_i is defined only if the degree $k_i > 1$ because of the terms k_i and in the denominator. A node must have at least two neighbors for any triangle to be possible.

$$C_i = \frac{2\tau(i)}{k_i(k_i-1)} \tag{2}$$

The clustering coefficient of the entire network is the average clustering coefficient C, which is used to understand the formation of the triangular route. The formula is as follows:

$$C = \frac{1}{n}\sum_{i=1}^{n} C_i \tag{3}$$

The average shortest path length is the average of the shortest network distances in the network that can reach the other ports. We define the average shortest path length $\langle l \rangle$ as follows: l_{ij} is the shortest path length between nodes i and j. The sum is over all pairs of nodes, and we divide it by the number of pairs to compute the average.

$$\langle l \rangle = \frac{\sum_{i,j} l_{ij}}{\binom{n}{2}} = \frac{2\sum_{i,j} l_{ij}}{n(n-1)} \tag{4}$$

The diameter l_{max} of a network is the maximum shortest-path length across all pairs of nodes (i.e., the length of the longest shortest path in the network). The formula is as follows:

$$l_{max} = \max_{i,j} l_{ij} \tag{5}$$

Degree centrality k_i is assumed to be centered on a node with a higher degree among the nodes in the network. We detect hub ports with the degree centrality. We denote the degree of node i by k_i. If the adjacency matrix of a network with n nodes is a_{ij}, then the degree centrality can be formulated as follows:

$$k_i = \sum_{j=1}^{n} a_{ij} = \sum_{j=1}^{n} a_{ji} \tag{6}$$

Degree centralization C_D measures are based on a normalized variance in the degree centrality to compare distinct networks based on their highest degree centralization scores (Freeman, 1979; Krnc & Škrekovski, 2020). We can measure whether the degree is biased toward high nodes in the network. The formula is as follows: f is a function of the maximum degree and degree of node i. k_{max} is the maximum degree. The more concentrated the network, the less homogeneous it is:

$$C_D = \frac{\sum_{i=1}^{n}(k_{max}-k_i)}{\max\sum_{i=1}^{n}(k_{max}-k_i)} \tag{7}$$

In network science, a community is defined as a group of nodes belonging to one group and connected with a higher probability than the nodes belonging to other groups. Community detection was performed using modularity optimization. Modularity is a measure of the quality of the community partitioning results. Modularity Q is defined as follows: L_c is the number of internal edges in community c, and k_c is the total degree of nodes in community c. L is the number of edges in the network.

$$Q = \frac{1}{L}\sum_{c}\left(L_c - \frac{k_c^2}{4L}\right) \tag{8}$$

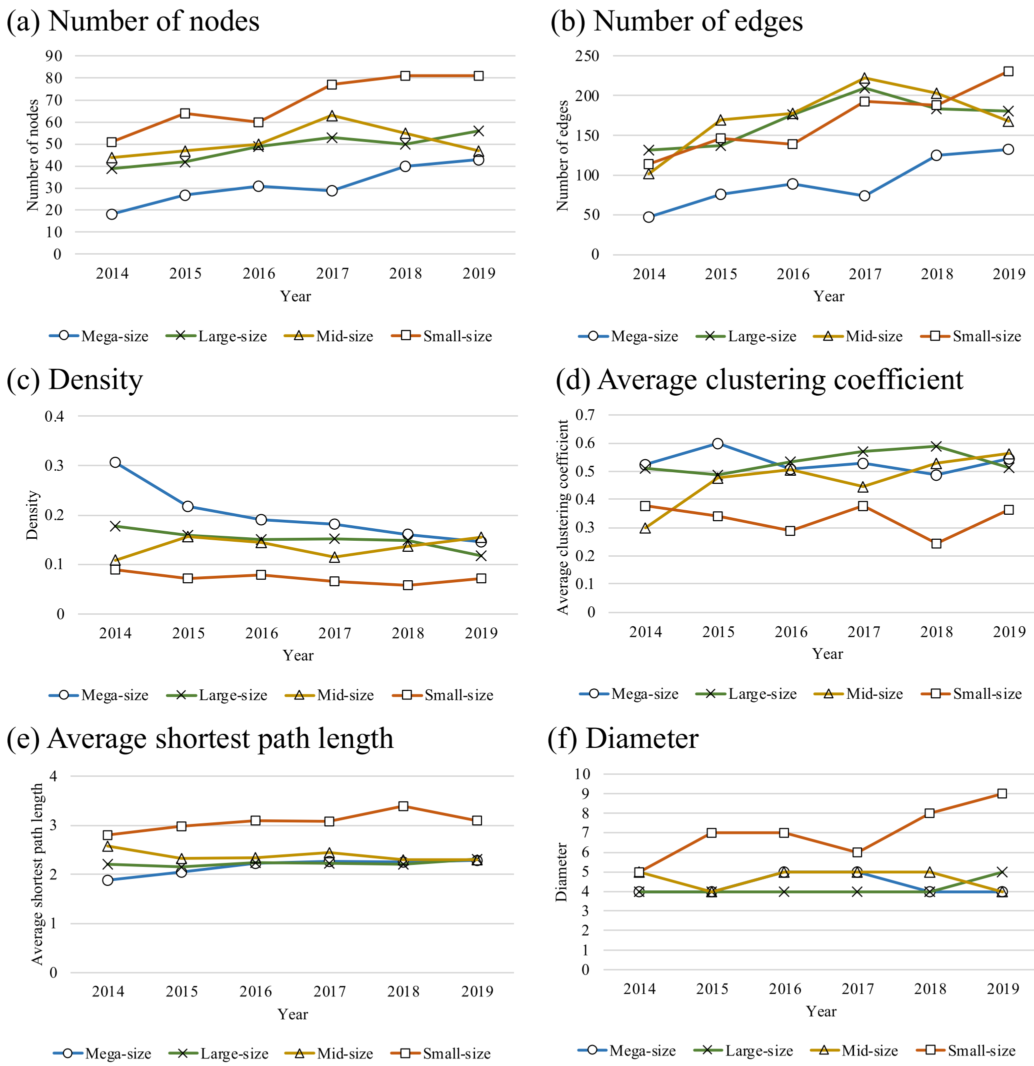

Fig. 2. Network structure.

In this study, we used the Louvain algorithm for modularity optimization (Blondel et l., 2008).

4. Results

4.1. Network structure

We analyzed the number of nodes and edges over time to examine changes in the number of ports and routes by ship size in Fig. 2(a) and (b). The number of nodes and edges was highest for the small-size ships and lowest for the mega-size ships. The changing trend was an increasing number of nodes and edges for small- and mega-size ships, whereas that of large- and mid-size ships decreased around 2017–2018. This indicates that small- and mega-size ships were driving growth in the Northeast Asian cruise market. In Fig. 2(c) and (d), observations were made using density and average clustering coefficients to understand changes in network density and the presence of triangular connection patterns. As a result, small-size ships had sparse networks and low triangular connectivity. The network of mega-size ships around 2014 was dense, but it tended to become sparse over time. It can be said that mega-size ships were dense in the early years of the market, but they gradually became sparse as the choice of ports of call increased. Furthermore, we analyzed changes in network size using the average shortest path length and diameter indicators in Fig. 2(e) and (f). The network of small-size ships was longer than that of other sizes, both in average shortest path length and diameter. In particular, the diameter of small ships has become increasingly longer since 2018.

4.2. Degree centrality

We detected hub ports by ship size in Figs. 3–5 using degree centrality to understand changes in the center of the Northeast Asian cruise network. The nodes of the same color belong to the same country. The size of each node represents its degree. We found that the mega-sized network has grown with Shanghai, Japan's Kyushu region, and South Korea's ports as hubs (Fig. 3). In 2014, there were still few ports with mega-size ships calling. Then, in 2015, the number of degrees in Shanghai, Nagasaki, Hakata, and Jeju increased. In 2016, these ports were joined by Hong Kong and Busan. From 2017, the number of degrees in Naha gradually increased. In 2018, Shanghai's degree increased even more, as did the degree of the Kyushu region in Japan, such as Kagoshima, Nagasaki, and Hakata. Additionally, Jeju disappeared from the network this year. In 2019, Busan, Keelung, and Naha grew as hub ports. Thus, we found that the group of hub ports where mega-size ships call had grown into a hub port with Shanghai as the center, together with the surrounding port groups in Japan, Korea, Taiwan, and Hong Kong. However, we found that there are few operations in the northern part of Japan (Hokkaido region), and they are not extensive.

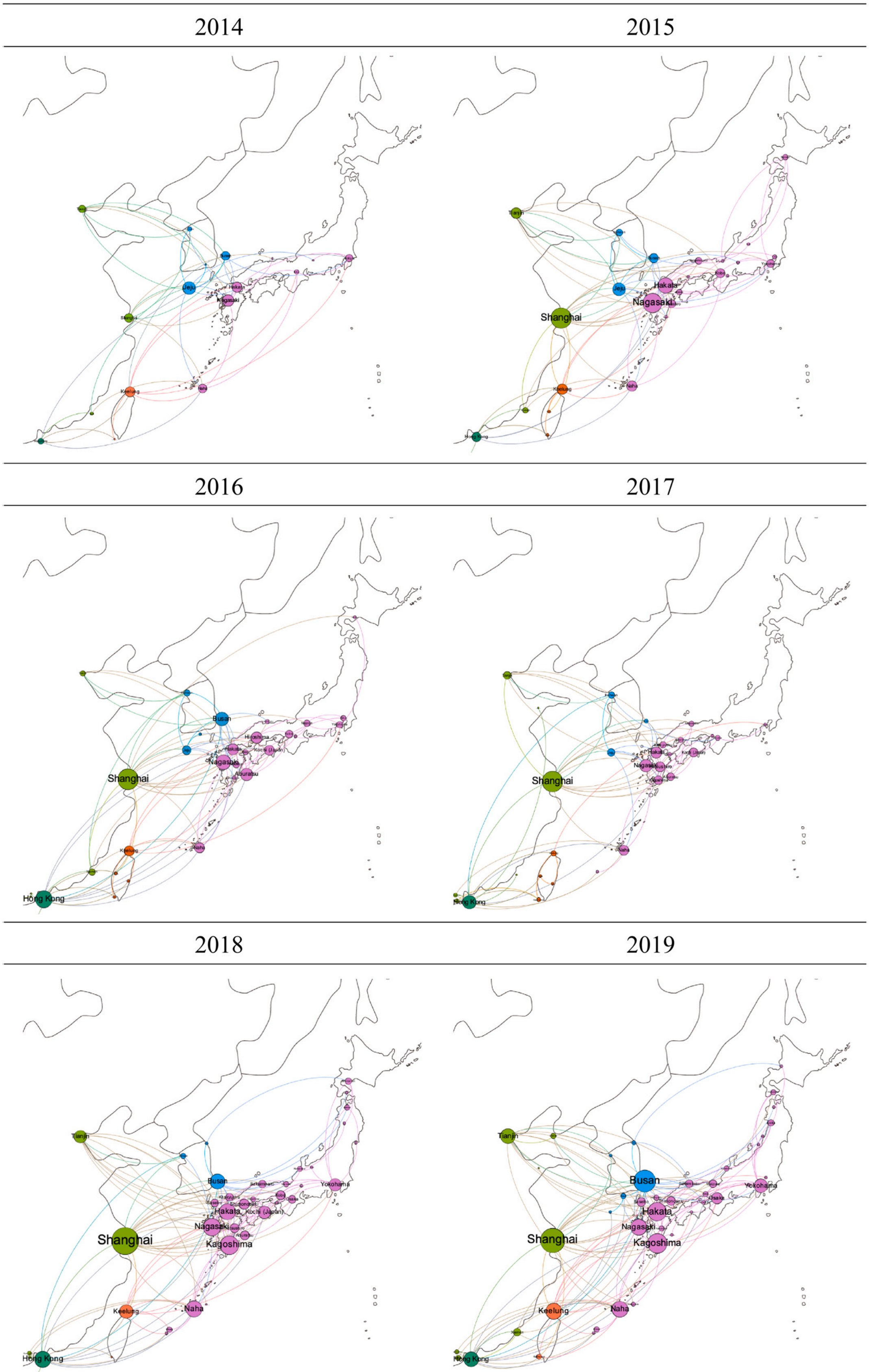

Fig. 3. Hub ports in mega-size ship network.

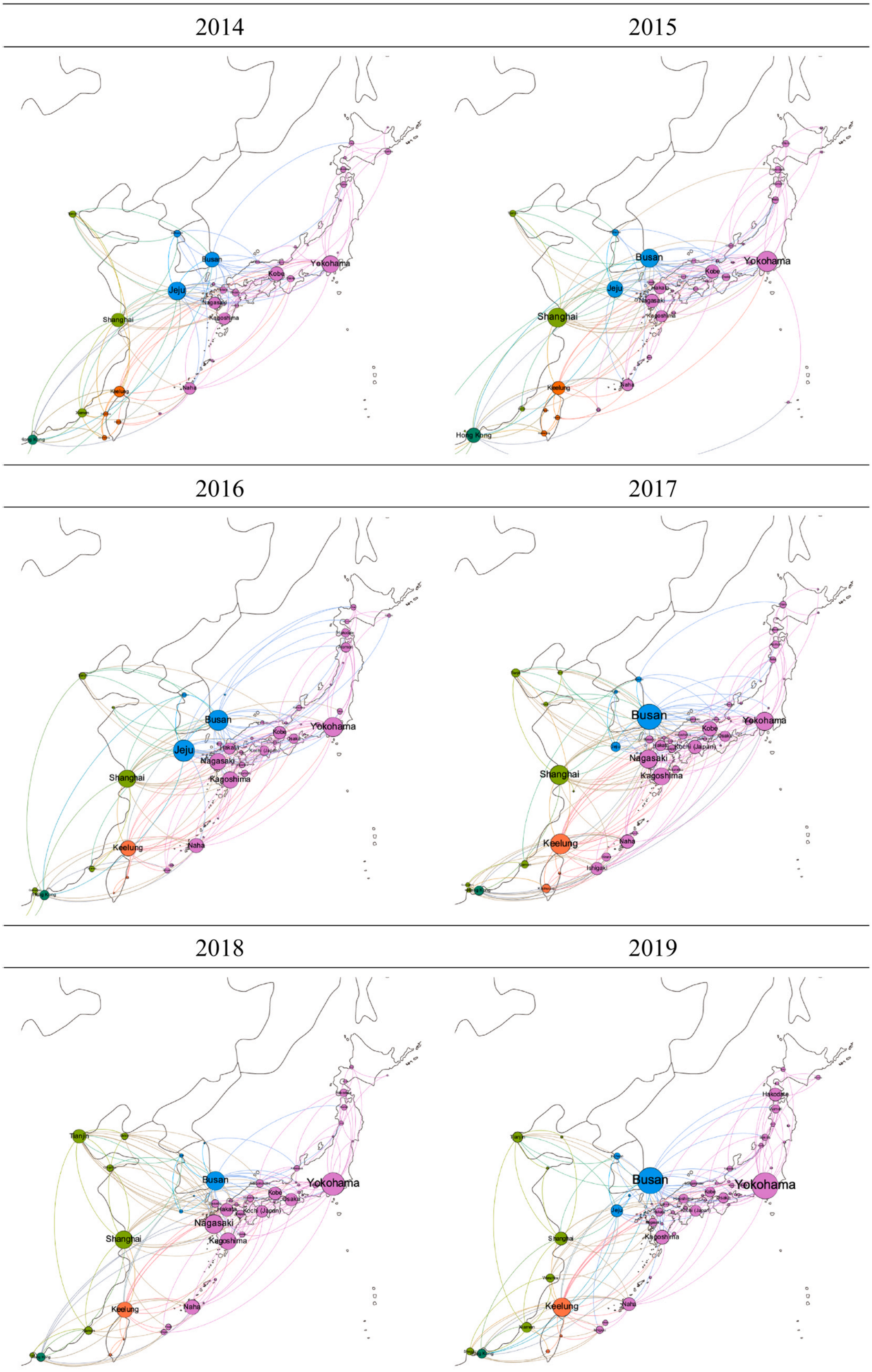

Fig. 4. Hub ports in large-size ship network.

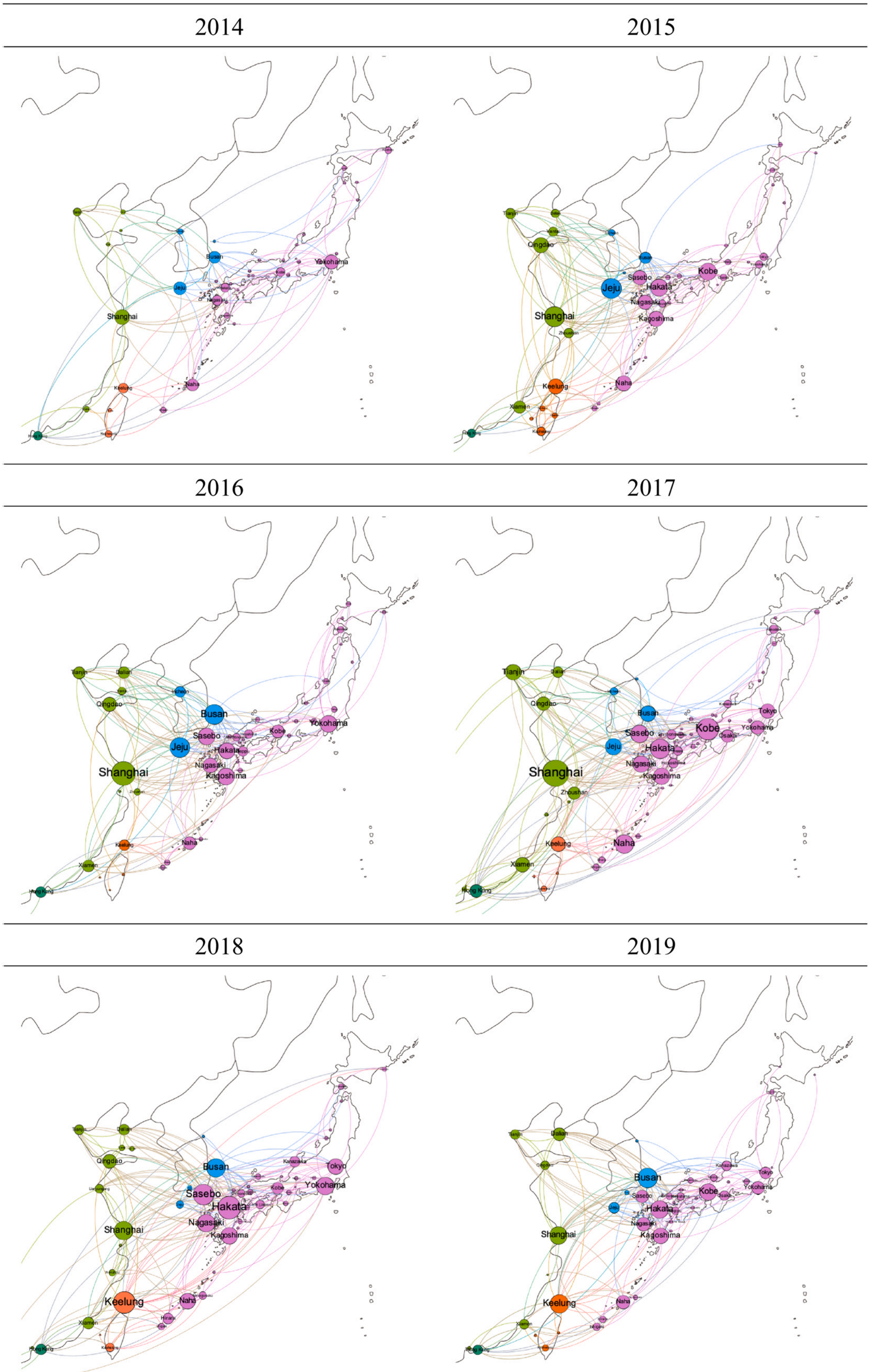

Fig. 5. Hub ports in mid-size ship network.

Fig. 4 shows the growth of the large-size network with Yokohama and Busan as hub ports. In 2014, the degree increased in Yokohama, Kobe, Busan, Jeju, and Shanghai. There were also cruise ship calls to the Hokkaido region, located in northern Japan. In 2015, the degree of Shanghai, Yokohama, and Busan increased. In 2016, in addition to these port groups, the degree of Jeju, Keelung, Nagasaki, and Kagoshima increased. In 2017, the degree of Busan, Shanghai, and Keelung increased further, as well as for many Japanese ports (including Yokohama, Nagasaki, Kagoshima, Kobe, Kochi, and Naha). In 2018, Tianjin's degree increased, and in 2019, Yokohama and Busan grew into huge hubs while Shanghai declined. Thus, the network of large-size ships consisted of Yokohama and Busan as hub ports, with multiple ports of call scattered around them. Ports of call were widely spread throughout Northeast Asia, with some as far north as Japan. We also found that the situation was not as Shanghai-centric as the mega-size network.

The mid-size network had grown with Shanghai and Jeju as hub ports until 2017, after which the hub ports shifted to Keelung in Taiwan, Busan in South Korea, and Kyushu region in Japan (Fig. 5). In 2014, Yokohama and Shanghai were the hub ports, but both still had low degree numbers. In 2015, several hub ports had emerged, mainly Shanghai, and Jeju, Hakata, Kobe, and Keelung had also increased their degree. In 2016, Yokohama and Busan joined this hub port group. In 2017, Shanghai grew into an even more massive hub port. Other ports such as Kobe, Hakata, Sasebo, and Naha also increased. However, the situation changed in 2018. While Shanghai, Tianjin, and Jeju declined, Hakata and Sasebo increased, and Keelung emerged as a hub port. In 2019, the degree shrank at many ports. Thus, the mid-size network was on a downward trend, as the trend toward expansion from 2014 to 2017 changed dramatically in 2018. The decline in the position of Shanghai and Jeju was noticeable.

In the small-size network, the development of Hiroshima and Kobe as hub ports can be seen in Fig. 6. No major hub ports were found in 2014, but the following were relatively high: Kobe, Otaru, Busan, Jeju, Shanghai, Keelung, and Hong Kong. Several hub ports have emerged around Japan since 2015. These hub ports are Hiroshima, Kobe, and Nagasaki. In 2016, Hiroshima and Kobe formed a huge hub port among these ports, followed by Jeju, Shanghai, and Keelung, which were gradually increasing. In 2017, in addition to Hiroshima and Kobe, Nagasaki, Busan, and Hong Kong were growing hub ports. It is also evident that cruise ship calls were operating over a wide area from the Hokkaido region in northern Japan to southern China. In 2018, Hiroshima emerged as a huge hub port. Moreover, numerous ports had emerged around Hiroshima. Furthermore, by 2019, an extremely large number of ports would emerge around Hiroshima, as well as Kobe, Osaka, and Nagasaki, while Hakodate would be next in line in northern Japan. Thus, it can be seen that the small-size network has grown with Hiroshima as its hub port in Japan, with several sub-hub ports in the vicinity working in tandem with each other. In the northern part of Japan, there were also signs of a hub port cluster forming around Hakodate.

Fig. 7 shows the degree by a port to observe changes in the hub ports by ship size. The legend lists the top 10 ports in 2019. Each country has a different color line. Pink, light green, light blue, green, and orange colors represent Japan, China, South Korea, Hong Kong, and Taiwan, respectively. The gray lines represent the degree of ports ranked 11th and lower in 2019. The mega- and small-size ship's hubs remain unchanged, while the large- and mid-size ship's hubs were gradually replaced. The transition of hub ports by ship size is described below.

Since 2015, the mega-size network was continuously highest in Shanghai, indicating that the hub port was fixed in only Shanghai. In 2019, Shanghai, Busan, and Kagoshima were higher. There was a temporary drop in the overall degree in 2017. It also shows that Shanghai, Kagoshima, and Hakata have changed at the same time since 2017. Large-size frequently swapped places in the rankings. Jeju was the highest in 2014 and 2016, Yokohama in 2015 and 2018, and Busan in 2017 and 2019. In 2019, Busan was the highest, followed by Yokohama and Keelung. For the mid-size, after the upward trend from 2014 to 2017, a downward trend was evident from 2018 onwards. Shanghai remained at a high level through 2017 but then fell sharply in 2018. This led to higher degrees in 2019 for Busan, Keelung, and Hakata, but none of these ports had been on an upward trend in recent years and remained flat. In terms of the small-size network, Hiroshima and Kobe have continuously had high degrees since 2015. In particular, Hiroshima's degree was high since 2018, indicating that the port was present as a hub port. In 2019, Japanese ports such as Hiroshima, Kobe, and Osaka ranked high. It also shows that the number of ports in the grey lines with a degree of 10 or less was high and densely populated.

The degree distribution is organized in Fig. 8 to examine changes in the degree by ship size. In this bar chart, the white bars represent 2014, the black bars represent 2019, and the rest represent the degree distribution for each year. The red line in the figure depicts the 2019 figures. The distribution bar charts for all sizes also had a shape with a long tail to the right-hand side, with the highest bar around degree two. The bar then shifts to the right-hand side over time. The mega-size was mostly degrees 2 and 4. The number of degrees after 13 increased over time, indicating that the trend was toward hubbing. Large-size wc, followed by degrees 10 and 13. In addition, ports with a higher degree of 27 were present. Mid-size had similar levels of degrees with a wide range of degrees from 2 to 9. This is in contrast to a large number of degrees 2 in the other sizes. The number of ports with higher degrees decreased over time. Small-size had higher degrees 2 and 4, followed by degrees 8 and 13. Compared with the other sizes, the tails on the right-hand side were shorter, indicating less obvious hub ports.

We further analyzed Fig. 9 using a measure of degree centralization to examine changes in network uniformity (i.e., the relative impact of higher degree hub ports) with ship size. From 2014–2018, the mega-size network was the highest. This is because the mega-size network means a heterogeneous network with some huge hub ports versus some that were not. The large-size network was on a gradual but upward trend. However, it declined from 2018 onward, with large-size having the highest values in 2019. Mid-size was on an upward trend until 2016, and it had been declining since 2017. The small-size network was at much lower levels indicating that it was more homogeneous than the other sizes.

4.3. Community detection

We used a method of community detection based on modularity optimization to observe temporal changes in the number of communities and geographic locations created by connections between ports by ship size (Fig. 10). We found that the mega-size network witnessed a rapid increase in the number of communities from two to five from 2014 to 2019. The mega-size network had two communities in 2014, one in northern China, Japan, and Korea, and the other in southern China, Taiwan, and eastern Japan. There were four communities in 2015–2016. The community in northern Japan disappeared in 2017, reducing the number of communities to three. The community in northern Japan community again emerged in 2018, bringing the number of communities back to four. Further, Tianjin and Kyushu regions in Japan formed a separate community from Shanghai in 2018. Another community emerged in the Hong Kong and Guangzhou areas in 2019, bringing the number of communities to five.

The large-size network remained stable with four to five communities from 2014 to 2019. The large-size already had five communities in 2014. Unlike the mega-sized communities of the same year, these communities were geographically widespread, including northern Japan. From 2015–2017, the community was fixed in four

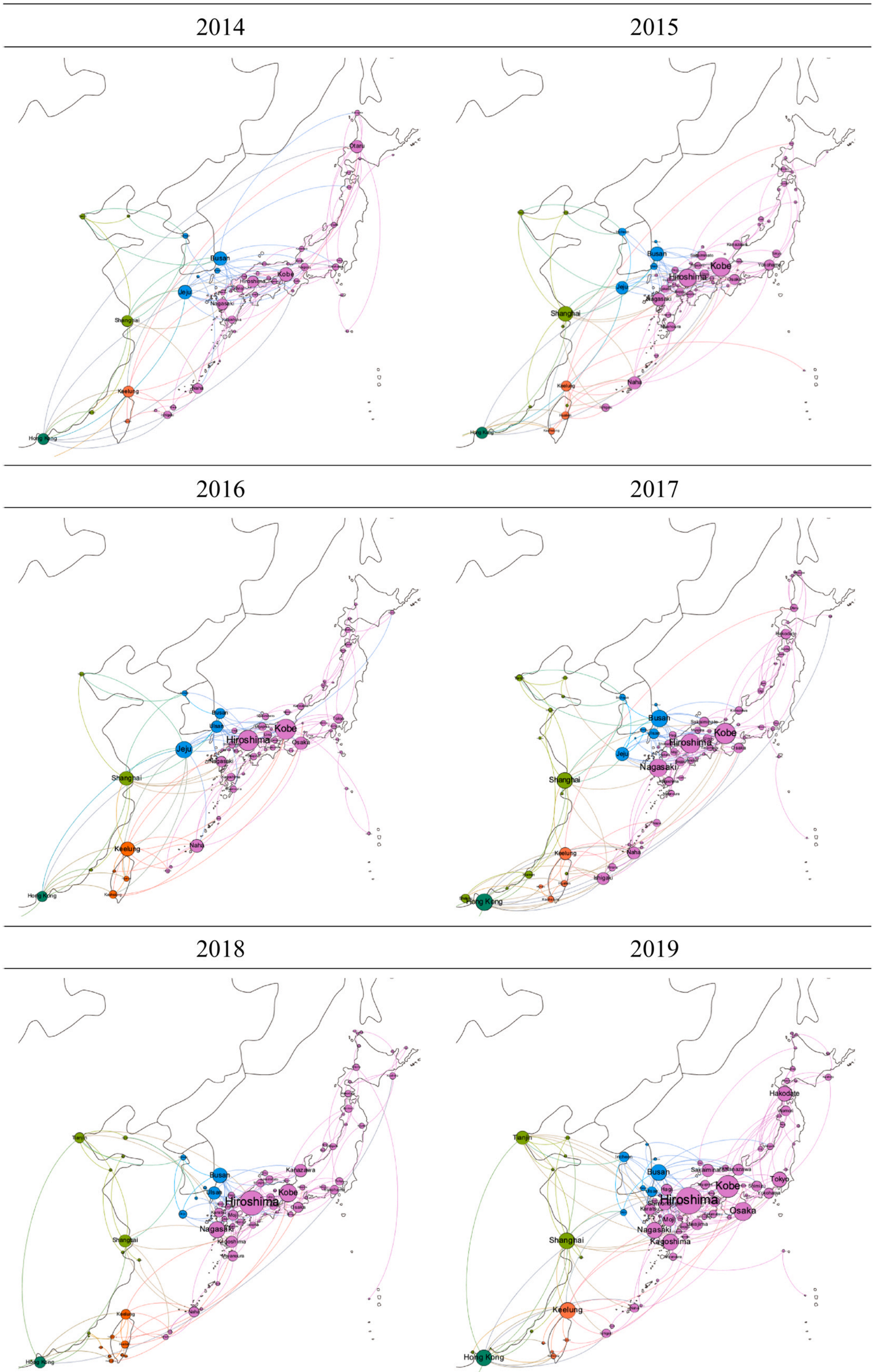

Fig. 6. Hub ports in small-size ship network.

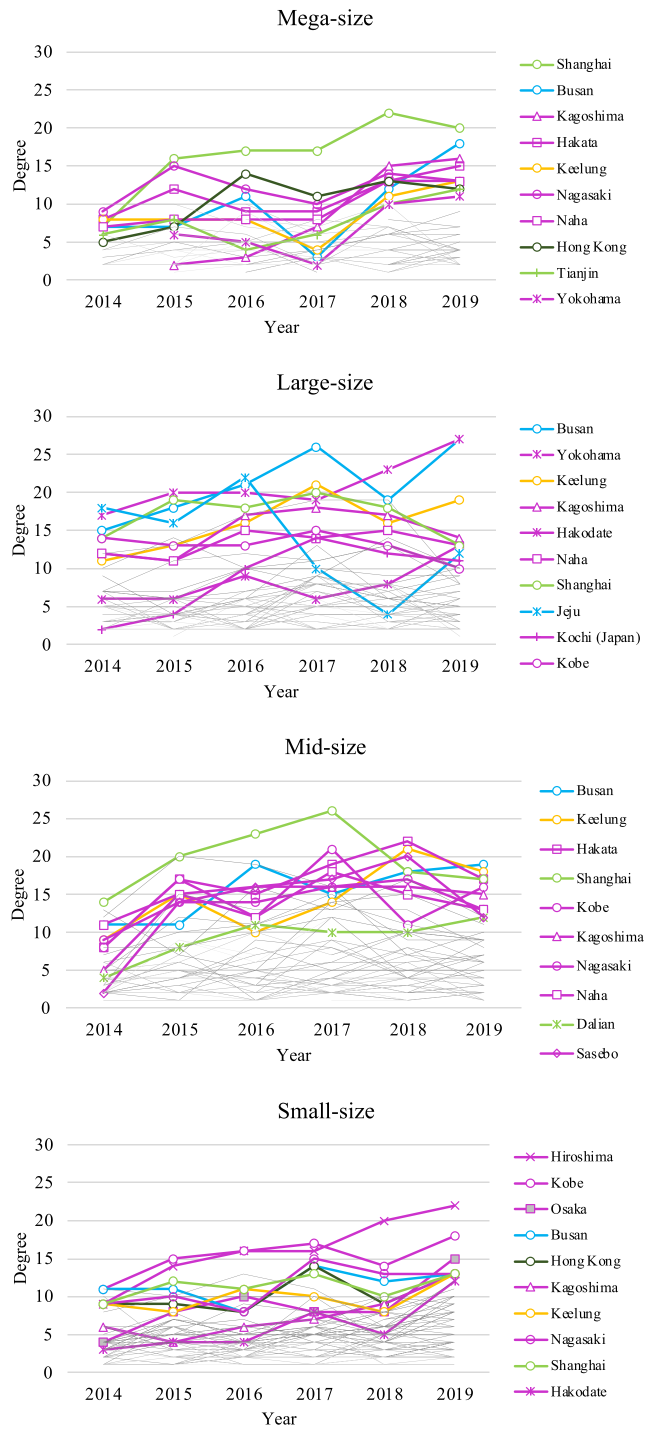

Fig. 7. Degree centrality.

communities: “northern China, western Japan, and South Korea,” “southern China, Hong Kong, Taiwan, and southern Japan,” “northern Japan,” and “eastern Japan.” However, the community in the central part of Japan split in 2018, and since then, five communities have emerged.

The mid-size, like the large-size, remained stable with four to five communities from 2014 to 2019. The location of the boundaries dividing the mid-size communities was also similar to that of the large-size. The similarity was also evident in 2018 when Jeju, located near Shanghai, left the northern Chinese community and joined the Japanese community. However, there were some differences between the mid- and large-size communities. The mid-size had more nodes in northern China (near Dalian and Qingdao), and fewer nodes in northern Japan and a new community emerged in southern China from 2016 to 2017.

The small-size community had a different structural evolution from other sized communities. The four main differences between the small size and the other sizes were the number of communities, geographic spread of nodes in the same community, location of the community boundaries, and areas where the nodes were concentrated. First, the number of small-size communities was already five in 2014, with seven emerging in 2015. Even in 2019, there were six communities. Second, several nodes located far away from each other were connected within the same community. For example, one of the communities in 2014 (in orange) was characterized by the geographic breadth of the community, with a node in northern Japan and a node in southern China belonging to the same community. Third, other than the small size network, there were two distinct communities, one centered in Shanghai and the other in Keelung. However, because of their small size, Shanghai and Keelung belonged to the same community in 2016, 2018, and 2019. Finally, many nodes have been continuously concentrated in the Seto Inland Sea in western Japan since 2014.

Note: Nodes of the same color belong to the same community.

Further analysis visualizes the differences in the way ports are connected by ship size (Fig. 11). Nodes of the same color belong to the same community. The size of each node represents its degree. We found that the network of mega-, large-, and mid-size ships had several high-degree hubs with several smaller nodes around them, forming a “hub and spoke” structure in each community, as well as connected edges across communities. Conversely, the network of small-size ships tended to be homogeneous in the degree of each node and had the smallest value of degree centralization. The appearance of some nodes being connected with some detours between them was also consistent with the longer average shortest path lengths and diameters. In other words, the small-size network was constructed by connecting ports “side by side.”

We analyzed the quality of the network's community partitioning by ship size using the measure of modularity, which is shown in Fig. 12. This implies that the cruise network increases the quality of community division over time. In addition, the modularity of the small-ship network was the highest compared with other sizes, although it has been declining since 2018. However, the lowest was the modularity of mega-ships.

5. Discussion

This study aimed to examine the structural changes in the cruise network by ship size in Northeast Asia. We found that the characteristics of structural changes in the cruise network varied with ship size. In particular, we found five key findings.

First, the number of nodes and edges in the mega- and small-sizes was growing faster than those in the other sizes in Northeast Asia. The small-size network had the highest number of nodes and edges. Generally, small ships are operated by luxury cruise lines, which target wealthy customers. Barron and Greenwood (2006) and Han and Hyun (2018) stated that the development of luxury cruise itineraries is critical to customer satisfaction. Hwang and Han (2014) and Lee and Kim (2019) stated that luxury cruise lines need to constantly offer new cruise products. As pointed out in these studies, small ships are always looking for new ports and routes, which leads to a large number of nodes and edges. Bagis and Dooms (2014) also noted that the itineraries of larger ships tend to be more fixed than those of smaller ships. The mega-sized network in this study may have the lowest number of nodes and edges, given the limited number of ports that can be called. Interestingly, however, the number of nodes and edges for mega- and small-size networks has been on the rise in recent years. In other words, the growth of the

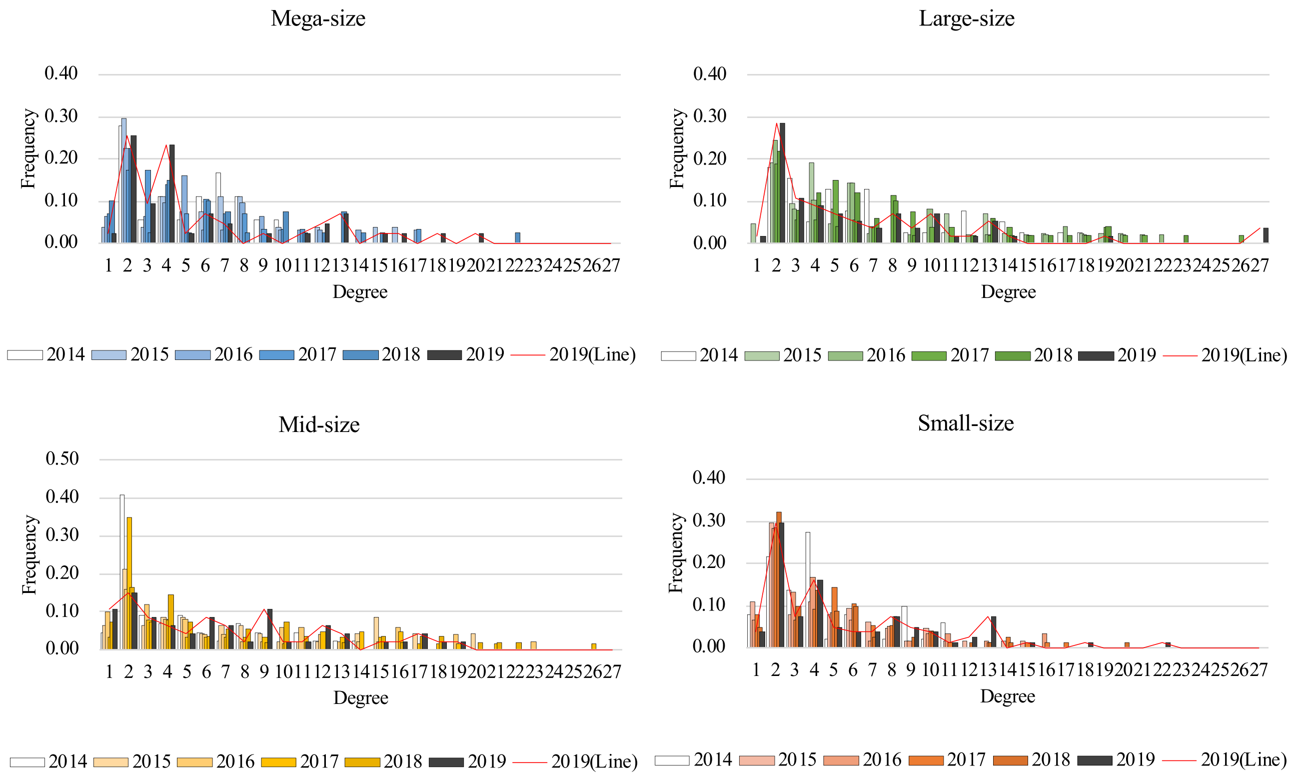

Fig. 8. Degree distribution.

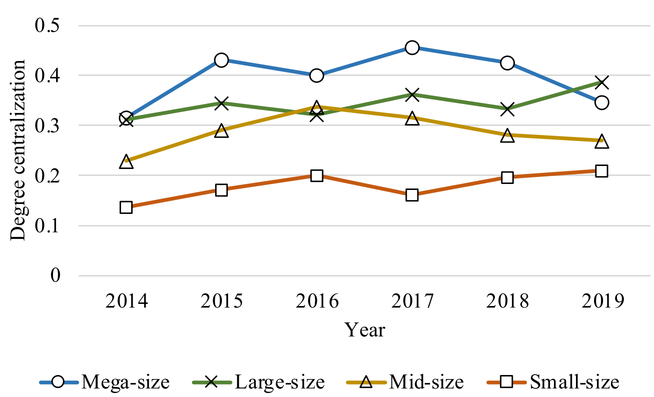

Fig. 9. Degree centralization.

cruise market in Northeast Asia in recent years may have been accomplished by two ship sizes: mega- and small-size.

Second, the growth pattern of the small-size network differed from that of the other sizes. Specifically, the small size grew uniquely, with low network density and an average clustering coefficient but a high average shortest path length and diameter. The low density may be due to the rapid increase in the number of nodes. Also, the low average clustering coefficient may be due to longer duration itineraries than other ship sizes, which results in fewer triangular routes. Furthermore, the high average shortest path length and diameter may be because there are fewer "hub and spoke" connections, and there are many patterns in which ports are connected "side by side" compared with other ship sizes.

Third, hub ports differed depending on the size of the ship. In 2019, the mega-size hub was Shanghai; the large-size ones were Busan and Yokohama; the mid-size ones were Busan and Keelung; the small-size ones were Hiroshima and Kobe. The mega- and small-size ship's hubs remain unchanged, while the large- and mid-size ship's hubs were gradually replaced. In terms of port calls to peripheral ports, mainly hub ports, the mega-, and mid-size networks were mainly to ports in the vicinity of Shanghai, Busan, and Keelung, which are closer together. Meanwhile, the large- and small-size networks were growing, with cruise ships operating over a wide area from northern Japan to southern China. Furthermore, as for the homogeneity of the network for hub ports, the small-size network was growing in a more homogeneous state than those of other sizes.

Fourth, Shanghai was a mega-size hub port. Shanghai was a hub port for large- and mid-size networks until 2017; however, since 2018, Shanghai was no longer a hub port due to its rapidly decreasing degree centrality. At the time, many of the major cruise lines were the first to deploy their new mega-ships to Shanghai to target the rapidly growing number of Chinese cruise passengers (Cruise Industry News [CIN], 2017; CIN, 2018; CIN, 2019a; CIN, 2019b). This resulted in the existing large- and mid-size ships in Shanghai being displaced by the new mega-size ships and shifted to Keelung, Hong Kong, Yokohama, and other ports. In the case of Princess Cruises, the deployment of the mega-size ship MAJESTIC PRINCESS to Shanghai in 2017 shifted the existing large-size ship, SAPPHIRE PRINCESS, from Shanghai to Keelung. As a result, Shanghai was a hub port in the mega-ship network, but it significantly reduced the number of degrees for large- and mid-size ships. This may reflect the cruise lines' port selection behavior of launching large- or mid-size ships in the early stages of the cruise market and then replacing them with mega-size ships when they are convinced that there is sufficient passenger demand in that port.

Finally, modularity increased for all sizes, which indicates that the community structure has become clearer over time. Moreover, the small-ship network had more communities and different boundaries than the other sizes. The number of mega-, large-, and mid-size ship communities was approximately four to five. On the contrary, only the small-ship network had seven communities in 2015 and six in 2019. Many communities were located in Japan, and the boundaries between the communities differed from other ship sizes. Unlike other sizes, in 2016, 2018, and 2019, small-ship

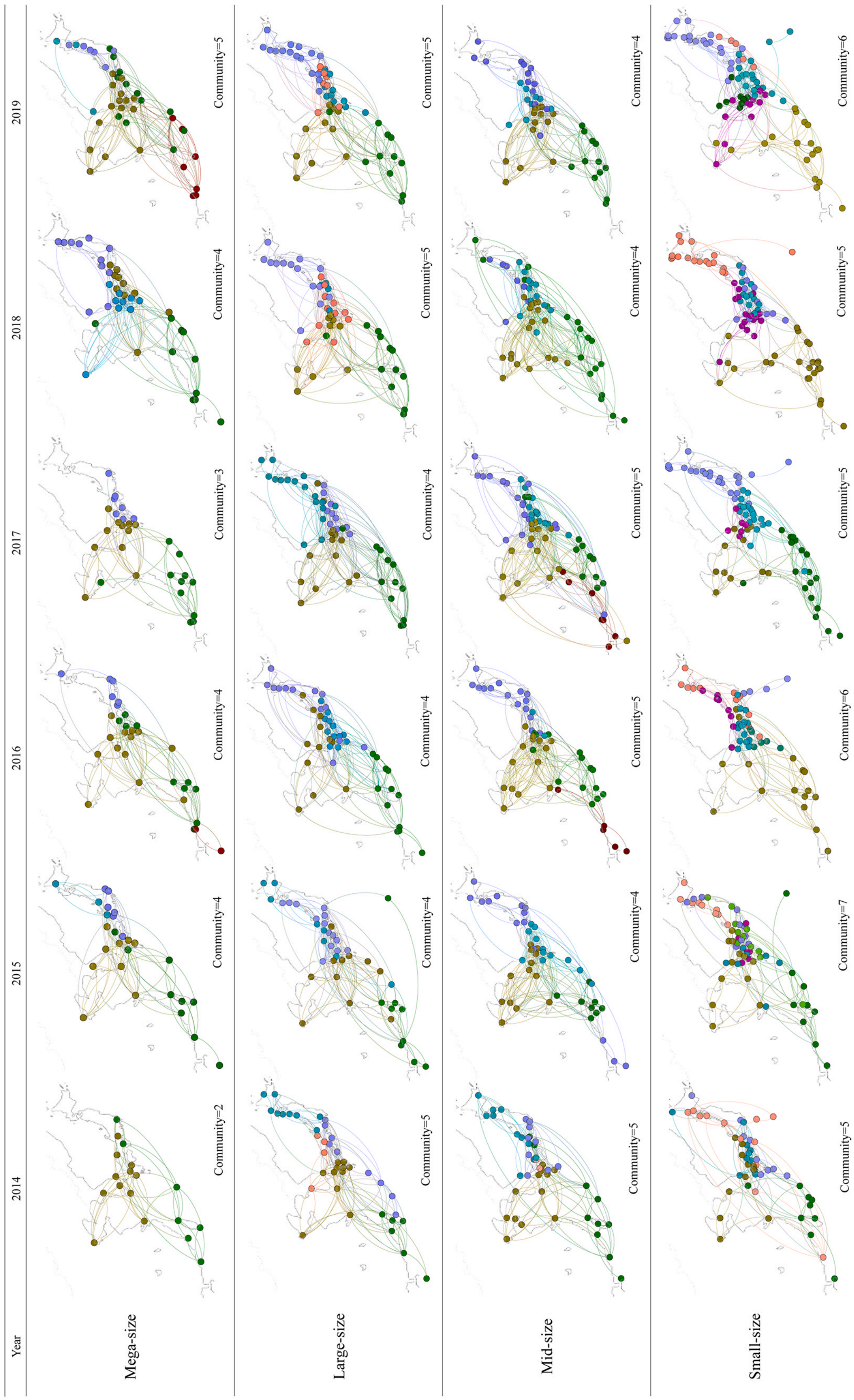

Fig. 10. Community detection.

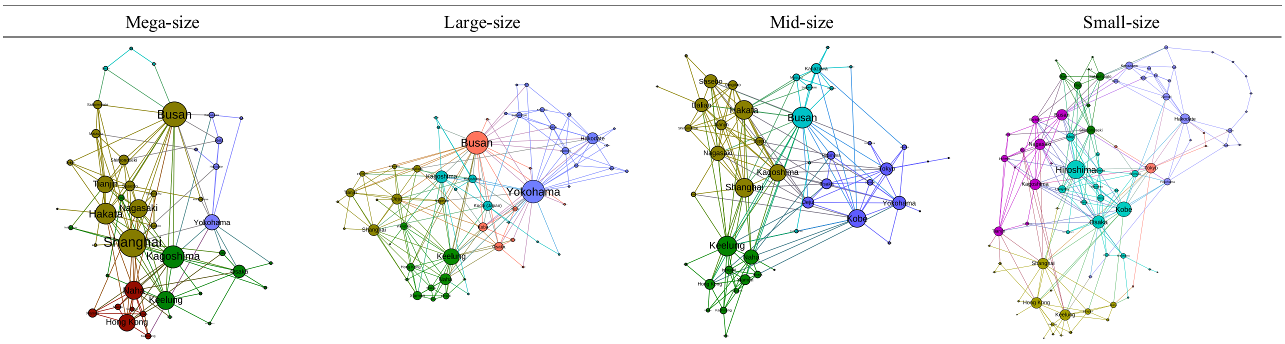

Fig. 11. Visualizing the 2019 Northeast Asian cruise network.

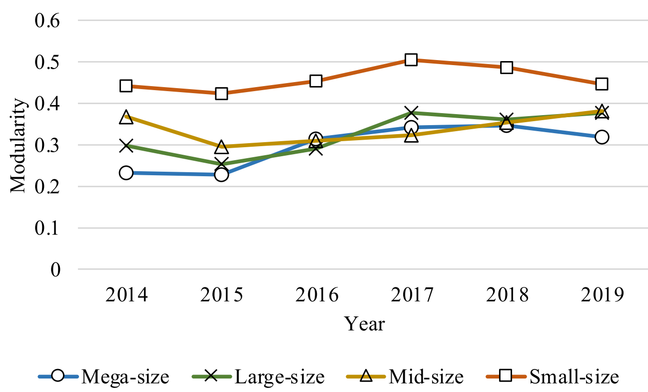

Fig. 12. Modularity.

networks had Shanghai in the same community as Hong Kong and Keelung, and many ports were concentrated around the Seto Inland Sea in Japan.

Our findings allow for a deeper analysis to clarify the structural changes in the cruise network by considering the following data limitations. First, AIS data show the movement of cruise ships but do not distinguish between arrival/departure ports and ports of call. Therefore, this study could not analyze the data on an itinerary basis. Second, AIS data do not provide the number of cruise passengers per route (edge). Ideally, if a network diagram could depict not only the movement of cruise ships but also the movement of cruise passengers, the process of evolution of the relationship between supply and demand could be analyzed.

6. Conclusion

In summary, by using AIS data and network science methods, the operational and commercial characteristics of the cruise lines were determined through observations of changes over time in the cruise network by ship size. The results from these data highlight the port selection behavior of cruise lines by ship size.

The mega-size ships choose Shanghai as their hub port and connect with nearby ports. Over time, they formed a network of "hub and spoke." The number of nodes and edges is small compared with other ship sizes, but that number has been growing rapidly in recent years. This may indicate that the development of ports in Northeast Asia has eliminated restrictions on port facilities, passenger handling, and other factors. Cruises, one of the tourism products, are supply-driven (Vogel & Oschmann, 2012; Rodrigue and Notteboom, 2013). Future development of the cruise market for mega-ships in Northeast Asia will require synchronization of port development and deployment of cruise ships by cruise lines.

Conversely, large-size ships used to have Shanghai and Jeju as their hub ports. However, since 2017, they have shifted to Busan and Yokohama, which is characterized by frequent changes in hub ports. Large-size ships operate over a wider area throughout Northeast Asia than mega-size ships. Similarly, mid-size ships were characterized by a shift from Shanghai and Jeju as hub ports to Busan and Keelung after 2017. To add, the impact of the deployment of new mega-size ships in Shanghai led to the replacement of hub ports within each network as existing large and mid-size ships were pushed out. This indicates that countries and ports need to closely monitor cruise ship deployment behavior by major cruise lines such as Royal Caribbean Cruises, Costa Cruises, MSC Cruises, and Princess Cruise Lines, which own three sizes of ships: mega-, large-, and mid-size ships.

Small-size ships have unique operational and commercial port selection characteristics. In the network of small-size ships, the Japanese ports of Hiroshima and Kobe became hub ports and grew higher over time. In addition, the number of nodes and edges in the small-size network is higher than for other ship sizes and has been increasing in recent years. This may indicate that luxury cruise lines operating small ships are successfully developing new ports and routes to improve customer satisfaction. Furthermore, small-size cruise ships operate side-by-side rather than the hub-and-spoke connection found on other ship sizes.

More specifically, the increasing trend in the number of nodes and edges was observed not only for small-size ships but also for mega-size ships, which indicates that the cruise market in Northeast Asia has been diversifying in recent years. Further development of ports where small-size ships can call at ports of call and tourist attractions should be further promoted, especially in Japan. Furthermore, it is necessary to create a market where not only small-size ships but also mega-, large-, and mid-size ships operate. This situation will help customers with diverse needs to choose their favorite cruise ship category. The government, ports, and cruise lines need to work together to diversify the cruise market.

Moreover, one characteristic of all ship sizes is the sudden disappearance of Jeju from the network in 2018. This phenomenon might be related to the Terminal High Altitude Area Defense missile (THAAD) event in March 2017. China banned group travel to South Korea in retaliation for the planned deployment of THAAD by US forces in South Korea's territory. This event hugely impacted the entire Korean cruise tourism industry(Park et al., 2019). Since then, all cruise ships from China to South Korea have stopped. This suggests that the cruise network is fragile and is affected by a variety of factors. Given such vulnerability, governments need to actively promote cross-border cooperation among ports. Specifically, ports must be prepared in advance to provide backup in the event of an emergency, and a system must be established to ensure that cruise ship operations do not come to a halt in the event of an emergency.

There are three challenges for future studies. The first is to expand the target cruise area from Northeast Asia to the world to clarify the geographical differences in the structural changes of the cruise network. The second is to conduct a more detailed analysis of units (e.g., monthly and quarterly) to show the seasonal differences in the structural changes of the network structure over time. The third is to understand the structure of connections between nodes based on their spatial characteristics, analyze the evolution process of cruise networks, and apply it to future prediction models.

Funding

No.

Appendix

Appendix 1
Cruise operators by ship size.

Mega-size ship operators	Large-size ship operators	Mid-size ship operators	Small-size ship operators
Costa Crociere SpA	Celebrity Cruises Inc	Aida Cruises	Azamara Club Cruises
Dream Cruises Management Ltd	Costa Crociere SpA	Astro Ocean Cruise	Hapag-Lloyd Kreuzfahrten GmbH
MSC Crociere SpA	Cunard Line Ltd	Costa Crociere SpA	Japan Cruise Line Inc
NCL Bahamas Ltd	Holland America Line NV	Cruise & Maritime Voyages Ltd	Mitsui Passenger
Princess Cruise Lines Ltd	NCL Bahamas Ltd	Crystal Cruises LLC	Noble Caledonia Ltd
Royal Caribbean Cruises Ltd	P&O Cruises	Diamond Cruise	Oceania Cruises Inc
	Princess Cruise Lines Ltd	Dream Cruises Management Ltd	P&O Cruises
	Star Cruises	Fred Olsen Cruise Lines Ltd	Phoenix Reisen GmbH
		Holland America Line NV	Plantours & Partner GmbH
		Maritime Holdings Group Inc	PONANT
		MSC Crociere SpA	Princess Cruise Lines Ltd
		Nina Services Corp	Regent Seven Seas Cruises Inc
		NYK Cruises Co Ltd	ROW Management Ltd
		Oceania Cruises Inc	Seabourn Cruise Line Ltd
		P&O Cruises	SeaDream Yacht Club Management
		Phoenix Reisen GmbH	Semester at Sea
		Royal Caribbean Cruises Ltd	Sete Yacht Management SA
		SkySea Cruises	Silversea Cruises Ltd
		Star Cruises	Voyages of Discovery Ltd
		Viking Ocean Cruises Ltd	Windstar Cruises LLC
		Yantai Bohai Ferry Int'l Ship	

Acknowledgments

No.

Declaration of interest

No.

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