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Keyword network analysis: Uncovering research trends on the Northern Sea Route

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ABSTRACT

The Northern Sea Route (NSR) has gradually become viable because of sea ice melting in the Artic. There is a large and diverse body of research on the NSR, investigating aspects such as weather, the environment, legal security, infrastructure and technologies, shipping transportation, and economic issues. However, there has been scant research carried out from a macroscopic perspective on NSR research trends. The purpose of this study is to analyze the trends in research about the NSR by applying a social network analysis. By collecting keywords from academic papers on the NSR, a network of keywords and two indexes (degree centrality and betweenness centrality) are accessed and analyzed. The results show that the trends can be divided into three periods (1899–1999, 2000–2009, 2010–2019). Throughout all periods, the issue of climate change causing the ice in the Arctic to melt has been a consideration for many scholars. In addition, "national security" and "oil exploitation" were important keywords in the first period. In the second period (2000–2010), in addition to words related to the environment, such as "sea ice" and "climate change," the term "ocean transport" appears and becomes a central topic of research. This is because when the NSR has a non-icy period, ocean transport through the NSR can be deployed. The research trends become obvious in the third period (2011–2019) with two primary research areas: climate change and shipping area, which accurately measure the benefit and cost. This paper shows the importance of the NSR, reviews the main research topics involving the NSR, and informs researchers and authorities as to the trends in academic research on the NSR.

1. Introduction

The Arctic Sea is one of the smallest and shallowest of the world's five major oceans (Pidwirny, 2006; Arctic Council, 2009). It is partially covered by sea ice throughout the year and almost completely covered in the winter, making it difficult to access and exploit (Arctic Council, 2009).

Over the last few decades, the Arctic Sea area has experienced a reduction in ice cover as a result of global warming (Hansen et al., 2016). Because the Arctic's sea ice is melting at a fast pace, there are numerous opportunities for development in the area, such as in shipping transportation and the offshoring of energy as well as servicing and supplying equipment to these industries. Countries are not only taking advantage of the vast quantities of natural resources that can be extracted (e.g., oil, gas, and minerals) but also utilizing Arctic shipping lanes for intercontinental transport (Xu et al., 2011; Hansen et al., 2016).

The two new shipping routes in the Arctic, which are considered maritime shortcuts between Europe and Asia, are the Northwest Passage and the Northern Sea Route (NSR) (Alvarinho, 2014). The Northwest Passage connects the Atlantic and Pacific Oceans, running along Canada's far northern coast and through the Canadian Arctic Archipelago (Østreng et al., 2013). In contrast, the Northern Sea Route follows the coast of the Russian Arctic from Novaya Zemlya in the west to the Bering Strait in the east, with a total length of 5600 km (Kitagawa et al., 2001; Blunden, 2012; Dushkova et al., 2017). In reality, the first commercial voyage along the Northwest Passage occurred in September 2013, while the traffic in the Northern Sea Route has been rising rapidly since 2009 (Blunden, 2012; Alvarinho, 2014). Many studies indicate that, compared to the NSR, the NWR is extremely underdeveloped in terms of shipping activities because of its more severe ice conditions (Xu et al., 2011; Hansen et al., 2016). Moreover, it is obvious that the NSR is shorter than conventional Asia-Europe shipping lanes, so many maritime countries have paid attention to it to exploit the enormous potential of the Arctic Ocean (Xu et al., 2011).

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Kitagawa et al. (2001) and Blunden (2012) confirm that the changes in the NSR region in terms of weather, ecosystem, and environment as well as in the technology for navigation and shipping transportation have drawn the attention of many countries, including Russia, China, and Canada.

Due to the importance of the NSR, numerous studies have been conducted relating to weather, climate change, and sea conditions (Borgerson, 2008; Maslanik et al., 2011; Morozov, 2012; Inoue et al., 2015); humans and the environment (Dushkova et al., 2017); infrastructure and technology (Sodhi, 1995; Johannessen et al., 1997; Buixadé et al., 2014); tariffs and legal issues (Skaridov, 2010; Gavrilov, 2015; Gritsenko & Kiiski, 2016); cruise tourism (Stewart et al., 2007; Stewart et al., 2013); and shipping activities (Rahman et al., 2014), including petroleum transport (Meschtyb et al., 2005; Faury & Cariou, 2016), container transport (Verny & Grigentin, 2009), and bulk transport (Schøyen & Bråthen, 2011; Pierre & Olivier, 2015). However, studies that focus on the trend in research relating to the NSR are very limited. In this respect, this study, which analyzes the NSR research trends, fills this research gap. It applies social network analysis (SNA) to inspect the keywords appearing in academic papers and reveal the important trend for each period.

The remainder of the paper consists of four parts and is structured as follows. In section 2, research topics related to the NSR are described. Section 3 describes the proposed methodology (SNA), and section 4 presents the result and findings of the analysis. Finally, section 5 summarizes the findings and proposes suggestions and recommendations for future research.

2. Literature review

The NSR is located between the Atlantic Ocean and the Pacific Ocean; it runs along the Arctic side of Russia and goes through five Arctic seas: the Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea, and Chukchi Sea (Blunden, 2012).

A decrease in both the extent and volume of sea ice in the NSR has been observed during the second half of the 20th century and early 21st century (Arctic Council, 2009). The sea ice cover remains in the winter, but at other times, the melting ice is continuing; therefore, no sea ice survives the summer melt season (Arctic Council, 2009; Xu et al., 2011). Even in the depth of ice in winter, thanks to the support of icebreakers, the NSR can be kept open (Kitagawa et al., 2001).

There are many studies on various topics related to the NSR. Some previous studies focus mainly on weather resulting from the climate change phenomenon and its impact on sea-ice conditions. Maslanik et al. (2011) observed sea ice records over a period of about 30 years, which revealed a decreasing trend in ice coverage in the Arctic Ocean. The authors also discuss the reasons behind this phenomenon. Inoue et al. (2015) analyze Arctic radiosonde observations to forecast the horizon flow of wind. From there, they predict weather that will be desirable for shipping navigation.

Further, a noticeable feature of the NSR is the sea-ice issue, so some previous studies propose modern infrastructure and technologies to monitor sea ice in the NSR, such as ice breakers for exploration (Sodhi, 1995) and an ice watch that uses satellite radar technology to monitor sea ice (Johannessen et al., 1997).

An important issue related to the NSR that is mentioned in many studies is tariffs and legal issues (Skaridov, 2010; Gavrilov, 2015; Gritsenko & Kiiski, 2016). Skaridov (2010) discussed legal issues related to economic benefits, security, and safety when the NSR becomes an international water way. Gavrilov (2015) incorporated historical perspectives, current Russian legislation, and international maritime law to explain the legal status of the NSR. In other study, Gritsenko and Kiiski (2016) observed and analyzed the ice-breaking tariff from 1991 to 2014, which is a pivotal factor affecting ice-breaking service demand. This issue is intimately related to the development of NSR shipping.

Moreover, some studies mention Arctic tourism as a complex system that is affected by many factors (Maher, 2007), and they suggest there is a critical need to build an arctic tourism observation system (Fay & Karlsdóttir, 2011).

A large number of studies discuss the speed of ice melt in the Arctic region and evaluate the many potential consequences. They indicate that the Arctic melt is an irreversible phenomenon, contributing to the formation of the NSR as shipping transportation route. This will have both a positive and negative impact on environmental, military, diplomatic, and economic issues (Morozov, 2012), causing environmental degradation, a deterioration in living conditions (Dushkova et al., 2017), and economic and security issue (Borgerson, 2008) as well as impacting society (Meschtyb et al., 2005) in the Arctic zone (Russia). Moreover, there is also research on the effect of the NSR on countries outside of the Arctic zone, such as Malaysia, because the decrease in vessel journeys via the Suez Canal and Straits of Malacca (Rahman et al., 2014).

Numerous studies have evaluated the economic viability of the NSR as an alternative route (Liu & Kronbak, 2010; Bekkers et al., 2018; Zhang et al., 2016), especially in particular cases, such as container shipping (Verny & Grigentin, 2009), bulk shipping (Schøyen & Bråthen, 2011; Pierre & Olivier, 2015), and oil tankers (Faury & Cariou, 2016). Many papers have evaluated the great advantage of the NSR in terms of decreasing the distance from Northern Europe to China, and vice versa; it is about 60% shorter than via the Cape of Good Hope and 40% shorter than via the Suez Canal (Schøyen & Bråthen, 2011; Liu & Kronbak, 2010).

However, few studies have analyzed the Northern Sea Route from a macroscopic perspective; that is, few have assessed the research trends relating to the Northern Sea Route. This research fills that gap by analyzing keywords appearing in academic papers to uncover NSR research trends.

SNA is an excellent method, and it has been applied in many fields in the social and behavioral sciences as well as in economics, marketing, and industrial engineering (Otte & Rousseau, 2002; Carrington et al., 2005). It can be used as a network approach to uncover trends in an area of research by analyzing keywords appearing in scholarly articles (He, 1999; Duvvuru et al., 2012; Shin et al., 2017). Through keyword network analysis, SNA helps to discover hidden connections among keywords to identify trends in a specific period (Duvvuru et al., 2012). For these reasons, this study applies SNA to identify research trends related to the Northern Sea Route.

3. Methodology

In recent years, the SNA method has brought many advantages to the social and behavior sciences, especially in an academic respect. This method analyses the top issues of consideration in terms of the relationship among interacting units in a study (Wasserman & Faust, 1994; Carrington et al., 2005). In the academic arena, studies always develop from fundamental knowledge obtained from previous research, creating a heterogeneous academic network. Academic networks are formed by entities, such as publications, which are linked, interacted with, and communicated through co-words (Kong et al., 2019). Therefore, SNA is an appropriate method to identify the trends in scholarly research about a particular issue through the scanning of keywords. In this study, the SNA is applied to determine NSR research trends based on two main indexes: degree centrality and betweenness centrality.

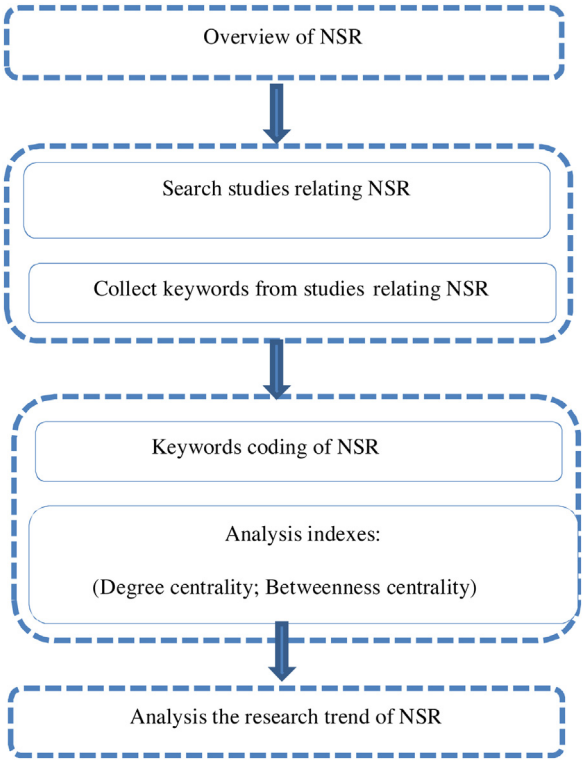

Fig. 1. The research flow.

The first index—degree centrality—is measured by counting the number of direct links of one node with other nodes in the network (Freeman et al., 1979). A high index value means that a node has more connection ties and is therefore located at the center of a network. In this research, a word with high degree centrality implies its importance in research on NSR. If two nodes, i and j, are connected, $a_{ij} = 1$; if not, $a_{ij} = 0$. The degree centrality is calculated as the following equation:

$$C_d(i) = \sum_{j=1}^{n} a_{ij}/(n-1) \quad (1)$$

The second index—betweenness centrality—indicates the median centrality of a node, which is calculated as the number of shortest paths passing through a node moderated by the total number of shortest paths between any two nodes (Freeman et al., 1979). The higher the betweenness index of a node is, the more important the node is to promoting the flow of information in a scholar network (Kong et al., 2019). In this study, the words with high betweenness index reflect important issues in forming the NSR research network. If $g_{jk(i)}$ is the number of shortest distances between node j and node k passing through node i, g_{jk} is the total number of shortest paths connecting node j and node k. The betweenness index is calculated as the following formula:

$$C_B(i) = \left(\sum_{j,k}^{n} \frac{g_{jk}(i)}{g_{jk}}\right)\left(\frac{2}{(n-1)(n-2)}\right) \quad (2)$$

The research flow is shown in Fig. 1.

4. Empirical analysis

4.1. Data collection

In order to obtain research trends for the NSR, the first step in data collection is to identify academic papers relating to the NSR. In this paper, the reliable sources used to find academic papers are: Science Direct, Scopus, Springer, and Taylor & Francis Online. The second step is to search for papers based on the output term "Northern Sea Route" and then extract the keywords in each paper.

As a result, 365 published academic papers were identified from 1899 to 2019. In addition, the keywords of all these academic papers are extracted and summarized as a database for further analysis. For identifying the changes in NSR research trends, the whole time period (from 1899 to 2019) is divided into three phases: 1899–1999, 2000–2009, and 2010–2019. The number of papers in each period dramatically increases to 34, 37, and 294 papers for the first, second, and third phases, respectively. It is obvious that there has recently been a huge increase in interest from many researchers all over the world; therefore, an analysis to determine the research trend is extremely necessary.

4.2. First period (1899–1999)

The result of the keyword network analysis from the 1899–1999 time period is shown in Table 1. For the degree centrality index, which shows the important keywords central to connect the network, the highest one (0.452) is "national security." This result indicates that some countries are taking an interest in security issues when researching this new Arctic route. In detail, these countries are Russia, Canada, and the US, because these country names appear in the three highest degree centrality indexes (respectively, 0.419, 0.258, and 0.258). Brubaker and Ostreng (1999) discuss the political issues between Russia and the USA regarding sovereignty. Russia has claimed it is an internal waterway, while the US believes it lies in international waters. Along with the word "national security," the word "military" (0.258) is among the top ten in terms of highest degree centrality. The result implies that the issue of national sovereign is a hot consideration of the nations in the North Pole region. These nations dispute territorial matters to gain advantages from the NSR and ensure national security.

Other important words that show high degree centrality are "environmental management," "climate change," and "permafrost." This means the issue of permanent ice in the Arctic is also considered in the climate change context. Grosswald and Glebova (1992) discussed the ice in the NSR and clearly showed its role in ocean development. Yazikova (1977), Treude (1991), and Khvochtchinski and Batskikh (1998) pointed out the transportation problem of the NSR: the ice level impacts the safety of navigation. In that time period, the studies on technology and infrastructure also related to the target "identify the ice level." Kondratyev et al. (1994) described the initial practical applications of radar imagery, which was applied to determine the ice age and specify the optimal navigation route. Johannessen et al. (1996, 1997) described an application to evaluate and monitor ice cover.

Moreover, "oil exploration," which has high degree centrality (0.258), implies that there is a great deal of consideration among countries about natural resources. It is undeniable that the NSR is abundant in oil and gas resources. Moe (1995) assessed the current situation and future of oil exploitation in the NSR. The United States Geological Survey (2009) concluded that a noticeable volume of the world's undiscovered natural resources lies under the Arctic Ocean (oil 13% and natural gas 30%).

In Table 1, apart from place names such as the Arctic and Russia, "national security" and "environmental management" have the highest betweenness centrality with, respectively, 0.168 and 0.06 in this period; this means these keywords play a considerable intermediate role in connecting other keywords to construct the network of studies on the NSR.

4.3. The second period (2000–2010)

The result of the keyword network analysis of published research papers for the period of 2000–2010 is shown in Table 2. In

Table 1
First Period (1899–1999).

No	Degree Centrality		Betweenness Centrality	
1	National security	0.452	National security	0.168
2	Arctic	0.419	Arctic	0.07
3	Russia	0.419	Russia	0.07
4	Environmental management	0.355	Environmental Management	0.06
5	Canada	0.258	Canada	0
6	Climate change	0.258	Climate change	0
7	Military	0.258	Container terminal	0
8	Oil exploration	0.258	Environment Northern seas	0
9	Permafrost	0.258	Feeder service	0
10	US	0.258	Global macro Strategic inter	0
11	Environment Northern seas	0.226	Industrial regulation	0
12	Industrial regulation	0.226	Internal waters	0
13	International cooperation	0.226	International cooperation	0
14	International policy	0.226	International Ice covered	0
15	Marine protection	0.226	International policy	0
16	Perspectives	0.226	Marine protection	0
17	Pollution control	0.226	Military	0
18	Global macro Strategic inter	0.194	Military security perception	0
19	Internal waters	0.194	Military strategy	0
20	International Ice covered	0.194	Offshore activities	0

Table 2
The second period (2000–2010).

No	Degree Centrality		Betweenness Centrality	
1	NWP	0.177	NWP	0.074
2	Ocean transport	0.168	Climate change	0.043
3	Sea ice	0.150	Arctic	0.026
4	Arctic	0.133	Canada	0.017
5	Climate change	0.133	Ocean transport	0.008
6	Canada	0.106	Suez Canal	0.007
7	Arctic ocean	0.097	Arctic shipping	0.005
8	Nordic seas	0.097	Sea ice	0.005
9	Ocean modelling	0.097	21 st century	0
10	Suez Canal	0.097	22nd century	0
11	Arctic engineering	0.080	Alternative route	0
12	Canadian Arctic archipelago	0.080	Anthropogenic scenario	0
13	Freight transport	0.080	Arctic basin	0
14	Labrador Sea	0.080	Arctic climate change	0
15	Laws and legislation	0.080	Arctic engineering	0
16	Lower halocline water	0.080	Arctic environment	0
17	Ocean structure	0.080	Arctic marine	0
18	Optimization	0.080	Arctic ocean	0
19	Pacific water	0.080	Arctic regime	0
20	Pipelines	0.080	Arctic sea ice	0

this period, except for place names, such as NWP, the word “ocean transport” shows the highest degree centrality value (0.168). This indicates that more studies assessed the NSR as a new ocean transport route. The reason why “ocean transport” becomes a popular keyword in this period is that the sea ice has been melting, making ocean transport possible (Rodrigues, 2008; Khon et al., 2010; Matishov, 2008) as an alternative route between Asia and Europe (Liu & Kronbak, 2010; Verny & Grigentin, 2009). Further, the words “sea ice” and “climate change,” which maintain high degree centrality show there is a great interest in research on climate change. In the period, the weather continues to warm up, causing ice to melt. In addition, the “Suez Canal” also appeared among the top ten words with high degree centrality (0.097). The NSR is considered as a new route from Asia to Europe as it could reduce the Asia-Europe shipping route by 40% compared to the Suez Canal (Liu & Kronbak, 2010)

For the betweenness centrality, “NWP,” “climate change,” “Arctic,” and “Canada” get the highest values, respectively, 0.074, 0.043, 0.026, and 0.017; therefore, they play a mediator role in connecting the network. This means these keywords appeared frequently in many papers and topics relating to the NSR (Figs. 2 and 3).

4.4. The third period (2011–2019)

This period has experienced a full bloom of research considering NSR issues (294 studies). Table 3 shows the degree centrality and betweenness centrality values for the period from 2011 to 2019. Excepting place names (Arctic and Russia), the four keywords with the highest value degree centrality are “shipping,” “sea ice,” “Artic shipping,” and “climate change” with 0.089, 0.077, 0.065, and 0.061, respectively. These four words could be divided into

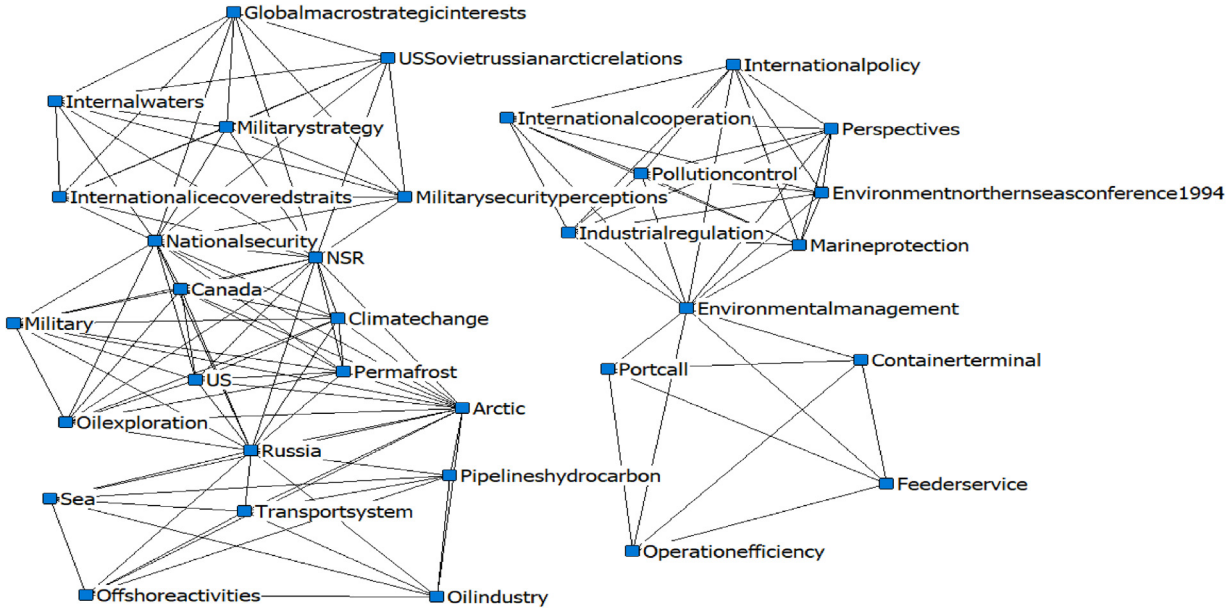

Fig. 2. First period network (1899–1999).

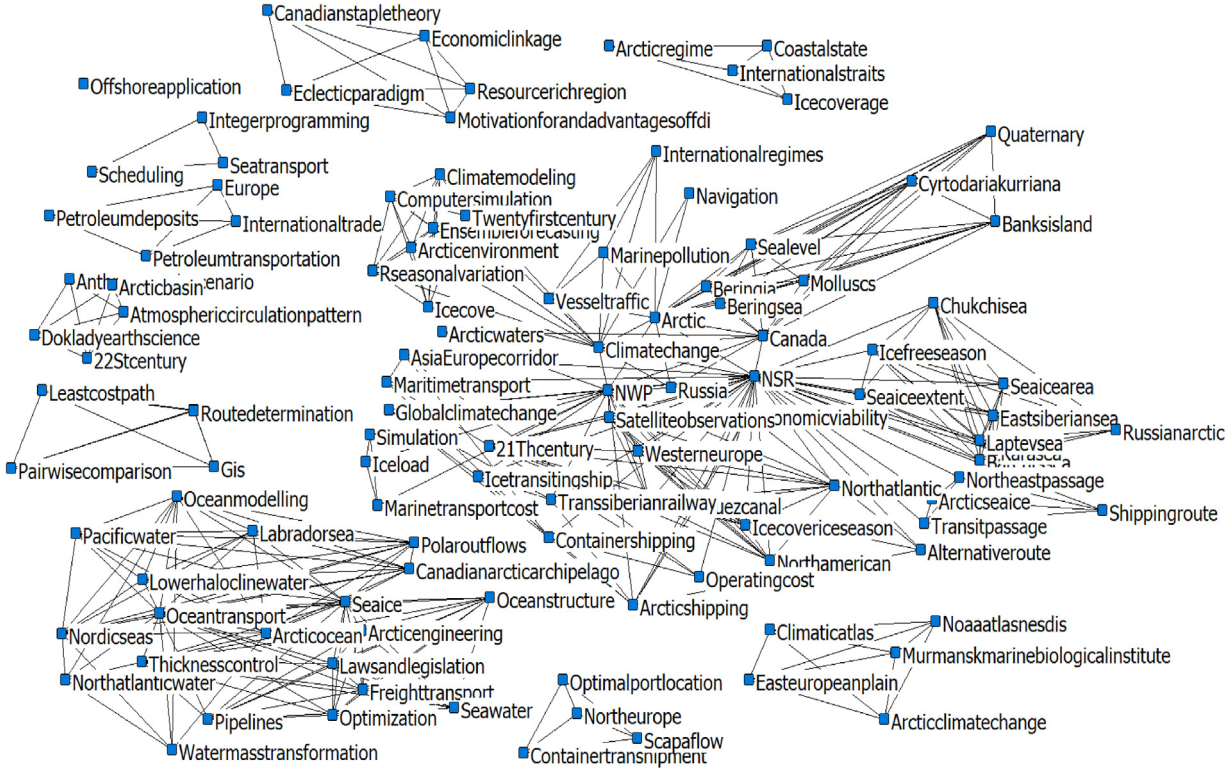

Fig. 3. Second period network (2000–2010).

two main issues, resulting in two important nodes in the network. The first issue/node is climate change, which is the global warming phenomenon. It has led to the melting of sea ice in the Artic area; therefore, it also opens many new aspects for approaching NSR research. Maslanik et al. (2011) recorded the sea ice level for 1980 through March 2011 and showed the real data about for this period; there was a decline from about 75% to 45%. Obviously, the ice coverage has been continuously decreasing in the Arctic, resulting in many changes. The second issue/node is the shipping area. The ocean transportation consideration already appears in the second period; however, in the third period, the research focuses on the economic aspect. This is illustrated by the keywords with high degree centrality, such as “cost,” “economic,” and “Decision Making.” This implies that the researches in this period focuses on evaluating costs in shipping transport through the NSR and comparing route choices in order to make decision. Similarly, the keywords with high betweenness centrality are also “sea ice” and “shipping.” This also means these words are bridges connecting to other words in the network. Further, the new keyword “CO_2” also

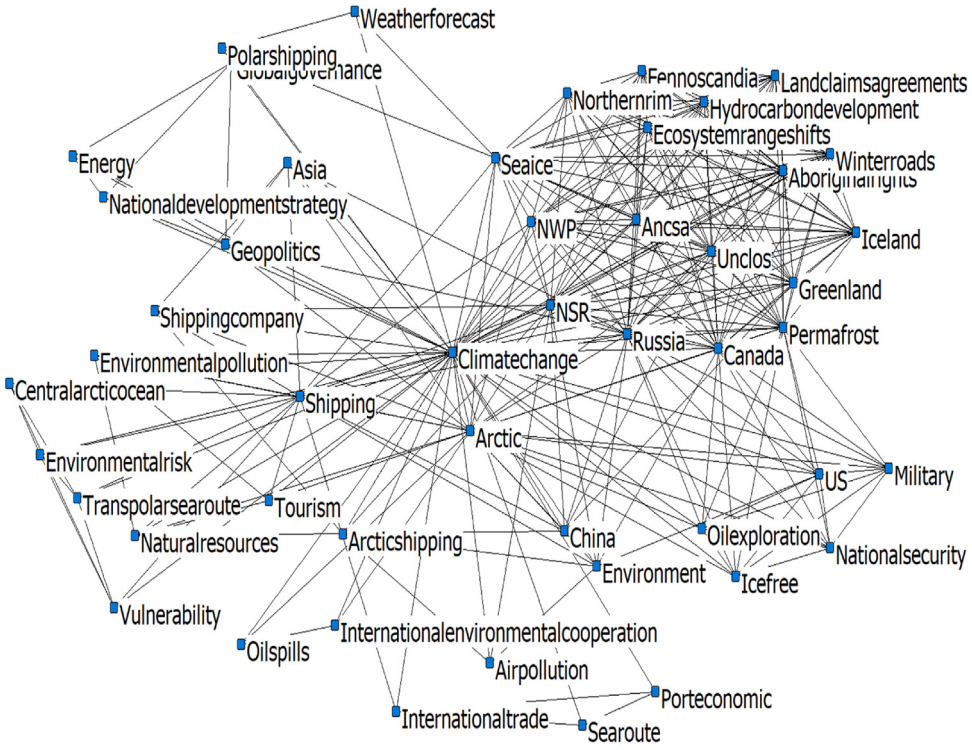

Fig. 4. Third period climate change ego network (2011–2019).

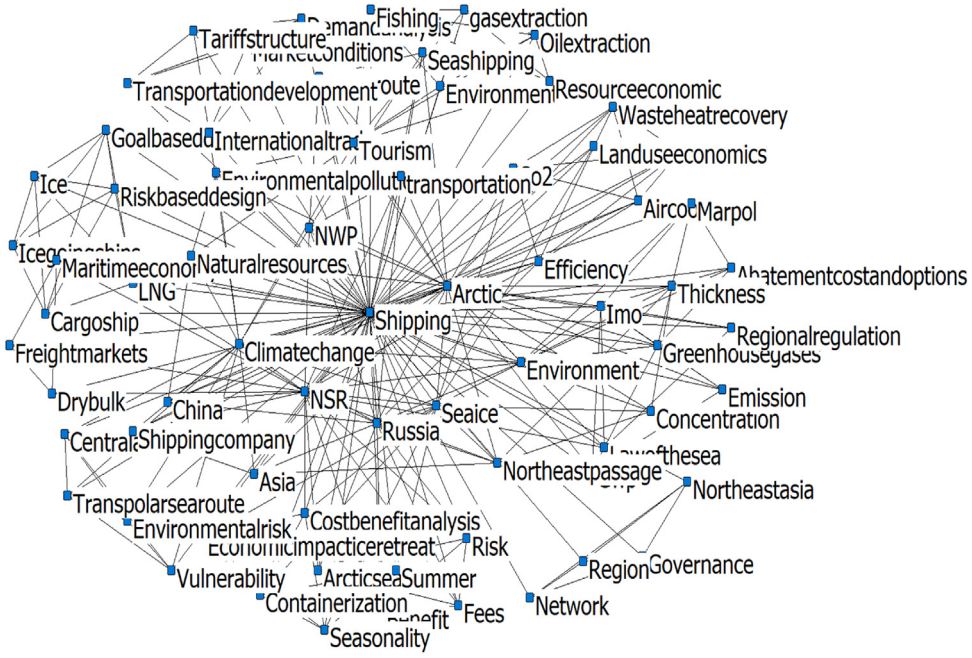

Fig. 5. Third period shipping ego network (2011–2019).

appears in the top for high betweenness centrality. This indicates that pollution has become a focus of many papers.

Figs. 4 and 5 show the two main ego networks of the third period, corresponding with the two main issues of NSR research in the third period (climate change and shipping). An ego network shows only the network related to a specific node. Fig. 4 shows the climate change ego network. As we can see, Arctic, shipping, and geopolitics as well as keywords related to country names, such as Russia, Canada, and the US, appear around the main ego point. The figure implies that climate change is the main issue raised in academic research in the 2011–2019 period. With this perspective, we learn that the countries and authorities in the Arctic region have kept a close eye on climate change in the Arctic.

Fig. 5 illustrates the shipping ego network. Around the shipping keyword, "sea ice," "tourism," "efficiency," "seasonality," and "Arctic" are shown. This indicates that researchers are interested in the NSR as a trade shipping route while considering many factors about sea ice level and economic efficiency.

Table 3
The third period (2011–2019).

	Degree Centrality		Betweenness Centrality	
1	Arctic	0.126	Arctic	0.158
2	Russia	0.091	Shipping	0.119
3	Shipping	0.089	Arctic shipping	0.111
4	Sea ice	0.077	Sea ice	0.108
5	Arctic shipping	0.065	Russia	0.099
6	Climate change	0.061	China	0.075
7	NWP	0.057	NWP	0.074
8	Russian Arctic	0.055	Russian Arctic	0.049
9	Ship	0.055	Climate change	0.048
10	China	0.051	Arctic Ocean	0.045
11	Arctic Ocean	0.05	CO_2	0.042
12	Canada	0.043	Waterway transportation	0.04
13	Waterway transportation	0.043	Container	0.034
14	Cost	0.042	Ice	0.034
15	Transportation route	0.04	Cost	0.032
16	Arctic engineering	0.039	Ship	0.03
17	Ice	0.038	Accident	0.029
18	Economic	0.037	Ocean transport	0.029
19	US	0.035	Maritime transport	0.027
20	Container	0.033	New silk road	0.026

5. Conclusion

In the context of increasing concern about many aspects of the Northern Sea Route, this study investigated research trends regarding the NSR using the SNA method. This study also determined the changes in the top issues for three time periods between 1899 and 2019.

This paper applied two indexes (degree centrality and betweenness centrality) to identify important keywords, which reveal the issues of significance research. In the first period (1899–1999), the studies mainly revolved diverse issues: "national security," "environmental management," and "oil exploitation." At that time, the extremely harsh weather caused the NSR to be under a permanent cover of ice; however, the countries in the NSR area still appreciated its huge potential for gas and oil resources and ocean development, and they were interested in sovereignty issues. For the second period (2000–2010), in addition to keywords related to the environment such as "sea ice" and "climate change"; the term "ocean transport" began to appear and become the main topic of research networks. This is understandable because when the NSR began to experience periods without ice cover, ocean transport through the NSR became possible. The research trends become obvious in the third period (2011–2019), with two primary research areas: climate change and shipping area. These topics were investigated and measured with more accurate numbers than before. For climate change, global warming continued to cause ice in the NSR to melt, opening up many new opportunities for the transport industry. In addition, research related to pollution began to increase. For shipping, research compared the benefit of different transportation routes connecting Asia and Europe and identified the economic potential of using the NSR as an alternative route.

To conclude, the climate issue was always a topic of interest throughout all periods, but interest has been developing in different shape: from "permafrost" issue in early period to "ice melting" issue in later years, and "air pollution" in recent years. As the result of climate change, trends in research on the NSR changed between the periods: from diverse topics such as "national security" and "oil and gas resources" to concentrating on "ocean shipping transportation" because of the increasing feasibility of transportation through the NSR and its advantages.

This study offers several important implications for academia and industry. For academia: (1) research trends relating to the NSR were first identified using SNA. (2) The results of the study provide an overall picture of the evolution of the NSR over time, which has affected human life and human activities in the area; and (3) the results show that academic research topics have been evolving to follow the changing reality in the NSR. This research provides important data on NSR studies, which will contribute to the academic field in the future and facilitate the follow-up research.

For shipping operators and the authorities of many countries around the NSR, this study provides valuable insight: (1) the findings of this research can help operators and authorities to predict how the NSR will evolve in the future. (2) They can also better understand the complex relationships and structures among the relevant critical factors for the NSR; and (3) this allows them to issue suitable policies when operating in and exploiting the NSR.

However, the research has some limitation. First, the paper could not collect all the materials relating to the NSR; just 365 academic papers from 1899 to 2019 were collected. Second, the weights of keywords are not reflected on the analysis process. In future research, a hub centrality analysis using keywords weights is needed. In addition, the problems of the NSR are needed to analyze to suggest the policy recommendations.

Conflicts of interest statement

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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