Industrial Engineering
& Management Systems
Vol 15, No 1, March 2016, pp.92-98
ISSN 1598-7248 │ EISSN 2234-6473 │
http://dx.doi.org/10.7232/iems.2016.15.1.092

Bibliometric Analysis of Collaboration Network and the Role of Research Station in Antarctic Science

Hyunuk Kim
Department of Industrial and Management Engineering, Pohang University of Science and Technology, Pohang, Korea

Woo-Sung Jung*
Department of Industrial and Management Engineering/Department of Physics, Pohang University of Science and Technology, Pohang, Korea

(Received: January 19, 2016 / Revised: March 22, 2016 / Accepted: March 22, 2016)

ABSTRACT

Due to the large scale of Antarctic science, scientific collaboration is required for conducting scientific research. In this study, we attempted to investigate collaboration network and the role of research station in Antarctic science based on bibliometric data from 1995 to 2014. We confirmed that geographical proximity tends to be important for scientific collaboration by employing community detection in the network. This result raises the question about what the role of research station in Antarctica is. We tried to reveal its role by focusing on five countries, Belgium, China, Czech Republic, India, and Korea that constructed new research stations during the last decade. Relative growth rate, a value to measure the growth of publications, didn't differ much around the construction period compared to those in other periods for these countries except Belgium. However, we found geographical keywords emerged around the construction for all five countries. These keywords were utilized to observe national research activities in Antarctica. They show where countries started to be concerned about after the construction.

Keywords: Antarctic Science, Network Analysis, Community Detection, Keyword Analysis, Antarctic Research Stations

* Corresponding Author, E-mail: wsjung@postech.ac.kr

1. INTRODUCTION

Antarctica is an important continent that provides insights for a sustainable future of the Earth. The Antarctic Treaty, which was established on 1 December 1959 by twelve countries, emphasizes peaceful cooperation in Antarctica, especially for scientific activities. Fifty-two countries signed the Treaty and have conducted fruitful research about Antarctica. Antarctica is an example for the governance of international area (Berkman *et al.*, 2011).

For this reason, Antarctic science is a good discipline to explore international collaboration structure. Scientific research activities in Antarctica show how international collaboration works in a shared region where the ownership does not belong to a country. Researchers began to study the structure of Antarctic science by using bibliometric methods (Dastidar and Persson, 2005; Dastidar, 2007; Dastidar and Ramachandran, 2008). In those studies, Antarctic science collaboration networks were constructed based on the Web of Science database for the period of 1980-2004. This collaboration network sheds light on the collaboration structure and scientific productivity not only at the international level but also at the institutional level. In addition, Persson and Dastidar (2013) analyzed citation network about the Montreal Protocol to capture important papers in Antarctic ozone hole research.

Leadership in the Antarctic Treaty was evaluated through the number of policy papers and scientific publications from Consultative Parties that manage activities in Antarctica (Dudeney and Walton, 2012). Argentina, Australia, Belgium, Brazil, Bulgaria, Chile, China, Czech Republic, Ecuador, Finland, France, Germany, India, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Peru, Poland, Russia, South Africa, Spain, Sweden, Ukraine, United Kingdom, United States, and Uruguay are Consultative Parties. Research trends within Antarctic islands (Benayas *et al*., 2013; Tejedo *et al*., 2015) and Latin America (Stefenon *et al*., 2013; Stotz *et al*., 2013); and the fields of study (Persson and Dastidar, 2013; Hua *et al*., 2014) were also the subjects of interest.

In this paper, we will construct Antarctic science collaboration networks during 1995-2014 and detect communities using modularity maximization algorithm. This algorithm is useful for observing international collaboration structures (Evans *et al*., 2011; Adams *et al*., 2014). Detected communities revealed that geographical proximity tends to be important for international collaboration. Characteristics of regional organizations will be given in terms of scientific productivity and the degree of collaboration.

Our network analysis threw a question about the role of research station in Antarctic science because research stations are expected to facilitate not only scientific experiments but also international collaboration with other countries. While the distances between research institutions were implemented in 'Gravity model' to study the role of geography in science (Ponds *et al*., 2007; Frenken *et al*., 2009; Pan *et al*., 2012), due to the installation of new research stations, it is hard to measure the effect of distances between research stations on collaborative research.

To overcome this difficulty, we calculated relative growth rate (RGR) and doubling time D_t for five countries (Belgium, China, Czech Republic, India, and Korea) that construct new research stations in the last ten years. These indices were usually used to study the growth in publications (Mahapatra, 1985; Bajwa *et al*., 2013). However, we couldn't find noticeable changes at RGR and doubling time for these countries except Belgium.

We also extracted emerging keywords during the construction period of research stations, while previous keyword analysis (Ji *et al*., 2014) was dealt with overall frequency trends during 1993-2012. Emerging keywords could be proxies which show what countries started to be concerned about after the construction of research stations. Geographical keywords that close to newly-built research stations were helpful for drawing the outlines of national research activities.

2. DATA DESCRIPTION AND METHODS

We collected bibliometric data about Antarctic science from Thomson Reuters Web of Science. "antarc*" was used as a search term in Title/Keywords/Abstract search. Bibliometric data of 42,082 papers published from 1995 to 2014 were collected and utilized to construct international collaboration networks. We assume that country names contained in authors' addresses for each paper as authors' nationalities. If a paper was written by an author with several affiliations, then we choose the country appeared in the corresponding author address as his/her nationality. A paper written by more than two authors with different countries was classified as a collaborative paper. 14,087 papers were categorized as collaborative papers. Publication trends are shown in Figure 1.

Collaboration network was constructed based on extracted nationalities of authors. Countries for each paper were fully connected with weight $2/n(n-1)$ so as the sum of weights between countries to be equal to 1. When a paper was written by authors from one country, then a self-loop is created with weight 1. In accordance with the Antarctic Treaty Parties, we integrated England, Scotland, Wales, and Northern Ireland into the United Kingdom.

To find community structure of collaboration network, we utilized modularity maximization algorithm. Modularity is defined as

$$Q = \frac{1}{2m}\sum_{vw}\left[A_{vw} - \frac{k_v k_w}{2m}\right]\delta(c_v, c_w)$$

where m is the number of edges existed in the network, v and w represent nodes in a network, A_{vw} is a weight of edge from v to w, and k_v, k_w are the sum of weights of edges connected with v and w, respectively. $\delta(c_v, c_w)$ is 1

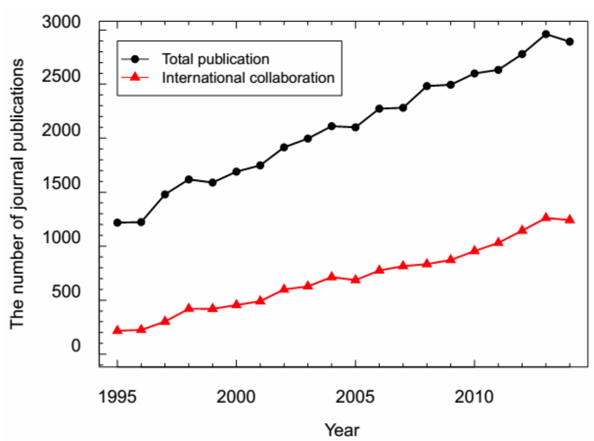


Figure 1. Publication trends during twenty years in antarctic science.

when v and w falls into the same community and 0 otherwise. High modularity value indicates there exists a community structure in the network (Clauset *et al*., 2004; Newman 2004).

Moreover, in order to examine the effect of research station, we calculate relative growth rate (RGR) and doubling time D_t by using the number of papers that estimated from our collaboration network. RGR measures the trend of publication growth and is calculated as

$$\text{RGR} = (\ln N_2 - \ln N_1)/(t_1 - t_2)$$

where N_1 and N_2 are the cumulative number of publications in t_1 and t_2 years (Mahapatra1985). If the number of publication increases exponentially, RGR value will be a constant. D_t is the expected time to reach as twice as the cumulative publication at the year t.

We also detected emerging keywords that reach more than 10% of its cumulative counts in before and after three years of installation. Hereafter this period will be referred to as a construction period. We assumed that emerging keywords during a construction period could be related to research stations.

3. RESULTS AND DISCUSSION

3.1 Collaboration Structure and Regional Differences in Antarctic Science

Collaboration network consists of 151 countries and its average degree is about 33. To calculate the number of papers for each country, we summed all weights of edges that country has, including a self-loop. The number of collaborative papers is calculated by subtracting a weight of self-loop from the number of papers. Table 1 shows Consultative Parties of the Antarctic Treaty have led Antarctic science and actively collaborated with others. The ratio of the number of collaborative papers to that of total papers was used to measure the degree of collaboration.

By implementing modularity maximization algorithm on the collaboration network, we detected twenty-four communities with a mean size of about six. Maximum modularity value of the network is 0.587 that is larger than 0.3 which considered as a good indicator of community structure in a network (Clauset *et al*., 2004). In Table 2, detected communities and member countries are listed in descending order of community size. The largest community has European countries and African countries, while the second community consists of South American countries with Portugal and Spain. North and East European countries are in the third community and African countries compose the fourth community. Other communities are also related to geographical proximity. It seems that geographical proximity plays an important role in forming international collaboration.

Table 1. Top 20 countries in scientific productivity for 20 years

Country	No. of papers	No. of collaborative papers	Ratio
USA*	12396.4	5139.4	0.41
United Kingdom*	5985.3	3169.3	0.53
Germany*	4298.7	2478.7	0.58
Australia*	4011.4	1990.4	0.50
France*	2959.9	1843.9	0.62
Italy*	2795.0	1110.0	0.40
Japan*	2196.5	820.5	0.37
China*	1876.5	632.5	0.34
Spain*	1735.7	874.7	0.50
Canada	1707.1	1123.1	0.66
New Zealand*	1672.2	1024.2	0.61
Argentina*	1325.1	573.1	0.43
Russia*	1175.3	546.3	0.46
Netherlands*	1040.2	647.2	0.62
India*	1029.9	226.9	0.22
Sweden*	819.3	516.3	0.63
Belgium*	791.3	550.3	0.70
Norway*	780.4	517.4	0.66
South Africa*	775.9	383.9	0.49
Brazil*	694.6	314.6	0.45

*: Consultative Parties.

We also investigate characteristics of regional groups in terms of scientific productivity and the degree of international collaboration (Figure 2). There are three regional groups of Europe, South America, and Asia. European Polar Board (EPB, established in 1995) has twenty-five member research institutes from eighteen countries. Reunión de Administradores de Programas Antárticos Latinoamericanos (RAPAL, established in 1987) is a consultative group of South American countries, Argentina, Brazil, Chile, Ecuador, Peru, and Uruguay. China, India, Japan, Korea, and Malaysia organized Asian Forum for Polar Sciences (AFoPS, established in 2004) to activate polar research.

EPB countries already have research capabilities while RAPAL shows an inequality in scientific productivity and the degree of international collaboration. The leading countries in RAPAL are Argentina, Brazil, and Chile. This corresponds to the research which reveals trends in Antarctic ecological research in Latin America (Stotz *et al*., 2013). Although AFoPS countries reach a certain standard in Antarctic science research, AFoPS shows a lack of international collaboration in Antarctic science. Especially, India's collaboration ratio is the lowest among twenty-nine countries.

Table 2. Detected communities contained more than five countries

Size	Countries
26	Algeria, Belgium, Botswana, Bulgaria, Burkina Faso, Chad, Cook Islands, Czech Republic, Ethiopia, Fr Polynesia, France, French Guiana, Gabon, Israel, Kenya, Luxembourg, Macedonia, Madagascar, Monaco, Morocco, New Caledonia, Niger, Reunion, Slovakia, Tunisia, Western Samoa
21	Angola, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, Gambia, Guadeloupe, Lithuania, Martinique, Mexico, Nicaragua, Panama, Paraguay, Peru, Portugal, Spain, Togo, Uruguay, Venezuela
14	Bolivia, Denmark, Dominican Rep, Estonia, Finland, Greenland, Hungary, Iceland, Kyrgyzstan, Mozambique, Norway, Romania, Sweden, U Arab Emirates
13	Brunei, Ciskei, Cyprus, Eritrea, Malawi, Namibia, Nigeria, Rep of Georgia, South Africa, Sudan, Tanzania, Zambia, Zimbabwe
11	Austria, Barbados, Benin, Germany, Jamaica, Jordan, Neth Antilles, Netherlands, Sri Lanka, Switzerland, Tajikistan
9	Bahamas, Bahrain, Bermuda, Ghana, Malagasy Republ, Rwanda, USA, Uzbekistan, Vatican
8	Bangladesh, Cameroon, Indonesia, Japan, Philippines, Singapore, Thailand, Vietnam
7	Byelarus, Croatia, Iraq, Poland, Slovenia, Turkey, Ukraine
6	Australia, Fiji, Mauritius, New Zealand, Papua N Guinea, Solomon Islands
5	Egypt, Iran, Kazakhstan, Malaysia, Pakistan
5	Bhutan, India, Maldives, Oman, Qatar
5	Ireland, Mongol Peo Rep, Seychelles, Trinid and Tobago, United Kingdom

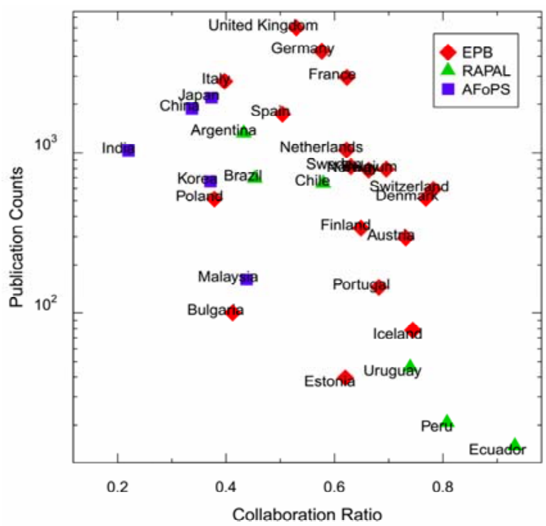


Figure 2. Countries' productivity and collaboration ratio by regional groups.

3.2 The effect of Newly-Built Research Stations on National Research Activities

As we have seen in the previous subsection, geographical proximity tends to be important in forming international collaboration. Then, what is a role of research station in Antarctica for national research activities? National governments strategically built research stations not only to improve research capacity but also to strengthen international collaboration in Antarctica. To find an answer, we focused on newly-built research stations to see the effect more clearly.

In 2014, eighty-four research stations are operated by twenty-nine countries. Most of research stations were built in the 20th century. During the last ten years, only five countries, Belgium, China, Czech Republic, India, and Korea built new Antarctic research stations in 2009, 2009, 2006, 2012, and 2014, respectively. Newly-built research stations of Belgium and Czech Republic are the first while that of Korea is the second, China and India are the third. Data for research stations is available at Council of Managers of National Antarctic Program (COMNAP) website (http://comnap.aq).

We assumed that the construction of research station enhances research capacity of each country and promotes international collaboration. Relative growth rate (RGR) and doubling time D_t were calculated using the number of total papers and that of collaborative papers during twenty years (Table 3).

Our assumption could be confirmed through dramatic decreases of D_t during the construction period. Five countries show different aspects of D_t values. Doubling time of Belgium for total papers decreases in 2011 from 8.88 to 7.31; and for collaborative papers decreases in 2011 from 7.35 to 6.27. Sudden decrease of D_t value in 2008 seems to be caused by an abnormal increase in 2007. RGR of Czech Republic and India vary frequently so that D_t trends are inconsistent. It makes difficult to see the effect of newly-built research stations. On the other hand, D_t values of China and Korea are relatively stable. Thus, we thought that only Belgium took advantages from the installation of research station while others may not in a quantitative manner. Even though a research station might not stimulate the growth

Table 3. RGR and D_t of Belgium, China, Czech, India, and Korea

	Total papers										Collaborative papers									
	Belgium		China		Czech		India		Korea		Belgium		China		Czech		India		Korea	
Year	RGR	D_t	RGR	D_t	RGR	D_t	RGR	D_t	RGR	D_t	RGR	D_t	RGR	D_t	RGR	D_t	RGR	D_t	RGR	D_t
1996	0.87	0.79	0.57	1.23	0.56	1.24	0.94	0.74	0.18	3.80	1.04	0.66	0.29	2.41	-	-	1.00	0.70	-	-
1997	0.74	0.94	0.52	1.34	0.50	1.40	0.28	2.51	0.46	1.51	0.44	1.58	0.88	0.79	0.41	1.71	0.20	3.40	0.41	1.71
1998	0.34	2.05	0.28	2.45	0.30	2.32	0.27	2.58	0.41	1.68	0.52	1.33	0.35	1.97	0.85	0.82	0.24	2.86	0.81	0.86
1999	0.29	2.41	0.35	1.97	0.03	21.8	0.23	2.99	0.30	2.32	0.34	2.03	0.60	1.15	0.13	5.19	0.16	4.33	0.47	1.49
2000	0.23	2.98	0.22	3.13	0.15	4.60	0.24	2.87	0.32	2.16	0.28	2.49	0.41	1.71	0.34	2.06	0.14	4.98	0.36	1.92
2001	0.21	3.32	0.21	3.29	0.08	8.94	0.13	5.14	0.40	1.75	0.25	2.79	0.25	2.78	0.09	8.10	0.18	3.78	0.41	1.67
2002	0.15	4.74	0.20	3.45	0.12	5.56	0.14	4.90	0.21	3.25	0.18	3.81	0.31	2.22	0.10	6.68	0.18	3.85	0.26	2.70
2003	0.16	4.39	0.29	2.39	0.22	3.12	0.12	6.01	0.25	2.77	0.18	3.76	0.22	3.16	0.22	3.15	0.29	2.39	0.23	2.98
2004	0.18	3.91	0.28	2.49	0.15	4.72	0.14	4.79	0.27	2.61	0.20	3.39	0.20	3.43	0.26	2.67	0.19	3.65	0.32	2.17
2005	0.12	5.82	0.22	3.22	0.21	3.25	0.16	4.38	0.19	3.70	0.18	3.83	0.21	3.35	0.16	4.47	0.13	5.38	0.17	4.01
2006	0.11	6.27	0.24	2.83	0.10	6.90	0.12	5.89	0.21	3.23	0.12	5.97	0.19	3.74	0.17	4.17	0.12	5.65	0.17	4.09
2007	0.07	9.29	0.24	2.93	0.18	3.86	0.14	4.92	0.29	2.42	0.09	7.90	0.20	3.43	0.28	2.47	0.13	5.47	0.17	4.08
2008	0.09	7.86	0.21	3.22	0.14	5.10	0.14	5.05	0.25	2.78	0.10	6.98	0.21	3.30	0.09	7.82	0.10	6.86	0.17	3.96
2009	0.08	8.28	0.18	3.92	0.23	3.04	0.10	6.84	0.19	3.67	0.10	7.24	0.18	3.85	0.27	2.54	0.08	8.90	0.17	4.07
2010	0.08	8.88	0.19	3.60	0.11	6.25	0.13	5.32	0.15	4.74	0.09	7.35	0.20	3.46	0.16	4.22	0.11	6.32	0.12	5.71
2011	0.09	7.31	0.16	4.46	0.08	8.60	0.16	4.32	0.15	4.74	0.11	6.27	0.15	4.57	0.12	5.80	0.15	4.68	0.10	7.00
2012	0.09	7.93	0.16	4.42	0.17	4.18	0.09	7.81	0.17	4.18	0.11	6.58	0.15	4.58	0.19	3.65	0.07	10.2	0.14	5.04
2013	0.08	8.56	0.17	4.15	0.18	3.93	0.12	5.84	0.15	4.47	0.08	8.18	0.18	3.92	0.15	4.63	0.12	5.83	0.17	4.10
2014	0.06	11.6	0.15	4.64	0.11	6.53	0.09	7.53	0.14	4.85	0.09	8.05	0.18	3.89	0.18	3.75	0.11	6.48	0.17	4.14

of publications for all five countries, it could motivate researchers to explore new topics that were hard to approach before.

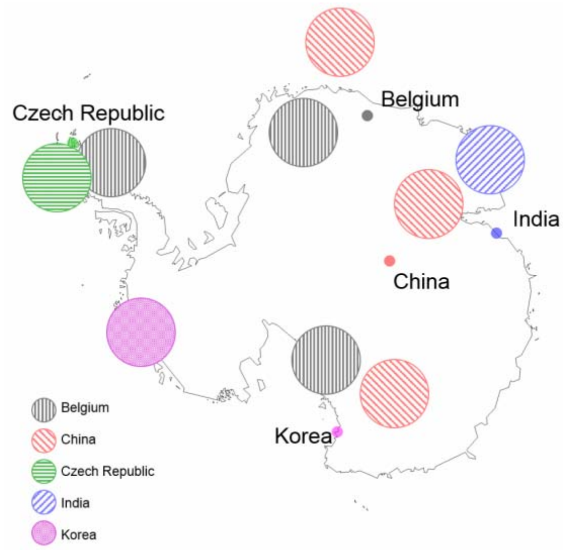
Another method that we try to find the effect on newly-built research station is to detect emerging keywords during the construction period. For detecting emerging keywords of five countries, we focused on keywords that appeared more than ten times for Belgium, China, Czech Republic, and India; five times for Korea because its new research station 'Jang Bogo' was built in 2014.

Several geographical keywords in Antarctica were found as emerging keywords. For example, six out of fourteen emerging keywords of Belgium are geographical keywords that are close to the construction site. China has three place names in the list, Southern Ocean, Prince Charles Mountains, and Victoria Land. Czech Republic shows sudden increases in overall Antarctic research around the construction period with keywords such as James Ross Island, South Shetland Islands, and East Antarctica. India has only one geographical keyword, Larsemann Hills. Amundsen Sea and Pine Island Glacier appeared in the emerging keyword list of Korea (Table 4).

When we plot location of research stations and geographical keywords on Antarctica map (Figure 3), it is possible to inspect countries' scope of research activity. Czech Republic and India focused on the surrounding places while Belgium and China tend to study many areas including far regions. In the case of Korea, they began to study geographical features that are far from the newly-built research station. There are some possible scenarios to explain the result of Korea. Korea already has operated a research station 'Sejong' at Shetland Islands, where Czech Republic built their research sta-

Table 4. Emerging geographical keywords of five countries

Country	Keyword	Counts
Belgium	South Shetland Islands	36
	McMurdo Dry Valleys	15
	Deception Island	14
	James Ross Island	13
	Dronning Maud Land	11
	Western Weddell Sea	10
China	Southern Ocean	71
	Prince Charles Mountains	15
	Victoria Land	11
Czech Republic	James Ross Island	23
	South Shetland Islands	20
	East Antarctica	15
India	Larsemann Hills	11
Korea	Amundsen Sea	6
	Pine Island Glacier	5



Small circles: research stations; Large circles: pointed regions of geographical keywords.

Figure 3. Location of newly-built research stations and geographical keywords for five countries.

tion in 2006, so that the pointed region could be a good region to maximize research capacity. Moreover, it may be hard to get the initiative for the surrounding regions due to the late installation of stationcompared to other countries. Four countries, Germany ('Gondwana,' first opened in 1983), Italy ('Mario Zucchelli,' first opened in 1986), New Zealand ('Scott Base,' first opened in1957), and USA ('McMurdo,' first opened in 1955) already owned research stations in that region. To validate whether these scenarios are plausible, it is needed to track Korea's research activities for a long time.

From the above results, we conclude that the construction of research station enables countries to improve its quantitative productivity in a few cases. Nonetheless, research station acts as an outpost for stimulating research projects about the neighboring area of the station.

4. CONCLUSIONS

In this study, we constructed Antarctic science collaboration network based on bibliometric data from Web of Science and detected communities to examine collaboration structure. Detected communities tend to be formed by following geographical proximity. Calculated scientific productivity and the degree of collaboration are used to compare regional consultative groups such as European Polar Board (EPB), Reunión de Administradores de Program as Antárticos Latinoamericanos (RAPAL), and Asian Forum for Polar Sciences (AFoPS). European countries have collaborated with other countries to some extent. However, AFoPS countries, China, India, Japan, Korea, and Malaysia, show a lack of collaboration. The disparity between South American countries exists in Antarctic science activities. This information would be helpful for establishing future strategy for these groups.

Our study also casts a question about the role of research station in Antarctic science because Antarctic science often requires experimental data that gained from research stations which considered as hubs for collaborative research. We focused on five newly-built research stations of Belgium, China, Czech Republic, India, and Korea. Relative growth rate (RGR) and D_t values were calculated to check rapid changes in national productivity. However, we couldn't find sudden changes in RGR and D_t except Belgium. It led us to think that the installation of research stations might not increase national productivity in a quantitative manner for all cases. However, these countries have place names as emerging keywords in the construction period. It seems that the installation of research station invigorates scientific research on Antarctic regions. Although they don't fully reflect countries' concentration area, they give an insight on the dynamics of national cooperation or competition in Antarctica. These analyses would be useful for science diplomacy and policy making process.

A study on a keyword network based on co-occurrence relations will be an intriguing subject to study the structure of Antarctic science with consideration of history by regional groups or countries. Similarity indices such as Jaccard coefficient could be used to classify countries according to their interests. Moreover, because community detection method that we applied in this study just assign one community to each country, overlapping communities might disclose detailed collaboration structure in Antarctic science by allocating more than one community. It could also be an interesting question whether the facilities at research stations, such as vessels, enhances scientific collaboration.

ACKNOWLEDGEMENTS

This work was supported by Mid-career Researcher Program through the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP) (NRF-2013R1A2A2A04017095).

REFERENCES

Adams, J., Gurney, K., Hook, D., and Leydesdorff, L. (2014), International collaboration clusters in Africa, *Scientometrics*, **98**, 547-556.

Bajwa, R., Yaldram, K., and Rafique, S. (2013), A scientometric assessment of research output in nanoscience and nanotechnology: Pakistan perspective, *Scientometrics*, **94**, 333-342.

Benayas, J., Pertierra, L., Tejedo, P., Lara, F., Bermudez, O., Hughes, K., and Quesada, A. (2013), A review of scientific research trends within ASPA Byers Peninsula, South Shetland Islands, Antarctica, *Antarctic Science*, **25**(126), 128-145.

Berkman, P. A., Lang, M. A., Walton, D. W., and Young, O. R. (2011), Science diplomacy, *Antarctica, Science and the Governance of International Spaces*, Smithsonian Institution Press, Washington.

Clauset, A., Newman, M. E., and Moore, C. (2004), Finding community structure in very large networks, *Physical Review E*, **70**, 066111.

Dastidar, P. G. (2007), National and institutional productivity and collaboration in Antarctic science: an analysis of 25 years of journal publications (1980 2004), *Polar Research*, **26**,175-180.

Dastidar, P. G. and Persson, O. (2005), Mapping the global structure of Antarctic researchvis-á-vis Antarctic Treaty System, *Current Science*, **89**, 1552.

Dastidar, P. G. and Ramachandran, S. (2008), Intellectual structure of Antarctic science: A25-years analysis, *Scientometrics*, **77**, 389-414.

Dudeney, J. R. and Walton, D. W. (2012), Leadership in politics and science within the Antarctic Treaty, P*olar Research*, **31**.

Evans, T., Lambiotte, R., and Panzarasa, P. (2011), Community structure and patterns ofscientific collaboration in business and management, *Scientometrics*, **89**, 381-396.

Frenken, K., Hardeman, S., and Hoekman, J. (2009), Spatial scientometrics: Towards acumulative research program, *Journal of Informetrics*, **3**, 222-232.

Hua, W., Li, Y., and Yuan, S. (2014), A quantitative analysis of Antarctic related articles inhumanities and social sciences appearing in the world core journals, *Scientometrics*, **100**, 273-286.

Ji, Q., Pang, X., and Zhao, X. (2014), A bibliometric analysis of research on Antarctica during 19932012, *Scientometrics*, **101**, 1925-1939.

Mahapatra, M. (1985), On the validity of the theory of exponential growth of scientific literature, *Proceedings of the 15th IASLIC conference*, 61-70.

Newman, M. E. (2004), Analysis of weighted networks, *Physical Review E*, **70**, 056131.

Pan, R. K., Kaski, K., and Fortunato, S. (2012), World citation and collaboration networks: uncovering the role of geography in science, *Scientific Reports*, **2**.

Persson, O. and Dastidar, P. B. (2013), Citation analysis to reconstruct the dynamics of Antarctic ozone hole research and formulation of the Montreal Protocol, *Current Science*, **104**, 835-840.

Ponds, R., Van Oort, F., and Frenken, K. (2007), The geographical and institutional proximity of research collaboration, *Papers in regional science*, **86**, 423-443.

Stefenon, V., Roesch, L., and Pereira, A. (2013), Thirty years of Brazilian research in Antarctica: ups, downs and perspectives, *Scientometrics*, **95**, 325-331.

Stotz, G. C., Salgado-Luarte, C., Rios R. S, Acuña-Rodriguez, I. S., Carrasco-Urra, F., MolinaMontenegro, M. A., and Gianoli, E. (2013), Trends in Antarctic ecological research in Latin America shown by publications in international journals, *Polar Research*, **32**.

Tejedo, P., Guti´errez, B., Pertierra, L. R., and Benayas, J. (2015), Analysis of published scientific research from Deception Island, South Shetland Islands, *Antarctic Science*, **27**,134-149.