JOURNAL OF
ECOLOGY AND ENVIRONMENT
http://www.jecoenv.org

Note
J. Ecol. Environ. 37(4): 217-223, 2014

Distribution pattern of *Pectinatella magnifica* (Leidy, 1851), an invasive species, in the Geum River and the Nakdong River, South Korea

Hyunbin Jo[1], Gea-Jae Joo[1], Myeoungseop Byeon[2], Dong-Gyun Hong[1], Jung-Soo Gim[1], Ji-Yoon Kim[1] and Jong-Yun Choi[1,*]

[1]Department of Biological Sciences, Pusan National University, Busan 609-735, Korea
[2]Environment Research Department, National Institute of Environmental Research, Incheon 404-708, Korea

Abstract

We conducted a distributional survey of *Pectinatella magnifica*, an invasive species, in the Geum River and the Nakdong River from July 12 to July 25, 2014. The spacing between the study sites was 10 km along the main channels for the Geum River (n = 12, 120 km) and the Nakdong River (n = 38, 380 km) from the estuarine barrage to upper part of main channel. *Pectinatella magnifica* was detected along the riparian zone (within 100 m) at each of the study sites. Presence rate of *P. magnifica* in Geum River and Nakdong River was 25% and 32.6%, respectively. The colony number of *P. magnifica* at Geum River (9.5 ± 3.1 colony/m, n = 3) was over 94 fold higher than that in the Nakdong River (0.1 ± 0.1 colony/m, n = 16). The Total length distribution of *P. magnifica* had a truncated bell shape at each rivers (mean length: 14.0 ± 1.2 cm for Geum River (n = 32), and 16.8 ± 1.4 cm for Nakdong River (n = 52)). These findings could provide basic information regarding the distribution pattern of *P. magnifica* in a new invasion area.

Key words: basic information, distribution, invasive species, *Pectinatella magnifica*

INTRODUCTION

Bryozoans are common animals that attach to submerged surfaces in freshwater, and they are found throughout the world. *Pectinatella magnifica,* one of the largest freshwater bryozoans, is a native of the area east of the Mississippi River from Ontario to Florida in USA (Wood 2001). In past decades, it has expanded throughout Northern America. *Pectinatella magnifica* has not only invaded Western North America region but also Europe and East Asia including Japan and South Korea (Wood 2001). According to the literature, there are 94 freshwater species (Massard and Geimer 2008) with 11 freshwater bryozoan species including *P. magnifica* being reported in South Korea (Seo 1998).

Scientific studies of *P. magnifica* have mainly been conducted in North America since the early 20th century (Davenport 1900, Wilcox 1906, Brooks 1929). Studies outside North America on *P. magnifica* began in the 1970's following the invasion of Japan (Mawatari 1973, Oda 1974). In the early 2000's, European countries started distributional studies of this species (Massard and Geimer 2002, Balounová et al. 2011, Šetlíková et al. 2013). According to Oda (1974), this species also spreads by zoochory (dispersal of statoblasts on feathers of birds). Dispersal by aquatic animals and transportation by fish (fingerling) in

http://dx.doi.org/10.5141/ecoenv.2014.026

Received 29 September 2014, **Accepted** 07 November 2014

***Corresponding Author**
E-mail: kokolove00@naver.com
Tel: +82-51-510-3344

  pISSN: 2287-8327 eISSN: 2288-1220

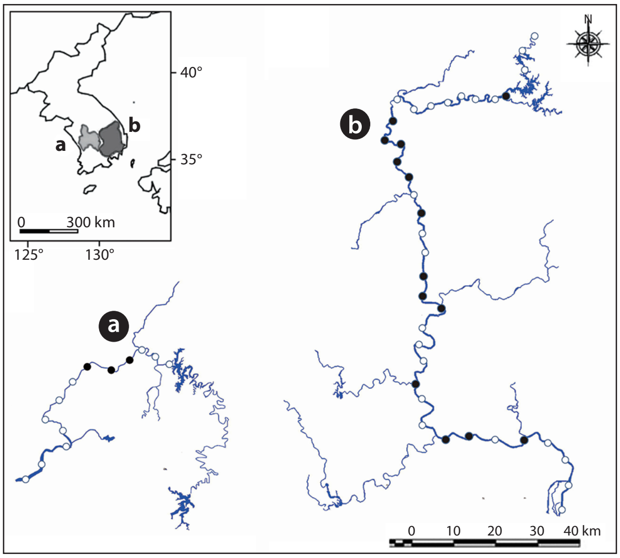

Fig. 1. Map of study sites. The left map in the upper right-hand corner shows the Korean Peninsula, and the (a) Geum River and (b) Nakdong River are marked by different gray colors. The circle in each river basin indicated sampling point (close circle (●), presence of *Pectinatella magnifica*; open circle (○), absence of *P. magnifica*).

aquaculture is also probable in South Korea (Seo 1998).

Using presence and absence information in lakes, most of the distributional studies have shown distribution patterns of this invasion species (Massard and Geimer 2002, Balounová et al. 2011, 2013). Quantitative information about colony size and biomass distribution has been rarely conducted (Joo et al. 1992, Šetlíková et al. 2013). In summer 2014, large colony developments were observed in four large rivers in South Korea. In this study, therefore, we conducted a survey of *P. magnifica* to determine the distribution pattern and the quantitative information about colony size and length between two different large rivers in South Korea.

MATERIALS AND METHODS

Distribution of *P. magnifica* was investigated on main channels of two different large rivers in South Korea (Fig. 1). One of large rivers was Nakdong River laid on south-eastern part of South Korea. Another is Geum River laid on west part of South Korea. The main channels were totally modified due to the four Large River Projects (4LRP) which implements large weirs along the main channels of 4 large rivers for flood control and water supplementation (Normile 2010). Specifically, eight large weirs (50% of all weirs) constructed along the main channel of the Nakdong River (300 km of total 514 km). The depth of the river changed from 1-2 m to 6-7 m while the channel width changed from 240-300 m to 350-530 m. Three large weirs were built in the Geum River main channel and this river suffered similar physical changes like the Nakdong River.

We conducted a distributional survey of *P. magnifica* from July 12 to July 25, 2014. The study site interval was 10 km along the main channel of the Nakdong River (n = 38; 380 km; "n" represent the number of sites hereafter) and Geum River (n = 12; 120 km) from the estuarine barrage to upper reaches of the main channel. We counted colony numbers of *P. magnifica* at randomly chosen locations (about 100 m) along the riparian zone at each sampling point (10 km intervals). Body length (mm) and weight (g) of *P. magnifica* were also measured. Additionally, water temperature, pH, conductivity, dissolved oxygen, and water velocity were measured. A DO meter (YSI Model 58; Fisher Scientific, Hampton, NH, USA) was used to measure water temperature and dissolved oxygen, while conductivity and pH were measured using a conductivity meter (Model 152; Fisher Scientific) and pH meter (Orion Model 250A; Cole- Parmer, Vernon Hills, IL, USA), respectively. Water velocity was measured using velocity instrument (Model 3631; Yokogawa, Tokyo, Japan) along the riparian zone. Other factors (e.g., biological oxygen demand, total nitrogen, total phosphate, and chlorophyll a) were obtained from K-water website (K-water 2014). The precipitation data were obtained from eight meteorological stations of the Korean Meteorological Administration (KMA) from March 1 to July 31, 2010 to 2014 (5 years), located in basin of the Geum River (Cheongju, Daejeon, Buyeo, and Gunsan) and Nakdong River (Taebaek, Andong, Yeongju, and Waegwan). To determine if any distri-

Table 1. Basic environmental factors at the Geum River (n = 12) and Nakdong River (n = 38) in from July 12 to July 25 in 2014

	Geum River	Nakdong River
Temperature (°C)	28.2 ± 0.7	28.9 ± 0.3
pH	7.4 ± 0.2	8.5 ± 0.1
Conductivity (μS/cm)	320.3 ± 12.8	288.6 ± 7.3
DO (mg/L)	7.6 ± 0.5	10.4 ± 0.3
DO (% saturation)	92.0 ± 6.8	126.9 ± 3.4
BOD (mg/L)	3.6 ± 2.0	2.1 ± 0.9
Total nitrogen (mg/L)	2.1 ± 0.2	1.8 ± 0.3
Total phosphate (mg/L)	0.1 ± 0.1	0.2 ± 0.1
Chlorophyll a (mg/m^3)	1.3 ± 0.4	1.0 ± 0.2
*Velocity (cm/sec)	6.7 ± 0.4	15.5 ± 3.4

Figures in the table indicate mean ± standard deviation (means of 3-4 measurements); n represents the number of sites; DO, dissolved oxygen; BOD, biochemical oxygen demand.

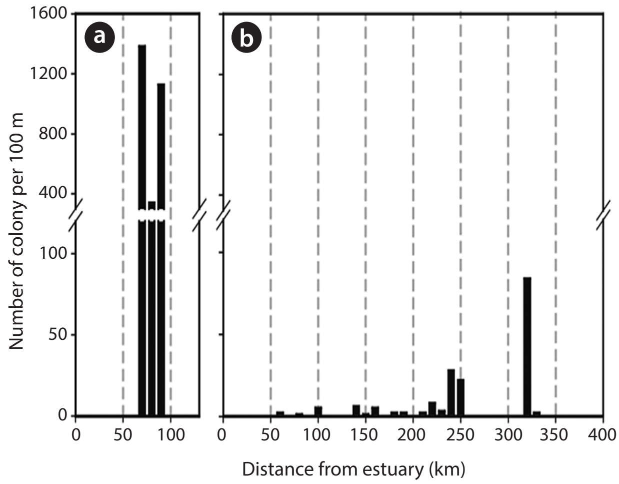

Fig. 2. Longitudinal distribution of *Pectinatella magnifica* colonies in study sites (a) Geum River and (b) Nakdong River (0 km: estuary barrage).

bution pattern existed in the literature, we searched distribution region of *P. magnifica* using literature, seminar reports and, media reports.

RESULTS AND DISCUSSION

Basic water quality showed difference between each sampling point in the two river ecosystems (Table 1 and Appendices 1 and 2). pH in Nakdong River (8.5 ± 0.1: mean ± standard deviation) was higher than that in the Geum River (7.4 ± 0.2). Comparatively, dissolved oxygen (mg/L, % saturation) in the Nakdong River (10.4 ± 0.1 mg/L, 126.9 ± 3.4%) was also higher than in the Geum River (7.6 ± 0.5 mg/L, 92.0 ± 6.8%). Biological oxygen demand (mg/L) in the Geum River (3.6 ± 2.0) was higher than in Nakdong River (2.1 ± 0.9). However, conductivity in the Geum River (320.3 ± 12.8 μS/cm) was higher than in the Nakdong River (288.6 ± 7.3). Nutrient such as nitrogen, phosphate, and chlorophyll a were similar in the two river ecosystem. Alternatively, water velocity in the Nakdong River (15.5 ± 3.4 s/cm) was 2.5 fold higher than that in the Geum River (6.7 ± 0.4 s/cm). Rainfall lead to increase of water velocity and decrease residence time in the river ecosystem (Jeong et al. 2007). Rainfall from March to July in 2014 was very low compared to previous years (2010–2013) in the Geum River (mean of rainfall in 2010 to 2013, 744 ± 138 mm; rainfall in 2014, 468 mm (62% of total rainfall) and Nakdong River (mean: 609 ± 117 mm; rainfall in 2014, 350 mm (51%)). Therefore, the massive development of *P. magnifica* possibly may be the result of very low rainfall and the interaction with other environmental variables.

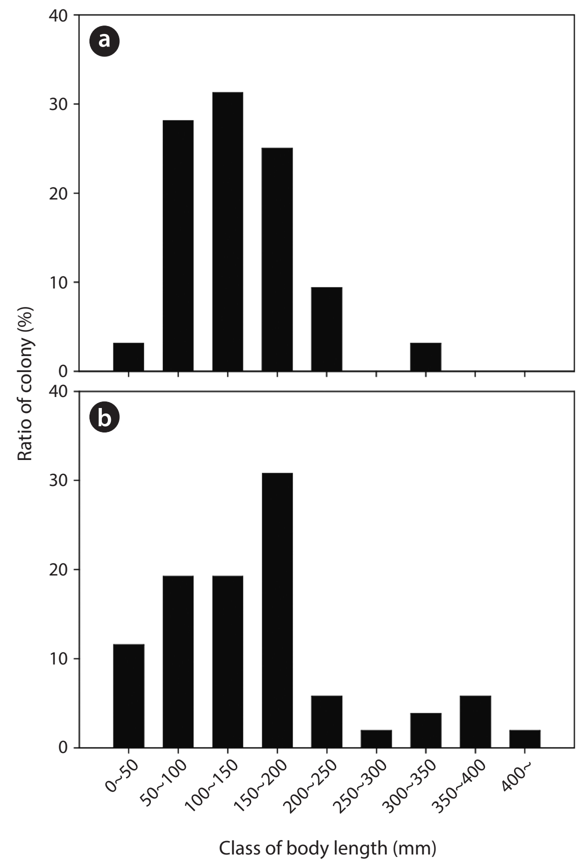

Fig. 3. Relative abundance (%) of *Pectinatella magnifica* colony (%) on body length class at the study sites, (a) Geum River (n = 32) and (b) Nakdong River (n = 52); n indicates the number of sites.

The distribution pattern of *P. magnifica* is shown in Fig. 1. The present rate of *P. magnifica* in the Nakdong and Geum Rivers was 32.6% and 25%, respectively. Looking at a comparison of *P. magnifica* colony numbers, colony number in the Geum River (9.49 ± 3.14 colony/m, n = 3) was more than 94 fold higher than in the Nakdong River (0.11 ± 0.05 colony/m, n = 16; Fig. 2). We observed higher value of water velocity at sampling point with presence of *P. magnifica* (on average, 17.4 cm/s) than that at point with absence of *P. magnifica* (8.3 cm/s). The total length distribution of *P. magnifica* had a truncated bell shape at each river: mean lengths were 14.0 ± 1.2 for Geum River (n = 32), 16.8 ± 1.4 for Nakdong River (n = 52). The body length of *P. magnifica* colonies in Nakdong River and Geum River ranged from 50 to 200 mm and 100 to 250 mm, respectively (Fig. 3). In the Geum River, *P. magnifica* colonies were abundant between 100 to 150 mm, while in the Nakdong River, colonies between 150 and 200 mm were most abundant.

According to Seo (1998), *P. magnifica* was observed

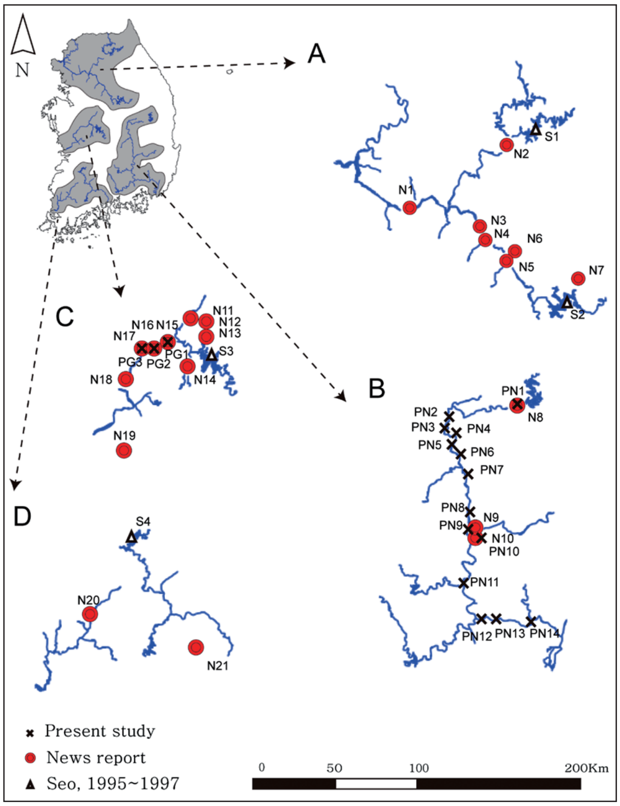

Fig. 4. Review of *Pectinatella magnifica* distribution in South Korea. The cross marks indicate present study (n = 50; n represents the number of sites); circles, news report (n = 28, 1994–2014); triangles, previous study from 1995 to 1997 (Seo 1998; n = 4). A, Han River; B, Nakdong River; C, Geum River; D, Yeongsan and Seomjin River.

mainly in lentic freshwater ecosystems such as lake and reservoirs in South Korea. However, in our review of *P. magnifica* distribution in South Korea, this species can be found in both lentic and in lotic ecosystems (Fig. 4). There are possibilities for diffusion due to several reasons (e.g., water flow, migratory birds, fish, fish farm, and boat); however, *P. magnifica* statoblasts are mainly thought to be dispersed by hydrochloric transport along the river on flow and between water reservoirs by water birds (Balounová et al. 2013). This indicates that the spread of *P. magnifica* is not a local characteristic but has occurred nation-wide simultaneously. Therefore, we could assume anthropogenic factors such as weir or dam construction (i.e., 4LRP) that might provide ideal habitat and contribute to the massive development of this invasive species.

In conclusion, our results provided a quantitative comparison of *P. magnifica* distribution between the Geum River and Nakdong River. We could also detect differences in distribution patterns, colony numbers, and total length distribution and the relationship between total length and weight of *P. magnifica* between the two different large rivers. These findings could provide basic information about the distribution pattern of *P. magnifica* in a new invasion area. At present, it is not clear why the massive development of *P. magnifica* has been observed in the middle reaches of Geum River and upper reaches of Nakdong River. The aforementioned studies of *P. magnifica* were limited to its distribution and basic ecology. We, therefore, need to determine food-web structure and interaction with other aquatic organisms using advanced technical tools like stable isotope analysis and molecular approaches in further studies. Detailed hydrological evaluation of the river section where colony development was exceptionally high is also needed for a better understanding of *P. magnifica* colony development.

ACKNOWLEDGMENTS

This research was supported by the Ministry of Environment, South Korea (2014).

LITERATURE CITED

Balounová Z, Pechoušková E, Rajchard J, Joza V, Šinko J. 2013. World-wide distribution of the Bryozoan *Pectinatella magnifica* (Leidy 1851). Eur J Environ Sci 3: 96-100.

Balounová Z, Rajchard J, Švehla J, Šmahel L. 2011. The onset of invasion of bryozoan *Pectinatella magnifica* in South Bohemia (Czech Republic). Biologia 66: 1091-1096.

Brooks CM. 1929. Notes on the statoblasts and polypids of *Pectinatella magnifica*. Proc Acad Nat Sci Philadelphia 81: 427-441.

Davenport CB. 1900. On the variation of the statoblasts of *Pectinatella magnifica* from Lake Michigan, at Chicago. Am Nat 34: 959-968.

Jeong KS, Kim DK, Joo GJ. 2007. Delayed influence of dam storage and discharge on the determination of seasonal proliferations of Microcystis aeruginosa and Stephanodiscus hantzschii in a regulated river system of the lower Nakdong River (South Korea). Water Res 41: 1269-1279.

Joo GJ, Ward AK, Ward GM. 1992. Ecology of *Pectinatella magnifica* (Bryozoa) in an Alabama oxbow lake: colony growth and association with algae. J N Am Benthol Soc 11: 324-333.

K-water. 2014. Environmental factors database. http://www.blogkwater.or.kr/. Accessed 23 September 2014.

Massard JA, Geimer G. 2002. Occurrence of *Pectinatella magnifica* (Leidy, 1851)(Bryozoa, Phylactolaemata) in the German-Luxembourg border region near Bech-Kleinmacher (Luxembourg) and Nennig (Germany). Arch-Inst Grand-Ducal Luxemb Sci Nat Phys Math 44: 107-120.

Massard JA, Geimer G. 2008. Global diversity of bryozoans (Bryozoa or Ectoprocta) in freshwater: an update. Bull Soc Nat Luxemb 109: 139-148.

Mawatari S. 1973. New occurrence of *Pectinatella magnifica* (Leidy) in a Japanese lake. Proc Jap Soc Syst Zool 9: 41-43.

Normile D. 2010. Restoration or devastation? Science 327: 1568-1570.

Oda S. 1974. *Pectinatella magnifica* occurring in Lake Shoji, Japan. Proc Jap Soc Syst Zool 10: 31-39.

Seo JE. 1998. Taxonomy of the freshwater bryozoans from Korea. Korean J Syst Zool 14: 371-378.

Šetlíková I, Skácelová O, Šinko J, Rajchard J, Balounová Z. 2013. Ecology of *Pectinatella magnifica* and associated algae and cyanobacteria. Biologia 68: 1136-1141.

Wilcox AW. 1906. Locomotion in young colonies of *Pectinatella magnifica*. Biol Bull 11: 245-252.

Wood TS. 2001. Bryozoans. In: Ecology and Classification of North American Freshwater Invertebrates (Thorp JH, Covich A, eds). 2nd ed. Academic Press, New York, NY, pp 505-525.

Appendix 1. Environmental factors and colony number of *Pectinatella magnifica* in Geum River (RK, River kilometer from estuarine barrage)

No.	RK	Water temperature	pH	Conductivity	DO (mg/L)	DO (%)	BOD (mg/L)	TN (mg/L)	TP (mg/L)	Chl a (mg/m^3)	Velocity (cm/s)	Number of colony
1	110	23.8	7.02	346.1	7.76	85.9	1.7	2.609	0.1	2.12	5.0	0
2	100	23	6.96	328.5	7.05	76.1	3.9	2.444	0.165	1.89	10.8	0
3	90	27.7	8.07	309.3	8.14	97.3	3.5	2.273	0.132	1.42	7.6	1126
4	80	28.6	8.9	354.8	11.97	145.7	3.2	2.338	0.186	1.37	6.1	340
5	70	28.8	6.83	322.69	5.83	70.9	2.9	2.051	0.205	1.29	5.7	1382
6	60	28.9	7	258.9	6.02	74.1	3.5	2.101	0.136	1.2	6.1	0
7	50	28.6	6.8	270.8	5.89	71.8	3.3	2.02	0.188	1.26	5.7	0
8	40	28.6	6.83	237.6	6.03	73	2.9	2.087	0.127	1.24	6.8	0
9	30	29.5	6.97	324.8	7.23	89.3	3.4	2.09	0.053	1.21	7.2	0
10	20	29.1	7.05	340.2	7.28	88.5	2.8	1.818	0.108	1.01	6.1	0
11	10	30.1	8.03	379.1	8.53	105.8	2.3	1.913	0.214	1.15	7.2	0
12	0	31.3	8.9	370.3	9.85	125	9.7	1.813	0.042	0.71	5.9	0
Average	-	28.1	7.4	320.3	7.6	92.0	3.59	2.13	0.14	1.32	6.7	237.3
SD	-	2.4	0.8	44.2	1.8	23.4	2.01	0.24	0.06	0.37	1.5	487.3

DO, dissolved oxygen; BOD, biochemical oxygen demand; TN, total nitrogen; TP, total phosphorous; Chl a, Chlorophyll a; SD, standard deviation.

Appendix 2. Environmental factors and colony number of *Pectinatella magnifica* in Nakdong River (RK: River kilometer from estuarine barrage)

No.	RK	Water temperature	pH	Conductivity	DO (mg/L)	DO (%)	BOD (mg/L)	TN (mg/L)	TP (mg/L)	Chl a (mg/m^3)	Velocity (cm/s)	Number of colony
1	370	28.6	8.77	326.6	9.45	113.3	0.8	1.706	0.196	1.12	10.6	0
2	360	29.3	8.96	316.5	10.27	135.7	0.9	1.595	0.161	1.03	7.2	0
3	350	30.7	7.77	286.3	9.02	113.7	1.1	1.592	0.148	1.08	5.0	0
4	340	22.8	7.87	237.7	9.87	107.8	1	1.681	0.089	1.12	11.4	0
5	330	30.1	9.04	227.3	11.94	151.1	0.9	1.468	0.022	1.11	6.5	2
6	320	28.7	8.60	235.2	10.62	120.0	1.1	1.63	0.209	1.08	5.6	84
7	310	25.5	7.89	257.1	10.01	115.4	0.9	1.755	0.18	1.06	23.7	0
8	300	28.3	7.86	239.6	9.50	114.5	0.9	1.617	0.145	1.07	67.2	0
9	290	27.9	7.91	248.6	9.09	108.6	1.3	2.041	0.412	0.86	97.7	0
10	280	29	8.74	245.2	15.28	185.1	1.9	1.395	0.35	0.73	7.3	0
11	270	32.1	7.55	248.5	8.81	115.2	1.9	1.435	0.087	0.89	82.0	0
12	260	34.7	9.07	270.2	11.67	156.7	1.9	1.344	0.336	0.83	13.7	0
13	250	33.2	8.42	252.8	11.55	152.1	1.7	1.509	0.283	0.94	7.6	22
14	240	28.9	8.42	247.9	11.49	141.2	2.3	1.836	0.068	1.06	5.0	28
15	230	29.8	8.70	269.4	12.06	148.4	2.2	1.513	0.252	0.75	7.3	3
16	220	29.1	7.54	318.8	8.80	108.1	2.5	1.509	0.274	0.7	7.3	8
17	210	29.9	8.59	274.7	9.03	116.3	2.1	1.547	0.109	0.86	7.3	2
18	200	29.3	8.65	312.0	9.97	125.1	2.6	1.361	0.223	0.71	7.3	0
19	190	28.7	8.70	349.2	10.90	133.8	3.2	1.452	0.333	0.85	9.6	2
20	180	28.5	8.81	315.4	11.67	141.9	3	2.374	0.319	1.42	5.0	2
21	170	28.5	8.64	281.2	10.36	126.1	2.7	2.48	0.272	1.44	7.3	0
22	160	28.5	8.47	247.0	9.05	110.2	-	-	-	-	7.3	5
23	150	28.1	8.44	283.4	9.14	110.5	2.3	1.918	0.136	0.92	7.3	1
24	140	27.7	8.40	319.7	9.23	110.7	2.3	2.505	0.21	1.51	7.3	6
25	130	28.5	8.64	281.2	10.36	126.1	2.1	2.145	0.15	1.13	7.3	0
26	120	28.4	8.52	270.5	9.52	115.6	2.9	2.294	0.141	1.38	8.1	0
27	110	28.1	8.44	283.4	9.14	110.5	3.6	1.545	0.067	0.9	8.1	0
28	100	28.1	8.49	294.8	9.58	115.7	3.2	1.633	0.095	0.87	28.2	5
29	90	28.2	8.51	290.5	9.70	117.4	2.4	2.126	0.148	1.24	7.1	0
30	80	28.3	8.53	278.4	9.67	117.4	3.1	1.829	0.083	0.91	7.1	1
31	70	28.2	8.48	282.9	9.41	113.9	2.7	2.152	0.148	1.28	7.1	0
32	60	28.1	8.48	289.5	9.47	114.5	3.1	1.812	0.083	0.91	11.2	2
33	50	28.2	8.51	287.9	9.65	116.8	3	2.138	0.1	1.25	8.1	0
34	40	28.2	8.51	283.9	9.60	116.2	2.9	2.121	0.123	1.25	36.0	0
35	30	28.6	8.24	342.4	9.02	114.0	2.3	1.839	0.079	0.95	12.4	0
36	20	29.4	8.70	352.8	12.60	153.0	1.8	2.055			10.2	0
37	10	30.5	9.66	459.0	19.05	199.0	0.8	1.706	0.196	1.12	8.1	0
38	0	29.7	8.64	358.8	10.65	131.8	0.9	1.595	0.161	1.03	7.3	0
Average	-	28.9	8.5	288.6	10.4	126.9	2.06	1.79	0.18	1.04	15.5	4.6
SD	-	1.9	0.4	44.7	1.9	21.2	0.85	0.32	0.09	0.21	21.1	14.4

DO, dissolved oxygen; BOD, biochemical oxygen demand; TN, total nitrogen; TP, total phosphorous; Chl a, Chlorophyll a; SD, standard deviation.

Appendix 3. Specific information of *Pectinatella magnifica* distribution

Name	GPS		References
N1	37°32′32.35″ N	127°1′39.81″ E	News report
N2	37°52′19.86″ N	127°42′47.15″ E	″
N3	37°24′53.56″ N	127°32′17.68″ E	″
N4	37°20′42.19″ N	127°35′0.18″ E	″
N5	37°13′33.65″ N	127°43′39.82″ E	″
N6	37°18′16.53″ N	127°48′30.66″ E	″
N7	37°10′23.11″ N	128°12′38.17″ E	″
N8	36°33′18.04″ N	128°44′25.61″ E	″
N9	35°50′33.95″ N	128°27′39.05″ E	″
N10	35°48′50.22″ N	128°28′50.65″ E	″
N11	36°36′34.19″ N	127°25′8.78″ E	″
N12	36°35′13.30″ N	127°30′4.26″ E	″
N13	36°32′36.54″ N	127°30′52.33″ E	″
N14	36°22′18.77″ N	127°23′25.90″ E	″
N15	36°28′36.56″ N	127°15′48.92″ E	″
N16	36°26′5.37″ N	127°12′41.32″ E	″
N17	36°27′57.53″ N	127°6′10.31″ E	″
N18	36°17′44.85″ N	126°54′48.88″ E	″
N19	35°54′25.99″ N	126°57′25.35″ E	″
N20	35°10′52.99″ N	126°50′31.43″ E	″
N21	34°55′40.84″ N	127°30′31.43″ E	″
PN1	36°33′34.71″ N	128°44′26.02″ E	Present study in Nakdong River
PN2	36°29′10.29″ N	128°17′1.10″ E	″
PN3	36°26′0.35″ N	128°15′0.44″ E	″
PN4	36°24′14.01″ N	128°17′47.49″ E	″
PN5	36°21′40.77″ N	128°17′49.14″ E	″
PN6	36°18′0.67″ N	128°18′48.94″ E	″
PN7	36°8′42.90″ N	128°23′37.98″ E	″
PN8	35°59′17.43″ N	128°19′47.29″ E	″
PN9	35°52′54.35″ N	128°23′17.04″ E	″
PN10	35°50′11.58″ N	128°27′23.86″ E	″
PN11	35°35′6.20″ N	128°21′10.69″ E	″
PN12	35°27′16.96″ N	128°22′22.49″ E	″
PN13	35°22′48.53″ N	128°33′7.51″ E	″
PN14	35°22′31.03″ N	128°48′56.40″ E	″
PG1	36°28′29.20″ N	127°16′8.30″ E	Present study in Geum River
PG2	36°26′45.35″ N	127°11′14.61″ E	″
PG3	36°27′52.85″ N	127°6′7.40″ E	″
S1	37°55′55.88″ N	127°53′30.22″ E	Seo 1997
S2	36°57′18.73″ N	128°4′16.00″ E	″
S3	36°27′20.35″ N	127°30′6.04″ E	″
S4	35°36′54.80″ N	127°6′37.73″ E	″