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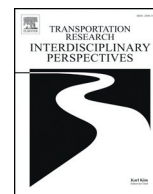
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# Changes in urban mobility in Sapporo city, Japan due to the Covid-19 emergency declarations



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### ABSTRACT

At the time of writing, the world is facing the new coronavirus pandemic, which has been declared one of the most dangerous disasters of the 21st century. All nations and communities have applied many countermeasures to control the spread of the epidemic. In terms of countermeasures, lockdowns and reductions of social activities are meant to flatten the curve of infection. Nevertheless, to date, there has been no evaluation of the effectiveness of these methods. Thus, the present study aims to interpret the change in the population density of Sapporo city in the emergency's period declaration using big data obtained from mobile spatial statistics. The results indicate that, in the time of refraining from traveling, the city's residents have been more likely to stay home and less likely to travel to the center area. This has led to a decrease of up to 90% of the population density in crowded areas. The study's outcomes partly explain the statement of reducing 70%–80% of contact between people in line with the purpose of the emergency declaration. Moreover, these findings establish the primary step for further analysis of estimating the efficiency of policy in controlling the epidemic.

### 1. Introduction

Since the new coronavirus (Covid-19) appeared in Wuhan, China at the end of 2019, it has spread rapidly worldwide and has become one of the most dangerous pandemics of the 21st century. By the middle of June 2020, the total number of infected cases has reached over 8,400,000 people, taking the lives of over 450,000 people (Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU), n.d.). Because of the severity of the pandemic, many governments have responded with measures designed to control the outbreak, to protect residents and to mitigate economic losses. One of the popular countermeasures is to lock down and break down communities. This method mainly focuses on the reduction of close contact to disrupt the channels of the epidemic and to isolate outbreaks. The term “social distancing” is now widely used to advise people to self-quarantine by keeping a suitable distance from others and avoiding unnecessary trips.

Since countermeasures have been applied, commuting worldwide has seen significant changes in both travel demand and behavior (De Vos, 2020). As summarized by Budd and Ison (2020), European air traffic decreased by about 90% during this period. Bucskey (2020) reported that the mobility level in Budapest reduced about 51% to 64% in March 2020. Meanwhile, the total trips generated in Australia dropped to just over

50% (Beck and Hensher, 2020). In the UK, (Hadjidemetriou et al., 2020) claimed that government restricted policies account for the reduction of driving, transit, and walking traffic to about 60%, 80%, and 60%, respectively. In terms of behavior, many reports indicate that travel mode share has transformed. Beck and Hensher (2020) found that Australian households shifted their means of transport from public to active mode at about 7% while the share of private vehicles was unchanged. In the case of the Netherlands, besides the reduction of the number of trips and distance traveled, 88% of Dutch prefer to commute by private mode than public mode (de Haas et al., 2020). Another study from (Parady et al., 2020) expressed the change in frequency of the trip by purpose in Japan. According to the authors, the pandemic had a higher effect on eating out and leisure trips more than shopping trips.

In Japan, since the first infected case was found on 15 January, 2020, the number of patients was 9601 on the 31st of May. The top cities with the disease include Hokkaido, Saitama, Chiba, Tokyo, Kanagawa, Osaka, Hyogo, and Fukuoka (Ministry of Health Labor and Welfare, 2020a). In the attempt to curb the pandemic, the Japanese government declared a state of emergency two times on the 7th and 16th of April. While the first emergency declaration (ED) targeted the six prefectures listed above, except Hokkaido, the second extended over the nation due to the sharp increase in the number of infections. Notably, before enforcing the national

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ED, the Hokkaido prefecture proactively announced a state of emergency on the 28th of February 2020 (The Hokkaido Governor, 2020). This declaration encouraged people to remain inside on weekends until the 19th of March. Soon after, the governors of Sapporo city and the Hokkaido prefecture announced a joint ED against the epidemic on the 11th of April (Hokkaido-Sapporo City, 2020). This time, it increased the level of restriction by asking people to stay home and refrain from travel to and from Sapporo city, not to go to restaurants and school, and closed public facilities.

In the first ED summary (Prime Minister of Japan and His Cabinet, 2020), the most important goal was the reduction by at least 70% to 80% of direct contact between people. This declaration was valid until the 6th of May or the end of Golden Week—one of the longest holidays in Japan. To achieve this target, the Ministry of Health, Labor and Welfare proposed a system which focuses on ten points. Remarkably, this instruction emphasized refraining from commuting for any purpose (e.g., meeting, traveling, or shopping). In addition, the government encouraged all kinds of activities to be changed to remote versions through the Internet.

After the state of emergency, the infectious cases in Japan decreased gradually and became stable by the end of Golden Week (Ministry of Health Labor and Welfare, 2020b). In contrast to the spread trend of Japan, Hokkaido seemed to face the first wave of the pandemic beginning in the middle of February (see Fig. 1). In Fig. 1, we can see the infected cases in Hokkaido were stable at around five people per day from the middle of March to the beginning of April. Remarkably, the infection wave peak points of Japan and Hokkaido skewed from each other with approximately two weeks' gap. Besides, the endpoints for the two waves were around the middle of May. The situation suggests an efficient use of social distancing. However, there was no confirmation about the achievement of reducing personal contact by 70%–80%. On the 26th of April 2020, the Japan Times reported that the pedestrian traffic volume in 47 prefectures in Japan was lower than the two months before by 50% to 80% (The Japan Times, n.d.). The article presented the number using the data of NTT DOCOMO, Inc. However, there was no explanation of how they produced the Figure.

In general, commuters moving will cause a change in the number of people at the trip's origin and destination. Meanwhile, the population density variation by time has a significant relation with the traffic volume. Thus, the resident concentration estimation by time and across the spatial area will partly explain the change in travel demand. Taking this into account, in this paper, we aim to examine the change in population density during the Covid-19 pandemic in Sapporo city, the largest city in Hokkaido prefecture. Hence, the study will clarify two questions: How did the population

distribution vary over time in the city? How much did the fluctuation of population density in this space relate to the government's restrictive policies?

The result of the present study contributes to the academic field in at least two ways. First, it partly explains and assesses the efficiency of policies in reducing residents' contact, especially the state of emergency declaration. Second, we introduce the method of using mobile spatial statistics data, in terms of big data, to calculate the population concentration. This idea may support transportation researchers to further determine the relationship between the population density and moving pattern. Besides, it can also apply to epidemiology and public health to estimate and control the spread mechanism of the new coronavirus.

## 2. Data and methodology

### 2.1. Mobile spatial statistics and population estimation

Mobile spatial statistics are demographic statistics created using the NTT DOCOMO mobile network mechanism (Terada et al., 2013). According to the company's instructions, the spatial data can reveal the position of devices in time-series and the operational data, which refer to the country code. There are three processes in the data production including non-identification, aggregation and concealment (Okajima et al., 2013). The first process, also called the primary security layer, removes the identifying information, such as names and telephone numbers. Additionally, this stage also converts the date of birth to age groups, then summarizes it in the output. The second step has the role of counting the number of devices by age groups and gender for a specific time and area. Finally, the last process will remove the areas that have a few persons to prevent the identification of individuals based on their location. Thus, personal identity is again protected as a second security layer. Consequently, the final data exhibits the distribution of population by area, gender, age group, and moving patterns at the multilevel within cities, from prefecture to prefecture or from foreign countries to Japan, etc. Note that the data with higher dimensions of information will have a lower quantity compared with data with only spatial information.

Since this study aims to examine the change in population distribution in Sapporo city, we first attempt to ensure that the mobile spatial statistics data can represent the resident density. As one of the largest mobile carriers in Japan, NTT DOCOMO accounts for about 44% of the total subscribers for mobile phones (TCA Telecommunications Carriers Association, 2020). Specifically, NTT DOCOMO has over 80 million and 2.3 million users in Japan

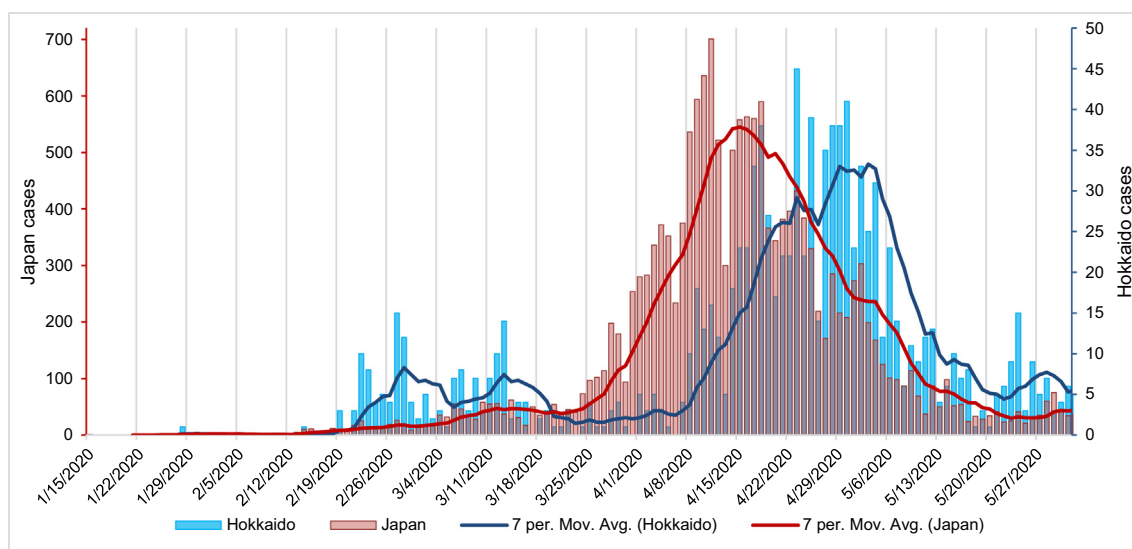


Fig. 1. Number of infected cases in Japan and Hokkaido by day.

(Source: Japan – Ministry of Health, Labor and Welfare (<https://www.mhlw.go.jp/english/index.html>) and Japan COVID-19 Coronavirus Tracker (<https://github.com/reustle/covid19japan-data>); Hokkaido – Hokkaido Government (<http://www.pref.hokkaido.lg.jp/index.htm>)).

and Hokkaido, respectively. Regarding the data quality and accuracy, the technical note produced by the cooperation of National Institute of Land and Infrastructure Management (NILIM), Tokyo University, and the NTT DOCOMO, Inc., provided the detail of the data collecting procedure and its application in the transport field as a reliable resource (NILIM, 2018). Besides, in the research of Arimura et al. (2016) and Okumura et al. (2020), the authors demonstrated that mobile spatial statistics data have a high correlation with the permanent population based on the city's census data. Moreover, we intend to reflect the actual number of people at a specific time; thus, the mobile spatial statistics are suitable and reliable for the analysis. Note that the population in the present study represents the number of mobile devices that appear in a 500 m square grid at a specific time. Thus, the determinants of (P) value includes three factors: the grid code (g), the day of year (d), and the time of the day (t).

Regarding the response to the pandemic, the NTT DOCOMO company provided a data set that contains the mobile spatial statistics from the 1st of January 2020 to the 7th of May 2020. Based on the characteristics of the pandemic spreading situation and the milestones of the state of emergency, we divide the time into the intervals shown in Fig. 2.

As Fig. 2 illustrates, the new year holiday ranged from the 1st to 12th of January 2020. Since people usually travel outside the city during these holidays, we decided not to use this data in the analysis due to the potential bias. In the remaining intervals, we focus on the four times, which is supposed to reveal a significant change in the city's population distribution. These are periods (b) of 27 days, from the 1st to the 27th of February; (c) of 21 days, from the 28th of February to the 19th of March; (e) of 15 days, from the 17th of April to the 1st of May; and (f) of 5 days, from the 2nd to the 6th of May. We compare these periods with the normal time which represents the period (a).

### 2.2. Spatial population distribution and changing rate over time

Since using a single data point at a specific time does not represent the whole period population distribution, we decide to use the average population concentration as defined in Eq. (1).

- Population concentration during a period and at a specific time:

$$\bar{P}_{g(s,w,t)} = \frac{\sum_{d=1}^n P_{g(d,t)}}{n} \tag{1}$$

where

- $\bar{P}_{g(s,w,t)}$ —the average population in a grid g in period s, on holidays or weekdays, at time of the day t;
- s—period of time (s = a, b, c, d, e, or f);
- w—day of the week (w = 0 if on weekdays, w = 1 if on weekends or holidays);
- t—time in the day (t = [0,23]);
- d—number of days in the period s (d is identified by the timeline defined in the previous section).

After producing the average population concentration by Eq. (1), we continue to compute the change in population in each grid by using the decrease rate defined by Eq. (2).

- The change of population concentration at two specific times:

$$Dec_g = \frac{\bar{P}_{g(a,w,t)} - \bar{P}_{g(s,w,t)}}{\bar{P}_{g(a,w,t)}} \times 100 \tag{2}$$

where

- $Dec_g$ —decrease in population in a grid g (%);
- $\bar{P}_{g(a,w,t)}$ — average population in a grid based on period (a) on weekdays or holidays (controlled by value of w) and the time of day (controlled by the value of t);
- $\bar{P}_{g(s,w,t)}$  - average population in a grid on periods other than the based period (controlled by value of s) on weekdays or holidays (controlled by value of w) and the time of day (controlled by the value of t).

Note that the value of  $Dec_g$  may be more or less than 0. When the  $Dec_g$  sign is positive, that means the population decreases, and vice versa. In the next sections, we propose to visualize the value of  $Dec_g$  using both geographic and tabular data.

## 3. Results

### 3.1. Distribution of population in Sapporo city

In this section, we express the overall population distribution in Sapporo city at different periods of time using the result from Eq. (1). Table 1 extracts the value from the output, which reveals the highest population in a grid at a working hour (14:00) and nighttime (22:00) on holidays and weekdays. Because of the extremely large result of the calculation process, we visualize the demographics in Figs. 3 and 4, which illustrate the population distribution at day and nighttime only.

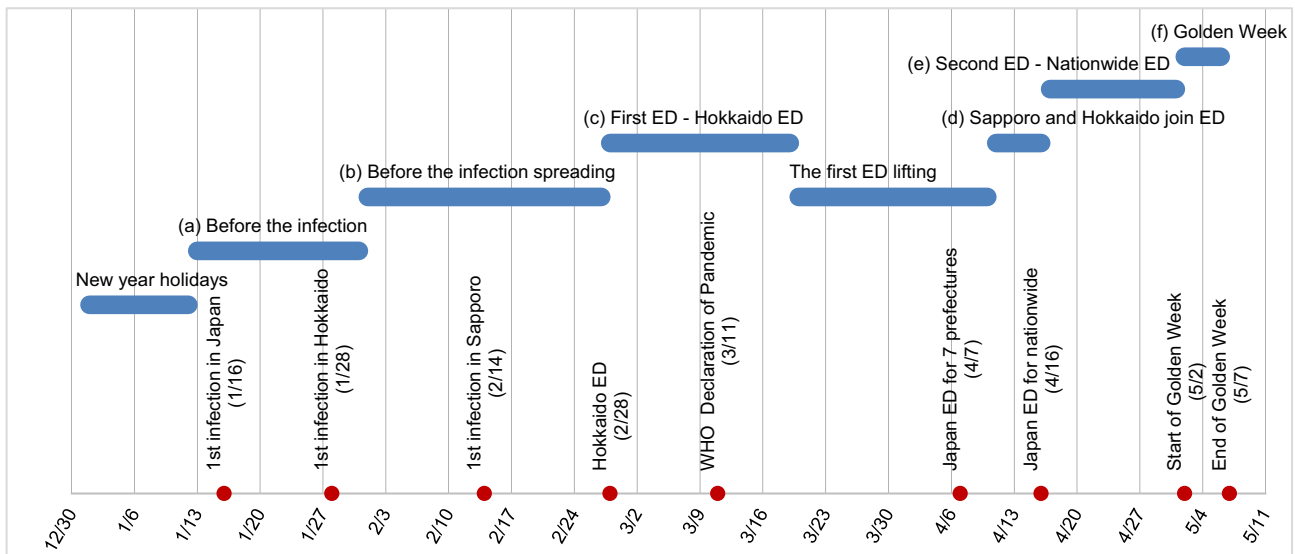


Fig. 2. Timeline for the periods of analysis. ED: state of emergency declaration.

**Table 1**  
Population distribution in Sapporo city on weekdays/holidays and day/night-time.

Period (s)	Time of day (t)	Highest population	Change in population (%) (*)
Weekday (w = 0)			
a	14:00	26,739	
b	14:00	26,622	-0.44
c	14:00	25,054	-6.30
e	14:00	15,409	-42.37
f	14:00	5100	-80.93
a	22:00	20,305	
b	22:00	19,064	-6.11
c	22:00	13,602	-33.01
e	22:00	5392	-73.44
f	22:00	5032	-75.22
Holidays (w = 1)			
a	14:00	21,732	
b	14:00	20,183	-7.13
c	14:00	14,066	-35.28
e	14:00	6795	-68.73
f	14:00	5100	-76.53
a	22:00	19,356	
b	22:00	19,708	1.82
c	22:00	12,283	-36.54
e	22:00	5202	-73.12
f	22:00	5032	-74.00

Note: a – Normal time (01/13–01/31); b – Before ED (02/01–02/27); c – First ED (02/28–03/19); e – Second ED (04/17–05/01); f (GW) – Golden Week (05/02–05/06).

(\*) The change in percentage compared with the normal time (a-period)

Generally, the highest population density is mainly located in the Center Business District (CBD) areas and along the subway and railway lines. The CBD here represents the areas situated around the Sapporo station, which is the biggest transportation hub in Sapporo, and also in Hokkaido prefecture. From Sapporo station, the main street (Odori Avenue) is directly to the south, as well as the Susukino streets that have a mass of business and financial offices and night activities. As illustrated in Fig. 3, the highest population in this area in the day-time on weekdays was 26,739 (in the base period, (a)) and decreased slightly in the next periods (b and c). At night-time, the Susukino area was the most attractive location that people visited, with a peak value of 20,305 before the first infection in Sapporo.

When examining the resident distribution at night during Golden Week (GW), the results indicate that the number of grids with a population exceeding 2000 was 184, which equals about 14.4% of the total city's grids (1276). The mean number of devices in the high-density grids was about 2721 compared to the mean value for the city overall, which was approximately 1121.

When comparing the days in a week, the data demonstrated that weekdays and holidays have a lower population density. Remarkably, the density value varies higher during the day than at night. Based on the values in Table 1, we found that the change in the afternoon was about 19% to 24%, while it did not vary much in the evening.

Notably, the city saw a significant decrease in density during the second ED and GW periods. As shown in Table 1, the highest reduction rate of the population was 80.93% on weekdays at 14:00. Except only in the afternoon of the e period, the other times had a reduction value of around 70% to 75%. Besides, this phenomenon mainly appeared in the Susukino area, where there was usually a high density of population during the evening.

### 3.2. The variation of population density in the city center

Since the largest change appeared in the CBD area, in this section, we attempt to reveal the population variation in this district. We select three grids in the CBD, including Sapporo station (grid code 644142881), the main street - Odori Avenue (grid code 644142781), and Susukino (grid code 644142683). Fig. 5 exhibits the fluctuation of the population in the three grids from the first day of the data set. Note that the value of 0 on the horizontal axis represents the 1st of January 2020.

The decline started from the first ED and fell sharply from the second ED. Notably, there was a slight increase in the period d when the first ED was removed. The graphs illustrate that the highest resident's density was in Sapporo station and the Odori during the day, whereas the Susukino area had a high value at night. Besides, the peak point of the population-density of Susukino skewed from the remaining grids. This shows that the most crowded area in Susukino is only on weekends and drops on Sunday, then rises gradually from Monday to Friday. Meanwhile, the other grids have an intensive concentration on weekdays and drop substantially on Saturday. Below, we explain the changes for each specific hour.

As shown in Table 2, at 10:00, the population density on the Odori was highest, with a maximum value of 20,320 people at the normal time (period a) on weekdays. This situation changed on weekends and holidays, when the difference in density among these three grids was not as great; the average was about 9000 to 12,000 people. At the time of period b, the change in people volume was not high in Sapporo station and Susukino. Notably, on the Odori, the density increased by 12.39%. When the first ED executed, the decrease in density was much higher, reaching about 25% to 29% in grids, then continued to drop at 57.48% and 64.68% in Sapporo station in the second ED and GW periods.

In the early afternoon, at 14:00, the trend of population variation was similar at 10:00 but with a higher amplitude. On the Odori area, the number of people reached 25,231 (about 25% higher than it was at 10:00). Sapporo station did not see a variation before the first ED with about 21,000 people. Meanwhile, people went to Susukino on weekends; its density rose to approximately 16,000 people. The decrease started mainly in the e and f periods. During the e period, the population in a grid varied from about 5400 to 6800, and the value during the f period reduced to about 4200 from 5100.

At 18:00, since this represents the end of the working hours, the commuters transferred from the Odori area to the station and night spots. Thus, on weekdays, the population in these areas seemed to be equal, whereas, on weekends, the Susukino was the most crowded area. Besides, the density reduction at this time was higher than its value at the time of 14:00. The number of people in Sapporo station and the Odori Avenue dropped to around 2500, while the value in Susukino remained at about 5300.

In contrast to the daytime, the gross resident in this area at night decreased except for Susukino. This time also showed the strongest decline in population density, when the total number of people on the Odori Avenue and at Sapporo station were only 447 and 904 during Golden Week. Meanwhile, Susukino's population dropped from 19,356 persons to 2863 persons—a decrease rate of 85.21%.

### 3.3. Changes in population concentration in Sapporo on weekdays and holidays

Using the results produced by Eq. (2), we visualize the decrease density rate in Figs. 6 to 9. While Figs. 6 and 7 illustrate the variation of population distribution during the day-time (at 14:00) and night-time (22:00) on weekdays, Figs. 8 and 9 express the percentage of change on weekends and holidays at the same time. Then, we summarize the highest variation value in Table 3.

Generally, the results indicate that the population density varied stronger in the day-time than in the night-time. As illustrated in Figs. 6 to 9, the number of grids with a high Dec value appeared commonly in the afternoon. More specifically, the CBD decreased sharply in density since the second ED period. The decline also appeared at attractive points, including supermarkets, shopping malls, stadiums, educational institutions, and leisure facilities. Meanwhile, residential parts of the city mostly showed an increased population density.

During the day, the increased density expanded over the city. On weekdays, the number of red grids rose to a maximum of 1250 for the e period. Meanwhile, the holidays saw the highest rise of 1142 on GW and the lowest value was 843 in the b period. Notably, the mean increased percentage rose three times during the e period on weekdays and GW (about 15%) compared with the b period (at 4.48% and 5.97% on weekdays and holidays, respectively). Regarding the decrease of Dec, the blue grids appeared with a much lower number compared with the red grids. The maximum of the

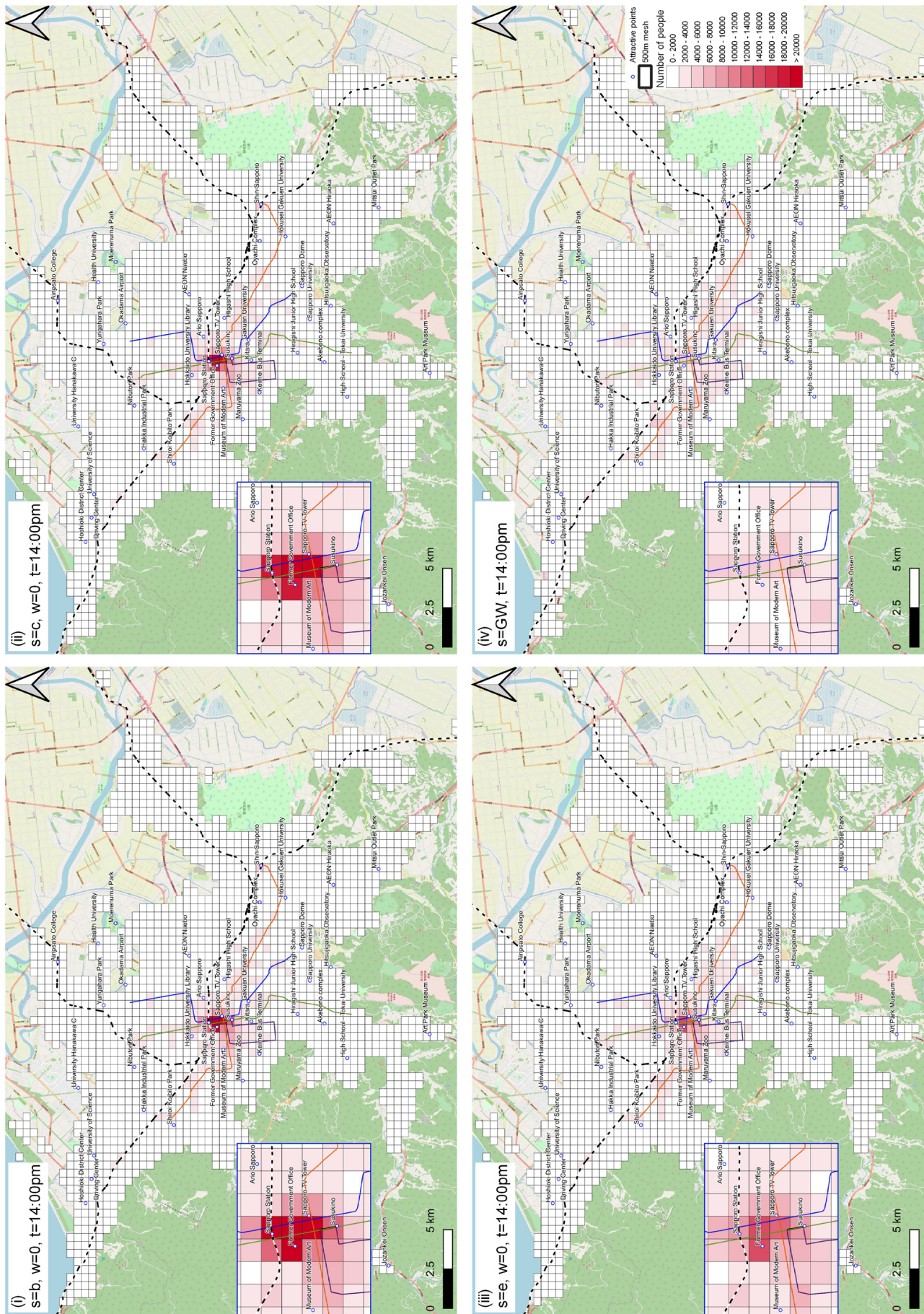


Fig. 3. Population distribution on weekdays, working hour (14:00) in the period before ED (i) and during the first ED (ii), second ED (iii) and Golden Week (GW) (iv).

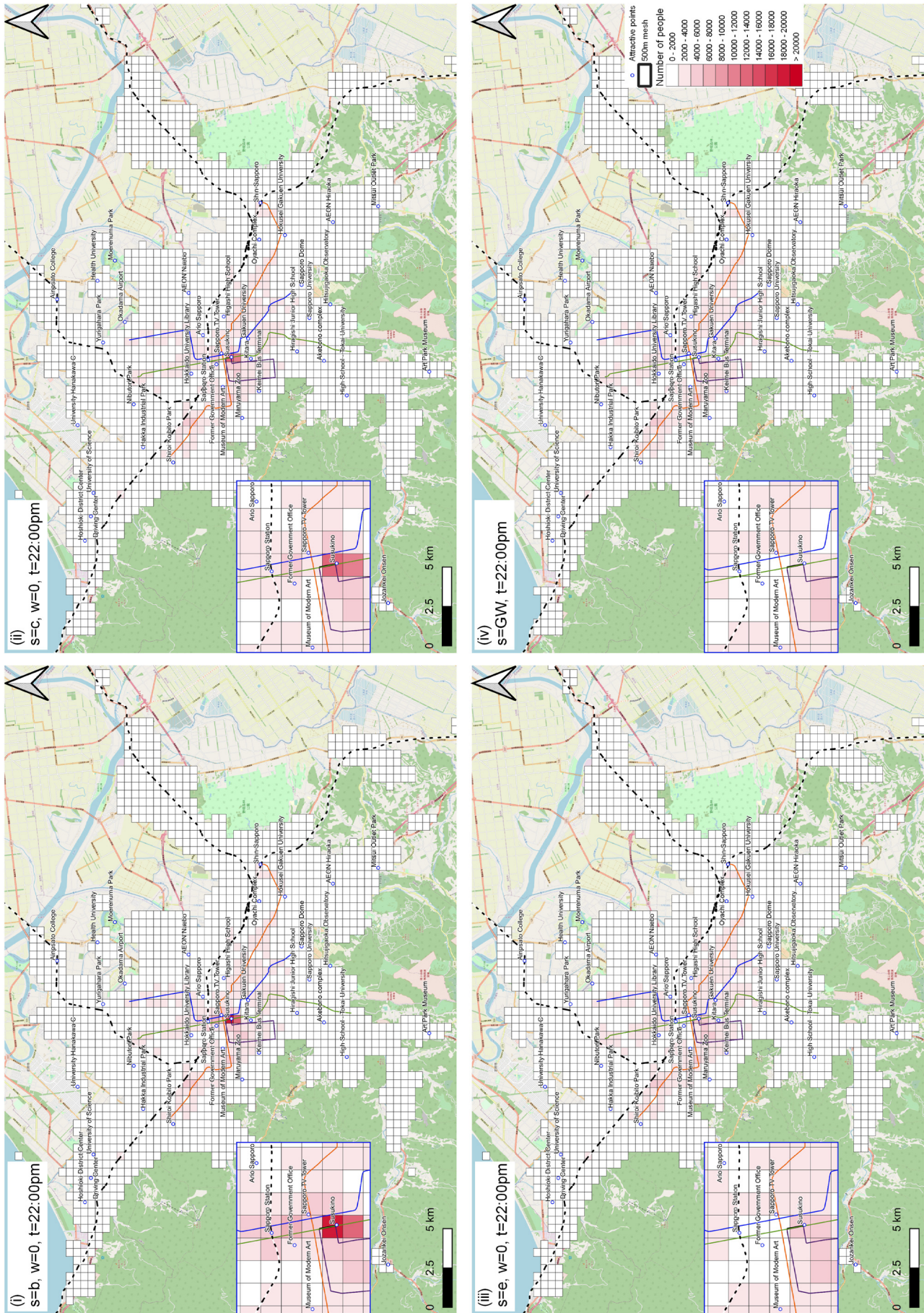


Fig. 4. Population distribution on weekdays, during the night-time (22:00) in the periods before ED (i), second ED (ii) and GW (iv).

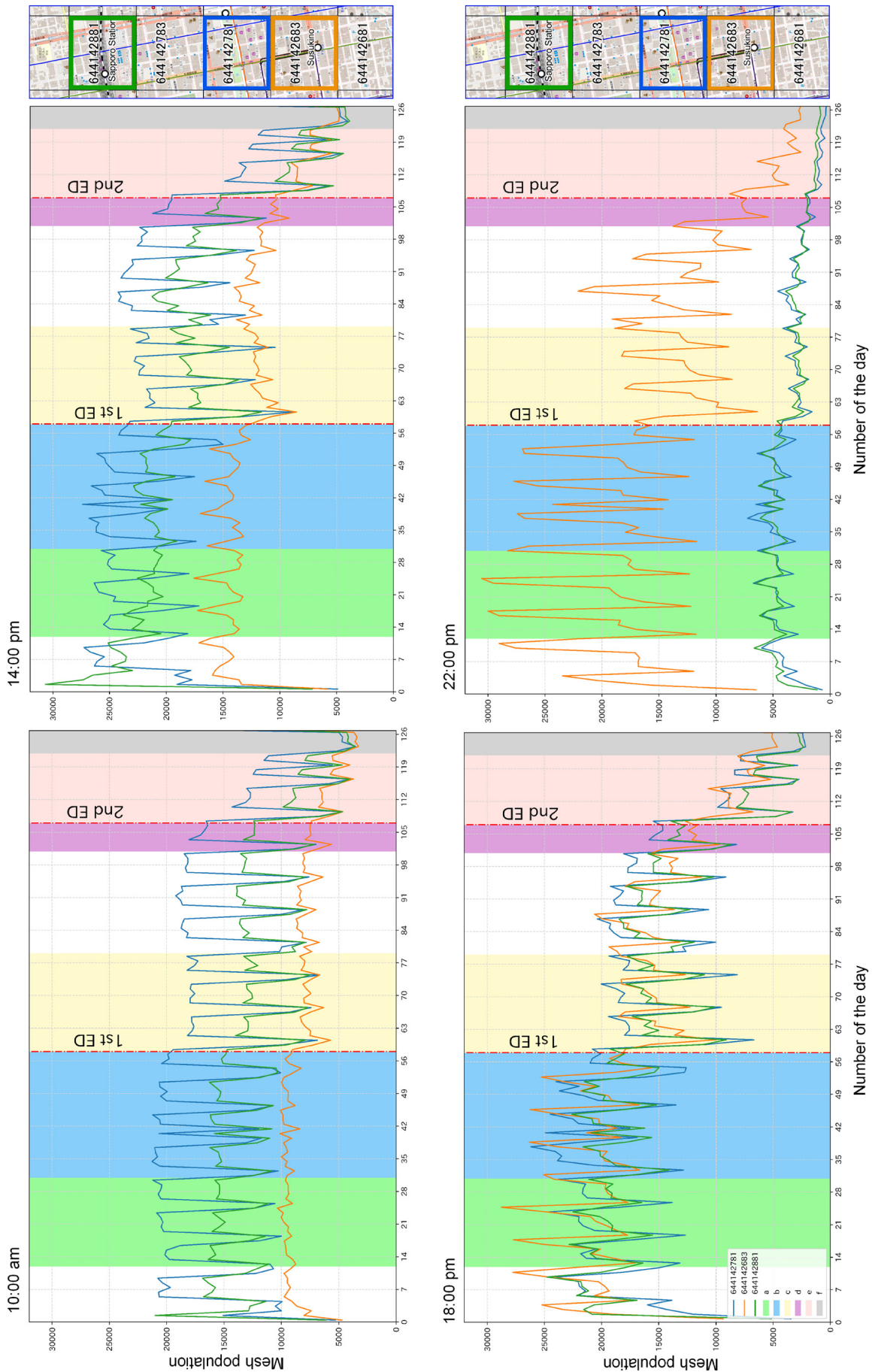


Fig. 5. Changes in population by days in the CBD area. (Day 0 is equal to 1st of January 2020).



**Table 2**  
Population in the Center Business District (CBD) area of Sapporo city.

Time/period	Sapporo station (Grid No. g = 644142881)				Odori (Grid No. g = 644142781)				Susukino (Grid No. g = 644142683)			
	Weekdays	Change (%)	Holidays	Change (%)	Weekday	Change (%)	Holiday	Change (%)	Weekday	Change (%)	Holiday	Change (%)
10:00												
a	15,687		11,772		20,320		11,172		9546		9388	
b	15,339	-2.22	11,733	-0.34	19,987	-1.64	12,556	12.39	9585	0.41	9269	-1.26
c	13,090	-16.55	8386	-28.77	17,944	-11.69	8291	-25.79	8038	-15.80	6804	-27.53
e	9042	-42.36	5006	-57.48	12,960	-36.22	5356	-52.06	6231	-34.73	4669	-50.26
f			4158	-64.68			4611	-58.73			3645	-61.17
14:00												
a	21,500		21,732		25,231		18,989		13,889		15,966	
b	21,316	-0.86	20,184	-7.13	24,963	-1.06	19,704	3.77	13,863	-0.19	15,241	-4.54
c	18,209	-15.31	14,067	-35.27	22,116	-12.34	12,478	-34.29	11,900	-14.32	10,974	-31.27
e	9697	-54.90	5434	-75.00	13,606	-46.08	5940	-68.72	8252	-40.58	6795	-57.44
f			4199	-80.68			4763	-74.92			5100	-68.06
18:00												
a	20,203		17,427		21,893		15,077		20,798		21,788	
b	19,983	-1.09	16,642	-4.50	22,181	1.31	16,732	10.98	20,208	-2.84	21,042	-3.42
c	16,618	-17.74	11,009	-36.83	18,508	-15.46	10,006	-33.63	15,968	-23.22	14,480	-33.54
e	7795	-61.42	3506	-79.88	9420	-56.97	3492	-76.84	8872	-57.34	7183	-67.03
f			2672	-84.67			2501	-83.41			5319	-75.59
22:00												
a	5048		4585		4937		4044		20,305		19,356	
b	4966	-1.63	4585	0.01	5001	1.31	4429	9.53	19,064	-6.11	19,709	1.82
c	3032	-39.94	2408	-47.47	3174	-35.71	2232	-44.81	13,602	-33.01	12,283	-36.54
e	1365	-72.95	1119	-75.60	1072	-78.28	720	-82.18	4873	-76.00	4214	-78.23
f			904	-80.29			447	-88.94			2863	-85.21

Note: a – Normal time (01/13–01/31); b – Before ED (02/01–02/27); c – First ED (02/28–03/19); e – Second ED (04/17–05/01); f (GW) – Golden Week (05/02–05/06). The change in percentage compared with the normal time (a-period).

blue grid was 786 on weekends during the *b* period, and the minimum value was 441 on weekdays in the *e* period. Nevertheless, the mean value of the *Dec* in each period seemed similar to the trend of red grids but was slightly higher. Remarkably, the *Dec* reached a great value in the *e* and GW periods, with a maximum of 84.98% and 85.61%, respectively. Besides, the decreased grids situate mainly around the CBD and attractive points (refer to Figs. 6 and 8). This phenomenon suggests that the ED has affected travel behavior.

At night, when most offices close and working activities end, the change in population distribution was weaker in terms of both space and magnitude. In terms of the increase in population density, the number of red grids on weekdays and holidays was lower than it was during the day-time at the same time periods. Commonly, the mean value of *Dec* at night was about half of those in the day-time during the same period. For instance, while the highest *Dec* values in the afternoon on weekdays and holidays reached 15% and 14.87%, respectively, those values in the evening were only 6.36% and 7.18%. By contrast, the change in the decrease of population was different. As the results demonstrate, the mean of the *Dec* value at night was about half of that in the day-time; the highest values at night were 7.81% and 8.21% on weekdays and holidays, respectively. The number of blue grids at night was reduced for all periods until GW, although the total in each period was higher than it was during the day.

#### 4. Conclusions and discussions

In the present study, the population distribution and its variation over time is visualized using mobile spatial statistics. The outcomes of the analysis at least satisfy the research's purpose in describing the change of behavior in terms of daily movements of people influenced by the declaration of the state of emergency.

Regarding the first research question, based on the night-time distribution (equivalent to the census data when revealing a registered resident), the population distribution in the city is quite flat. When removing the Susukino area, in which the concentration is associated mostly with night activities, the other parts of the city population density were not extremely

different. This suggests the city has an advantage for enacting the social distancing process due to the equivalent population distribution over various areas. However, in the CBD area, especially the Susukino streets, there is still a risk that exists when the high-density appears frequently.

Besides this, the change of the population distribution was significant in the day-time when the CBD population areas increased dramatically. This phenomenon reflects the fact that people from around the city move to the center to work on weekdays. Another reason supporting the flat population distribution of the city includes its well-organized and sufficient public transport system. During the fiscal year of 2018, the subway system of Sapporo carried about 631,000 passengers per day, while the bus system served nearly 288,000 passengers per day (City of Sapporo, 2019). The city faced two problems when the pandemic occurred. Firstly, the mass rapid transit system involves a risk of close contact due to the high passenger density inside the cab. Secondly, when the city is in lockdown, the suspension of the public transport system affects the citizens' travel demands. This may lead to a change in travel, transferring from public to private modes.

Related to the change in population density, the present study identifies that the high concentration decreases mainly appeared in the CBD and public facilities such as education, shopping malls, etc. Remarkably, in some areas, the density reduction was over 80%. This variation is relevant to the ED content (i.e., that people should avoid going to crowded areas where the high risk of close contact exists). Additionally, when the government released the lockdown statement, many businesses shifted to remote work, allowing staff to do their work at home. We argue that this action may have a large effect not only on the population distribution but the moving patterns of the city.

Notably, the trends in changes in population density indicate that the Sapporo resident movement relates to the level of the state of emergency declaration. As described in section 3.2, the density decrease began with the Hokkaido declaration of emergency, but the change was not significant. Since the Japanese government enacted the second nationwide ED, the resident density in this period declined significantly. This suggests that risk awareness increased over time. Moreover, people's response seemed to be

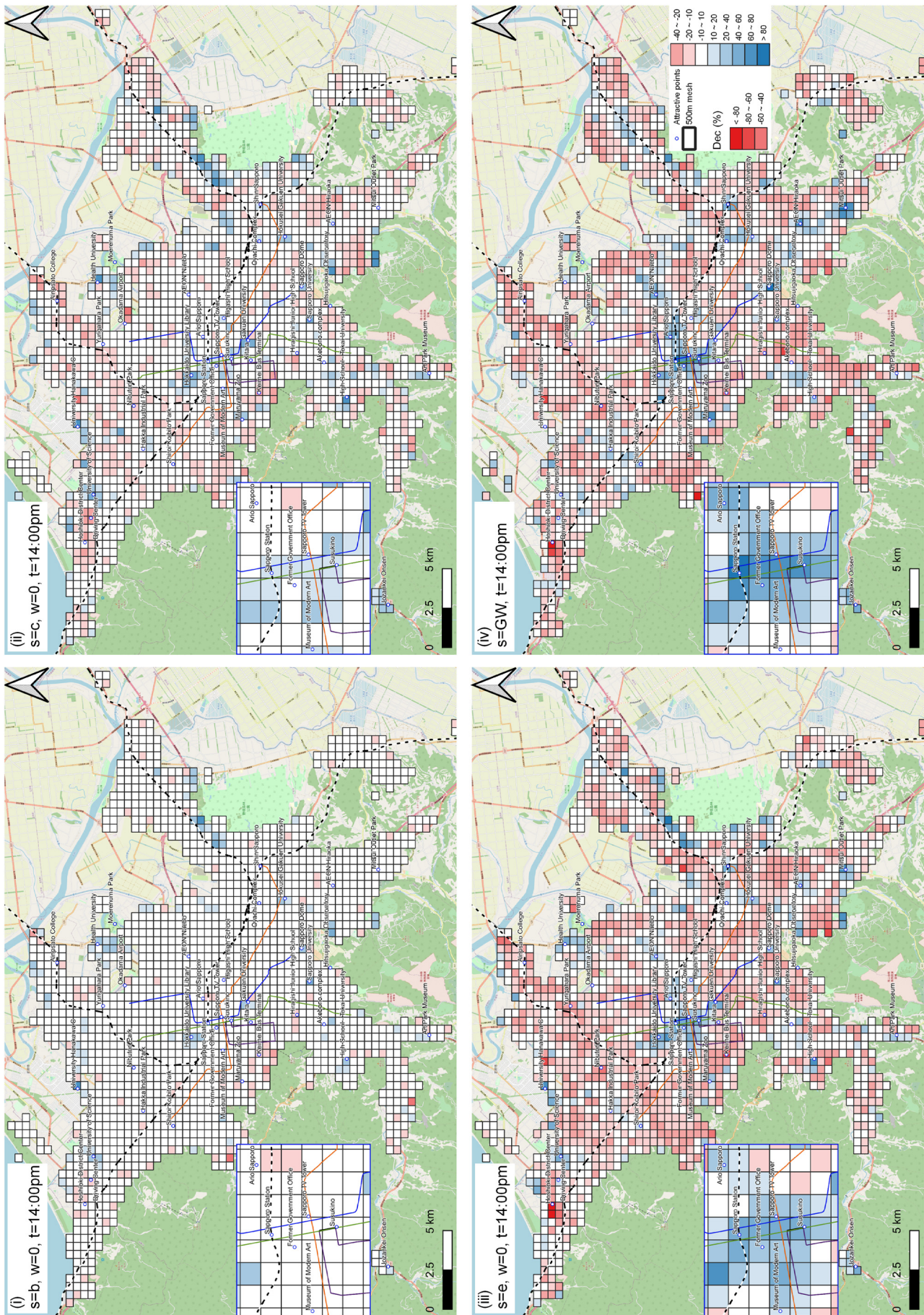


Fig. 6. Decrease in population concentration on weekdays, day time (14:00) in the periods of Before ED (i), First ED (ii), Second ED (iii), and GW (iv).

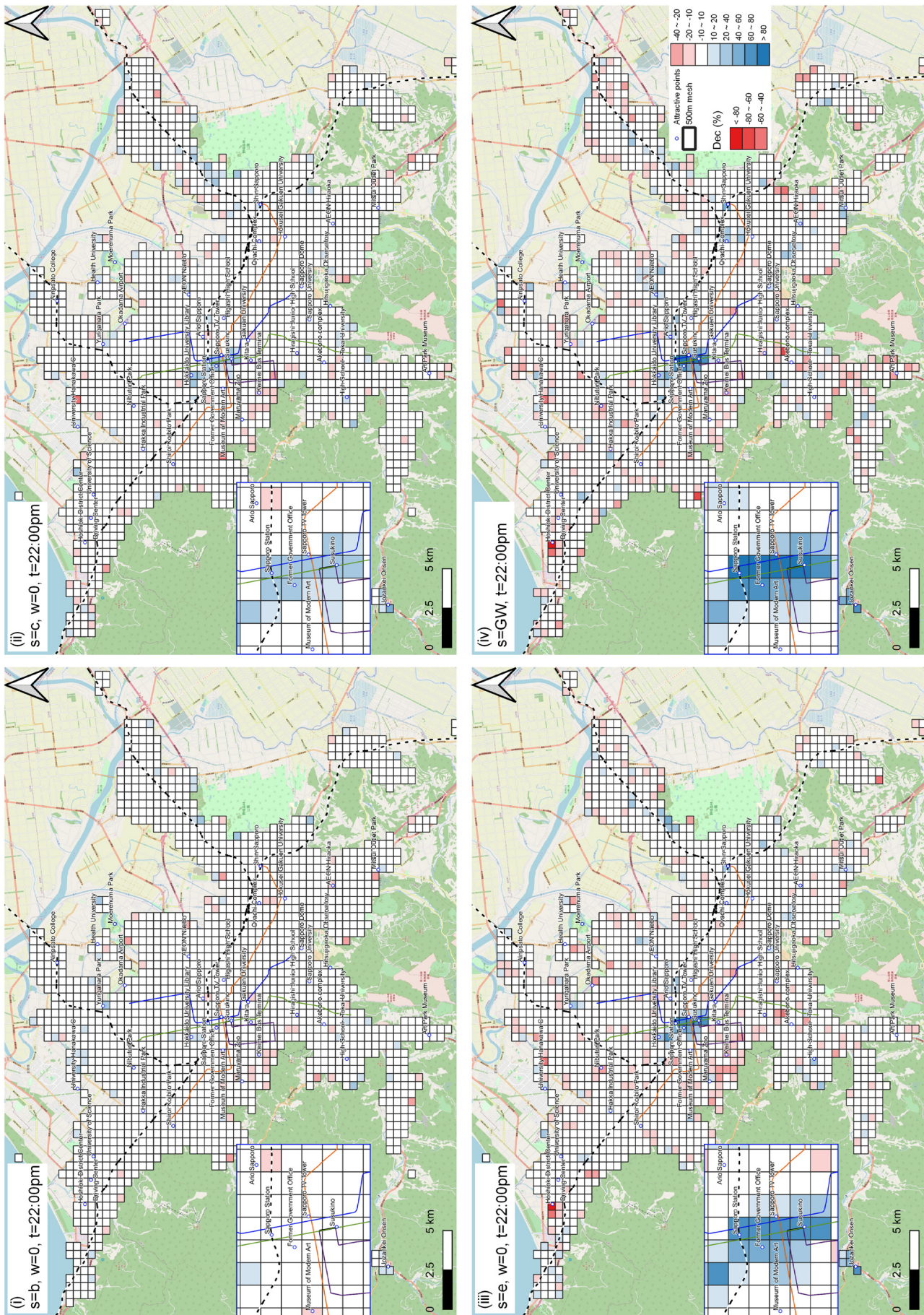


Fig. 7. Decrease in population concentration on weekdays, at night (22:00) in the periods before ED (i), second ED (ii), and GW (iv).

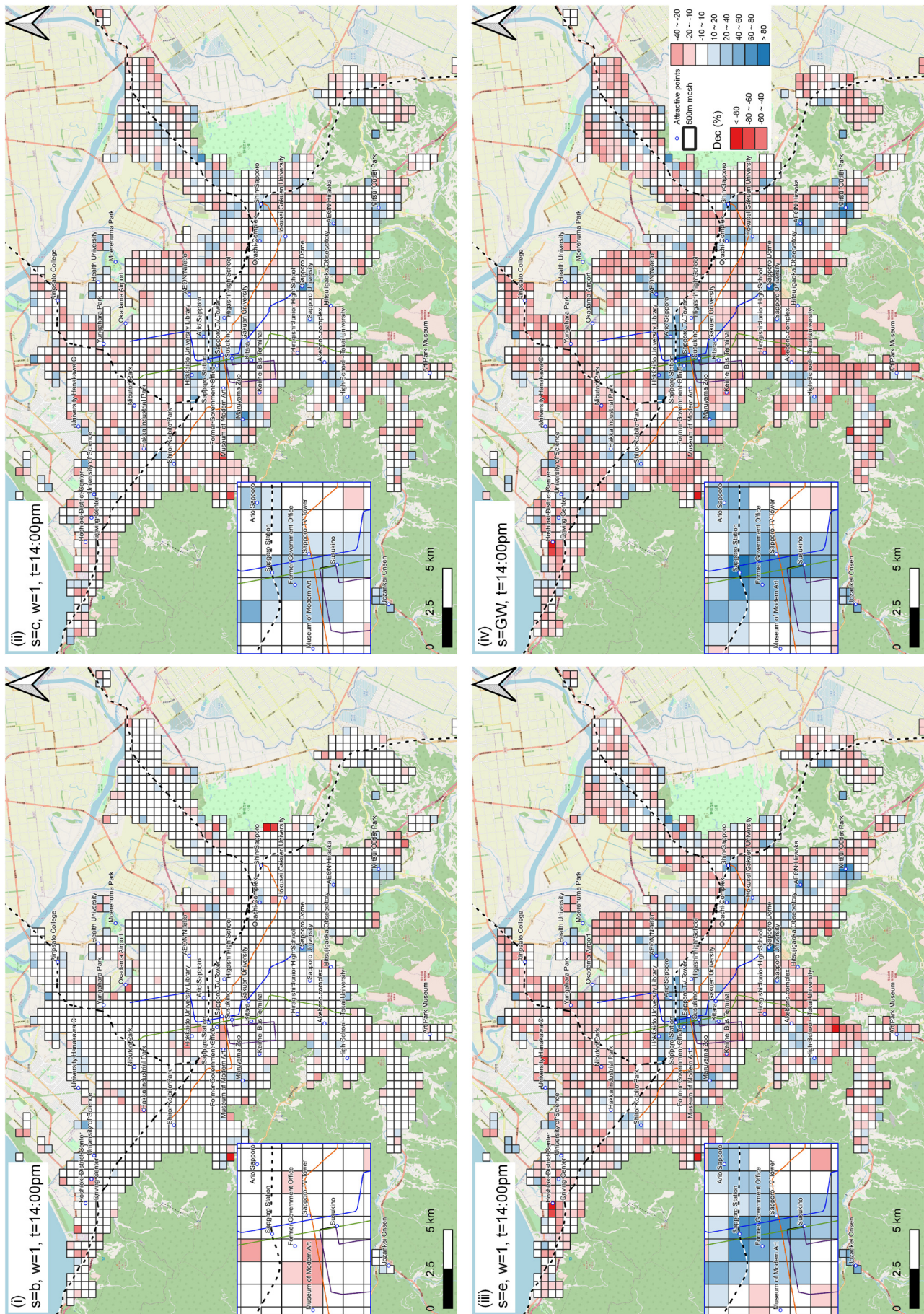


Fig. 8. Decrease in population concentration on holidays during the day (14:00) in the periods before ED (i) and during the first ED (ii), second ED (iii), and GW (iv).

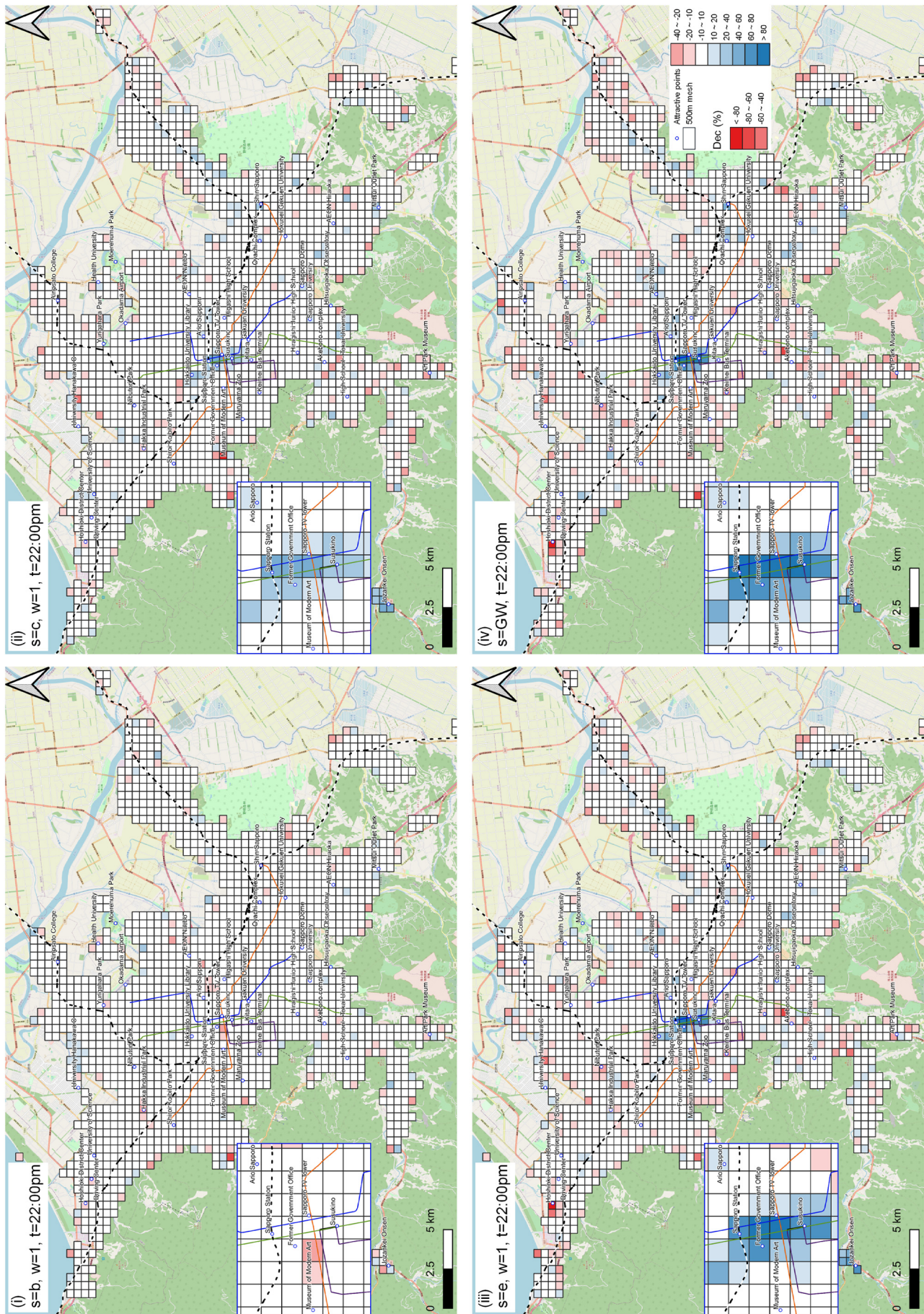


Fig. 9. Decrease in population concentration on holidays at night-time (22:00) in the periods before ED (i), second ED (ii), and GW (iv).

**Table 3**  
Summaries of population changes in Sapporo city.

Period (s)	Time of day (t)	Highest Increase (%)	Mean Increase (%)	Number increased meshes	Highest Decrease (%)	Mean Decrease (%)	Number decreased meshes
Weekday (w = 0)							
b	14:00	-42.01	-4.48	1132	64.97	3.26	562
c	14:00	-55.56	-8.67	1180	75.48	11.44	510
e	14:00	-113.74	-15.00	1250	84.98	15.07	441
b	22:00	-27.33	-3.20	849	33.74	3.19	752
c	22:00	-46.43	-4.10	932	42.32	4.79	662
e	22:00	-133.01	-6.36	1128	78.72	7.81	455
Holidays (w = 1)							
b	14:00	-145.71	-5.97	843	51.92	4.99	786
c	14:00	-77.25	-8.95	1087	75.00	10.68	528
e	14:00	-108.03	-13.21	1170	82.67	14.66	443
GW	14:00	-138.36	-14.87	1142	85.61	15.92	463
b	22:00	-67.62	-4.19	761	23.19	3.45	807
c	22:00	-97.47	-4.83	901	58.29	5.76	657
e	22:00	-149.07	-6.74	1050	82.18	7.99	510
GW	22:00	-151.62	-7.18	1043	89.37	8.21	507

Note: a – Normal time (01/13–01/31); b – Before ED (02/01–02/27); c – First ED (02/28–03/19); e – Second ED (04/17–05/01); f (GW) – Golden Week (05/02–05/06). The change in percentage compared with the normal time (a-period).

affected by the declaration of a national emergency more than the prefecture's statement.

In contrast to the census population data, which only reveals the fixed number of people at a location, the mobile spatial statistics give the dynamic population distribution over time. Using this data, we can not only understand the variation of population density by location but go further in examining the travel patterns in the city. We argue that this is one of the primary steps to determine how people move during the coronavirus pandemic. Moreover, our results can support researchers in other fields to estimate the speed of spread or to track an infection source.

Although mobile spatial statistics represent a promising method for estimating population and travel patterns, they still have some limitations that need to be handled carefully during the analysis. First, the data sets are statistics estimated by sampling. Therefore, bias may occur when a single user uses multiple mobile devices or when performing the confidential process. Secondly, children and teenagers commonly cannot make a contract with a carrier; thus, the spatial statistics cannot reveal this proportion of the population. Considering this, the NTT DOCOMO has projected the raw dataset to match the actual Fig. However, we cannot ensure this process makes the two sets exactly fit each other. We propose that practitioners and analysts can ease this problem by careful investigation, especially regarding the understanding of the data structure and the suitable research purposes. Last but not least, we recommend some materials for readers to better understand the mechanism of the mobile statistics data and its application (Ricciato et al., 2015; Steenbruggen et al., 2015; Wang et al., 2018; Wu et al., 2020; etc.).

In conclusion, the study visualizes the population density in time series, which could help policy-makers to assess the implicit risk of the locations and may make adjustments to motivate the policies' effectiveness. Besides, the study outcomes could serve as a fundamental step to analyze the travel behavior within, pre- and post-Covid-19 pandemic. Regarding the method, mobile spatial statistics have a promising application in disaster prevention and mitigation. In the long term, the resident density and mobility pattern will support assessing the influence of disasters on the community and creating prevention strategies. In the short term, identifying and estimating the people stuck in locations may help to create effective rescue plans. This is meaningful for countries that are facing many natural disasters (e.g., earthquakes, tsunamis, typhoons), like Japan.

#### CRedit authorship contribution statement

**Mikiharu Arimura:** Project administration, Supervision, Conceptualization, Data curation, Funding acquisition, Methodology, Resources,

Validation, Writing - review & editing. **Tran Vinh Ha:** Visualization, Conceptualization, Validation, Investigation, Writing - original draft, Writing - review & editing. **Kota Okumura:** Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization. **Takumi Asada:** Conceptualization, Investigation, Methodology, Software, Supervision, Validation, Writing - review & editing.

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#### Declaration of competing interest

None.

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