Thermal Environment of the Saga Castle Moat and Effect of Thermal Mitigation of Aquatic Plants

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Abstract

Many studies about urban thermal environment in large cities have been done, but few of them in small City, such as Saga city, Japan, have been done. There are castle moats and huge waterway system including rice fields in Saga City, Japan. The waterways in rural areas of Saga City have much water, but that in the urban area, especially residential area has less water and very slow flow rate. Generally heat capacity of water is larger than that of ground. Therefore, the moat and waterways, which have less water flow, store thermal energy from solar radiation during daytime and release that to air above water surface at night. An urban waterway, which has low flow rate, has been considered to give no impact to urban climate in the past studies, but the castle moats and the waterways, which have low flow rate, are considered to affect urban climate in this study. This paper describes the measurement results of air temperature distribution of the moat of Saga castle and surrounding area in both summer and winter. Incidentally, lotuses are increasing by a vegetation recovery in the south moat of Saga castle from 2011. Water chestnut also began to grow thickly as the secondary effect. This paper also describes the survey and the experimental result about the water temperature rise inhibiting effect of the moat by these aquatic plants.

Keywords: Urban climate, Heat capacity of water, Thermal effect of river and castle moat on surrounding air, Control of water temperature by aquatic plant

1. INTRODUCTION

The Saga castle moat is an important historical heritage of Saga city, has been widely familiar to the citizen. In addition, it has a role of tourism as a source of Saga, and it is required to provide a good landscape. Although many lotuses grew in the moat previously, they were wiped out in 2007 by predation of alien species. Then, the alien species are cleaned by a lotus recovery project in March 2010, and the possibility of lotus regrowth and the overgrowth of water chestnut have been found in a part of the moat.

In our past study, the air temperature above the downstream from the castle moat flow without aquatic plants is higher than that in elsewhere. Therefore, the downstream from the castle moat, whose water temperature is higher than the surrounding, is considered to prevent the air temperature drop of the surrounding area. If the water temperature is higher than the air temperature, it is pointed out in the past study that air temperature of the downstream becomes higher than that of surrounding. The reason of high temperature of water, the

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Figure 1: The southern castle moat

Figure 2: Regrown lotuses in the moat

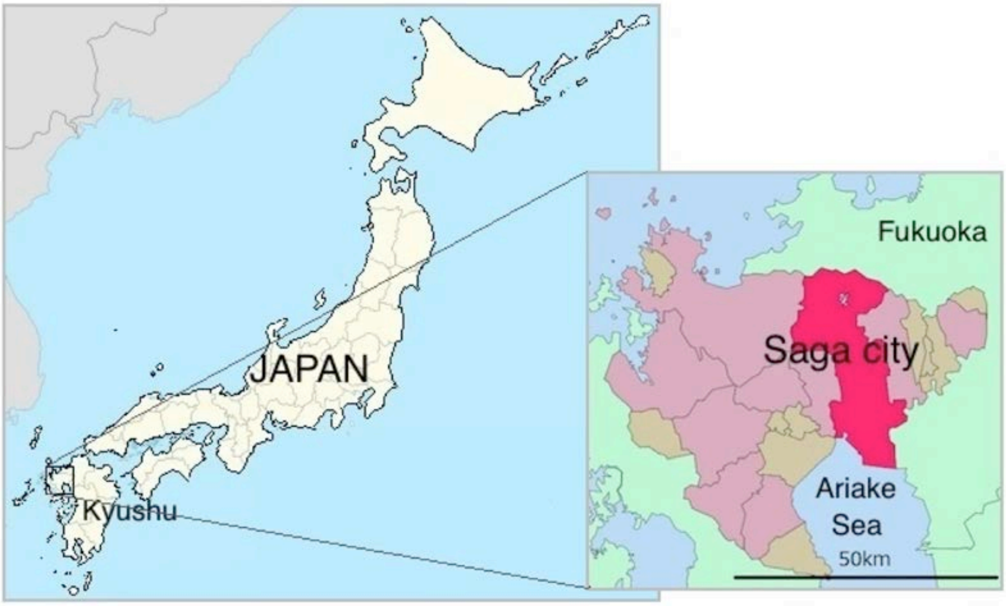

Figure 3: The location of Saga City

stagnant water absorbs the solar radiation during daytime.

However, according to a survey in summer of 2012, the local water temperature and air temperature were lower than before 2010. It is supposed that the regrowth of the aquatic plant influenced this phenomenon. In this paper, control of water temperature rise in summer by aquatic plants and Improvement of thermal environment in the region are verified by experiment and measurement.

2. MEASUREMENT OF THERMAL ENVIRONMENT IN SOUTHERN URBAN AREA OF SAGA CITY

2.1 Geographical Characteristic of Saga City

Figure 3 shows the location of Saga city. Saga city is a capital of Saga prefecture, located in northern Kyushu Island, Japan. The area of the city is 431.42km^2, and the population is about 235,995 on August 2013. The northern half of the city contains the Sefuri Mountains,

Table 1: Measurement date and instruments

Measurement items:	Air and water surface temperature
Measuring instruments:	Air temp. : TR-52(T AND D) Water surface temp. : Infrared thermometer IR-TE(CHINO)
Duration :	Sep. 3rd, 2009, 2:00a.m.～4:00a.m. Feb. 5th, 2011, 2:00a.m.～4:00a.m. Aug. 9th, 2012, 2:00a.m.～4:00a.m.
Measuring method:	Mobile measurement by bicycles (stay for 2 seconds at each measuring point)
Number of measuring points:	100 points

Figure 4: Measurement points in the southern urban area

and the southern half contains large lowland area at an altitude bellow 100m, bordered by the Ariake Sea to the south. The center of the city is about 8km far from the Ariake Sea which is a gulf having the biggest tideland in Japan. The city has a very long waterway system, which is the total length 2000km approximately. It is hot and humid in summer in Saga city because water vapor is generated from tideland and waterways.

2.2 Measurement Areas and Periods

In this section the effects of the presence of the castle moat and waterways on the air temperature distribution. Table 1 shows the measurement date and instruments. The winter measurement period in southern urban area is February 5th., 2009 and the summer measurement dates are September 3rd , 2011 and August 9th, 2012.

Figure 4 shows the measurement points in the southern urban area. Measurement method is similar to the previous measurement of urban area. In this measurement air temperature, water temperature of the castle moats and waterways were measured at every measurement point, if possible. Measuring area around the “Jonai” district of Saga city was 1.5km × 1.5km allocated evenly dividing the small measurement area of 100.

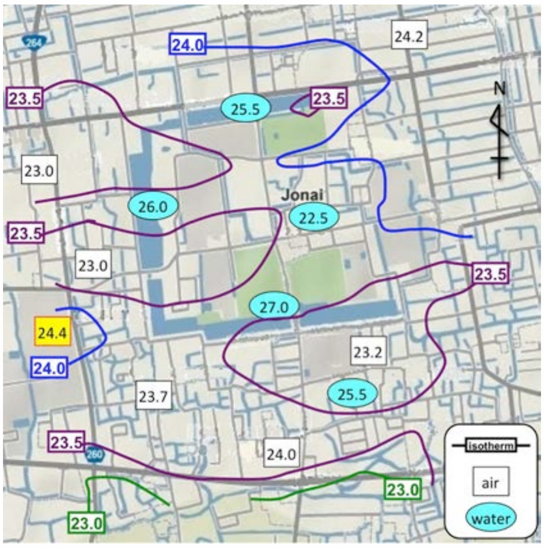

Figure 5: Temperature distribution in southern urban area on Sep. 3rd, 2009

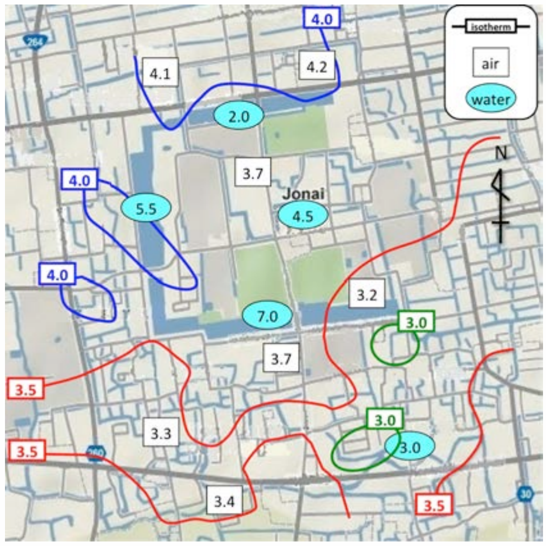

Figure 6: Temperature distribution in southern urban area on Feb. 5th, 2011

2.3 Measurement Result of Southern Urban Area in Summer 2009

Figure 5 shows the temperature distribution on the southern urban area measurement at midnight on September 3rd 2009 by isotherm. Here are some values of the measured air and water temperatures in the figure. The highest temperature 24.4℃ was measured at the residential area where is located at the west side of the west moat, and the lowest temperature 23.0℃ was measured in the most southern area and elsewhere thus the temperature difference between the highest and the lowest was 1.4℃.

The water temperature of the waterways, which were not flowed from the moat, was 22.5℃. On the other hand the temperatures of the moat and the downstream waterways were around 26℃, which is higher than the surrounding air temperature.

The air temperatures in the northeastern business area with many shops were more than 24℃. Meanwhile, the air temperatures in the southwest residential area were also around 24℃. It is considered the heat released from the hotter waterways to the air, so the air temperatures rose in the southern residential area.

2.4 Measurement Result of Southern Urban Area in Winter 2011

Figure 6 shows the temperature distribution on the southern urban area measurement at midnight on February 5th 2011 by isotherm. Here are some values of the measured air and water temperatures in the figure. The highest temperature 4.3℃ was measured at the commercial area where is closest to downtown, and the lowest temperature 2.8℃ was measured in the most southern area, thus the temperature difference between the highest and the lowest was 1.5 ℃. The following can be said as the overall trend of temperature distribution in the southern urban area. The isotherms were extended east-west direction, and the air temperature was lower in the south than in the north.

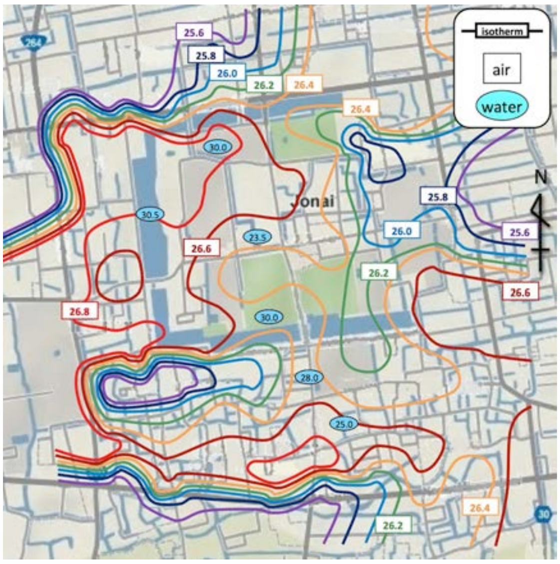

Figure 7: Temperature distribution in southern urban area on Aug. 9th, 2012

In the area that includes the Saga Castle Park and the west and south moat, the air temperature was higher than the southern residential area of south moat downstream, because the air was heated by warmer water of the castle moats.

Meanwhile, the area in the lowest temperature in the measurement is the middle area in the southern residential area, where the air temperature was lower than the surrounding. The area was not cooled especially but the surrounding is heated by warmer water of the castle moats, the commercial facilities and traffic from major road, so the temperature of the area was relatively lower than surrounding.

The water temperatures of the north moat, the west moat and the south moat were 2.0℃, 5.5℃ and 7.0℃, respectively. In addition, the water temperature of the downstream in the southern residential area is similar to that of the south moat. But water volume of the downstream waterways is very few in winter, so it couldn't heat surrounding air.

2.5 Measurement Result of Southern Urban Area in Summer 2012

Figure 7 shows air and water surface temperature transitions on Aug. 9th. The higher temperature area spread at north and west moats. As the reason for high temperature of these areas, it is conceivable that the effect of anthropogenic heat and heat storage by concrete and asphalt. Although air temperature surrounding the south moat is lower than other regions, the southern area of the south moat is a higher-temperature region. It is considered the heat released from the hotter waterways to the air, so the air temperature drop of the surrounding area was prevented.

Incidentally, the water temperature of downstream of south moat was about 5˚C lower than that of south moat. This temperature difference is greater than that in summer 2009. In addition, the water temperature of downstream of south moat was lower than the air temperature of surrounding air. This result is opposite to that in summer 2009. The difference

Table 2: Measurement period and instruments

Measurement items:	Air and water temperature, humidity
Measuring instruments :	Water temp. :　TR-52S (T AND D) Air temp. and humidity：TR-74Ui(T AND D)
Period:	Aug. 7th – Sep. 9th, 2012
Measuring method :	Measuring by the instruments set on the Styrofoam board floating on the moat and the river
Number of measuring points :	7 points

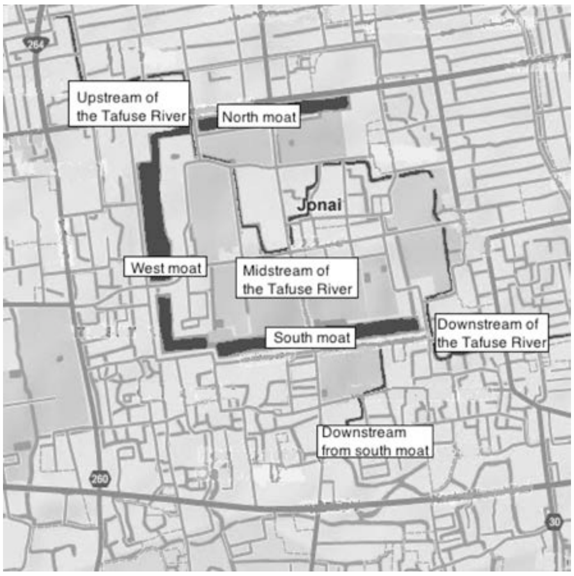

Figure 8: Measurement points of the castle moat and the river

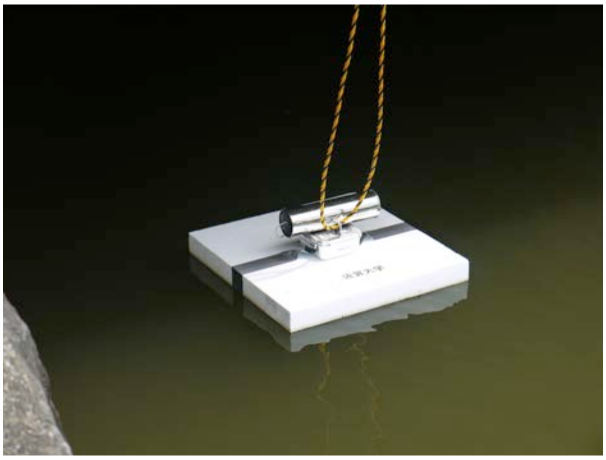

Figure 9: Measurement situation of water and air temperature

in the situation of the south moat in 2009 and 2012 is that the overgrowth of the water chestnut since 2011. In the next section, measured water and air temperature transitions in 2012 are examined.

3. FIXED POINT OBSERVATION IN MOAT AND SURROUNDING

3.1 Measurement Method

The tendency of the water and air temperature transition of the castle moat and the river is grasped by the fixed-point observation at the castle moats and the Tafuse River, which is the local major river in the castle area. Table 2 shows the measurement period and the instruments, and Figure 8 shows the measurement points. The measurement points of water and air temperature are seven places, which are the north, the west and the south moats of the Saga Castle and the downstream waterway from the south moat and the upstream, the midstream and the downstream of the Tafuse River.

Figure 9 shows the measurement situation as an example. Temperature and humidity sensors are housed in a metal cylinder of 6cm in length and 22cm in diameter. Temperature and humidity sensors were housed in the metal cylinder of 6cm in length and 22cm in

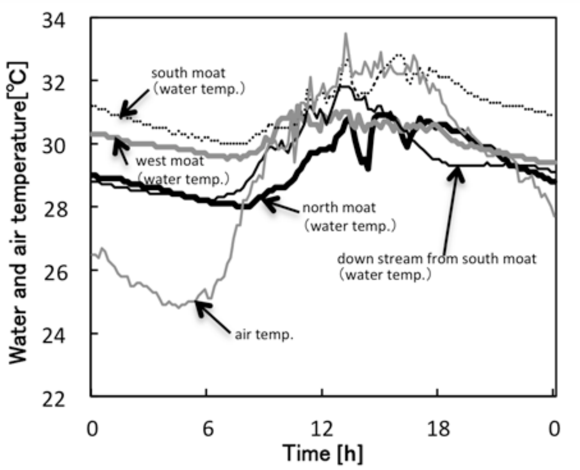

Figure 10: Water and air temperature transition of The Saga castle moat (Aug. 21st)

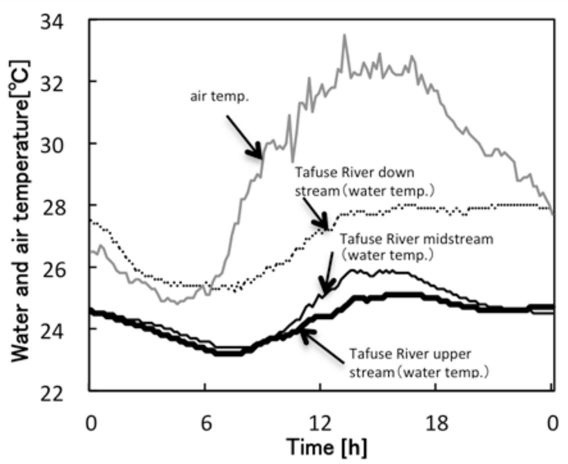

Figure 11: Water and air temperature transition of the Tafuse River (Aug. 21st)

Figure 12: Exuberant water chestnut in the east area of south moat

diameter that both ends are opened to shut out solar radiation and the long wave radiation. The water temperature sensors were installed so that the sensor tip measured the water temperature of the position of depth of approximately 5cm. In addition, these measuring instruments were installed to be located under the bridge to prevent from being exposed to direct solar radiation as possible.

3.2 Measurement Results

Figure 10 and figure 11 shows the transition of the measured water temperature of the Saga Castle moat and the Tafuse River and air temperature measured at the local meteorological observatory Saga on August 21st. From a comparison between figure 10 and figure 11, water temperature of the Tafuse River is lower than that of the Saga Castle moat. It is the reason that low temperature water flows from the upper stream in the Tafuse River, because the flow rate of the Tafuse River is faster than that of the Saga Castle moat.

It is considered that heat is released into the air from the water surface in the Saga Castle moat, because water temperature of the castle moat is higher than air temperature at night.

Table 3: Experiment for thermal mitigation by aquatic plants

Measurement items:	Water temperature, Air temperature, Solar irradiance
Measuring instruments:	Water temp. : RTR-71 (T AND D) Air temp. : TR-74Ui (T AND D) Solar irradiance: pyrometer ML-020VM (EKO Instruments) with Voltage logger LR5041 (HIOKI)
Period:	Aug.20th – Oct. 20th, 2012
Measuring method:	Cultivating aquatic plants in the water trough bottle filled with water. Comparing water temperature transition under solar radiation exposure.
Location:	Rooftop place on the Faculty of Science and Engineering Building 3 in Saga Univ.

In addition, the water temperature has risen to order upstream, midstream, downstream of both the Tafuse River and the Saga Castle moat. However, according to comparing the downstream from the south moat and the south moat, the water temperature of the downstream from the south moat is lower than that of the south moat. There was a luxuriant water chestnut between the measuring point and the measurement point downstream south moat south during the measurement period. Water temperature of this area is reduced by this water chestnut, there is a possibility that the low temperature water flowed into the downstream from the south moat. Figure 12 shows that the water chestnut grew thick in the south moat. Looking divided into east and west area by the bridge in the middle of the south moat, all the water surface of the east side of the south moat was almost covered by the luxuriant water chestnut. In this measurement, since the water temperature sensor was installed under the bridge of the center of the south moat, water temperature just before flowing into the water chestnut community of the east side of the central bridge was measured. Therefore, it was necessary to establish the measurement point in the downstream side of the water chestnut community to inspect cooling effect by the water chestnut.

4. EXPERIMENT OF WATER TEMPERATURE RISE INHIBITING EFFECT BY AQUATIC PLANTS

4.1 Experimental Method

It is expectable to control the water temperature rise due to receive solar radiation by aquatic plants covering the water surface. In this experiment, three kinds of aquatic plants are grown not in an actual moat or a waterway but in the larger container that filled water. Water temperature rise inhibiting effect is inspected according to the kind of the aquatic plant by comparing the water temperature change when the water is exposed to solar radiation and air.

Table 3 shows the measurement instruments and conditions. The water temperature change in the container which grew the water chestnut, the brazilian elodea, and the prickly water lily individually on the roof place of the faculty of science and engineering building 3,

Figure 13: Water chestnut
(Floating-leaved plant, Indigenous species)

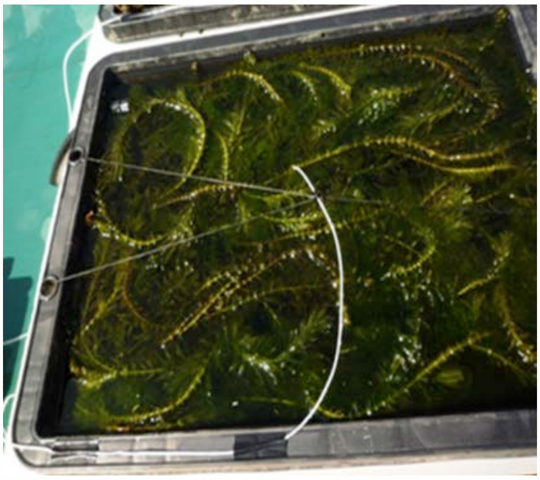

Figure 14: Brazilian elodea
(Submerged plant, Alien species)

Figure 15: Prickly water lily
(Floating-leaved plant, Indigenous species)

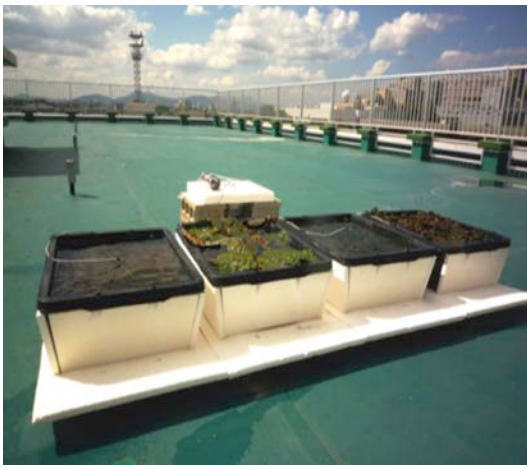

Figure 16: Experimental situation

Saga University, respectively, and the container into which no aquatic plants is observed.

Table 3 shows the experimental method and instruments. The containers that were used for the cultivation of aquatic plants are water trough bottles (length 190 mm × depth 455mm × width 600mm), which were insulated with foam of 200 mm in thickness. Soil was laid in the water trough bottles, which are filled water. Aquatic plants are planted in these containers.

All the aquatic plants used in this experiment are plants, which grow wild in Saga city. Moreover, since cultivation was slightly difficult for the lotus described at the introduction of this paper, it was excluded from this experiment. Figure 13-15 show three aquatic plants used in the experiment. In addition, Figure 16 shows the experiment situation on the roof place.

4.2 Measurement Results

Figure 17 shows the change of the water temperature in the case of all plants and no

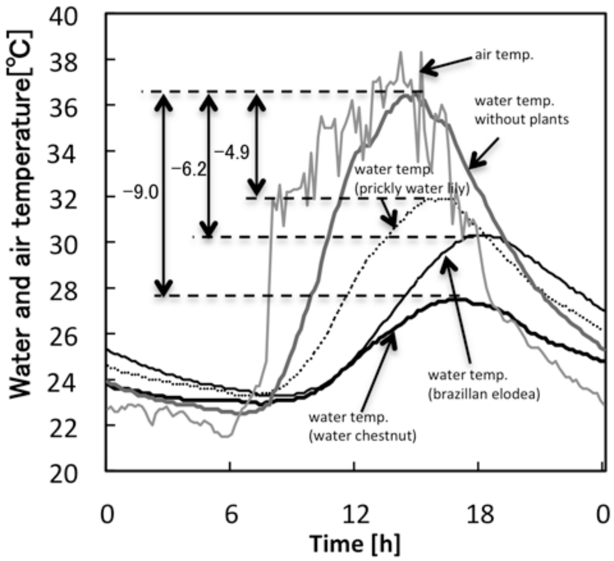

Figure 17: Water temperature transition of each aquatic plant (Sep. 12th,2012)

plants September 12. The water temperature in the case of no plants was higher among the four cases, and it was more than 36 ℃ on this day. In addition, the water temperature of the case of no plant was the lowest at night. It was lower about 9℃ than the temperature other case of no plants, and always remained at the lowest temperature in the four cases during the day. The water temperatures of the cases of brazilian elodea and of prickly water lily were also lower than that of the case of no plants. The temperature difference between brazilian elodea and no plants was 6.2℃ and that between prickly water lily and no plants was 4.9℃. Water temperature changed with difference due to the kinds of plants. The mechanism, which caused these differences, could not be determined by this experiment.

5. CONCLUSIONS

The control of water temperature rise of the castle moat in summer by aquatic plants was verified by the field measurement and the outdoor experiment in this paper. On the field measurement, it was shown that water chestnut community reduced water temperature of the south moat and lower temperature water inhibited air temperature rise in the area of downstream. On the outdoor experiment, it was also shown that water chestnut reduced water temperature best in three kinds of aquatic plants. Since the mechanism that water chestnut reduces water temperature is unknown, so that is our further subject to be solved.

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