Microclimate in the Fields with Cycas Hedges in Amami Oshima, Japan

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Abstract

In the Amami Islands, an original culture has been created and is still maintained. This study focused on the fields with Cycas hedges called “Sotetsu-Bate”, which means “fields with Cycas hedges”, in the Amami Islands. Sotetsu-Bate had established as a locality and specific cultural landscape, in order to protect farm products from wind and seawater. The objective of the present study is to clarify the effects of Cycas hedges on the thermal environment in the fields. Field observations of air temperature, humidity, wind direction, wind velocity, and solar and long-wave radiation were carried out in and around the fields with Cycas hedges in the Kasari area, Amami City, Amami-Oshima.

In summer and winter, the wind reducing effect of Cycas hedges appeared in the field with Cycas hedges, and it is an effective countermeasure against damage of strong wind and seawater. The wind reducing effect of Cycas hedges against seasonal wind is particularly significant. It is cleared that wind velocity in the field with Cycas hedges was decreased with about 20% of that at the sandy shore, on average. The wind reducing effect of Cycas hedges did not appear clearly at observation points on the north-south main road, compared with the results of observation points in the field with Cycas hedges. This north-south main road was narrower in the old days. It is considered that the wind reducing effect in the fields with Cycas hedges was decreased by road extension.

In winter and in the early morning of summer, the difference in air temperature, vapor pressure, and relative humidity in the observation site was small. In the daytime of summer, air temperature at observation points in the fields with Cycas hedges was higher than that at the sandy shore in many cases. It is considered that the outdoor sensible temperature formed in the fields with Cycas hedges is very hot and dangerous for human health in the daytime of summer because the air temperature is high and wind velocity is calm or very light. It is advisable to eschew a work in the fields with Cycas hedges in the daytime of summer.

Keywords: wind reducing effect, wind velocity, seasonal wind, sea breeze, fields with Cycas hedges

1. Introduction

Windbreaks planted around the farmhouse are one of the most important landscape elements in rural areas in Japan, and they are explained as the environmental design method developed to adapt to the local climate in each area over many years. In the 1930s, for example, the distribution of windbreak was investigated in the suburbs of Tokyo, Japan, and the relationship between the layout of the windbreak and the prevailing wind direction was clarified (Yazawa, 1936I; Yazawa 1936II; Ito 1939I; Ito 1939II). Horikoshi et al. (1990) studied changes in the landscape and dwellings with

windbreaks along the coast of Enshu, Japan. Sekiguti (1950) mentioned that hedges of tall trees are planted for a windbreak in front of a sort of wooden cover constructed on the gable wall in the Ina valley, Nagano Prefecture, Japan. Effects of windbreak around a farmhouse on the outdoor thermal environment were observed in mainly focused on the wind reducing effect in winter. For example, Furukawa et al. (1997, 1998) focused on the windbreak in Okinawa folkhouses, and they study on the wind reducing effect of windbreak by the measure of wind speed and wind tunnel tests. Recently, in the midst of advancing urban heat island

and global warming, there has been a renewal of interest in the cooling effect of windbreak in summer. For example, He et al. (2009) focused on the windbreak in the Tonami Plain, and they analyzed the microclimate effect in the summer of a windbreak based on field measurements and numerical simulation results. Natsume (2019) focused on the woodland in Kichijoji village which was a typical “shinden” (new field) settlement, and wind condition was analyzed based on a 3D reconstruction of the landscapes in early modern Japan.

These studies were concerned with windbreaks surrounding residences. On the other hand, windbreaks planted for the protection of cultivated land are also important rural landscapes. To take one example of many, large grids of trees as the windbreak for cultivated land was established in Hokkaido, Japan. Torita et al. (2007) studies on the wind reducing effect of windbreak for cultivated land in the Ishikari Plain in the central part of Hokkaido. Tsuji et al. (2005) reported the effectiveness of windbreaks for prevention storm damage in the Tokachi Region. In addition, windbreak for cultivated land is a large influence not only on the thermal environment but also on the growth and the yield of farm products is large (Burke, 1998; Nuberg, 1998).

Although a large number of studies has been made on windbreaks, there are ever so many more other important regional landscape of windbreaks in Japan. In the Amami Islands, an original culture has been created and is still maintained. In this study, we focused on *Cycas* (*Cycas revolute*) hedges planted for the protection of cultivated land in the Amami Islands. They are called “Sotetsu-Bate”. Sotetsu-Bate, which means “fields with *Cycas* hedges”, had established as a locality and specific cultural landscape, in order to protect farm products from wind and seawater. The objective of the present study is to clarify the effects of *Cycas* hedges on the thermal environment in the fields. Climatic conditions were observed in the fields with *Cycas* hedges in summer and in winter.

2. Method

Figure 1 shows the location of the Amami Oshima. The Amami Islands including Amami Oshima is an archipelago which is located in southwest of Japan. Aerial photographs show that there were fields with *Cycas* hedges in various parts of Amami Oshima in the 1940s, and most of them were terraced fields on slopes. Those fields have been abandoned, probably because they were inconvenient and difficult to mechanize the works and expand. At the present time in Amami Oshima, except a small field, there are only two fields with *Cycas* hedges, in the Kasari area and the Kominato area, Amami City. The fields with *Cycas* hedges in the Kasari area were selected as the object of this study.

Figure 1. Location of Amami Oshima

Figure 2. Location of Sotetsu-Bate in the Kasari area

Figure 2 shows the location of Sotetsu-Bate in the Kasari area. We considered that Sotetsu-Bate in the Kasari area is adequate to clarify the effect of the sea breeze in summer and the seasonal north wind in winter on the thermal environment in fields with *Cycas* hedges because they are located in the coastal area of northern Amami Oshima.

Figure 3 shows the aerial photograph of observation site. The object is located along the beach, and the fields are surrounded by *Cycas* hedges. *Cycas* hedges were planted along the border of fields (Figure 4). The major height of *Cycas* hedges is approximately 2-3m and maximizing *Cycas* hedge height is about 6m (Fuwa et al., 2014). In addition, windbreaks of *Pandanus odoratissimus* were planted along the coast (Figure 5). Sotetsu-Bate in the Kasari area are mainly planted with sugar cane (about 40%), with other crops such as onions, sweet potatoes, and garlic (Fuwa et al., 2014). Figure 6 shows the topography of the observation site. The neighborhood of the observation area is the field, and there are no houses or high-rise buildings in the area. The east side of the observation area is a

Figure 3. Aerial photograph of observation site (Geospatial Information Authority of Japan, 2008)

Figure 4. Field with Cycas hedges called “Sotetsu-Bate”

continuous coastline, with north-south main road along the coast. There is a hilly area in the west side of the observation site.

Observation days and times are shown in Table 1. The observation of climatic conditions has been carried out in summer and in winter. Field observations in summer were carried out on September 5th and 6th, 2013. Field observations in winter were carried out on February 14th and 15th, 2014. Climatic conditions

Figure 5. Coastal windbreaks of *Pandanus odoratissimus*

Figure 6. Topography of the observation site

were observed mainly in the daytime. On September 6th and February 15th, climatic conditions were also observed early in the morning. Figure 7 shows the observation site and points. Air temperature, humidity, wind direction, and wind velocity were observed at each observation point in or around the fields with Cycas hedges in the Kasari area. Air temperature and humidity were observed at a height of 0.9m by Assmann's ventilated aspiration psychrometer (54-EC,

Table 1. Observation days and times

Observation days	The start time of moving observation	Fixed observation point	Mobile observation points
September 5, 2013	15:00, 17:00	Observation point 22	Observation points 1 - 21
September 6, 2013	6:00, 10:00, 13:00, 15:00, 17:00	Observation point 22	Observation points 1 - 21
February 14, 2014	10:00, 15:00	Observation point 23	Observation points 1 - 21
February 15, 2014	6:30, 10:00, 13:00, 15:00, 16:00	Observation point 23	Observation points 1 - 21

Ota Keiki Seisakusho). Wind direction and velocity were observed at a height of 1.3m by Byram anemometer with wind vanes (Ando Keiki). These climatic conditions were measured at 1 fixed observation point and 21 mobile observation points. Five routes were set up for mobile observations, one observer was assigned to each observation rout and the fixed point. The fixed point was set up at the observation point 22 in the summer of 2013. The fixed point was set up at the observation point 23 in the winter of 2014 because the sugar cane was grown around the observation point 22 at that time. The observation point 10 was located on the sandy shore. The time correction was applied to the air temperature data and humidity data of the mobile observation using the data of fixed observation. It took about 20-30 minutes to make each observation.

In light of the results of the above study, field observation of air temperature, humidity, wind velocity, and solar and long-wave radiation were carried out on September 7th in 2016 from 14:00 to 15:00 and 17:00 to 18:00 at observation points A, B, C, and D. The observation point A was located in a sunlit field with *Cycas* hedges. The observation point B was located in a shaded field with *Cycas* hedges. The observation point C was located on the sandy shore. The observation point D was located on the north-south main road in the fields with *Cycas* hedges. The observation equipment of air temperature, humidity, wind direction, and wind velocity were the same as above. These climatic conditions were measured every 10 minutes at each observation point. Solar and long-wave radiation were observed at a height of 1.3m by the 4-component net radiometer (NR01, Hukseflux; MR-50, EKO Instruments). Data from the 4-component net radiometer were recorded every 1 minute, and averaged over 3 minutes. The UTCI (Universal Thermal Climate Index) (Bröde 2012) was calculated by these climatic conditions. The UTCI is a thermal index which is used to predict human health and comfort from climatic data. The UTCI is defined as the air temperature of the reference environment to give the same thermal strain as the actual environment. The reference environment is 50% rh, with calm air and radiant temperature equal to air temperature.

3. Results

3.1. Results in summer

Figure 8 shows changes in air temperature, water vapor pressure, and solar radiation at AMeDAS Kasari Station and Naze Meteorological Observatory on September 5th and 6th, 2013. The daily maximum air temperature was higher than 30 °C at Naze Meteorological Observatory, and that was lower than 30 °C at AMeDAS Kasari Station. Table 2 and 3 show changes in wind conditions at AMeDAS Kasari Station and weather at Naze Meteorological Observatory on

September 5th and 6th, 2013. On September 5th, winds mainly came from east-northeast and east in the daytime. On September 6th, winds mainly came from between east and south in the daytime. These were

Figure 7. Observation site and points
(Created based upon data from Fuwa et al., 2014)

Figure 8. Changes in air temperature, water vapor pressure, and solar radiation at AMeDAS Kasari Station and Naze Meteorological Observatory on September 5 and 6, 2013

sunny days. At Naze Meteorological Observatory, the normal daily maximum temperature in September is 30.2 °C. The observation period was probably in the climatic conditions of September.

Table 2. Changes in wind conditions at AMeDAS Kasari Station and weather at Naze Meteorological Observatory (September 5, 2013)

Time	Wind vel. m/s (Kasari)	Wind direction (Kasari)	Weather (Naze)
1:00	3.8	N	
2:00	2.5	NNW	
3:00	2.6	NNW	Sunny
4:00	2.2	N	
5:00	2.0	NW	
6:00	2.5	NW	Sunny
7:00	1.7	NW	
8:00	2.7	NNW	
9:00	2.6	NNW	Sunny
10:00	2.2	NE	
11:00	3.7	ENE	
12:00	3.2	ENE	Sunny
13:00	2.9	ENE	
14:00	2.6	E	
15:00	2.3	E	Sunny
16:00	1.8	E	
17:00	1.5	E	
18:00	1.7	E	Very sunny
19:00	1.3	E	
20:00	1.9	ENE	
21:00	5.4	E	Sunny
22:00	6.8	E	
23:00	3.0	ESE	
24:00	1.3	W	

Table 3. Changes in wind conditions at AMeDAS Kasari Station and weather at Naze Meteorological Observatory (September 6, 2013)

Time	Wind vel. m/s (Kasari)	Wind direction (Kasari)	Weather (Naze)
1:00	1.6	WSW	
2:00	2.5	WSW	
3:00	1.4	W	Very sunny
4:00	1.4	N	
5:00	0.5	NNW	
6:00	2.0	NW	Sunny
7:00	1.9	NW	
8:00	0.7	NNW	
9:00	1.1	E	Sunny
10:00	1.3	SE	
11:00	2.0	E	
12:00	1.7	SE	Sunny
13:00	2.5	S	
14:00	2.8	SSW	
15:00	3.3	S	Sunny
16:00	3.2	S	
17:00	3.1	S	
18:00	3.1	S	Sunny
19:00	3.2	SSW	
20:00	2.8	S	
21:00	0.4	W	Sunny
22:00	0.5	W	
23:00	1.8	NW	
24:00	1.8	NW

Figure 9. Results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 13:00 on September 6, 2013

south-southeast and east-southeast. At the observation point 10 where located on the sandy shore, the sea breeze from the southeast was blowing at a speed of 3.4 m/s. At observation points 1, 4, 5, 11, and 15, wind velocity was weaker than 0.5 m/s. These observation points were located in the field with *Cycas* hedges. At observation points 1, 4, 5, 6, 7, 9, 11, and 12, the air temperature was higher than 31.0 °C. At the observation point 13, the air temperature was lower than 30.0 °C. At observation points 5, 8, 18, and 21, water vapor pressure was higher than 33.0 hPa. At observation points 16 and 20, water vapor pressure was lower than 29.0 hPa. The relative humidity was from 60% to 75% at most of observation points. At observation points 8, 13, 18, and 21, relative humidity was higher than 75%.

Figure 10 shows results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 15:00 on September 6th, 2013. Winds mainly came from between south-southeast and east-southeast. At the observation point 10, the sea breeze from southeast was blowing at a speed of 3.5 m/s. At observation points 1, 5, and 11, wind velocity was weaker than 0.5 m/s. These observation points were located in the field with *Cycas* hedges. At observation points 1, 6, 11, 12, and 19, air temperature was higher than 31.0 °C. At observation points 5, 13, 17, and 22, air temperature was lower than 30.0 °C. Compared with results at 13:00, air temperature at observation points 4, 5, 9, and 17 were more than 1.0 °C lower, and air temperature at the observation point 19 was more than 1.0 °C higher. At observation points

11 and 12, water vapor pressure was higher than 29.0 hPa. At observation points 2, 4, 19, and 20, water vapor pressure was lower than 24.0 hPa. The relative humidity was from 50% to 65% at most of observation points. At observation points 10 and 13, relative humidity was higher than 65%. At the observation point 19, relative humidity was lower than 50%.

Figure 11 shows results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 6:00 on September 6th, 2013. The wind was calm or blowing at less than or equal to 0.5 m/s, except at observation points 19 and 20. At the observation point 19 where located on the west part of the observation site, west wind at a speed of 1.3 m/s was observed. The air temperature difference, the water vapor pressure difference, and the relative humidity difference in the observation site were small, compared with the results in the daytime. At observation points 10, 19, 20, and 21, air temperature was higher than 24.0 °C. These observation points were located outside of the field with *Cycas* hedges.

Figure 12 shows changes in air temperature, water vapor pressure, relative humidity, wind velocity, and solar radiation on September 7th, 2016. The air temperature between 14:00 and 15:00 was relatively high at observation points A in the sunlit field with *Cycas* hedges and C on the sandy shore, and relatively low at the observation point B in the shaded field with *Cycas* hedges. The air temperature between 17:00 and 18:00 was relatively high at observation points C on the sandy

Figure 10. Results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 15:00 on September 6, 2013

Missing data : Air temperature, water vapor pressure and relative humidity at the observation point 3

Figure 11. Results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 6:00 on September 6, 2013

Figure 12. Changes in air temperature, water vapor pressure, relative humidity, wind velocity, and solar radiation on September 7, 2016

shore and D on the north-south main road in the fields with Cycas hedges, and relatively low at observation points A and B in the field with Cycas hedges. At observation points A and B in the field with Cycas hedges, water vapor pressure and relative humidity were relatively high and wind velocity was weak. Solar radiation at the observation point B in the shaded field with Cycas hedges were low.

3.2. Results in winter

Figure 13 shows changes in air temperature, water vapor pressure, and solar radiation at AMeDAS Kasari Station and Naze Meteorological Observatory on February 14th and 15th, 2014. Table 4 and 5 show changes in wind conditions at AMeDAS Kasari Station and weather at Naze Meteorological Observatory on February 14th and 15th, 2014. On February 14th, it was rainy and cloudy day, and the daily maximum air temperature was 16.6 °C at 4:00 and 5:00 at Naze Meteorological Observatory. In early morning and afternoon on February 15th, it was sunny. On February 15th, the daily maximum air temperature was 15.7 °C at 15:00 at Naze Meteorological Observatory. The seasonal wind blew from between north and northwest on both days. At Naze Meteorological Observatory, the normal daily maximum temperature in February is 18.0 °C. The observation period was probably in the climatic conditions of February.

Figure 14 shows results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 13:00 on

Figure 13. Changes in air temperature, water vapor pressure, and solar radiation at AMeDAS Kasari Station and Naze Meteorological Observatory on February 14 and 15, 2014

February 15th, 2014. Winds mainly came from between north-northeast and north-northwest. At the observation point 10 where located on the sandy shore, the

Table 4. Changes in wind conditions at AMeDAS Kasari Station and weather at Naze Meteorological Observatory (February 14, 2014)

Time	Wind vel. m/s (Kasari)	Wind direction (Kasari)	Weather (Naze)
1:00	9.3	N	
2:00	8.2	N	
3:00	9.2	N	Cloudy
4:00	9.7	NNE	
5:00	9.5	N	
6:00	8.8	NNE	Cloudy
7:00	7.5	NNE	
8:00	7.3	N	
9:00	5.7	N	Rainy
10:00	4.5	NNW	
11:00	5.6	N	
12:00	3.3	NNW	Rainy
13:00	5.0	NNW	
14:00	5.7	NNW	
15:00	4.8	NNW	Cloudy
16:00	4.9	NNW	
17:00	4.2	NW	
18:00	4.6	NNW	Rainy
19:00	6.2	NNW	
20:00	6.6	NNW	
21:00	6.9	NW	Rainy
22:00	7.1	NNW	
23:00	7.8	NNW	
24:00	7.4	NNW	

Table 5. Changes in wind conditions at AMeDAS Kasari Station and weather at Naze Meteorological Observatory (February 15, 2014)

Time	Wind vel. m/s (Kasari)	Wind direction (Kasari)	Weather (Naze)
1:00	8.0	NNW	
2:00	6.7	NNW	
3:00	7.4	NNW	Rainy
4:00	6.8	NNW	
5:00	6.9	N	
6:00	6.5	NNW	Sunny
7:00	7.0	NNW	
8:00	7.0	NNW	
9:00	6.3	NNW	Rainy
10:00	10.1	NNW	
11:00	9.6	N	
12:00	9.8	NNW	Sunny
13:00	8.6	NNW	
14:00	10.9	N	
15:00	9.5	N	Sunny
16:00	9.6	N	
17:00	9.2	N	
18:00	6.7	NNW	Sunny
19:00	8.3	N	
20:00	8.7	N	
21:00	8.9	N	Sunny
22:00	8.7	N	
23:00	8.7	N	
24:00	8.4	N

Figure 14. Results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 13:00 on February 15, 2014

seasonal wind from north was blowing at a speed of 6.3 m/s. At observation points 19, 20, and 21 where located on the northwest part of the observation site, seasonal winds from between north and north-northeast at speed of 3.6–4.7 m/s were also observed. At observation points 9, 16, and 23 where located on the north-south main road in the fields with Cycas hedges, seasonal winds from between north and north-northeast at speed of 4.2–5.3 m/s were also blowing along the road. At observation points 3, 4, 8, 11, 15, and 17, wind velocity was weaker than 1.5 m/s. These observation points were located in the field with Cycas hedges. The air temperature was from 14.5 °C to 15.5 °C at most of the observation points. At observation points 4, 10, 14, 16, and 20, the air temperature was higher than 15.5 °C. Water vapor pressure was from 8.0 hPa to 9.0 hPa at most of the observation points. At observation points 3, 8, and 15, water vapor pressure was higher than 9.0 hPa. At observation points 1, 16, 19, and 20, water vapor pressure was lower than 8.0 hPa. The relative humidity was from 45% to 55% at most of observation points. At the observation point 8, relative humidity was higher than 55%. At observation points 16 and 20, relative humidity was lower than 45%. Compared with results in the daytime of summer, the difference in air temperature, vapor pressure, and relative humidity in the observation site was small.

Figure 15 shows results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 15:00 on February 15th, 2014. Winds mainly came from between

north-northeast and north-northwest. At the observation point 10, the strong seasonal wind from north was blowing at a speed of 9.2 m/s. At observation points 19, 20, and 21 where located on the northwest part of the observation site, seasonal winds from between north and north-northeast at speed of 3.8–4.2 m/s were also observed. At observation points 9, 16, and 23 where located on the north-south main road in the fields with Cycas hedges, seasonal winds from between north-northeast and north-northwest at speed of 4.3–6.5 m/s were also blowing along the road. At observation points 3, 4, 8, 15, 17, and 18, wind velocity was weaker than 1.5 m/s. These observation points were located in the field with Cycas hedges. The air temperature was from 14.0 °C to 15.0 °C at most of the observation points. At observation points 5 and 10, air temperature was higher than 15.0 °C. Water vapor pressure was from 8.0 hPa to 9.5 hPa at most of the observation points. At the observation point 10, water vapor pressure was higher than 9.5 hPa. The relative humidity was from 50% to 60% at most of observation points. At the observation point 21, relative humidity was higher than 60%. At observation points 2, 9, and 20, relative humidity was lower than 50%. Compared with results in the daytime of summer, the difference in air temperature, vapor pressure, and relative humidity in the observation site was small.

Figure 16 shows results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 6:30 on February 15th, 2014. Winds mainly came from between north and north-northwest. At the observation point 10,

Figure 15. Results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 15:00 on February 15, 2014

Figure 16. Results of air temperature, water vapor pressure, relative humidity, wind velocity, and wind direction at each observation point at 6:30 on February 15, 2014

the seasonal wind from north was blowing at a speed of 5.3 m/s. At observation points 19, 20, and 21 where located on the northwest part of the observation site, seasonal winds from the north or northeast at speed of 3.7-5.8 m/s were also observed. At observation points 9, 16, and 23 where located on the north-south main road in the fields with Cycas hedges, seasonal winds

from between north and north-northwest at speed of 4.3-5.6 m/s were also blowing along the road. At observation points 1, 3, 4, 8, 15, and 17, wind velocity was weaker than 1.5 m/s. These observation points were located in the field with Cycas hedges. The air temperature was from 12.0 °C to 13.0 °C at most of observation points. At observation points 10, 11, 12, and 13, the air

temperature was higher than 13.0 °C. At the observation point 21, the air temperature was lower than 13.0 °C. Water vapor pressure was from 8.0 hPa to 9.5 hPa at most of the observation points. At observation points 15 and 21, water vapor pressure was higher than 9.5 hPa. At the observation point 19, water vapor pressure was lower than 8.0 hPa. The relative humidity was from 55% to 65% at most of observation points. At observation points 15 and 21, relative humidity was higher than 65%. At observation points 1 and 19, relative humidity was lower than 55%.

4. Discussion

In the daytime of summer, the sea breeze from southeast was observed at the observation point 10 located on the sandy shore. And in winter, seasonal wind from between north-northeast and north-northwest was observed at the observation point 10 located on the sandy shore and at observation points 19, 20, and 21 located on the northwest part of the observation site. The seasonal wind from between north-northeast and north-northwest was also observed at observation points 9, 16, and 23 where located on the north-south main road in winter. On the other hand, wind velocity was weak at observation points in the fields with Cycas hedges. Therefore, this paper highlighted the effect of

Cycas hedges on wind velocity. Figure 17 shows the relation between wind velocity at the observation point 10 where located on the sandy shore and that at observation points in the fields with Cycas hedges (observation points 1, 3, 5, 8, 14, and 15). The following is an overview of each of observation points in the fields with Cycas hedges. The observation point 1 was located in the smallest field with Cycas hedges facing the narrow road in the fields with Cycas hedges. The observation point 3 was located in the narrow field with Cycas hedges. The observation point 5 was surrounded by Cycas hedges on three sides. The observation point 8 was located in the almost square field surrounded by Cycas hedges on four sides. The observation point 14 was located in the almost square field with Cycas hedges facing on the north-south main road and on the narrow road to the beach. The observation point 15 was located in the field with Cycas hedges facing on the narrow road to the beach. The wind reducing effect of Cycas hedges appeared in each observation point. At observation points 3, 8, and 15, the protecting effect of Cycas hedges against seasonal wind and sea breeze was observed more clearly, and wind velocity at these observation points were weaker than 1.5 m/s. At observation points 1, 5, and 14, wind velocity in the field with Cycas hedges was decreased with 20-30% of that

Figure 17. Relation between wind velocity at the observation point 10 and that at observation points in the fields with Cycas hedges (observation points 1, 3, 5, 8, 14, and 15)

Figure 18. Relation between wind velocity at the observation point 10 and that at observation points in the field with *Cycas* hedges and coastal windbreaks of *Pandanus odoratissimus* (observation points 12 and 13)

on the sandy shore. The observation point 1 was located in the field faced north-south narrow road, the observation point 14 was located in the field faced north-south main road, and the west side of the observation point 5 was not covered with hedges, therefore weak seasonal wind entered these observation points. Figure 18 shows the relation between wind velocity at the observation point 10 and that at observation points in the field with *Cycas* hedges and coastal windbreaks of *Pandanus odoratissimus* (observation points 12 and 13). The wind reducing effect of *Cycas* hedges and coastal windbreaks of *Pandanus odoratissimus* appeared in both observation points, wind velocity was decreased with about 30% of that on the sandy shore. Figure 19 shows the

Figure 19. Relation between wind velocity at the observation point 10 and that at observation points in the fields with *Cycas* hedges (observation points 1, 2, 3, 4, 5, 6, 8, 11, 12, 14, 15, 17, 18, and 22)

Figure 20. Relation between wind velocity at the observation point 10 and that at observation points on the north-south main road in the fields with *Cycas* hedges (observation points 9 and 16)

relation between wind velocity at the observation point 10 and that at observation points in the fields with *Cycas* hedges (observation points 1, 2, 3, 4, 5, 6, 8, 11, 12, 14, 15, 17, 18, and 22). It is cleared that wind velocity in the field with *Cycas* hedges was decreased with about 20% of that on the sandy shore, on average. The wind reducing effect of *Cycas* hedges appears in both summer and winter and is an effective countermeasure against damage of strong wind and seawater. The wind reducing effect of *Cycas* hedges against the seasonal wind is particularly significant. As described above, it seems that weak seasonal wind entered the field with *Cycas* hedges faced north-south main road. Figure 20 shows the relation between wind velocity at the observation point 10 and that at observation points on the north-south main road in the fields with *Cycas* hedges (observation points 9 and 16). The wind reducing effect of *Cycas* hedges has not appeared clearly, compared with results of observation points in the field with *Cycas* hedges. This north-south main road was narrower in the old days. It is considered that the wind reducing effect in the fields with *Cycas* hedges was decreased by road extension.

In winter and in the early morning of summer, the difference in air temperature, vapor pressure, and relative humidity in the observation site was small. On the other hand, higher air temperature was observed at some observation points include that where located in the field with *Cycas* hedges. Figure 21 shows the relation

between air temperature at the observation point 10 and that at observation points in the fields with Cycas hedges (observation points 1, 2, 3, 4, 5, 6, 8, 11, 12, 14, 15, 17, 18, and 22). In many cases, air temperature at observation points in the fields with Cycas hedges were higher than that at the sandy shore. In some cases at the observation point 1 where located in the smallest field with Cycas hedges and at observation points 11 and 12

where located in the field with Cycas hedges and coastal windbreaks of *Pandanus odoratissimus*, air temperature was more than 2.0 °C higher than that at the sandy shore.

It is obvious that the wind reducing effect appears in the fields with Cycas hedges in summer and winter. And air temperature in the fields with Cycas hedges is higher than that at the sandy shore in the daytime of

Figure 21. Relation between air temperature at the observation point 10 and that at observation points in the fields with Cycas hedges (observation points 1, 2, 3, 4, 5, 6, 8, 11, 12, 14, 15, 17, 18, and 22)

summer. Figure 22 shows changes in UTCI on September 7th, 2016. UTCI between 14:00 and 15:00 were relatively high at the observation point A in the sunlit field with Cycas hedges, and relatively low at the observation point B in the shaded field with Cycas hedges. According to UTCI Assessment Scale, the thermal environment in the sunlit field with Cycas hedges is estimated to be very strong heat stress (UTCI range +38 to +46 °C) and in the shaded field with Cycas hedges to be strong heat stress (UTCI range +32 to +38 °C). When the wind blew, heat stress at observation points C on the sandy shore and D on the north-south main road in the fields with Cycas hedges were slightly mitigated despite high intensity of solar radiation. It is considered that there is a high risk of heat stress in the sunlit field with Cycas hedges because the air temperature is high and wind velocity is calm or very light. It is advisable to eschew a work in the fields with Cycas hedges in the daytime of summer.

5. Conclusions

This study focused on the fields with Cycas hedges called “Sotetsu-Bate” in the Amami Islands, Japan. The summer of 2013 and the winter of 2014, field observations of climatic conditions were carried out to clarify the effects of Cycas hedges on the thermal environment in the fields. In summer and winter, the wind reducing effect of Cycas hedges appeared at observation points in Sotetsu-Bate, and it is an effective countermeasure against damage of strong wind and seawater. The wind reducing effect of Cycas hedges against seasonal wind is particularly significant. It is cleared that wind velocity in the field with Cycas hedges was decreased with about 20% of that on the sandy shore, on average. The wind reducing effect in the fields with Cycas hedges was decreased by road extension. In winter and in the

early morning of summer, the difference in air temperature, vapor pressure, and relative humidity in the observation site was small. It is advisable to eschew a work in the fields with Cycas hedges in the daytime of summer because the outdoor sensible temperature formed in Sotetsu-Bate is very hot and dangerous for human health in the daytime of summer.

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Figure 22. Changes in UTCI on September 7, 2016

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