Cooling Functions of Tidal Flats and Mangroves in Asssociation with Conversation of Ryukyu-Ayu, Plecoglossus Altivelis Ryukyunsis.

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COOLING FUNCTIONS OF TIDAL FLATS AND MANGROVES IN ASSOCIATION WITH CONSERVATION OF RYUKYU-AYU, *PLECOGLOSSUS ALTIVELIS RYUKYUENSIS*

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Abstract: The aim of this study is to examine the cooling functions of the water area at tidal flats and in mangroves, which act as a nursery for Ryukyu-ayu (*Plecoglossus altivelis ryukyuensis*). Ryukyu-ayu is one of the cold water sphere fishes inhabiting a subtropical region, Amami-ohima Island. These fishes are now endangered. During juvenile stages, they live in the estuary or the nearshore zone. However, developments at the river mouth and coast may have caused an increase in the water temperature of their habitats, which could be one of the main reasons for the recent decrease in their population. To investigate the effect of the development on thermal environments, we compared the water temperature of a natural tidal flat with that of an artificial area. Multipoint observations of the water temperature were conducted using 60 recordable compact thermometers so as to examine the fluctuation and distribution of the water temperature. The result showed that the average temperature of the seawater was 20.2°C and that of the river was 13.7°C. Further, the average temperature at the natural river mouth was usually less than 20°C. On the other hand, the water temperature hardly reached below 20°C, which is the critical temperature for juvenile Ryukyu-ayu, at the modified river mouth where a small tidal flat remained without mangroves. We speculated that the mixing of seawater and river water was promoted by the existence of tidal flats and mangroves. In addition, shallow areas provided by tidal flats and the blocking of sunlight by mangroves were believed to be important for maintaining the optimum environment for Ryukyu-ayu.

Keywords: Water Temperature, Tidal flats, Mangroves, Cooling function, Amami-oshima Island, Ryukyu-ayu (*Plecoglossus altivelis ryukyuensis*)

1. INTRODUCTION

Fig.1 Picture of Ryukyu-ayu (*Plecoglossus altivelis ryukyuensis*)

Estuaries are threatened by the harmful effects of global warming. For example, the rise in sea levels could result in the loss of approximately 20% of the wetland area (IPCC 2002). Although the previous research focuses on the rise in sea levels, we believe that the increase in the water temperature could damage the ecosystems in estuaries, which are limited water spaces influenced by land spaces. In addition, the statistical analysis showed that the sea water temperature has been increasing. For example, the temperature of East China Sea has been gradually increasing by 1.44°C for the past 100 years. To protect the species and restore the environment, it is important to control the temperature in estuaries.

Many natural estuaries have tidal flats and mangroves. The authors suspect these tidal flats and mangroves play important roles in cooling the water area. There are many researches and investigations about the presence of hydraulic and thermal environment in tidal flats. For example, Mizutori et al. (1985) researched about the natural distribution of water temperature on the tidal flat in the inner sea, Japan. According to this study, the heat transfer to tidal flats had a significant impact on the water temperature. It creates complex distribution of temperature during winter. Uchiyama et al. (1998) showed that solar radiation and advective flow were the main reasons for the change in the water temperature on the shallow sea in Tokyo Bay, Japan. Matsunaga et al. (1998) investigated the water and ground temperature on tidal flats and performed a one-dimensional simulation. The simulation results showed that the heat flux went from ground to water during daytime and in the reverse direction during night time.

On the other hand, studies about mangroves are not sufficient to estimate the function we suspect. Previous researches about mangroves were active in geography, forestry, and aquafarming. Water regime and properties were researched by Wolanski et al. (1992), Mazda et al. (1997), and Akamatsu et al. (2004). Nihei et al. (2001, 2002) focused on the cooling function of mangroves. They showed that the seawater running through swamp (mangrove forest zone) was cooled down by heat transfer to the ground.

Ryukyu-ayu (*Plecoglossus altivelis ryukyuensis*) is one of the cold-water sphere fishes living in the Amami-oshima Island, which is one of the major Japanese subtropical islands having a rich and unique ecosystem. They use the estuarine area when they are juvenile. Recently, their population has decreased. One of the causes is assumed to be the increasing temperature in their nursery area. They have died off already in the Okinawa Island, which is located south of the Amami-oshima Island.

The life history of Ryukyu-ayu is shown below. Their eggs are deposited at locations just above the estuarine basin from November to March. After eclosion, they are carried down the river to the estuary or nearshore zones. They survive by eating planktons just as copepods do. During spring, they migrate back to the river as they grow during spring. After they deposit their eggs in the next autumn, they usually die off; they are alive for only one year.

As a result of investigations, their growth reduced over a temperature of 20°C and almost all of them could not migrate back to their river (Kishino et al. 2005). This vulnerability is shown by the laboratory experiment (Kishino et al. 2008).

Almost all the estuaries of the Amami Island had been developed through linearlization and reclamation. As a result, they lost their tidal flats and mangroves. However, the Yakugachi River having the largest population has large tidal flats with mangrove forests. On the other hand, the developed river called as the Kawauchi River has small Ryukyu-ayu population.

For these reasons, it is assumed that tidal flats and mangroves can cool water. However, researches about it have not been sufficient to carry out specific countermeasures. Especially, studies on the cases that low temperature river water had significant impact on the water temperature. To carry out this function, we compared the thermal environment of a natural estuary with that of an artificial estuary by conducting multiple continual field observations of the water temperature.

2. FIELD INVESTIGATION AND ANALYSIS

2.1 ABSTRACT OF STUDY SITES

The Amami-oshima Island is one of the Ryukyu Islands lying roughly two-thirds of the way north of the islands chain. It is part of the Kagoshima Prefecture, in the Kyushu region of Japan. It has an area of 712.39 km^2, which is the third largest of all offshore islands in Japan.

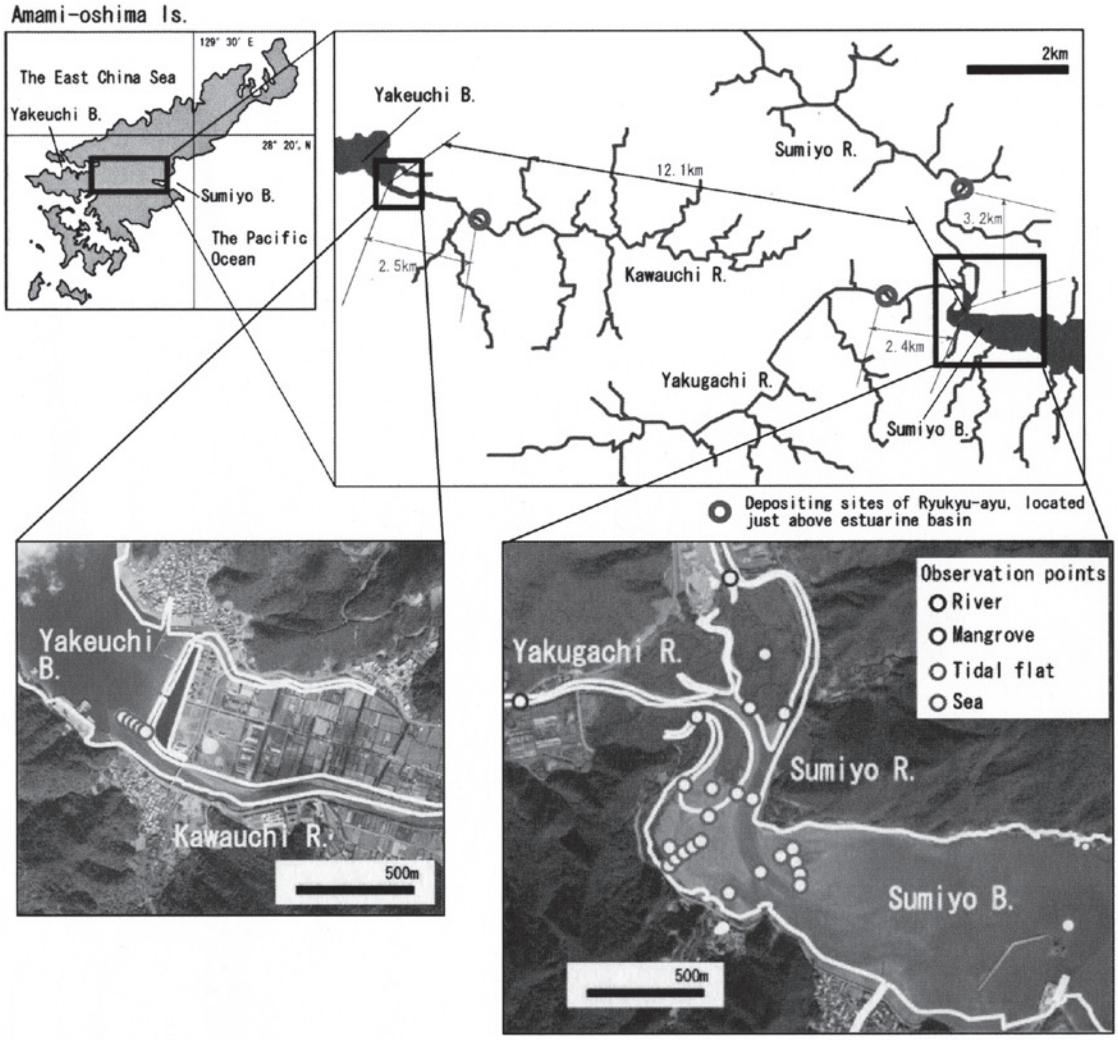


Fig.2. Locations of observation stations in the Yakugachi and Kawauchi Rivers flowing into Sumiyo and Yakeuchi Bays, respectively.

Its terrain is mountainous and its rivers are steep and short. There are 27 main rivers in the Amami-oshima Island, but in fact, almost all of them are developed.

The Amami-oshima Island has a rich and unique ecosystem because it is isolated since it was formed about one million years ago. You can take for instance the black Amami rabbits, *Pentalagus furnessi*; the Amami rabbit is a living remnant of ancient rabbits. Ryukyu-ayu is one of them, too. They are considered to have originated from the north region before the Amami-oshima Island was separated from Japanese islands and continents.

Natural and modified estuaries, the Yakugachi River and the Kawauchi River, were selected as study sites to compare with their thermal environments, as shown in **Fig.2**. They are located at the center of the Amami-oshima Island.

The Yakugachi River has the largest population of Ryukyu-ayu in the Amami-oshima Island. This river meets the Sumiyo River at the estuary and flows into the Sumiyo Bay opening toward the Pacific Ocean. Wide spread tidal flat and mangrove exists in the estuary that has been protected as a seminational park.

On the other hand, the Kawauchi River has recently lost its population of Ryukyu-ayu. It flows into the inner bay called Yakeuchi Bay opening toward the East China Sea. Almost all tidal flats and mangroves were cleared around the Kawauchi River as a result of land reclamation in order to develop houses and faming spaces. Its channel was linearlized and narrowed. Comparing their watershed, the river water quantities flowing into the estuary of the Yakugachi River can be estimated 2.4 times as that of the Kawauchi River.

2.2 RESEARCHING METHOD

We conducted multiple continual observations of the water temperature from 2008/2/7 to 2008/3/1 at 25 sites in Yakugachi River and 5 sites in Kawauchi River, respectively, as shown in **Fig.2**. These observation points were decided by referring to the results of the appearance ratio of juvenile Ryukyu-ayu investigated by Kishino et al. (2005). Compact thermometers with data logger, manufactured by Onset Computer Corporation, were set on the water surface and the bottom ground at each observation point. Logging interval was set to 10 min. The ground level of the points was surveyed to determine if the points were dried up or not. The data at the time when the tide level, which was observed at the Amami Observatory, was lower than the ground level was not used for analysis.

3. RESULT

3.1 SEAWATER AND RIVER WATER

Fig.3 shows the fluctuations of the average of water temperature flowing into the tidal flat and mangrove area in the Yakugachi River from 2008/2/8 to 2008/3/1. The average of the seawater temperature was 20.2°C. It hardly changed during the observation.

The river water temperature is lower than the seawater temperature by 6.5°C on an average. The river water temperature has cycles corresponding to the air temperature or solar radiation, as shown in **Fig.2**. The range of that increased with the air temperature.

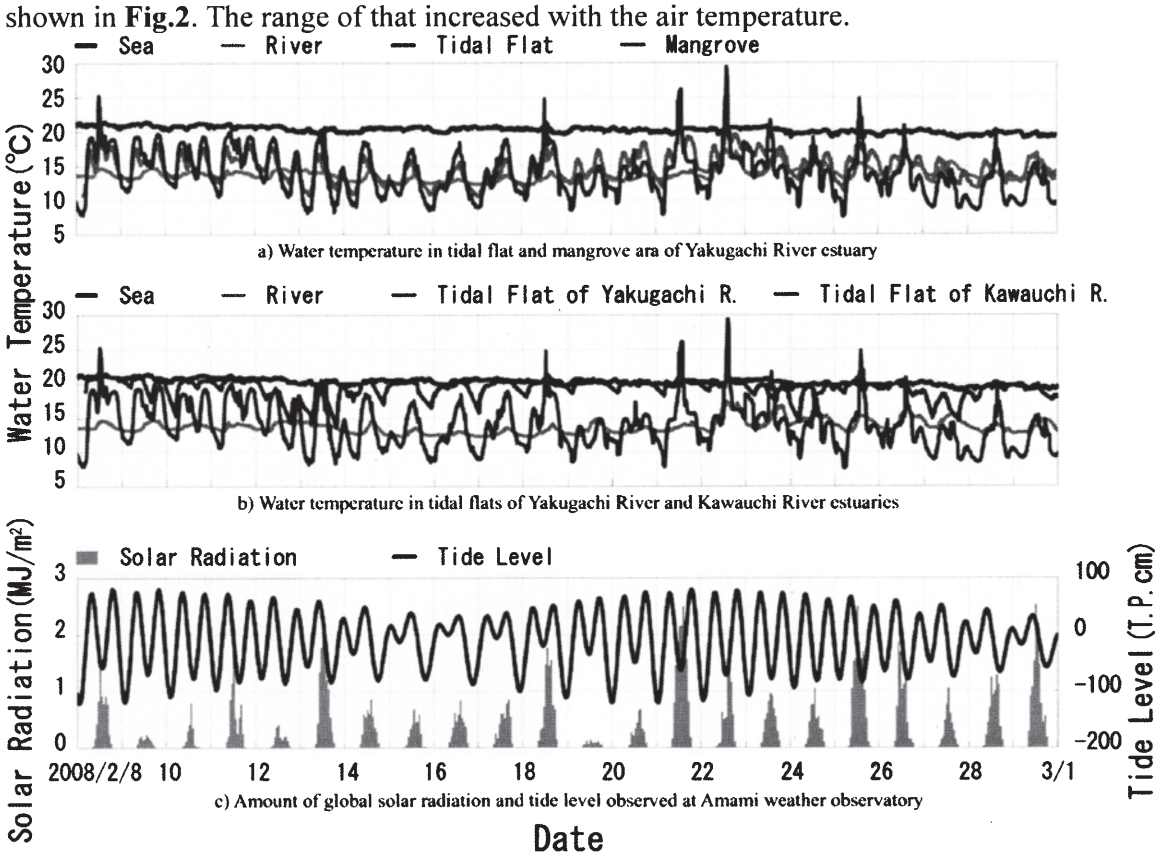


Fig.3 Fluctuations of water temperature on an average of each landscape unit in the Yakugachi River from 2008/2/8 to 2008/3/1. The black, gray, brown, and green lines indicate the sea, river, tidal flat, and mangrove, respectively.

3.2 NATURAL ESTUARY: YAKUGACHI RIVER

Fig.3 shows the water temperature in the natural estuary of the Yakugachi River. The black line represents seawater, gray represents river water, brown represents tidal flats, and green represents mangrove water temperature. Their fluctuations were significantly different from each other. The water temperature of the tidal flat was lower than that of the mangrove and its range was larger. There were two or three peaks in a day. The tide level seemed to have a large impact on the water temperature of the tidal flat and mangrove. The water temperature increased with the tide level.

The average temperature of the tidal flat was 13.9°C, which was much lower than that of the seawater temperature. Its daily range was 10.9°C on an average, which was less than that of the seawater and river water by 1.0°C and 1.9°C, respectively. During night time, a very low temperature under river water was observed on the tidal flat. On the other hand, a very high temperature was sometimes observed in case when the tide level was low and sunlight was strong. In the mangrove area, the water temperature was higher than the tidal flat on an average; however, there was no steep increase in temperature. The average temperature there was 15.8°C and its range in a day was 3.3°C. The average maximum temperature in a day of the mangrove area was 17.9°C, which was lower than that of the tidal flat by 2.3°C.

3.3 MODIFIED ESTUARY: KAWAUCHI RIVER

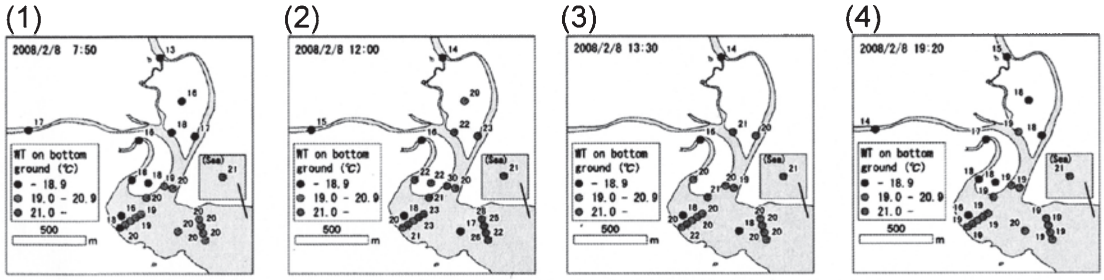
Fig.3 shows the fluctuations of the water temperature of the tidal flat in the modified estuary of the Kawauchi River. The average of that in this observation was 19.5°C. It hardly changed and it had few specific periodicities. The daily range of that was 3.3°C, which was smaller than that in the Yakugachi River. During this observation, it was close to the seawater temperature.

3.4 TIME SERIES OF THE DISTRIBUTION OF WATER TEMPERATURE

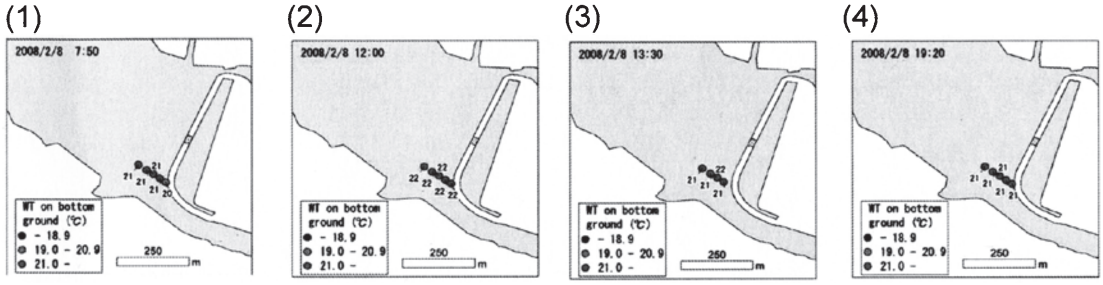
Fig.4 shows the distribution of the bottom water temperature in the Yakugachi River and Kawauchi river estuary in 2008/2/8 at 7:50, 12:00, 13:30, and 19:20. The points expected to dry up is invisible. 2008/2/8 was a spring tide day when the range of sea level between the flood tide and the ebb tide is 204cm. Flood tides were at 7:47 and 19:18. Ebb tides were at 1:16 and 13:29.

There are three peaks of water temperature at 7:50 (morning flood tide), 12:00 (right before ebb tide), and 19:20 (night flood tide).

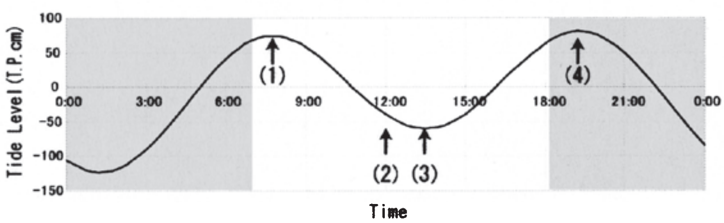
In the morning flood tide at 7:50, all observation points were covered with water. In spite of reaching over 20°C at all the points in the Kawauchi River, half the points in the Yakugachi River were under 19°C. Very warm area appeared on the tidal flat in the Yakugachi River at 12:00. However, mild area under 20°C was found in the mangrove area of the Yakugachi River.



(a) Yakugachi River estuary



(b) Kawauchi River estuary



(c) Time series of tidal level at Amami tide station

Fig.4 Distribution of water temperature at the bottom in Yakugachi and Kawauchi Rivers estuaries at 2/8/08 7:50, 12:00, 13:30, and 19:20, in (a) and (b), respectively. (c) shows changing of tide level on the day. If sea water level was lower than the ground level at each observation point at each time, we considered it was dried up and make it invisible in these figures.

4. CONCLUSION

As a result of the investigation, the Yakugachi River can be more comfortable than the Kawauchi River for juvenile Ryukyu-ayu. The natural estuary of the Yakugachi River provides a low temperature area under 20°C, which is the limit temperature of their existence. A temperature of over 20°C was observed in the Kawauchi River tidal flat more frequently than in the Yakugachi River. There are some thermal refuges in the Yakugachi River.

We considered the four causes for these differences below. (1) Difference in cool river water quantity flowing into the estuaries. (2) Difference in the extent of mixture between the seawater and the river water. (3) Existence of tidal flat: It creates a sensitive shallow zone. (4) Existence of mangroves, which block the sunlight. Of these causes, we suspect the mixture between the seawater and the river water is the most important element.

First, we discussed the difference in the cool river water quantity between the two study sites. The quantity of river water flowing into the estuary of the Yakugachi River can be estimated 2.4 times as that of the Kawauchi River. Therefore, it can be easy to form the cool area in the Yakugachi River estuary. Although the observation points in the Kawauchi River were set near by the stream line, proper temperature for juveniles were hardly observed. The result shows that it is necessary to estimate not only the river water quantity but also the mixing between the seawater and the river water.

We speculated that the mixing of the seawater and the river water was a main factor for the existence of low temperature zones. The conditions in which the water temperature decreased in the Kawauchi River was limited in the case when the sea level decreased or when it rained. In this case, the river water affects the estuary. The Kawauchi River narrowed its effective area of the river water by its straightened channel. The water temperature on the tidal flat was close to the seawater temperature. Therefore, it can be thought that the seawater flows directly to the estuary and the river water does not run through the tidal flat, nursery area of Ryukyu-ayu. On the other hand, natural estuary can be thought to have a lot of elements to mix the seawater and the river water. Tidal flat provides wide-spread room in order to expand the river water and keep it for a long time in the estuary. Mangrove has a complex structure of their root and shaft. One of reasons for this narrow range can be because of its vertical mixture. On the tidal flat, the seawater and fresh river water are not easy to mix due to their difference in density. Usually, they form brine wedge and there are remarkable fluctuations of temperature between the upper layer and the lower layer. As above, the natural estuary can keep the river water longer than the modified estuary. We thought that the system to hold on the river water in the estuary is necessary to protect Ryukyu-ayu.

In addition, we thought that tidal flat works to cool through other processes. First, it provides wide shallow area, which influenced the small heat flux because it has a small thermal capacity. When it dried up, its surface was cooled immediately and heat was absorbed from water as the sea level increased. We thought this is why we observed a very low temperature on the tidal flat in the early morning. In addition, it can have a function to resist seawater get through the estuary because its elevation is higher than that of modified estuary. However, the tidal flat can work to increase the water temperature. Sunlight warmed up the shallow water body and this effect appeared remarkably. This phenomenon was similar to the result of investigation by Uchiyama et al. (1998) in Tokyo Bay. They might occur every day; however, rapid increase in the water temperature on the tidal flat was not often observed. Strong solar radiation beyond 2MJ/h was not much frequently observed because of climatic and seasonal changes in the winter of the Amami-oshima Island, which had cloudy and weak sunlight.

We thought that mangroves have another function to cool water, too. During daytime, the water temperature increased on the tidal flat but it was mitigated in the mangrove area. Probably, it caused the mangrove canopy to block the sunlight. Mangroves can provide shelter for Ryukyu-ayu. Nihei et al. (2001, 2002) showed in their summer observation that the seawater was cooled by the mangrove ground when it runs through the mangrove forest. In our observation, the thermometers were not set in the mangrove forest area and so we could not examine the cooling function of mangroves. Another reason for low temperature in the mangrove area could be considered. The influence of the river water can be larger in mangroves than in tidal flats because they are located near than the tidal flat. We should estimate the inflow in the estuary to examine their effect.

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