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Case study of wild oyster spawning events in Western Japan

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Abstract
In Japan, the peak spawning period of the Pacific oyster, *Crassostrea gigas,* is from June to August. The ideal water temperature for spawning is 23–25 °C, and rapid temperature and salinity changes such as those caused by weather changes are known to stimulate spawning events. In this study, at approximately 15:50, on May 9, 2015, we observed the release of a turbid white solution from a wild population of the *C. gigas* oysters attached approximately at sea level to the harbor quay in Nagasaki Bay. Weather data for the area were obtained from the website of the Japanese Metrological Agency, and analyzed to identify changes in air temperature, rainfall, and tidal rhythm that occurred during or just prior to the observed event. Therefore, it was determined that on the day of the event, there was an increase in air temperature during the afternoon, because rainfall occurred in the morning. By the time of the event, the air temperature had reached 23 °C, which is considered the optimal temperature for *C. gigas* spawning. Thus, the observed event was identified as a spawning event.

Keywords: Oyster, Spawning, Weather, Tidal rhythm, Western Japan

1. Introduction
The Pacific oyster, *Crassostrea gigas*, is a dioecious oyster, and in Japan, its peak spawning period is from June to August, when water temperatures are within a range of 23–25 °C [1, 2]. In addition, rapid changes in water temperature and salinity, such as those caused by weather changes, may stimulate spawning events [1, 2]. Its egg diameter is 50–60 µm, and the egg is fertilized by sperm released underwater by male oysters. The fertilized eggs develop a D-type larva by about 24 h after the start of cell division [1, 2]. In the present study, the release of a turbid white solution from a wild oyster population attached to a quay was observed in Nagasaki Bay, West Japan. Weather conditions at the time of the event were also examined. This paper describes relationships between the environments such as air temperature, rainfall and tide level, and the spawning events of the wild oyster identified as *C. gigas*.

2. Materials and Methods
2.1 Observation
At approximately 15:50 on May 9, 2015, in the harbor of Nagasaki Bay (N 32° 44' 38.58", E 129° 52' 13.96"), the release of a white turbid solution by the wild oyster population attached to the quay at the water's surface was observed (Fig. 1). The phenomenon was photographed (Fig. 2 A). This event was not isolated; it occurred sporadically at several locations (≥6) in overlooks. In addition, the behavior of the small fish (Fig. 2 B) or mullets (Fig. 2 C) that preyed on the turbid white solution released by the oysters was observed.

2.2 Environment
In order to determine the tide level at the time of the phenomenon, tide level data collected from April 20 to May 20 in Nagasaki harbor (N 32° 44′, E 129° 52′) were obtained from the Japanese Meteorological Agency website (http://www.data.jma.go.jp/kaiyou/db/tide/suisan/suisan.php). The tidal changes were plotted on a graph. In addition, in order to clarify the environmental conditions present at the time of the spawning phenomenon, the temperature and rainfall data for Nagasaki city (N 32° 44', E 129° 52'), collected between March 1 and to May 31, 2015, were obtained from the Japanese Meteorological Agency website (http://www.data.jma.go.jp/obd/stats/etrn/view/daily_s1.php) and plotted. In addition, the hourly tide level data and 10-min pitch data of the temperature, rainfall, and sunlight duration

from 0:00 on May 9 to 0:00 on May 10 were obtained from the Japanese Meteorological Agency website (http://www.data.jma.go.jp/obd/stats/etrn/view/10min_s1.php). These data were used to establish a more detailed picture of the environmental conditions present at the time of the event.

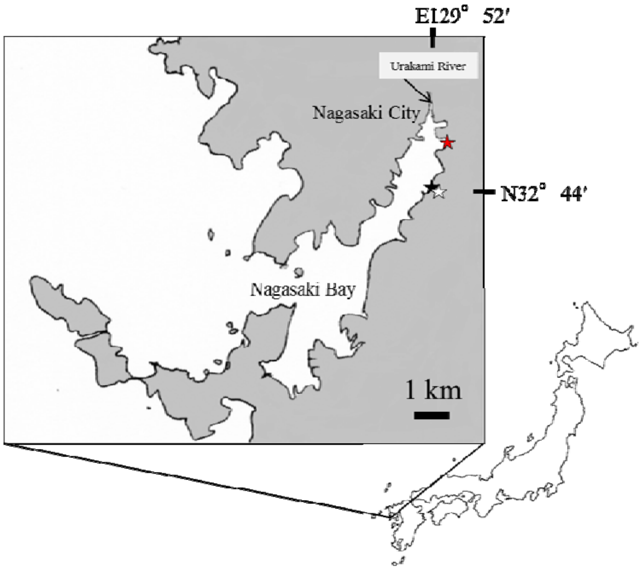

Fig 1: Location of the oyster observation site (red star) and the weather (white star) and tidal rhythm (black star) data collection sites run by the Japan Metrological Agency in Nagasaki, Western Japan.

3. Results and Discussion

3.1 Oysters

The following three genera of Ostreidae oysters are most commonly found in Japan: *Ostrea* (*O. denselamellosa* and *O. circumpicta*), *Saccostrea* (*S. mordax*, *S. kegaki*, and *S. echinata*), and *Crassostrea* (*C. gigas*, *C. ariakensis*, *C. sikamea*, and *C. nippona*) [3]. Among these, *O. denselamellosa* has recently become rare in Japan [3]. *O. circumpicta* species, which mainly thrives in reef areas, differs in shape from the wild oysters observed during this study [4]. In the genus *Saccostrea*, *S. mordax* and *S. kegaki* are mainly found on rocks located along the shoreline or in open sea [5]. These species differ in shape from the oysters observed in this study, as *S. mordax* exhibits a shell with wavy blackened edges, and *S. kegaki* shells feature many black spines on their surfaces. In addition, *S. echinata* individuals have been found living in Kyushu recently [6], but the species is rare in this area, and is more commonly found in southerly areas. Thus, the oyster population observed during this study was determined to belong to the genus *Crassostrea*. *C. ariakensis* has recently become rare even in Ariake Bay, which was reported as its native habitat [7]. Specific DNA marker-based analyses have established that *C. sikamea* populations are distributed in Yatsushiro Bay and Imari Bay, as well as in Ariake Bay on Kyushu Island in Western Japan [8, 9]. Moreover, the species was found to be distributed in low salinity areas (8~30 PSU) of Imari Bay [9]. According to year-round observations of the top 1-m of the water, the salinity of inner Nagasaki Bay was 25.9‰ in July during the rainy season, and 30‰ over during all other months [10]. Therefore, the salinity levels in inner Nagasaki Bay were determined to be too high for *C. sikamea* to tolerate. In addition, although the observed oyster population was determined to have entered its spawning season, the spawning season of *C. nippona* in West Japan occurs during August–October [11, 12], unlike the spawning season observed during May in the present study. Thus, the wild oysters observed to be spawning in May were identified as the Pacific oyster, *C. gigas*.

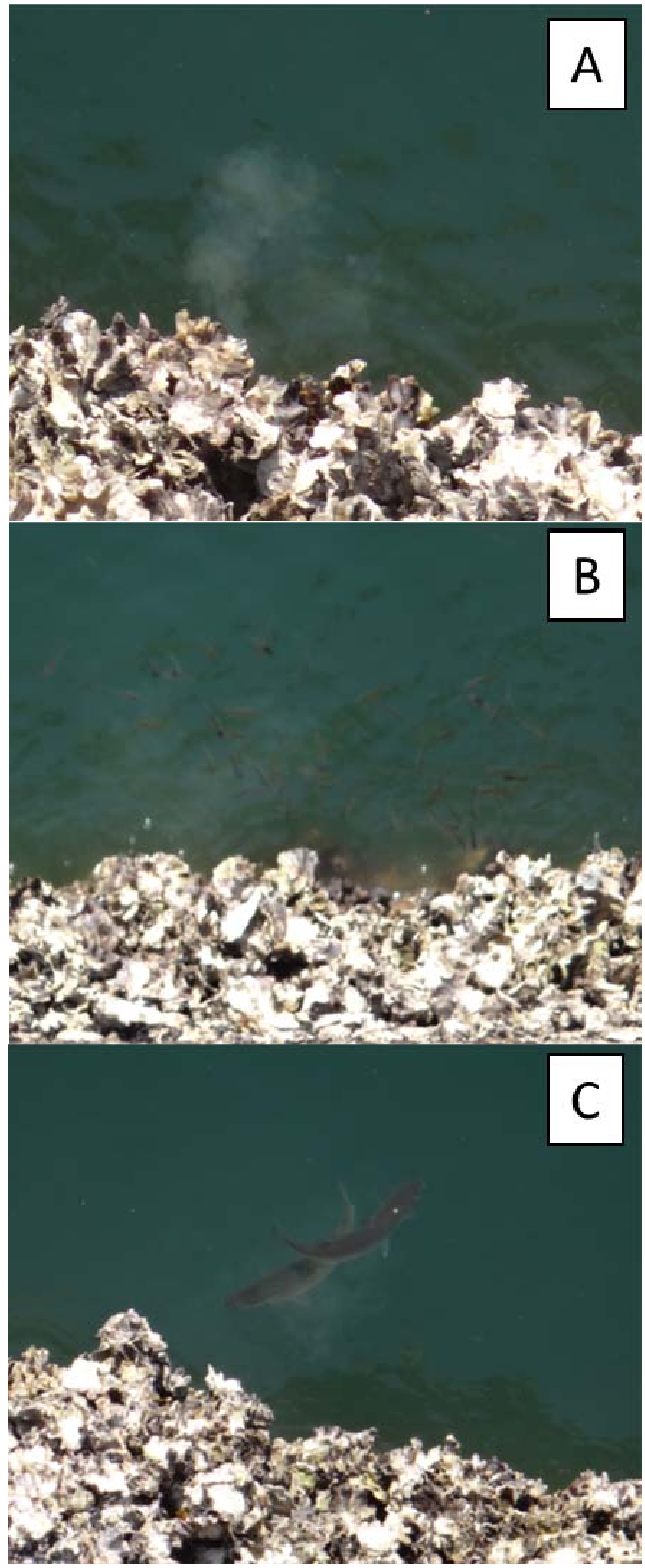

Fig 2: Photographs of the release a turbid white solution from the wild oyster population of Nagasaki Bay on May 9, 2015. A: The release phenomenon. B: Swarm of small fish in the turbid white solution. C: Swarm of mullets in the turbid white solution.

3.2 Environment

According to tide level data, the phenomenon observed on May 9 occurred at mid-tide, closer to a neap tide than a spring tide. In the intertidal zone around 15:50, the oyster population anchored to the quay was located at the water surface, and it was around 64 cm of the tide level (Fig. 3). Thus, this oyster population was found to be anchored in the low-tide zone of the intertidal zone. According to a description of the distribution characteristics of *C. gigas*, *C. sikamea,* and *C. ariakensis* in Ariake Bay [7], *C. gigas* is mainly distributed from the intertidal to the sub tidal zone in the brackish inner bay, while *C. sikamea* is distributed in the less consistently submerged shallower zone at the river's mouth, where it was higher approximately 1 m than the water depth. Finally, *C. ariakensis* is distributing mainly at a depth of 0 m in the river mouth. Thus, as the oyster population in question was anchored in the low-tide zone, it is likely that this population was made up of *C. gigas* oysters.

According to the temperature data, the daily maximum temperature in early March was often >15 °C; however, the frequency of days when the maximum temperature was ≥15°C gradually increased in late March, and the frequency of days when the maximum temperature was ≥20 °C in late April (Fig. 4 A). The highest levels of rainfall occurred in mid-March or early-middle April and May. On May 9, the release event occurred after a small-scale rainstorm that deposited 9.5 mm/day (Fig. 4 B). The temperature at the time of the phenomenon was at 23.0 °C (15:50) (Fig. 5). In addition, based on the 10-min pitch observation data, light rainfall (0.5 mm/10 min) occurred intermittently from 4:00 to 10:30 (Fig. 5). Therefore, sunshine was seen after 11:00, and the sky was completely clear after 13:00 (Fig. 5). In addition, there was a delay in the temperature increase due to the morning rain. Temperatures began to increase in the afternoon, and was maximum after 15:00 in the evening (Fig. 5). The temperature range known to be suitable for *C. gigas* spawning is 23–25 °C [1, 2]. The oyster community was anchored to the quay at sea level at the time of the phenomenon, which indicates that the surface water temperature covering the oysters was almost same with the air temperatures. Thus, the oyster population experienced a temperature level suitable for spawning. In addition, the tide level data revealed that the release phenomenon occurred at mid-tide just prior to low tide (Fig. 5 B).

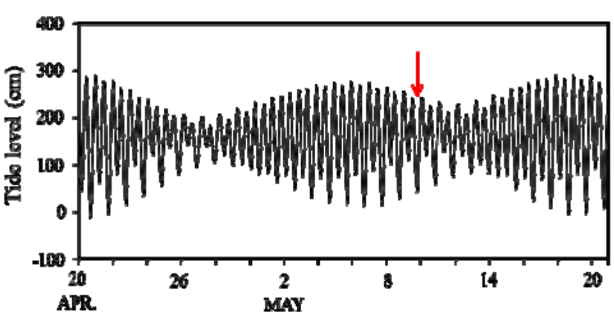

Fig 3: Tidal changes in Nagasaki Bay from April 20 to May 20, 2015. Data were collected by the Japanese Metrological Agency (http://www.data.jma.go.jp/kaiyou/db/tide/suisan/suisan.php). The arrow indicates the observation date.

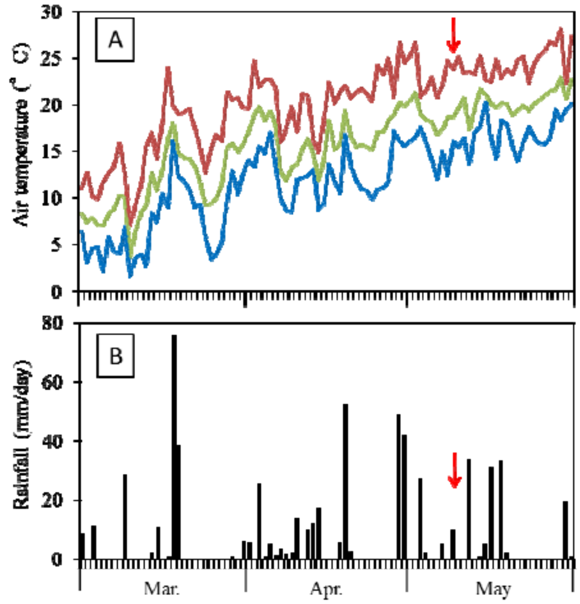

Fig 4: Daily changes in air temperature and rainfall amount in Nagasaki City, from March to May 2015. Data were collected by the Japanese Metrological Agency (http://www.data.jma.go.jp/obd/stats/etrn/view/daily_s1.php). A: Red line illustrates daily changes in maximum temperature, the green line represents daily changes in the mean temperature, and the blue line illustrates daily changes in the minimum temperature recorded. B: Daily changes in rainfall amount. The arrow in each graph indicates the observation date.

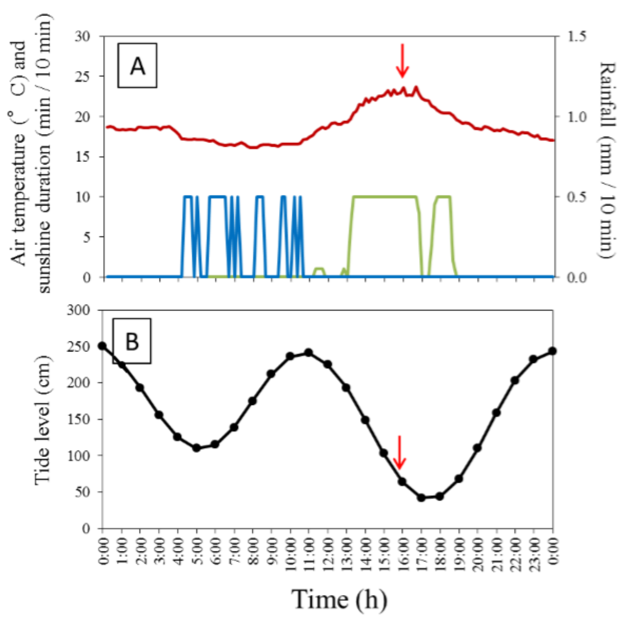

Fig 5: Every 10 minutes changes (graph A) in air temperature (red line), rainfall amount (blue line), and sunshine duration (green line) were recorded, as were the hourly tidal changes (graph B) in Nagasaki on May 9, 2015. Data were collected by the Japanese Metrological Agency (http://www.data.jma.go.jp/obd/stats/etrn/view/10min_s1.php). The arrow in each graph indicates the observation time.

4. Conclusion
The release of a turbid white solution by a wild oyster population identified as the Pacific oyster, *C gigas*, was observed in Nagasaki Bay at approximately 15:50 on May 9, 2015. According to the results of the weather data analysis, the air temperature had reached ≥23 °C at the time of the event, thus providing a suitable temperature for the spawning of the Pacific oyster. Thus, this phenomenon was identified as a spawning event. In addition, this release occurred at mid-tide, just prior to low tide.

5. Acknowledgement
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