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Observations of mobile macro-epifauna on pumice rafts generated by Fukutoku-Oka-no-Ba volcano in Oku Port, Okinawa Prefecture

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Abstract

We report the presence of mobile macro-epifauna on rafts of pumice generated by the Fukutoku-Oka-no-Ba volcano in 2021 in Oku Port, at the northern end of Okinawa Island. Most of the water surface in the harbor was covered by a thick pumice raft at the time of our observations. *Grapsus* crabs were the dominant species on the surface of the raft, and many crabs were visible near the quay. No crab was seen to burrow into the raft. These results show that mobile macro-epifauna can expand their distribution to the surface of a pumice raft. However, the presence of a raft is likely to make it difficult for crabs to move between land and water.

Key words: Crustacea; distribution; *Grapsus albolineatus*; *Coenobita rugosus*

Introduction

Pumice generated by volcanic activity and washed ashore in large quantities may have a variety of impacts on marine animals, including their widespread dispersal on pumice rafts (Bryan et al. 2012), coastal transportation of offshore fish (Okinawa Times 2021a), and mortality of farmed fish due to accidental pumice ingestion (Okinawa Times 2021b). However, the effects of the large amount of pumice on coastal animals have not yet been investigated.

Fukutoku-Oka-no-Ba is an underwater volcano located north of Minami-Iwo-To Island at 24º17’N, 141º28’E, and its activity has been confirmed frequently since 1904 (Japan Coast Guard 2021). Following an eruption in August 2021, pumice was generated and cast ashore over a wide area along the Pacific coast of Japan (Yoshida et al. 2022). Large amounts of pumice were observed along the coast of Okinawa Island (Ministry of Land, Infrastructure, Transport and Tourism 2021; Okinawa Prefecture 2022), which is located in the subtropical climate zone (United Nations Climate Programme 2022). Ports and harbors, which often enclose calm waters, tend to entrain drifting pumice, and the buildup of dense rafts of pumice in many ports on Okinawa Island interfered with shipping activity (Ministry of Land, Infrastructure, Transport and Tourism 2021). Dense and persistent pumice rafts can function as habitat for a wide variety of marine animals (Velasquez et al. 2018), and could be especially suitable for habitation in harbors. Here, we report on the presence of mobile macro-epifauna on a pumice raft in Oku Port, Okinawa Prefecture.

Materials and Methods

The survey was conducted at Oku Port, Kunigami Village, on northern Okinawa Island (Fig. 1). The port is located on the western side of

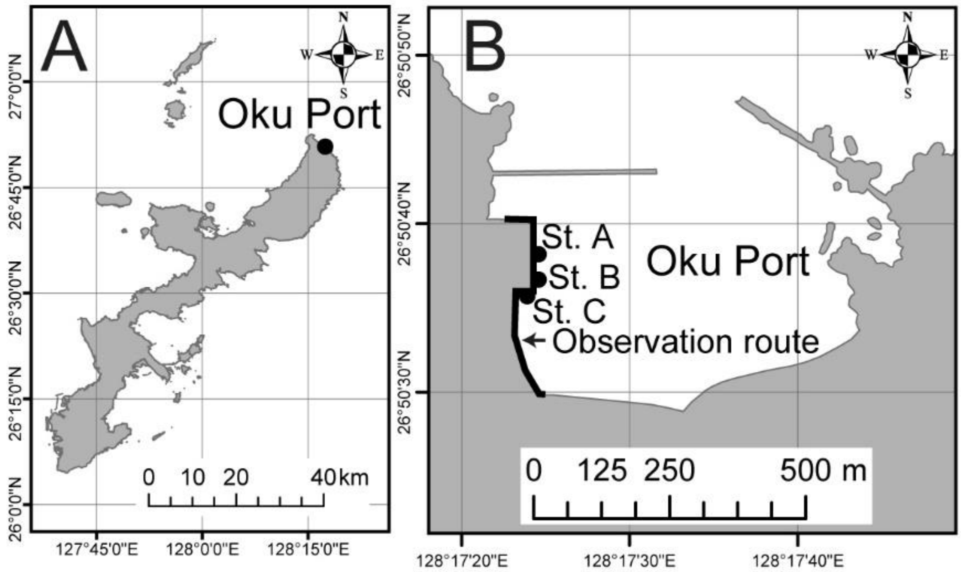

Fig. 1. Locations of Oku Port on Okinawa Island. A: Okinawa Island. B: Oku Port with the observation route.

a cove that opens northward. Shallow coral reefs are located to the east and west of the cove mouth, and breakwaters on both sides help maintain a calm environment within the cove. The presence of drifting pumice from the Fukutoku-Oka-no-Ba eruption was confirmed there on 26 October 2021 (Ministry of Land, Infrastructure, Transport and Tourism 2021). We conducted our survey on 4 November 2021 from 15:00 to 17:00 and on 5 November from 09:00 to 11:30. The latter sampling period occurred during the spring tide. Most of the water surface in the harbor was covered with a pumice raft during the survey (Fig. 2). The high and low tides in Hentona of Kunigami Village occurred at about 18:30 and 12:30 on 4 November and at 07:00 and 13:00 on 5 November, respectively (Surf Life 2022). Thus, the first survey period (on 4 November) was during a rising tide, and the second (on 5 November) was during a falling tide. The distance from the top of the quay to the sea surface was about 1–2 m during the survey. Two of us searched for mobile macro-epifauna on the surface of the quay wall and on the surface of the pumice raft by eye while walking along an observation route (Fig. 1). During the search, binoculars were not used. We recorded the substrate type, and noted the presence, horizontal and vertical position, and behavior of any animals. Some animals were recorded in still images or video taken with a digital camera (Stylus TG-3 Tough, Olympus, Tokyo, Japan). We also captured one crab, placed it on the pumice raft, and observed its behavior. To estimate the thickness of the raft on 4 November, we measured a vertical profile of turbidity with a multi-parameter water quality meter (AAQ-Rinko, JFE Advantech Co. Ltd., Hyogo, Japan) at three stations (A, B and C; Fig. 1). Because turbidity is usually measured with an optical backscatter sensor, readings are increased by strong reflected light from any matter near the sensor, consequently, turbidity is overestimated within a dense pumice raft. So, we used the water quality meter to estimate the thickness of the raft: At each station, the meter was lowered from the sea surface to the sea floor at about 10 cm s^{-1}. The measurement rate of the turbidity meter was set to 10 times s^{-1}. The obtained turbidity data were averaged over each 10-cm depth zone. The thickness of the pumice raft on 5 November was measured with a calibrated staff at the bottom of the raft layer at Stations A and B by means of an underwater video camera (FM-4100; QI Corporation, Kanagawa, Japan).

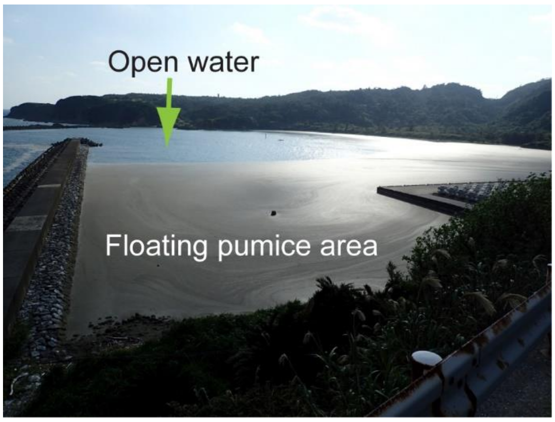

Fig. 2. A panoramic view of Oku Port on 5 November 2021.

Results

A northeasterly wind (mean speed: 3.5 m s^{-1}; Japan Meteorological Agency 2021) was blowing during our study, and the waves were gentle. Numerous pumice stones of size 1–30 mm (longest diameter) covered most of the surface of the harbor on both days (Fig. 2); the pumice layer was denser on 5 November. The pumice built up into a thick raft, and individual stones were suspended at low density to a depth of about 3 m below the raft. We also saw pumice rolling on the seafloor in the reciprocating wave flow. On 4 November, the sea surface in the vicinity of Stations B and C was covered with dense pumice. At Station B, the turbidity at ≤10 cm depth (>73 formazin turbidity units [FTU]) was greater than that at ≥20 cm depth (<6.2 FTU) except near the seafloor. Similarly, at Station C, the turbidity at ≤10 cm (>301 FTU) was greater than that at ≥20 cm (<4.5 FTU) except near the seafloor. In the vicinity of Station A, on the other hand, floating pumice stones were sparse, and patches of open water were observed; the turbidity gradually increased from the sea surface to the seafloor, with no sharp changes. From these results, we estimated that the thickness of the pumice raft on 4 November was <10 cm at Station A and 10–20 cm at Stations B and C. On 5 November, the thickness of the pumice raft recorded by the underwater camera was about 15 cm at Station A and about 19 cm at Station B. This means that the thickness of the raft at Station A increased by >5 cm from 4 to 5 November.

On the surface of the pumice raft, we identified the rocky shore crab *Grapsus albolineatus* Latreille in Milbert, 1812 (Decapoda: Grapsidae), the land hermit crab *Coenobita rugosus* H. Milne Edwards, 1837 (Decapoda: Coenobitidae), and one snake (unidentified Serpentes, Reptilia) (Fig. 3; Movie 1).

The ratio of eyestalk height to distance between

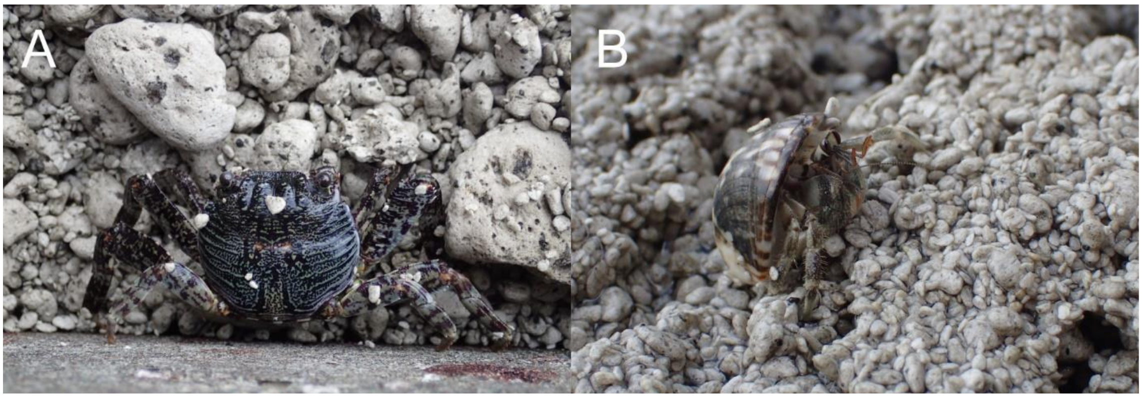

Fig. 3. Crustaceans found on the surfaces of accumulated pumice on the water surface in Oku Port. A: *Grapsus albolineatus*. B: *Coenobita rugosus*.

eyestalks is known to be 1:3 in *G. albolineatus* and 1:2 in the similar *Grapsus tenuicrustatus* (Herbst, 1783). Among the rocky shore crabs we observed, the ratio (as estimated within about 2 m away) was roughly 1:3, and the frontal region of the crab was less deflected than in *G. tenuicrustatus* (Fig. 3A). These morphological characteristics closely match the descriptions and illustrations of *G. albolineatus* in Sakai (1976) and Miyake (1983). Therefore, we assumed that the crabs were *G. albolineatus* or a closely related species, and designated them all as "*Grapsus* crabs".

Grapsus crabs were distributed on the vertical surface of the quay and the surface of the pumice raft within about 30 m of the quay on 4 and 5 November (Fig. 4). We saw at least 10 crabs of various size on the raft in the vicinity of Station B on 4 November and in the vicinity of Stations A and B on 5 November. Many crabs were observed on the pumice raft within about 5 m of the quay, and a few crabs were spotted even farther away. *Grapsus* crabs were the most common species among the mobile macro-epifauna on the raft. The crabs were either walking or stationary on the raft and no crabs were seen to jump between rafts separated by open water. We also saw at least 10 small to large *Grapsus* crabs on the quay wall. These crabs were also walking or stationary. Many crabs that we observed in the area had pumice particles attached to them (Fig. 3A), but no crabs were seen to jump down onto the raft or burrow into its surface even in situations when they might sense that they were under threat, such as when we approached them or immediately after release of the collected rocky shore crab onto the raft. Under these situations, the crabs walked at low or moderate speeds across the surfaces of the quays and pumice rafts. The rocky shore crab that was captured and then released onto the raft moved quickly across the surface for only the first few seconds. When we were far enough away that the crabs apparently did not sense any threat, the crabs spontaneously moved between the surfaces of the quay and rafts. One dead mid-sized rock crab was found on the quay, but the cause of death was unknown.

Only one hermit crab was observed on the surface of the raft, and was found near the quay in the innermost part of the harbor on 4 November (Fig. 3B). The hermit crab had a black band on the proximoventral surface of each eyestalk and was identified as *Coenobita rugosus* (Miura 2008). It had pumice attached to its body surface and its adopted shell, and it too was not seen to burrow into the raft. One snake meandered on the surface of the raft about 20–30 m from the quay (Movie 1).

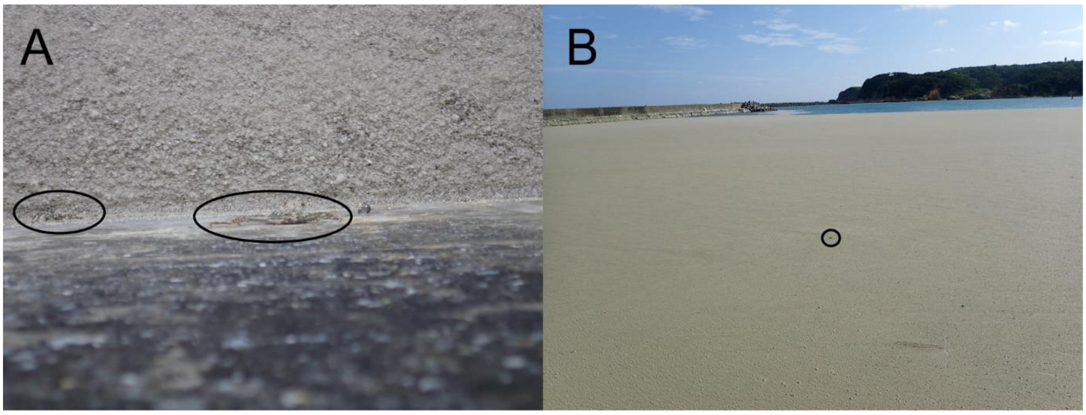

Fig. 4. *Grapsus* crabs living in various habitats in Oku Port. The locations of *Grapsus* crabs are indicated by open circles. A: two crabs on the vertical surface of the quay. B: the isolated crab on pumice rafts far from the quay.

Discussion

We identified several taxa of mobile macro-epifauna such as crustaceans on the surface of the pumice raft in Oku Port. This demonstrates that mobile macro-epifauna can expand their distribution to pumice rafts.

Grapsus crabs were observed on pumice rafts with estimated thicknesses of 10–20 cm. Such thick rafts are likely to prevent crabs from moving into the water. Rocky shore crabs jump into the sea when they sense imminent danger (Lee 2008), but the rocky shore crabs we observed did not attempt to escape into the sea, even when approached extremely closely. This was likely because access to the water surface was obstructed by the presence of the pumice rafts. Despite the need for coastal crabs to hydrate regularly in order to breathe (O'Mahoney & Full 1984), only one dead rock crab was found during the study. This indicates that short-term persistence of thick pumice rafts is unlikely to cause large increases in rock crab mortality.

The estimated thickness of the pumice raft at Station A increased by >5 cm from 4 to 5 November, and a large amount of pumice was reported to have disappeared overnight (Okinawa Times 2021c). It is unclear whether a pumice raft thick enough to affect the vertical movement of *Grapsus* crabs could be maintained over several days. However, if such a thick raft persisted over a long period, the crabs' survival rate would likely be reduced.

The hermit crab *C. rugosus* relies on burrowing and rehydration in the sea to maintain its abdomen humidity (Vannini 1976; Vosjoli 2005; Hutagalung et al. 2019), and doing so might be difficult when a thick pumice raft covers the sea surface. However, it is also possible that we did not observe burrowing during our study because we observed the crabs during a rising tide, when the frequency of burrowing is generally low (Barnes 2002). Further observations should be conducted to clarify the effect of pumice rafts on burrowing.

Adult and juvenile *C. rugosus* inhabits the supra-littoral zone, closer to the waterline than other *Coenobita* species (Barnes 1997; Hsu et al. 2018; Fujikawa et al. 2018). Thus, this species is more likely than its congeners to encounter and be affected by pumice rafts. All *Coenobita* in Japan, including this species, are designated as a protected species (natural monument) by the Agency for Cultural Affairs, Japan (Agency for Cultural Affairs 2022). Further investigations of the effects of pumice rafts on this species may be necessary to protect it.

Longer-term observations could reveal the use of pumice rafts by a more diverse range mobile macro-epifauna. Although our results reveal the effects of a pumice raft on the horizontal and vertical movement of coastal animals within a harbor, any effects on mortality were unclear and should be further examined in future studies. Sessile invertebrates such as bivalves and barnacles inhabit the intertidal zone of the quay in Oku Port, and were repeatedly struck by wave-borne pumice stones. The damage caused by this repeated impact is of concern, but was not examined in our study. The pumice rafts were eventually removed in Oku Port to ensure safe ship navigation, and this is likely to have restored the habitat for coastal animals.

Acknowledgments

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