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SHORT COMMUNICATION

Living on the edge: *Diadema mexicanum* in the upper Gulf of California

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Abstract Sea urchins play a crucial role in the health and dynamics of reef ecosystems. *Diadema mexicanum* is a dominant grazer and erosive agent of the substratum in reef environments in the eastern tropical Pacific. Its reported distribution extends from the middle of the Gulf of California (26° N) to northern Peru (6°23′ S), including oceanic islands. Here, we report the occurrence of *Diadema mexicanum* in Isla San Jorge (31°0′38.53″ N, 113°14′34.84″ W), the northernmost island in the Gulf of California, which extends its range an additional 600 km northward. Sea urchins, ranging in test size from 4.5 to 12.4 cm, were present at 2–6 m in October 2015. This test size was one of the largest reported for this species in the eastern tropical Pacific. Spine length in sea urchins in the upper gulf ranged from 3.3 to 15.6 cm. Variation in body size of sea urchin may reflect variation in more structurally complex reefs from isolated islands that provide shelter from predation. The reef structure of Isla San Jorge is formed by high coral cover of the scleractinian coral *Porites panamensis*, with an average colony height of 26.27 cm (standard error, SE ±1.58, $n = 60$), similar to coral reef communities of the southern Gulf of California. Although *D. mexicanum* is considered a great force of erosion to the substratum in reef environments in the eastern tropical Pacific, no evidence of erosion was observed at Isla San Jorge, indicating a balanced dynamic between herbivores, macroalgae, and corals.

Keywords Echinoidea · Urchin size · Sea urchin · Geographical range · High-latitudinal reef

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Introduction

Sea urchins play a crucial role in the health and dynamics of reef ecosystems. They are mainly algal consumers and this activity is essential for limiting the abundance of macroalgae to avoid overgrowth and support nutrient recycling (Muthiga and McClanahan 2007; Sherman 2015). Sea urchins can have a significant impact on reef structure by bioeroding the reef framework when they are overabundant during stressful conditions, especially El Niño events (Glynn 1997; Muthiga and McClanahan 2007).

Diadema mexicanum Agassiz, 1863 is a dominant grazer and agent of erosion of the substratum in reef environments in the eastern tropical Pacific. Its distribution (Fig. 1a) extends from the middle of the Gulf of California (Loreto National Marine Park, 26°07′ N; Holguín-Quiñones et al. 2000) to Isla Afuera in northern Peru (6°23′ S), including oceanic islands (Revillagigedos, Clipperton, Coco, and Galapagos; Alvarado et al. 2015). Their average test diameter in the eastern tropical Pacific is 4.38 (standard error, SE ±1.50) and the range is 0.37–12.30 cm (Alvarado et al. 2016). The largest individuals (6–12.30 cm) are found in the oceanic islands

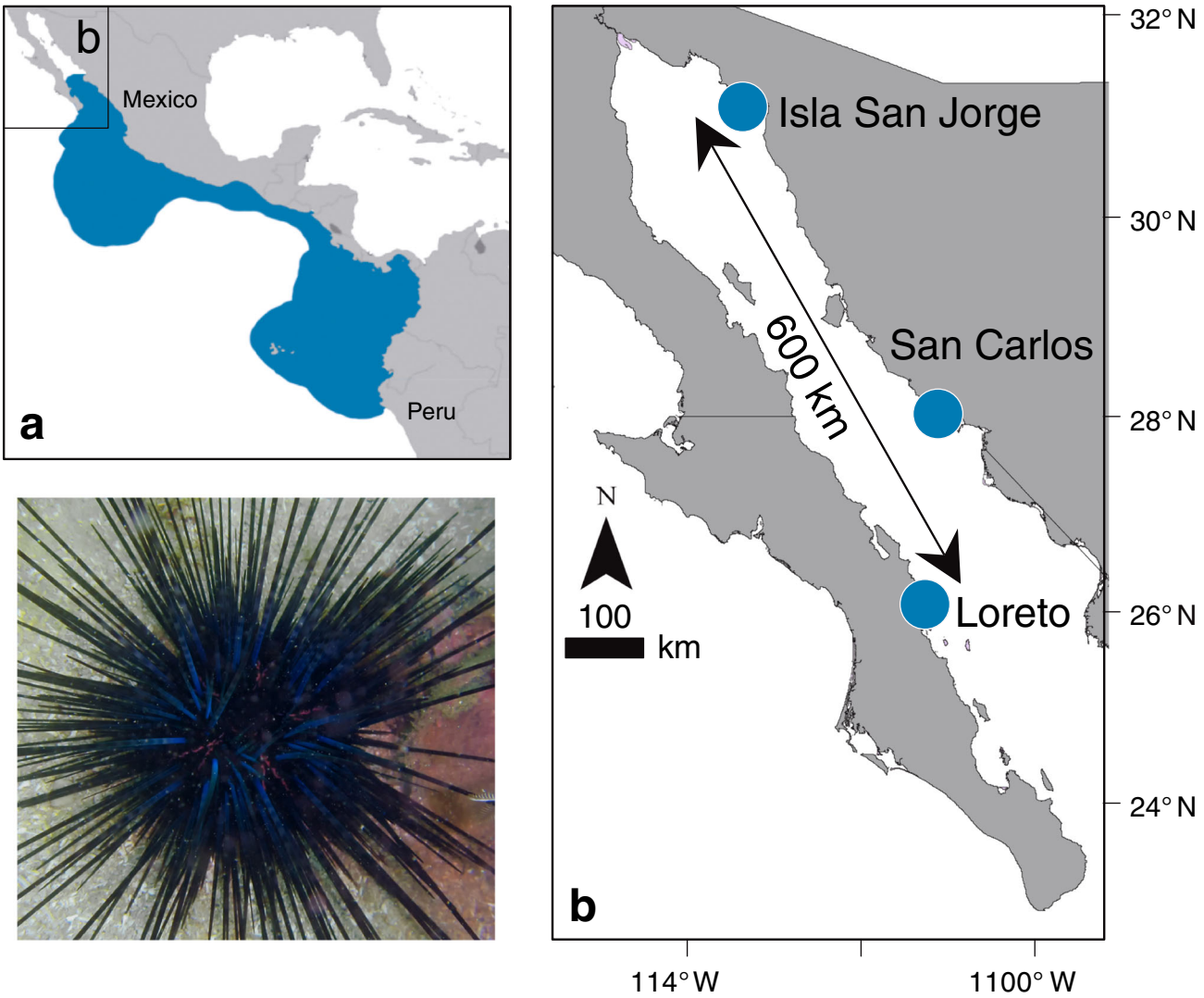

Fig. 1 **a** Distribution of *Diadema mexicanum* in the eastern tropical Pacific previous to this study. **b** Location of Isla San Jorge, a new record of *D. mexicanum* extending the range northward by 600 km. The picture of *D. mexicanum* shows the blue-purple vertical lines on each side of the genital pore that is extending to the ambitus, a characteristic trait of this species (Schultz 2010; Alvarado et al. 2015)

(Revillagigedos and Islas Marietas in Mexico, Isla del Coco in Costa Rica, and Las Perlas in Panama; Alvarado et al. 2016).

Several marine invertebrates are sensitive to fluctuations in seawater temperature. Although the rising temperatures worldwide may cause that marine species to shift their geographical range towards cooler environments (Yamano et al. 2011; Makino et al. 2014; Paz-García and Balart 2016), detailed information on such range shifts remains scarce.

Here, we report the occurrence of *D. mexicanum* in the upper Gulf of California, which extends its range an additional 600 km northward. This now represents the northernmost presence and one of the largest average sizes of this species in the eastern tropical Pacific.

Materials and methods

Surveys were conducted in September and October 2015 along the coast of the Gulf of California (supplementary material, Figure S1). In total, there were 20 sites in the middle and upper gulf (supplementary material, Table S1). Surveys and photographic records of *D. mexicanum* took place at depths of 2–5 m and

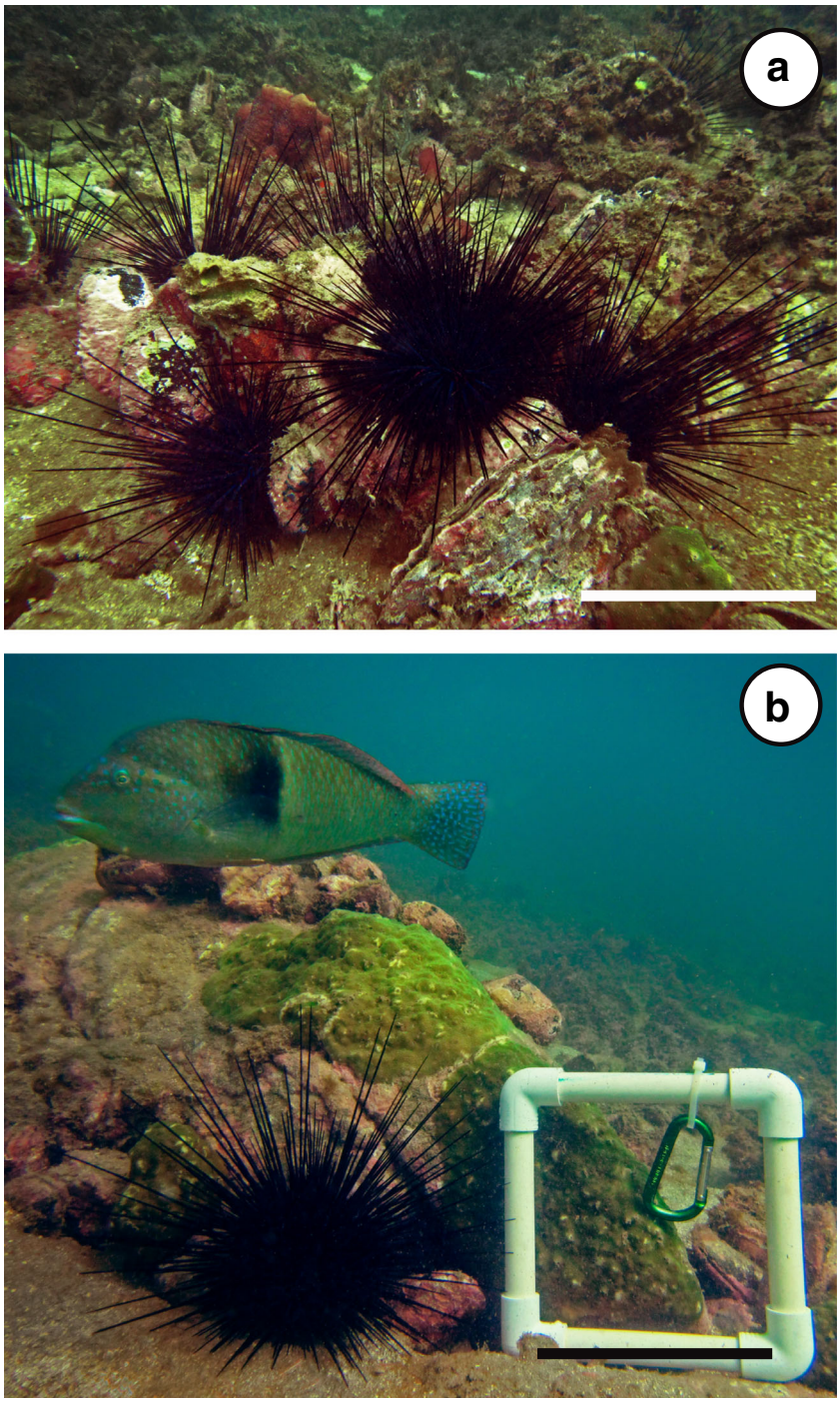

Fig. 2 **a** Sea urchins in the upper Gulf of California. **b** Largest sea urchin *Diadema mexicanum* found at Isla San Jorge in the Gulf of California. Scale bars = 15 cm. A quadrant of dimensions 20 × 20 cm is shown in **b**

10–15 m, spending 45 min at each depth. At Isla San Jorge, 20 sea urchins were photographed in situ with a Canon D30 camera. The test diameter and spine length of sea urchins was measured from photographs, using ImageJ 1.34 (http://rsb.info.nih.gov/ij/). Six to eight spines were measured per individual and images were calibrated with a 20 × 20-cm reference square. Additionally, 60 colonies of the scleractinian coral *Porites panamensis* were measured with the methods explained above to access reef development.

Results and discussion

We found two interesting results in our survey: one was the largest average size of the sea urchin *D. mexicanum* and its

northernmost distribution at Isla San Jorge, the most northern rocky island in the Gulf of California (Fig. 1b). Sea urchins had an average test diameter of 7.27 cm (SE ±0.43, $n = 20$) and a range from 4.5 to 12.4 cm at 2–6 m (Fig. 2a). The average size was larger than reports of this species in the eastern tropical Pacific, where the common test size is 3–4 cm and range from 0.37 to 12.30 cm (Alvarado et al. 2016). The spine length in sea urchins in the upper gulf averaged 8.8 cm (SE ±0.19, $n = 150$) and were 3.3–15.6 cm long. The largest sea urchin that we found at Isla San Jorge had a test size of 12.4 cm diameter and 12.9 cm spine length (Fig. 2b). Similar large individuals were reported at Isla del Coco in Costa Rica (12.30 cm; Alvarado et al. 2016). In general, the largest individuals are found in oceanic islands in the eastern tropical Pacific (Alvarado et al. 2016). Variation in the body size of sea urchins may reflect variation in food availability and more structurally complex reefs from isolated islands that provide shelter from predation (Alvarado et al. 2016). The reef structure of Isla San Jorge is formed by high coral cover of the scleractinian coral *P panamensis*, with an average colony height of 26.27 cm (SE ±1.58, $n = 60$; Fig. 3). Reef complexity and colony height was similar to coral reef communities of the southern Gulf of California (La Paz 24°N; Cabral-Tena et al. 2013).

Previously, the northern limit of *D. mexicanum* was reported at Loreto National Marine Park in the middle of the Gulf of California (26°07′ N; Holguín-Quiñones et al. 2000). Our findings extend the distribution 600 km northward to Isla San Jorge, off the coast of the State of Sonora (Fig. 1b). We also found *D. mexicanum* at La Manga (27°58′42″ N, 111° 8′ 2″ W), north of San Carlos, Sonora. This is ~200 km north of the islands in Loreto National Marine Park; Fig. 1b). Although we could not measure sea urchins in San Carlos due to high conditions of wave exposure, the average test size seemed similar to the southern populations of ~3–4 cm found by Alvarado et al. (2015, 2016). We did not find *D. mexicanum* in other locations along the coast of Sonora (supplementary material, Table S1). We assume that we were not able to find sea urchins in these locations because we avoided sites with high wave exposure and reefs with macroalgae communities, locations where *D. mexicanum* is usually abundant.

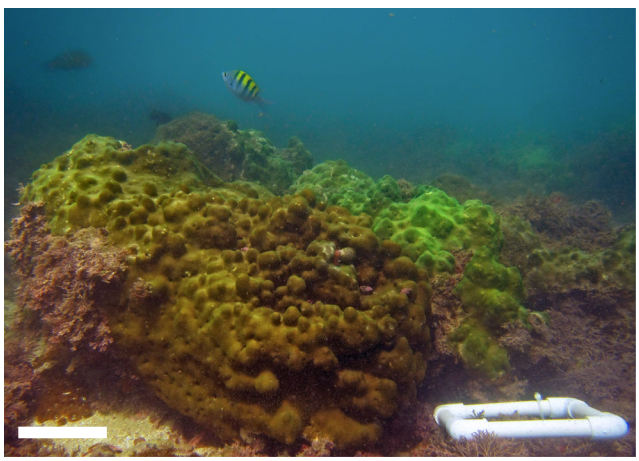

Fig. 3 Reef complexity formed by scleractinian coral *Porites panamensis*. Scale bar = 10 cm; quadrant dimensions = 20 × 20 cm

Although *D. mexicanum* is considered a great force of erosion to the substratum in reef environments in the eastern tropical Pacific, no evidence of erosion was observed at Isla San Jorge, indicating a balanced dynamic between herbivores, macroalgae, and corals.

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