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NOTA CIENTÍFICA

Earthquake induces mass-spawning event in two coral-reef sea cucumber species in Belize

Terremoto induce evento de desove masivo en dos especies de pepino de mar en arrecifes de coral en Belice

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ABSTRACT

Background. Electromagnetic pulses that precede earthquakes, and the ensuing crust deformations and vibrations, have been associated with unusual animal behavior (UAB), most commonly in terrestrial species but also in certain marine species, chiefly in the Chordata phylum (e.g. fish, cetaceans).**Goals**. This study explored the occurrence of earthquake-related UAB in an entirely new marine phylum, the Echinodermata. **Methods.** Formal and informal surveys conducted by fishing vessels pre- and post-earthquake along the southern coast of Belize (Central America) were collated. **Results.** The first cases of post-earthquake UAB in echinoderms were documented. They involved thousands of individuals of the holothuroids *Isostichopus badionotus* and *Holothuria mexicana* spawning on May 29, 2009 and January 10, 2018. These rare accounts represent the first direct correlation between an earthquake and spawning activity, which occurred outside the normal spawning season and at an unusual time of day. **Conclusions.** While a growing number of reports indicate that many terrestrial and a smaller number of marine species can change their behavior before and during an earthquake, post-earthquake effects related to reproduction have apparently never been reported before in the animal kingdom. While underlying mechanisms remain unclear, holothuroid echinoderms may be reacting directly or indirectly to seismic activity, or the pressure change generated by it.

Keywords*:* disturbance, echinoderm, *Holothuria mexicana, Isostichopus badionotus,* reproduction, unusual animal behavior

RESUMEN

Antecedentes. Los pulsos electromagnéticos que preceden a los terremotos y las consiguientes deformaciones y vibraciones de la corteza de la tierra han sido asociados con el comportamiento animal inusual (CAI), más comúnmente en especies terrestres sino también en ciertas especies marinas, principalmente en el filo Chordata (por ejemplo, peces, cetáceos). **Objetivos.** El presente estudio exploró la ocurrencia de CAI relacionada con terremotos en un filo marino completamente nuevo, el Echinodermata. **Métodos**. Se recopilaron encuestas formales e informales realizadas por barcos pesqueros antes y después del terremoto a lo largo de la costa sur de Belice (América Central). **Resultados.** Se document**ó** el primer caso de CAI post-terremoto en equinodermos. El caso involucró a miles de individuos de los holothuroidea*Isostichopus badionotus* y *Holothuria mexicana* desovando el 28 de mayo de 2009 y el 10 de enero de 2018, respectivamente. Estas ocurrencias raras representan la primera correlación directa entre un terremoto y la actividad de desove, que ocurrió fuera de la temporada de desove normal y en un momento del día inusual. **Conclusiones.** Mientras que un número creciente de informes indica que muchas especies terrestres y un número menor de especies marinas pueden cambiar su comportamiento antes y durante un terremoto, los efectos posteriores al terremoto relacionados con la reproducción, aparentemente nunca se han reportado antes en el reino animal.

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Si bien los mecanismos subyacentes siguen sin estar claros, los equinodermos holoturoideos pueden estar reaccionando directa o indirectamente a la actividad sísmica, o al cambio de presión generado por ella.

Palabras clave*:* comportamiento inusual, equinodermo, *Holothuria mexicana*, *Isostichopus badionotus,* perturbación, reproducción

Perturbations associated with earthquakes, such as changes in atmospheric pressure and gravity, ground deformations, acoustic signals and vibrations due to micro-crack generation, and the concurrent emission of gases and chemical substances, have been documented to cause unusual animal behaviors or UABs (Hayakawa, 2013). Moreover, Freund & Stolc (2013) showed that electronic charge carriers (called positive holes) were activated during the build-up of stress deep in the Earth before earthquakes. These positive holes can travel fast and far into the surrounding rocks, generating ultralow frequency electromagnetic waves, which may ionize air and generate hydrogen peroxides at the sea surface (Freund & Stolc, 2013). The latter authors suggested that the momentary disappearance of the toad *Bufo bufo* Linnaeus, 1758 in central Italy about 5 days before the L'Aquila earthquake of April 2009 (Grant *et al*. 2011) was triggered by chemical cues in the water, such as the release of hydrogen peroxide products resulting from an influx of hydron (cationic form of atomic hydrogen). Other variables related to earthquakes may be at play in the ocean, such as telluric currents produced through electromagnetic induction by the geomagnetic field or whenever a conducting body (e.g. seawater) moves because of tides or other processes across the Earth's permanent magnetic field (Lanzerotti & Gregori, 1986). These low-frequency currents travel large distances near the surface of the Earth (Lanzerotti & Gregori, 1986). In addition, amplitude anomalies of the telluric field have been detected before shallow earthquakes with magnitudes ≥ 4.5. These amplitude anomalies reached about 100-300 mv km^{-1} 3-16 days before the earthquake (Myachkin *et al*. 1972). All the above-mentioned earthquake-related changes (Nagao *et al*. 2002) have been identified as sources of UAB (Freund & Stolc, 2013), including in aquatic animals (Tributsch, 1982). For instance, geomagnetic sensitivity was related to stranding of dolphins and whales (Kirschvink, 1990), and of Humboldt squids (Than, 2009).

Here we describe for the first time an UAB in a member of the Echinodermata phylum and a side effect recorded post-earthquake. Monitoring the seafloor down to 5 m occurred during daily fishing activities in Belize (Central America) that included sea-cucumber harvests south of Laughing Bird Cay and in Port Honduras in 2009 and 2018, respectively. On January 9, 2018 at 21:51, an earthquake of magnitude 7.6-7.8 was recorded 200 km off the Caribbean coast of Belize. Aftershocks of magnitude 4.2-5.0 followed in the evening and early the following day. The earthquake had a shallow focus (~10 km) which amplified its effects, i.e., increased shaking/vibration levels (USGS, 2018). No tsunami was generated. In the morning of January 10, around 07:00, two species of coral-reef sea cucumbers, *Isostichopus badionotus* Selenka, 1867 and *Holothuria mexicana* Ludwig, 1875, underwent a mass-spawning event involving thousands of individuals (from the shore to ~5 m depth) in the entire Fore Reef (about 3.2 km^2). This spawning was uncharacteristic in that it was outside the normal reproductive season and occurred at sunrise rather than at sunset, as is usually the case (Mercier *et al*. 2007). While these sea cucumbers normally shelter in sand, seagrass, or among corals (especially from early morning to late afternoon), most individuals had emerged and displayed their typical spawning posture while broadcasting gametes in the water column (Fig. 1) in full daylight (the inverse of normal behavior). Inside a shoal area measuring 3.2 km long by about 1 km wide (16°12'05.61" N; 88°40'04.97" W), which was composed of patch reef and seagrass, nearly 100% of females and males (representing a maximum of 1-3 ind m^{-2}) spawned simultaneously for a duration of about 2 h (sexes determined based on the distinct appearance of male and female gametes in the water column). The water temperature was 30.9 °C, the salinity 33.6, with a recorded rainfall of 34.5 mm over the previous 24 h. There was no correlation with the full or new moon (as spawning after the earthquake occurred 2 days after the third moon quarter), or with the low or high tide or any

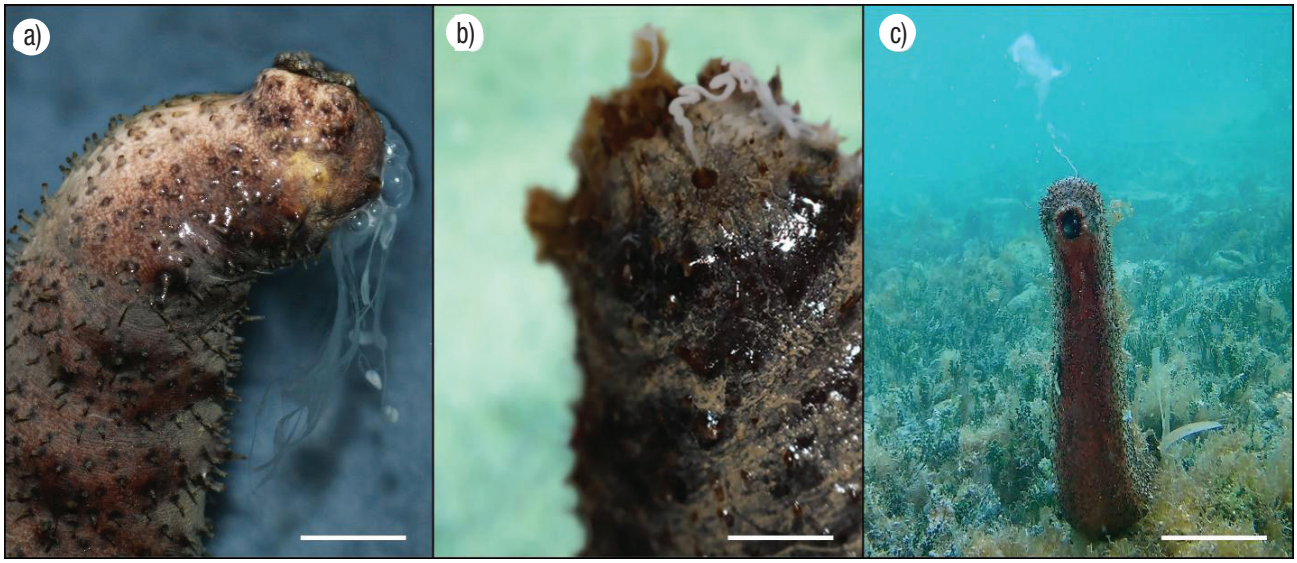

Figure 1 Close-up view of a spawning **a** male and **b** female of *H. mexicana* Ludwig, 1875 (photos Arlenie Rogers); **c** broader view of a spawning male of *H. mexicana* (photo Víctor Alamina). Scale bar: 3 cm in **a**, 1.7 cm in **b**, 5 cm in **c**

broad environmental factor known to coincide with the spawning period of those species in the study region, including a phytoplankton bloom (Rogers *et al*. 2018).

Despite a growing number of reports indicating that certain terrestrial and marine species can display unusual behaviors before and during earthquakes (Bhargava, 2009), to our knowledge no impact on the timing of reproduction has ever been documented in the animal kingdom. The present observation may also be the first to show the influence of an earthquake on a non-vertebrate marine benthic taxon. While explaining correlations of this magnitude is complex, it may be suggested that sea cucumbers are able to detect seismic events directly or indirectly, through anomalous telluric current changes, changes in atmospheric pressure, and changes in gravity, acoustic signals, vibrations, or ultralow frequency electromagnetic waves generated by earthquakes (Hayakawa, 2013). Exposure to physical stress is a common technique used to artificially induce sea cucumbers to spawn in captivity, especially in aquaculture facilities (Mercier & Hamel, 2009), and it can be assumed that earthquakes generate similar stressors. Despite the present spawning event was only confirmed from one area of the extensive coral reef system of Belize, it is not impossible that the phenomenon occurred in other locations along the coast. An anecdotal correlation between mass spawning of the same sea cucumber species and an earthquake was observed in Belize ~4 hours after the 7.3 magnitude earthquake that occurred at 03:24 on May 28, 2009 (Héctor Saldívar, pers. comm., September 2011), supporting this assertion and the potential disruptive impact of earthquakes on sea cucumber reproduction. If non-mature gametes are released in full daylight under out-of-phase conditions, development failure and higher predation pressure are likely to exacerbate propagule mortality rates.

Overall, the reaction to earthquake documented here may be interpreted as a strategy developed by slow-moving species to survive dangers by releasing dispersive pelagic propagules. It remains unclear how sea cucumbers might detect seismic events, although electric or electromagnetic sensitivity are probable candidates.

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