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High Density of the Black Sea Cucumber *Holothuria atra* off Hsiao Liouciou Island, Southern Taiwan

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Abstract

This article reports unusually high density and abundance of the black sea cucumber *Holothuria atra* on an intertidal reef platform at "Duzaiping," a reef off Hsiao Liouciou Island (22°20′55″N, 120°21′49″E), Southern Taiwan. Density reached 80.75±11.94 individuals m^{-2} (mean±std.dev; n=10), with the average being 5.60±1.42 individuals m^{-2} (n=20); both values are the highest ever recorded, and 198,240 sea cucumbers were estimated to be present across a 35,400 m^2 study area. The high abundance of the sea urchin *Echinometra mathaei*, which can provide abundant food (sand) and shelter to *H. atra* through its extensive burrowing activity, could explain these high densities and total numbers, as could the ability of *H. atra* to reproduce via binary fission.

Key words: Asexual reproduction, Echinoderm, *Echinometra mathaei*, *Holothuria atra*, Holothurian, Sea cucumber, Sea urchin

Introduction

Holothurians are ecologically important deposit feeders that can change the overall character of the marine benthos through their metabolic activity. Given their consequent role in marine nutrient cycling, declines in sea cucumber populations may dramatically alter reef communities (Viyakarn et al., 2020). *Holothuria atra*, which is widely distributed in the shallow waters of Indo-Western Pacific coral reefs and is the most common aspidochirotid holothurian on many tropical reef flats therein (Clark & Rowe, 1971; Conand & De Ridder, 1990), plays a particularly important role in reef

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nutrient cycling and can exhibit blooms on account of its ability to reproduce via binary fission (Pearse, 1968; Harriott, 1982; Chao et al., 1993).

Sea cucumber fisheries have developed rapidly in tropical waters over the last few decades due to high demand on the international market (Conand, 2004; Lovatelli et al., 2004; Choo, 2008). This increasing demand for sea cucumbers is causing over-exploitation of most high-value species (Setyastuti, 2014). Therefore, fisheries management has been shifting towards low-value ones such as *H. atra* (Lovatelli et al., 2004; Dissanayake & Stefansson, 2012). Nowadays, most Taiwanese do not harvest sea cucumbers except for some fisher folk from the Pescadores Island (a.k.a. Penghu; 23°34'N, 119°34'E) off Western Taiwan. Prior to 1990, however, the population of *H. atra* at Duzaiping, Hsiao Liouciou Island (Southwestern Taiwan) was nearly depleted by these fisher folk (authors' personal observations) before harvesting eventually stopped due to the consequent diminishing catch returns. Our preliminary survey of this species conducted in 1991 recorded only a few individuals (unpublished observations). Thirty years after the fishery's collapse, however, we noticed *H. atra* had recovered to an unusually high density. Herein we sought to characterize this bloom while attempting to speculate on the possible causes underlying it.

Materials and methods

Hsiao Liouciou Island is a small reef island of 6.8 km^2 in area. It is located about 14 km offshore from the coast of Southwestern Taiwan (Fig. 1A). The monthly average seawater temperature is 25.0-29.4°C (data from the Central Weather Bureau of Taiwan). "Duzaiping" (22°20′55″N, 120°21′49″E) is a wide, intertidal reef platform about 640 m in (coastline) length and 50 to 80 m wide at high to low tide, respectively (Fig. 1B). We surveyed an area of ca. 35,400 m^2 that included almost the entire reef platform in May and June 2020 (three survey days in each month). This platform is flat, with many shallow tide pools. Abundant black sea cucumbers (*H. atra)* share these pools with the burrowing sea urchin *Echinometra mathaei* (Fig. 2). In May 2020, we recorded high sea cucumber densities on this platform in tidal pools in the mid to low tide range and consequently carried out surveys using 10 0.5 m X 0.5 m quadrats during low spring tide to estimate density. To additionally estimate the total numbers, we deployed 20 belt transects (1 m X 50 to 80 m from the high tide line to the low tide line, respectively, i.e., varying

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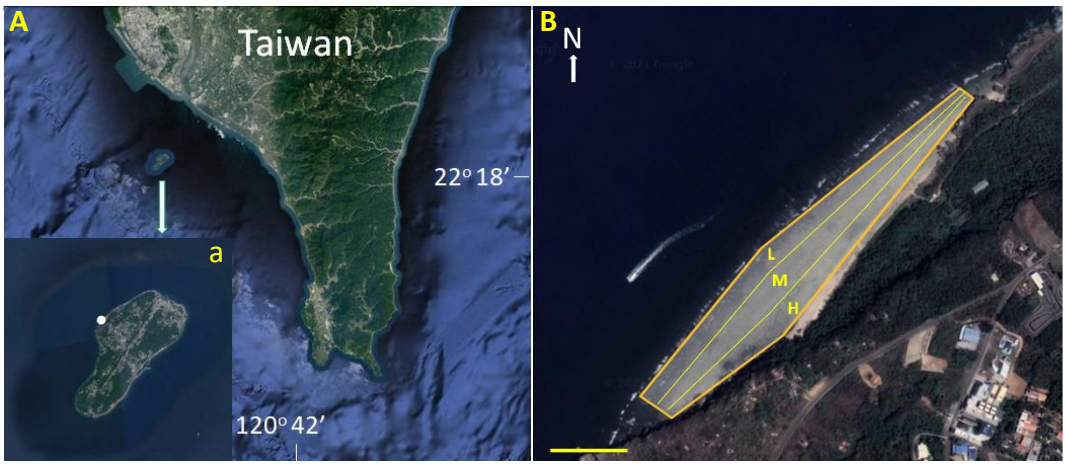

Fig. 1. Study site. A: Map showing Hsiao Liouciou Island off Southern Taiwan. Inset-a: Hsiao Liouciou Island, with a white dot showing location of Duzaiping. B: Aerial photograph of the 35,400 m^2 intertidal reef platform at Duzaiping; L, M, H, represent low, mid, and high tide areas, respectively; scale bar=100 m. "Snapshots" from Google Earth 2021 (Data SIO, NOAA, U.S. Navy, NGA, GEBCO Land Sat/Copernicus).

Fig. 2. Abundant *Holothuria atra* sharing a lower intertidal pool with sea urchins (*Echinometra mathaei*). Although these sea cucumbers are normally all black, the majority of their bodies were coated in sediments. Scale = 10 cm.

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with the width of the intertidal zone) in June 2020. Transects were 30 m apart, and we counted the number of *H. atra* in each belt transect (thereby covering an area totaling 1,300 m^2).

To determine the percentage of sea cucumbers undergoing fission, we randomly collected 367 individuals for visual examination. Individuals were categorized as either intact (no external signs of fission or regeneration) or divided (having external signs of regeneration). Bodies of individuals recently resulting from fission are short, stout, and lack head or anus; a regenerating anterior end has a small, narrow posterior end, and a regenerating posterior end has a small, narrow, anterior end (Chao et al., 1993) (Fig. 3).

Results and Discussion

The highest density of *H. atra* documented was 80.75±11.94 (mean±std.dev; n=10) individual m^{-2}, with the mean being 5.60±1.42 (n=20) individuals m^{-2}. This equates to 198,240 sea cucumbers across the 35,400 m^2 site. Upon perusing the literature (Tab. 1), this was found to be the highest density ever recorded, with the second highest being at nearby Wanlitung (Southern Taiwan; 21°59'N, 120°42'E) within Kenting National Park (Chao et al., 1993); indeed, harvesting of sea cucumbers is not permitted there (Chao et al., 1993). Harvesting of marine life from Hsiao Liouchiou is also prohibited by the local government of Pingtung County and has been for 30 years. This is partially because the island is commonly frequented by tourists, and the local residents and managers have attempted to preserve the marine habitats for the enjoyment of their visitors and descendants. The average density of *H. atra* at Duzaiping was 3.5 times higher than Wanlitung, and densities within tide pools were as much as 58 times higher. Both sites reflect the fact that, without disturbance, *H. atra* may reach astonishingly high levels of abundance; 30 years after fishing was halted (due to stock collapse & the aforementioned local governmental protection), the once-small population has grown to the highest ever recorded.

At Duzaiping, *H. atra* was often found nearby the burrowing sea urchin, *E. mathaei*, which was also abundant: density=21-35 individual m^{-2}. This sea urchin burrows into the carbonate platform of the intertidal zones of tropical reefs, a process that produces an abundance of sand that serves as a vector/reservoir of the preferred food particles of *H. atra*. As such, the high urchin densities could have driven the high densities of *H. atra* at Duzaiping. The burrows and holes made by these urchins are also the preferred lairs of *H.*

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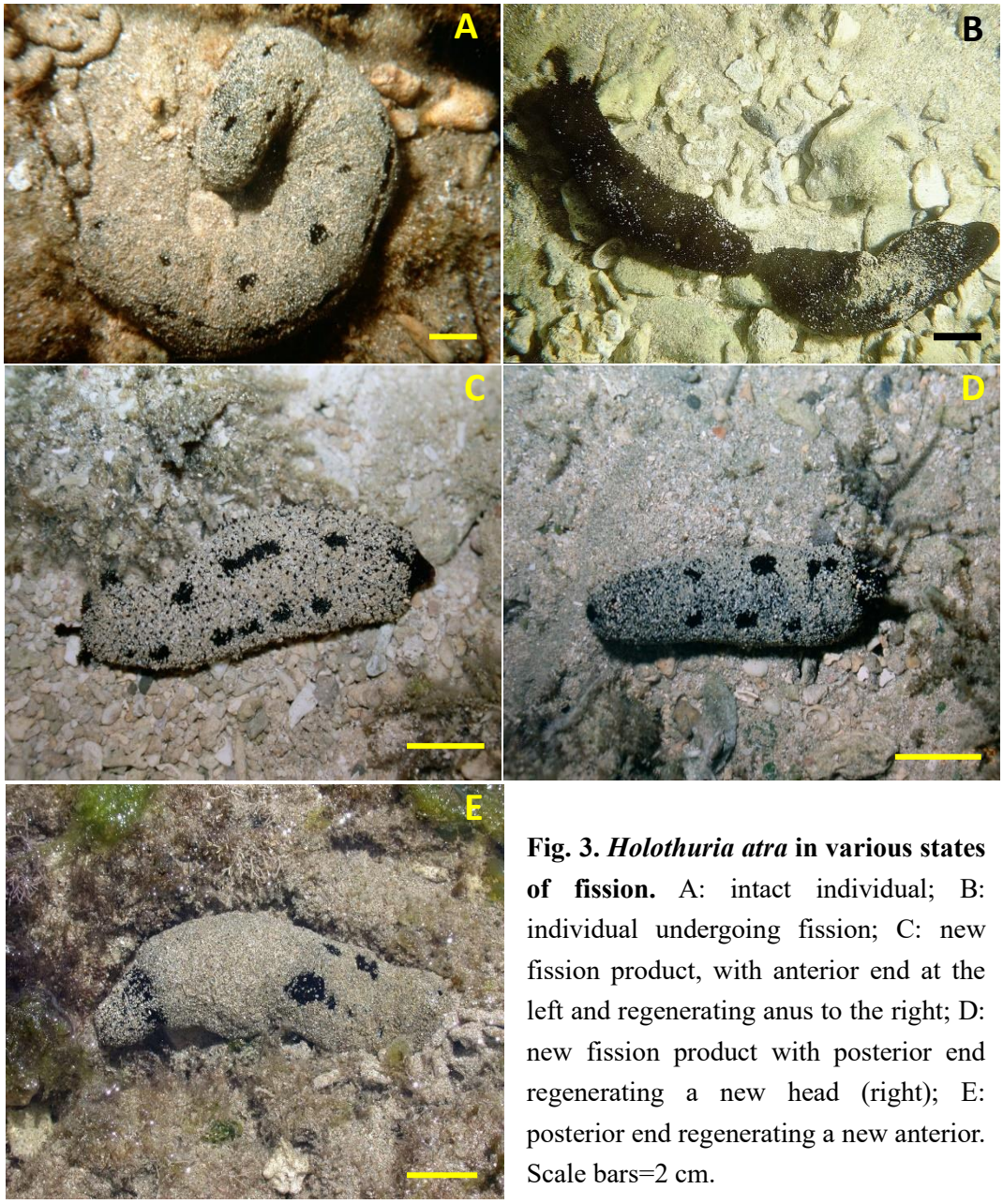

Fig. 3. *Holothuria atra* in various states of fission. A: intact individual; B: individual undergoing fission; C: new fission product, with anterior end at the left and regenerating anus to the right; D: new fission product with posterior end regenerating a new head (right); E: posterior end regenerating a new anterior. Scale bars=2 cm.

atra; collectively, then, the near-symbiotic relationship between *H. atra* and *E. mathaei* probably promoted the extraordinarily high abundance of *H. atra* at Duzaiping.

Of the 367 individuals examined, 129 (35%) were either recent fission products or were in the process of dividing (Fig. 3).

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Tab. 1. Density of *Holothuria atra* at different sites around the Indo-Pacific.

Latitude	Location	Habitat and/or associated fauna	Density (ind. m^{-2})	Source
22°20′N	Duzaiping: SW Taiwan	Reef platform	5.60	Herein
22°N	Wanlitung: tip of Southern Taiwan	Reef platform	1.59	Chao et al. (1993)
7°50'S	East Java, Indonesia	Seagrass beds	0.49	Setyastuti (2014)
8°N	Gulf of Thailand	Soft coral, hard coral, algae, rock, rubble, sand	0.2-0.5	Viyakarn et al. (2020)
19°50'-20°32'S	Mauritius	Lagoons: sand, live coral, coral rubble, seagrass, macroalgae, rocks	0.05-0.39	Lampe (2013)
11°22'N	Philippines	Mangroves	0.006	Romero (2014)
18°10'S	Fiji	Coral & sandy substrates	0.00125	Lalavanua et al. (2014)

Uthicke (1997) studied *H. atra* at Fantome Island on the Great Barrier Reef and estimated that at least 76% of all individuals underwent fission each year. Binary fission of *H. atra* is an important means of recruitment (Bonham & Held, 1963; Bakus, 1973; Ebert, 1978; Doty, 1977; Emson & Wilkie, 1980), and asexual reproduction indeed appears to drive the population dynamics of *H. atra* in tropical waters (Chao et al., 1993, 1994). Pearse (1968) suggested that fission of *H. atra* may be more frequent in surf-swept intertidal areas. This is supported by Harriott's (1982) finding of greater fission frequency in gutter and mid-reef habitats than in lagoonal habitats. We also noticed abundant small-sized individuals resulting from fission in the middle and lower tide zone pools.

Chao et al. (1993) inferred that fission at Wanlitung is probably triggered

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by stress-inducing levels of solar radiation during low spring tides, and, given overall similarities between Duzaiping and Wanlitung (i.e., wide intertidal reef platforms with abundant fission-produced populations of *H. atra* in tidal pools in the mid & low tide zones), similar abiotic factors could be promoting the high rates of fission at these sites.

Transplantation of sea cucumbers from these "hot spots" to over-exploited areas may help in ecosystem restoration efforts, especially if the outplant sites are already characterized by high densities of burrowing sea urchins (e.g., *E. mathaei*).

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