國立海洋生物博物館
NATIONAL MUSEUM OF MARINE BIOLOGY & AQUARIUM
Platax 20: 79-87, 2023
doi: 10.29926/platax.202312_18.0007

Mass mortality of the black sea cucumber *Holothuria atra* after heavy rainfall at Hsiao Liouciou Island, Southern Taiwan

Shu-Yu Chao[1], Li-Lian Liu[2], Chen-Pan Liao[3], and Shyh-Min Chao[3*]

[1, 2] Department of Oceanography, National Sun Yat-sen University, Kaohsiung, Taiwan

[3] National Museum of Natural Science, Taichung, Taiwan

[*]Corresponding author. Email: chaosm@mail.nmns.edu.tw

Abstract

In August 2021, after 15 days of heavy rainfall, a mass mortality event of the common black sea cucumber *Holothuria atra* was observed in the intertidal zone of "Duzaiping," Hsiao Liouciou Island, Southern Taiwan. The density of *H. atra* halved: from 5.60±1.42 m^{-2} individuals (mean±std.dev; n=20) in May of 2020 to 2.66±1.34 individuals m^{-2} (mean±std.dev; n=5) in September of 2021. The total number dropped from 198,000 to 94,000 across a 35,400 m^2 study area (mortality rate=52.5%). We surmise that the continuous heavy rainfall, in addition to high temperatures during low tide, were the major contributing factors that led to this sea cucumber die-off.

Keywords: *Holothuria atra*, marine ecology, mass mortality, rainfall, sea cucumber, Taiwan

Introduction

Mass mortality events have the capacity to drive persistent ecosystem changes (Hughes, 1994). Reports of mass mortalities of echinoderms have been largely anecdotal, despite their worldwide occurrence, and such unfortunate events provide insight into the nature of the impacts of both biotic and abiotic stressors on echinoderm population biology and community ecology (McClintock *et al*., 2018). Jurgens *et al*. (2015) tabulated mass mortality events of benthic marine species that had been documented across the globe between 2000 and 2013, and most of those featuring echinoderms were reports of sea urchins (*Paracentrotus lividus, Strongylocentrotus droebachiensis, Diadema mexicanum,* & *Strongylocentrotus purpuratus*) and sea stars (*Leptasterias* sp. & *Pisaster ochraceus*). In this table, no large-scale death of sea cucumbers was recorded. It can be seen that sea cucumbers rarely occur in large-scale death events. Disease

國立海洋生物博物館
NATIONAL MUSEUM OF MARINE BIOLOGY & AQUARIUM
Platax 20: 79-87, 2023
doi: 10.29926/platax.202312_18.0007

and high seawater temperatures were thought to be the major causes of many of the documented die-offs, though low salinity contributed to the decline of *S. purpuratus* in Hendler (2013).

Lawrence (1996) reviewed the abiotic factors that were responsible for mass mortality of echinoderms, with nine identified: volcanic activity, earthquakes, storms (obrution, current and waves), temperature and desiccation, salinity, hypoxia, noxiousness from phytoplankton toxins, ice, and pollutants. Of those driven by low salinity, most were related to riverine discharge, though heavy rains were to blame in some cases. In this review article, the mass deaths caused by reduced salinity are mostly sea urchins, but there are also three species of sea cucumbers (*Pentacucuma spyridophora, Thyone aurea and Opheodesoma spectabilis*). Decreased salinity from land runoff causes mass mortality of *Opheodesoma spectabilis* on reef flats at Hawaii if it occurs during low tide (Berrill, 1966).

Holothuria atra is widely distributed in the shallow waters of Indo-Western Pacific coral reefs and is the most common and abundant aspidochirotid holothurian on tropical reef flats (Clark & Rowe, 1971; Harriott, 1982; Conand & De Ridder, 1990). It is amongst the most conspicuous fissiparous species and presents one of two phenotypes: a small form (~<200 g) that reproduces asexually and a large one (~>300 g) that appears to reproduce only sexually (Chao *et al*., 1993). Given its abundance, it plays an important role in nutrient cycling on reefs and in the intertidal zone (Bonham & Held, 1963). On August 18, 2021, after 15 days of heavy rainfall, we noticed numerous dead *H. atra* on the intertidal reef flat at Hsiao Liouciou Island, Southern Taiwan. In 2020, we reported that this study site had the highest density of *H. atra* in the world (Chao *et al*., 2021). Herein we quantitatively characterize the decrease in both total number and density of this common sea cucumber after this disaster.

Materials and methods

The location and general environmental characteristics of the study site (Fig. 1) have been described by Chao *et al*. (2021). It is blocked by raised limestone rock at both ends forming a closed intertidal zone with ca. 650 m coastline. The distance from high tide line to low tide line is about 50 to 80 meters (Figure 1). It is a flat reef platform and contains many tide pools. The dominant species are *H. atra*, which is mostly distributed in mid- and low-tide areas. Other common species of echinoderms include sea urchins (*Echinometra mathaei, Stomopneustes variolaris*) and brittle star (*Ophiocoma scolopendrina*).

國立海洋生物博物館
NATIONAL MUSEUM OF MARINE BIOLOGY & AQUARIUM
Platax 20: 79-87, 2023
doi: 10.29926/platax.202312_18.0007

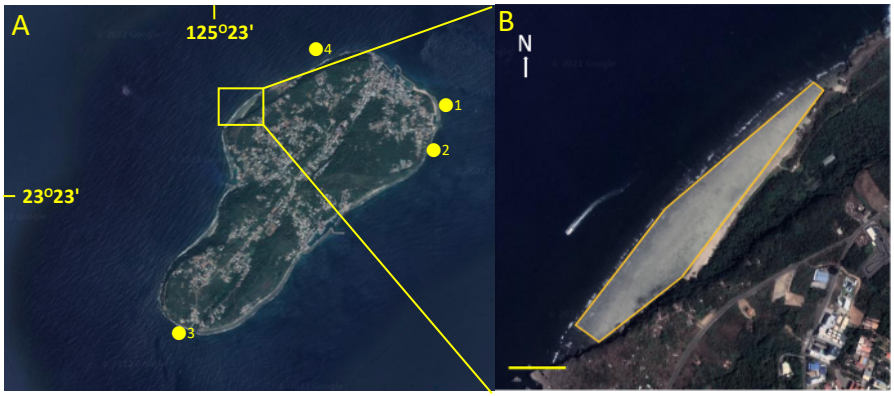

Fig. 1. Study area. A: Map showing Hsiao Liouciou Island. 1=Yuchengwei, 2=Lobster Cave, 3=Haizikuo, 4=Beauty Cave. Salinity was measured at each, and surveys were carried out Duzaiping. B: Aerial photograph of the 35,400 m^2 intertidal reef platform at Duzaiping. Scale bar=100 m. These "snapshots" were from Google Earth (accessed in 2021).

Heavy rain started from July 28 to August 14. After four days, on August 18 and 19, 2021, mass mortality of black sea cucumbers was observed. Pictures were taken, and seawater salinity and temperature were measured. We use a refractometer to measure the surface water temperature and salinity in tide pools (n=3) in the mid-tide area during low tide. The depth of the tide pool is 10 to 15 centimeters. In addition to the study site, we measured salinity at four other sites in the vicinity from 12 to 21 August during or after the heavy rainfall (Fig. 1A). Precipitation data were acquired from the Central Weather Bureau of Taiwan via their website.

On September 18, 2021 (one mother after mass mortality was observed), we used quadrats and belt transects to estimate sea cucumber density and abundance at Duzaiping. As higher sea cucumber densities on this shallow platform occurred in tidal pools (low- to mid-tide range), we deployed ten 0.5 m x 0.5 m quadrats during low tide to estimate density. To additionally estimate the total number and average density, we deployed five belt transects (1 m x 80 m from the high tide to the low tide line). Transects were 50-m apart, and we counted the number of *H. atra* in each belt transect (thereby covering an area totaling 400 m^2). The positions of the transect lines and quadrats were as similar to those of our 2020 surveys as possible (Chao *et al.*, 2021).

國立海洋生物博物館
NATIONAL MUSEUM OF MARINE BIOLOGY & AQUARIUM
Platax 20: 79-87, 2023
doi: 10.29926/platax.202312_18.0007

Results and Discussion

Fig. 2 shows the daily rainfall between July and August of 2021 at Hsiao Liouciou Island. From July 28 to August 14, except for three days, over 50 mm of rain fell on each of 15 days, with a particularly intense rainfall on Aug. 1 (275 mm of rain over the course of the day). The salinity was 15±0 ‰ (mean±std.dev; n=3) and the temperature was 37-39ºC (n=3) in the tide pools at Duzaiping, where hundreds of dead sea cucumbers were observed on August 18, 2021 (Fig. 3). At the other four study sites off the coast (Fig. 1 & Tab. 2), salinity ranged from 0 to 16, highlighting the immense degree of salinity stress experienced by local marine organisms after this particularly rainy period.

The next day (19 August), many dead sea cucumbers washed up on the beach (Fig. 5), and a strong, rotten smell permeated the air. On Sept. 18, 2021, one month after this mass mortality, the density in the formerly densest areas (lower inner tidal area) dropped from 80.75±11.94 (mean±std.dev; n=20) individuals m^{-2} (May 2020, Chao *et al.* 2021) to 49.40±11.82 (mean±std.dev; n=10) individuals m^{-2}. The average density of

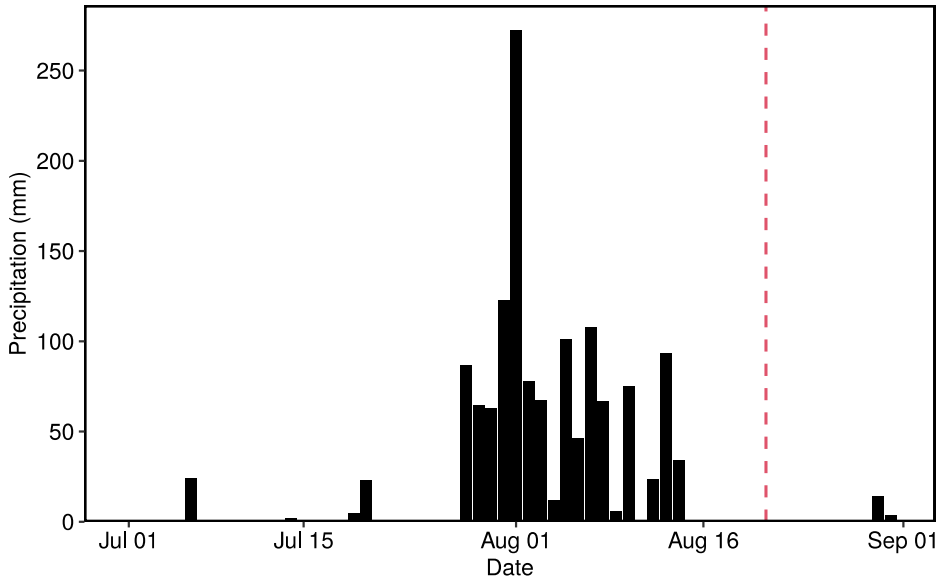

Fig. 2. Precipitation through July and August 2021 at Hsiao Liouciou Island. Black bars depict the total daily precipitation. The red dashed line indicates the date of the mass mortality event (18 Aug.). The rainfall data were from the Central Weather Bureau of Taiwan's website (//https://www.cwa.gov.tw/V8/C/).

國立海洋生物博物館
NATIONAL MUSEUM OF MARINE BIOLOGY & AQUARIUM
Platax 20: 79-87, 2023
doi: 10.29926/platax.202312_18.0007

five belts drop from 5.6±1.42 (mean±std.dev; n=20) individuals m^{-2} (May 2020) to 2.66±1.34 (mean±std.dev; n=5) individuals m^{-2}. The total number estimated by belt transects dropped from 198,000 (May 2020) to 94,000 individuals across this 35,400 m^2 study area. This 52.5% decrease is primarily attributed to this mass mortality event. In fact, we almost did not find a single living *H. atra* in the mid- and high-tide areas (i.e., from the high tide line to 45-m seaward). Most live individuals were found in the tidal pools near the low tide area.

Fig. 3. Numerous dead *H. atra*, one *H. cinerascens* (the brown individual), and two sea urchin tests in a tide pool at Duzaiping. Scale bar=10 cm.

Fig. 4. One large (476 g) and several small, dead *H. atra* in a tide pool at Duzaiping. Scale bar=10 cm.

國立海洋生物博物館
NATIONAL MUSEUM OF MARINE BIOLOGY & AQUARIUM
Platax 20: 79-87, 2023
doi: 10.29926/platax.202312_18.0007

Fig. 5. Many dead *H. atra* that had washed onto the shore after heavy rainfall on August 19, 2021 at the main study site of Duzaiping (Fig. 1). Scale bar=10 cm.

Both small (<50 g) and large sea cucumbers (>400 g) were affected by this event (Figs. 3-5). We deduce that this catastrophe was caused by heavy rainfall accompanied with high temperatures during low tides in the summer. Tab. 1 lists several other sea cucumber mass mortality events from the literature. Most involved a sudden increase in river discharge, but a few were due to heavy rains in restricted areas (Lawrence, 1996). Mass mortality of *Opheodesma spectabilis* on reef flats of Hawaii was triggered by decreased salinity from land-based runoff caused by heavy rainfall in Berrill (1966). This study is very similar to ours. Heavy rainfall on the island flowed into inshore areas caused this mass mortality could be the cause. Echinoderms are generally considered to be stenohaline (Russell, 2013), and Tuwo *et al*. (2020) noticed an increase of mortality of the commercially important sea cucumber *Holothuria scabra* (sandfish) during the rainy season; indeed, they suggested that, for cultivation in coastal ponds, salinity should not be allowed to fall below 18 ‰. Although *Apostichopus japonica* can tolerate a range of salinity from 22 to 36 ‰, most sea cucumbers cannot survive at salinities <16 ‰ (Yuan *et al*., 2006). Salinity measured from our five study sites of Hsiao Liouciou Island in August ranged from 0 to 16 (Tab. 2) during and after the heavy rainfall. Additionally, low spring tides during summer normally occur around noon in Southern Taiwan (Chao *et al*., 1994), the period at which temperatures are highest. Such extreme temperatures could have exacerbated the low-salinity stress experienced by *H. atra* at Hsiao Liouciou. As temperatures continue to climb on account of anthropogenic climate change (IPCC, 2013), it will be critical to continue to

國立海洋生物博物館
NATIONAL MUSEUM OF MARINE BIOLOGY & AQUARIUM
Platax 20: 79-87, 2023
doi: 10.29926/platax.202312_18.0007

Tab. 1. Mass mortality events of holothurians.

Species	Location	Causes	Effect	Reference
Cucumaria saxicolo	North Wales, Britain	Severe wintry weather	Mass mortality	Crisp, 1964
Opheodesma spectabilis	Reef flats of Hawaii	Decreased salinity from land-based runoff	Mass mortality	Berrill, 1966
Cucummaria planci *Holothuria tubulosa* *Thyone fusus*	Gulf of Trieste, Slovenia	Hypoxia attributed to a strong thermocline	Mass mortality	Stachowitsch, 1984
Pentacucuma spyridophora *Thyone aurea*	Off the coast of South Africa	Reduced salinities resulting from riverine floods	100% mortality	Branch *et al*., 1990
Holothuria princeps	Florida Panhandle	Low temperature-induced stress	Mass mortality	McClintock *et al*., 2018
Holothuria atra	Reef flats of Hsiao Liouciou Island, Taiwan	Decreased salinity from land-based runoff caused by heavy rainfall	Mass mortality (52.5%)	Herein

establish not only baseline marine ecosystem data, but also more thoroughly document mass mortality events such as these as a means of evaluating future climate impacts (McClintock *et al*., 2018). We expect that more frequent and extreme storm events driven by climate change, in addition to the associated higher seawater temperatures, will lead to an increasing number of mass mortality events of marine organisms in both Southern Taiwan and elsewhere.

國立海洋生物博物館
NATIONAL MUSEUM OF MARINE BIOLOGY & AQUARIUM
Platax 20: 79-87, 2023
doi: 10.29926/platax.202312_18.0007

Tab. 2. Mass Salinity from 10 to 20 August 2021 at five localities on Hsiao Liouciou Island (Fig. 1).

Location	Beauty Cave	Lobster Cave	Duozaiping	Yuchengwei	Haizikou
Date (August 2021)	10	12	18	19	20
Salinity	0 - 16	6	15	10	7

References

Berrill, M. 1966. The ethology of the synaptid holothurian, *Opheodesoma spectabilis*. Canadian Journal of Zoology, 44: 457-482.

Bonham, K. & E.E. Held. 1963. Ecological observations on the sea cucumbers *Holothuria atra* and *H. leucospilota* at Rongelap Atoll, Marshall Islands. Pacific Science, 17: 305-314.

Branch, G.M., S. Eekhout & A.L. Bosman. 1990. Short-term effects of the 1988 Orange River floods on the intertidal rocky-shore communities of the open coast. Transactions of the Royal Society of South Africa, 47: 331-354.

Chao, S.M., C.P. Chen & P.S. Alexander. 1993. Fission and its effect on population structure of *Holothuria atra* (Echinodermata: Holothuroidea) in Taiwan. Marine Biology, 116: 109-115.

Chao, S.M., C.P. Chen & P.S. Alexander. 1994. Reproduction and growth of *Holothuria atra* (Echinodermata: Holothuroidea) at two contrasting sites in Taiwan. Marine Biology, 119: 565-570.

Chao, S.Y., S.K. Chang & S.M. Chao. 2021. High density of the black sea cucumber *Holothuria atra* off Hsiao Liouciou Island, Southern Taiwan. Platax, 18: 17-24.

Clark, A.M. & F.W.E. Rowe. 1971. Monograph of shallow-water Indo-West Pacific echinoderms. Trustees of the British Museum (Natural History) London, No. 690, 1-238, plates 1-31.

Conand, C. & C. De Ridder. 1990. Reproduction asexuee par scission chez *Holothuria atra* (Holothuroidea) dans des populations de platiers recifaux. In De Ridder C., P. Dubois, M. Jangoux & M.C. Lahaye (eds.) Echinoderm research. Balkema, Rotterdam, pp 71-76 (in French).

Crisp, D.J. 1964. Mortalities in marine life in North Wales during the winter of 1962-1963. Journal of Animal Ecology, 33: 190-197.

Harriott, V.J. 1982. Sexual and asexual reproduction of *Holothurian atra* Jaeger at Heron Island Reef, Great Barrier Reef. Australian Museum Memoir, 16: 53-66.

Platax 20: 79-87, 2023
doi: 10.29926/platax.202312_18.0007

Hendler, G. 2013. Recent mass mortality of *Strongylocentrotus purpuratus* (Echinodermata: Echinoidea) at Malibu and a review of purple sea urchin kills elsewhere in California. Bulletin of the Southern California Academy of Sciences, 112: 19–37.

Hughes, T.P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science, 265: 1547-1551.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P. M. Midgley (eds.). Cambridge University Press, Cambridge, UK.

Jurgens, L.J., L. Rogers-Bennett, P.T. Raimondi, L.M. Schiebelhut, M.N. Dawson, & R.K. Grosberg. 2015. Patterns of mass mortality among rocky shore invertebrates across 100 km of northeastern Pacific coastline. PLoS ONE 10(6): e0126280.

Lawrence, J.M. 1996. Mass mortality in echinoderms from abiotic factors, p. 103–137. In: Echinoderm Studies, Vol. 5. Jangoux, M. & J.M. Lawrence (eds.). Balkema, Rotterdam, Netherlands.

McClintock, J.B.,W.C. Lancaster, C.M. Pomory & J.M. Lawrence. 2018. Mass mortality of the sea cucumber (*Holothuria princeps*) along the Florida Panhandle, December 2016. Gulf of Mexico Science, 34 (1): 73-75.

Russell, M.P. 2013. Echinoderm responses to variation in salinity. In Advances in Marine Biology. ed. M. Lesser. Elsevier 66: 171-212.

Stachwitsch, M. 1984. Mass mortality in the Gulf of Trieste: the course of community destruction. Marine Ecology, 5: 243-264.

Tuwo, A., I. Tasir, Syafiuddin, R. Aprianto, A. Yanti, A.D. Bestari & J. Tresnati. 2020. Low salinity reduces survival rate of a commercially important sea cucumber (Sandfish: *Holothuria scabra*). IOP Conference Series: Earth and Environmental Science, 564: 1-10.

Yuan, X., H. Yang, Y. Mao, Y. Zhou, Y. Mao, T. Chang &Y. Liu. 2006. Salinity effect on respiration and excretion of sea cucumber *Apostichopus japonicus* (Selenka). Oceanologia et Limnologia Sinica, 37: 354-60 (in Chinese).

國立海洋生物博物館
NATIONAL MUSEUM OF MARINE BIOLOGY & AQUARIUM
Platax 20: 67-87, 2023
doi: 10.29926/platax.202312_18.0006