The enigma of stones found in the body cavities of sea cucumbers

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Abstract

For the first time, industrial processors of the suspension-feeding sea cucumber *Cucumaria frondosa* (Holothuroidea: Dendrochirotida) have reported two individuals with pebbles or stones nestled inside their body cavities. The two sea cucumbers were harvested by bottom trawl off the coast of Newfoundland (eastern Canada) and later analysed. They measured 11.5 cm and 14.0 cm in length, respectively, and harboured stones weighing up 450 g (i.e. three to four times their whole wet weight). These individuals displayed a severely damaged or crushed aquapharyngeal bulb, open wounds through the integument, and other deformations. The absence of, or damage to, internal organs and the erosion of the podia rows pointed to severe trauma, rather than deliberate ingestion (i.e. gastrolith), as the cause of the phenomenon. Violent impact of metal gear components with stones present on the seafloor or in the trawl itself may forcibly push these stones into the sea cucumbers during harvesting. A concrete outcome is potential damage to industrial equipment used for processing these stone-bearing sea cucumbers. As the fishery intensifies, it is anticipated that harvested sea cucumbers harbouring stones may increase in frequency, raising questions around this harvesting method, and calling for ways to detect the presence of internal stones before processing.

Keywords: *Cucumaria frondosa*, Dendrochirotida, fishery, health, gastrolith, industrial processing, Northwest Atlantic

Introduction

The fishing gear presently used during the commercial fishery for *Cucumaria frondosa* in Newfoundland and Labrador is a form of bottom trawl, composed of a heavy steel front end (ironwork), chain grid, chaffing mat, and a braided polyethylene net bag drawn along the sea floor that captures benthic species into an attached net bag (Barret et al. 2007; Figure 1). Such trawls have been associated with low efficiencies for target size classes, high rates of bycatch, and substantial changes to the benthic habitat (Lambert et al. 2014; Pusceddu et al. 2014). Further, this method of harvesting sea

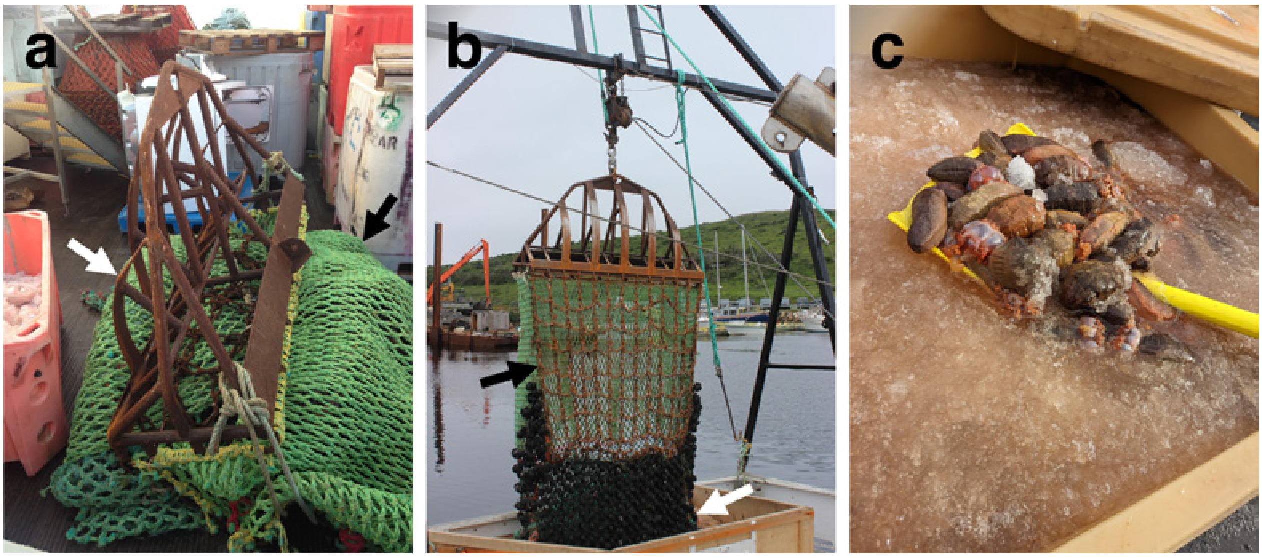

Figure 1. A Newfoundland sea cucumber bottom trawl, commonly referred to as a "drag" (a) placed on the ground of a wharf (white arrow indicates the steel front end and black arrow the green net bag), and (b) suspended in the air from a fishing vessel (black arrow indicates the chain grid and white arrow the chaffing mat), and (c) harvested sea cucumbers in a 1000-L insulated container packed with ice.
Photo credits: (a, b) R. Trenholm (photographed in November 2017 and July 2018); (c) K.C.K. Ma (September 2022).

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cucumbers contributes towards an inherently flawed high volume–low value model that has characterised the sea cucumber fishery in the eastern United States and Canada since it began in the 1980s, as described by Gianasi et al. (2021).

During production, landed sea cucumbers are typically handled and inspected to isolate any damaged and small individuals (though there is currently no official minimal size, those under ~10 cm are usually treated separately). In most high-volume production lines, standard-size individuals are processed by a (semi-) automated system that opens the body cavity and removes the viscera without further damaging the skin (integument) to produce butterfly cuts or cocoon cuts, depending on the equipment (Hossain et al. 2020).

The sea cucumber *C. frondosa* inhabits benthic environments that features some combination of gravely and rocky substrata (Gianasi et al. 2021). Like other sea cucumbers in the order Dendrochirotida, *C. frondosa* is a suspension feeder that gains sustenance from organic particulate matters (e.g. phytoplankton, microzooplankton) present in the water column (Hamel and Mercier 1998); it may also ingest larger organic particles (Gianasi et al. 2017) and small sand grains (Graham and Thompson 2009).

This paper documents and explores for the first time the presence of stones in the body cavities of adult *C. frondosa* captured by the trawl fishery. The location of the stones, the circumstances that may explain their presence, and the detrimental implications this phenomenon may have on processing equipment are presented and discussed.

Methods

Sea cucumbers were harvested between depths of 50 m and 100 m from the St Pierre Bank, off the south coast of Newfoundland (NAFO Subdivision 3Ps; Western Bed; south of 46°30’N and west of 56°28’W), during the 2022 fishing season. During post-harvest preparation for production at the Cape Broyle processing plant (eastern Avalon Peninsula) quality control found two uncharacteristic individuals of *C. frondosa*. One unusually heavy individual (14.0 cm in body length) was detected on 26 August 2022, and one misshapen individual (11.5 cm) on 5 October 2022. Digital still images and videos were taken and both individuals were dissected.

To contextualise how bottom trawling and post-harvest handling of sea cucumbers may be linked to the phenomenon as reported in this study, the steps involved were examined from past and recent interactions with the industry. Assessments of sea cucumber landings were conducted in 2017–2018 on the Burin Peninsula, including one in St Lawrence on 20 November 2017 and another at Fortune on 16–17 July 2018. Visits to the processing plant at Cape Broyle were conducted on 21 September and 15 October 2022 to gather additional information.

Results

Cucumaria frondosa *individual found in August*

The contracted body of the sea cucumber harbouring a large stone was approximately 8.3 cm wide and 14.0 cm long, and exhibited physical damage (Fig. 2). Most of the aquapharyngeal bulb (including the tentacles) was absent and anterior rows of podia were eroded (Fig. 2a). Perforation of the integument (i.e. an open wound towards the posterior end) partially revealed the stone and another wound (ventral side) exposed internal organ(s) (Fig. 2b). This perforation measured 1.9 cm in width and 2.6 cm in length. The individual was dissected longitudinally to fully reveal the stone, which was in the perivisceral cavity surrounded by muscle tissues. The stone was covered in crustose red algae, *Lithothamnion* sp. (Fig. 2c), and thus structurally abrasive. The stone had a Feret diameter of 8.0 cm (circumference of 22.1 cm), weighed 456 g, and had a total volume of 176 $cm^{3.}$

Cucumaria frondosa *individual found in October*

Excluding the aquapharyngeal bulb and tentacles, the deformed body of this individual was 3.1 cm wide and 3.3 cm long (Fig. 3a). The sea cucumber featured a large tissue pocket (about 4.1 cm in length) next to the extended aquapharyngeal bulb, which contained a stone. The stone was entirely enveloped by collagenous tissue and was partially visible through a perforation on the surface of this pocket, which measured about 1.6 cm in diameter (Fig. 3a). Upon dissection, the posterior portion of the integument was found to be folded inside the body cavity (Fig. 3b) and further examination revealed that the actual body length was 11.5 cm (Fig. 3c). The stone had a smooth surface (with no fouling organisms), and the Feret diameter was ~4.5 cm (weight and volume unknown; Fig. 3b, c).

Additional information about processing

During typical dockside offloading procedures (Fig. 4a), visible stones, debris and bycatch of other species are separated from sea cucumbers and set aside (Fig. 4b). Sea cucumbers are then placed in insulated containers (~1000 L) and transported to the processing plant (Fig. 1c). Small loose stones can still be found in the containers used during overland transport and, occasionally, some can be found still attached to sea cucumbers via their ambulacral podia. At the processing plant, inspections of sea cucumbers are performed prior to mechanical evisceration.

Operators and quality control personnel at the Cape Broyle processing plant had neither encountered nor been informed of any stone-bearing sea cucumbers before the ones documented in the present paper. However, loose stones hidden among the sea cucumbers were recovered from the processing plant (Fig. 4c), and an examination of these stones showed that a majority weighed between 0.5 g and 26.3 g (5.9 ± 4.9 g [mean ± SD]; n = 127). The largest loose stone detected during our visits to the plant weighed 111.7 g.

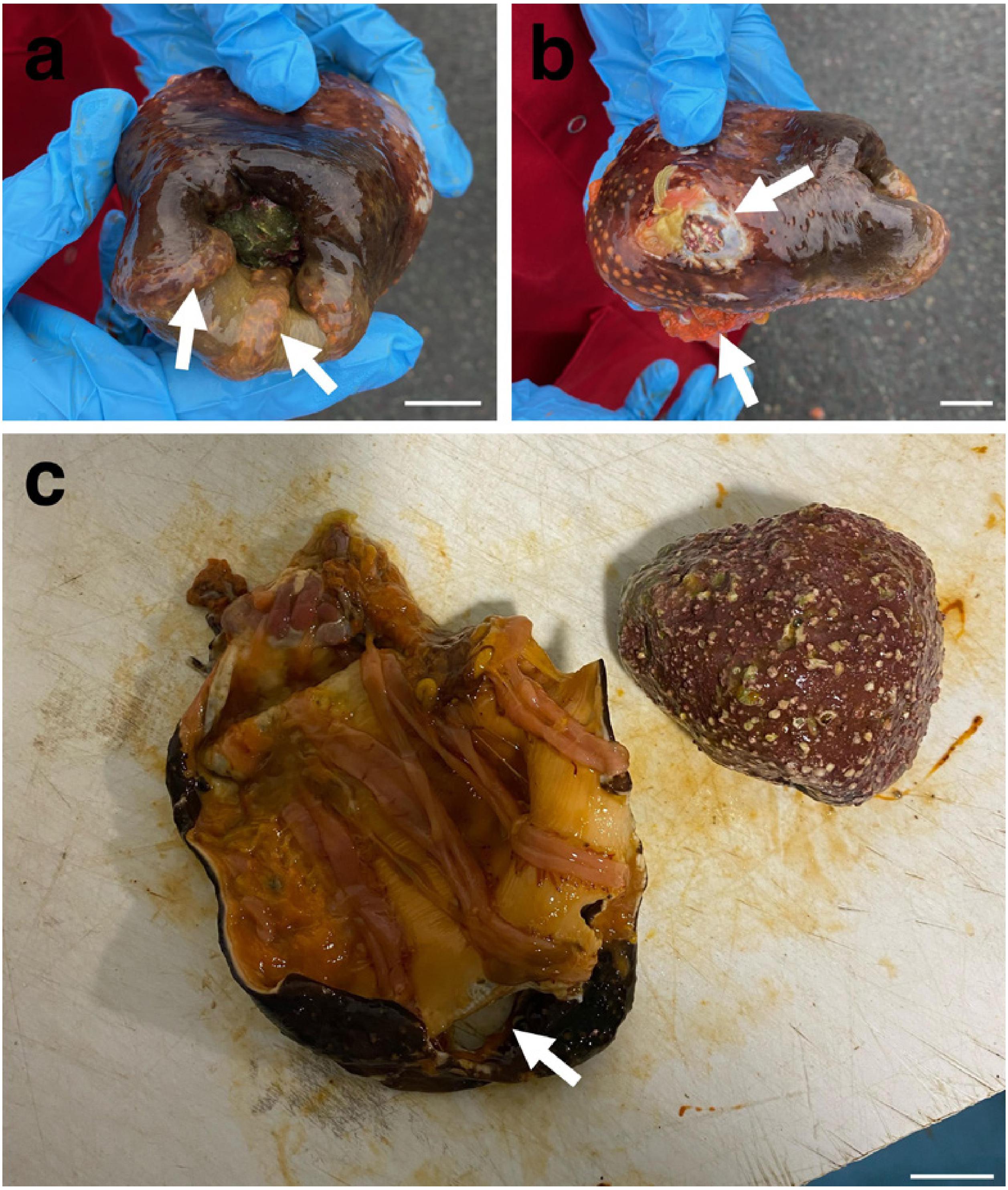

Figure 2. An individual of *Cucumaria frondosa* with a 456-g stone inside its body cavity that was harvested in late August 2022 off the south coast of Newfoundland, Canada: (a) ex situ anterior view with partial view of the stone and eroded rows of podia (white arrows), (b) ex situ side view with open wounds through its integument (white arrows), and (c) oblique view of the dissected individual and a fully revealed stone (to the right of the sea cucumber), providing an internal view of one of the wounds (white arrow). All scale bars represent ~2 cm. Photo credit: Quin-Sea Fisheries Ltd, a division of Royal Greenland

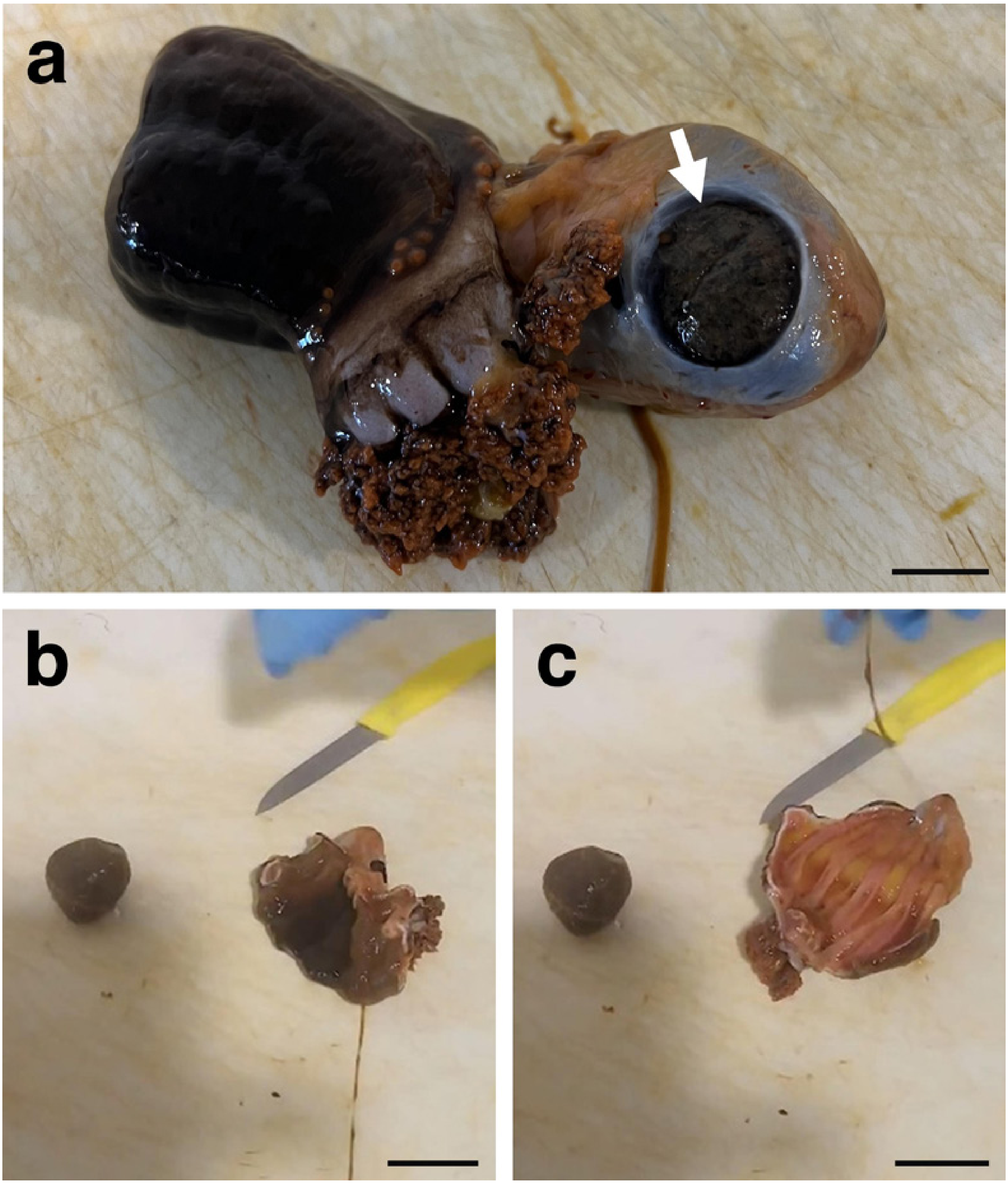

Figure 3. An individual of *Cucumaria frondosa* with a stone inside a pocket of collagenous tissue that was harvested in early October 2022 off the south coast of Newfoundland, Canada: (a) *ex situ* side view with partial view of the stone was visible through a perforation (white arrow), (b) oblique view of the dissected individual with the posterior portion of the integument folded inside the body and a fully revealed stone (to the right of the sea cucumber), and (c) oblique and internal view of the dissected individual with the integument unfolded. The scale bar represents ~1 cm in (a), and ~5 cm in (b) and (c).
Photo credit: Quin-Sea Fisheries Ltd, a division of Royal Greenland

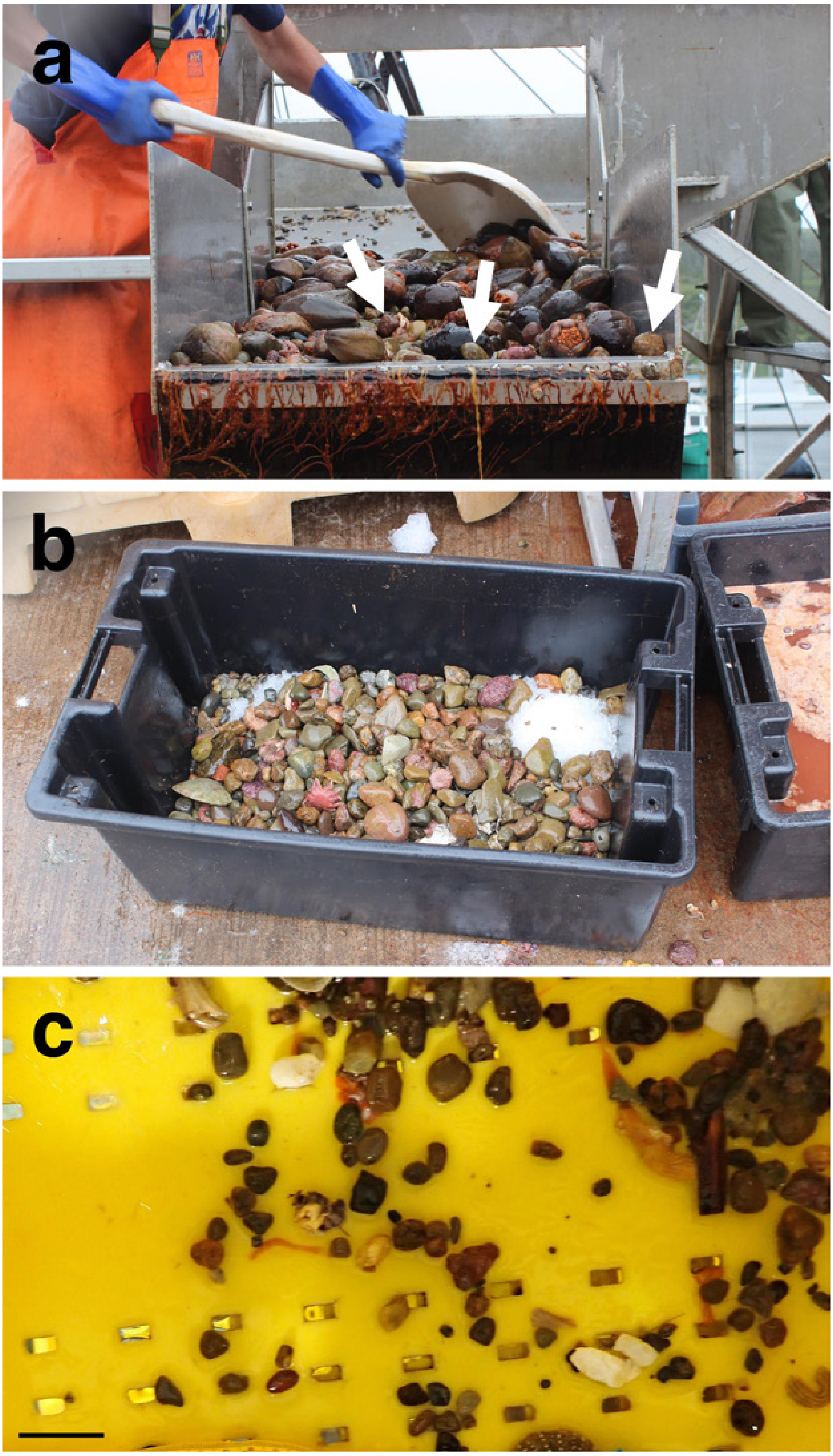

Figure 4. Field observations at: (a) the dockside where harvested sea cucumbers, loose stones, and bycatch were manually sorted (white arrows indicate stones); (b) the dockside where easily visible loose stones were set aside in a black container; and (c) the processing plant where leftover loose stones were set aside in a yellow container. The scale bar in (c) represents ~5 cm. Photo credits: (a, b) R. Trenholm (photographed in July 2018); (c) K.C.K. Ma (September 2022).

Discussion

The two sea cucumbers examined allowed us to document for the first time the occurrence of stones found inside freshly harvested individuals of the sea cucumber *C. frondosa*. The feeding habits of *C. frondosa* (and other species of dendrochirotids) made it unlikely that individuals would naturally or incidentally ingest stones, especially some as large as the ones found in the present study (relative to the size of the sea cucumber). Here, we determined that the stones were not swallowed but rather forcibly inserted into the body cavity (perivisceral coelom) of the sea cucumbers.

In contrast to most other commercial species of sea cucumber, *C. frondosa* does not eviscerate internal organs nor discharge Cuvierian tubules in response to stressors (Gianasi et al. 2021). Instead, it responds to stress and physical disturbance by contracting longitudinal and circular muscles, as well as longitudinal retractor muscles, such that an individual attains a firm ellipsoidal shape. Mutable collagenous tissue in the body wall often creates a firm dermis protecting the individual from punctures or predation (e.g. Mo et al. 2016; Motokawa 2019). In addition, *C. frondosa* can actively regulate its buoyancy (i.e. active buoyancy adjustment) through intake of seawater in its body cavity as a behavioural response to the presence of predators and other stressors (Hamel et al. 2019). Swollen individuals can tumble or float away, which augments dispersal potential for this otherwise sedentary benthic species (Hamel et al. 2019). A possible explanation for the presence of stones inside *C. frondosa* individuals could be the deliberate ingestion of substratum (i.e. gastrolith) as ballast to modulate the buoyancy response. However, the existence of this potential strategy was challenged by the current study, following informal discussions with processors and the examination of existing images and videos. Furthermore, while the occurrence of gastroliths for food processing and buoyancy is documented in other species (primarily in marine and terrestrial tetrapods; Taylor 1993; Rondeau and Gee 2005; Shuert and Mellish 2016), it has not been reported in sea cucumbers.

Overall, the finding of a stone inside *C. frondosa* was determined to be a non-natural phenomenon, possibly caused by bottom trawling during harvesting. This is supported by the serious injuries suffered by the sea cucumbers (e.g. open wounds, crushed and partially missing aquapharyngeal bulb), which were probably caused by contact with the bottom trawl towed along the seafloor. During harvesting, injuries (including blemishes) to sea cucumbers may also be inflicted by violent physical contact with stony bycatch. Conceivably, a sea cucumber could be forced beneath the drag and compressed against the seafloor, which could cause enough shear and force to press a stone into its body cavity; this sea cucumber could then be captured by a subsequent trawl. A possible but improbable consequence may be decreased fitness for individuals that would otherwise escape the trawl and heal their body wall around the stone. Yet, the exact chain of events during harvesting to produce the serious injuries that were reported here remains unconfirmed. Despite this, the August individual exhibited signs that the stone was forcibly inserted through the anterior end into the body cavity. While in motion, the stone covered with calcareous algae (rough surface) probably damaged the ambulacral podia rows on its way inside the perivisceral cavity of the sea cucumber. In contrast, the October individual presented signs that the stone was inserted through the posterior end, most probably at high velocity. The stone appeared to have invaginated the posterior portion of the integument through the body cavity and out the anterior end (next to the tentacles). A pocket of what remained of the collagenous tissue trapped the stone. Overall, damage to the tissues and internal organs (intestine, respiratory tree, and gonad) of both individuals suggests severe trauma associated with this phenomenon.

After about seven years of processing sea cucumbers, this was the first year the producers at the plant in Cape Broyle detected individuals containing stones (S. Botlagunta, pers. comm., 2022). Operators at another processing plant in Change Islands, Newfoundland and Labrador, Canada (near Fogo Island), have never reported any stone-bearing sea cucumbers since operations began around 2015 (S. Botlagunta, pers. comm., 2022). It thus remains uncertain if these observations were an isolated incidence or represent an ongoing impact of bottom trawling that was never previously discovered.

Although both cases were discovered by quality control personnel on the processing line at the earlier stages of production (i.e. before sizing and mechanical evisceration), they raised important concerns. Any stones (or other solid debris) hidden inside sea cucumbers can have detrimental consequences for industrial equipment, especially evisceration systems, at later stages of production (e.g. Singleton et al. 2016). Replacement parts to repair damaged blades of an evisceration system, such as those used at the plant in Cape Broyle to produce butterfly cuts, can cost between USD 150 and 200 per system (B. Payne, pers. comm., 2022).

It is likely that the presence of stones forced into the body of sea cucumbers is a more common phenomenon in trawl fishery than described here. Future investigations are needed to understand the exact causes and rate of incidence of this phenomenon, and to explore mitigation strategies to prevent any damage by undetected stones (hidden inside sea cucumbers).

Acknowledgements

We thank Quin-Sea Fisheries Ltd, a division of Royal Greenland, and its employees (especially Surendra Botlagunta, Mika Heilmann, Kranthi K. Manchikanti, Danielle O'Brien, Barry Payne, and Leona White) for their invitation to visit the plant at Cape Broyle, and for their permission to share images and information with respect to this unique phenomenon. We are also grateful to Juran C. Goyali (Fisheries and Marine Institute), who was present during the discovery in August, for sharing information and verifying the estimated dimensions of the sea cucumber and stone. This research was supported by grants from the Canada

Foundation for Innovation and the Natural Sciences and Engineering Research Council of Canada awarded to Annie Mercier. Some of the authors were supported by funding from the Canadian Centre for Fisheries and Innovation and Mitacs Accelerate (IT15224).

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