

Albinism in Orange-footed Sea Cucumber (*Cucumaria frondosa*) in Newfoundland

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Abstract

Orange-footed Sea Cucumber (*Cucumaria frondosa*; Echinodermata: Holothuroidea) is a dark-brown species that is broadly distributed in North Atlantic and Arctic waters. Here, we document the rare occurrence of colour morphs showing various degrees of albinism, from totally white to faint orange pigmentation. These unusually coloured individuals were found across a broad distribution range in eastern Canada and northeastern United States, with their occurrence in Newfoundland samples ranging from 0.2% to 0.5%. Two fully albino individuals were noticeably smaller than other colour morphs. The occurrence of rare, unusually coloured sea cucumbers is important from an ecological standpoint and may also have commercial implications.

Key words: Orange-footed Sea Cucumber; *Cucumaria frondosa*; albinism; colour diversity; Holothuroidea; sea cucumber; North Atlantic

Introduction

Unusually coloured and albino (white) sea cucumbers are rare in nature and typically have higher market value, particularly in Asia. Albino individuals have sold at auction for US\$23 000/kg (normal value US\$2000–2500/kg for the species; Tse 2015). To date, published records of albinism in holothuroid echinoderms (nomenclature according to World Register of Marine Species; WoRMS 2019) include Japanese Sea Cucumber (*Apostichopus japonicus*) in the temperate Western Pacific (Lin *et al.* 2013), White Teatfish (*Holothuria fuscogilva*) in the tropical Indo-Pacific (Friedman and Tekanene 2005), Brown Sea Cucumber (*Isostichopus fuscus*) in the tropical eastern Pacific (Fernández-Rivera Melo *et al.* 2015), Four-sided Sea Cucumber (*Isostichopus badionotus*) in the Caribbean (Wakida-Kusunoki *et al.* 2016), Climbing Sea Cucumber (*Ocnus planci*) in the temperate and tropical Atlantic (Casellato *et al.* 2006), along with some anecdotal reports and pictures of white sea cucumbers scattered in the literature (Trefry 2001; Feindel *et al.* 2011; Benoit 2016).

Colour variants, including complete lack of colour, in *A. japonicus* have been described (Yang *et al.* 2015). The body wall of albino *A. japonicus* adults

contains ~0.24% melanin compared with ~3.12% in normal adults (Zhao *et al.* 2015). As albinism is known to occur in only a limited number of individuals in any given species (0.00001–0.1%; Mouahid *et al.* 2010), a directed search for these could fuel over-exploitation in some already overfished or vulnerable species (Purcell *et al.* 2014). Albinism may also affect the behaviour, growth rates, and physiology of sea cucumbers, although these effects remain incompletely understood (Lin *et al.* 2013; Bai *et al.* 2016; Xia *et al.* 2017).

Orange-footed Sea Cucumber (*Cucumaria frondosa*, Gunnerus 1767) is the most common sea cucumber along the eastern Canadian coast, with a distribution spanning the North Atlantic, Arctic, and Barents Sea (Paulay and Hansson 2013). A commercial fishery for *C. frondosa* is rapidly developing in several countries (e.g., Canada, United States, Russia, Greenland, and Iceland), which makes it one of the most important wild sea cucumber fisheries in the world (Therkildsen and Petersen 2006; Nelson *et al.* 2012). As of 2016, market values for *C. frondosa* ranged from \$120–140/kg (Hansen 2016) up to about \$300/kg (Guangzhou market, China; J.-F.H. pers. obs.); a separate market for unusual colour morphs has not yet developed.

Here, we describe colour morphs reported for wild *C. frondosa* populations from northeastern North America. We also report the results of a survey of *C. frondosa* populations from the Grand Banks of Newfoundland to determine the relative abundance of colour morphs to improve ecological knowledge of this important commercial species.

Methods

Records of unusually coloured *C. frondosa* were collated from numerous sources, including specimens collected by hand, SCUBA, and fishing vessels across various locations in eastern Canada (e.g., the estuary and Gulf of St. Lawrence, Quebec; Saint-Pierre Bank and southeastern coast of Newfoundland; Figure 1, Table 1).

Two batches of sea cucumbers ($n = 600$) were examined in June and July 2017 to establish the percentage of orange and white individuals relative to normally coloured ones (dark-brown and grey-brown); no colour standards were used. Samples were obtained from the commercial fishery (trawled using modified scallop gear) in the Grand Banks area of Newfoundland, Canada. No restrictions are placed on animal size, shape, or colour in the fishery; thus, harvests are usually a good representation of local populations. Total wet weights of sea cucumbers, as well as the contracted lengths and widths were measured from fully contracted individuals according to Singh *et al.* (2001). These measurements were taken for all white and orange individuals and from 150 haphazardly selected dark-brown and grey-brown individuals. For white and orange individuals collected in the Grand Banks area of Newfoundland in 2013, two additional measurements were included.

Internal organ colours were also compared in pale versus normal individuals.

Results

Summary of colour morphs in northeastern North America

Four main colour variants have been reported for *C. frondosa* in northeastern North America: dark-brown, grey-brown, orange, and albino (i.e., white and off-white individuals; Figure 2). Dark-brown and grey-brown are the most common colours for this species and, thus, represent normally coloured individuals (Figure 2a,b). The tentacles and tube feet of dark-brown and grey-brown *C. frondosa* are dark-brown and dark-orange to brown, respectively. Orange-tinged tube feet are common, hence the common name (Paulay and Hansson 2013). Orange and white individuals are the rarest colour morphs and can be described as a gradient of little to no melanin pigment deposition (Figure 2c–g). The tentacles and tube feet of orange and white individuals are typically pale orange and white, respectively.

Frequency of colour morphs in Newfoundland trawls

All four colour morphs were found off the Grand Banks, Newfoundland (trawled at 40–70 m depth) and in coastal areas near the Avalon Peninsula (collected by SCUBA at <10 m). The survey from the Grand Banks area revealed that orange-coloured individuals made up 0.5% of the population ($n = 3$ in 600), but that white individuals were rarer in that sample ($n = 1$ in 600, <0.2%). The internal organs (muscle bands, gonad, and intestine) of these white and orange individuals were the same colour as those of dark-brown and grey-brown individuals. Orange individuals were also similar in size to brown individuals (mean wet

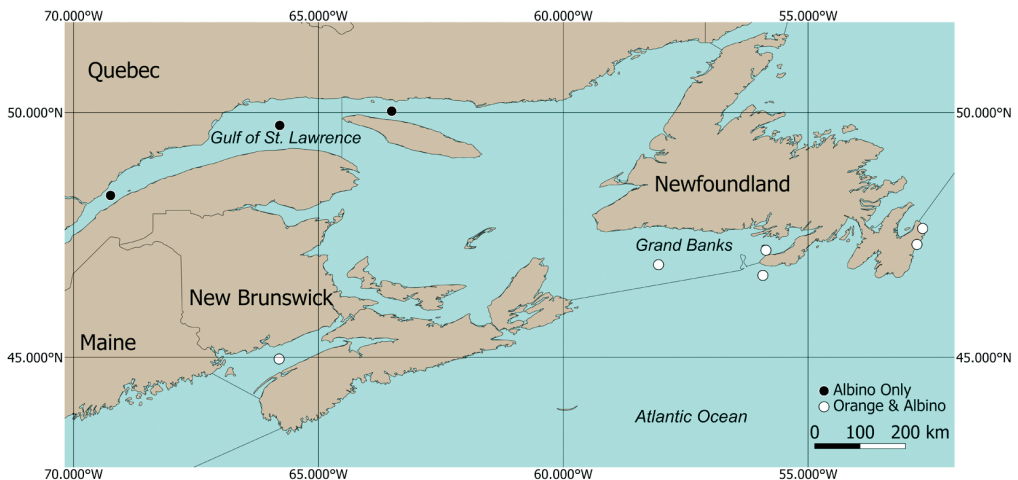


FIGURE 1. Locations in northeastern North America where unusually coloured Orange-footed Sea Cucumbers (*Cucumaria frondosa*) were observed and/or collected.

weight 246 ± 87 [SD] g versus 235 ± 74 g; Table 2). The mean wet weight of the two white individuals, including the one in our 2017 survey and another from 2013 (B. Gianasi pers. comm. October 2017), was 78.6 ± 3.4 g (versus mean wet weight of 235 g in normally coloured individuals; Table 2).

TABLE 1. Locations in North America where unusually coloured Orange-footed Sea Cucumber (*Cucumaria frondosa*) occur, based on reports from the literature and the present study.

Province or state, country	Region	Coordinates	Colour observed	No. (total sampled)	Date	Source
Maine, USA	NA	NA	Orange	NA	NA	Feindel <i>et al.</i> 2011
	NA	NA	Albino	NA	NA	Feindel <i>et al.</i> 2011
Newfoundland, Canada	Fortune Bay, Grand Banks	47.18597933°N, 55.86135864°W	Orange	3 (600)	2017	E. Montgomery (current study)
		47.18597933°N, 55.86135864°W	Albino	1 (NA)	2017	E. Montgomery (current study)
	St. Pierre Bank, Grand Banks	46.67205647°N, 55.92315674°W	Orange	3 (NA)	2017	E. Montgomery (current study)
		46.67205647°N, 55.92315674°W	Albino	NA	2017	E. Montgomery (current study)
	Unnamed site, Grand Banks	46.89023157°N, 58.05450439°W	Orange	3 (NA)	2013	B. Gianasi (current study)
		46.89023157°N, 58.05450439°W	Albino	1 (NA)	2013	B. Gianasi (current study)
	Logy Bay	47.6295369°N, 52.66073227°W	Orange	NA	NA	Memorial Field Services
		47.6295369°N, 52.66073227°W	Albino	NA	NA	Memorial Field Services
Bay Bulls	47.3048439°N, 52.77677536°W	Orange	NA	NA	Memorial Field Services	
	47.3048439°N, 52.77677536°W	Albino	NA	NA	Memorial Field Services	
Quebec, Canada	Mingan Archipelago	50.02538762°N, 63.50372314°W	Albino	NA	1990s	J.-F. Hamel
		49.73513141°N, 65.78887939°W	Albino	NA	1990s	J.-F. Hamel
	Gaspé Peninsula	48.30512072°N, 69.24407958°W	Albino	NA	1990s	J.-F. Hamel
		44.96479793°N, 65.80261230°W	Orange	NA	NA	S. Robinson (DFO)
New Brunswick, Canada	Bay of Fundy	44.96479793°N, 65.80261230°W	Orange	NA	NA	S. Robinson (DFO)
		44.96479793°N, 65.80261230°W	Albino	NA	NA	S. Robinson (DFO)

Note: DFO = Department of Fisheries and Oceans, NA = data not available.

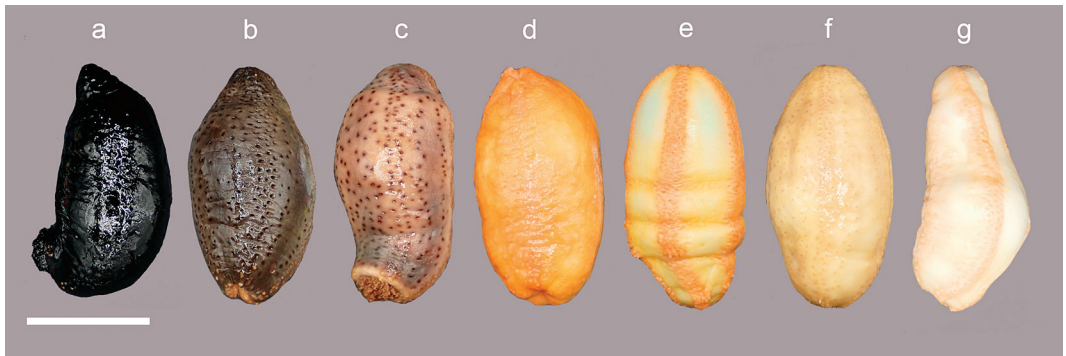


FIGURE 2. Colour diversity in adults of Orange-footed Sea Cucumber (*Cucumaria frondosa*) collected off Newfoundland, eastern Canada. a and b. Typical colours: dark-brown and grey-brown. c to g. Increasing discolouration/albinism: pale brown, orange, pale orange, beige, and white. Sea cucumbers that match c, d, or e are considered “orange”, and those like f and g are considered “white”. Photos were taken with uniform illumination and have not been edited for brightness, contrast, or colour. Scale bar represents 5 cm for a–f and 3 cm for g. Photos: E. Montgomery.

TABLE 2. Size of individuals of Orange-footed Sea Cucumber (*Cucumaria frondosa*) sampled in southeastern Newfoundland during the present study. Mean values for orange and white colour morphs are pooled across individuals collected in this area, 2013–2017. Mean values for fully pigmented morphs were obtained from individuals collected in 2017.

Colour morph	<i>n</i>	Mean weight, g ± SD	Mean con-tracted length, cm ± SD
White (fully albino)	2	78.7 ± 3.4	8.2 ± 1.5
Orange (partly albino)	9	246.3 ± 87.1	12.7 ± 1.9
Dark-brown/ grey-brown (fully pigmented)	150	235.1 ± 74.0	13.3 ± 0.5

Discussion

Four main colour morphs of the body wall have been reported for *C. frondosa* from northeastern North America. However, it is important to note that a continuum of degree of pigmentation exists in this species, ranging from dark-brown to white. White and orange individuals from Newfoundland had normally coloured internal structures and organs, suggesting that this species may display leucism (partial or complete loss of pigment), rather than true albinism (no pigment deposition). In fact, some of the dark individuals housed in the laboratory for several months displayed a tendency to bleach over time (B. Gianasi pers. comm. 2017).

In the present study, white and orange individuals were seen and collected in all known populations of *C. frondosa* sampled in eastern Canada, suggesting that loss or decrease of pigmentation is not geographically constrained. An anecdotal reference to unusually coloured individuals is also made in a fisheries report from Maine (Feindel *et al.* 2011), further supporting the suggestion that the phenomenon likely occurs across populations of *C. frondosa* in North America, northern Europe, and the Arctic, as a gene flow study of So *et al.* (2011) indicates a supply source along southeastern Newfoundland. Further study will be needed to confirm the factors involved in pigment absence and/or loss in this species, as the phenomenon seems to be geographically widespread.

We noted that different colour morphs of *C. frondosa* were collected in Newfoundland from different depths. Dark-brown sea cucumbers occurred in shallow water <10 m deep (collected by SCUBA) and grey-brown individuals in deeper water (40–70 m; collected by trawl) where less ultraviolet (UV) light penetrates, and weaker pigment protection may be required, as also proposed for *A. japonicus* (Jiang *et al.* 2015). Also of note is the fact that white individuals were present in all sampled locations, mixed with the normally coloured morphs (Figure 1). Despite this, it

remains possible that these individuals may be more susceptible to UV light than normally coloured individuals and may seek cover more readily than darker individuals. In the lower subtidal area of the St. Lawrence Estuary and the Mingan Archipelago of Quebec, pale individuals were reported mainly from discrete areas at the base of rocks or under dense algal cover (J.-F.H. pers. obs.), suggesting that they are actively seeking shelter against exposure to strong light, similar to increased covering behaviour reported in albino urchins in the Caribbean (Kehas *et al.* 2005).

Paler sea cucumbers reported from the Bay of Fundy, New Brunswick, did not appear to differ in size from dark-brown and brown individuals (S. Robinson pers. comm. October 2017), which is consistent with the current samples. Although any size difference remains to be confirmed with further sampling, white sea cucumbers stand out against the background substrate colour, which may generate more stress and, together with decreased UV protection, might explain why they would be generally smaller than normally coloured individuals (Table 2). Their relatively smaller size may also be explained by metabolic factors, as white sea cucumbers have previously been reported as less efficient at protein metabolism than other colour morphs (e.g., *A. japonicus*, Bai *et al.* 2016).

Our data document the presence of uncommon colour morphs of *C. frondosa* across most of its eastern Canadian distribution (Figure 1) and other areas from its general geographic distribution. This deserves further investigation from both ecological and economical perspectives.

Author Contributions

Writing – Original Draft: E.M. and T.S.; Writing – Review & Editing: E.M., T.S., J.-F. H., and A.M.; Investigation: E.M., T.S., J.-F. H., and A.M.; Formal Analysis: E.M. and T.S.; Funding Acquisition: A.M.

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