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CASUAL HERMAPHRODITISM IN GONOCHORIC *ISOSTICHOPUS FUSCUS* (LUDWIG, 1875) (ECHINODERMATA: HOLOTHUROIDEA) OF THE SOUTHERN GULF OF CALIFORNIA, MEXICO

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Simultaneous hermaphroditism is a phenomena in which male and female sex organs are found in the same individual. It occurs in most invertebrate Phyla, and it is relatively common in echinoderms (Hyman, 1955; Lawrence, 1987; McEuen, 1987). One of its variants is called "accidental functional hermaphroditism" (Coe, 1943), or "casual hermaphroditism", when in typical gonochoric species, occasional monoecius individuals appear (Mackie, 1984). Due to the low frequency of this particular event in echinoderms, few studies have been undertaken, and detailed analyses and histological descriptions are lacking (Lawrence, 1987).

The holothurian *Isostichopus fuscus* (Ludwig, 1875) is an important commercial species in México. It is a large species (19–25 cm average length; Herrero-Pérezrul et al, 1997; Fajardo-León et al., 1995) that inhabits shallow waters (0–40 m) from the Baja California peninsula, México, to Ecuador (Maluf, 1988). The populations of *I. fuscus* in the Gulf of California (26° to 28°N), were heavily fished from 1989 to 1993 (Fajardo-León et al., 1995). To this date this holothurian is considered as an endangered species (NOM-059-ECOL, 1994) and catches are not currently allowed except for scientific purposes.

The sea cucumber *I. fuscus* reproduces annually during summer (July to September) in the Gulf of California, when sea-water surface temperature is above 27°C (Herrero-Pérezrul et al., 1997; Fajardo-León et al., 1995).

The objective of this paper is to report the occurrence of two casual hermaphroditic individuals of *I. fuscus* in the southern Gulf of California, and to describe histologically the main features of their gonads. This is the first detailed description of the gonads of hermaphrodite specimens from gonochoric holothurians.

Specimens were collected monthly from July 1992 to September 1993 (as part of a larger study on the reproductive biology of the species) over sandy bottoms at Bahía San Gabriel, Isla Espíritu Santo, in the west coast of the Gulf of California (24°25′N, 110°20′W) at 1–3 m depth. Specimens were fixed with 10% sea-water formalin. At the laboratory, the gonads were dissected, weighted and measured, then were histologically processed and embedded in paraffin. Sections of the gonads (7 μm thick) were obtained in different planes with a rotatory microtome and stained with Hematoxilin-Eosin. The stages of the gametogenic cycle were determined by morphological observations of the different cell types in the gonad (Cameron and Fankboner, 1986; Conand, 1993).

The first hermaphrodite specimen was observed in September 1992. It weighed 205.6 g and measured 16 cm, and the second one in August, 1993, weighed 480.3 g and measured 21 cm. In comparison, they were small specimens (average size and weight of the sampled population were: 19 ± 0.18 cm and 351.5 ± 5.5 g; n = 173 (Herrero-Pérezrul et al., 1997).

The gonads of the casual hermaphrodites consisted in one tuft of numerous tubules. Male tubules were more abundant than females. The gonads of the two casual hermaphrodites were in the stage of early gametogenesis (Fig. 1) and their histological character-

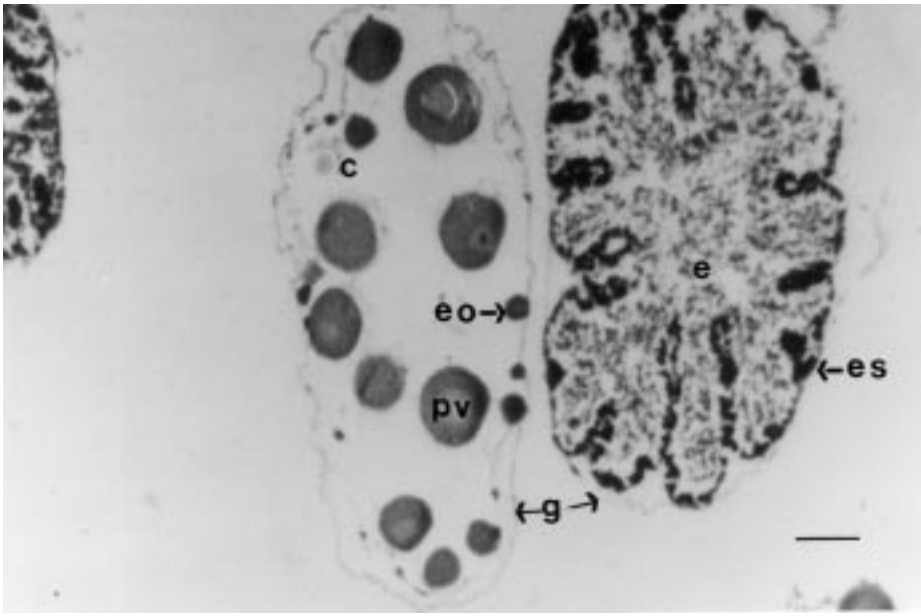

Figure 1. Gametogenesis in the hermaphrodite specimens of *Isostichopus fuscus* in the southern Gulf of California. es: developing spermatocytes; e mature spermatozoa; eo: early oocytes; pv: previtellogenic oocytes; g: gonad wall; c: connective tissue. Scale Bar = 100μm.

istics did not differ from those of the gonochoric individuals. The gonad wall of the ovaries was thick and contained early oocytes (<10 μm diameter) with basophilic nuclei, arranged in a single layer. Previtellogenic oocytes (>20 μm diameter) were surrounded by small follicular cells or accessory cells (Tyler and Gage, 1985). The nucleus is well defined, with one or two eccentric nucleoli. Previtellogenic oocytes were distributed near the lumen. No mature oocytes were observed. In male tubules, thick longitudinal folds were observed extending to the lumen; these folds later disappeared when maturity was attained in gonochoric specimens (Herrero-Pérezrul et al., 1997). This extensions greatly increased the surface area for spermatocyte production, and became thinner to allow more space for gametes. A row of developing spermatocytes were near the inner side of the gonad wall. Some mature spermatozoa lied free in the lumen. They had rounded head (1–2 μm diameter), strongly stained with Hematoxilyn. In both female and male tubules, the connective tissue was abundant. Male tubules were slightly more developed than the female ones; the testis presented mature spermatozoa whilst the ovaries did not have mature oocytes yet (Fig. 1). Consequently, it is possible that male gametes would be released first, but this observation is not an accurate indication of protandry. Another observation was that the casual hermaphrodites of *I. fuscus* were found in gametogenesis, despite that the gonads of the gonochoric individuals sampled in the same sites and months were either ripe or spawned. It is possible that this delay in the reproductive timing may have been caused by the excess of energy needed to produce both kind of gametes in the same individual.

The presence of casual hermaphroditism in other gonochoric holothurians is shown in Table 1. Most of them are cold-water, Atlantic or cosmopolitan species that inhabits abys-

Table 1. General characteristics of gonochoric holothurians with hermaphroditic specimens. References: 1. Harriot (1982); 2. Tyler et al. (1985); 3. Tyler et al., (1987); 4. Herrero-Pérezrul et al. (1997).

Species	Order	Depth of collection (m)	Site of collection	Habitat	Distribution	Maximum body size (mm)	Reproductive timing	Maximum oocyte diameter (μm)	Casual hermaphroditism incidence
1. Holothuria atra	Aspidochirota	—	23° 27′S, 151° 55′E	benthic	Indo Pacific	180	May to June; December to January	—	2 of 155 ind.
2. Peniagone azorica	Elasipodida	2,264	57° 08′N, 10° 22′W	benthic	Cosmopolitan	58	Not well defined	300	1 of 113 ind.
2. P. diaphana	Elasipodida	4,000	49° 46′N, 14° 01′W	benthopelagic	Cosmopolitan	—	Not well defined	300	1 of 30 ind.
3. Cherbonniera utriculus	Molpadida	2,800–4,050	54° 40′N, 12° 16′W	benthic	North Atlantic	7	Not well defined	200	1 of 429 ind.
4. Isostichopus fuscus	Aspidochirota	1–3	24° 30′N, 110° 25′W	benthic	Eastern Pacific	290	June to September	104	2 of 173 ind.

sal depths (>2000 m) and high latitudes. Nevertheless, casual hermaphroditism also occurs in other tropical species as *Holothuria atra* (Harriot, 1982), although in this case, it may be due to sex reversal.

It is clear that, in general, this type of hermaphroditism does not follow a phylogenetic pattern, as it has been reported for species from different Orders. On this basis, we suggest that this character may have a direct mutational origin in holothuroids. A consequence of the hypothesis is that casual hermaphroditism should be noticed in some populations, but not in others of the same species. This seems to be the case for *I. fuscus* in the southern Gulf of California (24°N), and in the entire eastern Pacific. In the northern Gulf of California (28°N), the tropical Pacific (17°N) or in the Galapagos Islands (0°N), there have been no reports of casual hermaphroditism or hermaphroditism of any kind (Tapia Vázquez and Castro, 1994; Fajardo-León et al., 1995; P. Martínez, Charles Darwin Research Station, pers. comm., 1996), while they do have appeared (although in low frequencies) at Bahía de La Paz (24°N).

Theoretical considerations have shown that in places when the population density of a species is so low that conspecifics are rare, selection may favor hermaphroditism and even self-fertilization. Also, if population density increases, the presence of hermaphrodites will decrease (Ghiselin, 1969). Under this scenario, casual hermaphroditism may have been caused by the strong decrease in *I. fuscus* populations in the gulf, as a product of over-fishing. In addition, if the character is mutational in origin and later conserved by selective forces, it might be expected that after 1994 (when the species was protected), the incidence of casual hermaphroditism would decrease. Notwithstanding, more profound studies have to be completed in order to test the generality of this hypothesis for the Class Holothuroidea.

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Literature Cited

Cameron, J. L. and P. V. Fankboner. 1986. Reproductive biology of the sea-cucumber *Parastichopus californicus* (Stimpson) (Echinodermata: Holothuroidea). I. Reproductive periodicity and spawning behavior. Can. J. Zool. 64: 168–175.

Coe, W. R. 1943. Sexual differentiation in mollusks. I. Pelecypods. Quart. Rev. Biol. 18: 154–164.

Conand, C. 1993. Ecology and the reproductive biology of *Stichopus variegatus*, an Indo-Pacific coral reef sea cucumber (Echinodermata: Holothuroidea). Bull. Mar. Sci. 52: 970–981.

Fajardo-León, M. C., E. G. Michel, J. Singh-Cavanillas, J. A. Vélez, B. and J. A. Massó. 1995. Estructura poblacional y ciclo reproductor del pepino de mar (*Isostichopus fuscus*) en Santa Rosalía, B.C.S., México. INP-SEMARNAP. Ciencia Pesquera 11: 45–56.

Ghiselin, M. T. 1969. The evolution of hermaphroditism among animals. Quart. Rev. Biol. 44: 189–208.

Harriot, V. 1982. Sexual and asexual reproduction of *Holothuria atra* Jaeger at Heron Island Reef, Great Barrier Reef. Aust. Mus. Mem. 16: 53–66.

Herrero-Pérezrul, M. D., H. Reyes Bonilla, F. García Domínguez and C. E. Cintra Buenrostro. 1997. Reproduction and growth of *Isostichopus fuscus* (Ludwig, 1875) (Echinodermata: Holothuroidea) in the southern Gulf of California. Mar. Biol. submitted.

Hyman, L. H. 1955. The Invertebrates: Echinodermata, the coelomate bilateria. McGraw Hill, New York. 763 p.

Lawrence, J. 1987. A functional biology of echinoderms. Croom Helm, London. 340 p.

Mackie, G. L. 1984. Bivalves. Pages 351–418 *in* A. S. Ompa, N. H. Verdonk and J. A. M. Van den Bigeelar, eds. The Mollusca. Academic Press, New York.

Maluf, L. Y. 1988. Composition and distribution of the central eastern Pacific echinoderms. Tech. Rep. no. 2. Nat. Hist. Mus. Los Angeles Co. 242 p.

Mc. Euen, F.S. 1987. Phylum Echinodermata, Class Holothuroidea. Pages 574–596 *in* F. M. Sthratmann, ed. Reproduction and development of marine invertebrates of the northern Pacific coast. Univ. Washington Press, Seattle.

NOM-059-ECOL-1994, que determina que las especies y subespecies de flora y fauna silvestres y acuáticas en peligro de extinción, amenazadas, raras y las sujetas a protección especial, y que establece especificaciones para su protección. Mayo 16, paginas 2–59.

Salgado Castro L. R. 1994. Opciones de manejo del recurso *Isostichopus fuscus* del Mar de Cortes, B.C.S. México. Resúmenes del V Congreso de la Asociación de Investigadores del Mar de Cortes, A.C. Universidad Autónoma de Baja California Sur, La Paz.

Tapia Vazquez, O. M. and G. J J. Castro. 1994. Análisis microscópico y determinación de la madurez gonádica del pepino de mar *Isostichopus fuscus* y *Parastichopus parvimensis*. Abstr. X Int'l. Symp. Mar. Biol. Universidad Autónoma de Baja California, Ensenada. 0–195.

Tyler, P. A., J. D.Gage and D. S. M. Billet. 1985. Life-history of *Peniagone azorica* and *P. diaphana* (Echinodermata: Holothuroidea) from the north-east Atlantic Ocean. Mar. Biol. 89: 71–81.

_____, D. S. M. Billet and J. D. Gage. 1987. The ecology and reproductive biology of *Cherbonniera utriculus* and *Molpadia blakei* from the N.E. Atlantic. J. Mar. Biol. Ass. U.K. 67: 385–397.

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