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Review

Beauties and beasts: A portrait of sea slugs aquaculture

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ABSTRACT

Research on sea slugs production has steadily increased in the last decades as a result of their use as model organisms for biomedical studies, bioprospecting for new marine drugs and their growing demand for academic research and the marine aquarium trade. However, standardized methods for culturing sea slugs are still limited to a reduced number of species. The main bottlenecks impairing sea slugs aquaculture are the lack of knowledge on suitable larval diets and settlement cues that can induce metamorphosis in competent larvae. Additionally, the stenophagous feeding regime displayed by several species requires the collection and/or culture of their prey, which commonly impairs large-scale production. Nevertheless, significant breakthroughs have been achieved in recent years through the development of innovative culture techniques. The present review summarizes the major issues impairing the culture of sea slugs and presents relevant biological and ecological data that can assist on the development of suitable culture protocols. Information on the most suitable husbandry, larviculture and grow-out techniques are critically discussed, with emphasis to their application on some of the most relevant groups of sea slugs from an academic and commercial point of view: sea hares (*Aplysia* spp.), nudibranchs (e.g., the marine ornamental species *Aeolidiella stephanieae*) and the "solar powered" sacoglossan (e.g., *Elysia* spp.).

Contents

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1. Introduction

Sea slugs are delicate, colored and "sludgy" gastropod mollusks commonly referred to as the underwater version of the butterfly and the caterpillar combined (Debelius and Kuiter, 2007). Outwardly defenseless and often displaying a bizarre silhouette, these gastropods have always been fascinating subjects for marine biologists. Several scientific works already investigated and discussed their morphology (Gosliner, 1994; Mikkelsen, 2002), life cycle (Avila et al., 1997; Clark, 1975; Harris, 1975), ecology (Angeloni and Bradbury, 1999; Carefoot, 1987), feeding habits (Aboul-Ela, 1959; Hoover et al., 2012; Ritson-Williams et al., 2003) and systematics (Bouchet et al., 2005; Jörger et al., 2010; Schrödl et al., 2011).

Sea slugs are currently considered members of the Heterobranchia (according to the most recent classification proposed by Jörger et al., 2010) (Fig. 1), a highly diversified and successful group of marine gastropods presenting a global distribution and occupying a wide range of ecological niches. Sea hares, *Aplysia* spp. (Anaspidea), (Fig. 1) are probably one of the most well studied groups of sea slugs because of their key role in medical research (Sattelle and Buckingham, 2006). Their popular use as model organisms, particularly in neurobiological sciences, prompted researchers to develop suitable culture protocols to allow their mass production under controlled conditions (Capo et al., 2009). Nudibranchs (Nudipleura) (Fig. 1) have been of interest to researchers in biotechnology due to their potential for the bioprospecting of new marine natural products (e.g., *Felimida* spp., formerly known as *Chromodoris*) (Leal et al., 2012a). Additionally, nudibranchs are also widely used as biological tools for scientific research (e.g., *Aeolidiella stephanieae* and *Spurilla neapolitana*), particularly to study their chemical ecology and photosymbiotic associations (Carroll and Kempf, 1990; Cimino and Ghiselin, 2009; Greenwood, 2009). The most dazzling colored nudibranchs are also highly popular among marine aquarium hobbyists, with a number of these ornamental species (e.g., *Felimida* spp.) already being produced in captivity and reaching high retail values in the marine aquarium trade (Olivotto et al., 2011). Sacoglossan sea slugs (Sacoglossa) (Fig. 1) are also popular in the marine ornamental trade (e.g., *Elysia crispata*) because of their ability to control the growth of nuisance algae (Sprung, 2002). Nonetheless, the culture of sacoglossans (e.g., *Elysia chlorotica*, *Elysia timida* and *Elysia viridis*) has mostly provided biological material to researchers addressing one of the most puzzling features displayed by marine invertebrates — the ability to keep functional algal chloroplasts within their animal cells (Johnson, 2011). This remarkable feature has provided these sacoglossans the nickname of "solar-powered sea slugs" or "photosynthetic animals" (Rumpho et al., 2000, 2011).

The present review provides a comprehensive overview of the most significant breakthroughs on sea slugs aquaculture, as well as

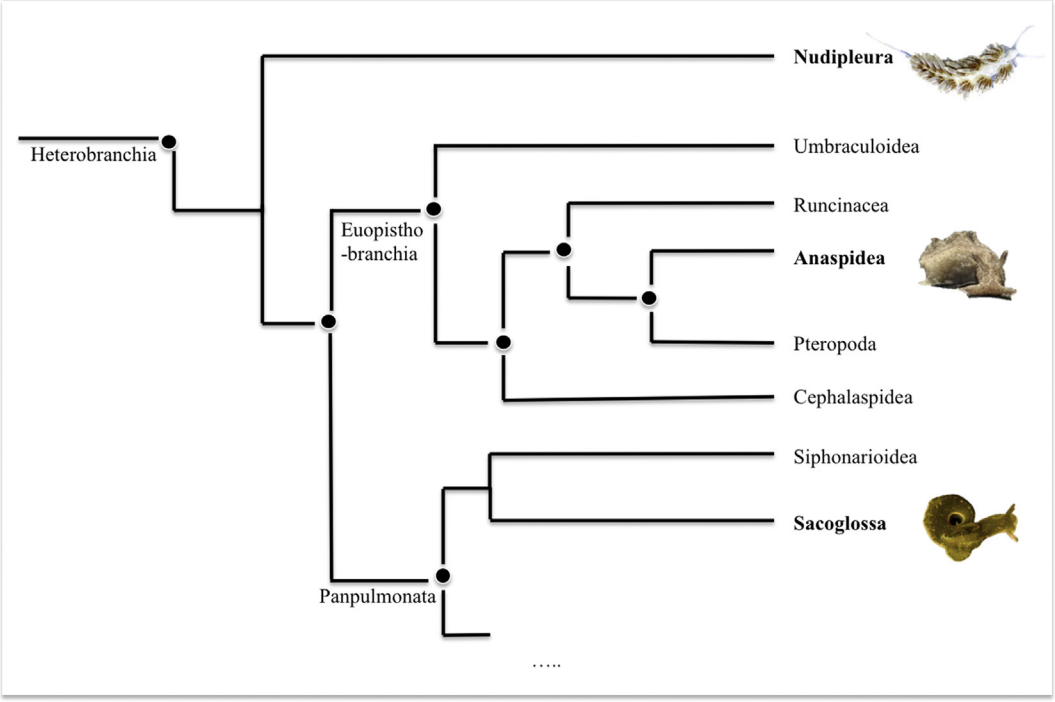

Fig. 1. Simplified classification of the most commonly cultured groups of sea slugs (adapted from Jörger et al., 2010). The differences between branches reflect a measure of divergence time. Black nodes show significant support. Nudipleura are represented by *Aeolidiella stephanieae*, Anaspidae by *Aplysia* sp. and Sacoglossa by *Elysia viridis*. (Note: the group Panpulmunata is not represented in the figure.)