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On the occurrence and ecology of *Glaucus atlanticus* Forster, 1777 (Mollusca: Nudibranchia) along the Southwestern Atlantic coast

RAPHAEL M. PINOTTI [1], FABIO C. BOM[1] and ERIK MUXAGATA[2]

[1]Laboratório de Ecologia de Invertebrados Bentônicos, Instituto de Oceanografia, Universidade Federal do Rio Grande/FURG, Av. Itália, Km 8, Campus Carreiros, 96203-900 Rio Grande, RS, Brazil
[2]Laboratório de Ecologia do Zooplâncton, Instituto de Oceanografia, Universidade Federal do Rio Grande/FURG, Av. Itália, Km 8, Campus Carreiros, 96203-900, Rio Grande, RS, Brazil

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Abstract: Unlike the majority of the nudibranchs, Glaucidae lives adrift at the sea surface within Tropical and Subtropical ocean basins, feeding on cnidarians or using them to attach their egg strings as a reproductive strategy. The latitudinal distribution of *Glaucus atlanticus* throughout the Brazilian Province is influenced by the Brazil current and, in its austral limit, by seasonal shifts in the Subtropical Convergence Zone (especially under the influence of ENSO *El Niño* events). Once over the shelf, seasonal wind patterns and meteorological events can force a passive displacement of the species towards the shore. Such onshore displacements may result on strandings of *Glaucus* spp. and other pleustonic species of the "blue plankton" community, like already reported worldwide and recently at the Southern Brazilian / Uruguayan coasts. Although fascinating, *Glaucus* spp. should be considered harmful to humans and people should thus avoid direct contact; if this accidentally occurs, short-term treatments can be implemented besides looking for medical attention. The current geographical distribution of *Glaucus atlanticus* over the Brazilian coast reveals some inaccuracy and gaps; the present study not only revises the ecology of this species but also evidences the occurrence of summer strandings and its austral distribution into subtropical shores.

Key words: biogeography, cnidarians, holoplankton, nudibranch, strandings.

Nudibranchs (commonly known as sea slugs) form the most diverse order of opistobranch gastropods and are easily recognized by the soft and elongated shell-less body, with the majority of the species within this order being epibenthic crawlers. More than 3,000 species are worldwide described (Wägele and Klussmann-Kolb 2005) and around 100 species have already been reported in the Brazilian coast (da Costa et al. 2010).

Ecological changes in cold and temperate waters may act as biogeographical barriers controlling the dispersion of species (Naranjo et al. 1998, García and Bertsch 2009) especially for tropical nudibranchs. Such cold-water barrier can play a significant role for the lowest diversity of opistobranchs within the Southern Brazilian Shelf (García et al. 2006) due to its proximity to the Subtropical Convergence Zone (Garcia 1997)

Correspondence to: Raphael Mathias Pinotti
E-mail:pinottirm@gmail.com
ORCiD: http://orcid.org/0000-0002-2281-8618

and the Southwest Atlantic Shelves Province (sensu Longhurst 2006), in which eurythermal and euryhaline species generally occurs (Boschi 2000).

Coastal reefs and rocky shores can also contribute for the occurrence of relatively high diversity of bottom-dwelling nudibranchs along the Tropical Southwest Atlantic - particularly within the Southern Brazilian Bight - and a decreasing diversity towards the Subtropical Southern Brazilian Shelf (García et al. 2006). Such lower diversity may be attributed to morphology changes on the coastal plain - from the Rio Grande do Sul state (≈ 29º S) to the northeastern Uruguayan coast (≈ 34º S) - in which rocky shores are replaced by sandy shores, environments recognized as unfavorable for benthic nudibranch species (Franz 1970). A different story can be told to those species adapted to the pelagic realm: only few nudibranchs are truly holoplanktonic, displaying complete life cycles in the water column, like the pleustonic species of the family Glaucidae that are usually found floating at the sea surface (Lalli and Gilmer 1989) and thus not influenced by bottom composition and its morphology.

Due to morphological and anatomical synapomorphies, *Glaucus* was previously reported as the single valid genus inside the Glaucidae family, with only two valid species: *Glaucus atlanticus* Forster, 1977, which presents a cosmopolitan Tropical / Subtropical distribution; and *G. marginatus* (Reinhardt & Bergh, 1864) (previously recorded as *Glaucilla marginata*), more restricted to the Indian and Pacific Oceans (Valdés and Campillo 2004). A recent molecular and phylogenetic approach revealed distinct cryptic species within the informal clade '*marginatus*', raising up to five the number of valid species within *Glaucus* (Churchill et al. 2014a): *G. bennettae* limited to the South Pacific Ocean and *G. thompsoni* and *G. mcfarlanei* restricted to the North Pacific Ocean. Another DNA study on *G. atlanticus* suggests that the species appear to be panmictic within ocean basins but not globally, given the presence of geological barriers (continents) and the low water temperatures of Arctic / Southern Oceans (Churchill et al. 2014b).

Displaying a carnivorous (and rarely cannibalistic) behavior, *Glaucus* species usually preys on pleustonic cnidarians like the by-the-wind sailor *Velella velella* (Linnaeus, 1758), the blue-button *Porpita porpita* (Linnaeus, 1758) and the Portuguese man-o'-war *Physalia physalis* (Linnaeus, 1758) (Bieri 1966, Thompson and Bennett 1970, McDonald 2014). When feeding, *Glaucus* use their jaws and the radular teeth to grab and tear the soft tissues and tentacles of these cnidarians (Lalli and Gilmer 1989). As a reproductive strategy, *G. atlanticus* can further use uneaten parts of their prey (e.g., *Velella* in Gliesch 1930) and even the bubble raft of the violet-sea-snail *Janthina* spp. Röding, 1798 (Laursen 1953 apud Lalli and Gilmer 1989) to attach their egg strings. Unfortunately, there is no sufficient data about the reproduction and development of *Glaucus* spp. in nature, except under laboratory conditions (Ross and Quetin 1990).

The distribution of *G. atlanticus* throughout the Western Atlantic Ocean is highly associated with the gyre systems in both hemispheres and limited by the (warm) water temperature: (i) within the Caribbean Province, up to Bermuda Islands and (ii) within the Brazilian Province, up to Brazil / Uruguay border (García et al. 2006, Padula et al. 2012). The Subtropical Convergence Zone, where Brazil Current (warm, weak and oligotrophic) and Malvinas Current (cold, strong and nutrient-rich) converge is the most relevant oceanographic feature of the Southwestern Atlantic (Garcia 1997), reaching higher latitudes during the austral summer (Maamaatuaiahutapu et al. 1994, Barré et al. 2006) and especially under the influence of ENSO *El Niño* events (Ortega and Martínez 2007). The seasonal migration of the Convergence Zone modify the characteristics of water masses over the Southern

Brazilian / Uruguayan shelf, with a predominance of Tropical and Subtropical Waters along the summer-autumn seasons (Lima et al. 1996, Garcia 1997, Ortega and Martínez 2007), which thus can be responsible for the distribution of *G. atlanticus* bounded to this water mass.

The intrusion of Coastal and Tropical Waters over the Southern Brazilian / Uruguayan shelf during summer (Ortega and Martínez 2007) favors the passive displacement of the species towards the shore, a movement largely influenced by the seasonal wind patterns and strong S-SW winds related with frontal systems and cyclonic events (Marone and Camargo 1994, Krusche et al. 2002). Such onshore displacements of *Glaucus* spp. may result on strandings like those already reported on Brazil (Gliesch 1930, Vannucci 1939, Rios 2009), South Africa (Macnae 1954), India (Srinivasulu et al. 2012), Australia (Iredale 1940, Bennett 1966, Thompson and Bennett 1970), El Salvador (Segovia and López 2015) and Costa Rica (García-Méndez and Camacho-García 2016). Other pleustonic species of the "blue plankton" community are frequently associated with *Glaucus* spp. strandings (Gliesch 1930, Vannucci 1939, Bieri 1966, González et al. 2014, Segovia and López 2015).

Massive strandings of the blue dragon *G. atlanticus* were registered along the Southwestern Atlantic Ocean coast during the summers of 2011 and 2017 (Figure 1). In 2011, scattered strandings of *G. atlanticus* and large quantities of the pleustonic species *V. velella*, *P. porpita*, *P. physalis* and *Janthina* spp. were recorded from Cassino Beach - Southern Brazil to La Paloma - Uruguay (≈ 350 km of distance) after the passage of two consecutive cold fronts associated with a cyclonic event. Another stranding phenomenon was recorded in

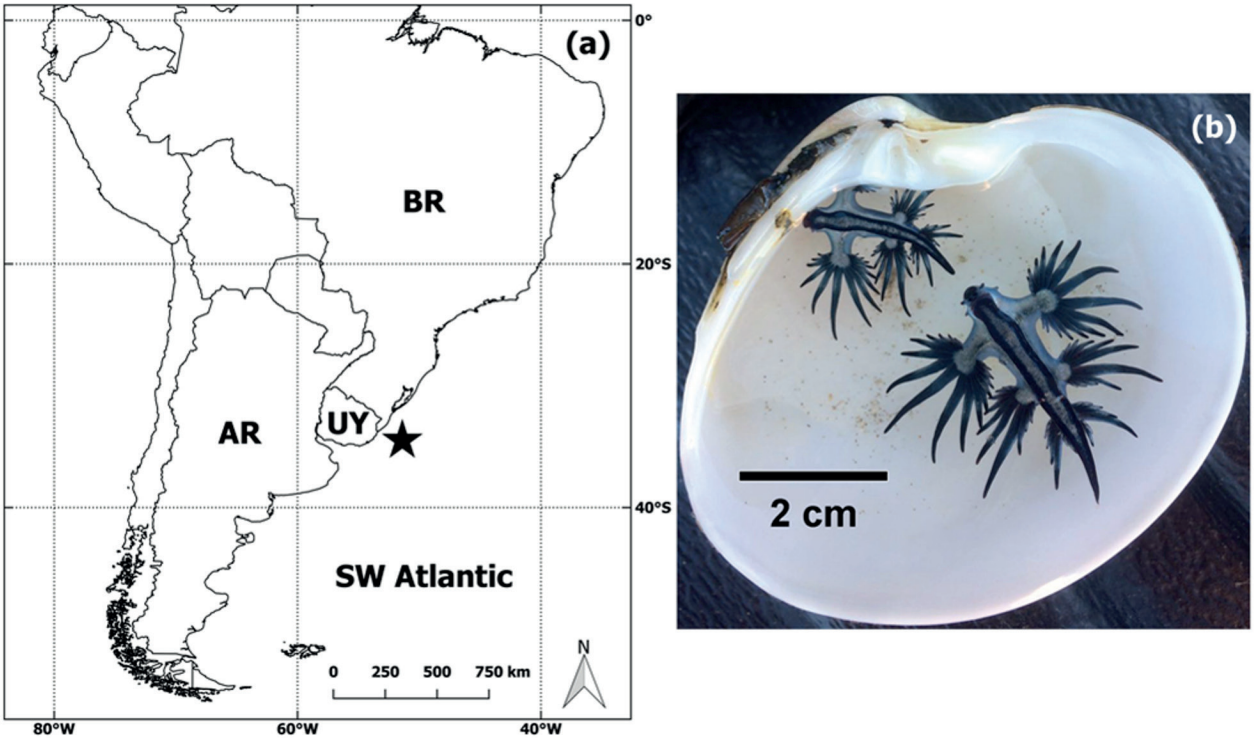

Figure 1 - Brazilian (BR), Uruguayan (UY) and Argentinean (AR) shores, evidencing the area in which *Glaucus atlanticus* was reported during the summers of 2011 and 2017 (**a**). During the 2017' strandings, *G. atlanticus* (**b**) and several cnidarians were found scattered within the upper intertidal at Cassino Beach (32.174º S; 52.134º W).

2017 from Cassino Beach to Concheiros Beach, both in Southern Brazil (≈ 200 km of distance) two days after a storm (moderate SW winds of 4.4 ms^{-1} on average; wind gusts up to 13.7 ms^{-1}; oceanic wave heights up to 3 m). During this later stranding event, *G. atlanticus* specimens (15 - 35 mm; 20 individuals per running meter) were found scattered within the upper intertidal, among large quantities of *V. velella* and a few *Janthina* spp.

Although fascinating to regular tourists which swarm the beaches (especially during the summer season) or even artistic inspiring to the young generations (Cavallari 2015), *Glaucus* spp. should be considered as harmful to humans as their prey. Given their soft body and the absence of a protective shell, *Glaucus* species use the ingestion of both fired and undischarged nematocysts of their prey as a defensive strategy, concentrating them inside cnidosacs located at the tip of each cerata (Thompson and Bennett 1970). Along the Southwestern Atlantic Ocean, *G. atlanticus* mainly feed on *V. velella*, *P. porpita* and *P. physalis* cnidarians. The nematocysts of those species may cause skin irritation (Johnson and Allen 2012) or even death when *Physalia* toxin is involved (Burnett and Gable 1989, Edmonds 1995).

Humans who have had contact with *G. atlanticus* that had feed on *Physalia* may present clinical issues similar to *P. physalis* envenomation (Thompson and Bennett 1969, Edmonds 1995, Williamson et al. 1996, Tibballs 2006) including nausea, pain, vomiting, acute allergic contact dermatitis, erythema, urticarial papules, potential vesicle formation and post-inflammatory hyperpigmentation (Ottuso 2009). People should thus avoid direct contact with *Glaucus* spp. as for any other wild animal but if this accidentally occurs, treatment of stings may include the use of potent topical steroids, cool compresses and antihistamine therapy (Ottuso 2009) besides seeking medical attention immediately.

The current geographical distribution of *G. atlanticus* in the Western South Atlantic reveals some inaccuracy and gaps in the species occurrence, given the reduced sampling efforts on nudibranchs towards the Southern Brazilian / Uruguayan Subtropical waters, which finally results in underestimated diversity (García et al. 2006). So far, the species distribution over the Brazilian coast has been reported from Alagoas state (Padula et al. 2012) to Rio Grande do Sul state (Gliesch 1930, Rios 1975, 2009) with the later essentially based on outdated literature with vague information. This study not only verifies the distribution of *G. atlanticus* into Uruguayan shores (La Paloma, Rocha: Figueiras and Sicardi 1980, Scarabino 2004) but also evidences the nowadays occurrence of massive strandings during summer (when issues related to public health may occur), raising the importance of studies on the species' ecology within its austral limit of distribution.

AUTHOR CONTRIBUTIONS

RMP and FCB wrote the manuscript with support from EM. 2011 data were provided by EM and 2017 by RMP and FCB. All authors discussed the results and contributed to the final version of the manuscript.

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