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Growing Up in the Deep-Sea

Protected development in deep-sea invertebrates: A case study in the southwestern Atlantic Ocean

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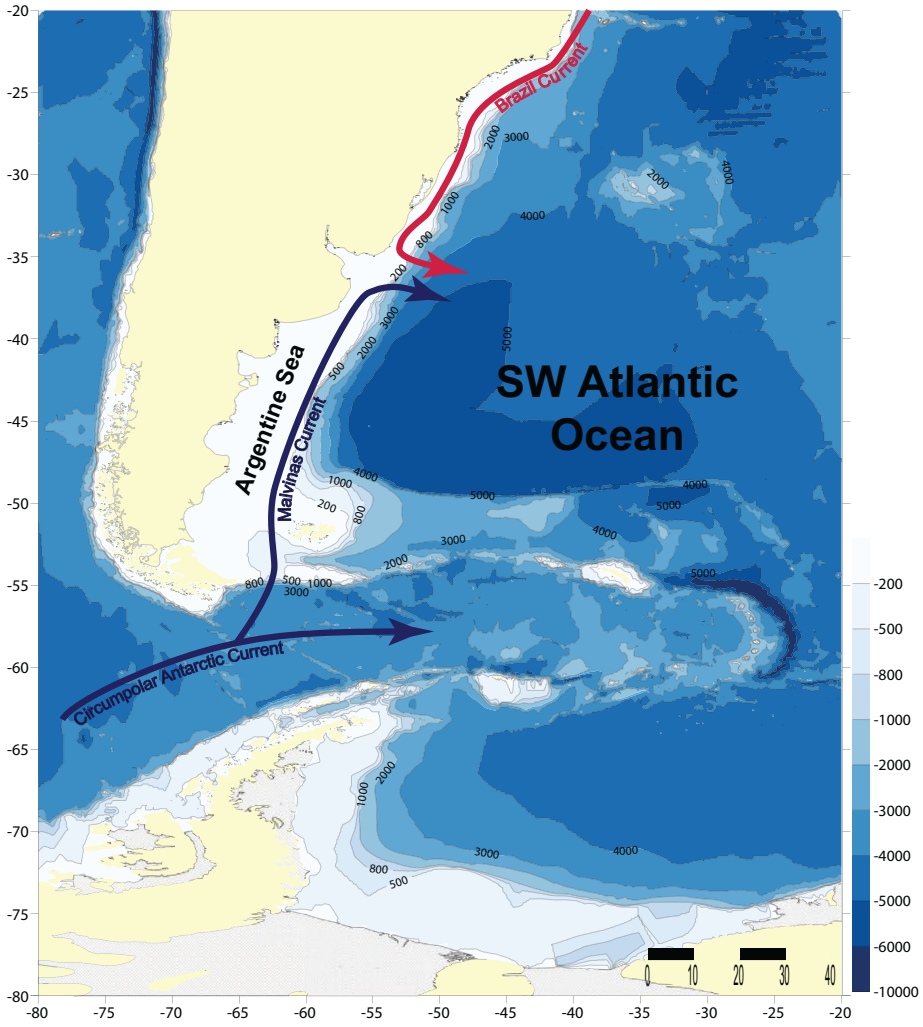
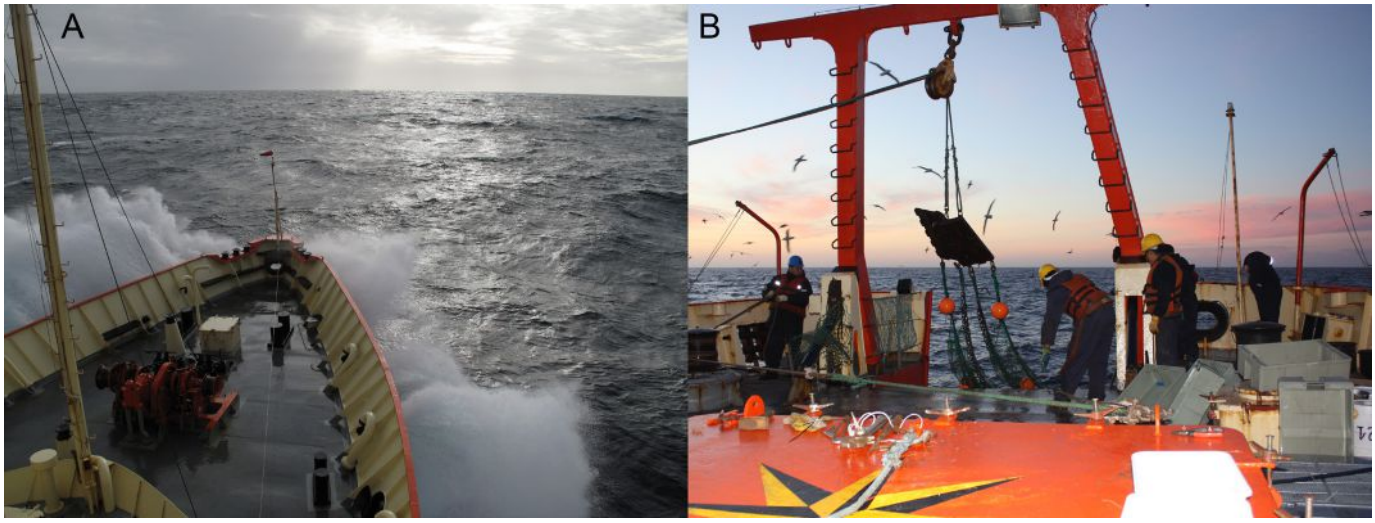
Marine invertebrates display a range of reproductive strategies, from external fertilization to several methods to protect the young. Both brooding or protected development of benthic species and direct development species (when juveniles born in a smaller version of its adult form) involves reducing the time that the larvae and/or juveniles spend in the plankton. The different forms of juvenile protection are often associated with the taxonomic group, although certain groups are much diversified in terms of their reproductive modes. However, the area where the species live also seems to play a key role. Several authors have indicated the unusual proportion of brooding species in the Southern Ocean, in particular in the southwestern Atlantic, including its adjacent deep-sea. The knowledge about the reproductive characteristics of most of the fauna in this area remains unknown. Proof of this are the great number of studies carried out in recent years, describing the reproductive features of several species (many also new), with some of them having many peculiarities about their biology.

The southwestern Atlantic shelf extends from Cape Frio, Brazil (~ 22° S) to Tierra del Fuego and Burdwood Bank, Argentina (~ 55° S[1]). It is the largest continental shelf in the southern hemisphere. The Mar del Plata Canyon is located in this area and belongs to the continental margin of Argentina at about 38º S, reaching over 3,500 meters deep. It is one of the largest canyons in the Argentinean continental margin and it has been the focus of biological and geological research in recent years. The geomorphology of the external shelf and the submarine canyons of



Southwestern Atlantic Ocean, featuring its main currents and isobates.



*Research vessel "*Puerto Deseado*" heading toward a sampling site (A), and a bottom net trawl on its deck (B).*

the Argentinian continental margin are strongly influenced by the Malvinas Current, a branch of the Antarctic Circumpolar Current that runs towards the northeastern Argentinian margin. The Malvinas Current transports cold sub-Antarctic water and collides with the Brazil Current, which carries warm waters along the continental slope of South America. This collision generates one of the most energetic regions in the world. Given its biological diversity, geographic position and geological characteristics, it may be a suitable region to create a Marine Protected Area (MPA).

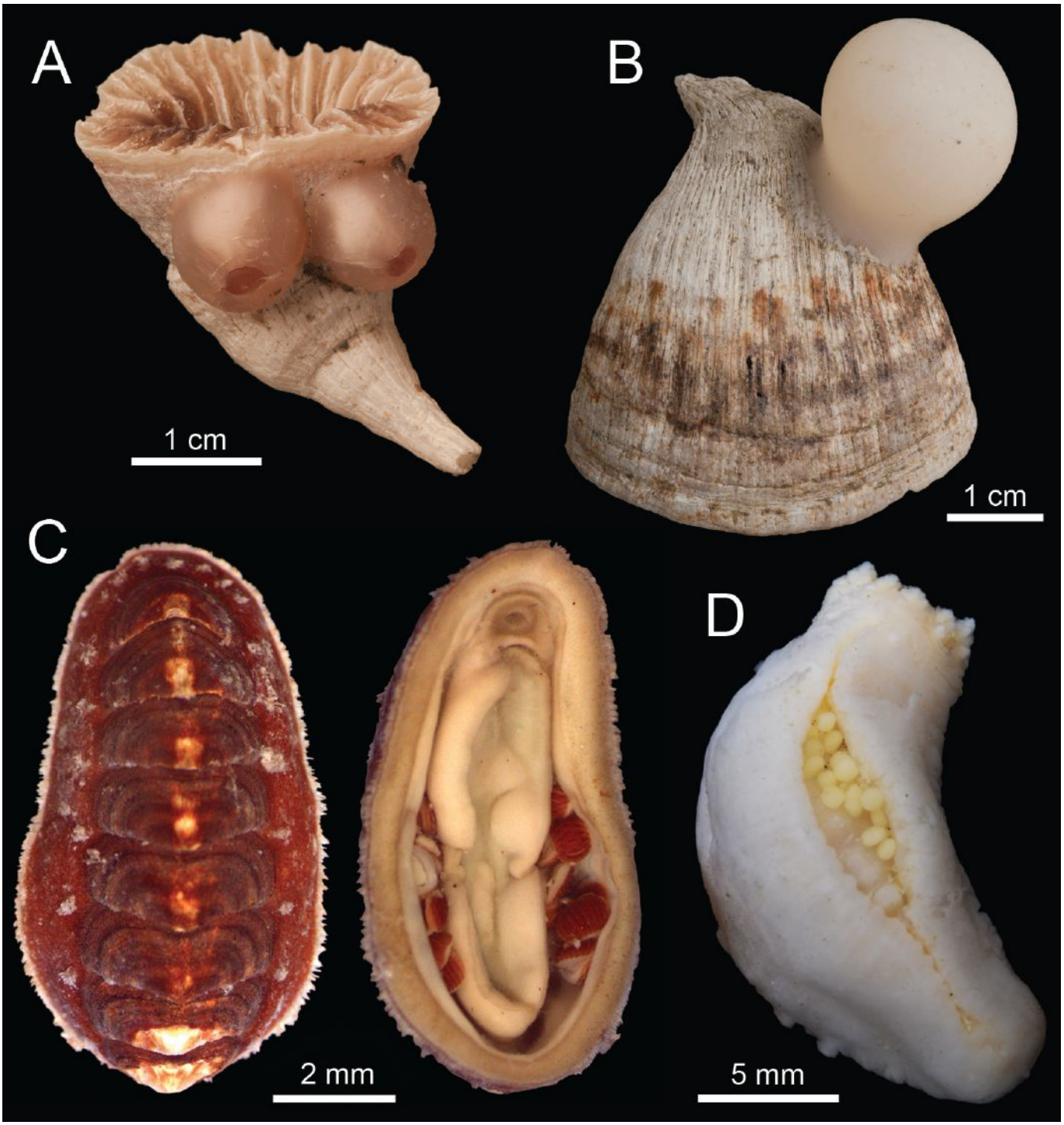
Since 2012, we have studied the reproductive mode of deep-sea invertebrates from the southern region of the southwestern Atlantic[2] by a series of cruises on board the Argentinian research vessel *Puerto Deseado* (between 2012-2014 and 2016-2017), focusing on the Mar del Plata Canyon (up to 3,500 meters depth) and the vicinity of the Burdwood Bank (up to 1,000 meters depth). The living organisms of this submarine canyon are poorly known and it may be a key component in the conservation of the marine biodiversity of the area since, like many other deep-sea submarine canyons, it could be a hotspot of biodiversity. Focusing our research in a potential hotspot area reduces the sampling time and helps in our challenge to know more about this benthic community and the negative effects of human impact. Although the latter takes place in the deep sea, it is not safe from the dangers of human activities and its consequences, including ocean warming, ocean acidification and the potential sinking of litter such as microplastics.

The Burdwood Bank, at around 54° S, 59° W, is included in the MPA Namuncurà Burdwood Bank, a submerged plateau with relatively shallow waters, 50 meters to 200 meters depth approximately, surrounded by the deep-sea. It is a remote and difficult-to-study site, located at the southern area of the continental margin of Argentina, and is considered the entry area of the Malvinas Current to the Argentine Sea. Our preliminary results show that there is a connection between Burdwood Bank and the deep-sea area off Mar del Plata based upon biodiversity, most probably due to the Malvinas Current. This was evident in our observations of a great proportion of coincidence in the species found in both areas.

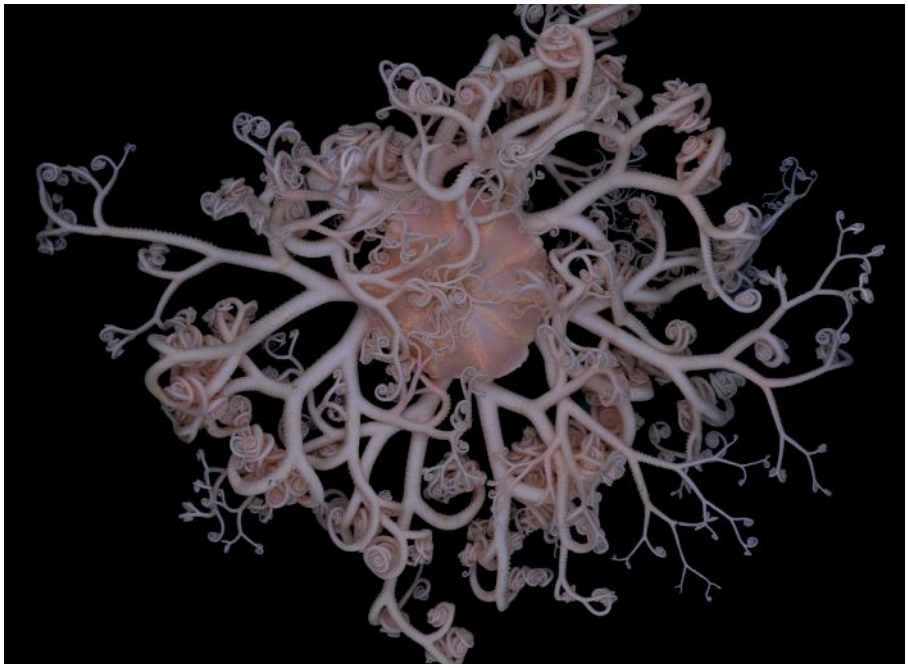
To collect the specimens for our studies, we used three different sam-

The black coral Dendrobathypathes grandis *after collection.*

pling gears: bottom net trawl, modified Agassiz dredge and Rauschert dredge. Once on the vessel, the specimens were selected according to the research goal and fixed accordingly, usually in 70 percent or 96 percent ethanol, 4 percent formalin or frozen at -80ºC. The bottom net trawl is a cone shaped net of about two meters wide and six meters long, with two lateral wings in the extremes that help to keep its mouth open. The dredges were made of a metallic frame that encloses (and protects) a small net inside. Nets are usually used in soft and regular bottoms, and they have the advantage of collecting a relatively great number of specimens, of considerably large size. Dredges are much smaller, but more resistant to the impact of rocks, so they are usually used in unknown bottoms or irregular ones. Since the fishing gear can take up to six hours to reach the bottom and go up, when sampling at 3,000 meters depth, it is normal to work a full day, taking turns to rest when the gear is in the water.



Ovigerous capsules of the marine gastropods Aforia obesa *(A) and* Odontocymbiola pescalia *(B) attached on corals* Flabellum *sp., polyplacophoran (C) brooding juveniles and a sea cucumber (D) featuring its marsupium with broods inside.*



Basket star from the Argentine Continental Shelf.

Many of the more than 400 species of benthic cnidarians, mollusks and echinoderms found are being studied and new species are being described. Among these, several new cases of protected development were observed in the study area in different phyla, with avoidance or reduction of a free-swimming larval stage. Among Cnidaria, an enlargement of the oocyte (ovarian cell) was found in the only black coral known in the area, *Dendrobathypathes grandis*, with a diameter of up to 1.5 mm, when oocytes in *Antipatharia* are usually under 0.2 mm. This may be related to the presence of a particular structure in the oocytes that may facilitate the transport of nutrients to the oocyte. The sea anemone *Actinostola crassicornis* broods its juveniles internally (mostly females, but also males) until the release of a small but completely developed juvenile. Meanwhile, *Epiactis* sp. is an external brooder, the juveniles remain attached to the column of the adult after the release.

Many deep-sea gastropods show encapsulated direct development, by the presence of supplementary food for the embryo as nurse eggs and / or adelphophagy (one embryo eats sibling embryos) in *Americominella longisetosa* and *Trochita pileus,* proteins in the intracapsular liquid in *Bulbus carcellesi, Falsilunatia eltanini, Toledonia biplicata, Provocator corderoi* and *Odontocymbiola pescalia*, or by means of gigantic eggs of about 1.8 mm in diameter in *Aforia obesa*. Peculiar egg mass morphologies are reported in the moon snail *Bulbus carcellesi* where the egg capsules are the largest ever recorded for this family (8.8–14.1 mm in diameter vs 3 mm of the largest previously known). Females of the chiton *Hemiarthrum setulosum* brood their eggs to the juvenile stage under the girdle, in the mantle cavity. Brooding is found in the five classes of Echinodermata. The sea stars *Ctenodiscus australis* and *Bernasconiaster pipi* protect its broods, the first one in the dorsal side between paxillae and the second one in the oral area. For crinoids, *Isometra vivipara* shows two phases of protection, one with eggs brooded in a marsupium and a second phase in the cirrus. In some sea cucumbers such as *Cladodactyla crocea, Psolus patagonicus,* and *Psolus lawrencei* broods could be found externally, in a dorsal marsupium, the sole and brooding oral pouches, respectively. Recently, internal brooding has been observed, as brood sacs were found in the cucumarid *Pentactella perrieri.* This species has one of the largest egg sizes with 1.6 mm and is reported as a hermaphroditic species. In the sea urchin A*ustrocidaris canaliculata* a morphological transformation of the apical system into a marsupium takes place, allowing the brooding of their offspring. Brooding chambers have also been reported in ophiuroids, such as *Astrotoma agassizi* and *Ophiochondrus stelliger*.

Several authors support the idea that brooding is characterized by a stable and structured environment of low temperature, as this developmental mode is more frequent when the latitude and depth are greater. These results showed that some kind of protected development, with avoidance of free-swimming larval stage, could be much more frequent than we previously thought. This new evidence gives more support to several publications from the last years that try to explain why the southwestern Atlantic is the scenario with a large proportion of species with protected development when compared to the intertropical and cold regions of the northern hemisphere.

Plenty new species and reproductive strategies have been reported since the first expeditions and it is possible that more will come. The data obtained allow us to push the frontiers of the knowledge of deep-sea southwestern Atlantic waters and to reanalyze the abundance and diversity of species that, even now, are considered low for the area. We expect that the knowledge acquired regarding the biodiversity and reproductive strategies of different taxa will be useful to understand the complexity of life in such stressful conditions. It will also help in the decision making process of stakeholders to protect sea life. We expect that these findings foster the continuity of scientific policies and allow the large scale development of marine studies in such a challenging but extraordinary area as the deep-sea.

For more information:

To read more about the characteristic of continental margin of Argentina sea Matano RP, Palma E.D., Piola A.R., (2010). The influence of the Brazil and Malvinas currents on the southwestern Atlantic shelf circulation. Ocean Science Discussions, 7:1–35 and Voigt I., Henrich R., Preu B.M., Piola A.R., Hanebuth T.J.J., Schwenk T., Chiessie C.M. (2013). A submarine canyon as a climate archive—interaction of the Ant-arctic Intermediate Water with the Mar del Plata Canyon. Marine Geology, 341:46–57.

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https://www.researchgate.net/profile/Guido_Pastorino