THE SOUTHERN OCEAN: OUR BEST OPPORTUNITY?

O Oceano Antártico: nossa melhor oportunidade?

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ABSTRACT

The Southern Ocean has a significant importance in global climate regulation because its great potential to sequester atmospheric carbon and its enormous contribution to the transport of heat and mass in the global ocean. Antarctic benthos presents unique characteristics developed after millions of years of evolution and greatly contribute to the maintenance of the global biodiversity and genetic pool. Ongoing anthropogenic pressure seriously threatens Southern Ocean’s current characteristics and the ecosystems services they provide. In my opinion, individual actions toward environmental protection emerges as the fastest alternative to ameliorate the current situation.

Keywords: Antarctica, climate change, anthropogenic impacts, social behavior.

RESUMO

O Oceano Antártico tem importância significativa na regulação do clima global devido ao seu grande potencial para sequestrar carbono atmosférico e sua enorme contribuição para o transporte de calor e massa no oceano global. O bentos antártico apresenta características únicas, que foram desenvolvidas após milhões de anos de evolução, e contribui para a manutenção da biodiversidade global e do patrimônio genético. A pressão antropogênica contínua ameaça seriamente as características atuais do Oceano Antártico e os serviços ecossistêmicos que ele fornece. Na minha opinião, as ações individuais voltadas para a proteção do meio ambiente surgem como a alternativa mais rápida para amenizar a situação atual.

Palavras-chave: Antártica, mudanças climáticas, impactos antropogênicos, comportamento social.
INTRODUCTION

Antarctica and its polar climatic conditions started developing approximately 30 million years ago when the opening of the Tasmanian Gateway enabled the onset of the Antarctic Circumpolar Current, which modified the global ocean circulation (Scher et al., 2015) and greatly contributed to the near thermal isolation of the current white continent. This geophysical characteristic gives to the Antarctic region a significant importance for the global climate regulation. Due to the massive sinking of cold, dense water, it has a major force in the ocean’s thermo-haline circulation (also known as the global conveyor belt), which drives energy and matter around the globe, balancing heat among the equator and the poles (Gordon, 2001). Its enormous white colored surface (up to 40 million km² in winter and half of it during summer) has a high solar radiation reflective capacity or albedo, a very valuable aid to reduce global warming (Laine et al., 2008). Further, the upper ocean mixing caused by strong westerly winds around the continent, makes the Southern Ocean (SO) very effective at absorbing the greenhouse gas carbon dioxide (CO₂) from the atmosphere, alleviating the ongoing increasing concentration trend of this gas. Most of CO₂ sequestration from the atmosphere takes place during summer. In this season, the SO hosts massive phytoplankton blooms, which transform gaseous carbon from the atmosphere (in the form of CO₂) into particulate organic material that sinks and feed abundant life forms thriving both in the water column and on the seabed, where eventually gets buried for thousands, even millions of years. The importance of the Antarctic region for life on Earth, as we know it nowadays, is fundamental; however, invisible.

The fauna dwelling on the Antarctic seabed has a long history too. The Antarctic continental shelf benthos has been evolving separated from its lower-latitude counterparts in rather constant conditions of low temperature, salinity and darkness since the late Cretaceous, millions of years ago (Arntz; Brey & Gallardo, 1994; Gili et al., 2006). At shallower depths, benthos has been exposed to a drastic seasonality in light availability and sea ice cover, which strongly modulates life in the Antarctic. Unique environmental conditions of low temperature (mainly between -2°C and 5°C, depending on water depth), salinity (mainly between 34.6‰ and 34.9‰) and seasonality in sea ice extent and primary production, shaped the contemporary Antarctic benthic assemblages. These communities can reach biomasses representing > 3 kg of wet weight per m², both at shallow (<100 water depth) and deep areas (>300 m water depth) (Sáiz-Salinas et al., 1997; Isla & Gerdes, 2019). Approximately 17 000 species of marine invertebrates constitute these communities, which show the highest endemism proportion of any continent and unique evolutionary characteristics (Arntz; Brey & Gallardo, 1994; Peck, 2018). Nevertheless, environmental conditions are dynamic and had changed since the Cretaceous. Along this time span, the Antarctic has undergone several glaciations and interglacial periods, with environmental conditions that modulated the geographic and bathymetric distribution of benthic fauna (Thatje; Hillenbrand & Lartes, 2005), with the last glacial maximum approximately 15000 to 18000 years ago. It has been proposed that since then, deep-sea benthic fauna recolonized the open space at the continental shelf, preserving the unique evolutionary characteristics observed at present (Thatje; Hillenbrand & Lartes, 2005; Thatje et al., 2008). Currently, environmental changes derived from industrial activity are modifying the Antarctic marine environment at an unprecedented pace, which challenges the adaptation capacity of its biota, developed after millions of years of evolution (Arntz; Brey & Gallardo, 1994; Gutt et
Losing Antarctic marine biota will severely impact the maintenance of global biodiversity and genetic pool, which are some of the key ecosystem services that the Antarctic provides (Grant et al., 2013; Pertierra et al., 2021). Ecosystem services are the benefits that mankind obtains from natural ecosystems and, in the case of the Antarctic, in spite of being thousands of kilometers away from any human settlement not related to scientific activities. Other key Antarctic ecosystems services are the provision of fishery products, nutrient cycling, climate and air quality regulation and the cultural and marvelous aesthetic benefits, which we all can enjoy despite not being there.

**Major threats**

At present, climate change is perhaps the most important threat for Antarctic ecosystems (Gutt et al., 2021). For example, ocean acidification will eventually impact the entire Antarctic region (Gutt et al., 2015). Information on anthropogenic pollution is steadily increasing on both, its spatial extent and the presence of different types of pollutants, especially for plastics. However, regardless of the research line, understanding on the various biogeochemical and physical processes involved in the ongoing transformation of the Antarctic environment and the consequences for its biota, is still poor. To tackle this situation, International and cross-disciplinary scientific actions are urgent due to the rapid transformation pace of the SO and the impact on its inhabitants (Kennicutt II et al., 2019; Gutt et al., 2018, 2021). During the last decade there have been substantial advances in identifying knowledge gaps and organizing future scientific directions to better understand the Antarctic system and its influence on Earth’s climate (Kennicutt II et al., 2015, 2019; Gutt et al., 2021). These advances aim to provide basis for accurate predictions to enlighten politicians, decision makers and the general public to take action towards a proper management and preservation of a continent, where it seems the anthropogenic footprint is still comparatively weak at a global scale.

The Antarctic already faces several anthropogenic threats and most likely the number will increase as human and industrial pressure and the measuring tools and their detection levels will do so. To describe all the ongoing and potential threats for the Antarctic will be sufficient to write a book but, given the limits of the present contribution, a good way to summarize, at least some them, is by their geographic extent (Gutt et al., 2015), which in many cases can overlap, locally increasing their impact. For example, on the continental shelf and the coastal zone, where several of the most evident ongoing threats co-occur.

**Ocean warming - shift of the polar front**

Ocean warming affects the entire sea surface; however, temperature increases which may produce significant physiological responses in marine organisms have been identified in about 1 K (Peck, 2011; Peck et al., 2014). This temperature increase affects already about 3% of the 50 m water column of the SO (~ 1 x 10⁶ km²), where the western Antarctic Peninsula (WAP) stands as the most affected (Gutt et al., 2015). However, the deep ocean also carries a warm signal (Gille, 2002); the water masses flowing between 700 m and 1000 m water depth are about 0.2°C warmer than in the 1950’s and periodically intrude onto the continental shelf (~ 3 x 10⁶ km², taken from Peck, 2018), which represents about 9% of the SO. This temperature increase has not reach 1 K yet; however, it is already contacting with the benthic fauna dwelling on the Antarctic continental shelf (Isla & Gerdes, 2019). Most of
these continental shelf communities are constituted by sessile animals, which show low adaptation capacities and most likely won’t be able to avoid temperature stress (Peck, 2018). Increasing temperatures may also produce an impact in the oxygen ventilation of the SO, nutrient fluxes and a possible collapse of ice-shelves, which could have an impact on entire marine communities (Gutt et al., 2021). As temperature increase at the sea surface, the Antarctic Polar Front, dividing cold (5°C to 2°C) from freezing (< 2°C) waters, migrates to the South together with its accompanying fauna, reducing the northern limit for Antarctic biota and enhancing the chances for non-indigenous fauna to colonize the Antarctic (Griffiths; Meijers & Bracegirdle, 2017). The southward migration of the Antarctic Polar Front represents an area of approximately 7% of the SO (~ 2 x 10^6 km²).

**Sea ice season length and extent**

Sea ice extent is also changing in the Antarctic. Unlike the Arctic trend, sea ice in the Ross and the Weddell Seas presented sea ice extent increases in contrast to the evident retreats registered off the WAP (Gutt et al., 2015). Observed sea ice extent increase maxima during 1979 to 2012 occupied approximately 3% of the SO in the Ross Sea and Weddell Sea sectors (~1 x 10^6 km²), whereas decreases mainly off the WAP, were only 1.8% (0.6 x 10^6 km²). Nevertheless, in the 2016/17 season an unprecedented rapid decrease and larger spatial retreat in sea ice extent was observed for the Weddell Sea (Turner et al., 2017, 2020).

Up to date, sea ice loss for the Antarctic seems to be balanced with sea ice increase; however, locally these variations produce impacts on the distribution of pelagic species such as salps and krill (Atkinson et al., 2004; Montes-Hugo et al., 2009). Krill populations are migrating toward the South, where colder and polar conditions persist at the time that salps occupy the northern areas, where warmer temperatures coexist with less sea ice. Krill is especially important in the Antarctic food web because its protein and energy content (higher than that in salps) maintains large biomasses of fish, mammals and birds (Savage & Foulds, 1987; Dubischar et al., 2012; Harmelin-Vivien et al., 2019). In addition to the cascading effects on the Antarctic trophic levels, especially for species primarily feeding on krill, the transfer of organic carbon to the sea floor may be also compromised. An 11-year time series off the WAP revealed that zooplankton community migration may have an impact on particle fluxes collected at 350 m depth (Ducklow et al., 2007). Higher abundance of salps led to higher particle fluxes, whereas the dominance of krill was weakly related to smaller fluxes. In consequence, the supply of biogenic matter (e.g., organic carbon and biogenic silica) to sea floor may be also changing; hence, impacting benthos and the storage of carbon in sediment column (Sañé et al., 2011, 2012; Isla & DeMaster, 2018).

**Ice shelf disintegration and iceberg scouring**

Warming of the ocean and the atmosphere is contributing to make ice shelf disintegration a regular event every austral summer. Ice shelf collapses reduce the albedo capacity of the Antarctic, negatively feeding back global warming. Since the 1960’s this process affects 0.03 x 10^6 km² (Gutt et al., 2015). In the absence of peer reviewed literature (at least to the author’s knowledge) and based on public media information, during the last 6 years, this area has increased at least in 10 000 km², adding 4320 km² of iceberg A-76 and 6000 km² from the massive iceberg A-68, which calved from the Ronne (https://www.esa.int/esearch?q=a-76) and Larsen C Ice Shelves (https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-1/Sentinel_satellite_captures_birth_of_
behemoth_iceberg), respectively; both events occurred in the Weddell Sea. Ice shelf collapses also open space for primary production at the sea surface (Bertolin & Schloss, 2009) and a subsequent flux of organic matter to the seabed that stimulates benthic colonization of the sea floor (Sañé et al., 2011, 2012). It has been speculated that eventually, the sediment column beneath areas where ice shelves recently collapsed (e.g. years to decades ago), will accumulate carbon, alleviating ongoing global warming. However, it has been observed that carbon accumulation in these areas may take decades before becoming an effective carbon sink (Isla & DeMaster, 2018). Large icebergs generated after ice shelf collapses strongly erode the seabed, completely removing macrobenthic life but also stimulating recolonization processes, which are fundamental to maintain biodiversity (Gutt & Starmans, 2001). Projections for the end of the present century suggest that 65% of the entire Antarctic shelf will be affected by iceberg scouring (Gutt et al., 2015). Given that the ice shelves at the western Weddell Sea are under high climate stress (Hellmer et al., 2017), the northward circulation path of the Weddell Gyre and that iceberg scouring typically occurs over areas down-stream from the iceberg’s starting drifting point, the eastern continental shelf of the Antarctic Peninsula emerges as an area especially favorable for iceberg scouring. Large icebergs can also release abundant and diverse microbial life and nutrients into the adjacent water column along their drifting paths, stimulating biological production and generating a positive effect for the marine biota (Smith Jr. et al., 2007; Boetius et al., 2015).

**Marine glacier retreats**
Antarctic marine glacier fronts have been retreating, particularly on the Antarctic Peninsula and the islands nearby, where 90% of glacier fronts showed clear retreats since the second half of the past century (Davies et al., 2012; Cook et al., 2016). It has been calculated that approximately 1% of Antarctic circumference has been affected by this process so far (Gutt et al., 2015). Most likely the spatial extent of this process will increase in the future given the ongoing temperature increasing trend. Despite that fact that melting of glaciers may represent a comparatively small spatial extent, the local impact of this process could be of high importance because of its cascading effects on the biota. On a first step, melt water inputs may fertilize the marine water column stimulating algal blooms and sinking organic carbon fluxes (Gutt et al., 2021); however, eventually, the sediment loads from glacier inputs may collapse entire zooplankton populations and the adjacent benthic communities interrupting the flux of organic carbon to higher trophic levels (Sahade et al., 2015; Fuentes et al., 2016). It has been observed that the bays and fjords shaping the Antarctic Peninsula coast line host high primary production rates, which enable the export of organic carbon to the open sea maintaining pelagic life there (Isla et al., 2004; Höfer et al., 2019). However, if production near the coast is compromised it may propagate its negative effects to the areas off shore. Further, releases of anthropogenic pollutants accumulated on top of the ice caps can reach the adjacent water column via glacier runoffs and eventually affect the Antarctic marine biota (please see the Anthropogenic Pollution Section).

**Ocean acidification**
So far, ocean acidification (OA) appears as the single factor able to affect the entire SO in the near future (Gutt et al., 2015). The SO is especially sensitive to OA because of its
great extent and consequent atmospheric CO\textsubscript{2} absorbing capacity, the enhanced solubility of CO\textsubscript{2} at lower temperatures, naturally low levels of calcium carbonate (added to higher solubility in projected more acidic water masses) in its waters, and a lower buffering capacity to attenuate acidic effects (Petrou \textit{et al.}, 2019; Hancock \textit{et al.}, 2020). Further, strong upwelling, bringing deep CO\textsubscript{2}-rich waters to the surface, produces a synergistic effect (Land \textit{et al.}, 2015; Hancock \textit{et al.}, 2020). OA affects important species in the pelagic and benthic systems such as calcifying coccolithophorids and pteropods, echinoderms and corals (Doney \textit{et al.}, 2009; Riebesell & Tortell, 2011; Bednaršek \textit{et al.}, 2012; Wittmann & Pörtner, 2013), consequently, several trophic interrelationships could change. It is expected that the efficiency of phyotosynthesis and the biological carbon pump may be also compromised (Riebesell \textit{et al.}, 2007; Tortell \textit{et al.}, 2009; Hofmann \textit{et al.}, 2011a,b). For example, reductions of 30% to 35% in foraminifera shell weight compared to preindustrial weights were found at the northern margin of the SO (Moy \textit{et al.}, 2009). However, given the central position of krill in the Antarctic trophic relationships (e.g., feeding fish, mammals and birds), it is of great concern that the development and the carbonate structures of young Antarctic krill, echinoderms and molluscs may be disrupted (Bylenga; Cummings & Ryan, 2017). Further, the hatching success and suitable habitat of krill is projected to decrease (Kawaguchi \textit{et al.}, 2013).

\textbf{Anthropogenic pollution}

Anthropogenic pollutants are widespread over the Antarctic, mainly due to long-range atmospheric transport (LRAT), which drives pollutants thousands of kilometres along a sequence of deposition and resuspension events (Grannas \textit{et al.}, 2013). LRAT moves semi-volatile organic pollutants to high latitudes with an estimated transport time of a week or less from their sources at lower latitudes (Wania, 2003; Grannas \textit{et al.}, 2013). Once at the SO, anthropogenic pollutants also accumulate on top of Antarctic ice caps and remain latent until snow and glacier melting occurs, driving these molecules into the adjacent water column and eventually in the food web (Corsolini, 2009). For example, DDT has been found in penguin fat despite been banned or severely restricted since the 1970s, most likely because DDT deposited onto glaciers surface, has been released into the adjacent water column, where it incorporated into the marine food web (Geisz \textit{et al.}, 2008). Persistent organic pollutants or POPs (e.g., polycyclic aromatic hydrocarbons (PAHs), polychlorobiphenyls (PCB), organochlorine pesticides) have been observed along the Antarctic trophic food web from phytoplankton to birds (Risebrough \textit{et al.}, 1976; Chiuchiolo \textit{et al.}, 2004; Geisz \textit{et al.}, 2008). Antarctic low temperatures and long periods of darkness, “cold-trap” anthropogenic pollutants, enhancing their persistence in this polar setting (Potapowicz \textit{et al.}, 2019). Further, POPs have been detected in the high-latitude Antarctic 235 km away from the coastline; although, with lower levels than those observed in the Arctic (Kallenborn \textit{et al.}, 2013). In addition to POPs, the presence of plastics, particularly microplastics, is becoming more evident every season, despite it seems to be more concentrated near touristic and research facilities. Apparently, the major source of microplastics to the marine environment is the laundry activity of these facilities (Alurralde \textit{et al.}, 2022). Heavy metals also reach the Antarctic via LRAT (e.g., from mining and combustion); however, paint debris and inadequate waste management from vessels and research stations have been identified as a source of these pollutants too (Bargagli, 2008). Up to date, the predominant heavy metals found in the Antarctic are Al,
Ca, Cd, Cr, Cu, Pb and Zn with the highest concentrations in the vicinity of polar stations (Potapowicz et al., 2019).

Challenges

Preserving our planet’s environment is currently our major challenge because life as we know it nowadays, depends on this. Within this frame, Southern Ocean’s environment, is fundamental because of the important role as global climatic regulator and biodiversity reservoir. Geophysical boundaries are no longer effective; anthropogenic pressure already demonstrated its strength in breaking barriers and its effects on the Antarctic are already visible. In the scientific community, there is consensus on the need for urgent international plans to improve our knowledge on the physical and biogeochemical processes governing the transformation of the Antarctic, which appears as a challenge due to the organization level that these plans may require and the rapid pace of ongoing climate change (Kennicutt et al., 2019). For example, implementing a coordinated network of systematic, cross-disciplinary circumpolar oceanographic expeditions to produce simultaneous physical-biogeochemical data sets and a Pan-Antarctic picture of the current environmental variation. Coordinating satellite data acquisition with field observations to better understand ocean-atmosphere coupling processes. Establishing a network of long-term (decadal) observing stations to generate comparable data sets along the Antarctic and accurately distinguish natural and anthropogenic variations to develop environmental predictions with higher confidence. However, in my opinion, two other important challenges emerge; on the one hand the scientific community should provide clear, convincing messages to stake-holders, who may trigger effective actions directed to reduce the deterioration of the environment and preserve the Antarctic. On the other hand, another set of messages, if different to those for stake-holders, directed to the general public aiming to change the way we live on daily basis. From my point of view, the solution to change the direction we are moving on, is based on individual behavior/actions. We, as individuals, families, neighborhoods and ultimately countries, should act thinking on how our behavior will impact the environment. Not only on the Antarctic, also on our parks, cities, urban water and garbage systems, etc. Any action counts.

We now know that despite some of our “business as usual” actions are not visible nearby, they produce an effect in remote places. The Antarctic is perhaps the least impacted region of the planet and its ecosystem services benefit all of us, so taking care of our nearby, and consequently, our remote environment, it is perhaps, our best opportunity to demonstrate ourselves that we really can change for our own good.

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REFERENCES


