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OPINION

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Perspective: Increasing blue carbon around Antarctica is an ecosystem service of considerable societal and economic value worth protecting

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Abstract

Precautionary conservation and cooperative global governance are needed to protect Antarctic blue carbon: the world's largest increasing natural form of carbon storage with high sequestration potential. As patterns of ice loss around Antarctica become more uniform, there is an underlying increase in carbon capture-to-storage-to-sequestration on the seafloor. The amount of carbon captured per unit area is increasing and the area available to blue carbon is also increasing. Carbon sequestration could further increase under moderate (+1°C) ocean warming, contrary to decreasing global blue carbon stocks elsewhere. For example, in warmer waters, mangroves and seagrasses are in decline and benthic organisms are close to their physiological limits, so a 1°C increase in water temperature could push them above their thermal tolerance (e.g. bleaching of coral reefs). In contrast, on the basis of past change and current research, we expect that Antarctic blue carbon could increase by orders of magnitude. The Antarctic seafloor is biophysically unique and the site of carbon sequestration, the benthos, faces less anthropogenic disturbance than any other ocean continental shelf environment. This isolation imparts both vulnerability to change, and an avenue to conserve one of the world's last biodiversity refuges. In economic terms, the value of Antarctic blue carbon is estimated at between £0.65 and £1.76 billion (~2.27 billion USD) for sequestered carbon in the benthos around the continental shelf. To balance biodiversity protection against society's economic objectives, this paper builds on a proposal incentivising protection by building a 'non-market framework' via the 2015 Paris Agreement to the United Nations Framework Convention on Climate Change. This could be connected and coordinated through the Antarctic Treaty System to promote and motivate member states to value Antarctic blue carbon and maintain scientific integrity and conservation for the positive societal values ingrained in the Antarctic Treaty System.

KEYWORDS
Antarctic Treaty System, biodiversity conservation, blue carbon, carbon sequestration

1 | INTRODUCTION

With societal momentum building towards more environmentally conscious living and awareness of growing anthropogenic stresses to nature, it is troubling that the environmental cost of carbon emissions is set to increase dramatically over the next three decades (Bongaarts, 2019; European Commission, 2006). An unusually optimistic finding has been that of increasing capacity of natural carbon capture (by biological processes) leading to bolstered storage and sequestration around the Antarctic continental shelf in the form of biological growth, accumulation and ultimately burial of benthic organisms in the seabed (Antarctic blue carbon; Barnes et al., 2018). Indeed, there has been recent advocacy towards changes in international law and policy to increase protection of these areas to conserve Antarctica's capacity as a region of carbon capture and efficient conversion to storage and potentially on to sequestration (Gogarty et al., 2020).

Given the typically slow growth rates, low annual productivity and the lack of current exploitation threats to the Antarctic seafloor, it appears to be a curious focus of conservation effort. This publication puts the natural carbon sequestration capacity of the Antarctic continental shelf into perspective, highlighting its efficiency over other industrial climate mitigation strategies. Although it may appear low in terms of carbon storage per unit area or volume over time, the sheer magnitude of area available on the Antarctic continental shelf multiplies up a small value to a considerable one (Goel et al., 2019).

2 | CARBON CAPTURE AND SEQUESTRATION

Carbon capture and sequestration, increasing energy efficiencies and increasing use of renewables have been put forward as the three most likely areas where technology can assist in mitigating climate change (Hankin et al., 2019). Actively capturing carbon as a by-product of industry and sequestering it (removal from the carbon cycle and locking it away) as mitigation of climate change is proving to be difficult, expensive and not sufficient to reduce countries' emissions impact in a substantive way (Johnston & Radeloff, 2019). Popular non-technological measures are also unlikely to be as effective as hoped. For instance, reforestation has been popularly cited as an important mitigation strategy, but presently accounts for <1% of carbon emissions and is more a storage strategy, rather than sequestration. Additionally, forests are vulnerable in many geographical locations to processes such as burning which increase carbon dioxide emissions (e.g. the Amazon and Australian bush fires in 2019 and west coast North American wild fires of 2020; Brando et al., 2019) and local political and market forces (Sgouridis et al., 2019), which often fail to operate sustainably. Given this is the case, the present approach to climate mitigation primarily favours transitioning to renewable energy alternatives with carbon capture and sequestration taking a minor role (Speelman et al., 2009).

Human-engineered carbon capture to sequestration is not the only mechanism for locking away anthropogenic carbon; natural systems have been involved in this for the duration of life on Earth and are exceptionally effective. A prime example is the *Azolla* event in the Arctic 49 million years ago. That event involved a bloom of freshwater fern across a shallow Arctic lake, which captured and stored enormous amounts of atmospheric carbon dioxide (Thomas, 2008). Much of this biological material was buried in sediments rather than rotting, effectively sequestering the carbon as opposed to recycling it, as would happen if it were allowed to decompose and release carbon dioxide back into the atmosphere. The *Azolla* event was so profound that it fundamentally changed the global climate from the Paleo-Eocene thermal maximum to the much cooler world of the Oligocene (Thomas, 2008; Whaley, 2007). It was the specific environmental conditions at the time—anoxic deep water lake—that facilitated the magnitude of the *Azolla* event. Similar carbon capturing processes are occurring across the world's oceans, even if at less magnitude. This has been termed 'blue carbon'.

The world's oceans are estimated to have absorbed 40% of anthropogenic atmospheric carbon (DeVries, 2014; Sabine & Tanhua, 2009) and have the capacity to hold enough to bring the atmospheric levels back to preindustrial levels over time if emissions were to cease (Lord et al., 2016). The realised benefits provided by nature as a whole have been financially valued at close to 26 trillion pounds annually (US$33 trillion, exceeding $53 trillion if adjusted for inflation; Costanza et al., 1997). The ecosystem service provided by the ocean is already vastly more effective than industrial carbon capture and storage, and has further potential. Importantly, as a natural process it costs nothing. That is, so long as the process is not undermined from anthropocentric or other interference (Nellemann & Corcoran, 2009). This could be made more efficient by removing carbon from the ocean carbon cycle—sequestering it rather than storing it—for hundreds or thousands of years, or even millions of years as was the case of the arctic *Azolla* event.

3 | BLUE CARBON

The carbon that is captured and stored by biological systems is outlined in Figure 1 to provide a pictorial guide to Antarctic blue carbon capture, storage and sequestration and provides definitions specific to this text. Oceanic carbon is in flux with the atmosphere such that as atmospheric carbon dioxide increases, there is an increase of carbon entering the water. The available dissolved inorganic carbon is utilised by phytoplankton that convert it via photosynthesis to organic carbon, or energy, resulting in a net loss of dissolved inorganic carbon in the surface waters and maintaining the draw-down of atmospheric carbon dioxide into the ocean. This can then be seen as carbon capture as inorganic carbon is assimilated into organic carbon—a fundamental process that spans the entire ocean surface where phytoplankton grow and fix carbon. This carbon is only stored short term in phytoplankton (hours to months) as the cells either die or are eaten. When eaten, part of the carbon is built into the biomass

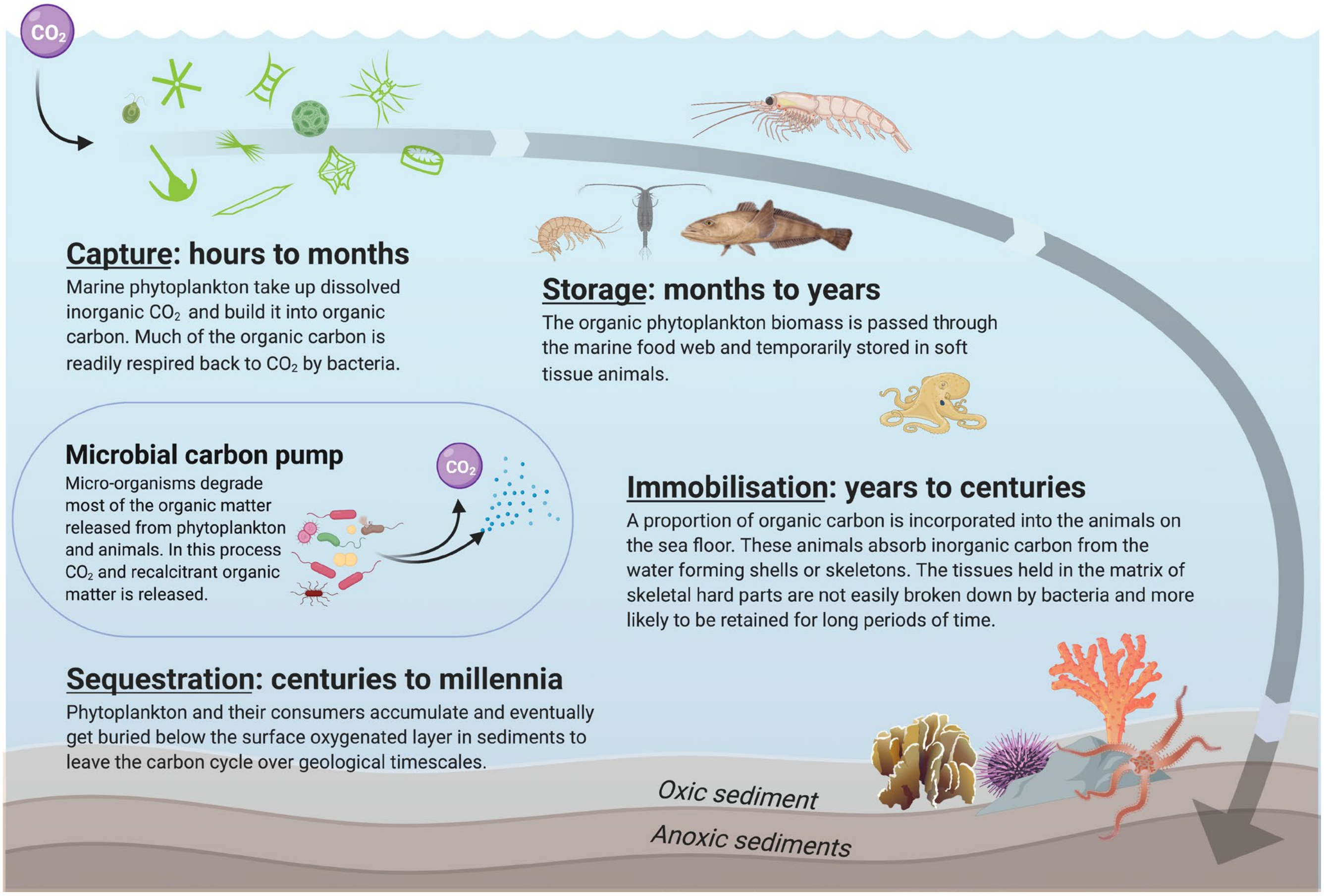

FIGURE 1 Illustration of blue carbon capture, storage, immobilisation and sequestration including definitions specific to this manuscript. Created with BioRender.com

of soft tissue pelagic animals where it can be stored for months to years. As organic carbon fuels marine food webs, it is transformed to CO_2 by the process of respiration and released back into the water. Then, when cells and organisms die, the dead organic material is broken down by bacteria in the microbial loop and partly respired to CO_2. If the release of carbon is greater than the uptake of carbon by phytoplankton, CO_2 outgasses back into the atmosphere.

The part of dead organic matter that is not respired by microorganisms or constructed into new microbial biomass is transformed to recalcitrant organic matter, which may have a turnover time of centuries (Jiao et al., 2014). The microbial production of recalcitrant organic matter (also termed the microbial carbon pump) is considered to function as carbon sequestration; however, it is a rather temporary carbon storage, as it is still somewhat active in the ocean carbon cycle. Carbon sequestration is a denomination that is reserved for the long-term removal of carbon from the carbon cycle (100 or more years in United Nations terminology and economic value). Removing carbon from the carbon cycle for millennia is only possible if buried deep in anoxic (oxygen-free) sediments.

This can happen when the carbon-based energy in phytoplankton makes its way either directly to or through the food chain to the animals on the seafloor (benthos), many of which have hard carbon-based skeletons or shells. This process is termed carbon immobilisation as the carbon is taken out of the carbon cycle for years to centuries as the tissues held in the matrix of skeletal hard parts are not easily broken down by bacteria. A proportion of both benthic and pelagic organisms are buried in the anoxic sediments after death. In the oxygen free environment, organisms cannot be broken down by bacteria or re-enter the microbial loop. In this case the carbon is genuinely sequestered on geological timescales, therefore we only refer to this process as true carbon sequestration.

Here we point out that there are complexities in the carbon cycles that involve blue carbon sequestration, specifically relating to which form the carbon takes—inorganic or organic. Traditionally blue carbon relates to organic carbon, but there is no doubt that inorganic carbon in the form of skeletal hard parts (shells) can also be buried and thus taken out of the carbon cycle. How organic and inorganic carbon cycles interact and affect blue carbon is one of the 10 big questions identified by Macreadie et al. (2019) and we do not attempt to address it apart from pointing out that both organic and inorganic carbon can be sequestered and understanding the efficiencies of this is still an open research topic.

Although huge amounts of carbon are cycled through the oceans, only a small fraction is taken out and sequestered in biological systems. Of this, half is sequestered by coastal systems with the majority of sequestration occurring in mangrove forests, seagrass beds and saltmarshes, the most efficient carbon sequestering systems on earth (Duarte et al., 2004; The Blue Carbon Initiative, 2019). Efficient carbon pathways to sequestration, such as by salt marshes, accumulate carbon at ~2.4 t C ha^{-1} $year^{-1}$ (Ouyang & Lee, 2014). At a current (2019 UK gov) value of CO_2 (£29–£59/t), this equates to £25 500 to £52 000 per km^2 per year. Even in oligotrophic environments where accumulation is likely to be much slower, the potential for long-term storage and sequestration has its value. A recent paper estimates that the value of carbon sequestered around the shallow coastal waters of Ascension Island and its associated seamounts is between £1 and £2 m (Barnes et al., 2019), despite being tiny in area. This demonstrates that even blue carbon systems an order of magnitude less efficient than mangroves, seagrass and saltmarshes still have considerable value as an ecosystem service.

4 | BLUEING OF THE POLES

It is acknowledged that in terms of efficiency the big blue carbon sequestering ecosystems are mangroves, seagrass beds and saltmarshes (Duarte et al., 2004). Although efficient per unit area (50% of carbon burial in marine sediments), these coastal regions are small globally (0.2% of the ocean surface). They are also under intense pressure from urban and industrial expansion and are in rapid decline (Ouyang & Lee, 2014).

In contrast, blue carbon storage in polar regions is increasing, due to relatively minimal levels of human occupation and exploitation, combined with major losses of marine ice, both in time and space (Figure 2)—what Barnes (2015) terms the 'blueing of the poles' (Barnes et al., 2018). Shrinking polar sea ice, glaciers and ice shelves are generating a negative feedback loop: increased atmospheric carbon drives regional warming leading to further marine ice reductions, creating new and sustaining existing phytoplankton blooms, drawing down more atmospheric carbon. The critical point here is that where the new blooms are occurring—where ice shelves and sea ice are being lost—is increasingly over shallower waters (continental shelf) so that the bloom and associated zooplankton predators (krill and copepods) are in contact with the benthic animals, increasing the chance of carbon moving from the oceanic storage stage into the immobilisation and sequestration stage (pelagic–benthic coupling). Crucially, and unlike other carbon sinks, there is evidence that polar blue carbon has been increasing in response to regional warming and shorter sea ice duration (Barnes, 2015; Barnes et al., 2019) and this could increase even more rapidly under moderate (+1°C) ocean warming (Barnes, 2017).

The seabed is the site of sequestration and animals on the seabed are key sequesters, not just because they are closest to it but because, apart from in the <100 m shallows (due to operating depths of iceberg scouring), they face less disturbance (anthropogenic or natural) than elsewhere in the world's continental shelf environments.

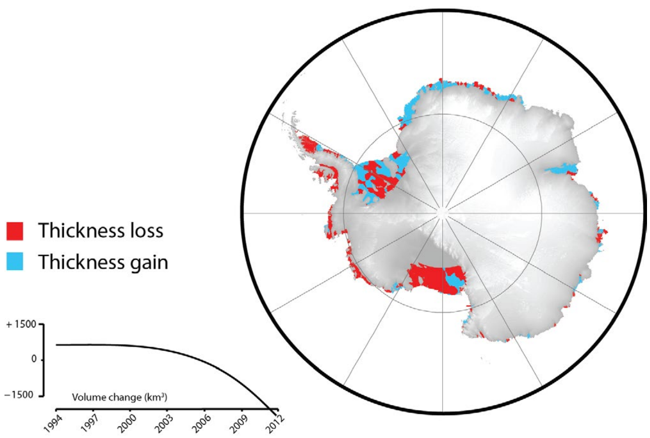

FIGURE 2 Observed thickness change of all ice shelves around the Antarctic continent with colours showing the absolute change per decade between 1994 and 2012. Modified from Paolo et al. (2015, 2016)

5 | THE VALUE OF ANTARCTIC SHELF BLUE CARBON

To date, benthic blue carbon has been little considered alongside the larger and better understood carbon sinks of the Southern Ocean. However, several new projects, such as the 'Antarctic Seabed Carbon Capture Change (ASCCC)', 'Impact of ice loss and deglaciation on Antarctic coastal benthic ecosystems (ICEBERGS)' and the 'Changing Arctic Ocean Seabed (ChAOS)', have been established to try and quantify the various aspects of the biological side of carbon storage and sequestration in the polar regions (Gogarty et al., 2020). Even if the total amount of carbon sequestered into a square metre of sediment is tiny compared with mangrove forests, seagrass beds and salt marshes, it occurs over many million square kilometres (Ashton et al., 2017). To put this into context, the blue carbon ecosystem service for the Ascension Island EEZ (<3%, 328.5 km^2 of its EEZ is shallower than 1,000 m) was estimated as £1–2 million (Barnes et al., 2019). The South Orkney Islands, a maritime archipelago to the east of the Antarctic Peninsula, have been identified as a 'biodiversity hotspot' with carbon immobilisation estimated as 9.2 t C/km^2 (Barnes et al., 2016; supplementary information). Using the high value for South Orkney Islands (0.289 t C bryozoan immobilised/km^2) and the lowest value from the Weddell Sea (0.022 t C bryozoan immobilised/km^2), coupled with the high and low values for the current cost of sequestered carbon dioxide (£59 and £29 respectively), we estimate the total financial value of sequestered carbon in the benthos around the Antarctic continental shelf at between £0.65 and £1.76 billion pounds sterling. Whereas detailed studies have provided an accumulation of blue carbon over time in other environments such as salt marshes, the big unknown for Antarctic blue carbon is what is its accumulation over time and crucially, the potential for gains over time. We know that carbon capture is increasing around the Southern Ocean (Barnes, 2015), we know that this is due to sea ice loss or longer bloom periods (Barnes, 2017; Barnes et al., 2016) and we know that there is a general pattern of increasing sea ice loss around the Antarctic. What needs refining is how the warming translates into sequestration of carbon per unit area per year across the Antarctic continental shelf—what seems certain is that it is increasing and across a vast area.

Although there are few studies of Antarctic shelf blue carbon, there are many detailing quantitative biomass (Arntz et al., 1994), which can be converted into approximate stored carbon. Of perhaps more importance than current Antarctic blue carbon stocks and value is how this is likely to alter with time and climate-forced physical change. Regional variability in sea ice and its non-linear trends in extent with time have hampered prediction of how Antarctic blue carbon is likely to alter. Pineda-Metz et al. (2020) found that zoobenthic carbon on the Weddell Sea shelf decreased by an order of magnitude in the two and a half decades up to 2014 as Antarctic sea ice increased by a million km^2. Over this same period, Barnes (2015) reported a doubling of zoobenthic carbon in West Antarctic seas, where tens of thousands of km^2 of sea ice were lost. Since 2014, sea ice patterns around Antarctica have become a more uniform loss (Pineda-Metz et al., 2020) and based on past changes we would expect zoobenthic blue carbon on the shelves underlying this to increase by an order of magnitude. However, complexity and uncertainty are added by sea ice loss during winter probably having little impact on blue carbon (because darkness prevents phytoplankton blooms) and how much impact sea ice losses have in water depths deeper than the continental shelf remains unknown.

6 | THE CASE FOR PROTECTION

The potential contribution of Antarctica's continental shelves to sequestering atmospheric carbon dioxide is massive and must be considered as part of global efforts to mitigate climate change. So far that has not been the case, with most scientific and governance attention concentrating on warm, rather than cold blue carbon sites. This was exemplified by the recent 2019 IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, which dedicated significant attention to polar ice melt and blue carbon separately, but made only passing reference to the emergence of blue carbon in areas of ice melt around Antarctica (Barnes, 2017; Barnes et al., 2018). Similarly, whilst it considered the carbon mitigation potential of blue carbon, it focused on what it saw as the 'main blue carbon habitats' in warm climates—mangroves, tidal marshes and seagrass meadows—without equivalent consideration of Southern Ocean sites (IPCC, 2019). By consequence, its recommendations for the protection and promotion of blue carbon centred around habitat restoration and creation in coastal sites within the jurisdiction of nation states. Similarly, the December 2019 Conference of the Parties of the UN Framework Convention on Climate Change (UNFCCC) largely ignored the potential for Antarctic blue carbon to contribute to global mitigation efforts. This is despite the special focus of the meeting being on the oceans and cryosphere.

Antarctic blue carbon is biophysically and geographically different to its lower latitude counterparts. As noted, Antarctic blue carbon is growing, rather than shrinking. This means that leveraging off blue carbon's climate feedback potential will not be a consequence of ecosystem restoration, but rather precautionary conservation, fostering resilience and facilitating its ecosystem service.

What also distinguishes Antarctic blue carbon is the legal system within which it is found. Unlike vegetated coastal ecosystems, Antarctic benthos are located within areas of cooperative global governance, rather than being the legal responsibility of any one state. Under the Antarctic Treaty System (ATS), the Antarctic continent and Southern Ocean are a unique territorial space, where dispute over claims of state sovereignty over both physical territory and the biological ecosystems situated within it have been set aside through Article IV of the Antarctic Treaty. At the same time, however, states with territorial claims have asserted EEZs off these territories but apply these provisions only to their nationals. This sensitive territorial balance means that no one state is responsible for conservation of Antarctic blue carbon (as would be the case for vegetated coastal ecosystems within the EEZ of a nation state). Rather, the management and/or protection of marine areas around Antarctica require the collective agreement of Antarctic fishing states under the *Convention on the Conservation of Antarctic Marine Living Resources* ('CCAMLR').

CCAMLR is a strongly precautionary convention that adopts an ecosystem-based management approach, but it is still one which is permissive of fishing. It has, however, been active in establishing principles and practices establishing areas designated as vulnerable marine ecosystems, but again these are developed in relation to its fisheries management processes. This, and its reliance on consensus decision-making before taking conservation action, has historically frustrated attempts to establish large areas of the Southern Ocean as no-take harvesting zones in Marine Protected Areas. Given the sheer size of Antarctic blue carbon sites on Antarctic shelves, it can be expected that there will be even more diplomatic resistance from some active fishing states to any efforts to increase protection of these areas. This is especially the case as the jurisdictional circumstances of the ATS area mean that states would be reluctant to (and arguably are legally prohibited from) claiming any carbon value of the blue carbon stock in Antarctic ice shelves as part of their 'national' contributions to reducing carbon emissions under the Paris Agreement to the UNFCCC. However, Paris has an unexplored cooperative provision which could overcome such impediments.

Gogarty et al. (2020) propose incentivising the protection of Antarctica's continental shelf by building a 'non-market framework' under the mechanisms anticipated by (but currently undeveloped) in Article 6 of the UNFCCC Paris Agreement. Under Article 6 states are encouraged to cooperatively reduce carbon emissions through 'integrated, holistic and balanced' coordination 'across instruments and relevant institutional arrangements' (Paris Art 6.8–6.9). If fishing states agree to forgo future commercial harvesting in Antarctic waters, they might be able to count the blue carbon sequestered there as part of their international obligations to reduce carbon emissions (e.g. as nationally determined contributions).

Since these states are not fishing there yet, the incentive seems especially high.

Connecting and coordinating across the ATS and UNFCCC frameworks would allow for the collective carbon accounting and attribution of protection for the carbon stocks of the Southern Ocean. It may also serve to encourage states that might otherwise wish to commercially exploit newly ice-free areas of the Southern Ocean to instead protect and conserve them, in the understanding there is a national benefit for doing so.

Importantly, the Paris Agreement is designed around incremental actions and baseline commitments which can be 'ratcheted up' over time. This would allow a blue carbon non-market approach to be constructed over time, as our scientific knowledge develops. This is important because our present understanding of the productivity, standing stock and drivers of blue carbon sinks is not matched by an equivalent understanding of the threats to these sites. This would need to be addressed for such a proposal to work, given the Paris Agreement only allows states (individually or cooperatively) to count carbon emission reductions that occur as a result of demonstrable acts (or cessation from acts) that reduce emissions beyond a 'business as usual' case. Specifically, for a non-market approach to work, the following assessments must be made:

1. A temporal–spatial baseline assessment of the carbon stock in Antarctic shelves must be established which assumes no direct human interference (fishing, scientific trawling, marine traffic and other human activities).
2. An assessment of what human activity might occur in a blue carbon site now and into the future.
3. A framework to assess the impact of human activities at different temporal and spatial scales on the carbon sequestration of a site—for instance, through disturbance of the seabed, reduction in biological diversity or incidental impacts on blue carbon and associated ecosystems.
4. A mechanism to assess which states might have genuinely undertaken activities that undermine the sequestration potential of blue carbon sites, the level of those activities and therefore the carbon value in agreeing to cease those activities.

Assessments (2) and (4) above are arguably already achievable within the ATS CCAMLR framework, which possesses existing competencies in mapping, monitoring and managing conservation (including rational use) of living marine resources in the Southern Ocean. This would allow states to lodge claims based on existing or historic use of incidental fishing zones as evidence of the legal quotas they might have otherwise been allocated in nominated blue carbon conservation areas. Doing so would set the parameters against which each relevant state could be attributed a benchmark 'business as usual' versus cessation action value. This leaves (2) and (3) above as necessary indicators of the resultant real carbon value.

Importantly any Antarctic carbon accounting regime under the Paris Agreement—and arguably international law more generally—would need to involve demonstrable 'additionally' (Schneider & La Hoz Theuer, 2019). Simply ratifying and becoming a member of the ATS would be insufficient. States would need to show that their agreement to conservation measures involves a genuine restriction on harvesting or other activities that they would have otherwise undertaken in the relevant zones. This would require evidence-based, dynamic regime bridging between the UNFCCC and Paris to ensure that any sequestration claims are justified, genuine and avoid double-counting. For instance, CCAMLR, which possesses existing technical capacity to map and attribute ecosystem service contributions in the Southern Ocean, could leverage this institutional expertise to evaluate and endorse attribution claims on a Paris Agreement register based on existing and projected harvesting uses of state parties. To the extent that CCAMLR's jurisdictional competency is restricted to the ATS system, the Scientific Committee on Antarctic Research (SCAR), which has an official role in both the ATS and climate regime, could act as a nexus body for these purposes (Hughes et al., 2018).

7 | THE KEY IS POTENTIAL

The value of Antarctic blue carbon as an ecosystem service even now is considerable but is crucially increasing. The estimates presented here are, out of necessity, rough estimates because so little polar shelf has been surveyed, but it is based on the best available data to date. More comprehensive sampling across the Antarctic continental shelf is likely to provide the detail used to refine these estimates and it is likely to show we have made substantial underestimates. Multinational projects (such as EU RISE—CoastCarb) collating relevant big data and pooling multidisciplinary expertise should aid seeing the bigger picture. What is important to appreciate is that these figures represent the first estimate of a baseline that is likely to grow. The aspect of Antarctic blue carbon that is worth protecting now is its potential. The area we used to calculate the estimates was 4.4×10^6 km^2 which is the area of continental shelf seafloor that is not currently covered by ice shelves. This area is predicted to grow as glaciers retreat and ice shelves break up, creating a larger expanse of seafloor for carbon to be immobilised and sequestered (Hughes et al., 2018).

A significant proportion of the seafloor we considered in the calculation is currently covered by sea ice some or all of the year reducing its efficiency for carbon capture and sequestration. Indeed, one of the rare studies quantifying carbon on the seafloor over time demonstrated that increasing sea ice around Kapp Norvegia/Auståsen during the years 1988–2014 saw a reduction of productivity resulting in seabed carbon decline from approximately 10 to 0.02 g C/m^2 (Pineda-Metz et al., 2020). Over the past 4 years sea ice has massively declined and the trend appears to be continuing (Barnes et al., 2020; Meehl et al., 2019; Turner & Comiso, 2017). It is likely that the carbon losses recorded in areas of sea ice increase will rapidly turn into gains as sea ice continues to decline. Furthermore, it has been demonstrated that growth or rebound of benthic assemblages can be rapid with slow growing sponges recording two to threefold increases after two growing seasons (Fillinger et al., 2013). With reduction of sea ice over shallow shelf areas comes increase in solar radiation and resulting blooms that cover greater area and last longer providing a longer feeding duration for the benthos increasing the potential of blue carbon capture and sequestration. Finally, a recent study has shown that a small warming of the water can considerably increase the growth rates of the benthic animals present (Barnes et al., 2019). Surface water temperatures around the Antarctic are predicted to rise and as they do, the benthos will grow faster, with a doubling of the growth rate after a water temperature rise of just 1°C. Each aspect leads to an increase of the potential of the benthic animals to store and sequester blue carbon across the Antarctic seafloor, compounding its value over time. As the environmental cost of carbon pollution increases, the value of carbon sequestration will further increase and nowhere on earth is there a natural system like the Antarctic continental shelf that is under such little direct anthropogenic pressure and has increasing carbon sequestration potential.

8 | SUMMARY

In a world where atmospheric carbon dioxide levels continue to increase and industrial solutions are yet to be effective, nature is leading the way, absorbing, storing and sequestering carbon. The most efficient natural sequestration routes—coastal mangrove, seagrass and salt mash regions—are under threat due to industry and population spread and are rapidly declining in area and thus effectiveness. The benthic animals on the Antarctic continental shelf have been shown to be strong storers and sequesters of carbon. Although this may be at rates much less than warm water coastal regions, the areas involved are so vast that the total amount of carbon sequestered is considerable and of economic significance. Furthermore, the study cited herein by Fillinger et al. (2013) showing that growth or rebound of benthic assemblages can in fact occur after only two growing seasons illustrates that rich benthic communities develop much faster than originally thought and if resources can arrive quickly, so too can the associated fisheries and resource extraction efforts.

Antarctic blue carbon has the potential to expand due to retreating glaciers and disintegrating ice shelves, and become more efficient due to annual reduction in sea ice. With the rise of water temperature, growth rates are set to double, further increasing the efficiency and effectiveness of the Antarctic continental shelf as an area of blue carbon capture and sequestration. Such sites fall within existing governance regimes, so long as parties are willing to utilise the legal mechanisms available to them and forgo certain national interests for the benefit of the planet. We propose that strong protection is required for the Antarctic continental shelf, not just for what it is—a significant natural negative feedback to climate change—but for what it has the potential to become. A unique window in time exists now, before the establishment of fisheries in the newly ice-free Southern Ocean shelf regions. A time where the establishment of a protection and incentive system can serve as an alternative to traditional economic exploitation, and ultimately satisfy multinational commitments to protect life on Earth (Paris Agreement).

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AUTHOR CONTRIBUTION

N.B. and C.J.S. co-wrote the draft manuscript. B.G. contributed the main text on policy with input from J.M. and M.H. C.H., R.V.D. and D.K.A.B. provided discussion and input across multiple working drafts. C.S. calculated Antarctic blue carbon estimates based on available literature. C.S., N.B., D.K.A.B., M.L.P., B.G., C.H. and R.D. addressed the first round of reviewer comments. C.S., N.B., D.K.A.B., M.L.P. and C.H. addressed reviewer comments upon manuscript acceptance. C.V.E.M., B.M. and M.L.P. produced the graphics associated with the manuscript. All co-authors were invited to review and edit content prior to manuscript submission. N.B. formed this science–policy collaboration for the ASCCC project in 2017 and coordinated text contributions and finalised the manuscript.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no new datasets were generated or analysed during the current study.

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