Extended abstract

Carbon storage by Kerguelen zoobenthos as a negative feedback on climate change

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As oceans warm, reducing the extent of sea-ice and-ice shelves, increased carbon capture by phytoplankton and storage by southern polar benthos (sea bed organisms), is potentially the largest negative feedback on climate change. Teasing apart biological processes within and between geographic regions is vital to our understanding of global carbon capture. One of the biggest sources of error in this regard is understanding the extent to which this feedback is the direct and indirect effect of recent climate forcing on sub-Antarctic benthos performance (growth, metabolism, reproduction etc). This type of carbon sequestration, termed blue carbon, is hypothesised to increase, so long as sea-ice and ice-shelf losses continue to be sustained in the Antarctic. The sub-Antarctic may differ, due to reduced, or in some cases, no sea-ice duration. Our research project, titled Antarctic Seabed Carbon Capture Change (ASCCC, www.asccc.co.uk) aims to understand the temporal and spatial complexity of polar benthic blue carbon sinks, and the marine ice-free Kerguelen Plateau provides a unique geographic testing ground for this.

Blue carbon and the Antarctic seabed carbon capture change project

The 'blue carbon initiative' of the International Union for Conservation of Nature (IUCN) (thebluecarboninitiative.org) focuses on coastal seagrass and kelp forest carbon drawdown. These ecosystems (along with salt marshes and mangrove swamps), whilst being important, are decreasing (Macreadie et al., 2017), whereas there is evidence that polar marine zoobenthos is increasing in biomass on some continental shelves and therefore in capacity for carbon storage. This 'ecosystem service' is most valuable if the carbon is stored long-term, and genuinely sequestered. Evidence is mounting to suggest that a Polar feedback loop increases 'blue carbon' storage capacity leading to strong sequestration possibilities on the seafloor. This seems to be driven by lengthening phytoplankton blooms (caused by sea-ice losses over the continental shelf) and sea temperature increases (Barnes, 2015; Barnes et al., 2016; 2018). The ASCCC project is focused on understanding this increased carbon storage capacity in relation to temperature increases, heightened ice-shelf and sea-ice losses, by studying a number of key calcifying animals, such as corals, bryozoans, echinoderms, crustaceans and calcareous sponges (the zoobenthos) and their biological contribution to polar carbon storage.

Hypothesis

Under the current ASCCC working hypothesis, carbon is transported via pelagic food webs to benthic ecosystems (bentho-pelagic pump). Photosynthetic algae (such as diatoms, ciliates and flagellates) fix CO_2 in surface waters (primary production), which are consumed by suspension-feeding invertebrates on the seafloor, leading to carbon storage in their tissues and skeletons. Heavily calcified benthos is more likely to resist microbial loop breakdown and reworking of carbon, such that the carbon it stores is immobilised in the seabed. This carbon can be sequestered long term, when the zoobenthos die and become buried in sediment (carbon sequestration). In benthic ecosystems, including the sub-Antarctic and west Antarctic Peninsula, the ASCCC project documented a correlation between increased zoobenthic skeletal growth, decreasing sea-ice and longer lasting phytoplankton blooms (Barnes, 2015; Barnes et al., 2016, 2018). This linkage suggests that extended periods of food availability may translate to extended seasonal growth periods whilst slight temperature rises increase growth rate (Ashton et al., 2017). These recent environmental changes have led to increased seasonal growth and fecundity for some taxa, which has resulted in increased carbon storage and immobilisation and likely sequestration over time, thus offsetting a portion of global CO_2 emissions.

Blue carbon in the sub-Antarctic

The many sub-Antarctic archipelagos, with different continental shelf sizes, positions and conditions, offer a valuable opportunity to understand the complexity of benthic carbon pathways. In west Antarctica, zoobenthic carbon storage has increased in response to marine ice losses in various ways. Ice shelf collapses have generated new phytoplankton blooms, which Peck et al. (2010) suggested should lead to zoobenthos biomass and growth increases, later demonstrated by Fillinger et al. (2013) and quantified by Barnes et al. (2018). Seasonal sea ice losses around west Antarctica have been coincident with even bigger phytoplankton bloom changes, zoobenthos growth and carbon storage increase Barnes (2015). Although the amounts of carbon storage are small (compared with forests for example) the negative feedback is large (carbon storage has doubled in two decades). Marine ice loss around the Antarctic coastline not only leads to more open ocean for photosynthetic algal blooms and greater heat absorption from reduced albedo, but also increased destructive ice scour from icebergs on the fragile calcified seabed zoobenthos. In contrast, there is no ice scour or albedo change (due to negligible sea-ice losses) over sub-Antarctic shelves, where rising sea temperatures are likely to be the only environmental driver increasing carbon storage by animals (due to faster enzyme action and thus meal processing time – see Ashton et al., 2017). Sub-Antarctic South Georgia and the South Orkney Islands are amongst the best studied localities with respect to zoobenthic carbon storage standing stock and change (Barnes et al., 2016; Barnes and Sands, 2017). The habitat type and age in the former and sea-ice duration variability in the latter show how complex carbon drawdown and storage can be. The Antarctic Circumnavigation Expedition (ACE) scientific cruise created the opportunity to compare these locations with places like the vast Kerguelen Plateau, where there is no sea-ice, and where warming of the Southern Ocean could directly influence benthos across a broad latitudinal span of environmental conditions. This new project will contribute to our understanding of the complexity of these Southern Ocean systems, and provide ample scope for decoupling the mechanisms behind polar benthic carbon sequestration.

Kerguelen Plateau as a unique 'biological laboratory' for blue carbon

The most powerful current in the world, the Antarctic Circumpolar Current (ACC), flows eastwards around the Southern Ocean. The only place the ACC flows over a continental shelf, is at the Kerguelen Plateau; a 2.2 million km^2 region of the sub-Antarctic, where sea-ice is rare (Park et al., 2014). Sea temperatures and large algal blooms have been found to increase seasonally in this region (see Park et al., 2014 and Blain et al., 2008 and the SOCLIM project: soclim.com/location-en.php). The strongest jet of the ACC, the Polar Front, creates a thermal barrier between the Southern Ocean from the Atlantic, Indian and Pacific Oceans – and migrates considerably at locations such as the Kerguelen Plateau. Conditions north of the Polar Front are warmer and 'temperate' waters are >2°C warmer than waters south of the Polar Front, whilst environmental conditions across the shelf see the Polar Front 'meander' northwards and southwards in a single season, but considerably more over geological time scales. During past glaciations, the Polar Front moved further north, and with future climate change, it is expected to retreat further south (see Guillaumot et al., 2018). This means that in recent periods of rapid environmental change during past glaciations, sessile or slow moving 'temperate' animals around Kerguelen would have settled on the seabed, only for the Polar Front to move north and expose them to polar conditions. Likewise, at other locations, polar animals will have settled on the seabed, and the front movement would have exposed them to warmer temperate conditions. In the future, it is hypothesised that there will be a reduction of polar-adapted seabed organisms on the Kerguelen shelf, and an expansion of temperate-adapted organisms with broad tolerances. This is also hypothesised for the future of all sub-Antarctic islands, in which polar-adapted animals will have settled on the seabed, and the predicted southerly front movement will expose them to warmer temperate conditions. Thus, we can regard the Kerguelen Plateau as a unique 'biological laboratory' for blue carbon research, as it spans these key oceanic gradients. With climate change, the entire Polar and sub-Antarctic Frontal zones is expected to move further south, exposing the Kerguelen Plateau to warmer conditions semi-permanently (Park et al., 2014). The pivotal question that the ASCCC is trying to answer is: Will this lead to an increased carbon deposition on longer timescales? Furthermore, because of the huge area involved, will this be of global significance? Specimens of seabed organisms from the Kerguelen Plateau will allow us to gauge a baseline for how each type of seabed animal would manage predicted changes.

Therefore, we will be able to estimate a seabed carbon storage budget, and how this is likely to be modified with predicted future climate change.

Research findings

Our recent research has revealed for the first time that Antarctic benthos is estimated to store tens of millions of tonnes of carbon per year (Barnes et al., 2018), which is worth hundreds of millions of dollars (at 2019 shadow price of carbon US$ equivalent of £29–59 per tonne). The storage increases are coincident with seasonal sea-ice and ice-shelf losses, and in the last 25 years this ecosystem service is estimated to have doubled around western Antarctica, which translates to potentially tens of millions of tonnes in carbon seabed storage over the last two decades (see page 11 of Barnes et al., 2018 for calculation of carbon gain). Beyond these estimates, we know very little about how much carbon capture and storage (let alone sequestration) there is around the polar regions, especially the remote, vast Southern Ocean. Currently, our knowledge is sparse on how carbon storage and sequestration is changing around the Antarctic, and carbon capture could be even greater within the surrounding productive sub-Antarctic region.

The Antarctic Circumnavigation Expedition (ACE) in 2016/17 provided the opportunity to sample most of the sub-Antarctic islands, including around Kerguelen. Analysis from these specimens is ongoing, and video footage from inside customised mini-trawls suggests that the vast Kerguelen shelf is (i) a very important blue carbon store, (ii) patchy in blue carbon by habitat type and which functional groups (organism types) hold it; and (iii) some of the Kerguelen suspension feeders have increased growth in the last decade suggesting increased carbon storage with (i.e. forming a negative feedback on) climate change. Therefore, the vast 2.2 million km^2 Kerguelen Plateau could dwarf the known carbon capture values found at the South Orkney Islands.

Research, conservation and climate change implications and collaboration

As a research community, we have the technology, research capacity and imperative to continue to increase our understanding of benthic systems, blue carbon natural capital stock and ongoing ecosystem services. The ASCCC team are keen to join any research voyages with the opportunity to sample further along the Kerguelen Plateau, which we see as critical to understanding spatio–temporal change in polar blue carbon storage. Benthic carbon capture and storage is a global ecosystem service, as such, the integrity and resilience of these systems is becoming increasingly recognised in terms of international research priorities. The independent and international research body, the Scientific Committee of Antarctic Research (SCAR) has, during a recent Horizon Scan, highlighted: (i) understanding the biodiversity and functioning of marine and terrestrial biological systems and how to protect them; and (ii) understanding ocean–cryosphere–atmosphere interactions, including the behaviour of ice sheets and global sea level variation (www.scar.org/about-us/horizon-scan/overview). The ASCCC blue carbon research bridges the gap between these two future research needs, by utilising the Kerguelen Plateau as a 'biological laboratory' to decouple the mechanisms behind benthic carbon sequestration of living organisms, which may be the key to informing future global climate change mitigation efforts, and some unexplained variability in climate models.

The complexity of the carbon cycle predetermines that multi-disciplinary collaboration across the ocean's food webs (e.g. microbial loop, phytoplankton, zooplankton and zoobenthos), is imperative to coupled ocean-climate models. The benthic realm, due to its inaccessibility and complexity, has been traditionally neglected in sub-Antarctic ocean-climate models which generally only utilise data from subsurface waters (see Schallenberg et al., 2019; McCormack et al., 2019 and Trebilco et al., 2019). Therefore, shifting our focus to include the benthos is integral to effective ocean-climate modelling. Polar blue carbon is not a 'silver bullet' to reversing increased anthropogenic CO_2, but by re-focusing our research efforts as a community, blue carbon initiatives combined with research presented at the Second Kerguelen Plateau Symposium in 2017, will greatly increase our arsenal towards the development and understanding of complementary climate mitigation tools. For example, combining our research with iron fertilisation initiatives (as discussed by Blain et al., 2019; Coffin et al., 2019; van der Merwe et al., 2019), ongoing ecosystem protection measures (see Azam et al., 2019), fisheries management protocols (e.g. Ziegler and Welsford, 2019) (which presently include policies of carbon offsets and neutrality in the Australian program: e.g. Austral fisheries www.australfisheries.com.au), marine protected area (MPA) frameworks (see Eléaume et al., 2019) and spatial planning initiatives (see Hill et al., 2017, 2019), strengthens our future research outcomes. A multifaceted collaborative effort in one geographic region would see the Kerguelen Plateau become a case study of international relevance on blue carbon initiatives.

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