Blue carbon gains from glacial retreat along Antarctic fjords: What should we expect?

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Abstract
Rising atmospheric CO₂ is intensifying climate change but it is also driving global and particularly polar greening. However, most blue carbon sinks (that held by marine organisms) are shrinking, which is important as these are hotspots of genuine carbon sequestration. Polar blue carbon increases with losses of marine ice over high latitude continental shelf areas. Marine ice (sea ice, ice shelf and glacier retreat) losses generate a valuable negative feedback on climate change. Blue carbon change with sea ice and ice shelf losses has been estimated, but not how blue carbon responds to glacier retreat along fjords. We derive a testable estimate of glacier retreat driven blue carbon gains by investigating three fjords in the West Antarctic Peninsula (WAP). We started by multiplying ~40 year mean glacier retreat rates by the number of retreating WAP fjords and their time of exposure. We multiplied this area by regional zoobenthic carbon means from existing datasets to suggest that WAP fjords generate 3,130 tonnes of new zoobenthic carbon per year (t zC/year) and sequester >780 t zC/year. We tested this by capture and analysis of 204 high resolution seabed images along emerging WAP fjords. Biota within these images were identified to density per 13 functional groups. Mean stored carbon per individual was assigned from literature values to give a stored zoobenthic Carbon per area, which was multiplied up by area of fjord exposed over time, which increased the estimate to 4,536 t zC/year. The purpose of this study was to establish a testable estimate of blue carbon change caused by glacier retreat along Antarctic fjords and thus to establish its relative importance compared to polar and other carbon sinks.

KEYWORDS
Blue carbon, climate change, fjord, glacier retreat, sequestration, Southern Ocean

1 INTRODUCTION
Declarations of ‘climate emergency’ and more urgent aim at developing carbon neutral economies have drastically increased interest in carbon capture, storage and sequestration. Saban, Chapman, and Taylor (2018) have shown that global greening, and thus potential carbon capture, have increased with rising atmospheric CO₂ levels but what of storage and sequestration? Blue carbon (held within...
marine organisms) is prolific in capture and efficient in sequestration rate to the extent that Duarte, Middelburg, and Caraco, (2005) estimate blue carbon to be responsible for 50% of all oceanic carbon burial. Typical blue carbon habitats, such as mangrove swamps, seagrass beds and salt marshes are declining across global habitats, for example the International Union for the Conservation of Nature estimates ~7% per year for seagrasses (see https://www.iucn.org/content/seagrass-habitat-declining-globally), making them essentially positive feedbacks on climate change. Very little is known about blue carbon in the polar regions where mangroves, salt marshes and seagrasses are absent. Fjords with marine terminating glaciers can be highly productive (e.g. in the Arctic, Meire et al., 2017) and accumulate considerable fjord floor carbon (e.g. in the Antarctic, Grange & Smith, 2013). It is becoming clearer that climate-mediated losses of marine ice over high latitude continental shelf areas are a rare, valuable negative feedback on climate change, albeit globally small in magnitude (Barnes, 2017; Barnes, Fleming, Sands, Quartino, & Deregibus, 2018). As many glaciers are retreating from Antarctica’s fjords, the newly emerging seabed creates a brand new habitat for primary and secondary production and this acts to counter the present effects of climate change. Blue carbon (produced by marine biological activity) standing stock and production are high in shallow water but require the sediments, usually associated with low energy habitats, for burial and ultimate sequestration.

Antarctica is the only continent with no open-water, nearshore low energy environments. The West Antarctic Peninsula (WAP) coast, however, has many ice-filled small fjords, which are progressively opening up due to glacier retreat. They are probably playing an important and increasing role in carbon sequestration which is little evaluated. There are ~240 glaciers along the WAP of which nearly 90% (~216) are now retreating, and their retreat rates are increasing (Cook et al., 2016). Given the importance of natural carbon sinks which involve genuine sequestration and the rarity of negative feedbacks it would appear crucial to evaluate an emerging one in Antarctica’s opening fjords (Grange & Smith, 2013). Is lack of quantification of fjords’ role as an increasing capacity for carbon sink important as a source of uncertainty for climate models? Marine ice losses comprise multiple sources; sea ice (such as fast ice), ice shelves and glaciers. For seasonal sea ice losses and ice shelf disintegration, the quantification of blue (marine biological) carbon has been attempted (Barnes, 2017; Barnes et al., 2018) and is ongoing with the Changing Arctic Ocean Seafloor project throughout the Barents Sea. For glacial retreat, a third source of marine ice loss, the calculations for carbon sink capacity are problematic, as previous work has estimated average retreat rates rather than areas of glacier lost (=habitat gained; Cook et al., 2016). Here we erect a testable estimate of WAP fjordic blue carbon gains by calculating areas of glacier lost and fitting existing regional blue carbon data to it. The regional blue carbon data we used to do this was zoobenthic seabed carbon values from the geographically closest analogous environments; fjords retreating at South Georgia (in Barnes, 2017).

2 | METHODS; HOW TO ESTIMATE EMERGING FJORDIC BLUE CARBON?

The work presented here attempted to derive a testable estimate for seabed biological carbon gains as a result of recent rapid glacier retreat along selected WAP fjords (see map in Figure S1). Firstly we calculated the area of fjord emergence (=glacier loss) from literature data (Cook et al., 2016; georeferenced shape files in ArcGIS) of glacier fronts for three study fjords (Figure 1). The study fjords were Marian Cove (King George Island), Börgen Bay (Anvers Island) and Sheldon Cove (Adelaide Island). These have retreated 1.71, 7.8 and 7.8 km² from 1978/79 to 2019, and as such are representative of WAP glaciers (Cook et al., 2016). Mean annual glacier area loss rates for Marian Cove, Börgen Bay and Sheldon Cove since 1978/79 were 0.042, 0.191 and 0.191 km²/year. We then mapped the seabed of each fjord using multibeam swath (using Kongsberg EM122) and collected images of the seabed at multiple distances (sites in Figure 1; Figure S2). We multiplied recently emerged area by blue carbon literature data per unit area for each of the three fjords to generate estimated X tonnes carbon km²/year. New areas of fjord are recorded as starting to emerge in 1950–1970 (Cook et al., 2016), but change has been non-linear and varies between fjords (glacier front by year is shown in Figure 1a–c). The literature data we used were Inner fjord environments at South Georgia, which typically generate 0.4 (muds), 3.7 (moraines) and 17.4 (shallows and walls) tonnes immobilized carbon, km²/year (Barnes, 2017). This assumes that newly emerging fjords along the WAP would have similar blue carbon content to retreating glaciers around South Georgia, but there is currently little literature on succession in benthic carbon standing stock with glacier retreat time. Assessment of mega-faunal patterns along two WAP fjords (Grange & Smith, 2013; Sahade et al., 2015) suggests intra-region variance may be as considerable as that between regions, at least with respect to composition of biota. The mean carbon value that we derived across our three study areas was then multiplied by the number of retreating fjords along the WAP (216; see Cook et al., 2016).

We tested this initial estimate by capturing and analysing 204 high-resolution seabed images (each 405.7 × 340.6 mm, 12 MB, 5 MegaPixel) along study fjords from research cruise JR17001 (2017). Images were analysed for the density of each of the 13 functional groups of benthos (as per Barnes, 2017). The 13 functional groups were defined as follows: suspension feeder pioneers (A), climax suspension feeders (B), sedentary suspension feeders (C), mobile suspension feeders (D), deposit feeding crawlers (E), deposit feeding vermiform (F), deposit feeding, shelled burrowers (G), calcareous grazers (H), scavenger/predator, sessile soft bodied (J), scavenger/predator, sessile calcareous (K), scavenger/predator, mobile soft bodied (L), scavenger/predator, mobile calcareous (M), scavenger/predator, arthropod (N) and flexible strategy (P). We fitted the resulting density of functional group data to the following model:

The model used to give carbon in g/m² (tonnes/km²) was, per shelf underwater camera system image = (($0.06*A) + (0.11*B) + (0.09*C) + (0.18*D) + (0.13*E) + (0.15*F) + (0.5*G) + (0.17*H) + (0.11*I) + (0.12*K) + (0.25*L) + (0.45*M) + (0.13*N) + (0.16*P)).