Appreciating interconnectivity between habitats is key to blue carbon management

Smale, Dan A.; Moore, Philippa; Queirós, Ana M.; Higgs, Nicholas D.; Burrows, Michael T.

Published in:
Frontiers in Ecology and the Environment

DOI:
10.1002/fee.1765

Publication date:
2018

Citation for published version (APA):
Smale, D. A., Moore, P., Queirós, A. M., Higgs, N. D., & Burrows, M. T. (2018). Appreciating interconnectivity between habitats is key to blue carbon management. *Frontiers in Ecology and the Environment*, *16*(2), 71-73. https://doi.org/10.1002/fee.1765

Appreciating interconnectivity between habitats is key to blue carbon management

We welcome the recent synthesis by Howard *et al*. (2017), which drew attention to the role of marine systems and natural carbon sequestration in the oceans as a fundamental aspect of climate-change mitigation. The importance of long-term carbon storage in marine habitats (ie "blue carbon") is rapidly gaining recognition (Figure 1a) and is increasingly a focus of national and international attempts to mitigate rising atmospheric emissions of carbon dioxide. However, effectively managing blue carbon requires an appreciation of the inherent connectivity between marine populations and habitats. More so than their terrestrial counterparts, marine ecosystems are "open", with high rates of transfer of energy, matter, genetic material, and species across regional seascapes (Kinlan and Gaines 2003). We suggest that policy frameworks, and the science underpinning them, should focus not only on carbon sink habitats but also on carbon source habitats, which play critical roles in marine carbon cycling and natural carbon sequestration in the oceans. Howard *et al*. (2017) concluded that certain habitats and taxa (eg kelp forests, large vertebrates) are "unimportant" in natural carbon sequestration, which we argue is an oversimplification that fails to account for not only the magnitude of carbon transfer between living components of the cycle but also the interconnectedness of the highly dynamic and open marine environment. Crucially, developing carbon budgets for habitats in isolation – without considering their connectivity and functioning as carbon "fixers", "donors", and "recipients" – is neither representative of marine ecosystems, nor a useful approach for prioritizing management. Here, we highlight the importance of carbon transfer between habitats, which is not currently recognized within policy frameworks, through two pertinent and widespread processes.

First, marine macroalgae generally exhibit very high rates of growth and primary productivity and are likely to play key roles in carbon cycling as fixers and donors. Kelp forests are particularly critical, given that they represent some of the most productive habitats on Earth and are geographically widespread across temperate regions in both hemispheres (Mann 1973; Teagle *et al*. 2017). As noted by Howard *et al*. (2017), kelp forests support high standing stocks of carbon (Smale *et al*. 2016; Figure 1b), but as the turnover of material is generally rapid they do not store carbon in situ at timescales relevant for sequestration (note: some kelp species persist for >15 years [Kain 1979], not the ~1 year stated by Howard *et al*. [2017]). Furthermore, the vast majority (>80%) of kelp-derived organic matter is typically exported from the kelp forest, rather than being consumed or remineralized within the source habitat (Krumhansl and Scheibling 2012). Kelp-derived matter may be transported many kilometers from its source (Vetter and Dayton 1998; Vanderklift and Wernberg 2008; Krause-Jensen and Duarte 2016) and eventually accumulate in blue carbon habitats with the capacity to bury organic matter, such as seagrass meadows and deep-sea sediments (Hill *et al*. 2015; Krause-Jensen and Duarte 2016; Figure 1c). Allochthonous carbon (that is, organic matter which originated some distance from its current position) derived from kelp populations may be trapped, buried, and stored belowground, thereby substantially contributing to the amount of carbon fixed and stored in situ. Recent evidence suggests that macroalgae may be important carbon donors due to their high rates of biomass accumulation and export, extensive geographical distributions, and the chemical and physical properties of macroalgal detritus (Hill *et al*. 2015). Although more research is needed to quantify burial rates and residence times, kelp and other macroalgae play key roles in carbon sequestration (Krause-Jensen and Duarte 2016) and should be considered in the management and conservation of blue carbon ecosystem services.

Second, marine vertebrates play a major role in the removal of carbon from surface waters and its transfer to and sequestration in the deep ocean. Although some marine vertebrate biomass is recycled and respired over short timescales (Howard *et al*. 2017), once exported to the deep ocean it remains sequestered for 1000-year timescales. Mesopelagic fish respire ~10% of global surface primary production at depth by feeding in shallow waters and migrating to deep water, accounting for ~15% of total carbon export (reviewed by Drazen and Sutton 2017). Deep-sea demersal fish also sequester carbon by consuming vertically migrating plankton. On the UK–Irish continental margin alone, this mechanism prevents an estimated 3.5–6.2 × 10^5 metric tons of carbon per year (t C yr^{-1}) from recycling back into the atmosphere (Trueman *et al*. 2014). Passive export occurs through the sinking of dead carcasses: whale detritus (Figure 1d) exports 2.7 × 10^5 t C yr^{-1} globally (Pershing *et al*. 2010), and cumulative vertebrate carcass export accounts for 4–11% of particulate carbon flux to the deep sea (Higgs *et al*. 2014). The deposition of carcasses into deep-sea habitats markedly increases the organic carbon content of surrounding sediments and therefore represents a fundamental process for local carbon sequestration. This "biological pump" of carbon from surface waters to the deep ocean is currently operating at reduced efficiency because of anthropogenic changes to the size structure of marine vertebrate populations. Policies aimed at rebuilding stocks of marine vertebrates can therefore have a positive impact on carbon sequestration at a global scale and should be valued accordingly (eg Martin *et al*. 2016).

We commend Howard *et al*. (2017) for promoting the conservation of marine carbon stores as a promising aspect of climate-change mitigation. We also appreciate that their review focused on carbon sink habitats, which fall within existing management and policy frameworks. We suggest, however, that scientists, managers, and policy makers should consider carbon source habitats as well as sinks in future assessments of the importance of marine systems in natural carbon sequestration. By managing and protecting effective and widespread carbon donors, such as kelp forests and large vertebrates, the magnitude of carbon capture and transfer, as well as the efficiency of assimilation into storage habitats, will be maintained or even enhanced. For example, carbon crediting schemes currently exclude allochthonous carbon from their evaluations, despite emerging evidence of the importance of externally sourced organic matter for natural carbon sequestration. As the wider understanding of coastal carbon cycling advances, policy frameworks such as the United Nations Framework Convention on Climate Change (UNFCCC) should evolve to incorporate processes that promote natural carbon sequestration by, for instance, acknowledging the role of carbon donors in crediting and management. More broadly, evaluating the role of marine systems in climate-change mitigation can be meaningful and effective only through a wider appreciation of the interconnectivity and interactions between marine habitats and taxa, rather than by adopting a simpler approach of carbon budgeting habitats in isolation in order to prioritize their management.

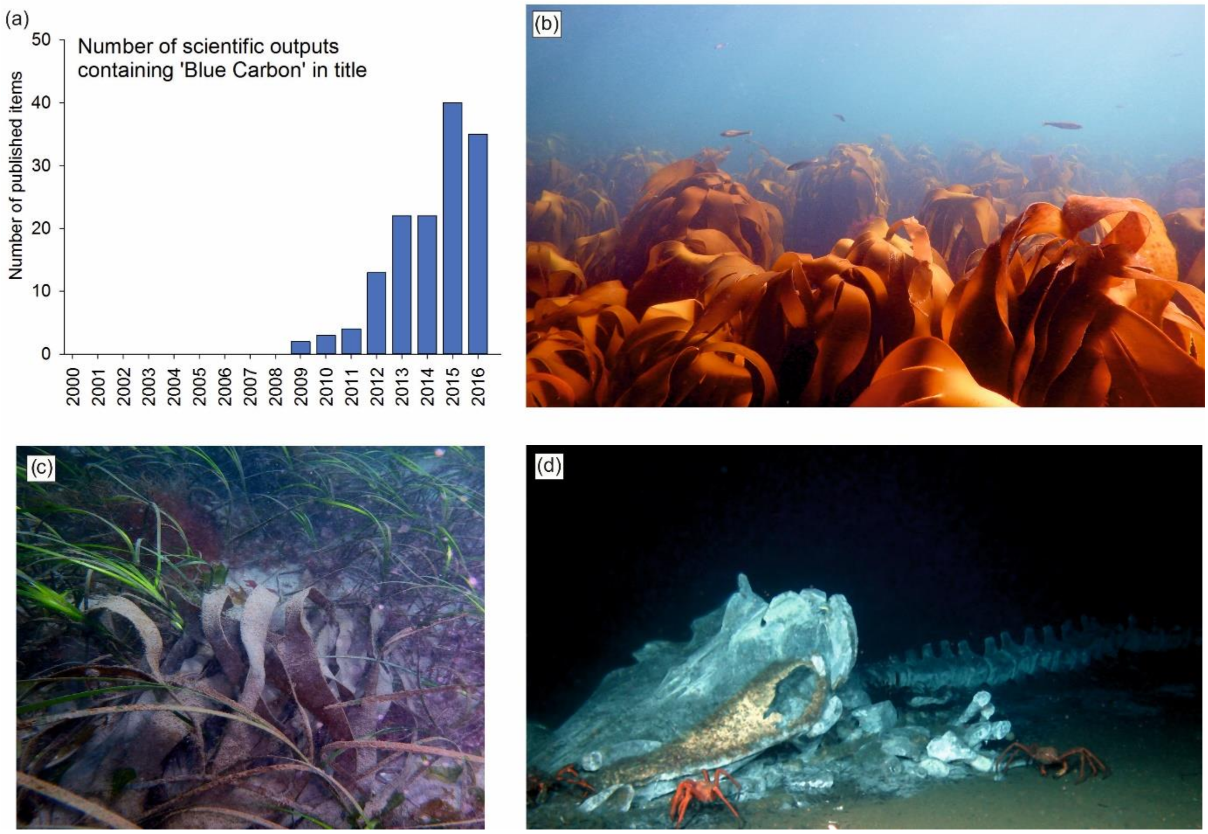
Dan A Smale[1*], Pippa J Moore[2,3], Ana M Queirós[4], Nicholas D Higgs[5], and Michael T Burrows[6]

[1]Marine Biological Association of the United Kingdom, Plymouth, UK [*](dansma@mba.ac.uk); [2]Institute of Biological, Environmental and Rural Sciences, Aberystwyth University, Aberystwyth, UK; [3]Centre for Marine Ecosystems Research, School of Natural Sciences, Edith Cowan University, Joondalup, Australia; [4]Plymouth Marine Laboratory, Plymouth, UK; [5]Marine Institute, Plymouth University, Plymouth, UK; [6]Scottish Association for Marine Science, Dunbeg, UK

Drazen JC and Sutton TT. 2017. Dining in the deep: the feeding ecology of deep-sea fishes. *Ann Rev Mar Sci* **9**: 337–66.

Higgs ND, Gates AR, and Jones DOB. 2014. Fish food in the deep sea: revisiting the role of large food-falls. *PLoS ONE* **9**: e96016.
Hill R, Bellgrove A, Macreadie PI, *et al*. 2015. Can macroalgae contribute to blue carbon? An Australian perspective. *Limnol Oceanogr* **60**: 1689–706.
Howard J, Sutton-Grier A, Herr D, *et al*. 2017. Clarifying the role of coastal and marine systems in climate mitigation. *Front Ecol Environ* **15**: 42–50.
Kain JM. 1979. A view of the genus *Laminaria*. *Oceanogr Mar Biol Ann Rev* **17**: 101–61.
Kinlan BP and Gaines SD. 2003. Propagule dispersal in marine and terrestrial environments: a community perspective. *Ecology* **84**: 2007–20.
Krause-Jensen D and Duarte CM. 2016. Substantial role of macroalgae in marine carbon sequestration. *Nature Geosci* **9**: 737–42.
Krumhansl K and Scheibling RE. 2012. Production and fate of kelp detritus. *Mar Ecol-Prog Ser* **467**: 281–302.
Mann KH. 1973. Seaweeds: their productivity and strategy for growth. *Science* **182**: 975–81.
Martin SL, Balance LT, and Groves T. 2016. An ecosystem services perspective for the Oceanic Eastern Tropical Pacific: commercial fisheries, carbon storage, recreational fishing, and biodiversity. *Front Mar Sci* **3**: 50.
Pershing AJ, Christensen LB, Record NR, *et al*. 2010. The impact of whaling on the ocean carbon cycle: why bigger was better. *PLoS ONE* **5**: e12444.
Smale DA, Burrows MT, Evans AJ, *et al*. 2016. Linking environmental variables with regional-scale variability in ecological structure and standing stock of carbon within kelp forests in the United Kingdom. *Mar Ecol-Prog Ser* **542**: 79–95.
Teagle H, Hawkins SJ, Moore PJ, and Smale DA. 2017. The role of kelp species as biogenic habitat formers in coastal marine ecosystems. *J Exp Mar Biol Ecol* **492**: 81–98.
Trueman CN, Johnston G, O'Hea B, and MacKenzie KM. 2014. Trophic interactions of fish communities at midwater depths enhance long-term carbon storage and benthic production on continental slopes. *P Roy Soc B-Biol Sci* **281**: 20140669.
Vanderklift MA and Wernberg T. 2008. Detached kelps from distant sources are a food subsidy for sea urchins. *Oecologia* **157**: 327–35.
Vetter EW and Dayton PK. 1998. Macrofaunal communities within and adjacent to a detritus-rich submarine canyon system. *Deep-Sea Res Pt II* **45**: 25–54.

Figure 1. *(a) The number of scientific articles focusing on blue carbon has greatly increased in recent years (publications per year with blue carbon in the title and pertaining to inshore carbon cycles; Google Scholar search conducted on 24 Feb 2016). (b) Kelp forests are very productive and represent extensive coastal vegetated habitats. (c) The majority of kelp-derived matter is exported and may accumulate within blue carbon recipient habitats such as seagrass meadows. (d) Sinking vertebrate carcasses represent an important flow of particulate carbon to deep-sea sedimentary habitats.*


(a)
Number of scientific outputs containing 'Blue Carbon' in title
Number of published items
0
10
20
30
40
50
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
(b)
(c)
(d)