Notes on “Microbial productivity of the Sargasso Sea and how it compares to elsewhere” and “The role of the Sargasso Sea in carbon sequestration—better than carbon neutral?”

M.W. Lomas, N.R. Bates, K.N. Buck, and A.H. Knap

Number ⑥ Sargasso Sea Alliance Science Report Series

SARGASSO SEA ALLIANCE

GOVERNMENT OF BERMUDA

When referenced this report should be referred to as:

Lomas, M.W., Bates, N.R., Buck, K.N. and A.H. Knap. 2011b. *Notes on "Microbial Productivity of the Sargasso Sea and How it Compares to Elsewhere", and "The Role of the Sargasso Sea in Carbon Sequestration–Better than Carbon Neutral?"* Sargasso Sea Alliance Science Report Series, No 6, 10 pp. ISBN 978-0-9847520-8-9.

The Sargasso Sea Alliance is led by the Bermuda Government and aims to promote international awareness of the importance of the Sargasso Sea and to mobilise support from a wide variety of national and international organisations, governments, donors and users for protection measures for the Sargasso Sea.

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The Secretariat of the Sargasso Sea Alliance is hosted by the Washington D.C. Office of the International Union for the Conservation of Nature (IUCN).

Website is **www.sargassoalliance.org**

This case is being produced with generous support of donors to the Sargasso Sea Alliance: Ricardo Cisneros, Erik H. Gordon, JM Kaplan Fund, Richard Rockefeller, David E. Shaw, and the Waitt Foundation. Additional support provided by: WWF Sweden and the Pew Environment Group.

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ISBN 978-0-9847520-8-9

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BIOS

Bermuda Institute of Ocean Sciences (BIOS), Inc.
Founded in 1903 as the Bermuda Biological Station
17 Biological Station, St. George's, Bermuda

Foreword

BETWEEN 2010 AND 2012 a large number of authors from seven different countries and 26 separate organisations developed a scientific case to establish the global importance of the Sargasso Sea. A summary of this international study was published in 2012 as the "Summary science and Supporting Evidence Case." Nine reasons why the Sargasso Sea is important are identified in the summary. Compiling the science and evidence for this case was a significant undertaking and during that process a number of reports were specially commissioned by the Sargasso Sea Alliance to summarise our knowledge of various aspects of the Sargasso Sea.

This report is one of these commissioned reports. These are now being made available in the Sargasso Sea Alliance Science Series to provide further details of the research and evidence used in the compilation of the summary case. A full list of the reports in this series can be found in the inside back cover of this report. All of them can be downloaded from **www.sargassoalliance.org.**

Professor Howard Roe
Science Advisory Committee Chair
Sargasso Sea Alliance

Professor Dan Laffoley
Science Coordinator
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Microbial Productivity of the Sargasso Sea and How it Compares to Elsewhere

Despite low nutrients and the designation as oligotrophic, the Sargasso Sea, per unit area, has a net annual primary production rate as high as some of the most productive regions in the global ocean.

The biological carbon pump, which is the photosynthetic formation of particulate and dissolved organic carbon in surface waters and its subsequent export to deep water, is characterized by a gross flux of about 15 Gt C yr-1 (Falkowski et al., 1998), with roughly 2.5 Gt C yr-1 being exported from the upper 100 m and 0.15 Gt C yr-1 reaching the abyssal sea floor. This export production and its attenuation mediated by marine biota might potentially play an increasingly important role in the net oceanic uptake of atmospheric CO_2 (Falkowski, 1997; Karl et al., 1997; Sabine et al., 2004; Sarmiento et al., 1998; Winguth et al., 2005). In this respect, sub-tropical gyres, such as the Sargasso Sea, and the transition zones at their boundaries clearly play an important role in the ocean's biological pump, and not only because they occupy 65% of the ocean's surface area (Koblentz-Mishke et al., 1970). Emerson et al., (2001) found that annual export production on a per area basis is actually higher in the sub-tropics than in the sub-polar regions that are generally considered to be more important. This apparent contradiction could in part be due to additional nitrogen inputs via mesoscale and submesoscale processes (Oschlies, 2002; McGillicuddy et al., 2003) and nitrogen fixation (Capone et al., 2005; Michaels et al., 2001) which support enhanced export production but are poorly quantified. A corollary to this observation is that net phytoplankton primary production in the sub-tropics also may be higher than in the sub-polar region on an annual basis.

As an example of these ideas let's compare one of the most productive 'seas' the Bering Sea, with the Sargasso Sea, which is commonly considered to be oligotrophic. Primary productivity per liter of Bering Sea water is often (>50% of ~500 observations) as high as 0.2g C m^{-3} d^{-1} (Lomas et al., 2011), whereas in the Sargasso Sea primary productivity per liter seawater has only been >0.04g C m^{-2} d^{-1} 12 times in over 2200 observations (Lomas et al., http://bats.bios.edu). Despite these disparities, the annual primary production per meter of sea surface area is very similar between the two seas at ~150 gC m^{-2} y^{-1} (Rho and Whitledge 2007, Lomas et al., 2011, Steinberg et al., 2001). The difference is even more dramatic when primary production is integrated over the surface area of the Bering and Sargasso Sea, which are of similar size, Bering Sea 2.6 million km^2 and Sargasso Sea 3.6 million km2. Annual primary production by the Sargasso Sea is roughly 500 Tg C y^{-1}, which is ca. 3-fold greater than the Bering Sea at 160 Tg C y^{-1}. The primary difference between these two seas in terms of productivity is that in the Bering Sea (as in other polar seas, Carlson et al., 1998) a major fraction (>50%) of the net primary production is channeled to harvestable resources (e.g., crab, shellfish, pollpock) (Mathis et al., 2010, Moran et al., 2011 and references therein) whereas in the Sargasso Sea a much smaller fraction (~10-20%) of primary production is channeled to harvestable resources, and most of the production is recycled by bacteria (Carlson and Ducklow 1996, Carlson et al., 1996, Steinberg et al., 2001). These patterns have important implications for our present understanding of the oligotrophic gyres as well as future changes (see sections 1, 3 and 4 of SSA report No 6).

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Role of the Sargasso Sea in Carbon Sequestration—Better than Carbon Neutral?

The Sargasso Sea plays an important role in the oceanic sequestration of carbon and on an annual basis is a net sink for atmospheric carbon dioxide.

On societally relevant timescales (e.g., decades to centuries), the global ocean sequesters large quantities of carbon dioxide (CO_2) from the atmosphere. Photosynthetic fixation of CO_2 into particulate matter coupled with the subsequent downward transfer via settling of these particles represents a quantitatively important export of carbon to the ocean interior. These processes are collectively termed the ocean biological carbon pump and it sequesters carbon into the deep ocean on the timescale (hundreds to thousands of years) of the global overturning circulation (e.g., Broecker and Peng, 1982; Gruber and Sarmiento, 2002). The reservoir of carbon in the global ocean is approximately 60-70 times greater than that of the atmosphere. As such, even a small change in the ocean reservoir of carbon has a significant impact on the atmospheric concentration of CO_2 and the response of the climate system to the release of anthropogenic (i.e., human produced) CO_2.

At present, the global ocean sequesters about 25% of anthropogenic CO_2 in the atmosphere, with the total amount of anthropogenic carbon sequestered in the ocean estimated at ~120-140 Pg (Pg = 10^{15} g) of carbon (e.g., Sabine et al., 2004; Khatiwala et al., 2009). The net (fixation minus re-mineralization) global ocean uptake of CO_2 is estimated at ~1.4 to 2.5 Pg C per year (e.g., Takahashi et al., 2002, 2009; Manning and Keeling, 2006), with the ocean uptake increasing with time (e.g., Le Quéré et al., 2009) as the amount of anthropogenic CO_2 released to the atmosphere has increased (Friedlingstein et al., 2010). Thus, the sequestration of CO_2 into the global ocean is one of the primary mechanisms that controls the concentrations of CO_2 in the lower atmosphere and the impact of human produced CO_2 on the climate system (IPCC, 1990, 2001, 2007).

Understanding the time-varying magnitude and dynamics controlling the sequestration of carbon requires a detailed study of the biological, geological and chemical processes that control the transfer of carbon across the air-sea interface and into the deep ocean. Long-term observations at the BATS site indicate two important observations. First that on an annual time-scale the northwestern Sargasso Sea is a net sink for CO_2. During the summer, CO_2 outgases from the surface ocean, but this is offset by the strong net sink of CO_2 in the winter (Bates et al., 2002, Bates 2007) that is actually increasing along with the increases in primary production and phytoplankton biomass (Lomas et al., 2010). Second, total dissolved inorganic carbon (DIC) in surface and deeper water layers have increased at divergent rates since 1988 (Bates et al., 2002; Gruber et al., 2002). In deeper subtropical mode waters (STMW), the mean rate of change of DIC (1988-2001) was twice as high as in surface waters (Bates et al., 2002). The STMW of the North Atlantic Ocean is formed each winter by cooling and convective mixing at the northern edges of the subtropical gyre south of the Gulf Stream (Klein and Hogg, 1996; Hazeleger and Drijfhout, 1998). The shallow depths of the subtropical gyre (~250-400m deep) are ventilated during STMW formation and the STMW layer is found throughout the subtropical gyre (Klein and Hogg, 1996; Jenkins, 1998; Hanawa and Talley, 2001; Alfutis and Cornillon, 2001). Since 1988, ~0.6-2.8 Pg (10^{15} g) of CO_2 has accumulated within the gyre STMW, ~0.04 – 0.26 PgC per year, representing a long-term oceanic sink of CO_2 (>10 years) in this region. The Sargasso Sea biological carbon pump sequesters ~0.06 Pg C yr-1. Combined these two terms account for the net sink of CO_2 in the Sargasso Sea and they represent ~7% of the global net biological carbon pump.

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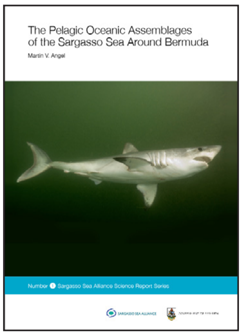
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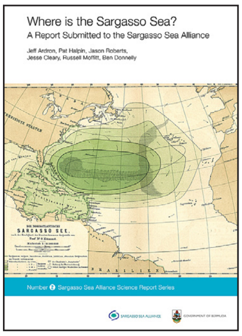
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A Report Submitted to the Sargasso Sea Alliance
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2

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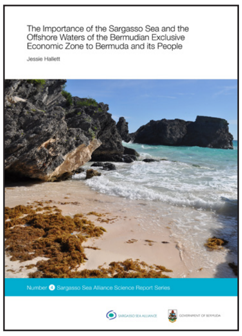
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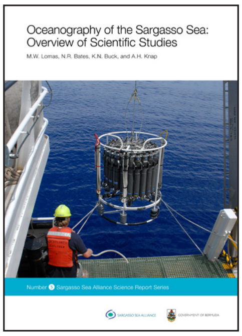
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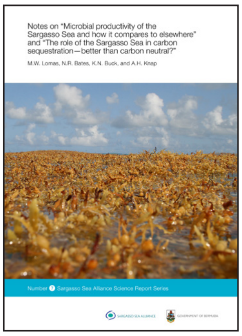
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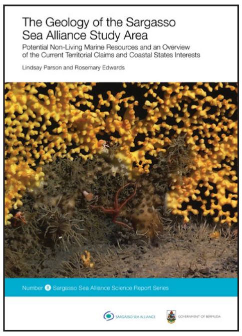
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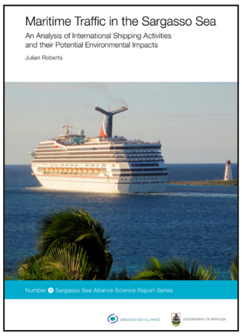
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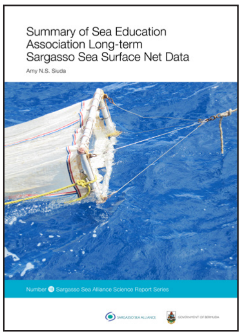
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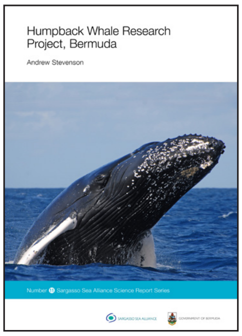
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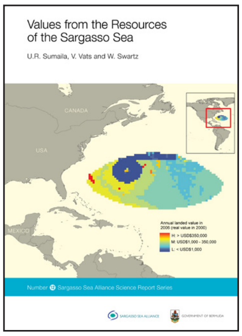
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SARGASSO SEA ALLIANCE

Since the initial meetings the partnership around the Sargasso Sea Alliance has expanded. Led by the Government of Bermuda, the Alliance now includes the following organisations.

PARTNER	TYPE OF ORGANISATION
Department of Environmental Protection	Government of Bermuda
Department of Conservation Services	Government of Bermuda
Mission Blue / Sylvia Earle Alliance	Non-Governmental Organisation
International Union for the Conservation of Nature (IUCN) and its World Commission on Protected Areas	Multi-lateral Conservation Organisation
Marine Conservation Institute	Non-Governmental Organisation
Woods Hole Oceanographic Institution	Academic
Bermuda Institute for Ocean Sciences	Academic
Bermuda Underwater Exploration Institute	Non-Governmental Organisation
World Wildlife Fund International	Non-Governmental Organisation
Atlantic Conservation Partnership	Non-Governmental Organisation