GRID ARENDAL
A Centre Collaborating with UNEP

Blue Climate Solutions
A project of The Ocean Foundation

FISH CARBON

EXPLORING MARINE VERTEBRATE CARBON SERVICES

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GRID-Arendal, a Norwegian foundation and Centre collaborating with UNEP, is located in southern Norway. Established in 1989 by Norway's Ministry of Environment, GRID-Arendal's activities specifically support UNEP's Programme of Work. GRID-Arendal's mission is to provide environmental information, communications and capacity building services for information management and assessment. Together with its partners, GRID-Arendal's core focus is to support decision-making processes aimed at securing a sustainable future.

Blue Climate Solutions, a project of The Ocean Foundation, is a non-profit organisation with a mission to promote the conservation of the world's coasts and oceans as an innovative, proactive and viable solution to the climate change challenge. Blue Climate Solutions was established in 2008 and works in the arenas of policy, science, communications, and management. Blue Climate Solutions seeks to better understand the roles that coastal and ocean ecosystems play in addressing climate change and explore how those values can be translated into improved and sustainable ecosystem management.

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PREFACE

Upon first voyaging into space, Astronauts were enthralled by the beautiful blue marble they found themselves circling above. American Astronaut, James Irwin, remarking on travelling to the moon in 1971, "As we got further and further away, it [the Earth] diminished in size. Finally it shrank to the size of a marble, the most beautiful you can imagine. That beautiful, warm, living object looked so fragile, so delicate, that if you touched it with a finger it would crumble and fall apart."

The ocean is Earth's life support system. The ocean regulates temperature, climate, and weather. The living ocean governs planetary chemistry; regulates temperature; generates most of the oxygen in the sea and atmosphere; powers the water, carbon, and nitrogen cycles. It holds 97% of Earth's water and 97% of the biosphere. We know that most of the oxygen in the atmosphere is generated – and much of the carbon dioxide is taken up – by mangroves, marshes, sea grasses, algae and especially microscopic phytoplankton in the ocean. Quite simply, no ocean, no life. No blue, no green. If not for the ocean, there would be no climate to discuss or anyone around to debate the issues.

Recently, the largest gathering of world leaders ever to address climate change met in New York City. However, the largest factor in our climate cycle, the ocean, was absent from the discussions. The ocean's importance to earth and climate is well understood and documented, with substantial evidence gathered over the last 50 years. Knowing what we now know, it is alarming that the ocean was excluded so completely from the UN General Assembly meetings in September 2014.

While this blue engine provides environmental services critical to human life on Earth, human actions directly threaten the ocean. Over 99% of the ocean is open to extractive activities, drilling, dredging and dumping. While industrial fishing removes millions of tons of marine life from ocean ecosystems, tons of discarded plastics and derelict fishing gear continue to kill more marine life indiscriminately throughout 100% of the ocean. The ocean has also been a place to discard our wastes. This practice has come back to haunt us by way of hundreds of toxic dead zones in coastal waters. The burning of fossil fuels is causing changes in ocean chemistry and increasing the acidity of the water. The effects are already being observed in the thinning shells of young oysters in the Pacific Northwest, the disintegration of the skeletons of young corals, and of sea snails in Antarctic waters.

Both oceanic and terrestrial impacts of global climate change are exacerbated by increased human interference with oceanic cycles: the cycles that are crucial for our life support system. "Business as usual" threatens to squander perhaps the only chance we have to put things right before climatic changes become wholly irreversible.

There is still time if we act now. In terrestrial ecosystems climate policy addresses the release of carbon dioxide by industrial activities. This report is a key step in increasing our understanding of the ways that marine vertebrates contribute to the global carbon cycle, one of the vital functions of our life support system, and how they buffer against ocean acidification.

'Fish Carbon: Exploring Marine Vertebrate Carbon Services' highlights the direct relevance of marine vertebrates to climate change mitigation and presents an opportunity to secure this service, at this critical juncture, through the protection and conservation of marine vertebrates.

Acknowledging the importance of marine life in climate change will not only provide much needed opportunities in climate mitigation, but will simultaneously enhance food security for coastal and island communities, while safeguarding biodiversity and marine ecosystems on a global scale, particularly in the unprotected high seas. It is important that we build upon this knowledge and act accordingly. By protecting the ocean, we can continue to benefit from these services, and to secure the viability of Earth as a blue planet conducive to supporting human life.

Now we know. As go the oceans, so goes the fate of life on Earth. The ocean doesn't care one way or another about us, but for all that we hold dear, including life itself, we must care about the ocean as if our lives depend on it, because they do.

Sylvia A Earle

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This text is based on Sylvia Earle and John Bridgeland's Op-ed titled 'The Big Blue Elephant in the Room' published by the Huffington Post on September 30, 2014.

SUMMARY

Climate change presents a serious global challenge for current and future generations. It has been termed a defining issue of our era and "poses a severe threat to human welfare, biodiversity and ecosystem integrity, and possibly to life itself" (COMEST 2010). In March of this year, Rajendra K. Pachauri, Chairperson of the Intergovernmental Panel on Climate Change (IPCC) stated that "nobody on the planet will be untouched by climate change" (United Nations 2014).

If we are committed to addressing climate change and making a smooth transition to a low carbon economy, then we must reduce and mitigate the impacts of atmospheric carbon without delay. Key to this is the need to reduce emissions of greenhouse gases (GHG). However, we must also explore the capacity and mechanisms of nature to mitigate climate change, such as carbon capture and storage. The green and blue biospheres[1] of the Earth present such options – natural systems from rainforests to seagrass meadows that have been providing climate services in a tried and tested way for millennia (Duarte *et al*. 2005, Nabuurs *et al*. 2007, Laffoley and Grimsditch 2009, Nellemannn *et al*. 2009, Crooks *et al*. 2011, Donato *et al*. 2011, Pan *et al*. 2011, Fourqurean *et al*. 2012, Pendleton *et al*. 2012).

The blue biosphere is vitally important to life on our planet and to global climate change. The ocean encompasses over 70% of the Earth's surface, and plays a crucial role in oxygen production, weather patterns, and the global carbon cycle (Denman *et al*. 2007). The ocean is by far the largest carbon sink in the world: it accumulates 20 to 35% of atmospheric carbon emissions (Sabine *et al*. 2004, Houghton 2007) and "some 93% of the earth's carbon dioxide is stored and cycled through the oceans" (Nellemann *et al*. 2009). It has been estimated that annual carbon capture and storage by high seas ecosystems is equivalent to "over 1.5 billion tonnes of carbon dioxide" (Rogers *et al*. 2014), with a total ecosystem service or social benefit value of $148 billion USD annually (with a range between $74 and $222 billion) (Rogers *et al*. 2014).

The importance of terrestrial forest ecosystems in removing carbon dioxide (CO_2) from the atmosphere is scientifically recognized (Nabuurs *et al*. 2007, Pan *et al*. 2011) and included in climate change programmes such as the United Nations collaborative initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD) in developing countries (UN-REDD 2008). The importance of coastal marine ecosystems, such as mangrove forests, kelp forests, seagrass meadows, and saltwater marshes, in storing and sequestering atmospheric carbon (also referred to as coastal 'Blue Carbon' and 'Blue Forests') is also recognized in science (Duarte *et al*. 2005, Laffoley and Grimsditch 2009, Nellemannn *et al*. 2009, Crooks *et al*. 2011, Donato *et al*. 2011, Fourqurean *et al*. 2012, Pendleton *et al*. 2012). The importance of the blue biosphere in climate change is beginning to be acknowledged in the policy and management arena (Murray *et al*. 2012, Ullman *et al*. 2012, Hoegh-Guldberg *et al*. 2013, CNRWG 2014), including through on-the-ground initiatives such as the Abu Dhabi Blue Carbon Demonstration Project (AGEDI 2014a) and the Global Environment Facility's Blue Forests Project (IW:LEARN 2014).

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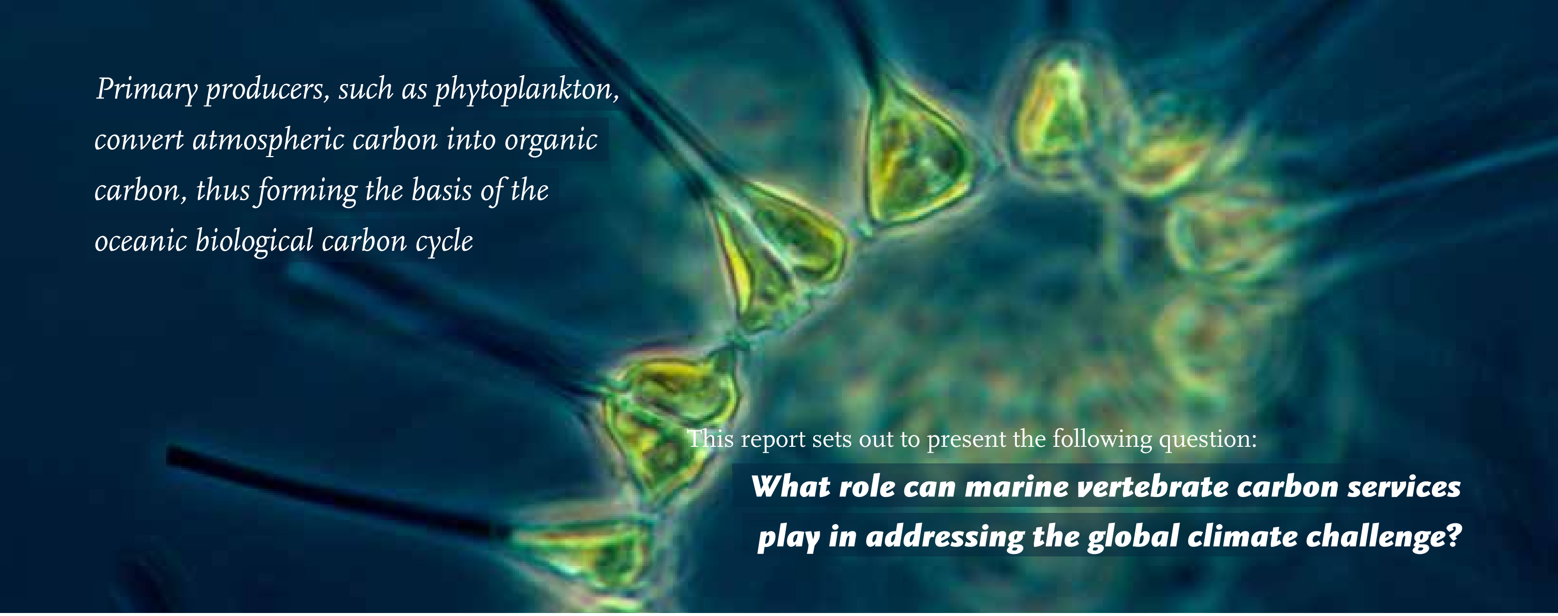
[1] The terrestrial and oceanic areas occupied by living organisms, respectfully.



Primary producers, such as phytoplankton, convert atmospheric carbon into organic carbon, thus forming the basis of the oceanic biological carbon cycle

This report sets out to present the following question:

What role can marine vertebrate carbon services play in addressing the global climate challenge?

To date, much of the scientific focus of the oceanic carbon cycle has been on the roles of phytoplankton and zooplankton in carbon sequestration (Doney *et al.* 2001, Moore *et al.* 2004, Hofmann *et al.* 2008) and there is much yet to be discovered regarding the intricate biological pathways involved in carbon cycling and the associated implications for climate regulation (Schmitz *et al.* 2014). The role of higher level marine life, the vertebrates, in global climate change and carbon sequestration is largely invisible, as marine vertebrates are not included in most models of carbon cycling (Pershing *et al.* 2010, Roman and McCarthy 2010, Davison *et al.* 2013). However, an increasing number of studies are being published that explore the value of marine biota, other than plankton, in the biological carbon pump (Saba and Steinberg, 2012, Lebrato *et al.* 2013, Marlow *et al.* 2014, Roman *et al.* 2014). In healthy ecosystems, marine vertebrates (and other animals) may have disproportionately large impacts on carbon uptake, storage and release through “multiplier effects, whose magnitudes may rival those of more traditional carbon storage estimates” (Schmitz *et al.* 2014).

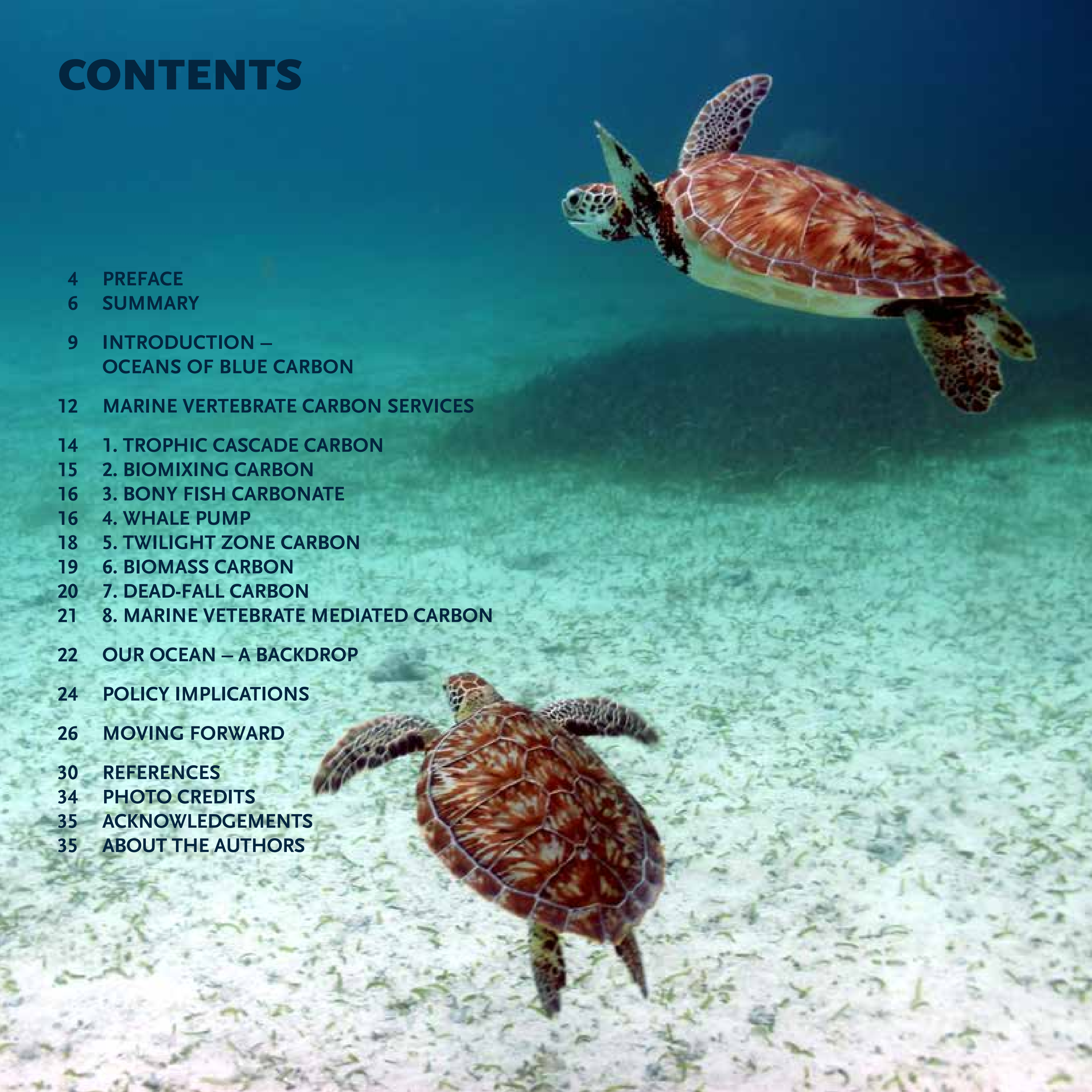
Although entitled ‘Fish Carbon’, our objective is to highlight the role that all marine vertebrates including fish, mammals and turtles, play in oceanic carbon cycling, and it’s potential application to addressing the global climate challenge. The aim is to assist policy makers to mainstream the natural value, or benefit, of Fish Carbon into marine management, climate change discussions, and to further scientific research on this subject. This report highlights seven biological mechanisms provided by marine vertebrates that result in carbon sequestration, and one mechanism which may provide a buffer against ocean acidification, all of which may help in the mitigation of climate change.

Much scientific endeavour remains to be accomplished regarding Fish Carbon, including understanding the potential total contribution of Fish Carbon to oceanic carbon cycling in comparison to the role of plankton. However, the mechanisms presented in this report enable new and innovative outlooks on addressing the global challenge of climate change, such as promoting the role that schools of fish and pods of marine mammals may play in enhancing uptake of atmospheric carbon into the ocean, and subsequently transporting carbon between ocean surface and sediment.

While reducing emissions remains at the forefront of national and international climate change initiatives, the vital function of healthy ocean ecosystems as carbon sinks, including the contribution of marine vertebrates, is largely overlooked in the policy arena and may be undervalued.

This report sets out to present the following question:

What role can marine vertebrate carbon services play in addressing the global climate challenge?



CONTENTS

INTRODUCTION – OCEANS OF BLUE CARBON

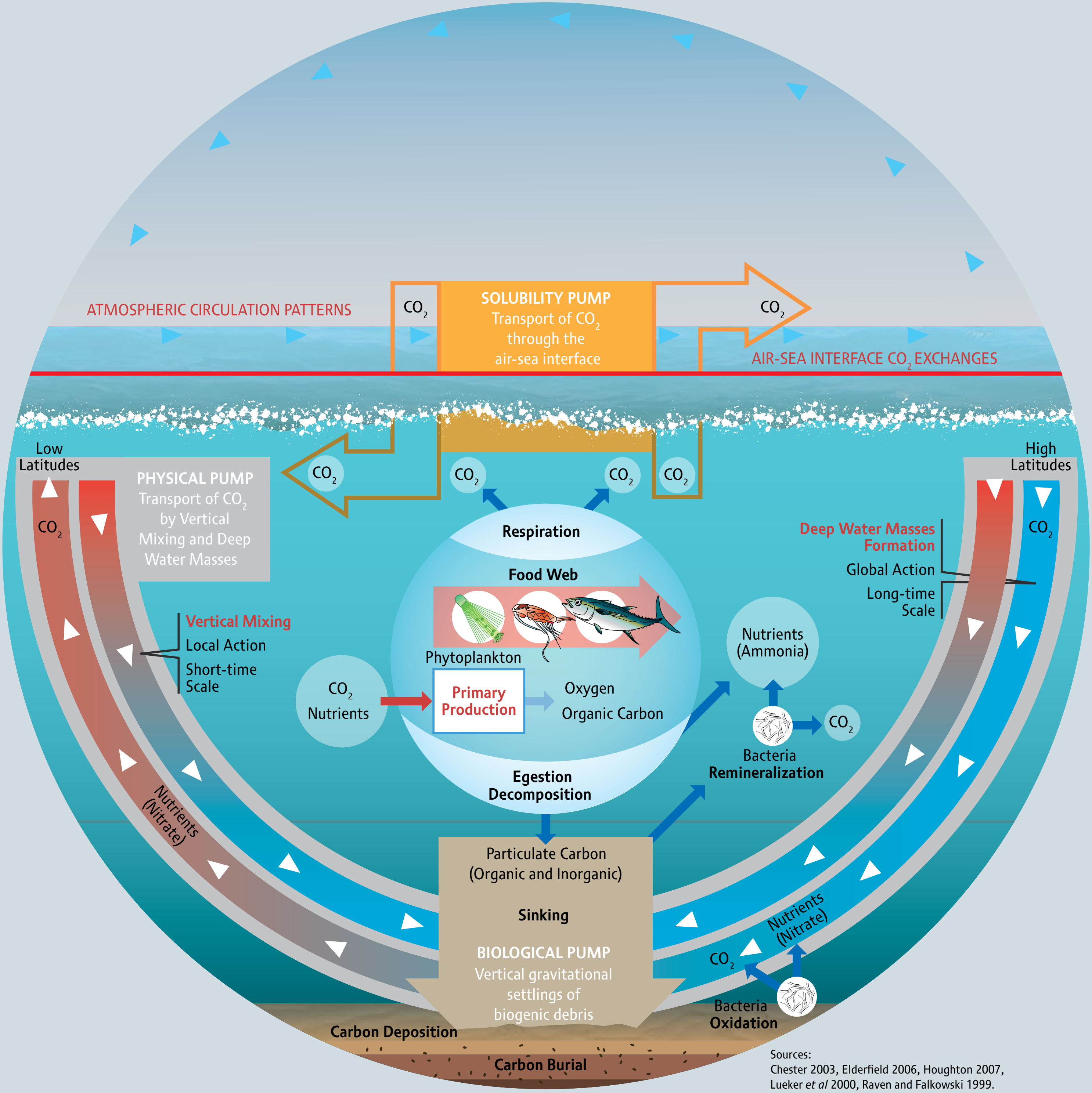
Human consumption of Earth's natural resources has resulted in global scale environmental modifications with significant implications for the welfare of current, and future, human society (Crutzen 2002, Wilkinson 2005, McLellan *et al*. 2014). Potentially the greatest global challenge is climate change, driven in part by human activities and particularly the combustion of fossil fuels and other industrial processes which release gases, such as carbon dioxide (CO_2), into the atmosphere. Elevated concentrations of atmospheric CO_2 influence global weather and ocean processes, resulting in a variety of alterations to human and natural systems, and in many cases posing risks to human well-being and other forms of life on Earth (Antle *et al*. 2001, Easterling *et al*. 2007, Battisti and Naylor 2009).

Some of the most serious threats that result from these changes manifest themselves in the ocean, such as ocean acidification. While overall still alkaline, increased amounts of dissolved carbon lower oceanic pH to levels too acidic for many marine organisms (Hönisch *et al*. 2012, Wittmann and Pörtner 2013, Mathis *et al*. 2014). Oceanic changes occurring on a global scale include rising sea levels, warming, deoxygenation, and increasingly severe storm surges.

Blue Carbon – is a concept that describes carbon linked to the marine environment through coastal and open ocean ecosystems. The planet's blue biosphere "is a major component of the global carbon cycle, responsible for roughly half of the annual photosynthetic absorption of CO_2 from the atmosphere" (Lutz *et al*. 2007).

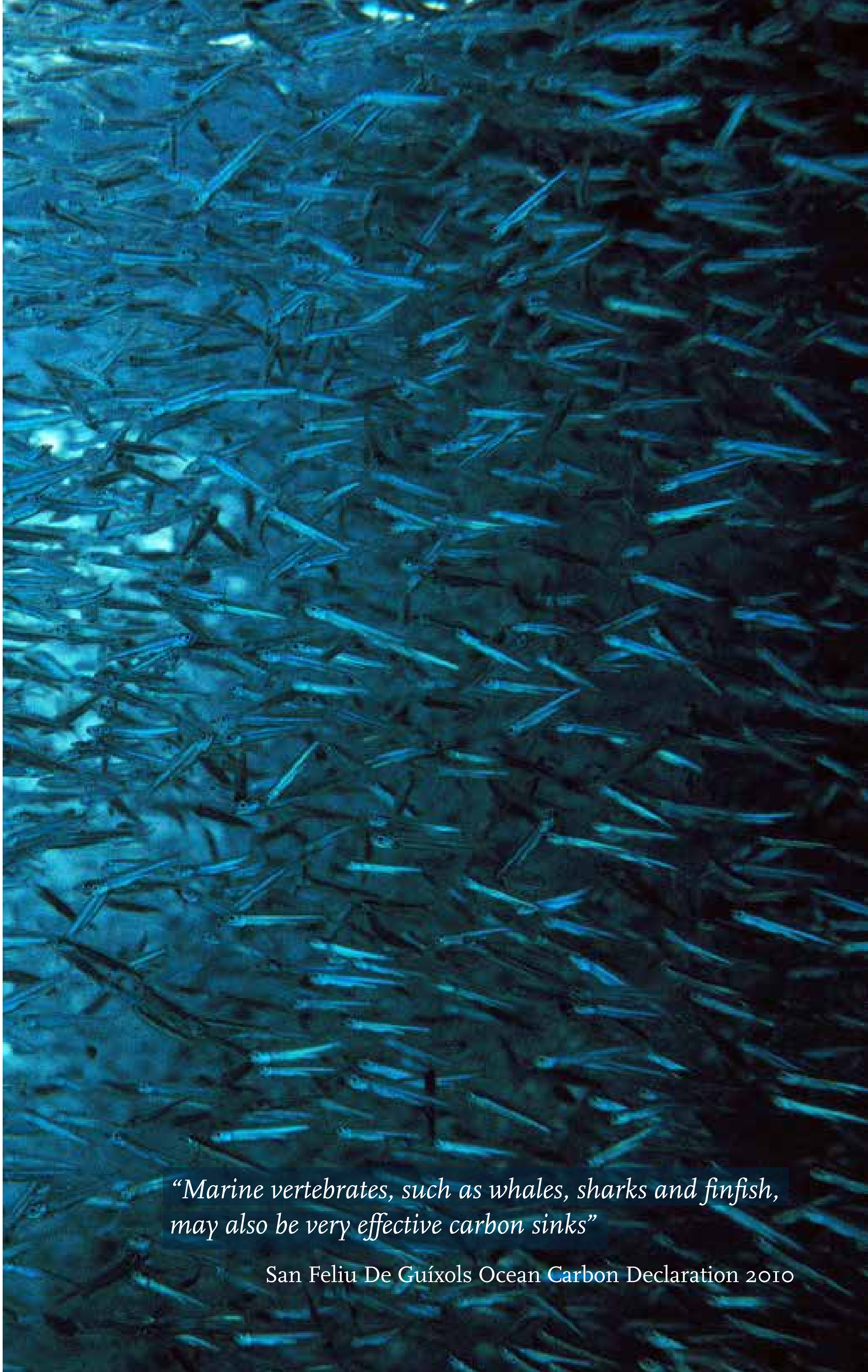
Carbon dioxide gas exchange, or flux, between the ocean and atmosphere is largely controlled by sea surface temperatures, circulating currents, and by the biological processes of photosynthesis and respiration (Figure 1). In short, marine ecosystems critically aid climate change mitigation by sequestering carbon from the atmosphere and providing natural carbon storage in biomass and sediments.

Blue Carbon initiatives currently underway focus on three coastal ecosystems identified as significant for atmospheric carbon storage and sequestration: mangrove forests, saltwater marshes, and seagrass meadows (Duarte *et al*. 2005, Laffoley and Grimsditch 2009, Nellemannn *et al*. 2009, Crooks *et al*. 2011, Donato *et al*. 2011, Fourqurean *et al*. 2012, Pendleton *et al*. 2012). Recent publications have also alluded to a stronger connection between marine vertebrates and effective oceanic carbon sequestration (e.g. Naber *et al*. 2008, Arnason *et al*. 2009, Lutz 2011, AGEDI 2014b, Roman *et al*. 2014). The San Feliu De Guíxols Ocean Carbon Declaration, authored in 2010 by 29 Pew Fellows in Marine Conservation and advisors, acknowledged that "marine vertebrates, such as whales, sharks and finfish, may also be very effective carbon sinks" and recommended "targeted research to improve our understanding of the contribution of coastal and open ocean marine ecosystems to the carbon cycle and to the effective removal of carbon from the atmosphere" (San Feliu De Guíxols Ocean Carbon Declaration 2010). Recognizing a value for marine vertebrates in oceanic carbon cycling expands the current Blue Carbon approach within and beyond the coasts and has the potential to advance our understanding of global climate processes and their application to mitigation and adaptation.



Sources:
Chester 2003, Elderfield 2006, Houghton 2007,
Lueker *et al* 2000, Raven and Falkowski 1999.

⬅ **Figure 1: Marine Carbon Cycling.** The amount of CO_2 dissolved in sea water is mainly influenced by physicochemical conditions (sea water temperature, salinity, total alkalinity), physical (upwelling, downwelling), and biological processes, (primary production, respiration, microbial metabolism). The flux of carbon dioxide across the air-sea interface is a function of CO_2 solubility in sea water (solubility pump), while various biological processes govern the transport of particulate organic carbon within the ocean (biological pump). The oceans carbon sink capacity is therefore regulated by the interconnected solubility and biological pumps, which uptake atmospheric CO_2 into ocean surface waters, and transfer the carbon to deep waters. The net effect of the biological pump alone maintains atmospheric CO_2 concentrations at around 70% less than what they would otherwise be (Siegenthaler and Sarmiento 1993). In general, the greater the depth that particulate carbon reaches before remineralization occurs, the longer the time taken for it to return to surface waters as dissolved CO_2, and to potentially re-enter the atmosphere. The vast majority of particulate carbon produced in surface waters, which is associated with microbes, phytoplankton and zooplankton, sinks slowly and is remineralized in the relatively shallow mesopelagic zone[2] (Eppley and Peterson 1979). This carbon may re-enter the atmosphere within decades (Lutz *et al.* 2007). Particulate carbon that reaches the deep ocean (>1500 m) and deep ocean sediments has a residence time in the thousands to millions of years respectively (Lutz *et al.* 2007). (Figure caption and illustration adapted with permission from Nellemann *et al.* 2009).



“Marine vertebrates, such as whales, sharks and finfish, may also be very effective carbon sinks”

San Feliu De Guíxols Ocean Carbon Declaration 2010

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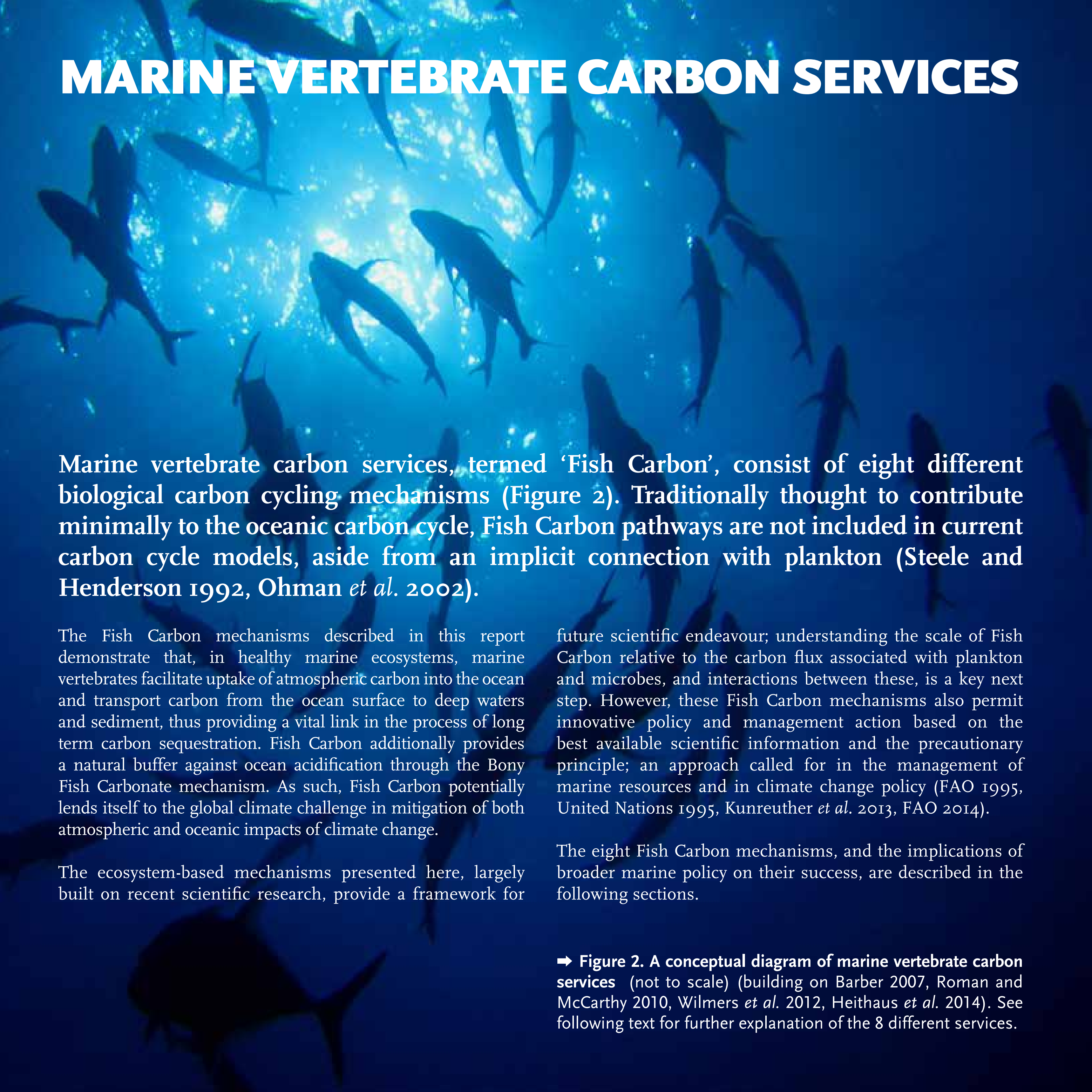
[2] Ocean water column at depths between 200-800m.

MARINE VERTEBRATE CARBON SERVICES



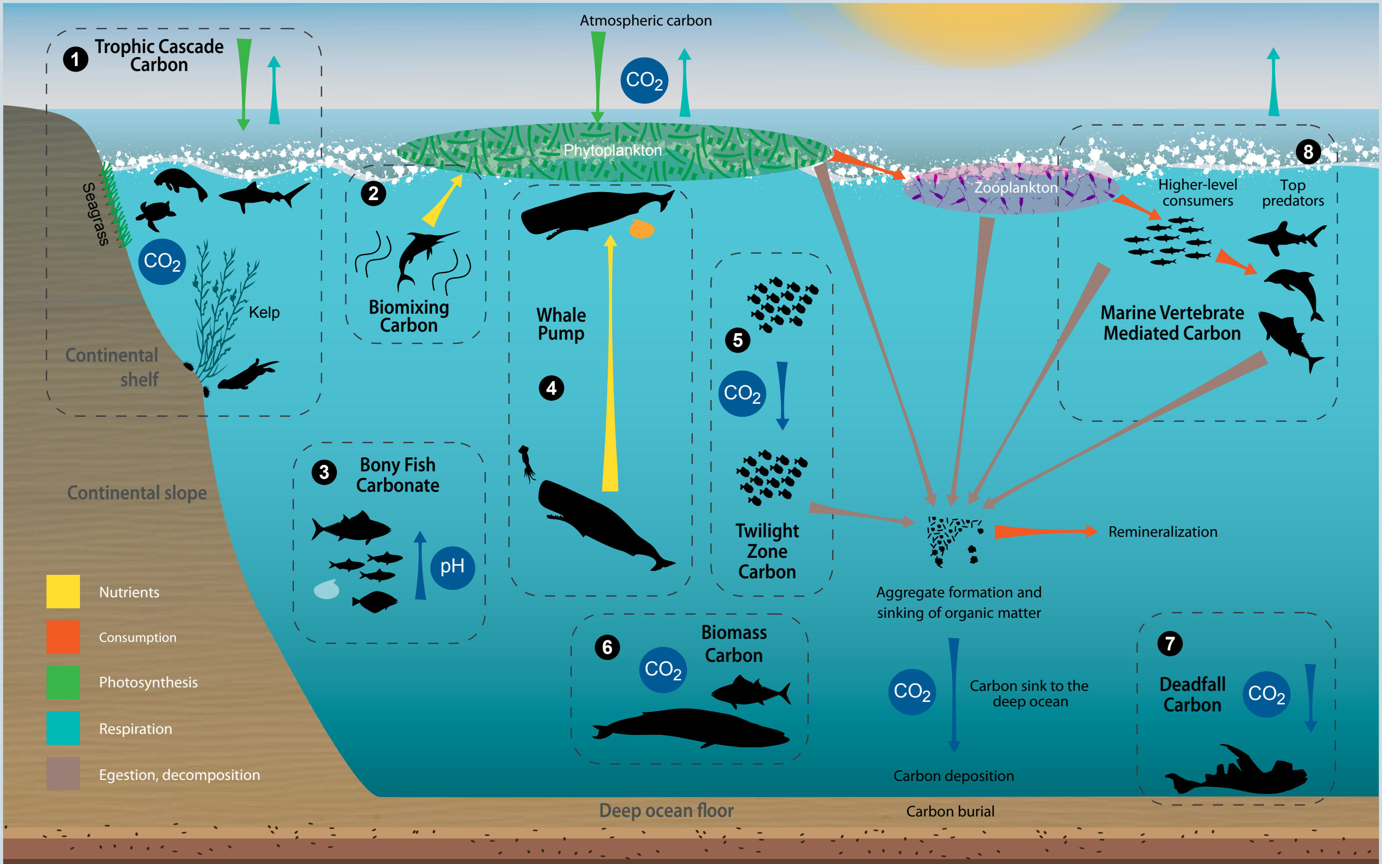
Marine vertebrate carbon services, termed 'Fish Carbon', consist of eight different biological carbon cycling mechanisms (Figure 2). Traditionally thought to contribute minimally to the oceanic carbon cycle, Fish Carbon pathways are not included in current carbon cycle models, aside from an implicit connection with plankton (Steele and Henderson 1992, Ohman *et al.* 2002).

The Fish Carbon mechanisms described in this report demonstrate that, in healthy marine ecosystems, marine vertebrates facilitate uptake of atmospheric carbon into the ocean and transport carbon from the ocean surface to deep waters and sediment, thus providing a vital link in the process of long term carbon sequestration. Fish Carbon additionally provides a natural buffer against ocean acidification through the Bony Fish Carbonate mechanism. As such, Fish Carbon potentially lends itself to the global climate challenge in mitigation of both atmospheric and oceanic impacts of climate change.

The ecosystem-based mechanisms presented here, largely built on recent scientific research, provide a framework for future scientific endeavour; understanding the scale of Fish Carbon relative to the carbon flux associated with plankton and microbes, and interactions between these, is a key next step. However, these Fish Carbon mechanisms also permit innovative policy and management action based on the best available scientific information and the precautionary principle; an approach called for in the management of marine resources and in climate change policy (FAO 1995, United Nations 1995, Kunreuther *et al.* 2013, FAO 2014).

The eight Fish Carbon mechanisms, and the implications of broader marine policy on their success, are described in the following sections.

➡ **Figure 2. A conceptual diagram of marine vertebrate carbon services** (not to scale) (building on Barber 2007, Roman and McCarthy 2010, Wilmers *et al.* 2012, Heithaus *et al.* 2014). See following text for further explanation of the 8 different services.



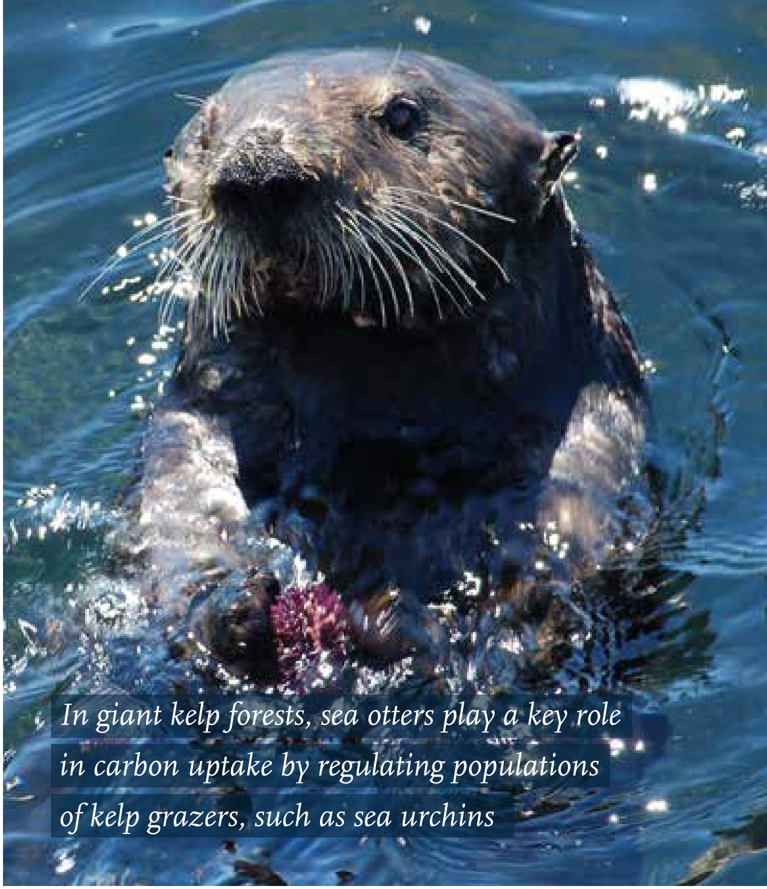
①	**Trophic Cascade Carbon**	Food web dynamics help maintain the carbon storage and sequestration function of coastal marine ecosystems (e.g. the health of primary producers such as seagrass meadows and kelp forests is maintained by herbivory and predation).
②	**Biomixing Carbon**	Turbulence and drag, associated with the movement of marine vertebrates, causes enhanced mixing of nutrient rich water from deeper in the water column towards the surface, where it enhances primary production by phytoplankton and thus the uptake of dissolved CO_2.
③	**Bony Fish Carbonate**	Bony fish excrete metabolised carbon as calcium carbonate (CaCO3) enhancing oceanic alkalinity and providing a buffer against ocean acidification.
④	**Whale Pump**	Nutrients from the faecal material of whales stimulate enhanced primary production by phytoplankton, and thus uptake of dissolved CO_2.
⑤	**Twilight Zone Carbon**	Mesopelagic fish feed in the upper ocean layers during the night and transport consumed organic carbon to deeper waters during daylight hours.
⑥	**Biomass Carbon**	Marine vertebrates store carbon in the ocean as biomass throughout their natural lifetimes, with larger individuals storing proportionally greater amounts over prolonged timescales.
⑦	**Deadfall Carbon**	The carcasses of large pelagic marine vertebrates sink through the water column, exporting carbon to the ocean floor where it becomes incorporated into the benthic food web and is sometimes buried in sediments (a net carbon sink).
⑧	**Marine Vertebrate Mediated Carbon**	Marine vertebrates consume and repackage organic carbon through marine food webs, which is transported to deep waters by rapidly sinking faecal material.

1. TROPHIC CASCADE CARBON

The trophic cascade of carbon through marine systems is regulated by food web dynamics. Consumption of primary producers by grazers and predation of grazers contributes to the complex carbon capture, storage and sequestration function of coastal marine ecosystems, such as in kelp forests and seagrass meadows (Figure 2, service 1).

Kelp are a large, fast growing brown marine algae that grow into marine forest ecosystems anchored to the sea floor and convert atmospheric carbon into carbon stored in their biomass through photosynthesis (Laffoley and Grimsditch 2009). Kelp forests are highly productive ecosystems important to many commercial and recreational fisheries, and are found in temperate and arctic regions throughout the world. In healthy giant kelp forests in the North Pacific, populations of sea urchins and other herbivorous invertebrates are regulated by a single predator: the sea otter. When a healthy population of otters is present, over an area of approximately 5,100 km^2, the effect of sea otter predation on giant kelp grazers is estimated to increase the total carbon storage capacity of kelp forests by an additional 4.4 to 8.7 megatons (4.4 to 8.7 billion kg), valued at $205 million to $408 million USD on the European Carbon Exchange (Wilmers *et al.* 2012). Sea otters therefore play a key ecological role in maintaining the health and stability of giant kelp forests, and in regulating the oceanic carbon function of these ecosystems (Wilmers *et al.* 2012).

Seagrasses, flowering plants that can form large marine meadows, are another coastal ecosystem found around the world that provide Blue Carbon services (Laffoley and Grimsditch 2009, Nellemann *et al.* 2009, Fourqurean *et al.* 2012). Seagrass meadows provide nursery grounds for juvenile fish, protect coastal land from erosion, maintain high water quality and support incredibly diverse communities (Hendriks *et al.* 2008), including many commercially important species of fish and shellfish, as well as sharks, turtles and dugongs. It is estimated that coastal seagrass beds store up to 83,000 metric tons of carbon per km^2, predominantly in sub-surface sediments where they can be preserved for millennia (Fourqurean *et al.* 2012, Wilson 2012). In contrast, a terrestrial forest stores about 30,000 metric tons per km^2 (Fourqurean *et al.* 2012, Wilson 2012).



In giant kelp forests, sea otters play a key role in carbon uptake by regulating populations of kelp grazers, such as sea urchins

It has been suggested that selective grazing by dugongs and sea turtles, through causing a disturbance to seagrass beds, stimulates regenerative growth and maintains diverse seagrass species composition, thus promoting health of seagrass ecosystems and associated primary production, and therefore carbon sequestration (Preen 1995, Aragones and Marsh 2000, Aragones *et al.* 2006, Kuiper-Linley *et al.* 2007). However, recent research shows that in many of the world's coastal ecosystems where top predators are overfished, particularly tiger sharks, sea turtles over-graze sea grasses (Heithaus *et al.* 2014), causing lower levels of photosynthesis and consequently reduced carbon fixation (Fourqurean *et al.* 2010). Experimental research found that predatory fish in freshwater environments also help sequester carbon through trophic cascades (Atwood *et al.* 2013). Thus maintenance of balanced food chains and healthy top predator populations may promote carbon cycling in coastal and marine ecosystems, through trophic dynamics.

As they move across oceans and between surface and depth, tuna and other marine vertebrates mix waters and nutrients, potentially enhancing uptake of carbon through photosynthesis

While much work remains in better understanding the complexities of Trophic Cascade Carbon and quantifying its effects, the implication for ocean carbon cycling is that maintenance of healthy populations of marine vertebrates, which support healthy ecosystems through trophic interactions, will help restore and maintain the efficacy of ocean carbon capture, storage and sequestration.

2. BIOMIXING CARBON

The movement of marine vertebrates and other organisms has been associated with the mixing of nutrient rich water throughout the water column, enabling primary production by phytoplankton in otherwise nutrient poor waters and thus enhancing uptake of atmospheric carbon (Figure 2, service 2) (Dewar *et al.* 2006, Lavery *et al.* 2012). Estimates of Biomixing Carbon have attributed one-third of ocean mixing to marine vertebrates, comparable to the effect of tides or winds (Dewar *et al.* 2006), although this conclusion has been disputed by other researchers (Visser 2007, Subramanian 2010).

Larger marine animals, such as whales, have been suggested to cause significantly greater biomixing than smaller animals (Subramanian 2010). For example, the Biomixing Carbon function of the Hawaiian sperm whale population of 80 whales is estimated to transport 1 million kg of nutrients to surface waters per year, and stimulate sequestration of 600,000 kg of carbon per year (Lavery *et al.* 2012). This is equivalent to the carbon sequestered by 250 square miles of U.S. forests in one year (EPA 2014), an area 3.6 times the size of Washington D.C.

Whilst quantification of this mechanism is currently contested (Visser 2007, Dabiri 2010), the suggestion that larger marine animals exert greater biomixing potential supports the implication that maintenance of healthy populations of marine vertebrates, especially larger species, could promote carbon uptake.

Production of calcium carbonate shells and skeletons is affected by ocean acidification; the effects of this are already being observed

3. BONY FISH CARBONATE

Calcium carbonate is thought to help increase the alkalinity of the oceanic pH balance and could be considered as a buffer against ocean acidification (Wilson *et al.* 2009, Wilson *et al.* 2011). The production of calcium carbonate in the oceans is usually attributed to marine plankton, however bony marine fish such as tuna, halibut, and herring also produce calcium carbonate as a waste product (Figure 2, service 3) (Wilson *et al.* 2009). In the intestines of bony fish, hydrocarbonate ions, largely derived from metabolic CO_2, and calcium, ingested through drinking of seawater, precipitate into calcium carbonate crystals, which are produced continually and excreted at high rates (Wilson *et al.* 2009).

When rates of calcium carbonate excretion are combined with estimates of global fish biomass, marine bony fish appear to contribute 3-15% of total oceanic carbonate production (Wilson *et al.* 2009). As a function of their metabolism, which has an inverse relationship with body size, small fish in high temperatures have the highest rates of carbonate production (Wilson *et al.* 2009). It has been suggested that in a warming ocean and with increased dissolved CO_2, higher rates of Bony Fish Carbonate production will increasingly contribute to the inorganic carbon cycle (Wilson *et al.* 2011), therefore becoming more important as a buffer against ocean acidification.

The implication of Bony Fish Carbonate is that, as total carbonate production is linked to fish size and abundance (Wilson *et al.* 2009, Jennings and Wilson 2009), and bony fish support the vast majority of the world's commercial marine fisheries, management of fishing effort, maintaining and sustaining fish populations could enhance the ecosystem service of buffering ocean acidification, with global benefits (Jennings and Wilson 2009).

4. WHALE PUMP

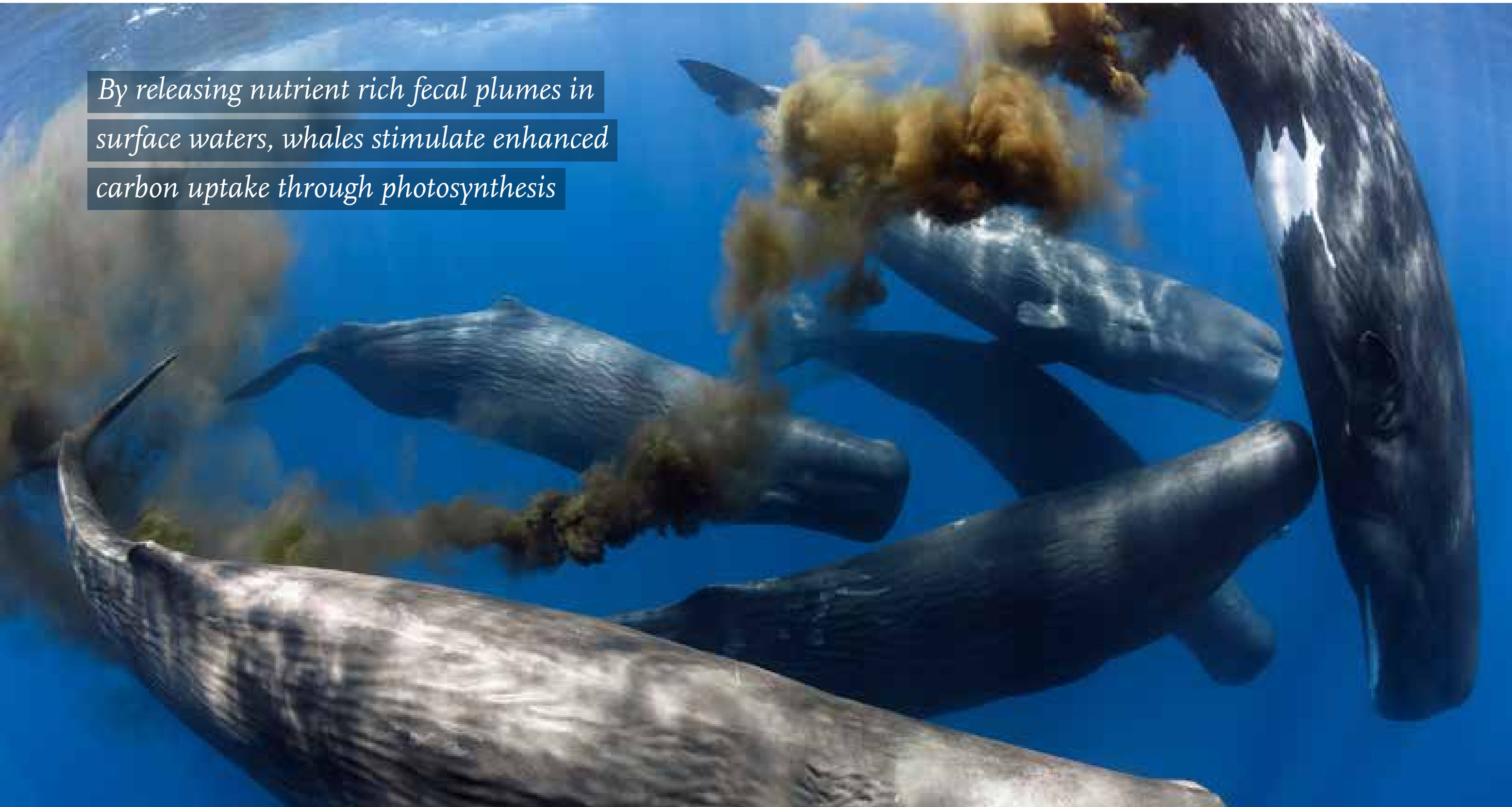
The Whale Pump is a mechanism by which whales transport nutrients both vertically, between depth and surface, and horizontally, across oceans promoting primary production and thereby the fixing of atmospheric carbon (Figure 2, service 4) (Roman and McCarthy 2010, Roman *et al.* 2014).

Migratory baleen whales travel across oceans often bringing nutrients via their urine, placenta, carcasses, and sloughed skin from highly productive feeding grounds to low latitudes with reduced nutrient availability (Roman *et al.* 2014, Roman pers. comms.). For example, blue whales in the Southern Ocean are estimated to transport 88 tons of nitrogen annually to their birthing grounds in lower tropical latitudes (Roman *et al.* 2014). Through the Whale Pump, blue whales not only promote uptake of atmospheric carbon by phytoplankton, but also stimulate fisheries growth in the Southern Ocean by enhancing ecosystem productivity (Lavery *et al*. 2014, Roman *et al*. 2014), thus potentially facilitating additional carbon cycling through other Fish Carbon mechanisms.

Many whale species consume prey at depth and release nutrient rich faecal plumes upon return to the surface (Roman *et al*. 2014). Sperm whale waste is rich in iron, the limiting nutrient in the Southern Oceans, while the nitrogen-rich faecal plumes of baleen whales fertilize the nitrogen-limited surface waters of the North Atlantic (Roman *et al*. 2014, Pearson pers. comms.). This facilitates the transfer of nutrients from deep waters to the surface, stimulating the growth of phytoplankton and consequent uptake of carbon into surface waters (Roman and McCarthy 2010, Roman *et al*. 2014).

In the North Pacific, the humpback whale population is increasing annually at a rate of 7% (Allen and Angliss 2010), with potential to enhance carbon sequestration through increased defecation. The Southern Ocean population of sperm whales is currently estimated to facilitate accumulation of 200,000 tons of carbon annually from the atmosphere into the ocean (Lavery *et al*. 2010), roughly equal to the amount of carbon emitted annually by energy use of over 18,000 US homes' (EPA 2014). Prior to industrial whaling, sperm whale populations were an order of magnitude larger than they are today (Baker and Clapham 2002). It is estimated that if sperm whale populations were at pre-whaling levels, an extra 2 megatons of carbon would be removed every year (Lavery *et al*. 2010).

To further advance this concept a better understanding of the total contribution of the Whale Pump to carbon cycling relative to planktonic and bacterial actions; interactions between the various aspects of the biological pump; and the contribution of vertebrates, other than whales, may be required. For example, sea birds may also act as vectors for nutrient transport throughout the oceans (Wing *et al*. 2014). However, available research implies that maintenance of healthy whale populations is important for nutrient transport and atmospheric carbon uptake in the ocean.



By releasing nutrient rich fecal plumes in surface waters, whales stimulate enhanced carbon uptake through photosynthesis

5. TWILIGHT ZONE CARBON

Mesopelagic fish that live in deep waters undertake a vertical migration at night to feed on zooplankton in the surface waters of the ocean. During the day, to avoid predation, these fish descend back to the ocean's 'twilight zone' at depths of 200 to 1000 meters, transporting substantial quantities of organic carbon away from the surface and ultimately releasing it as faeces, which sink further into the depths (Figure 2, service 5) (Davison *et al*. 2013). Through this mechanism, carbon is effectively transported below the upper thermocline, the depth zone in which most carbon remineralization occurs (Davison *et al*. 2013).

Commercial fisheries do not currently target mesopelagic fish and it has been suggested that these fish undertake net-avoidance behaviour, which reduces their accidental capture in current fishing gears (Irigoien *et al*. 2014). Twilight Zone Carbon may be under-valued in current estimates of oceanic carbon cycling, as recent research suggests that the total biomass of mesopelagic fish may be between 1,000 to 10,000 megatons; ten times higher than previous estimates (Irigoien *et al*. 2014).

Twilight Zone Carbon, possibly the most intact biological mechanism of marine vertebrate oceanic carbon cycling (Irigoien *et al*. 2014), appears to provide a direct two-step route from the ocean surface to the deep sea and sediment, where carbon can be stored for millennia or longer (Lutz *et al*. 2007).

Vertical migration of mesopelagic fish transports carbon away from surface waters to depths of 200-1000m

Carbon is accumulated and stored in the biomass of whales throughout their long lives

6. BIOMASS CARBON

Carbon is stored in the biomass of every living creature on the planet. As marine vertebrates feed and grow, carbon naturally accumulates in their bodies and is stored for the life of the animal (Figure 2, service 6). While marine vertebrates store only a small percentage of total oceanic carbon, the life spans of large and deep sea marine vertebrates are prolonged: bluefin tuna can live for decades, the orange roughy may live for over a century and the bowhead whale for two centuries (Atlantic Bluefin Tuna Status Review Team 2011, Fenton *et al.* 1991, George *et al.* 1999). Thus sequestration in the tissues of large vertebrates is comparable to the centennial timescale of carbon storage associated with terrestrial forests (Sedjo 2001).

Large marine vertebrates require less food to maintain their biomass than small marine vertebrates, and are therefore are more effective at storing carbon (Pershing *et al.* 2010). Additionally, older, larger individuals may have much higher reproductive success than younger, smaller individuals, though this may not always be the case (Palumbi 2004).

While sustainable fishing practices should not overly compromise marine vertebrate populations and their role as carbon sequesters, preferentially harvesting of the largest species both reduces the number of individuals most effective at storing Biomass Carbon, and the number of individuals most effective at reproducing (Pauly *et al.* 1998, Estes *et al.* 2011). Thus, overexploitation may reduce the ocean's potential for carbon storage via Biomass Carbon, due to altered fish size-structure and abundance (Fenberg and Roy 2008, Jennings and Wilson 2009).

A better understanding of the total contribution of Biomass Carbon may be needed to further advance this concept, including the fate and significance of carbon associated with bycatch and with fish consumed by humans. However, the implication of Biomass Carbon for oceanic carbon cycling is that sustainable fishing practices, that support healthy fish and whale populations, secure the capacity for oceanic biomass storage, and thereby the efficacy of Biomass Carbon as a contributor to the oceanic biological carbon pump.

7. DEAD-FALL CARBON

When the Biomass Carbon of marine organisms is not already removed by fishing, or redirected through the oceanic carbon cycle by predation, their carcasses sink to depth and the carbon stored in their biomass may enter deep sea ecosystems (>1500 m) (Figure 2, service 7), where it can be stored on timescales of thousands to millions of years (Lutz *et al*. 2007).

The carcass of a single large marine vertebrate transports organic carbon, naturally accumulated in its body when it falls to the sea floor. Here it represents a bounty of food for deep sea and benthic organisms, and effectively sequesters carbon from atmospheric release at ocean depth (Smith and Baco 2003). Primarily reported for whales (Smith and Baco 2003, Pershing *et al*. 2010, Roman *et al*. 2014), Dead-Fall Carbon has recently been reported for other marine vertebrates such as whale sharks and mobulid rays (Higgs *et al*. 2014).

It has been estimated that if whale populations were at pre-whaling levels, an additional 160,000 tons of carbon would be exported to the deep sea annually through whale dead-falls alone (Pershing *et al*. 2010). This figure is roughly equivalent to the greenhouse gas emissions of 33 thousand cars per year (EPA 2014).

Interactions between Dead-Fall Carbon and the broader carbon cycle are yet to be established and quantified, however the implication for oceanic carbon cycling is that maintenance of healthy populations of large marine vertebrates will enhance levels of carbon transfer to the deep ocean through Dead-Fall Carbon.

Carbon can be transported into deep sea ecosystems through marine vertebrate carcasses that sink to the ocean floor

Through their fast-sinking faeces, marine vertebrates facilitate rapid transport of carbon away from the ocean surface

8. MARINE VETEBRATE MEDIATED CARBON

Marine vertebrates feed on lower trophic levels (e.g. plankton, smaller fish) and repackage that material into rapidly sinking faecal material (Figure 2, service 8) (Saba and Steinberg 2012). Faecal matter of many marine vertebrates contains high amounts of carbon, and sinks at rates exponentially greater than the rate of carbon associated with sinking plankton (Robison and Bailey 1981, Bray *et al*. 1981, Staresinic *et al*. 1983, Saba and Steinberg 2012). Faecal material of mid-water fish was found to have similarly high sink rates with low rates of dissolution (Robison and Bailey 1981), while in one study Peruvian anchovy faeces represented up to 17% of total organic carbon captured in sediment traps (Staresinic *et al*. 1983). The rapid sinking and low dissolution rates associated with these particles indicate that Marine Vertebrate Mediated Carbon efficiently transports carbon to depth (Saba and Steinberg 2012).

Faecal material of marine vertebrates is often not included in models of the biological pump, as current Earth System Models (e.g. Bopp *et al*. 2013) rely on simplified representations of the diverse processes of zooplankton mortality that may, or may not, include fish and sinking material from fish (e.g. Steele and Henderson 1992, Ohman *et al*. 2002). The current key instrument used to understand oceanic carbon cycling, sediment traps, may present a bias toward capturing planktonic contributions and be insufficient to register the contributions of marine vertebrates (Saba and Steinberg 2012, Davison *et al*. 2013). Additionally, sediment traps "are believed to underestimate total carbon export because they undersample large, rare particles and flux episodes [e.g. marine vertebrate faecal material] on short time scales, and because they do not sample active transport" (Davison *et al*. 2013).

Much scientific endeavour remains to be accomplished regarding Marine Vertebrate Mediated Carbon, including quantifying its role in the flux of biological carbon relative to that of plankton and bacteria. However, carbon passed through the marine food web appears to be an important vector in carbon transfer between the ocean surface and the deep sea and sediment.

The implication for oceanic carbon cycling is that maintenance of marine vertebrate populations, from anchovies and cod to whales, sea turtles and sharks, may facilitate rapid carbon transport from the upper waters to the deep ocean and sea floor, where it can be sequestered on millennial time scales or greater (Lutz *et al*. 2007). Many marine vertebrates are already managed or protected to some degree by various agreements, laws and resource management policies, however the potential effects of these measures on carbon sequestration has not been considered.

OUR OCEAN — A BACKDROP

A healthy ocean is vital to our life on Earth. Covering nearly three-quarters of the surface of the planet, the ocean provides a wide range of resources and services that support human life, well-being, societies, cultures and economies. As pressure on the ocean to provide these resources and services increases, its ability to deliver many of them is compromised.

Many human activities that impact ocean health and are directly relevant to marine vertebrates, and potentially to the carbon services they provide. Amongst others, these activities include:

Climate change and ocean acidification – Impacts are estimated to cause potential disruption of 60% of the ocean's present marine biodiversity by 2050, through local or global extinctions and changes in the pattern of species' distributions (Cheung *et al.* 2009). Climate change is driving marine vertebrate migration away from the tropics and toward the poles, with implications for food security in coastal and island states in the tropics (Cheung *et al.* 2013, Jones and Cheung, 2014); the impact of this movement for nutrient cycling are largely unexplored.

Rising levels of atmospheric carbon leads to increased amounts of dissolved carbon in the oceans; while overall still alkaline, the additional carbon lowers oceanic pH levels (Hönisch *et al.* 2012): current rates of this process, termed ocean acidification, are unprecedented in geological history (Hönisch *et al.* 2012). Ocean acidification impacts the formation of calcium carbonate (CaCO3) structures and impacts the larvae and adult stages of many marine vertebrates (Fabry *et al.* 2008) and invertebrates: the impacts on corals and shellfish are expected to present a serious challenge for the sustainability and way of life for coastal and island communities (Wittmann and Pörtner 2013, Mathis *et al.* 2014). Through its effects on phytoplankton, ocean acidification may also impact the formation of clouds and weather patterns globally (Six *et al.* 2013, Arnold *et al.* 2013).

Fishing – An important food source, both by direct consumption as well as through fish meal and oil, marine capture fisheries produced 79.7 million tonnes of almost 1,600 species in 2012 (FAO 2014). While several countries have taken measures to reduce unsustainable practices (FAO 2014), over-fishing and otherwise destructive fishing practices, exemplified by collapsed and severely depleted populations, have affected almost 60% of world fisheries (Pitcher and Cheung 2013). In the past 50 years, severe population declines of up to 90% have been reported globally for tuna, billfish, and sharks (Myers and Worm 2003, Pauly *et al.* 1998), and predator diversity has declined tenfold in all regions of the ocean (Worm *et al.* 2005). Methods such as bottom trawling, which causes extensive damage to open ocean benthic habitats (Chuenpagdee *et al.* 2003), reduces carbon and other nutrient flux to sediments, thus disrupting nutrient cycles, local food chains and reducing biodiversity in trawled areas (Pusceddu *et al.* 2014). Such destructive practices also destroy many ocean ecosystems before they, and their role in biogeochemical cycling, can be studied (Nicholls 2004). Bycatch, which has become an inevitable part of modern fishing, has major impacts on populations of large marine vertebrates such as sea turtles (Spotila *et al.* 2000, Global Ocean Commission 2014). Illegal, unreported, and unregulated (IUU) fishing, which includes the targeted take of large commercially valuable species, such as tuna and sharks, is a globally shared problem (Worm *et al.* 2013).

Marine pollution – Nutrient over enrichment increases susceptibility of marine ecosystems to additional stressors (Breitburg 2002); in 2011 there were over 500 human-related hypoxic areas or deadzones globally, with predictions for occurrences to worsen, become more frequent, intense and longer in duration (Diaz and Rosenberg 2011). Marine debris and plastics cause mortality by entanglement, injestion and suffocation and pose a rapidly growing threat (Barnes *et al.* 2009), impacting over 260 species of marine vertebrates worldwide. Marine debris and plastics are estimated to affect 86% of all sea turtles, 44% of all sea birds, and 43% of all marine mammal species (Laist 1997). Toxic chemical contamination, such as mercury which has tripled in concentration in surface waters since the industrial revolution (Lamborg *et al.* 2014), can impact the health, growth and reproduction of marine vertebrates (Birge *et al.* 1979, Friedmann *et al.* 1996) .

Degradation and loss of ecosystems – Degradation and development of coastal marine ecosystems results in the loss of vital habitat for many marine vertebrates. Mangrove forests and seagrass meadows are known to support juvenile and adult life stages of various marine vertebrates, including many species of commercial and recreational importance (Mumby *et al.* 2004, Unsworth *et al.* 2007). Globally, historical coverage of mangrove forests has been reduced by 35% (Valiela *et al.* 2001), and seagrass meadows by 29% (Waycott *et al.* 2009). Impacts of this loss go beyond fish stocks, as ecosystem services provided by these habitats include carbon cycling, protection of coastal land from storm surges, sediment stabilisation, and maintenance of water quality (Hendriks *et al.* 2008, Laffoley and Grimsditch 2009).

Ocean uses and associated stressors on the marine environment invariably include overarching issues, such as noise and shipping (Popper 2003, Abdulla and Linden 2008), and have the potential to change rapidly with potentially unknown environmental impacts, for example oil and gas exploration in the Arctic (Porta and Bankes 2011), the expansion of fishing and seafloor mining into deeper waters (Norse *et al.* 2012, UNEP-GEAS 2014), and installation of renewable energy infrastructure (e.g. wind farms) in both coastal and offshore environments (Gill 2005). These and other human activities combined exhibit complex cumulative impacts on the ocean and its functions (Boehlert and Gill 2010).

Natural levels of resilience to change, while existent, are not well understood. Recognizing the value of marine vertebrates' role in carbon sequestration may provide incentive for improved management of human activities and resource extraction as a positive action toward mitigating climate change.

POLICY IMPLICATIONS

Fish Carbon provides a direct channel through which governments and the private sector can meet national, regional and global commitments on climate change and sustainability. The recognition and valuation of marine vertebrate carbon services may support policies to improve oceanic carbon function, thereby helping to mitigate climate change, and to improve marine ecosystem management.

There is growing consensus amongst the scientific community that where there is enough evidence to support positive action, the precautionary principle with the best available knowledge should be applied (Cressey 2014). As cutting edge science, the biological carbon cycling interactions, measurements and figures associated with Fish Carbon continue to be refined (Saba and Steinberg 2012, Siegel *et al*. 2014). However, in the interests of climate change mitigation, the practical application of Fish Carbon could be explored through innovative national and local policy, and with further development, internationally. Accounting for Fish Carbon allows a broader consideration of the functional role of higher marine life in the carbon cycle and could provide a strategic opportunity, consistent with many current efforts to manage the marine environment, for management and policy to identify and implement new options for mitigating the climate challenge.

Policies that include Fish Carbon can potentially support and complement existing national and international efforts and commitments on biodiversity, conservation and climate change mitigation. Examples include the following:

Climate challenges

Global cooperation – New directions and opportunities for international agreements and coalitions which govern the climate challenge and the management of ocean areas beyond national jurisdiction.

United Nations Framework Convention on Climate Change – Convention Article 4.1(d) of the United Nations Framework Convention on Climate Change (UNFCCC) states that all parties shall: "Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all GHGs not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems." (UNFCCC 2013).

Nationally Appropriate Mitigation Actions – Developing Country Parties to the UNFCCC are called to take voluntary measures for mitigating GHG emissions in the context of sustainable development, supported and enabled by technology, financing and capacity-building, aimed at achieving reduced emissions (UNFCCC 2013).

Marine management and biodiversity conservation

Convention on Biological Diversity – Each Party to the Convention on Biological Diversity (CBD) has been called upon to develop national strategies for the conservation and sustainable use of biological diversity, including enhancing ecosystem resilience, the contribution of biodiversity to carbon stocks, and climate change mitigation.

Fisheries – The sustainable management and restoration of fish stocks is a general objective for fisheries management globally. Fish Carbon complements this objective and would add a new dimension to policies that seek to maintain sustainable fisheries, for example incorporating Fish Carbon objectives into addressing the global threat of IUU fishing (Worm *et al*. 2013) and reassessing subsidies for high seas commercial fishing, estimated to support up to 25% of their income (Sumaila *et al*. 2010) to include the value of Fish Carbon.

Marine protected areas – Marine protected areas suffer from lack of funding, enforcement and local engagement, and therefore often never reach their true conservation potential (Devillers *et al.* 2014). A baseline estimate for the carbon service value of marine life in the high seas of over $140 billion USD (Rogers *et al.* 2014) is 7 to 28 times greater than the estimated annual cost for a global marine protected area (MPA) network covering 20 to 30% of the world's seas (Balmford *et al.* 2003). Payment of Fish Carbon services could potentially support MPA management and help enable MPAs to meet their full potential, both in terms of conservation and climate change mitigation.

Threatened species – Many of the world's largest marine vertebrates that are central to the carbon cycling mechanisms presented here appear on the International Union for Conservation of Nature (IUCN) red list as endangered or critically endangered species or on Appendices I or II of the Convention on the Conservation of Migratory Species of Wild Animals. These include the largest animal ever known to have existed, the blue whale, as well as other notable species such as bluefin tuna, leatherback sea turtle, and multiple species of grouper (CMS 2012, IUCN 2014).

Although the Fish Carbon question remains to be fully answered, in addition to securing a sustainable future the mechanisms presented here may help provide opportunities to secure long-term and meaningful sources of finance for environmental governance of the oceans. The $140 billion USD baseline estimate for the carbon service value of marine life in the high seas is 560 times greater than the annual spending for marine conservation in the U.S.A. (estimated at $250 million USD) (Spalding pers. comms.). Through exploration of mitigation metrics for the valuation of marine vertebrate carbon services, financial resources may be mobilised to support improved coastal and pelagic management, including to address the challenges, such as climate change, faced by our planet and oceans.

As well as providing options for meeting global commitments on climate change, Fish Carbon also complements existing policies on sustainable marine resource use and protection of biodiversity

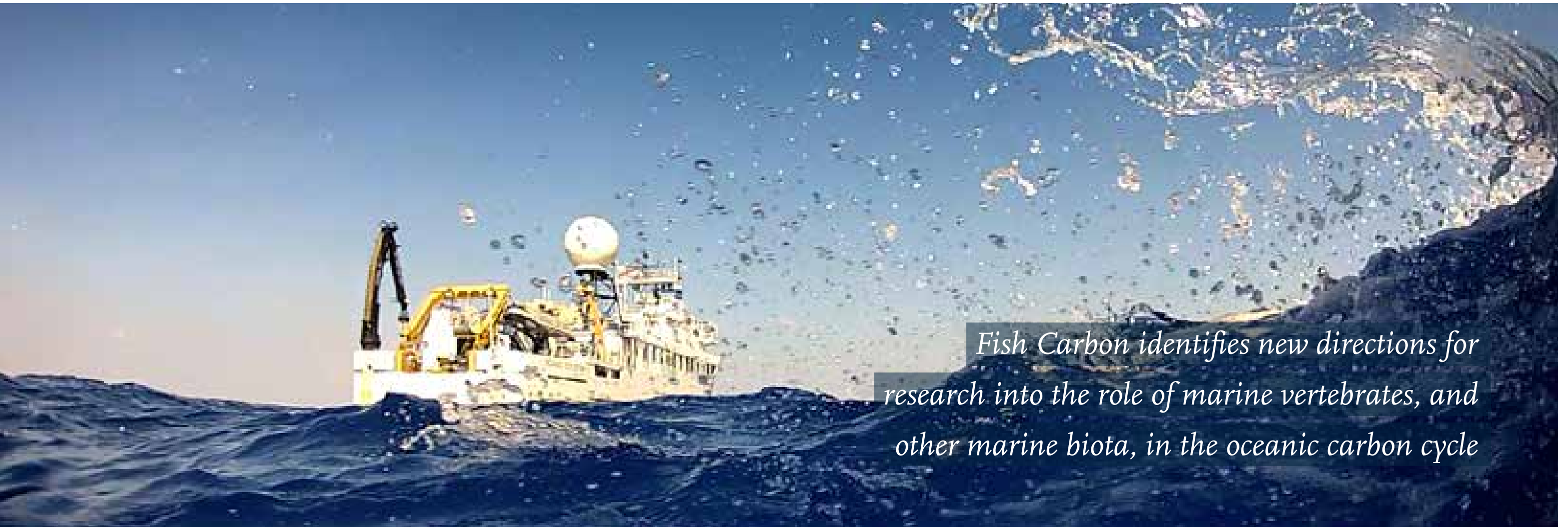
MOVING FORWARD

Improved understanding of the eight mechanisms presented here is required to appreciate the true potential of Fish Carbon's mitigating role in the climate challenge. Nonetheless, the question of Fish Carbon readily poses an innovative opportunity for the world to potentially protect ocean ecosystems from coastal waters to high seas, with the objective of harvesting long term benefits from the ocean's diverse resources and services while simultaneously mitigating climate change.

A better understanding of the total contribution of marine vertebrate carbon services is needed to advance the concept, however the research to date presents a new and exciting direction for global climate change policy and has potentially far reaching implications for the sustainable management of coastal and pelagic ecosystems. Marine vertebrates do not exist in isolation and are wholly dependent on the physical, chemical and biological processes of the ocean (Cheung *et al.* 2009). Many of these processes are yet to be fully understood. The greatest diversity of life on Earth is in the ocean, and less than a quarter of those species have been identified (Ausubel *et al.* 2010). The life history of many identified species is unknown, and age estimates of even some of the most well known species can vary by a century (George *et al.* 1999).

The composition of even the most abundant organisms, such as zooplankton which constitute a group as complex as any rainforest, is speculative (Lilley *et al.* 2011), and new microbial habitats that contribute significantly to nutrient cycling are still being discovered (Marlow *et al.* 2014). Almost all marine vertebrates are dependent on bacteria and invertebrates, including zooplankton, krill and squid, to provide vital access to the bottom of the food chain, and thus to engage in the nutrient cycling mechanisms outlined in this report. Protection and sustainable management of these resources to maintain healthy ecosystems would support the delivery of Fish Carbon services, including mitigation of climate change.

Fish Carbon may open new windows on climate mitigation, such as schools of fish being viewed as the 'swimming animal forests of the ocean', with the possibility of marine vertebrates playing a climate balancing role similar to that of terrestrial forests. Ever-increasing evidence illustrates that "healthy ecosystems maintaining high levels of biodiversity are more



Fish Carbon identifies new directions for research into the role of marine vertebrates, and other marine biota, in the oceanic carbon cycle resilient to external pressure and consequently better able to sustain the delivery of ecosystem services to human society" (TEEB 2008). Safeguarding healthy marine ecosystems will increase the security of Fish Carbon services for climate change mitigation: from now on the management of ocean resources can be seen as being linked to carbon cycle services, and therefore to global climate change.

Considerable progress has been made in recent years in advancing coastal Blue Carbon science and policy, with demonstration projects implemented worldwide. Fish Carbon provides the opportunity to develop the concept of Blue Carbon within and beyond the coasts, into the open oceans. Moving forward, the recognition of marine vertebrate carbon services could encompass a range of actions, including the following key research objectives and opportunities:

Education and outreach

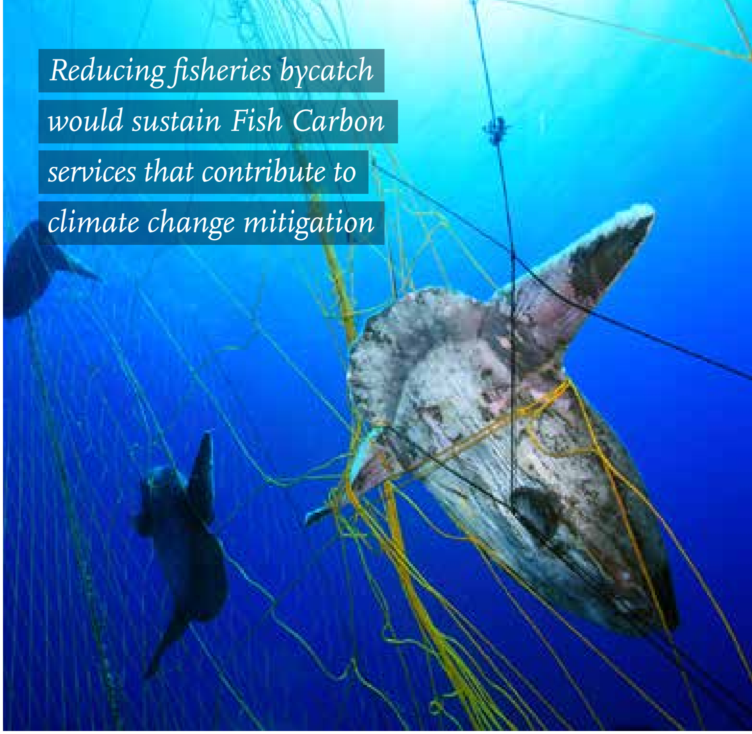
The engagement and education of marine stakeholders, policy makers, and the general public to raise the profile of the loss of ocean ecosystems and marine vertebrates as a contributor to global climate change, and their restoration and protection as a way toward climate change mitigation.

Policy and management

The development of policies and strategic management approaches based on the best available evidence and acting in the best interests of the global community, with particular awareness of vulnerable groups such as small island developing states and coastal communities. Incorporation of Fish Carbon policies into national and international legislation and frameworks through adaptation of existing or development of new arrangements.

Coordinated research

Marine science – Coordinated and targeted field, laboratory and computational research of the mechanisms presented here to improve understanding of marine vertebrates' contribution to the carbon cycle, their links to other marine biota and physical processes, particularly the removal of carbon from the atmosphere, the building of scientific consensus, and the generation of global models to inform effective policy and management approaches.



Reducing fisheries bycatch would sustain Fish Carbon services that contribute to climate change mitigation

Socioeconomic – The exploration of potential benefits and impacts resulting from the application of Fish Carbon policies to marine stakeholders, including societies, economies, fisheries, coastal and island food security and the global population, including in terms of global climate security and marine services.

Climate change is a global challenge that cannot be addressed through discrete or disconnected actions. Human society as a whole must act to mitigate and adapt to its challenges (Myers 2008). The world is looking to its leaders to make decisions on whether and how to act in the best interests of the planet and human society. World leaders require a sound understanding of the options available for mitigation and adaptation if they are to act wisely and implement policies that effectively address climate change and allow continued sustainable development (Myers 2008). While not a 'silver bullet', and other actions must be taken simultaneously, particularly the reduction of GHG emissions, the broad global relevance of Fish Carbon presents an excellent potential collaborative opportunity with which to further explore the concepts outlined, combine marine resource and ecosystem-based management with climate policy, and build consensus and form coalitions for meaningful, effective and immediate climate change action.

Through Fish Carbon, the management of marine ecosystems is intrinsically linked to the global climate challenge

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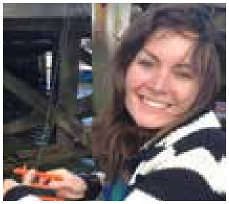

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