# Fish poo and the climate challenge

Image: Steven Lutz.

**Angela Martin** looks at the science behind the headlines

Over the past few years, stories about how whales, sharks, fish and other marine vertebrates are important for tackling climate change have been appearing in mainstream news. In 2014, the UK's ITV News covered how 'Fish capture and store 1 million tonnes of carbon', while *The Guardian* newspaper in the UK ran a story titled 'Why whale poo matters'. Are these bold claims a case of the media not letting facts get in the way of a good story, or is there a real fire beneath the smoke?

Ultimately, the causes of climate change need to be directly addressed, including extraction and use of fossil fuels, emissions driven by unsustainable patterns of consumption, and inefficient agricultural practices. As part of a multi-dimensional solution, under article 5 of the recent Paris Agreement, nations have additionally committed to protect and enhance natural carbon sinks. The ocean is the world's largest active carbon sink, and is estimated to have removed 50% of anthropogenic emissions of $CO_2$ from the atmosphere (Sabine *et al*., 2004). The ocean is known to capture atmospheric carbon through physical processes (diffusion of $CO_2$ as a gas) and biologically, through photosynthesis. When carbon reaches deep ocean waters and sediments, it can be stored for centuries. Thus, understanding the processes that contribute to carbon cycling by the ocean is a key factor to improving our understanding of climate change and managing its impacts.

Since the 1970s, sediment traps have been the primary apparatus used to measure movement of carbon from surface waters to the deep. These traps sit on the sea bed collecting particles that drift to the bottom of the ocean. Bacteria and tiny marine organisms called plankton, easily caught in sediment traps, are the most studied vectors of transport for biological ocean carbon. However, sediment traps do not effectively measure carbon movement by marine vertebrates. This is one potential reason that marine vertebrates are not included in most models of carbon cycling. Interest in the ocean's role in atmospheric chemistry and technological advancements has improved the data quality and range of observations at sea. Over the past ten years, many scientific publications have reported direct connections between large animals and nutrient cycling, and particularly carbon cycling (Roman *et al*., 2014; Wilmers *et al*., 2012).

Fish carbon, an over-simplified but accessible term, is used to describe the carbon interactions of all marine vertebrates: turtles; sea birds; mammals such as whales and dolphins, and fish such as sharks, tuna and sardines. Fish carbon research focuses on increasing understanding of how marine vertebrate activity and natural life processes provide pathways, pumps and trophic cascades that:

- Enhance uptake and long-term storage of atmospheric carbon into the oceans via photosynthesis of dissolved $CO_2$ by marine plants (plankton and seagrasses)
- Facilitate transport of biological carbon from ocean surface to deep water and sediment (via biomass, carcasses and excretion)
- Provide a pH buffer against ocean acidification (through metabolic activity of bony fish)

The current scientific evidence suggests that marine vertebrates play various undervalued roles in carbon cycling. Very few studies have quantified the impact of marine vertebrates on carbon capture and storage per year. The figures quoted in this article are based on fragmented data, and therefore provide an indication only of the potential significance. Below is a short summary of the published information thus far.

There are eight fish carbon mechanisms described in the scientific literature (see Diagram 1 below), these are:

**1. Trophic Cascade Carbon**

Several recent studies have found that natural predation of grazing and burrowing animals in seagrass meadows and saltmarshes helps to maintain the optimal carbon function of these ecosystems. A publication by Heithaus *et al.* (2014) found that healthy seagrass ecosystems in Australia were maintained by shark populations, which restricted grazing activity by sea turtles. In areas where shark populations had declined, the study found that the structure of seagrass meadows was altered due to sea turtle grazing. In these instances, the carbon capture and storage function of the ecosystem was degraded. Heithaus *et al.* (2014) also found that in areas with few turtles, carbon function of seagrass meadows was also diminished, as the meadows were dominated by algae. A follow up study by Atwood *et al.* (2015) found that, in all coastal vegetative ecosystems that capture and store atmospheric carbon (seagrass, saltmarsh and mangroves), predation is critical to maintenance and increasing reserves of carbon. This study found that recreational overfishing of predatory fish and crabs from the Cape Cod marshes contributed to the reduced carbon storage capacity of the ecosystem by 17,000 tonnes of carbon annually.

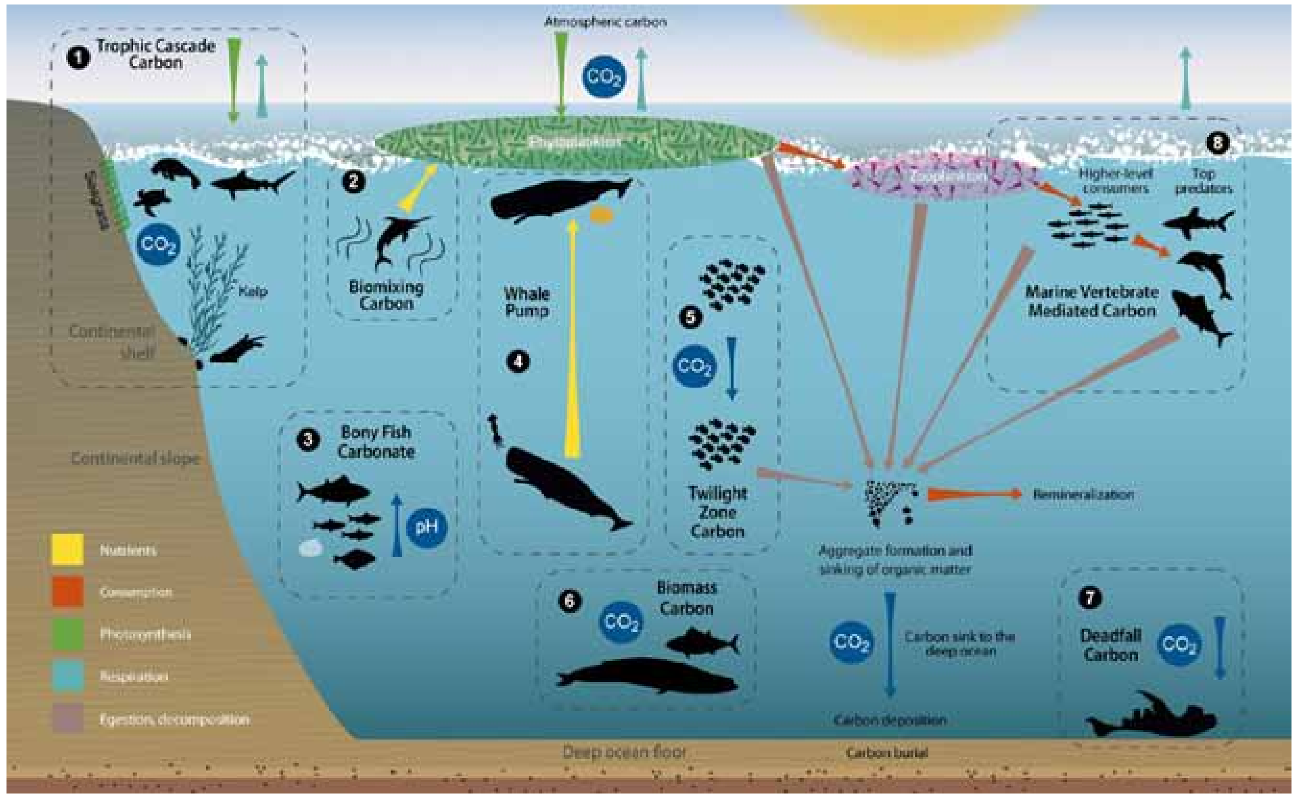
**2. Biomixing Carbon**

Movement of animals through the water column mixes water and moves nutrients. In the open ocean, marine vertebrates can bring nutrients from the deep to otherwise nutrient-limited surface waters, enhancing primary production by phytoplankton, and thus uptake of atmospheric $CO_2$. Biomixing of nutrients through movement has been reported for all sizes of marine animals, and a study by Dewar *et al.* (2006) estimated that biomixing by marine vertebrates contributed one-third of the total ocean mixing, comparable to the effect of tides or winds. Building on this, Lavery *et al.* (2012) found that the population of 80 sperm whales in Hawaii could enhance carbon capture by 60,000 tonnes annually through biomixing.

**3. Bony Fish Carbonate**

A study by Wilson *et al.* (2011) reported that bony fish (teleosts) constantly consume seawater, the calcium ions from which react with their intestinal gut fluid to form high magnesium calcite, a form of calcium carbonate with magnesium carbonate in the crystals. These authors found that this waste product is produced and secreted at high rates throughout the life of bony fish, and even in the absence of feeding. Dissolution of calcium carbonate,

Diagram 1: Marine vertebrate carbon services: eight carbon pathways, pumps and trophic cascades (Lutz and Martin (2014)).



which is alkaline, can act as a pH buffer. The magnesium content of these secretions, combined with shallow depth and warm water, increases the likelihood that it will dissolve. Through the natural process of consuming seawater, bony fish produce a waste product that can provide a natural pH buffer against ocean acidification.

**4. Whale Pump**

Movement of nutrients by whales, known as the whale pump, can occur both vertically, between depth and

Whales accumulate and store carbon in their biomass, and move nutrients across oceans, stimulating photosynthesis. At the end of their long lives, the carbon stored in whales' bodies may enter deep-sea food chains and sediments, where it can be stored on millennial timescales. Image: Peter G. Allinson.

surface, and horizontally, across oceans. In areas where nutrients are limited, the whale pump provides a rich source of nutrients for photosynthesis by phytoplankton, and therefore increases uptake of atmospheric $CO_2$ into oceans (Roman *et al.*, 2014). The article in *The Guardian* 'Why whale poo matters' is based on this mechanism. Vertical movement of nutrients occurs when deep-diving whales feed at depth, and excrete nutrient rich, faecal plumes upon return to surface waters. Horizontal movement of nutrients, also known as the great whale conveyor belt, occurs when whales migrate. Baleen whales move from rich feeding grounds to breeding grounds with reduced nutrient availability, where they release nutrients through urine, dead skin cells and placenta. 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). This enables photosynthesis and carbon capture by phytoplankton.

**5. Twilight Zone Carbon**

Deep water (twilight zone) fish feed on organisms in the upper ocean and transport consumed organic carbon to deeper waters, where it is stored in biomass or excreted. Because the release of this carbon is at depth, the carbon is less likely to be remineralized, and thus can be stored in the oceans and out of the atmosphere for centuries (Davison *et al.*, 2013). The amount and value of carbon sequestration by twilight zone fish off the UK–Irish continental slope is estimated to be over one million tonnes of carbon per year (Trueman *et al.*, 2014); the basis of the ITV News item mentioned earlier. In terms of equivalent carbon finance, this represents between £6 and £10.5 million per year (Trueman *et al.*, 2014).

**6. Biomass Carbon**

As with all living creatures, marine vertebrates store carbon in their biomass. However, as marine vertebrates include the largest animals, and the longest-lived, such as whales, the carbon in these animals is stored out of the atmosphere on timescales comparable to some trees (Pershing *et al.*, 2010).

**7. Deadfall Carbon**

When the carcasses of marine vertebrates sink, the biomass carbon is exported to the ocean floor, entering benthic food webs and sometimes sediments. Pershing *et al.* (2010) estimated that the combined global populations of eight species of whales sequestered 29,000 tonnes of carbon per year through the deadfall carbon pathway. This study also estimated that the pre-whaling populations of these same eight species would have contributed closer to 200,000 tonnes of carbon per year.

**8. Marine Vertebrate Mediated Carbon**

Through food webs, marine vertebrates consume carbon. Where this carbon is not incorporated into their biomass, it can be transferred to deep waters via faecal material. Carbon particles associated with fish waste are orders of magnitude larger than those associated

The roundnose grenadier *Coryphaenoides rupestris*. Deep sea fish contribute to carbon storage: research in 2014 estimated that deep sea fish off the UK-Irish continental shelf sequester over 1 million tonnes of $CO_2$ every year. Image: MAR-ECO/Odd Aksel Bergstad.





with plankton, and in the few species that have been studied these rapidly sink to depth (Saba and Steinberg, 2012). Fish excrement provides an efficient mechanism to export carbon from surface waters to sediments, where it may be sequestered on geological timescales.

So, while the fire that fuels the sensational media stories seems to be well alight, it is still in its infancy. Each of the studies quoted has described only one or two of a potential eight mechanisms of carbon movement within the ocean water column. Most of the studies were focused on a single population or species. Further knowledge gaps to be considered include release of $CO_2$ by marine vertebrates through respiration, and the fate of biological carbon that reaches the sea floor. Based on the current fragmented data, it is impossible to estimate the total significance of fish carbon, but this figure is absolutely worth knowing. Ocean conservation is one route to meet national commitments to article 5 of the Paris Agreement, with real potential to improve atmospheric carbon capture. Restoration of marine vertebrate populations and ocean ecosystems would also have additional benefits, including supporting biodiversity conservation and sustainability targets. Protecting marine ecosystems and organisms to enhance their contribution to carbon capture and storage might just be a cost-effective, cross-cutting and high impact component of broader climate change mitigation and adaptation plans.

Angela Martin MSc. Mem.MBA, Blue Climate Solutions, A Project of The Ocean Foundation, Essex, UK.

**Blue Climate Solutions** is dedicated to promoting conservation of the world's oceans, its ecosystems and biodiversity, as a proactive and viable action to reduce the impact of climate change. Our objective is to protect and enhance the natural carbon sinks provided by coastal and ocean ecosystems and organisms. A particular focus of BCS is improving understanding of the role of marine vertebrates in capture of atmospheric carbon and long-term carbon storage in the ocean, a concept we have termed Fish Carbon. www.bluecsolutions.org

**Further reading**

Lutz S.J. and Martin A.H. 2014. Fish Carbon: Marine Vertebrate Carbon Services. GRID-Arendal, Arendal, Norway. ISBN: 978-82-7701-146-2

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Trueman C.N., Johnston G., O'Hea B., MacKenzie K.M. 2014. Trophic interactions of fish communities at midwater depths enhance long-term carbon storage and benthic production on continental slopes. *Proc. R. Soc. B* 281:20140669