Whale Fall: an oasis of unique marine life on the seabed

Mum: what happens to whales when they die?

("Whale's Tail", 2018)

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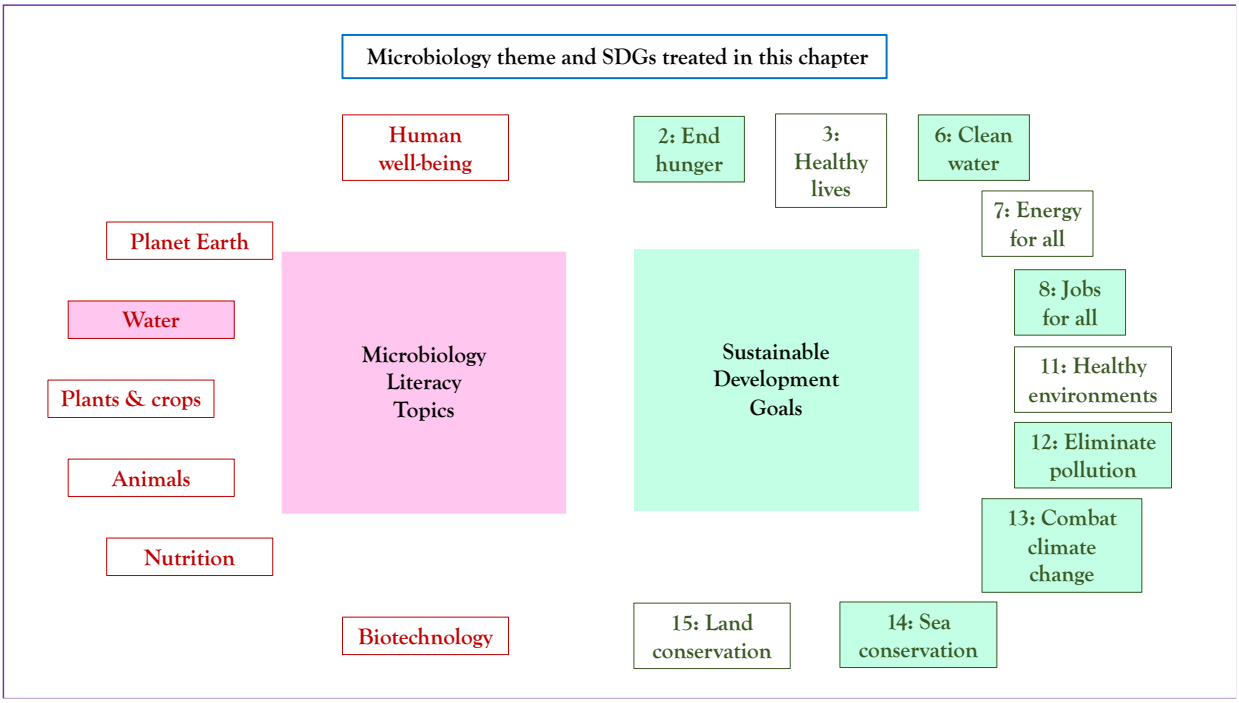
Whale Fall

Storyline

Whales are the largest animal on this blue planet and some, like the blue whale, are even larger than the largest dinosaurs were. After decades of swimming in the vast ocean, they will eventually die and sink to the sea bottom or abyssal plain. Their bodies become the food of other life forms living on the ocean floor, many of which are microbes. The heterotrophic microbes degrade the organic matter from the dead whale and convert it to carbon dioxide, ammonia, hydrogen sulfide and so on, which can on the other hand sustain the growth of chemoautotrophic microbes. This is the balance of nature, but different kinds of pollution and whale hunting kill thousands of whales every year, which may ultimately cause this animal to become extinct. Thus, protection of our environment and implementing effective whale conservation measures are important Sustainable Development Goals.

The Microbiology and Societal Context

The microbiology: intestinal microbes; heterotrophic and autotrophic microbes; cold seeps and hydrothermal vent ecosystems; polluted water treatment; ecosystem balancing. *And, peripherally for completeness of the storyline*: sea bottom microbiome; active sludge wastewater treatment; marine eutrophication and acidification. *Sustainability issues:* health; food and energy; economy and employment; environmental pollution; global warming.



Whale Fall: the Microbiology

1. ***Whales: the largest animal in the world.*** Whales are mammals that live in the ocean. Some whales are very large, with the largest body length up to 30 meters. The shape of a whale is like that of a fish, but the whale's ancestor lived on the ground, like hippos. After millions of years of evolution, their ancestor completely adapted to the marine environment. The arms and legs of these ancestors evolved into fins on their backs and horizontal fins on their tails, which are now the main organs of propulsion. There is a thick layer of fat under the skin, which can keep them warm and reduce the body's specific gravity. Whales use lungs to breathe: they can inhale air on the surface of the water, then dive into the deep ocean for 10-45 minutes. Some whales are hunters, hunting for small animals, molluscs – like snail – and fish, but many large whales consume zooplankton – small floating single cell animals – or microbes as their food.

2. ***The microbes within.*** Microbes grow on and cover the external and internal surfaces of the whale – the whale microbiome, or its second skin. The microbes in its intestinal tract, the enteric microorganisms, help it to digest food by breaking down the zooplankton or fish meat into small molecules. Enteric microbes also provide a variety of nutrients that are essential components of the whale diet. Interestingly, one study showed that the intestinal microbes of baleen whales are similar to those of terrestrial herbivores – plant-eating land animals. This supports the idea that both diet and evolutionary history help shape the intestinal microbe composition of mammals.

Although diet is the main factor determining the composition of intestinal microbes in mammals, the overall composition in some animals is similar to that of their close relatives, even though their diets may be completely different. For example, microbes within giant pandas eating bamboo are similar to their close relatives bears. The baleen whale is a kind of marine carnivore, which evolved from terrestrial herbivorous ancestors similar to cattle and hippos. Researchers analyzed microbial genes in fecal samples from 12 baleen whales from three different species. This information was then compared with similar information obtained from other marine or terrestrial mammals with different diets. The results showed that the overall microbial composition and functional range of baleen whales were similar to those of their terrestrial herbivorous relatives. However, specific metabolic pathways of the baleen whale intestinal microbiota are more similar to those of terrestrial carnivores. This study helps to clarify the complex interactions between diet and evolution that determine the composition of intestinal microbes.

3. ***The four stages of whale body recycling.*** When whales come to the end of their lives, they die and fall onto the seafloor. In general, the floor of the deep ocean where whales live has little food that can support life. Because of its great size, and hence the enormous quantity of food it represents, when a whale falls to the seabed, it creates an oasis of life in an otherwise almost endless desert, an oasis where a new ecosystem is generated. How can a new ecosystem build up upon whale's body? What happens? The new ecosystem experiences four stages.

a. *The mobile scavenger phase*. The first thing that happens is that different kinds of small animals such as blind eels, sharks, and some crustaceans feed on the soft tissue of the whale carcass. Whale carcasses provide food for many forms of marine life and, depending on the size of the whale, this process can last for at least four to 24 months during which 90% of the carcass will be eaten.

b. *Enrichment opportunist phase*. Then, some invertebrates, especially polychaetes – like worms –, crustaceans and mussels, *etc.*, plus heterotrophic microbes that degrade organic matter, colonize the remains of the whale carcass, using it as a habitat and eating the remains.

c. *Sulphophilic phase*. During this period, a large number of anaerobic microbes enter

the whale bone and other tissues, decompose the lipids, using sulfate dissolved in seawater as an oxidant and producing hydrogen sulfide. Chemoautotrophic bacteria, such as sulfide-oxidizing bacteria, then colonize the skeleton, using the hydrogen sulfide as a source of energy and oxidizing it with dissolved oxygen in water to obtain energy. These microbes can be either free-living or symbionts, living in the tissues of bivalves and worms, providing their hosts with energy supplements.

d. *Reef phase.* When the organic matter in the remnant whale colony is exhausted, the mineral remains of whale bone will be used as reef rock and become the habitat of other organisms.

Thus, a whale fall provides a complex habitat for many benthic organisms – organisms living on the sea floor – for periods of up to 4-5 years, depending on the size of the whale, so it can be regarded as a transient marine ecosystem! The relationship between whale carbon and oxygen flux is illustrated in Fig.1.

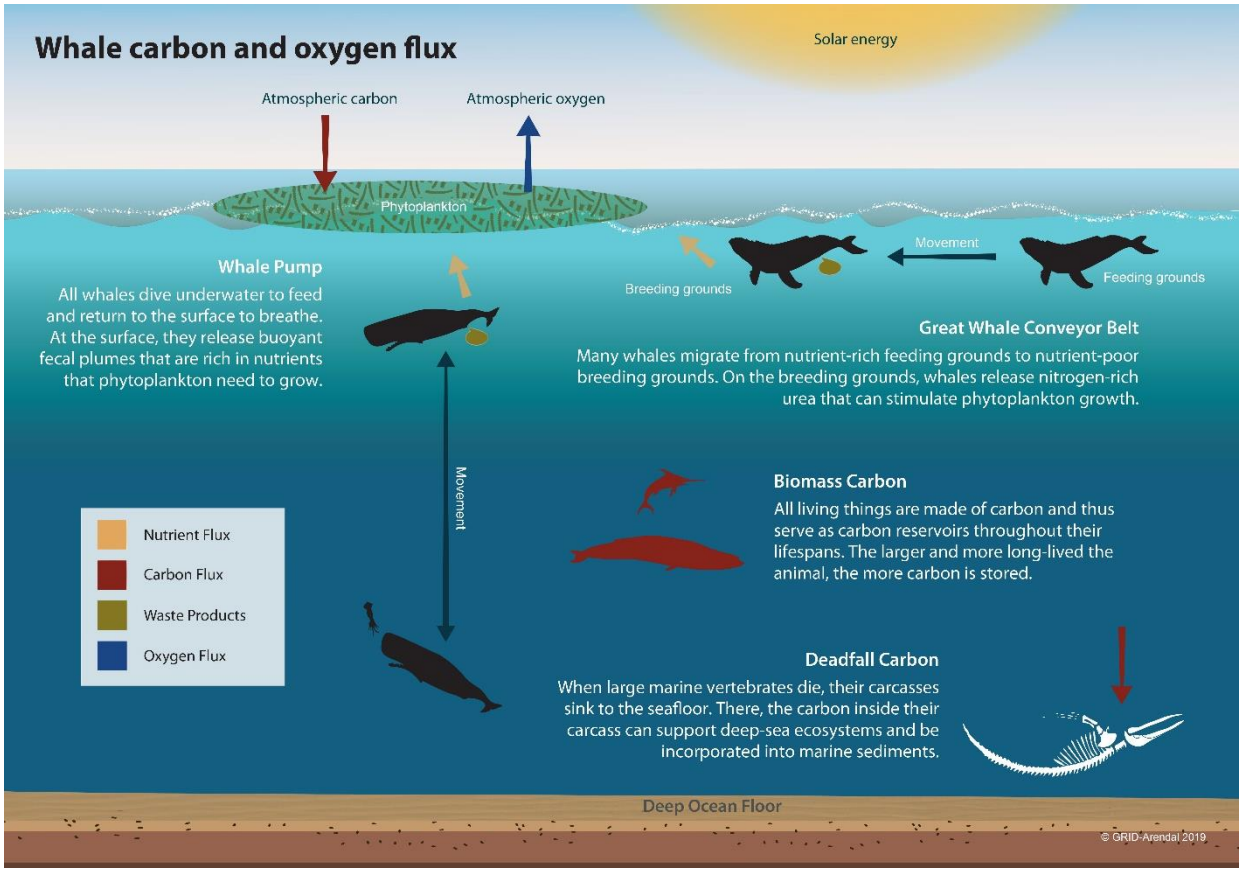


Fig. 1. Whale carbon and oxygen flux (GRID-Arendal, 2019)

4. Other ecosystems on the sea floor. After the whale dies, we now know that an extraordinary whale fall ecosystem will be formed on the bottom of the sea, and will establish an "oasis" of marine life. Deep in the barren ocean, whale fall supports a large number of organisms, including a few invertebrates that coexist with them. In the deep sea of the North Pacific, there are at least 40 species, 12,000 organisms, which depend on the whale's dead bodies, some of which are endemic to the whales. At the same time, whale fall also promotes the transportation of organic matter from the surface of the ocean to the bottom of the ocean, and plays a role in the marine carbon sink. Yet, in addition to the whale fall, are there other life "oases" on the sea floor? Yes, hydrothermal vents and cold seeps also can support large amounts of microbes. We also can compare these "oases" with whale falls.

Hydrothermal vents are normally the result of volcanic activities between two tectonic plates. The temperature of emergent fluids can be more than 400 °C, but surrounding water is cooler. Diverse microbes live around the vents, as do animals like tube worms and bivalves. The primary energy for these thermophilic – heat-loving – microbes comes from the chemical energy provided by the rising fluid from the Earth's mantle and the interaction of rock and sea water. These chemoautotrophic microbes are the primary producers – the source of all food – in hydrothermal ecosystems. As the base of the food chain, microbes have two relationships with other animals who are living at hydrothermal vents: (i) they are used directly as food, or (ii) they are symbionts of the animals. These thermophilic microorganisms not only depend on submarine hydrothermal activities, but also play an important role in shaping hydrothermal environments. The hydrothermal vents are also considered to be a window to study the deep biosphere and of great significance for understanding the origin of life.

The cold seep is usually considered as another "life oasis" in the dark seafloor. This is another case of a continual spilling out of materials from under the sea floor. The fluid emerging from a cold seep contains carbon dioxide, hydrogen sulfide and hydrocarbons (methane or higher molecular weight hydrocarbon gases). Since the temperature is close to that of the surrounding sea water, it is called cold seep, as opposed to the hydrothermal vents. Cold seeps also create food chains with chemoautotrophic microbes as primary producers, which are the basis of an ecosystem with a unique community structure, that forms a "desert oasis" on the deep seabed, similar to those at hydrothermal vents. Reliant on this base of primary producers are tube worms, clams, mussels, polychaetes, then primary consumers, such as starfish, sea urchins and sea shrimp, and then secondary consumers such as fish, crab and cold-water coral. Finally, they are decomposed by nematodes and returned to nature, forming a complete set of cold seep ecosystem. At present, more than 200 species of cold seep organisms have been discovered, including sponges, coelenterates, molluscs, arthropods, brachiopods, echinoderms, bryozoans, foraminifera and vertebrates.

5. Human activity causes water pollution, resulting in eutrophication and acidification, leading to death of ocean animals and microbes. Marine pollution usually refers to human activities that have changed the original state of the ocean and poisoned the marine ecosystem to some extent. The pollution caused by harmful chemicals entering the marine environment causes eutrophication and acidification of ocean water and harm marine life, including whales. Owing to the ocean's vast area and huge water storage capacity, the ocean has long been the most stable ecosystem on Earth. However, in recent decades, with the fast growth of industry, marine pollution has become increasingly serious, particularly affecting coastal regions, and is getting worse. Marine pollution is difficult to influence since it results from many sources, and many pollutants are persistent and diffuse and are carried by currents over wide ranges. Seawater muddiness caused by marine pollution reduces light penetration into the water column and thereby seriously reduces photosynthesis by marine phytoplankton, and hence productivity of the sea area, and is also harmful to fish and whales. Toxic substances such as heavy metals and toxic organic compounds accumulate in the sea water and poison marine animals and other animals that feed on them, resulting in bioaccumulation up the food chain. Oil pollution creates a large oil film on the surface of the ocean, preventing the oxygen in the air from dissolving into the sea water. At the same time, the decomposition of oil also consumes dissolved oxygen in the water, resulting in depletion of oxygen in the sea, creating so-called oxygen minimum zones that are harmful for marine organisms. Red tides – blooms of (sometimes toxic) red-pigmented dinoflagellates resulting from natural increases in nutrients or eutrophication caused by fertilizer run-off from coastal farms – also create anoxic zones, leading to the death of marine organisms, as do toxic blooms. Marine pollution also causes acidification, which results in the death of coral reefs, which in turn impacts coastal tourism resources. Marine pollution therefore attracts more and more attention of the international

community and is the justification of a key Sustainability Development Goal.

Relevance for Sustainable Development Goals and Grand Challenges

The microbial dimension of whale fall relates to several SDGs (*microbial aspects in italics*), including

- **Goal 3. Ensure healthy lives and promote well-being for all at all ages** (i*mprove health, reduce preventable disease and premature deaths).* Although whale fall itself happens in the deep sea and does not influence human health directly, it feeds different types of animals and microorganisms which contribute to the marine biodiversity. Biodiversity is very important for healthy marine ecosystems, because they provide so many things that promote our well-being: seafood for both human beings and animals, raw materials for medicines from animals and microorganisms, such as arabinosides extract used in the treatment of herpes infections, and even construction materials from coral rock and sand.

- **Goal 6. Ensure availability and sustainable management of water and sanitation for all** (*assure safe drinking water, improve water quality, reduce pollution, protect water-related ecosystems, improve water and sanitation management).* Sea water is very salty (see topic Water activity by John Hallsworth and Terry McGenity for a more detailed treatment of this subject); the amount of salt can sometimes reach more than one thousand grams per cubic meter. So people cannot drink sea water as our body cannot get rid of that much salt easily. Humans get rid of excess salt by the kidneys producing urine, but we need freshwater to dilute the salt for the kidneys to work properly. Nevertheless, sea water is still one of our sources of drinking water after processing to remove its salt. Some studies suggest that deep sea water is fairly nutritional with many beneficial minerals. So protecting the sea water from pollution is important.

- **Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all** (p*romote economic growth, productivity and innovation, enterprise and employment creation).* When the whale is alive, the fishermen in some countries hunt them and sell their meat. Meanwhile, others organize whale watching events. Moreover, the whale fall ecosystems contain new biodiversity and there is currently much excitement and activity in the exploration of marine biodiversity for new drugs, materials, and other products for biotechnological applications. These are all activities creating job opportunities. But we have to be aware that these may not all be sustainable: if whales are killed and their meat is sold, neither the whale fall, nor the sea bottom recycling of dead whale bodies can happen anymore.

- **Goal 12. Ensure sustainable consumption and production patterns** (*achieve sustainable production and use/consumption practices, reduce waste production/pollutant release into the environment, attain zero waste lifecycles, inform people about sustainable development practices).* As mentioned above, the whale's corpse is used as much as possible and continues to contribute in the seabed. Firstly, it feeds many marine organisms. Second, it provides shelter to benthic organisms. Last but not least, it promotes the transportation of organic matter from the upper layer of the ocean to the middle and lower layer of the ocean. From life to death, whales demonstrate how they do good in their entire lifecycle. This is consistent with sustainable marine development practice. However, one thing that people should pay attention to is that the number of whales is decreasing and whale falls discovered by humans are very rare. We should protect the marine environment and provide them a good living environment.

- **Goal 13. Take urgent action to combat climate change and its impacts** *(reduce greenhouse gas emissions, mitigate consequences of global warming, develop early warning systems for global warming consequences, improve education about greenhouse gas production and global warming)*. When whale is alive, it excretes iron and nitrogen necessary for phytoplankton to grow, which can fix a large amount of CO_2. When phytoplankton die, the majority of carbon gets recycled at the ocean's surface. However, some of the dead phytoplankton sinks and transfers captured carbon to the bottom of the sea. When a whale dies and sinks to the bottom of the sea, it also transfers captured carbon to the bottom of the sea: on average of 33 tons of carbon dioxide! The absorption of CO_2 that we humans create when we burn fossil fuels by ocean animals is an important global warming mitigation effect that we must protect.

- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development** *(reduce pollution of marine systems by toxic chemicals/agricultural nutrients/wastes like plastics, develop mitigation measures for acidification, enhance sustainable use of oceans and their resources)*. The whale is always huge. So, after it dies, it serves as food for a lot of deep sea organisms, including fish and invertebrates, but also microorganisms. However, whale also devours plastics or other wastes people throw into the sea. When these whales die, the wastes in their bodies may not be degradable. Moreover, other animals may also eat these plastics, get poisoned, and transfer the pollutants up the food chain, thereby polluting ocean life in general. The deep sea resources are slow-growing and the marine ecosystem is formed very slowly. Hence, once polluted, the marine environment needs a lot of time to recover. To conserve the ocean and our planet, we human beings must avoid excessive fishing and careless sailing, and recycle wastes to keep our ocean the ideal home for marine life and enhance the sustainability of Earth.

In conclusion, a whale is valuable not only to the ocean environment, but also beneficial to to the fishing industry, travel industry and carbon capture, etc. (Fig. 2).

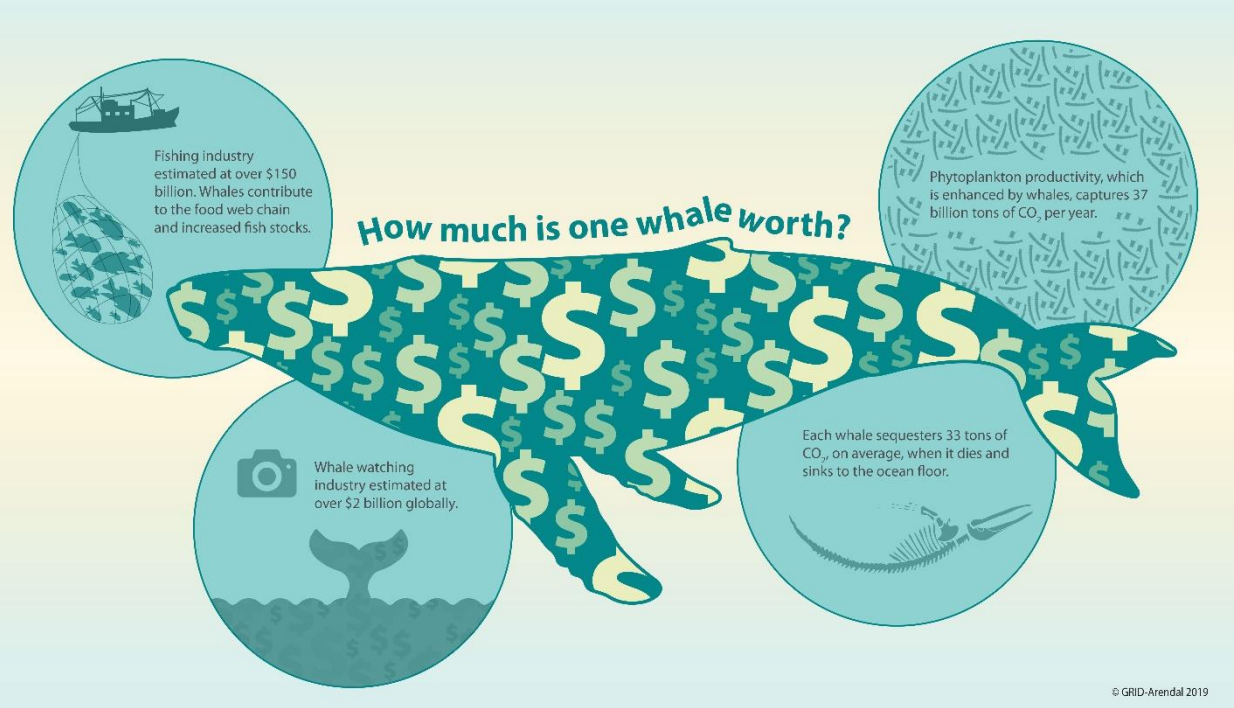


Fig. 2. How much is one whale worth (GRID-Arendal, 2019)

Potential Implications for Decisions

1. ***Individual***
   - **a.** Household waste separation in every family may make a difference to whale's living environment
   - **b.** Weighing up the pros and cons of attending whale watching event

2. ***Co*mmunity policies**
   - ***a.*** Local environmental consequences (find strategies to avoid explosion of dead whale washed ashore as it may pollute public spaces and do harm to human health)
   - ***b.*** *Non-microbial parameters: provide support to local fishing business*

3. ***National policies***
   - **a.** Environmental pollution
   - **b.** Greenhouse gas production and global warming,
   - ***c.*** *Non-microbial parameters: policies relating to fisheries*

Pupil Participation

1. ***Class discussion of the issues associated with whale fall***

2. ***Pupil stakeholder awareness***

a. Whale fall has many positive consequences for the SDGs. Which of these are most important to you personally/as a class?

b. If the whale body is stranded on the shore, it can be very dangerous as it cannot be consumed by the marine ecosystem without human involvement. What would you do if see a whale stranding?

3. ***Exercises (could be made at any level, but these are probably secondary education level)***

a. Some countries like Iceland and Japan are still hunting whale to sell their useful parts such as meat and blubber, although these activities are becoming fewer and fewer. Discuss what impact it has on whales?

b. Can you think of anything that might be done to reduce the chance of whale stranding? Fishing? Imagine what may happen to the decomposition of whale body on the land and compare it to whale fall in the sea.

c. Looking at the SDGs, it is sometimes difficult to make balance between sustainable economic growth and ocean conservation. Create a sustainable activity that can reach win-win outcome to protect abyssal marine ecosystem.

The Evidence Base, Further Reading and Teaching Aids

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Glossary

ammonia: a pungent colorless gaseous alkaline compound of nitrogen and hydrogen;
anoxic: greatly deficient in oxygen or without oxygen;
benthic organisms: organisms that live on or in the bottom of a body of water;
biota: the flora and fauna of a region;
blubber: the fat of whales and other large marine mammals;
chemoautotrophic: requiring only carbon dioxide or carbonates as a source of carbon and a simple inorganic nitrogen compound for metabolic synthesis of organic molecules (such as glucose) and oxidizing inorganic compounds as a source of energy;
endemic: restricted or peculiar to a locality or region, here refers to microbes from whales;
heterotrophic: requiring organic compounds of nitrogen and carbon (such as that obtained from decomposed plant or animal matters) for metabolism and biosynthesis;
hydrothermal: a hot spring, on the floor of the ocean, mostly along the central axes of the mid-ocean ridges, where heated fluids emerge from fissures in the Earth's crust;
polychaete: any of a class (Polychaeta) of chiefly marine annelid worms (such as clam worms) usually with paired segmental appendages, separate sexes, and a free-swimming trochophore larva;
phytoplankton: microscopic, single-celled photosynthetic organisms that live suspended in water;
thermophilic: of, relating to, or being an organism living at a high temperature;
sludge: a muddy or slushy mass, deposit, or sediment;
strand: run aground;

zooplankton: free-living small protozoa and small crustaceans in fresh or marine water body;