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**Under the Sea:   
What’s happening in our Oceans?**

Professor Carolyn Roberts

Tonight, I am going to talk about the Earth’s ocean environment. I want to surprise and delight you, to challenge you with some of the issues that are problematic for oceans, to look at some potential solutions, and perhaps to provoke you think about these issues in a more critical and connected way. Environmental scientists are finding increasing evidence of human-induced damage to oceans at vast scale – destruction of fish and coral ecosystems, and massive gyrating pools of plastic refuse, for example. Moreover, we may be storing up heat and trouble for ourselves in relation to future sea level changes. What attempts are being made to reduce the footprint of human activity on the oceans, and can they succeed in restoring the damage to the largest living space on earth? I use the words ‘living space’ advisedly, since significant numbers of architects are now seeing ‘floating ocean-going cities in international waters’ as an answer to problems of crowding in major conurbations – a challenge I will look at in more detail in my next talk on ‘Megacities’. I gather there may be tax advantages to a perennially floating existence and, some would allege, freedom from burdensome regulation and the ‘ability to pursue enterprises that would be possible onshore’, but perhaps that’s something for the Gresham Professor of Commerce rather than me to contemplate. These images show recent designs for such ocean-going communities – personally I think they look rather limiting, and even if they were inhabited solely by wealthy tax exiles, one wonders where the food and water would come from. Not cattle ranching, I think. The early ones are likely to be converted ships, but the ‘experts’ at the Seasteading Institute (on the West Coast of the USA) suggest that semi-submersible floating cities would be more stable in the face of changeable weather and currents. But the point is that oceans are a resource, and a valuable one at that, not only for living space but for other things too. That leads to differences of opinion.

Closer to home, the recent controversy over the potential of Swansea Bay for generating renewable tidal energy, highlights the conflicts that can arise when human need for energy interacts with the ecological interests of various other species including birdlife, a theme to which I will return in a few minutes.

Conversely, oceans are the least well-known major component of the Earth’s environment. In times past, they were the mysterious location of dragons, and other terrible and terrifying beasts as illustrated on these historic charts from the sixteenth and seventeenth centuries. Even today, we can still be extremely surprised by what is emerging from oceanographic research. Measurements in February 2013 at an automated buoy by the World Meteorological Organisation, for example, detected record breaking 19 metre waves in the North Atlantic. This is the sort of apocryphal size formerly dismissed as a sailor’s tall story. The buoy is part of the Marine Automatic Weather Stations network that includes ships and satellite imagery. Actually it was not just one freak wave, but a series of them over a stormy twenty minute period. That, I think, could give the libertarian residents of floating cities something to think about should they stray away from the warmer climes of the American West Coast.

That’s on the surface. When we pass below the waves, there is a much greater level of ignorance of things that may be only a couple of kilometres below the surface. In practice only about 10% of the ocean has ever been explored, and it comprises about 1.3billion cubic kilometres – the largest ecosystem on earth. The rest has been the subject of speculation until very recently and even the major configurations of the oceans, with their complex volcanic ridges and abyssal trenches reflecting the slowly shifting patterns of plate tectonics, only emerged in the last sixty years.

Don Walsh and Jacques Piccard went to the bottom of the Mariana trench, 11 kilometres down, in a bathyscaphe for the first time only in 1960. In fact they saw very little because the water was milky from stirred up sediment that did not disperse, though they thought they saw some sort of halibut. The feat has never been repeated. Richard Branson was intending to have a go in 2011, but in 2014 he quietly shelved his plan for Deep Flight Challenger to ‘fly’ to the bottom of the Mariana trench. Apparently, the submersible proved unable to withstand the pressures at that depth, at least for repeat ‘flights’, and developed fractures. Even though we can walk on the moon, human technology is not yet good enough for us personally to traverse the ocean floor.

Other creatures do have the ability to withstand the extreme pressures. Deep sea frill sharks, for instance are an example of a larger organism thriving at high pressures, and about which little is known. This specimen was found in shallow water off Japan, and died shortly after being caught. Here’s another organism that thrives at high pressures, usually in the darkest depths, a huge spider crab, again found close to Japan. Similarly new discoveries are being found in other dark, deep and cold environments. Alexander Semenov, for example, has photographed a range of stunning organisms in the Arctic Ocean, working out of the White Sea Biological Station near the Arctic Circle in the six months when it is ice free. In newly explored areas of oceans, we find all types of novel organisms, of all sizes, including worms, sea cucumbers, starfish, jellyfish and types of fish far too many to enumerate. Mammals such as whales, dolphins and walruses too, with their complex social patterns are starting to be understood. I particularly liked the recent research findings by Dr Darren Croft from Exeter University that showed wild, male orca whales are highly dependent on their mothers and return to their home ‘pod’ after breeding. The mothers live to be 90, but stop reproducing at 30 in order to support their sons (less so their daughters) – does that all sound rather familiar, ladies? These diverse animals move around mysteriously, and colonise every ecological niche, everywhere, it seems. Beautiful too, and sometimes astonishing organisms are found unexpectedly close to the UK, as are these colourful jellyfish in the Irish Sea.

Since discovering last week from some American politician’s *aide* that ‘alternative facts’ are as equally acceptable as scientifically verified material, I am including this image of some ‘alternative’ deep sea organisms, courtesy of Disney.

It is important not to omit microscopic organisms, on top of which rests the majority of the oceanic food chain. Recent discoveries by Danish scientists on the deep Pacific Ocean floor include bacteria and the distinct single-celled *archaea* that lack a cell nucleus, and challenge our ability to understand what ‘being alive’ is. They are found in vanishingly small numbers, maybe a thousand in a cubic metre of clay sediment. Their metabolic processes such as respiration are so slow, a response to the extremely limited food supplies far from nutrient sources, that it would take hundreds or thousands of years for them to generate enough energy to reproduce, and some are probably thousands of years old. That’s a lot older than the longest-living vertebrate on earth, likely to have been a Greenland shark, which was dated by Danish scientists from the radiocarbon in the lenses of its eyes, at 392 years old. The lethargic *archaea* perked up and divided when fed with nutrient soup in the laboratory. Interestingly, the latest research work suggests that *archaea* in turn are host to novel viruses and parasites, again something we know next to nothing about. These and other extremophiles living in exceptionally hostile (to us) environments, support the global ecosystem in ways we do not yet understand, living on the nutrients generated from geologically-slow processes. They are certainly very important in the planetary-scale carbon recycling system on which we all rely. Kelp, for instance (and I have not forgotten vegetation) is a crucial carbon store perhaps more significant that tropical forest.

So not only do geological inputs influence the biosphere, but the converse is also true: animals (not just humans) influence chemical cycling in the oceans. We know that large mammals play a previously unknown role in recycling nutrients from ocean depths, stirring up sediments with fertilising potential (including increasingly sought-after nutrients such as phosphorus) and allowing them to disperse around the world. The Environmental Change Institute in Oxford University, for instance, has recently established that the massive reduction in large oceanic mammals such as whales has reduced this capacity to a tiny fraction of what it was before these mass extinctions.

Specific groups of extremophiles even live in the superheated acid environments close to mid-oceanic hydrothermal vents, where they are potentially very vulnerable to damage from deep sea mining for metals such as copper, zinc and gold, using drag lines or (coming soon to an ocean area near us) remotely-controlled ocean bed crawlers. Many of these areas of hydrothermal vents are very deep and they were only discovered in 1977. Early exploration of the oceans depended upon imprecise surveys from ships, measuring bathymetry and water temperatures by ‘swinging the lead’ and dropping thermometers on lines as they traversed across the sea. Painfully slowly, these were built up into generalised bathymetric maps, but it was only in the mid-20th Century that a broader understanding of ocean topography, based on sonar depth observations (again from ships) and plate tectonics, developed. Scientists such as the largely unrecognised Dr Marie Tharp, of Colombia University, were instrumental in this work, producing the familiar ocean floor map that now adorns almost every school’s geography classroom.

Beyond topography, whilst deep ocean exploration has enabled great advances in understanding the nature of sea floors, we are only now starting to understand patterns of marine circulation patterns of water and air across the and how these have changed over time. Observations made from boats were exceptionally time consuming, and only six Atlantic transects where water temperature and salinity was measured at depth have been made since the 1950s. Autonomous underwater vehicles and robots are capturing most of the imagery and samples today, minimising the need for people to travel to the sea bed, or for ships to drop samplers. Satellite-borne altimeters, in combination with drone vessels, drifters or wave gliders and buoys, are enabling us to understand far more about the nature of the ocean, and the way water of different characteristics moves around it. Previously, some Earth Observation satellites were actually turned off as they passed over the ocean in order to save energy, but the newer ones, including microsatellites, are now recording sea levels, wave heights and water temperatures with astonishing precision. The American National Oceanic and Atmospheric Administration’s new GOES-16 satellite, for instance, measures ocean meteorology from 36,000km up, and other satellites look specifically at oceans, allowing heat exchange between air and ocean and other parameters such as biomass content to be calculated.

One of the UK’s newest universities, the University of the Highlands and Islands, is something of a specialist at this type of oceanographic research, their Environmental Research Institute researching wave power using data from the tiny SAREL satellite and the solar powered Wave Glider. Wave Gliders can sail for a year, covering thousands of miles without fuel, collecting and transmitting data about meteorology, bathymetry, waves, water temperatures, currents and fish stocks back to a remote base. Other robotic craft can travel down to 6000 metres, including underneath floating ice sheets. The recently-christened ‘Boaty McBoatface’ long range autosub that will be operating from the new research vessel RRS Sir David Attenborough in the Antarctic next month, is an example managed by the National Oceanography Centre at Southampton University. No doubt some people will remember the controversy over the choice of a name for the prestigious research vessel – the obvious dangers of holding a public referendum! ISIS is another deep sea sub, already being operated by Southampton’s environmental scientists, and which is able to examine the sea floor and document habitats and sea life 3000 metres down. In combination with equipment on board the surface vessels, incredibly detailed information can be gathered remotely about the topography of the ocean floor and objects on it, natural or made by humans, and the materials on it. We see here an image showing a wreck that was picked up during high-resolution benthic mapping in Belfast Lough. It is also now possible to identify bed materials such as shell and sand lenses from boats without the need for extensive sampling, which is invaluable for ecological surveys, as well as (of course) for commercial mineral resource analysis.

We need to contrast this plethora of new information about our oceans with the paucity of data in the last century, in order to grasp what scientific progress is now capable of delivering. It is really exciting. In 1959, I was given a child’s version of a book on oceans by one of the world’s greatest environmentalists, Rachel Carson, author of Silent Spring. In general terms we now know a lot more about ocean water circulation, the basis for understanding much else, than was included in that. The slide here shows an example of recent satellite imagery from Sentinal-3, where tiny changes of 10 or 20 centimetres in the altitude of the sea surface tell us how warm and cold ocean currents are functioning in real time, at planetary scale. This image is for March and April 2016, where you can see the warm Gulf Stream and other currents in the Southern Oceans that are much less easy to investigate. We now know that the general water circulation of the oceans is dynamic, with a complex pattern reflecting the atmospheric drivers and the location of major continents. The Gulf Stream is only one part of a global conveyor system where warm surface waters and cold deep waters swing around the planet. Focussing in on the Atlantic, it has also been suggested that rapid ice sheet melting in Greenland might interrupt the patterns more typical of recent centuries. We know, for instance that the Atlantic Meridional Overturning Circulation (AMOC) that brings heat from the tropics towards Northern Europe is highly seasonal, and that it weakened dramatically between 2009 and 2010. We can see that it is sensitive and volatile. The decline was linked to an unprecedented and surprising rise in sea level on the Eastern seaboard of the USA. Now the results have to be incorporated into our understanding of climate systems.

The new robotic technology has also been picked up by the oil and gas industry, BP and others, to try to assist in monitoring oil spills, and it is to a small range of oceanic environmental challenges that I now want to direct my attention.

Let me turn first to issues of pollution – specifically plastic in the ocean, although there are challenges from all sorts of substances entering waters, including pharmaceutical products. Almost all the plastic ever produced is still with us and according to research at the University of the Highlands and Islands, about 8m tonnes of plastic litter enter the ocean each year, with dramatic effect on litter and marine life. About 100,000 marine mammals and a million seabirds per year are killed by eating waste or becoming entangled in discarded plastic including fishing nets, which make up 10% of the waste. By 2025, there could be one tonne of plastic in the ocean for every three tonnes of finfish. And yet it could be recycled into socks and trainers.

The biggest collection of plastic rubbish is found in the Northern Pacific Gyre, a direct result of the ocean currents we were looking at a few minutes ago – a vast swirling mass of microscopic fragments of polymer that have been partly broken down by the sun, and are individually too small to be seen from satellites (perhaps less than 5 mm across), and may be invisible even from boats. Sampling shows that they were once plastic bags (polyethylene), plastic bottle caps (polypropylene), plastic water bottles (polyethylene terephthalate) and expanded polystyrene. A small fraction of it is the plastic microbeads that seem to appear in everything from toothpaste to facial scrubs, about which the UK Government is currently prevaricating. We release about 86 tonnes per year of this unnecessary stuff into the ocean from skin exfoliants alone, along with the usual range of other materials, and most of it is likely then to float north-westwards towards the Arctic. It includes microfibres from artificial textiles in washing machines without filters. Elsewhere on the planet even more plastic is released per capita, ending up in the vortices on the ocean surface, elsewhere in the water column, and subsequently in the bodies of ocean and bird life (and in our bodies too, if we eat fish, as recent research has demonstrated). The images here come from research published by Imperial College London. I am sure many of you will be familiar with the harrowing photography showing the contents of sea bird’s stomachs, including cigarette lighters, toothbrushes and tampon casings. Australian research published by the National Academy of Sciences in 2015 found that 90% of all seabirds had ingested plastic, and it made up 10% average bodyweight. It has also been found in turtles, fish and dolphins, and wrapped around organisms effectively strangling them. Turtles seem to think plastic bags are jellyfish.

Why do birds in particular eat plastic? University of California scientists from Davis have established by field testing that the plastic becomes coated with algae, which when consumed by krill release a sulphur compound called dimethyl sulphide, or DMS. DMS is also a trigger for petrels and shearwaters, who associate it with the krill, one of their favourite foods, and they eat it. Bird ‘junk food’, almost. Since it cannot be digested, they fill up and die. The plastic is also a new floating habitat for some insects (the water strider *halobates sericeus*, for example), again attracting birds and fish to consume it.

We could control this, if we wished, most sustainably by reducing the amount of plastic we use, and not putting it into the sea, and some progress has been made. Tesco are banning microbeads, and Unilever have said they will use only biodegradable plastic from 20, but there is as yet no legislation in the UK. New types of biodegradable plastic are being made, that break down under the influence of UV light into gases, or dissolve. Some can be used in anaerobic digesters, to generate power and fertiliser. A new production plant in Birmingham opens this year to produce polyvinyl alcohol polymer, to replace food pouches, for instance. But overall, the amount of plastic being used globally is likely to double by 2025 (work by Jambeck et al, 2015) so methods of recovery are being considered. The highest profile project is a ‘trash collecting’ Ocean Clean Up system piloted by the Dutch in 2013, that sees barriers being towed into areas in the Northern Pacific identified from planes as having large pieces of plastic debris, allowing currents to move the floating material into a trap where it could be recovered back to shore. It will apparently be operational by 2020. Other researchers including the Canadian scientist Chelsea Rochman, point out that it is more effective to collect the waste closer to the shore, specifically off the coast of China and in Indonesia, where it is denser. She and others suggest that 31% of the modelled microplastic mass, that totals an estimated 51 trillion particles, could be removed by 2025 using that evidence-based strategy. But the sustainable solution is to reduce production and consumption of plastic, trap it on land, and reuse it. That needs legislation.

The second problem I want to look at is ocean warming. The scientific evidence for human-induced climate change was the subject of an earlier lecture at Gresham College, and I will not repeat that here. Whether or not the shift is the result of human activity in increasing greenhouses gases, the evidence of the recent temperature trend is now clear, as illustrated on NASA’s graph of mean surface temperature variability since 1880 when records began. We also know that ice sheets are in retreat in most parts of the globe, particularly the Arctic and Antarctic. The little video shows a great summary of this pulsating annual cycle of ice cap growth and decay in the Arctic, and the significant progressive change over the last few years, as recorded from satellites. For the Antarctic, early explorers’ log books by Shackleton and Scott have indicated a more complex decadal cycle, with only a 14% volume loss so far. Ice volume seemed to peak in the 1950s, as compared with the end of the nineteenth century, according to Reading University scientist Jonny Day. Sea ice as recorded from satellites has actually increased as ice is lost from glacier fronts. So, the Northern and Southern Hemispheres are reacting differently, perhaps unsurprisingly when we consider those ocean current pathways. The news is not all bad, as there is evidence from Bristol University that melting Antarctic icebergs release nutrients, particularly iron compounds ferrihydrite and schwertmannite, into the Weddel Sea and that this boosts the growth of plankton, which then take up the atmospheric carbon dioxide – a partly self-regulating system. However, it not likely to be in balance with the losses, and Japanese scientists have found that ocean waters in the tropical Sea of Japan are taking up less carbon dioxide that previously. On balance, oceans are estimated to take up about a quarter of all the CO2 produced globally.

The impact of this is manifest in several ways, amongst which are sea temperatures and sea level change. Increasing sea temperatures, together with increasing acidity from dissolved atmospheric carbon dioxide and sea level change are putting pressure on the coral reefs that protect many coastlines from the ravages of flooding. Many carbonate reefs (and there are now known to be silica reefs as well, recently found at 760 metres in the Mediterranean, and a legacy of ancient organisms such as sponges) are experiencing ‘bleaching’ and death of their constituent microorganisms, polyps. Bleaching can be part of the natural cycle of coral reefs, and has an association with natural aerosols emitted from volcanoes (which protect them), and the strength of the cycles of sea currents associated with El Nino, so it is sometimes difficult to establish that widespread bleaching such as observed in the Great Barrier Reef, is actually the result of water temperature change. But it seems likely. Cold water corals are also likely to be affected, including common North Atlantic species such as Lophelia, which have been shown to become more brittle with acidification – a type of coral reef osteoporosis. Collapse of the basic structural elements of a reef can initiate wider changes in the marine ecology, with new species arriving to replace some of the rarer incumbents. It may also leave coastal areas open to inundation at high tides and in storms. Clearly some form of protection is required, but it cannot just be a locally-based solution as in most cases this will not address the fundamental cause of the bleaching.

Microorganisms such as phytoplankton, at the bottom of the food chain are also likely to alter their distribution in response to the changed water temperatures, tending to migrate away from the equator. This would not necessarily matter, except that research by Simon Simpson at Exeter University suggests that this is associated with a reduction in biodiversity and reduced ocean productivity. Fish life could be affected. The International Programme on the State of the Ocean (IPSO) described this in 2011 as an ocean apocalypse of mass extinction, comparable to the Paleocene-Eocene Thermal Maximum of 55 million years ago when 2.2 gigatonnes of carbon dioxide were estimated to be released every year into the atmosphere, whereas today we release 25 gigatonnes every year. The increased carbon dioxide may also affect fish ability to navigate, and studies in fish farms by Exeter University suggest that fish hearing, sight and smell is compromised. They may start swimming towards predators, which is clearly not a good plan.

That brings me, finally, to fish and over fishing. Fish have always been a vital part of the world’s human diet, and 90% of all fisheries are in the developing world where population is increasing. The pressure is on. Fisheries are also an area where global legislation and enforcement is weak, and governance arrangements are patchy. Research by Richard Bailey in the Oxford Martin School has produced some most interesting findings, and ways to think about the questions. Take for example cod stocks in the North West Atlantic in the 1990s, which fell to 1% of the biomass of the previous yields as a result of overfishing. The UN FAO has suggested that this is not untypical of other fisheries, where they estimate that 75% are at maximum capacity or overfished. The technology of fishing improved very quickly in the 1980s and 1990s, for the same reasons that oceanography understanding improved rapidly – GPS, new sensors and similar technologies. Vested interests, financial subsidies and uncertainty produced a political environment in which international competition could thrive, with an overarching view that there were plenty of fish in the sea. As the boats became bigger and more sophisticated, and despite some regulation, ecosystems were degraded with a ‘Tragedy of the Commons’ as everyone took more or less what they wanted in case others got there first. The combination of what he calls high ‘subtractability’ (what’s lost is lost), and difficult ‘excludability’ (everyone can get in to fish quite easily) has generated this situation. Basically, as soon as policy measures were put into place, shorter boats, for instance, fishermen adapted their boats to make them wider. Cutting the days at sea – fishermen work longer hours per day. And a fifth of all estimated fish catches are illegal, with the same boats probably being used for drug dealing and people smuggling. We now have large and very efficient fishing fleets. The catch figures show the result. Pressurised also by climate change and localised pollution, considerable damage has been done to North Atlantic fisheries and we are now in a position where we do not know if the ecosystems will fully recover to their previous positions. They may lock into a new, less productive, situation. With or without the agreements currently in force with Europe.

Perhaps what is required is Marine Conservation Areas where fishing and mineral extraction are prohibited, protected areas where fish and other organisms can recover, and here we do report some successes close to the UK and beyond. With the new technologies we can now see ship lights from space, use synthetic aperture radar from aircraft to spot even small ships at sea by observing their wakes, and ‘chip’ or tag boats electronically so we know where they are all the time. Perhaps there is some cause for optimism that fish stocks will recover and our reefs and other vulnerable systems will be protected.

Environmental journalist George Monbiot, writing powerfully in the Guardian newspaper last month, said that encounters with huge basking sharks and sunfish whilst canoeing off the Hebrides triggered in him a raw set of feelings, a vestigial genetic memory from a time when ocean circumstances obviously directly shaped human lives. Less obviously today, ladies and gentlemen, they still do.

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