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From Cook to Cousteau: The Many Lives of Coral Reefs

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INTRODUCTION

Anyone interested in marine environmental history today is likely to feel some concern about the present and future of coral reefs. Living reefs face a range of threats, from direct physical damage and the effects of local pollution to problems presented by deforestation on dry land, which leads to erosion and ultimately to damaging sediment being deposited on reefs. Reef-building corals are threatened too by rising ocean temperatures, which can cause coral bleaching, a phenomenon in which coral polyps lose the alga-like photosynthetic organisms that dwell within them. If that weren't enough, increasing acidification of ocean water weakens corals' mineral skeletons.[1] It is no surprise, therefore, that a great deal of contemporary reef science is aimed at conserving reefs by mitigating the threats posed to them by human activities.[2]

Not long ago, however, scientific curiosity and popular interest in coral reefs were driven instead by the threats that reefs posed to human activity. Far from feeling that reefs needed to be protected, navigators, naturalists and naval administrators in the eighteenth and nineteenth centuries believed that generating scientific knowledge of reef growth might provide some measure of protection to humans undertaking the risks of navigating the tropical oceans or investing in maritime commerce.

This essay aims primarily to recapture that former view, and to show how it changed only gradually over two centuries. In sketching this history of Western attitudes toward coral reefs, I trace a broad shift from

1 On the current threats to coral reefs, see Bryant 1998 and Burke and World Resources Institute 2012. A useful text on corals and their evolution and distribution is Veron 1995.

2 For an overview of the science of reef-management, see Birkeland 1997a.

the view that they were robust and threatening natural phenomena to the view, characteristic of the mid-twentieth century, that they were resilient and benign. In closing I offer a preliminary account of why, in the last few decades, reefs have come to be seen as fragile and threatened.

REEFS AS THE PRODUCT OF CORAL GROWTH

The range of views I examine in this essay all depended on the idea that coral reefs were organic formations. Whereas the notion that corals were animals rather than plants (or minerals) dates to the early eighteenth century, the distinct idea that the whole submarine structure of reefs owed their origin to coral growth was first proposed by Johann Reinhold Forster in the 1770s.[3] A polymath from Polish Prussia who had emigrated to England in 1766, Forster served as naturalist on Captain Cook's second voyage to the Pacific (1772–1775). This was the voyage in which Cook made a series of traverses in an effort to find (or disprove the existence of) a conjectured great continent in the Southern hemisphere. Cook's route provided Forster with several opportunities to observe the central Pacific's distinctive low, ring-shaped islands and reefs that are now known as atolls. These 'low islands' were familiar to Europeans from earlier voyages of exploration, including the 1766–1769 circumnavigation by the French naval officer Louis-Antoine de Bougainville, who had identified a central paradox to their existence. On the one hand, the islands were so slight and flat they seemed on the verge of being swallowed by the ocean, mere 'strips of land that a hurricane could bury at any moment beneath the water'. Of these 'almost drowned' islands, Bougainville wondered, 'Is this extraordinary land rising, or is it in ruins?' On the other hand, the unassuming appearance that made the islands seem potentially ephemeral meant that they were a terrible hazard to navigation, particularly if a ship were making sail in the dark or in bad weather. Discovering a cluster of these islands east of Tahiti, Bougainville named the area *l'Archipel Dangereux*.[4]

Before Forster, it was understood that such reefs offered fertile ground for the growth of corals, whose stony skeletons formed a substance called

3 The best information on Forster is to be gleaned from Hoare 1976 and the introductory essays in Johann Reinhold Forster 1996 [1778].

4 L.-A. de. Bougainville 1772; L.-A. de Bougainville, Bideaux and Faessel 2001. On the Bougainville expedition in the broader context of French exploration in the Pacific, see Moureau 2004.

'coral rock'. This coral rock could be found on the reefs of the low islands and on the extensive shoals that Captain Cook had discovered on the east coast of New Holland [Australia] during his first voyage. Amidst this 'labyrinth' that became known as the Great Barrier, Cook's ship *Endeavour* had run aground despite his men taking every precaution to prepare for suddenly shoaling water. His journal for 11 June 1770 records that a few minutes before 11:00 p.m., the depth was '17 [fathoms (102 feet)] and before the Man at the [sounding] lead could heave another cast [to measure the water's depth] the Ship Struck and stuck fast ... upon the SE edge of a reef of Coral rocks' (Cook 1955, Vol. 1, p. 344). Though he was able to save the ship, it took the *Endeavour*'s company two months to sail clear of the reefs for good (Beaglehole 1974, pp. 236–246).

Sailing on Cook's next voyage, Forster's innovation was to suggest that, rather than merely inhabiting reefs and other shallow areas, corals had created the entire structure of the low islands. Upon viewing the low islands of Takaroa and Takapoto in August 1773, Forster entered into his journal a new account of how animalcules would produce a circular reef.

> Both [of these low islands] have the longer sides [oriented south-north] & the shorter ones [oriented east-west,] ie the long sides are exposed to the East-wind, which probably was the first origin of these curious Isles: for there being some little Elevation or inequality in the bottom of the Sea the Coral-Animals began to raise their large rocky branching out habitations; & as soon as the Animals came nearer to the surface of the Sea, they extended their branches more North, in order to shelter themselves against the Surf of the Sea, & at last this work formed a Lagoon in the middle.[5]

Given the immense depth of the ocean around these islands (Cook did not carry a rope long enough to sound the bottom), Forster was claiming coral growth on a massive scale. He advanced this theory in his 1778 *Observations Made During a Voyage Round the World*, in which he concluded that 'the method employed by the animalcules in building only narrow ledges of coral rocks, to secure in their middle a calm and sheltered place ... seems to me to be the most probable cause of THE ORIGIN of all THE TROPICAL LOW ISLES, over the whole South-Sea' (J.R. Forster 1778, p. 151).

Forster's claim about the role of corals' 'instinct' in building reefs received support from the British navigator Matthew Flinders, whose 1801–1803 survey of the Australian coast led him to declare that the

5 Entry for 18 April 1774. Johann Reinhold Forster and Hoare 1982, vol. 3

geographical extent of 'the reefs, which form so extraordinary a barrier to [northern] New South Wales ... is not to be equalled in any other known part of the world' (Flinders 1966 [1778], pp. 101–02). Along with drawing attention to the reefs' sheer magnitude, Flinders offered a precise account of how successive polyp generations might contribute to these structures. 'It seems to me', he explained, 'that when the animalcules which form the corals at the bottom of the ocean, cease to live, their structures adhere to each other, by virtue either of the glutinous remains within, or some property of salt water; and the interstices being gradually filled up with sand and broken pieces of coral washed by the sea, which also adhere, a mass of rock is at length formed. Future races of these animalcules erect their habitations upon the rising bank, and die in their turn, to increase, but principally to elevate, this monument of their wonderful labours.' Although the reefs Flinders encountered were not the ring-like low islands that Forster had seen, he too saw evidence that coral polyps shared an 'instinctive foresight' to coordinate their behaviour against the power of the wind. He argued that '[t]he care taken to work perpendicularly in the early stages, would mark a surprising instinct in these diminutive creatures. Their wall of coral, for the most part in situations where the winds are constant, being arrived at the surface, affords a shelter, to leeward of which their infant colonies may be safely sent forth.' (Flinders 1966, p. 115)

THE BENEFICENT POWER OF CORALS

The implication of observations by Forster, Flinders and others was that corals potentially could produce major changes to the face of the globe. In the early nineteenth century, this power of mere animalcules to create great physical structures was interpreted in a variety of ways. For those who inclined toward natural theology, the belief that one could come to know God through the study of his creation, corals were agents of providence. These unassuming creatures were a divine means of refreshing the earth with new landforms to compensate for the erosion of the old. For others, less certain that all creation was beneficent, Forster's claim was cause for concern. The combination of wonder and fear at corals' marvellous potential was the stuff of the sublime.

In the young science of geology at the time, there was a general concern about the degradation of the present continents and a question

about whether and how new land might be formed. The ongoing second great age of discovery had introduced the possibility that newer continents were emerging to replace those older centres of civilisation. In his *Modern Geography* (1802), the mapmaker John Pinkerton wrote that 'the isles of Sunda, the Moluccas, and others in the Indian ocean, are gradually enlarging, and may in time, with Australasia and Polynesia, form a vast new continent, while one or other of the ancient continents will be submerged under the ocean' (quoted in Frost 1988, p. 235). Pinkerton, though he was not in general convinced of the acuity of Forster's observations during Cook's second voyage, did believe that corals were capable of enlarging existing land masses. Joseph Banks, who became president of the Royal Society after travelling as the self-supported botanist on Cook's first voyage, wrote 'Who knows but that England may revive in New South Wales when it has sunk in Europe?' (quoted in Frost 1988, p. 235)

For navigators who followed in the wake of Cook and Flinders, the notion of what mere polyps could do shaped the experience of discovering new reefs and islands. Otto von Kotzebue, the Baltic-German commander of a privately-financed Russian voyage of exploration in the Pacific and Arctic, wrote of his amazement as the European discoverer of an atoll in the group now known as the Marshall Islands.

> The spot on which I stood filled me with astonishment, and I adored in silent admiration the omnipotence of God, who had given even to these minute animals the power to construct such a work. My thoughts were confounded when I consider the immense series of years that must elapse, before such an island can rise from the fathomless abyss of the ocean, and become visible on the surface. At a future period they will assume another shape; all the islands will join and form a circular slip of earth, with a pond or lake in the circle; and this form will again change, as these animals continue building, till they reach the surface, and then the water will one day vanish, and only one great island will be visible. It is a strange feeling to walk about on a living island, where all below is actively at work.[6]

Shocked, as Bougainville had been, that human beings had somehow come to live upon ephemeral slips of land atop coral reefs, Kotzebue wondered, 'to what corner of the earth can we penetrate, where human beings are not already to be found? In the remotest regions of the north, amidst mountains

6 Kotzebue 1821 vol. 2, 36. Emphasis added.

of ice, under the burning sun of the equator, nay, even in the middle of the ocean, on islands which have been formed by animals, they are met with!'[7]

This admiration and gratitude for the fact that corals laboured on behalf of humans was shared by many Europeans who had never seen reefs themselves. Among the most remarkable paeans to the providential power of corals was the 1828 poem 'The Pelican Island', by the British poet, author and hymn-writer James Montgomery. In this reverent epic, which drew explicitly from the voyage narratives of Flinders and Basil Hall, coral 'worms' were the almighty's vehicle for bringing forth new land that man could inhabit.

> Each [coral] wrought alone, yet all together wrought,
> Unconscious, not unworthy, instruments,
> By which a hand invisible was rearing
> A new creation in the secret deëp.
> [...]
> Atom by atom thus the burthen grew,
> Even like an infant in the womb, till Time
> Deliver'd ocean of that monstrous birth,
> – A coral island. (Montgomery 1828, p. 18)

'Compared with this amazing edifice, / Raised by the weakest creatures in existence', Montgomery asked, 'what are the works of intellectual man?'[8]

MALEVOLENT CORALS

This belief in the potency of corals had a darker side, however. For those who were more concerned with carrying out European maritime ambitions than with the rather long-term question of where civilisations could flourish when the continent of Europe had been reduced to silt, coral activity was an unalloyed menace. This tension between the positive and negative consequences of coral growth was evident as early as the 1790s, when the surveyor John Macdonald concluded a report on the reefs of Sumatra with an imaginative proposal to harness their work. Though he was convinced that coral rock was derived from plants rather than animals, he attested to the facts 'not only of the very rapid growth of coral, but also of the formation of islands from it, as a necessary, and observed, consequence'. Coral structures expanded at a high rate because coral grew upon and consolidated sand and stones, and Macdonald foresaw that the islands of the East Indies would 'in the process of time, become continents or insular tracts or spaces of land' as a result of coral activity. He therefore proposed the creation of a sheltering island in front of the exposed anchorages at Madras, where ships frequently came to grief, by planting coral offshore. 'To attempt to effect this, a considerable quantity of coral might be transported from this coast, at no great expence, and sunk, with stones and other substances, in seven, eight, or eleven fathoms of water. In the course, probably, of forty or fifty years, an island might be formed by the growth of this substance.' In response, the sitting president of the Asiatick Society of Bengal, Sir William Jones, warned Macdonald that the inevitable precursor to potentially beneficial coral islands were treacherous reefs. 'The idea of making islands, for the protection of ships at anchor, is very sublime; but it might be feared, that very dangerous reefs of coral would be formed, before an isle could appear above the water.' (MacDonald 1798, pp. 6–15)

7 Kotzebue 1821 vol. 2, 36. Emphasis added.

8 On a similar trope of admiration for the humble grains of sand that God had endowed with the power to repel the ocean, see Corbin 1994, pp. 26–27.

The prospect of corals bringing forth new continents was itself cause for alarm in many quarters. The French botanist and zoologist J.V.F. Lamouroux, whose *Histoire des Polypiers* was primarily a systematic work aimed at revising the taxonomies of Cuvier and Lamarck, contemplated the activity of the reef-building corals with wonder that was matched with concern. He was impressed by the scale of the coral structures that must lie beneath the comparatively insignificant portion of reefs visible at the ocean's surface, and he considered the polyps to be winning a contest with the water. 'Every day the naturalist who traverses the coral islands in formerly water-covered equatorial regions is astonished at the grandeur and the perfect conservation of these masses of polyps; it seems', he marvelled, 'that the sea has just surrendered these areas.' How long would this battle continue in the corals' favour? Lamouroux conjectured that they might flourish so successfully throughout the world's equatorial oceans that they would eventually form a girdle of reefs that blocked navigation between the northern and southern hemispheres altogether (Lamouroux 1816, p. lix).

This idea that corals had the potential, for good or ill, to reshape the globe was dealt a blow in the 1820s by the observations of two French naval surgeons, J.R.C. Quoy and Paul Gaimard. Their examination of fossilised banks of coral upraised at Timor, augmented by their study of living reefs, convinced them that corals could live at a maximum depth of only twenty or thirty feet, and were therefore capable of forming nothing more than thin veneers atop other submarine structures. 'In reconsidering these zoophytes with more attention', they argued, 'we will no longer see them filling the basins of the sea, raising islands, augmenting continents, and menacing future generations by forming a solid circle around the equator.' (Quoy and Gaimard 1825, pp. 289–290) Disputing what they considered to be fanciful claims by Forster and others that instinctive corals were responsible for the annular shape of low islands, Quoy and Gaimard proposed that beneath each ring-shaped reef was a submarine volcano whose crater stood in the shallow depths at which corals could colonise its rim. The Frenchmen succeeded in convincing most contemporary students of geology and zoology that coral activity was limited to a narrow band of depth just below sea level. However, even if corals were busily modifying the submarine topology only in the shallowest thirty feet, these were precisely the thirty feet of depth that mattered for safe navigation.

It was therefore despite Quoy and Gaimard's work that the naval surveyors of Europe became obsessed with documenting and explaining the work of corals. Beginning with the 1831 instructions written for Robert FitzRoy, Commander of H.M.S. *Beagle*, the Hydrographic Office of the British Admiralty made the study of reef formation one of the standard orders for surveys headed to the tropics. FitzRoy was directed to use standard hydrographic surveying methods to examine a coral island. In the end it was his passenger, Charles Darwin, who exploited the island survey to offer a new explanation for the formation of low islands and barrier reefs. Darwin claimed that barrier reefs were formed during the sinking of a landmass that had a reef growing on its shore. If the sinking occurred sufficiently slowly, corals would grow quickly enough to maintain the surface of the reef at or near sea level, and the horizontal distance between the reef and the land would grow as the sloped shoreline receded. If the landmass were an island encircled by a reef, and if the island itself eventually sank completely beneath the waves, what remained would be a ring-shaped reef marking the shape of the former island's shoreline. This theory (which is generally accepted as true today) gained Darwin great acclaim after the voyage; he was a celebrated theorist of reef formation before he had jotted his first private note about natural selection (Sponsel, forthcoming).

Before the *Beagle* had even reached any coral islands, however, back in England the Hydrographer of the Admiralty, Francis Beaufort, had continued his efforts to solve the problem of reef growth. He requisitioned a well-boring apparatus for the 1835 voyage of the *Sulphur* in order that the deep structure of a reef could be studied for clues to its formation. When, in 1842, Francis Price Blackwood was sent to survey the Torres Strait at the northern end of the Great Barrier Reef because so many vessels had been lost after becoming 'entangled within the reefs', Beaufort exhorted him, 'Do not hurry over the hidden dangers which lurk *and even grow* in that part of the world'.[9] Beaufort made the reason for such substantial investments of naval time and money clear in his 1846 directions to Owen Stanley upon dispatching him to make a further survey of the Great Barrier. It was not merely that reefs were dangerous, but that coral growth potentially made the act of surveying marine hazards a fruitless endeavour. '[T]here would be much of discouragement attached to such surveys', Beaufort wrote, 'if changes should be constantly & rapidly at work in [coral] seas'. Stanley was encouraged, therefore, to 'direct [his officers'] attention more particularly to the formation and growth of coral reefs'.[10] If it were possible to account for these processes, one could suggest where reefs were likely to spring up and indicate how long existing charts might be relied on before new reefs would render them obsolete.

A natural consequence of the threat posed by coral reefs was the widespread desire among practically-minded men to find a way to destroy them or limit their growth. Beaufort's American counterpart, the Superintendent of the US Coast Survey Alexander Dallas Bache, instructed the Harvard zoologist Louis Agassiz not merely to study the formation of reefs in the Florida Keys, but to determine 'whether the growth of coral reefs can be prevented, or the results remedied, which are so unfavourable to the safety of navigation' (Agassiz 1852, p. 158). Agassiz argued that there was no possibility of checking the spread of reef building corals 'beyond the bounds which nature itself has [already] assigned to their growth', and urged instead that a close knowledge of the natural tendencies of reef formation would allow mankind 'at least to avoid the evil consequences'. For

9 'Proposed orders for Captain Blackwood'. UK Hydrographic Office (UKHO) MB 3: September 1837–May 1842, pp. 409–416. Francis Beaufort to Francis Blackwood, UKHO LB 12, quoted in Goodman 2005, p. 13(emphasis added).

10 Beaufort reported these concerns from Lord Auckland, then First Lord of the Admiralty, to Owen Stanley on his dispatch to survey the perilous Torres Straits. Francis Beaufort to Owen Stanley, 28 November 1846. UKHO LB 14, pp. 214–215. Emphasis added. See also Cock 2003, n. 420.

example, Agassiz declared, in the Floridian case he believed that the reefs would never extend any farther from the shore than they already did because the slope of the sea bottom outside the present-day reef sank 'rapidly to unfathomable depths' and left 'no opportunity for the growth of a new reef' (Agassiz 1852, pp.158–9). In Britain, the geologist Roderick Impey Murchison hailed Agassiz's work in his 1853 presidential address to the Royal Geographical Society.

> Professor Agassiz has successfully shown how all such surveys ought to be made in conjunction with naturalists. For, quite independent of the important additions to natural-history knowledge which are obtained, statesmen as well as hydrographers thus ascertain the causes of increase or decrease of coral reefs, and learn, that whilst no human power can arrest the growth of such reefs, there are channels amidst them which will remain deep for long periods of time, and the outlines of which, when well defined by lighthouses, may be the salvation of much life and property (Murchison 1853, p. cxvi–cxvii).

The best way to deal with reef growth, then, was to manage its unwanted consequences.

CORAL REEFS DISENCHANTED

Through the rest of the nineteenth century, the enchanted view of corals' activities was in the main limited to popular and fiction writing, while in the specialist scientific literature it was generally agreed that the rate of reef growth was much slower than had previously been feared. Gradually what had been concurrent tropes, of corals as providential wonders and as threats to human enterprise, began to decline.

As a result of his participation in the US Exploring Expedition (1838–1842) to the Pacific, the American geologist James Dwight Dana was more familiar with coral reefs than almost any other Western authority. Although he was a devout Christian, he considered it his responsibility to disabuse his readers of the notion that corals were agents of providence. '[T]o the present day', he complained in 1853, 'the subject [of coral growth] is seldom mentioned without the qualifying adjective *mysterious* expressed or understood ... Very many of those who discourse quite learnedly on zoophytes and reefs, imagine that the polyps are mechanical workers, heaping up these piles of rock by their united labors.' Pointing out that the secretions

of stony coral were enclosed within the living polyp rather than being their hives or habitations, he added, '[i]t is not more surprising, nor a matter of more difficult comprehension that the polyp should form coral, than that the quadruped should form its bones, or the mollusc its shell.' (Dana 1853, pp. 47–8) Dana also matter-of-factly dismissed the romantic notion that the low tropical islands were a paradise, commenting, 'The coral island in its best condition is but a miserable residence for a man. There is poetry in every feature: but the natives find this a poor substitute for the breadfruit and yams of more favored lands.' (p. 43) In his 1874 book, *Corals and Coral Islands*, which was intended to present the scientific understanding of the subject to a lay audience, Dana appended a similar set of observations with the note that 'It is not, perhaps, within the sphere of science to criticize the poet. Yet ... more error in the same compass could scarcely be found than in the part of Montgomery's "Pelican Island" relating to coral formations ... There is no "toil", no "skill", no "dwelling", no "sepulchre" in the coral plantation any more than in a flower garden.' He concluded 'The poet oversteps his license, and besides degrades his subject, when downright false to nature.' (Dana 1874, p. 19)

Notwithstanding Dana's pleas, wonderful and industrious corals continued to colonise the pages of popular fiction and children's writing, from the South Sea tales of Robert Louis Stevenson to the children's fiction of Robert Ballantyne and the non-fiction of Charles Kingsley. Dana himself had delighted in many of his experiences on coral islands, 'their groves, and beautiful life, above and within the waters', and many other men of science found that they could not resist the visual charm of a reef.[11] The zoologist Alfred Russel Wallace expressed a common sentiment in writing,

> The bottom was absolutely hidden by a continuous series of corals, sponges, actiniae and other marine productions, of magnificent dimensions, varied forms, and brilliant colours ... It was a sight to gaze at for hours, and no description can do justice to its surpassing beauty and interest. For once,

11 Dana 1874, p. 4. He continued, 'Even the beauty of natural objects had, at times, a dark back-ground. When, for example, after a day among the corals, we came, the next morning, upon a group of Fee-Jee savages with human bones to their mouths, finishing off the cannibal feast of the night; and as thoughtless of any impropriety as if the roast were of wild game taken the day before. In fact, so it was.' Along with the beauty of coral islands, he listed among his 'agreeable memories ... beyond all [the others] ... man emerging from the depths of barbarism through christian self-denying, divinely-aided, effort.'

the reality exceeded the most glowing accounts I had ever read of a coral sea. (Wallace 1869, vol. 1, p. 463)

By the early twentieth century there were at least two sciences of coral reefs. Whereas nineteenth-century students of reefs such as Darwin and Dana had sought to make themselves expert in the whole process of reef formation, from the growth of individual polyps to the local and global-scale geological and chemical phenomena that created the conditions of possibility for reef formation, most reef scientists of the twentieth century were trained in a particular scientific discipline, usually either geology or zoology/biology. Two transitional figures, both of whom had trained as graduate students at Harvard in the 1890s, were the palaeontologist T. Wayland Vaughan and the zoologist Alfred Goldsborough Mayer (he changed his surname to the less-Germanic 'Mayor' in 1918). In 1904, Mayer founded the Carnegie Institution of Washington's marine biological laboratory at the Dry Tortugas coral islands in the Florida Keys. There he oversaw intensive study of the local reefs, which included pioneering experimental and ecological approaches to the understanding of reefs and their development. Among these were Vaughan's experiments on the rate of coral growth, in which he affixed living corals to terracotta slabs and 'planted' them at different points on the reef. The experiments were aimed at determining the rate of coral accretion, which could be measured by retrieving and weighing the slab to determine the mass of new coral affixed to it, and at understanding how the shape of growing coral colonies was determined by their environmental conditions. Mayor also oversaw and participated in early use of a diving helmet to study reefs from below sea level. At American Samoa in 1919, for example, the new technology allowed him to plant living corals down to a depth of 52 feet. He reported to his sponsor at the Carnegie Institution, 'We really entered a new world in so far as scientific study is concerned when we got down on the submarine precipice under the breakers, and many new facts have come to light.'[12]

While Mayor's audience was primarily scientific, a much wider public was introduced to the experience of coming face to face with the submerged parts of a reef in the following decade by museum exhibitions that included submarine photographs taken during Roy Waldo Miner's helmet dives, and by the writings of William Beebe.[13] Beebe's 1928 book *Beneath Tropic Seas* described his jaunts on and around the reefs at Haiti in language designed to make them seem at once exotic and accessible. He claimed that '[a]s far as the actual experiences are concerned, any reader of this volume may duplicate them. The diving helmet, hose and pump, with which all the research was done, are as inexpensive as they are simple in operation', and to this end he included appendices on the technical aspects and cost of his outfit (Beebe 1928, p. v). In 1930 Beebe and Otis Barton made the inaugural dives in their 'bathysphere' at Bermuda, descending hundreds of feet deeper than the sun's light reached off the reefs of Nonsuch Island (Beebe 1934).

No sensational dive brought as much attention to a coral reef as did the events of July 1946, when the US Navy tested two nuclear devices on a target fleet anchored in the lagoon at Bikini Atoll in the Marshall Islands.[14] Operation Crossroads was the largest peacetime undertaking that had ever been carried out by the US military, employing 42,000 personnel including a corps of scientists who conducted surveys before and after the bomb blasts. The plan of operations – and by extension the expectations for what was knowable by these surveys – was based on the assumption that an atoll should be understood as a discrete unit. In the minds of those who determined how knowledge would be produced by Operation Crossroads, Bikini was not merely the location where the bombs were tested: Bikini Atoll was, among other things, what the bombs were tested on. The extent to which the bomb's effects over time would be distinguished from seasonal changes in the atoll biota depended on the extent to which an atoll could serve as an experimental system. Bikini emerged as more than a local field site; it became a model to be compared against other islands in the Marshalls that were studied as 'control atolls'. Perhaps the most striking example among the myriad atoll-level studies produced by Crossroads research was Marston Sargent and Thomas Austin's path-breaking paper about Rongelap (which is upwind from Bikini), 'Organic Productivity of an Atoll' (Sargent and Austin

12 Mayor to Woodward, 28 September 1919. Carnegie Institute of Washington RG Marine Biology, box 1, folder 18, 'Tortugas Lab – Mayer's Trips, 1912–1920.' On earlier use of the diving helmet at Tortugas in 1915, see Stephens and Calder 2006, p. 130.

13 'Human Exploration under the Sea', Reidy, Kroll and Conway 2007, ch. 7.

14 According to the official report of Operation Crossroads, the requirements for any test site were 'A protected anchorage at least six miles in diameter … a site which was uninhabited, or nearly so … a location at least 300 miles distant from the nearest city … a location within 1000 miles of a B-29 base … freedom from severe cold and violent storms … predictable winds directionally uniform at all altitudes from sea-level to 60,000 feet … predictable water currents of great lateral and vertical dispersion … [and] control by the United States.' Shurcliff 1947, pp. 16–17.

1949). In a much better known paper that became one of the founding documents of ecosystems ecology, Howard and Eugene Odum cited Sargent and Austin's 'ingenious' methods as inspiration for the Odums' study of 'these inherently stable reef communities' (Odum and Odum 1955).

Among the messages to emerge from the post-bomb resurveys of Bikini were official press releases describing the atoll as a benign laboratory for basic scientific research. The release for 24 July 1947 begins:

> Sun-tanned sailors and scientists observed the anniversary of the world's first underwater atomic bomb explosion today by going swimming in the clear blue-green 84° warm waters of Bikini lagoon. They swam from beaches that one year ago were lashed by high and angry waves thrown outward from the explosion point.
>
> When the Baker Day atomic bomb exploded, half a million tons of water boiled up out of Bikini Lagoon in a mile high cylinder and fell back like rain on the CROSSROADS target fleet in what was probably the most impressive man made spectacle ever staged.
>
> One year later the scientists and military personnel now engaged in an intensive six week scientific resurvey of Bikini Atoll can find few visible effects of that blast. Except for the activities of the 700 man Bikini Scientific Resurvey Task Group, Bikini is the same placid palm ringed lagoon on which [the native Bikinians who had been deported before the tests] King Judah and his subjects sailed in outrigger canoes.[15]

The 1946 tests had been politically controversial demonstrations of power after the previous year's bombings of Hiroshima and Nagasaki, and the Operation Plan for the 1947 resurvey suggests that such press releases were part of a considered strategy to rehabilitate the undertaking.[16] Under the heading 'Public Information Plan', this formerly classified document emphasised '[t]he importance of providing a continuing series of newsworthy press releases to the public, through established public information channels during the course of the operation ... Interesting, newsworthy stories from Bikini, that concern the operation, will forestall much press criticism and speculation of a harmful nature.' These were to include '[s]cience stories concerning the study to be made of the Bikini reefs, and the geological

15 'Bikini Scientific Resurvey Press Release No. 16', 24 July 1947. L.P. Schultz Papers, Smithsonian Institution Archives (SIA), Box 26, folder 3, 'Bikini Scientific Resurvey, Correspondence, Press Releases, etc.'

16 On the political controversy, see Graybar 1986, Weisgall 1994.

structure of the atolls'.[17] The most dramatic of the geological studies was the core-drilling carried out by a team of Oklahoma oilmen under the supervision of US Geological Survey palaeontologist Harry Ladd. They bored to 2,500 feet below sea level and retrieved samples aimed at testing Darwin's subsidence theory of reef formation (and at checking the previous year's seismic surveys of the deep structure of the reef, which had been carried out primarily in order to assess the physical damage that the bombs might produce) (Sponsel 2009, ch. 5).

CORAL REEFS SINCE 1950

The results of the drilling and the rest of the geological work at Bikini and later at Enewetak were published in a series of 35 US Geological Survey reports, compiled and edited by Ladd, that began to appear in 1954. The introduction to the first volume was written by Roger Revelle, who had helped to coordinate the scientific operations at Bikini before becoming director of the Scripps Institution of Oceanography in 1950. He began his essay by echoing all the tropes familiar from romantic literature on reefs:

> Of all earth's phenomena, coral reefs seem best calculated to excite a sense of wonder. And of all the forms of coral reefs, the atolls have appeared to men of science to be the richest in mystery and the most strange. Rising alone from the empty sea, these ancient structures, growing now slowly, now fast, toppling when the sea retreats and flung up in haste when sea level rises, are like a Gothic cathedral, ever building yet never finished, infinite in detail yet simple and massive in plan. Tiny plants and animals are their builders. Their architects are the giant ocean and the restless wind.[18]

Upon reading the draft introduction, Ladd's junior colleague Joshua Tracey declared that the 'first two paragraphs are a bit flowery and reminiscent of "The Sea Around Us"', referring to the best-selling 1951 book by Rachel Carson.[19] In fact, Carson scarcely mentioned coral reefs in the first edition of the book. The chapter entitled 'The Birth of an Island' was about Ascension, which is of volcanic origin. Nor was the book particularly oriented toward

17 'Operation Plan' for Bikini Scientific Resurvey, pp. L-1- L-2. (US) National Archives and Records Administration II, RG 374, Defense Nuclear Agency, Entry 47B, Bikini Resurvey, Box 156, Folder A3 'Organization and Management'.

18 Roger Revelle, 'Foreword', in Emery et al. 1954, p. iii.

19 Tracey to Ladd, 5 August 1952 (from Guam). Tracey papers, SIA Accession 02-021, box 4, folder 'Ladd 51-52.'

conservationism or to pointing out harmful effects of human activity. On the contrary, a chapter called 'Wealth from the Salt Seas' touted the opportunities for mineral extraction and petroleum drilling. The idea of concern for the health of coral reefs had yet to be conceived by those familiar with reefs at mid-century.

In the middle of the twentieth century, the prevailing assumption remained that reefs were extremely resilient. This was perhaps partly owing to long traditions that held coral reefs to be durable and incontrovertible hazards of the tropical ocean. In *Beneath Tropic Seas* Beebe described the beautiful reef as a harsh and hardy environment:

> The inner side of the reef was level and shallow, wadable at low water ... Farther out, there came an abrupt drop to several fathoms, the barrier wall being tall growths of elkhorn coral, down which, with care, we could clamber to the general reef floor. It did not do to attempt this in any but a calm sea, for every helpless toss against the stone-thorned branches revealed the pitifully thin-skinned defence of our bodies ... [T]here was a cruel, interlaced, cobweb of sharp-edged ivory overhead, and escape was possible only by slow deliberate choice of passage. As I painfully made my way down nearer the level of the ground corals, I encountered portières of the stinging millepores. When I reached these I unslung the hammer at my back and pounded off the outer layers (Beebe 1928, pp. 138–140).

If anything, the nuclear weapons tests at Bikini served to reinforce this earlier idea of reefs' resilience. From the perspective of those who didn't happen to share the Bikinians' desire to reinhabit the atoll, the remarkable fact was that Bikini and its nonhuman inhabitants seemed to be recovering normally from the physical impact of the human activities there, while admittedly harbouring a higher proportion of radioactive isotopes than beforehand. Revelle summed up these findings with a redemptive statement: 'Bikini Atoll appears, on the whole, to be a healthy, flourishing structure ... The most important groups [of organisms] contributing to the atoll are ... [the] same groups [that] have been building up the massive foundation of the present reefs at least since mid-Tertiary times.'[20]

The beginning of activist concern for reefs seems to have coincided with the general rise of environmentalism in the 1960s and 1970s. In their history of science and policy on the Great Barrier Reef, James and Margarita Bowen link the origin of local environmental regard for that largest of reef

20 Revelle, 'Foreword', in Emery et al. 1954, p. vii.

systems to a confluence of events in the mid-1960s. Public and scientific anxiety about an infestation of corallivorous predators (*Acanthaster planci*, the crown of thorns starfish) that had denuded the reef coincided with a new awareness of pollution on the reef resulting from a government-supported increase in petroleum prospecting there after World War II, and with worldwide anger about the effects of pollution on wildlife following the *Torrey Canyon* oil spill off the coast of Cornwall in Britain in 1967. Widespread belief that the government would endorse a controversial proposal to mine the reef for limestone galvanised support for a 'Save the Reef' campaign (Bowen and Bowen 2002, ch. 19). Further explanation for the rise of environmental consciousness among reef scientists is adduced by Jan Sapp in his history of the global *Acanthaster* crisis, in which he argues that many of those who entered reef studies in the 1960s did so because of aesthetic or emotional fondness for reefs, with which they were familiar through avenues including Jacques-Yves Cousteau's 1953 *The Silent World* (Sapp 1999, pp. 77–78, 96–100). Many of them presumably wanted to study reefs using self-contained breathing apparatus, as pioneered by Cousteau and his colleagues and developed through the 1950s.[21]

I can offer a further speculation about the possible role of SCUBA not only in reshaping the direct way in which reefs were studied and perceived, but indirectly in helping fundamentally to modify scientific and cultural meanings and associations attached to the notion of 'coral reefs.' I conjecture that because SCUBA allowed scientists in greater numbers to study reefs underwater, it greatly expanded the proportion of scientists who identified the 'reef' particularly with its living component. For eighteenth- and nineteenth-century naturalists and navigators who arrived at oceanic reefs by way of the very ships that were most vulnerable to destruction on a solid shoal, the 'reef' referred to the whole rigid physical structure upon which a ship might founder. As early as the 1820s, when Quoy and Gaimard advanced the claim that reef-building corals could live only in shallow water, it was widely agreed that the 'living' portion of a reef represented only a tiny fraction of its entire mass. Nevertheless, for most of the nineteenth century, the science of coral reefs was aimed at explaining the origin and shape of the overall reef structure, fossil and living. This remained true into the 1950s, even for a palaeontologist like Ladd, who hoped among other things that his drilling at Bikini would settle fundamental questions about

21 On Cousteau's persona as an explorer, see Kroll 2008, ch. 6.

the formation and history of the whole atoll from its oldest and deepest foundation, including the thousands of vertical feet composed of long-dead material. There were controversies, to be sure, from the mid-nineteenth to the mid-twentieth century over whether these questions would more likely be solved by studying coral organisms or geological phenomena, but the primary scientific question about coral *reefs* was to explain the origin and shape of the whole physical structure (Sponsel 2009, ch. 4–5). Other studies of coral organisms simply belonged to invertebrate zoology.

Before SCUBA, with the few exceptions of those who made helmet dives, scientists who studied coral reefs worked almost entirely above the surface of the water. Lead-lines made it possible to plot the submarine profile of a reef and grappling hooks and dredges made it possible to bring up samples of living and dead coral. One could walk atop a reef flat or make a transect of a coral islet. One could study upraised fossil reefs, but the often-lamented inability to work in any serious way underwater served to reinforce the existing tendency to identify the reef with the whole submarine structure.

It was likely only the post-war creation of a truly underwater science of coral reefs, which, it should be noted, was still limited to the relatively shallow depths at which reef-building organisms flourish, that helped to ensure that a new generation of scientists would find the living portion of the reef to be most appealing and most intellectually intriguing. That so many more scientists and enthusiasts were going underwater also increased the likelihood that events such as episodes of coral disease and transient infestations of coral predators would be noticed and deemed worthy of concern, research and eventual management. While there is now a wide public discourse about the 'death' of coral reefs, little comment is made about the fact that the great bulk of every reef is already dead.

Management has become a virtually ubiquitous watchword for contemporary reef studies, while current knowledge tends to reinforce rather than to resolve the paradoxes presented by coral reefs. As Charles Birkeland writes in the introduction to his edited volume on the science applicable to reef management, entitled *Life and Death of Coral Reefs*,

> Despite having the power to create the most massive structures in the world made by living creatures (including humans), the thin film of living tissue of coral reef seems particularly vulnerable to natural disturbances and the effects of human activities. Coral reefs and other animal-plant reefs have always been the first to go during periods of climate change, but they have always come back (although not always with the same components). This combination of attributes – creative power and fragility, resilience and sensitivity, productivity and vulnerability to overexploitation – makes management of coral-reef systems a special challenge to science (Birkeland 1997b, p. 2).

Developments in the sciences of reef ecology and paleoecology have undermined the Odum brothers' claim, made just sixty years ago, that reefs are inherently stable communities. Under the present view that reef ecosystems are fundamentally dynamic, moving between various states of imbalance, complexity is seen to go hand-in-hand with vulnerability. However, as Birkeland's comment indicates, reefs are now recognised to have been extraordinarily robust over geological time. Virtually all the world's reefs have 'died' during various mass-extinction events only to be recolonised and reanimated. Yet there is ever more evidence that reef systems are extremely brittle on the human timescale, susceptible to very rapid deterioration. As Pamela Hallock points out, if one takes the long view '[i]t can be argued that humans are simply part of nature; that exploding human populations are naturally generating another episode of mass extinction from which the Earth will recover in 20 or 30 million years' (Hallock 1997, p. 42). Most of Hallock's colleagues, and most of the rest of us, join her in feeling that the geological perspective – i.e., the likely endurance of the physical reef structure regardless of what we do – is small consolation when so many of the earth's 'living' reefs are mortally threatened by increased sediment deposition caused by deforestation and by the many deleterious effects of anthropogenic climate instability.

CONCLUSION

Like the history of ideas about the deep ocean described by Helen Rozwadowski, the sentiments about coral reefs that I have sketched here were shaped by cultures of exploration, science and popular media (Rozwadowksi 2005). However, the deep sea remained an alien environment which, until recently, could only be encountered remotely and whose very existence could be ignored. Coral reefs, on the other hand, could never be overlooked by those who wished merely to cross the tropical ocean and, far from being alien environments, much of their curiosity arose from the fact that they harboured native humans and held the potential to create new lands to be colonised by civilised society.

Environmental and cultural historians of large animal predators offer accounts that parallel the trajectory I have described for coral reefs, from mysterious, powerful, resilient and treacherous to fragile and susceptible to harm from everyday human activity. Wolves, sharks, whales and even gorillas, once feared and vilified, are now widely viewed as threatened beings that should be prized and preserved as part of the natural world. Just as many biologists feel compelled to defend the predators they study, production of scientific knowledge about reefs now very often goes hand-in-hand with activism for their preservation.

It may be possible to extend this comparison between predators and reefs to include other dangerous or extreme environments and locations such as high altitudes and polar latitudes. The phenomenon now known as the 'rainforest', which is often likened ecologically and metaphorically to coral reefs, has traced a similar arc in Western cultural history. When 'the jungle' was largely unfamiliar and Europeans who encountered it were at comparatively high risk, it seemed both threatening and magnificent.[22] Now that rainforests are (like coral reefs) being damaged by human activities ranging from resource extraction to pollution, they are seen as threatened rather than threatening and have become the object of widespread environmentalist concern.

The narrative I have sketched in this paper suggests several reasons why coral reefs can now seem so benign. Technological changes in navigational instruments and watercraft, as well as the development of weather prediction, sonar and air travel, have reduced the risk that reefs actually pose to human activity. The result of nineteenth- and twentieth-century exploration and mapping is that the circumstances of tropical seafaring are now quite different from what they used to be (although, to be sure, there are plenty of modern boats and tankers stranded upon the world's reefs). Finally, there is ample evidence that the number and extent of healthy reefs is in decline and that a variety of human activities on the local and global scales have contributed to the deteriorating situation. All these features would seem to apply equally well to the histories of animal predators: technology made humankind less vulnerable to predation, and changes to human activity and

22 On Western notions of the 'tropical jungle' and the 'rain forest', see Stepan 2001, Enright 2012.

to the environment mean that fewer humans are placed in harm's way, even while the existence of the predators themselves is threatened.

My purpose in this essay has been to explain why it is no coincidence that coral reefs have occupied a place in culture similar to that of the large animals who make (or made) humans their prey. When coral reefs entered the Western cultural consciousness, their status was precisely that of a mysterious and elusive predator, one that lay in waiting to consume humans, one boatload at a time. Their very name records this fact. The word 'reef' simply referred to any shallow-water area that presented a threat to navigation. 'Reefs of coral rock', or 'coral reefs' as we now call them, were by definition navigational hazards made of or by corals. If our ears were still attuned to this general meaning of reef, 'coral reef' would sound just as ominous as 'man-eater' once did. The Western history of oceanic reefs is inextricable from the way they were encountered and, when encountered in wooden-hulled ships in unfamiliar places, they were no less threatening than the real and imagined beasts in an unfamiliar jungle.

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