Ocean Thinking

The Work of Ocean Sciences, Scientists, and Technologies in Producing the Sea as Space

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ABSTRACT: How do scientists produce the ocean as space through their work and words? In this article, I examine how the techniques and tools of oceanographers constitute ocean science. Bringing theoretical literature from science and technology studies on how scientists "do" science into conversation with fine-grained ethnographic and sociological accounts of scientists in the field, I explore how ocean science is made, produced, and negotiated. Within this central concern, the technologies used to obtain data draw particular focus. Juxtaposed with this literature is a corpus by ocean scientists about their own work as well as interview data from original research. Examining the differences between scientists' self-descriptions and analyses of them by social scientists leads to a productive exploration of how ocean science is constituted and how this work delineates the ocean as a form of striated space. This corpus of literature is placed in the context of climate change in the final section.

KEYWORDS: anthropology of science, climate change, oceans, oceanography, science and technology studies, sociology of science, space and place

Thinking about the Ocean

> "When I think of climate . . . it's very much shaped by, I think, my ocean thinking . . . "

When I asked a paleoceanographer about changes in the climate around southern Iceland, he answered by referencing ocean circulation patterns and the layering of subtropical and subpolar waters.[1] What this answer highlighted was the pivotal role of the ocean in the functioning of Earth systems. Awareness of and information about this role are the fundamental contributions of ocean sciences to human knowledge about Earth. In bringing together work on oceanography in science and technology studies with the sociology and anthropology of ocean sciences, this review article draws into view the ways in which science is implicated in organizing, classifying, exploring, and exploiting ocean space. Ocean sciences are approached as multidisciplinary endeavors that incorporate geology, hydrography, physics, chemistry, biology, microbiology, climatology, engineering, and paleontology. This article attends to the plurality of disciplinary structures that make up "ocean science," examining its divergent practices, epistemologies, and ontologies; its biologies, geologies, and coastal hydrologies; and the multivariate disciplines at work in producing science at sea. Following the interconnections of water, which can harden to

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ice or run from rain down mountains into rivers and lakes and then out through deltas into the seas, oceanography is linked to hydrology, glaciology, and delta studies, and these sister sciences are also drawn into this analysis.

Sociologist John Hannigan (2016: 15) has argued that through the works of ocean scientists, the ocean is constructed as an undifferentiated mass, a smooth surface to be delineated by human action (see also Steinberg 1999). Drawing on poststructuralist philosophers Gilles Deleuze and Félix Guattari's (1987) theorization of space as produced via human action in defining it as either striated or smooth in a dialectical relationship, Hannigan (2016: 12–15) develops four cultural narratives about the geopolitics of oceans: sovereignty games, governing the abyss, ocean frontiers, and saving the ocean. Hannigan locates ocean scientists primarily in the "saving the ocean" narrative, perceiving the ocean as a distinctive and imperiled ecology that they feel responsible to produce information about, especially concerning the anthropogenic impacts on fragile marine ecosystems. While noting that ocean scientists participate in the remaining three narratives, Hannigan describes oceanography as a "crisis discipline" with the notion of saving their subject matter embedded in the fundamental fabric of science (16).

Critical human geographers describe the seas as "maritime assemblages," both affective and haptic, that defy and undermine classification and categorization (Steinberg and Peters 2015: 250). Recognizing that, Philip Steinberg's (2001: 6) "territorial political economy" perspective on how different groups construct ocean space as social space informs the argument of this review article. Through defining what remains undefinable, ocean scientists engage in the fluidity of power in maritime space, a place in continual formation. Oceanographers try to overcome the unpredictability of the ocean through models, maps, and specialized technologies: they aim to render the ocean predictable (3). Science is situated in a reciprocal and mutually constitutive relationship with commerce, industry, transportation, and the military, all of which use the ocean and need to know about its actions and conditions. The ocean is a space perceived, used, and abused by different social actors, and is a geophysical actor with political agency in itself (Lehman 2013). The actions of scientists in measuring, modeling, and mapping the ocean are thus pivotal in this multivariate production of ocean as space.

The literature that this article draws together is therefore a confluence of social studies of science at sea framed by the work of Hannigan and Steinberg. The discipline of social studies of science began through delineating science as a social process, structured by paradigms that determine which questions are worth asking, indeed are possible to ask, and the criteria through which answers are evaluated (Kuhn 1962). Refusing the notion of pure science—that is, a science free from society and its norms, assumptions, and irrationalities—social scientists ask how scientists come to know what they know, what is understood as science, and what on the other hand is excluded from this domain: in short, how modern science has been invented (Barnes and Edge 1982; Collins and Evans 2007; Haraway 1991, 2008; Knorr Cetina 1981, 1999; Latour 1987, 1999; Latour and Woolgar 1986; Rabinow and Dan-Cohen 2005; Stengers 2000). Yet, these studies remained for the most part lab-bound and terrestrially privileged, neglecting the fluid power dynamics that science at sea involves.

Ocean sciences emerged from the vortex of nationalism, extractivism, and imperialism spun by the expansion of colonial frontiers across the seas. The singular "discovery" of fifteenth-century ocean-bound adventurism was the feasibility of direct seagoing routes between continents (Rozwadowski 2019: 71–72). Knowledge of ocean space enabled the emergence and consolidation of imperial power and colonization by European nations, entailing a shift from experiential understanding of local seas by coastal peoples to a systematized methodical study of the aquatic world. Control of resources and territory, so central to national projects of colonialism and competition, relied on the various disciplines of ocean science and its specialized technology from the outset. Scientists were part of the construction of the ocean as knowable, traversable space. Colonial authorities funded science that enabled imperialism in a reciprocal, mutually enabling relationship (101–102).

The question of whom science operates for, who and what is developed, and which "others" are rendered as objects is neither trivial nor a distraction from the real work of science (Harding 1991). Scientific reductionism obscures how humans and nonhumans co-participate in knowledges, privileging white, male languages that enforce certain translations and conversions (Haraway 1991). Acknowledging the place of scientific development in advancing colonial interests and causing ecological damage, as well as diagnosing and mitigating it, is the hard, necessary work of salvaging science from capitalist-captured techno-science (Plumwood 2002). For social scientists, acknowledging the theoretical potential of the sea shifts "natureculture" to "nature/culture/seawater" (Haraway 2008; Helmreich 2011). While acknowledging the double estrangement between the hard/natural/exact sciences and the soft/human/social sciences (Segal 2001), the circulation of knowledges, practices, categories, and statuses of science at sea transgress and transcend simplistic oppositions of hard/soft, natural/human, and nature/culture.

In this article, Hannigan's themes are employed to organize works from history of science, science and technology studies, and the anthropology and sociology of science that explore how ocean science enables and encourages sovereignty claims and disputes, marine governance, resource exploitation, and frontierism while maintaining a self-image as saving and preserving the ocean. While these themes overlap, this organization highlights the extensive complicity of ocean sciences with the human use and abuse of marine environments alongside the countervailing theme of oceanographers as self-appointed guardians and protectors of the deep-sea wilderness. The section on saving the ocean focuses on ocean scientists and their accounts of their own research to contrast with the previous three sections summarizing the literature on ocean sciences in science and technology studies, anthropology and sociology, and history of science. The final section homes in on the current ecological devastation wrought on the ocean by human activity through the impacts on coral reefs and Arctic sea ice. In this section, the intersubjective relationship between ocean scientists and their subject matter is the central theme in order to contextualize and complexify the contrast drawn through the previous sections. The social studies of ocean science explore the complexities of how scientists produce science, particularly the ways in which the effects of their work can often deviate from their intentions.

Knowing the Ocean: Drawing Liquid Lines

The sea as a space on which nation-states project and contest territorial boundaries is the theme of Hannigan's narrative of sovereignty games (2016: 77–104). The sheer extent of ocean mass challenges any act of drawing boundaries, through both planetary and extraplanetary forces that compel movement, rapidity of changes between physical states, and massive volume (Steinberg and Peters 2015: 254). How space is transformed into territories goes beyond terra (Peters et al. 2017). Ocean scientists have been involved and implicated in the pyrrhic task of drawing lines in the liquid mass of the seas. For the seas to be marked as territory requires processes of deterritorialization and reterritorialization, practices that make territory out of sea (Phillips 2017: 54–59). As ocean science emerged from seafaring, its history is intimately interconnected with Anglo-American colonialism and imperial expansion.

Historian of science Helen Rozwadowski writes a history of sea from the ocean's perspective, and humans make an appearance by the second chapter, after billions of years of oceanic biota evolving without us (2019: 36–39). For much of human history, a systematic method of knowing the seas was not deployed outside of local practices of fishing, canoeing, and water-entangled subsistence. Important antecedents of Western oceanography can be traced through the marine biological observations of Aristotle and the experimental work of seventeenth-century natural philosophers such as Robert Hooke. As long-distance seafaring increased through the fifteenth to seventeenth centuries, maps and cartography were of central importance, which led ships to include specialists who became the first hydrographers in nineteenth century; their work changed the seas from a place of monsters to blank blue space on maps (79–86). By the eighteenth century, Captain Cook's inclusion of botanists Joseph Banks and Daniel Solander on his first voyage cinched the enmeshment of seafaring, biology, and colonial expansion, symbolized by the naming of their landing place in Australia, "Botanist's Bay" (later Botany Bay), after Banks and Solander (98–99; see also Jones and Jones 2009; Richardson 2005)

The early nineteenth century saw the professionalization of Anglo-American science by what historian Philip Rehbock calls the "philosophical naturalists."[2] Edward Forbes and Charles Lyell in the 1830s and 1840s were examining fossils brought up on dredging missions along the coasts of Britain, making connections between marine zoology and geology, laying the seeds of modern ecology and paleoecology (Rehbock 1983: 138–139). Charles Darwin boarded the HMS *Beagle* in 1831 to build on Lyell's theory of gradual geological change and established the seas as an essential site for biological fieldwork (MacLeod and Rehbock 1994). Thomas Henry Huxley, pulling double duty aboard the HMS *Rattlesnake* as surgeon and naturalist, helped advance Darwin's theory of evolution through establishing the existence of Ernst Haeckel's category of Protista, eukaryotic organisms that are neither animal, fungus, nor plants, which he posited as the origins of organic life (Rehbock 1975). Predecessors of ocean scientists were such dredgers, explorers, hydrographers, submarine telegraph engineers, marine naturalists, and yachts people engaging in increasingly systematic studies of the contours and contents of undersea worlds from 1840 to 1880 (Rehbock 1979; Rozwadowski 2019: 104–129). However, Rozwadowski (1996, 2005) pinpoints the emergence of oceanography to the 1880s and 1890s and the maritime nations of the United States and the United Kingdom.

The boundaries of the fledgling discipline were delineated by the HMS *Challenger* expedition of 1872–1876, in which space was made on an oceangoing vessel for scientists to work side by side with the crew for the first time. The physical structure of the ship was rearranged, and so was the social structure of the crew, with the addition of middle-class scientists viewed by sailors as "idlers." The different interests and expectations of crew and scientists were already present on this first voyage, as tensions emerged between the need to maintain the seaworthiness of the ship and the desire to collect scientifically valuable data. Subsequent voyages throughout the last decades of the nineteenth century cemented the need for crews, especially navigation officers skilled in hydrography, to work with the new scientific class to develop techniques for sounding and dredging the oceans.

Questions of whether anything lived in the dark ocean beyond the coastal zones (the azoic theory of ocean life) were put to rest when dredging equipment pulled living marine animals up from the depths. The ocean was suddenly no longer an empty, unknowable abyss. It became demarcated as a space to be probed and known, indirectly, through proxy instruments able to take samples. Even then, the seas were compared to the harshness of Arctic expeditions, and the unfamiliarity of the depths to outer space, with deep-sea sounding pioneer Matthew Fontaine Maury comparing the behavior of the Gulf Stream to the orbit of the planets (Rozwadowski 2005: 29–30). The imperial maritime nations saw economic benefits as motivation to fund oceanographic expeditions, such as information about the shores of their colonies and the decline of fisheries, particularly whaling. From its outset, then, oceanography was implicated in producing knowledge that would be useful for exploiting marine life and diverse peoples of the world, benefitting Anglo-American interests through making objects of study of those forms of life identified as nature.

From the late nineteenth to the early twentieth centuries, oceanography became an established Western academic discipline through the creation of institutional centers: the Scripps Institute of Oceanography in La Jolla, California, in 1903; the Woods Hole Oceanographic Institute in Woods Hole, Massachusetts, in 1930; and the Marine Biological Association in Plymouth, England, in 1884. The World Wars then went on to prove the utility of ocean science to the military. From a strategic standpoint, the ocean was a dangerous environment to leave unknown, and ocean scientists earned their keep by developing methods to detect enemy submarines. The entwinement of military needs, governmental policy, and ocean science continued after the war as the Cold War required improvements to anti-submarine technologies, surveillance techniques, and undersea communication (Hamblin 2005; Laughton et al. 2010; Oreskes 2003; Robinson 2018). The US Navy funded ocean science in this period for instrumental reasons, viewing the data it produced as central to national security, often in opposition to scientists' own opinions of the utility of their work (Hamblin 2002). In contrast to the military focus on the seas as space in which nationalist claims are staked, the financial and institutional support given in return for these applications allowed for the creation of large-scale international scientific networks to expand and elaborate the practice of oceanography.

The involvement of science with such territorial claims is illustrated in the case study of the SEALAB experiments (1964–1968), during which "aquanauts" were living and working in underwater habitats for up to 45 consecutive days, under the continental shelf off the coasts of Bermuda and California. Calculating the volume of the sea as a three-dimensional space was very important to the US Navy and the Office of Naval Research during the Cold War, as they perceived it as an unknown space full of hiding places for the enemy (Squire 2017: 221). Rachael Squire interprets the experiments as a territorialization of the seafloor and waters, an occupation of the sea as US military territory that went beyond mere control of space for communication and transportation. SEALAB scientists explicitly framed their work as a continuation of frontier expansionism in American history, in which the sea was both fascinating and extraordinary, its exploration and territorialization both necessary and inevitable.

The cross-fertilizations of science, scientists, nationalism, and territorialism is most potent in the histories of oceanography in the United States and the United Kingdom. Furthermore, edited volumes on the place of technology in the development of ocean science and the development of oceanography spreading out from the Pacific add important global perspectives (Benson and Rehbock 2002; Rozwadowski and van Keuren 2004). Other nations with different political priorities have cultivated ocean scientists for their own, not necessarily colonial or territorial, purposes. Yet, those who attempt to draw lines in the sea often find those efforts complicated by law, geophysics, and ocean political ecologies.

Governing the Ocean: Technologies of Management and Governmentality

National interest in controlling ocean boundaries is tempered by international agreements and laws that attempt to regulate human activity on the seas that aim to manage it as a public commons, available to all but owned by no one (Hannigan 2016: 50–76). A concomitant need for "management" of the oceans arose in the mid-twentieth century onward, with marine governance developing as a subdiscipline and the institution of marine reserves as an aquatic equivalent of terrestrial nature reserves (Claudet 2011). These were places marked out for conservation and preservation, despite the fluidity and connectivity of marine flourishing that shifts organisms in and out of protected zones. Rather than thinking of the ocean as a boundless living thing, Western governance regimes construct ocean space as an aquarium, organized and subject to the rationalized, totalized control of human technological systems (Pálsson 1998). For example, accessing more than a few feet underwater requires technology to overcome the physical limitations of humans as terrestrial-bound, oxygen-dependent mammals. From its outset, oceanography has required nets and boxes that could be dropped under the surface, dragged along the seafloor, and drawn up to inspect whatever could be found (Earle 2005: ix). Now a network of satellites beams images of the ocean depths up to space and then back down to Earth to be processed by supercomputers far beyond the data holding capacities of the early ships' logs. This technological foundation of marine governance implicates oceanographers in its realization.

A principal means of gathering such data on marine environments is research vessels. An early anthropological analysis of the activities of ocean scientists juxtaposed ethnographic material with numeric data to describe the social structure of a research vessel. In some ways echoing Rozwadowski's observations from the historical literature on the introduction of oceanographers on to seagoing vessels, H. Russell Bernard and Peter Killworth (1973) analyzed the difficulties that emerge between crew members and scientists while living at sea. Betraying their own assumptions, conflict is concluded to come from having two leaders (the captain and the chief scientist) when the cultural norm is one, and from the mixing of classes that tend toward segregation. Bernard and Killworth (1974) followed up with a further field study on board a vessel in which they again described a class conflict between intellectuals and workers that was dealt with through complaining, practical jokes, and systematic physical separation of scientists and crew during the day. The authors then produced a summary of their studies on ocean scientists, describing how others see them—not only the crews of research vessels but also government policy makers and their colleagues in the Global South. Perhaps the most revealing passage is where Bernard and Killworth (1977: 267) relate the response to their own work from marine scientists, which was often angry and dismissive. One scientist contacted Bernard with apologies that Bernard's year doing ethnography at Scripps was "unproductive and disappointing." Another published an editorial in *Nature* calling anthropology "flagging," reproducing what was contained in the news release about the article without having read the article itself (Anonymous 1975). Bernard and Killworth incorporate these reactions as data that support their thesis that others often see scientists as "remote, withdrawn, conventional, arrogant, aloof, and unresponsive to other people's needs," even if this is the opposite of how scientists often see themselves.

Work by anthropologists and sociologists of marine science illustrates how science is produced through ocean-human-technology relations. In proposing a maritime sociology or a "sociology of oceans," the first observation made by sociologists is often that their discipline has not paid much attention to the ocean, treating it as an extension of terrestrial social systems (Cocco 2013; Hannigan 2016, 2017; Longo and Clark 2016; Longo et al. 2015). Yet, the human dimension is an important part of addressing complex marine ecological concerns in these authors' works. While Hannigan concerns himself with a discursive analysis of oceanic geopolitics, Stefano Longo et al. (2015) go further with a critical, Marxist-inspired metabolic approach, which leads them to conclude that the contradictions between the need for constant resources to fuel economic growth in a capitalist model and the requirements of natural ecosystems to continue to flourish are so perverse that attempts at "sustainability" are mostly pointless. This perspective renders recommendations for improving policy and infrastructure as effective as the management of chair locations on the deck of the *Titanic*. Instead, for them, only wholesale socioeconomic change will suffice.

The work of ocean scientists provides the data that the emergent marine sociology analyzes to understand ocean-human-technology relations. There is a critical look at the human side of that interaction, but so far little attention has been paid to "ocean science" itself within sociology: it is taken sui generis as useful information from which to launch sociological analyses. By contrast, the analytic lens in anthropology has been shifted to explicitly inspect how ocean scientists do their work, as already indicated by the work of Bernard and Killworth (1973, 1974, 1977). The most significant body of work in this regard has been produced by Stefan Helmreich (2003, 2007, 2009, 2011, 2016). Describing the work of marine microbiologists and narrowing in on the microbial life of the ocean, Helmreich opens up the bounded self-understanding of marine microbiologists through examining how cultural beliefs about the ocean inflect oceanography. Microbiologists render the ocean as both enabling and constraining, in Helmreich's account, a space of "promise and apocalypse" (2009: 15). The ocean's uncertainty undermines the fundamental classificatory power that science claims, and in its deepest reaches, it becomes a model for extraterrestrial life (Paxson and Helmreich 2014). The ocean as another world entirely calls for its own form of Foucauldian governance, a symbiopolitics as well as a microbiopolitics, "the governance of relations among entangled living things" (Helmreich 2009: 15). This is an account of oceanic governmentality leagues away from the promise of improved policy and infrastructure on the one hand, and the Marxist diagnosis of fatal contradictions within capitalism on the other.

During the course of interviews with ocean scientists, this process of balancing sentimental, sensory, and technical ways of knowing marine environments became apparent. A marine biologist by training, who in his later work focused on the governance of marine-protected areas, described to me how he produced a taxonomy of 36 possible objectives for marine conservation that evolved through 50 (to date) case studies of how to incorporate the objectives into a governance framework. Although he started off in the biological sciences, he came to realize that more research on ecology was not going to tell him why some marine-protected areas worked and some did not, so he had "unwittingly" become a human geographer. He disdained the notion that science could operate freely from politics, calling this "a delusion of separation," and saw governance as incorporating every aspect of planning marine protected areas, including the science. This put him at odds with some of his more disciplinarily rigid colleagues in marine biology. For him, the only way to understand how to conserve marine areas was to incorporate science alongside politics. He approached conservation through a pragmatic and anthropocentric lens. Protecting the oceans for him meant ensuring that it could continue to deliver more services and resources for humans.

Mining the Ocean: Exploiting Vast Pools of Resources

The ocean as a frontier space to be explored in order to be exploited as a source of resources, wealth, and sustenance for humans has been a driving motivation behind scientific investigation of the seas (Hannigan 2016: 19–49). Oceanography is a key part of a stewardship model for the exploitation of ocean space (Steinberg 2001: 176–180). In this model, the resources of the oceans need stewarding by nation-states, international organizations, and scientific agencies for the common good, managing risks such as pollution and overfishing while enabling extraction. The ocean is seen as rich in resources but also a fragile ecosystem with a delicate balance. The exploitation of ocean resources is tied to territorial claims, as well as systems of international governance, as the United Nations Convention on the Law of the Sea grants coastal states the resources below their surrounding waters, such as food and minerals, but holds that the water column, abyssal plane, and seabed beyond the continental shelf are unclaimed commons. This framework positions the high seas as a "space of salvation" with untapped wealth for the betterment of humanity (Squire 2017: 224).

The information produced through the ocean sciences is central to efforts to tap the perceived riches of the seas. Data about the ocean's surface, temperature, plankton blooms, wave height, and the migration patterns of large sea animals can be harvested through sensors and satellites, yet less than 5 percent of the ocean below one hundred feet has been sensed. Blind sampling with nets, trawlers, and dredging equipment has been replaced with direct observation by submersible and ship-based sampling, which in turn has been superseded by remote and robotic sensing (Lehman 2018). Oceanographic knowledge has always depended on interactions between nonhuman animals, technologies, water, and humans, but the form of those technologies changes how that knowledge is produced. Remote sensing and robotic proxies grant new opportunities, yet they shift how the ocean is represented (Marlow 2019). It has become more abstract, physically distant from scientists, yielding fewer direct sensory engagements.

Much of the data yielded from these engagements goes to managing, developing, and maintaining fisheries. The major contribution of maritime anthropology thus far has been the development of an anthropology of fishing (Acheson 1981). This relates to ocean science when differing expectations, complexities of translation, and problems of representation are drawn out through anthropological research. The ambivalences of extraction, the implication of conservation with exploitation, are explored. Anthropologists have studied, for example, the conservation attempts of marine biologists working with scallops and fishers in Saint-Brieuc Bay, France (Callon 1984). The needs of fishers to extract from the waters, even through the use of dynamite and cyanide, also bring divergent ways of knowing into conflict in Indonesian coral reefs (Ammarell 2014). The exclusion of fishers' knowledge in the scientific quantification of fish stocks occluded the declining value of those stocks, to the point where the collapse of the Newfoundland fisheries was a shock to scientists but not to fishers (Bavington 2010; Finlayson 1994; Telesca 2017). Who and what is invasive—lionfish or fishers—in the eyes of international fisheries science also comes into question in marine management in the Bahamas (Moore 2012). And similar to how marine biologists attempt conservation, fishers attempt to pursue their livelihoods on the seas, and biodiversity attempts to survive offer conflicting overlaps and intersections (Lowe 2006). Extraction of the ocean's resources for both scientific and subsistence purposes continues, unabated, often with disastrous impacts.

The necessity of exploiting ocean resources for survival drives the daily lives and social habits of diverse peoples along rivers and their deltas, on coasts and islands, and at sea (Hastrup and Rubow 2014; Krause 2017; Rasmussen and Orlove 2015; Wagner et al. 2018). The cognitive approaches of those who make their lives navigating at sea offers alternative ways of knowing water to scientific methodologies (Genz 2014). The way in which scientists are able to conceptualize water and its creatures is often at odds with other perspectives. In naming her haptic-optic approach "fingeryeyes," Eva Hayward (2010) is able to bring out her multisensory interaction with cup corals in a way the marine biologist she shared a lab with was unable to voice in her published work. Marine biologists, in particular, continue to engage in close, sensory relations with their aquatic subjects in ways similar to those making their lives through intimate, everyday interconnections with the waters.

By naming such interconnections local/traditional/indigenous ecological knowledge, anthropologists have been able to hold in tension the varying perspectives of indigenous peoples, fishers, and local governmental managers with that of ocean scientists (García-Quijano 2007; Johnsen et al. 2014; Lauer and Aswani 2009; Walley 2004). For whalers and whale biologists on the Alaska North Slope, Inupiaq and scientific worldviews were found to be mutually useful while retaining distinct cosmologies (Bodenhorn 2012). However, it is not as simple as demarcating local ecological knowledge and scientific knowledge production along a subjective/objective axis, critiquing the assumptions of the latter. Antarctic glaciologists form intimate, sensorial relationships with the shifting, unpredictable, and hostile environment they work in, when modeling that environment digitally as well as engaging with it physically through fieldwork (O'Reilly 2016). Having a sense of the ice allows glaciologists to anticipate the future behavior of the ice sheet, which informs how they do their work even as it is written out of their final published accounts.

Complex computational models are part of the development of material infrastructures for ocean science that has allowed for a shift away from coastal fisheries to extraction from the deep ocean, as has the shift from people and ships to robots and satellites. Deep-sea ocean engineering is a techno-science at its core, requiring not just individual pieces of technology but also networks of cables and sensors, as well as institutional cooperation at national and supranational levels, and between scientific, governmental, commercial, and military agencies (Berkowitz 2014; Steinhardt 2018; Steinhardt and Jackson 2014). In her study of the US Ocean Observatories Initiative, Stephanie Steinhardt (2018) has delineated the material pushbacks against these infrastructures, inhibiting their ability to deliver consistent data. The physical hostility of the ocean renders many technologies impotent, yet oceanographic funding bodies and program managers consistently emphasize technological sustainability at the expense of labor and human sustainability. The human costs of ocean science, including sexual harassment in the field, high levels of turnover and overwork in a precarious academe, and the vicissitudes of career-building in a competitive professionalized discipline all impinge on infrastructure plans as much as marine mammals negatively interacting with underwater cables. The limits of techno-utopianism means that robots are sometimes taken better care of than are human scientists, and research goals are directed toward resource outputs, privileging, for example, anything that will impact fisheries or energy exploration.

The overreliance on technology means that when a massive error occurs, such as the explosion of the *Deepwater Horizon* deep-sea oil rig, the ocean itself becomes a scientific laboratory to manage and master hydrocarbons, an experimental cleanup space for the sequestration and inspection of oil (Bond 2013). *Deepwater Horizon* was operated by a Swiss company on behalf of a British petrochemical conglomerate, under lease from the US Minerals Management Service, following lax regulations for drilling in US waters, with the US federal government left to clean up, suggesting the conflicts of zonation that occur when the ocean is seen as a space of resources to be used for the public good that are extracted by private corporations seeking to make personal profit (Steinberg 2011).

Deep-sea engineering is behind a growth area of mining and resource extraction: deep-sea mining (DSM), a form of remote mining (Jacka 2018: 71). The techno-science of deep-sea engineering is the foundation of the so-called blue economy, extracting resources for accumulating wealth and economic development from the deep seas, in which the legitimacy of private use of ocean resources calls into question the concept of social license to operate developed through corporate social responsibility approaches to terrestrial mining (Voyer and van Leeuwen 2019). For example, the first "experiment" in DSM, the Solwara 1 area off the coasts of New Britain and New Ireland, is unlikely to cover the cost of exploration or the development of new technologies required to extract the minerals, making it profitable for Nautilus Minerals, the Canadian mining company, but not for the people of Papua New Guinea (Filer and Gabriel 2018). The exploitation of this 0.1 square kilometer deep seabed will last only two to three years before it is exhausted, fueling the development of specialized "ploughs," "trenchers," and computers that form a human/nonhuman/technological assemblage that compresses space-time by pumping up in minutes mineral-rich ore formed over millions of years (Childs 2018).

The raw data produced about the ocean is now so vast that no single person could interpret and manipulate it by themselves. Computer models form the analytical technologies of much of what constitutes ocean science today. Data is used to construct scenarios that are projected far into the past and future, compared with other numerical simulations of Earth's ecosystems to construct numerical-computational-social collectivities (Sundberg 2010, 2011). Yet, these collectivities always contain black boxes, called uncertainties or forcings. They also produce a certain weirdness, like the ice sheets always drawn as squares not as the natural Antarctic topography (O'Reilly 2016: 36). Or take the storm surge model built by a Danish PhD student I spoke to at a conference in Brussels who saw the coast as a flat plane or wall because she was yet unable to incorporate hydrological data. The straight lines of models chafe and bruise the fluidity and mobility of the ocean (Steinberg and Peters 2015: 253). Modelers know their models are always approximations, and they know when they are fudging (Hastrup and Skrydstrup 2013). Yet, glaciological modelers retain a similar sensory appreciation toward ice as field scientists (O'Reilly 2016: 37). Models provide a different rendering of data, which can be put to different uses than observational data. The proliferation of models speaks to a need for certainty and predictability as a return on investment for the high costs of developing and funding ocean science. In the context of rapid ecological extraction, pollution, and change, such models take on new prophetic valences. They are asked to tell us the future.

Saving the Ocean: Protecting Marine Wilderness

The frontier mentality of some scientists working at sea has been tempered by a growing environmentalism, especially since the 1980s (Rozwadowski and van Keuren 2004: 317–318). The desire to save the ocean, to preserve it as space for biodiversity, even wilderness, is strong in scientists' self-presentations of their work (Hannigan 2016: 105–134). Ocean scientists writing about their own ways of knowing, learning, and gathering fragments of the ocean from which to extrapolate theory tend to focus on this theme when they write for the public, while also giving a glimpse of the sensorial and intersubjective elements of their methods. Ed Ricketts was a marine zoologist without a university degree who paid homeless people to collect samples for him from the shores of Monterey Bay, California. *Between Pacific Tides* (Ricketts and Calvin [1939] 1985) is considered a classic work of marine biology, a guide to marine invertebrates of the North American Pacific shore. Categorizing the animals by habitat rather than phylum or family gave the work an ecological rather than taxonomic organization, starting from the uppermost oceanic zones and then proceeding into the depths. Ricketts offers a subjective and experiential perspective, sharing sympathetic inferences of animal experience, such as the enthusiastic behavior of hermit crabs. By prioritizing his subjective interaction with marine invertebrates, Ricketts provides an account of how a scientist engages sensorially with the creatures he wants to know better. He both smells and tastes the invertebrates, mirroring the haptic-optic approach that Hayward employed decades later (2010: 585). While he did not use the term, Ricketts gives an account of what Hayward calls fingery eyes, in a way that if he were professionalized he would likely not have dared to print.

While expressing less sensory engagement, Rachel Carson's *The Sea Around Us*, part of a trilogy of works on the ocean, gives some glimpses of what the instrumented ocean (with a nod to Steinhardt 2018) can offer to the imagining of the deep sea. She describes how in 1860 the sounding line of the HMS *Bulldog* plunged 1,260 fathoms to cut through the notion that the ocean was lifeless, revealing 13 starfish that hinted at a "living cloud" of mysterious creatures swirling the depths (1951: 37–38). As with the scallops in Saint-Brieuc Bay (Callon 1984: 214–219), a tiny piece of data, 13 echinoderms, stood as a proxy for something much larger and, until that point, unknowable. The soundscapes evoked by Helmreich (2007) are referenced in her description of how echo sounding allowed ships to listen for the bottom of the ocean floor, a technology that was implemented to further military and economic ends. This was not the silent world romantically depicted in the earliest days of scuba diving (Cousteau and Dumas 1956).

What Hannigan (2016: 15–16) would identify as a saving the ocean "grand narrative" is in full force in Sylvia Earle's (1995) *Sea Change*, in which she explicitly uses the story of her work as a marine biologist to advocate for better stewardship of ocean resources. Highlighting overfishing, coral bleaching, pollution from agriculture, plastics, and oil spills, Earle diagnoses a tragedy of the commons on a grand scale. The solution to the problem she presents is dissemination of accurate information produced by scientists. Unlike Carson's poetic discourse, the language is economistic, echoing my own interviews with ocean scientists discussing the human impacts on the oceans, referring to the environmental capital of ocean resources. There is an overlapping of the ocean as space of resources and as a space of preservation in Earle's work. The ocean is worth saving because it has things that humans need.

Alexandra Morton (2002) values ocean life for its own sake as she describes a sensory engagement with her subject, orcas and other whales, shifting her life to the cetacean rhythms, living in Echo Bay, Canada, listening to them on a hydrophone, recording their sounds, and watching them interact with the world around them. After 25 years studying orcas, she expresses hope that she will not watch them die out. Their large brain size—her initial puzzle, given the high oxygen cost for animals that live underwater—allows for long accurate memories, complex relationships, and use of language and even dialect between family groups. Falling into the saving the ocean narrative, she calls for the extension of rights of personhood to cetaceans, criticizing anthropocentric assumptions of consciousness based on terrestrial models of intelligence.

Aaron Hirsh (2014) similarly argues for marine conservation from an ethical standpoint. In his account of taking a group of students on a summer field trip to the Vermilion Sea in Baja California, Mexico, he witnesses the degradation of the marine environment that he has known over time caused by the familiar human culprits of overfishing, commercial development, and pollution. It is telling how easily anthropogenic impacts are rendered passive in scientists' accounts, as if humans killing and eating too many fish just happens, an inevitable consequence of our existence, rendered in that simple term "overfishing." Yet, Hirsh holds out hope for narrative: more than simple conveyance of accurate information, he wants to find a role for telling healing stories about damaged places, a way to still feel transcendence in nature despite the degradation.

Many scientists write about their work for popular audiences online. It is relevant to include climate scientist and modeler Tamsin Edwards's aptly named *All Models Are Wrong* blog. Edwards (2019) elaborates on the importance of uncertainty in the production of scientific knowledge, which she names "polar thinking," holding two apparently contradictory possibilities in mind at the same time. Weaving her story about writing an article assessing the accuracy of models projecting Antarctic ice shelf collapse and its contribution to sea level rise with her concurrent personal challenges, she intersperses her text with emails from *Nature* about the progression of the article as she submits and resubmits, and emails to and from friends and family about a suspected case of irritable bowel syndrome that turns out to be a colon tumor and her subsequent chemotherapy treatment. These two story lines incorporate both bad and good news. Edwards recounts how she was unable to unravel the Antarctic article from the cancer diagnosis, and in the process, gives a valuable glimpse at the personal travails that scientists must negotiate as they produce knowledge. At the end, she invites her readers to hold the two possibilities simultaneously: The cancer either comes back or it does not; the ice sheet either collapses or it does not. Contradictions can be held, at least until there is further observational data to confirm the outcome.

Feeling the Ocean: Sensing Intersubjective Depths

Tension between knowing and not knowing, between living and dying simultaneously, permeates scientific work as climate change progresses. Its impacts accumulate, ample data proves the trends, yet a solution remains resolutely out of scientists' control, in the sloppy, woolly world of the social. Environmental scientists' accounts reliably begin with their excitement at doing their work only to be tempered and undermined as that work is lost, species going extinct before they can be classified or counted (Kolbert 2018; Terborgh 1999; Turvey 2008). I turn now to two specific threats to the ocean—the melting of Arctic sea ice in the summer, and coral bleaching from rising temperatures—to survey how emotions and intersubjectivity have arisen in the literature as scientists recount the loss of the habitats they devoted their careers to studying. The gradual loss of Arctic ice in the summer months has shifted scientists to publicly state their fallibility and to explicitly state their emotional connections to what they study. To bring the immense loss painfully, sensorially home for those who may not be living in Alaska, which saw its surrounding waters warm 15 degrees Celsius more than normal in 2016, journalist Dahr Jamail (2019) tells us, "I have come to realize that only by sharing an intimacy with these places can we begin to know, perhaps love, and certainly care for them." Intimacy comes from admitting intersubjectivity, not simply presenting accurate data to raise awareness.

Ocean physicist Peter Wadhams powerfully attests to the potentially devastating effects a loss of Arctic ice could have for the livability of the planet, and that it is "a spiritual impoverishment of the Earth" (2017: 5). The urgency of the situation provides moral impetus for him to overcome the typical scientific reticence of giving personal, emotive accounts. It is a deeply raw subject for Wadhams, and his frustration rises from the page as he seethes about humanity's greed and ignorance. He does not temper his fire with hope: he states directly that "by now it is too late" to simply cut greenhouse gas emissions (192). The difficulty of achieving negative emissions is not as consequential as doing nothing, because "if we don't solve it, we are finished" (206). The register shifts from affective to millenarian. Wadhams is predicting nothing less than the end of human society as it is currently organized.

In general, scientists tend toward caution and conservatism, hedging until more data makes a theory stronger. That Arctic scientists make such pronouncements should itself be a signal of the seriousness of the situation. The process by which the knowledge that causes this alarm has been produced is outlined by Mark Serreze (2018), director of the National Snow and Ice Data Center. He describes how he did not confirm climate change as the cause of summer sea ice melt until sufficiently large data sets became available to prove long-term changes beyond natural variability. Acknowledging the susceptibility of scientific process to human subjectivity, he portrays scientists as fallible and the process of producing knowledge as prone to shifts, setbacks, and wrong turns.

A similar sense of pessimism emerged from my interview with a paleoceanographer who studied Arctic sea ice formation and North Atlantic circulation patterns. While he held out hope for negative feedbacks that could allow the sea ice to recover, he cited his "intuition from studying" to conclude the opposite: that the sea ice in the Arctic would soon be gone over the summer months. Interestingly, he referred to intuition here, that unquantifiable sense informed by years of working in this field. It suggested a personal, intimate relationship with his subject. He described a trip kayaking off the coast of Svalbard, an island in the Arctic Circle, looking at the ice and feeling "really sad . . . this is one of the most beautiful things . . . it was so tranquil and amazing, and it's gonna go." Pessimism also pervaded his sense of the political situation in the United Kingdom, where his university was based, which he felt lacked the "will" to change the level of carbon emissions on the scale required. Harking back to his first big international conference in 2006, and watching climate scientist James Hansen speak, he felt then that it was still a technical problem with a concrete solution that scientists could discover. But now he felt "we could solve global warming if we wanted" but that politics was not structured in such a way to allow that to happen. He likened it to poverty in the UK, which he thought could be solved if people wanted that, "but that isn't the way society works . . . There's too many people with vested interests." A career spent researching the complexities of ocean currents left him defeated when facing a social problem, concluding only that "society," "politics," and "we" were to blame for the impending doom he foresees.

The loss of vast ice sheets melting into the oceans is linked to tiny marine creatures through the devastating effects of increasing temperatures. Corals and coral reefs are now a potent symbol in the literature on ocean science of the declining health of the oceans, another clarion call to humans about the effects of their activity. The series of mass bleaching events, causing widespread dying of corals around the world, has caused an existential crisis among coral scientists (Braverman 2018). Irus Braverman classifies the coral scientists she interviewed along a "hope-despair pendulum" (2018: 3). Those who maintain hope to save the reefs advocate intervention through assisting corals to adapt by reseeding reefs and selectively breeding those with higher heat tolerance. They are predominantly younger women from more diverse backgrounds. Those who view the reefs as inevitably doomed consider this work futile, and advocate only preservation of the remaining reefs, attempting to rid them of human impacts. Both positions resound with an emotional intensity brought on by the gravity of the situation. Braverman locates the existential crises of coral scientists within a broader trend of the transforming role of the scientist. The "myth" of homogenous, objective science is no longer tenable; instead, coral scientists have been forced out of talking within their specialism to become spokespeople for the coral (16–17). The emotional register of this shift is clear in Braverman's comparison of coral scientists as people trying to "save a dying loved one" (22).

This emotional register was also apparent during the interview I conducted with a marine biologist based in Belgium. Working primarily on reefs in Indonesia, he had not yet seen bleached reefs himself, although the impacts of other human activities such as dynamite fishing and industrial pollution were readily apparent. The futility of efforts to save and restore marine ecosystems was weighed down further with a sense of debt because "the ocean saved us . . . from the very drastic consequences of climate change." If the oceans had not absorbed around 90 percent of the heat-trapping gases emitted by human activity, then we would no longer be able to live on land. He conceptually inverted the ocean from being a space saved by humans to a space that is actively saving us.

Social studies of science reveal how ocean scientists produce ocean space in multifaceted ways. In assisting military expeditions, scientists help create the ocean as an empty space bordering national territories. Through enabling extraction, they open ocean space as a vast pool of resources for human enrichment. In collecting data, they assist governance regimes. Yet, the self-presentation of ocean scientists in their work is as purveyors of accurate information that can help preserve and save the ocean. Social studies of science indicate how complex this desire to save the ocean is, given the coexisting entanglements of ocean science in extraction, nationalism, and governance regimes. The literature of the social sciences on ocean science muddies the waters of scientists' self-presentation as those who can produce accurate information to preserve and conserve the ocean's resources. The continued use of the ocean supported by the technologies and knowledges produced by ocean scientists produces the ocean as a space that will continue to be depleted.

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NOTES

1. Semi-structured interviews were conducted in person in April 2018 in the United Kingdom and in May 2019 in Belgium. Respondents referred to in this article were all university-based scientists studying various aspects of marine ecosystems, and I refer to them by way of their scientific specialization in order to maintain anonymity agreed prior to interviews. These interviews were part of a longer series of 35 interviews conducted for the European Research Council–funded NARMESH project, of which 15 were with environmental scientists.
2. See also the complete Phil F. Rehbock Papers held at the Online Archive of California, https://oac.cdlib.org/findaid/ark:/13030/c8cz3dfh/entire_text.

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