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THE SEA: THE CURRENT AND FUTURE OCEAN
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Advancing science from plankton to whales—Celebrating the contributions of James J. McCarthy

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1. Introduction: The Early Years

Hailing from Sweet Home, Oregon, where his father introduced him to the fascinations of pond water (McCarthy 2018), Jim McCarthy graduated from Gonzaga University, and in the late 1960s joined the Food Chain Research Group at the Scripps Institution of Oceanography, where he received his doctorate in 1971. The Food Chain Research Group, which was becoming recognized as the premier research group on plankton, was at that time directed by such distinguished scientists as John Strickland and Dick Eppley, among others. The goal of the Food Chain Group was to understand plankton dynamics and trophodynamics, "to a degree that will enable man to exercise satisfactory control of the environment and make useful predictions" (Institute of Marine Resources annual report, 1968, cited in Shor 1978:143) and "to predict the formation and transfer of nutrients through the full cycle of life in the ocean" (Shor 1978:140). It was there that Jim became immersed in all aspects of nutrients, plankton, and the marine food web.

> So, the researchers scrutinized bacteria, phytoplankton, zooplankton, and the constituents of sea water. Diurnal rhythms of diatoms and other minute plants were tampered with, aided by a searchlight bright enough to bring complaints from residents on Mount Soledad, four miles away. Minute organisms were kept alive in laboratory jars, but at first they were annoyingly uncooperative in reproducing. Plankton communities were placed in a 70,000-liter tank for controlled-environment studies. (Shor 1978:141) The planktologists also went to sea. … (Shor 1978:142)

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Although he embraced the study of phytoplankton physiology and productivity, Jim was drawn to the characteristically broad, comprehensive, and interdisciplinary approach gleaned from the Food Chain Research Group, which remained a guiding philosophy throughout Jim's career.

Jim published a series of seminal papers in those early years, including articles on algal enzyme activity (e.g., McCarthy 1970) and nitrogen uptake saturation kinetics (e.g., Eppley, Rogers, and McCarthy 1969). Little was known at that time about the sources and fates of urea, a topic Jim focused on for his dissertation (McCarthy 1972a, 1972b). His work on urea inspired later research by Jim's graduate students, "adopted" students, and grand-students (e.g., Horrigan and McCarthy 1981, 1982; Lomas et al. 2002; Fan et al. 2003; Glibert et al. 2006; Solomon et al. 2010). During his doctoral studies, Jim surprisingly discovered that an infestation of blue sharks could make a big difference in ocean urea concentrations (McCarthy and Kamykowski 1972). He also measured the nitrogen excretion products of anchovy and jack mackeral (McCarthy and Whitledge 1972). Years later, having never forgotten the importance of large marine organisms on nutrient recycling, he published influential studies on the whale pump, an important mechanism by which nutrients are returned to near-surface oceanic waters (Roman and McCarthy 2010; Roman et al. 2014). In fact, estimates of nitrogen from the whale pump were shown to be greater than that delivered by atmospheric deposition or riverine sources to the Gulf of Maine.

Jim left Scripps for a postdoctoral position at Johns Hopkins University, which at that time oversaw the Chesapeake Bay Institute, the then-premier laboratory for Chesapeake Bay studies. Several years of monthly cruises led to some of the first publications documenting nitrogen spatial gradients and rates of nitrogen uptake and productivity in the Chesapeake (e.g., McCarthy, Taylor, and Loftus 1974; McCarthy, Taylor, and Taft 1975, 1977). These papers have grown in importance over time, as they document concentrations, rates, and processes of nutrient cycling during the years before the rapid acceleration of eutrophication of the Chesapeake (e.g., Lomas et al. 2002). Jim also established in these papers the complex interactions of the key nitrogen species NO_3^- and NH_4^+, laying important groundwork for much of the physiological studies that followed (e.g., Horrigan and McCarthy 1982; Dortch 1990; Dugdale et al. 2007; Glibert et al. 2016, among many others). The Chesapeake Bay remained an important site for his research, even long after he left Johns Hopkins. Together with students, and postdoctoral fellows, Jim contributed to the study of nitrogen uptake kinetics (Wheeler, Glibert, and McCarthy 1982), nitrification (McCarthy, Kaplan, and Nevins 1984; Horrigan et al. 1990), and natural ^{15}N isotopic composition of particulate matter (Montoya, Horrigan, and McCarthy 1990) in the Chesapeake Bay environment.

2. The Harvard Years

Moving to Harvard University as an assistant professor, Jim focused on phytoplankton physiology in both field studies and the laboratory. He worked on the N_2-fixing cyanobacterium *Trichodesmiun* (e.g., Carpenter and McCarthy 1975; McCarthy and Carpenter 1979), which at that time was considered enigmatic as its importance to global oceanic nitrogen cycling was not yet fully appreciated. Our understanding of the role of N_2 fixation in the oceans has subsequently been advanced considerably by the work of Jim's students and grand-students (e.g., Montoya, Voss, and Capone 2007; Landrum, Altabet, and Montoya 2011; Weber et al. 2017; Loick-Wilde et al. 2018). Jim was also deeply involved in asking physiological questions about how phytoplankton in oligotrophic water could obtain their requisite nitrogen, and he explored this topic in detail with Joel Goldman of the Woods Hole Oceanographic Institution through chemostat experiments. Together they published seminal papers in *Science* and *Nature* (Goldman, McCarthy, and Peavey 1979; McCarthy and Goldman 1979). These papers were key in identifying the linkages between marine phytoplankton nutrient status and growth rate, and were central to the then-current debate about how phytoplankton can grow at near maximum rates in nutrient-depleted waters (e.g., Glibert et al. 1982; Goldman and Glibert 1982). Jim's reviews of nutrient kinetics (McCarthy 1981a, 1981b) remain important reading for biological oceanography students today.

During the following years, Jim was a driving force of the Gulf Stream Warm Core Rings Program (e.g., Altabet and McCarthy 1985; McCarthy and Nevins 1986; McCarthy, Garside, and Nevins 1992; Montoya, Wiebe, and McCarthy 1992) and the U.S. Joint Global Ocean Flux Study (JGOFS 2007), projects that took him to all the world's oceans, from the North Atlantic (Robinson et al. 1993; McGillicuddy, McCarthy, and Robinson 1995; McGillicuddy, Robinson, and McCarthy 1995) to the Equatorial Pacific (e.g., McCarthy et al. 1996; Aufdenkampe et al. 2001), Arabian Sea (McCarthy, Garside, and Nevins 1999; Dickson et al. 2001), and later the Black Sea (McCarthy et al. 2007). By applying his arsenal of nitrogen isotopic techniques, Jim focused in these projects on many of the key questions that biological oceanographers were asking, namely: What are the growth rates of phytoplankton in oligotrophic waters? How is near-surface production coupled to material flux to the deep sea? What limits production in oligotrophic waters?

Even with the large amounts of time that he spent at sea, Jim actively mentored students and played substantial roles at Harvard in education and administration. He routinely taught "Biological Oceanography," a course that attracted both undergraduate and graduate students from Harvard and MIT (Fig. 1). He held the title of Alexander Agassiz Professor of Biological Oceanography in the Museum of Comparative Zoology, where he was also director for two decades, from 1982 to 2002. His commitment to undergraduates was underscored by his years as Master of Harvard's undergraduate Pforzheimer House. Jim and his wife Sue also led many Harvard expeditions, including to the Arctic and Greenland.

3. An International Voice on Global Climate Change

From the 1980s to 2000s, Jim McCarthy turned his energy and passion to understanding and communicating the global changes that were beginning to come to light. He chaired the International Geosphere-Biosphere Programme, from 1986 to 1996. The vision of the IGBP is to "provide essential scientific leadership and knowledge of the Earth system to

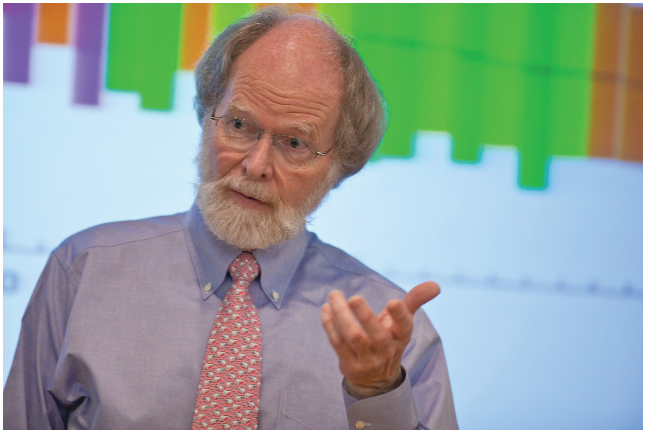

Figure 1. Jim McCarthy. From *The Harvard Gazette*, September 1, 2009. File photo/Harvard University.

help guide society onto a sustainable pathway during rapid global change" (IGBP 2010). This was Jim's second guiding philosophy.

Jim became the founding editor of the American Geophysical Union's journal *Global Biogeochemical Cycles*. He then co-chaired the United Nations Intergovernmental Panel for Climate Change Working Group II, which had responsibility for assessing the effects of global climate for the IPPC's Third Assessment Report (McCarthy et al. 2001). He was one of the IPPC's lead scientists when it shared the 2007 Nobel Peace Prize with former U.S. Vice President Al Gore, Jr. Jim's work was among the first that brought to light the rapid decline of ice cover in the Arctic in the early 2000s. He was singled out by Gore as among "a small group that played a particular role in advising" him for his influential book and movie about global change, *An Inconvenient Truth* (Gore 2006:323). In 2012 McCarthy was appointed by President Barak Obama to the U.S. Arctic Research Commission (*Harvard Gazette* 2012).

Jim's contributions to the climate change literature are substantial in their scientific assessments for both the broader community of scientists and the public (e.g., McCarthy and McKenna 2000; McCarthy et al. 2001; Turner et al. 2003; Frumhoff et al. 2007; McCarthy, 2008, 2009; McCarthy and Wirth 2010). He even contributed to an assessment of reindeer vulnerability with changing climate (Tyler et al. 2007)! Jim was inducted into the Royal Swedish Academy of Sciences, and was elected a Fellow of the American Association for the Advancement of Science. He also served as AAAS president and was chair of the Union of Concerned Scientists. Together with Paul Falkowski, Jim was awarded the 2018 Tyler Prize for Environmental Achievement, a crowning achievement. These important contributions are chronicled in more detail by his Harvard colleague and President Obama's science advisor, John Holdren (Holdren 2019). Overall, Jim's contributions highlight how far we have come in understanding plankton dynamics and trophodynamics and in "making useful predictions," but also show there is much work yet to done in a world that is changing ever so rapidly.

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