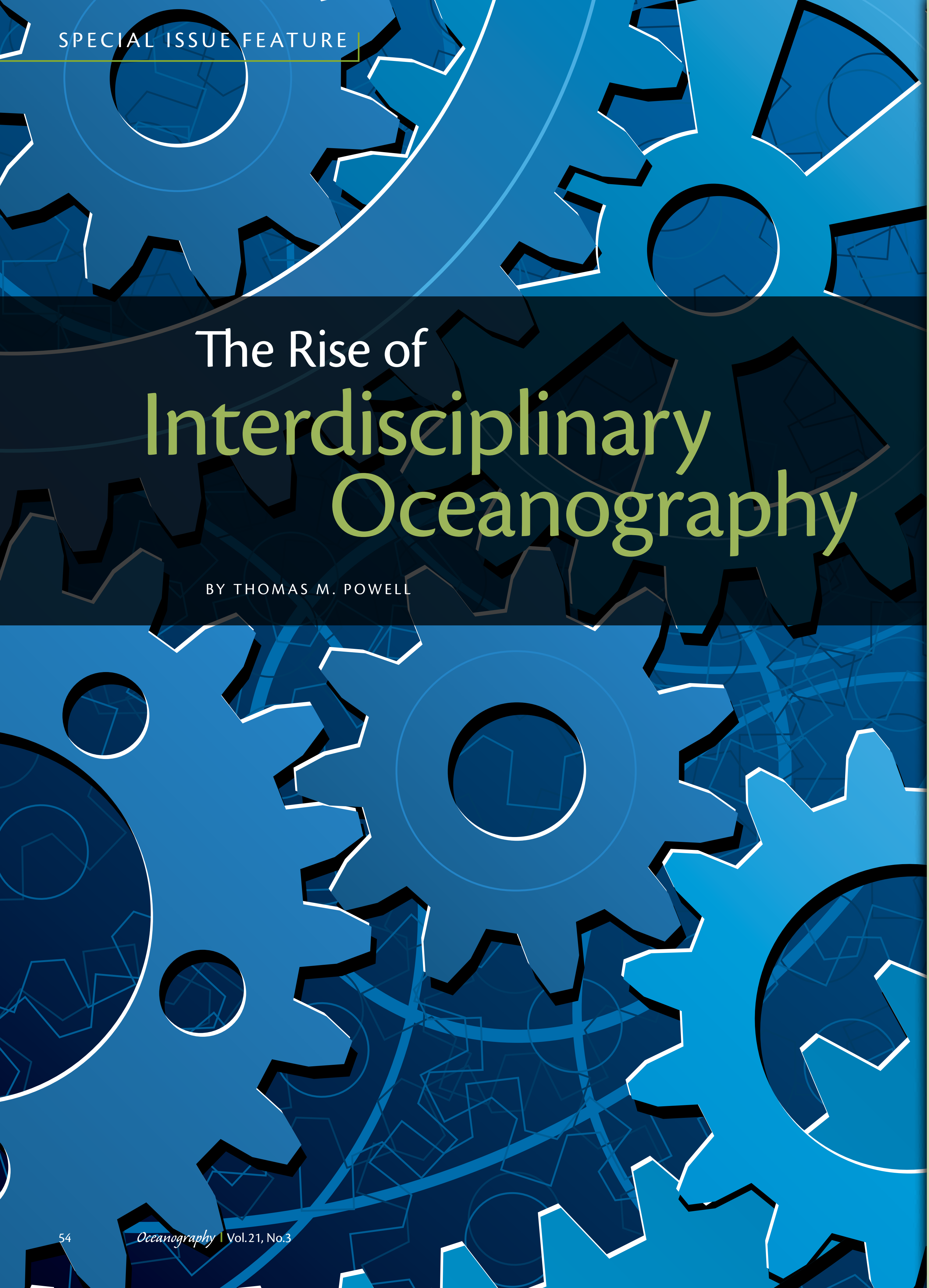

The Rise of Interdisciplinary Oceanography

BY THOMAS M. POWELL

OCEAN SCIENCE HAS long been interdisciplinary. Each great ocean feature has a physical, chemical, biological, and geological signature. Phenomena associated with these features have led curious scientists to collaborate on important questions. One example is the investigation by physical and biological oceanographers of warm- and cold-core eddies (rings) spun off the Gulf Stream in a well-known sequence of productive, coupled projects in the 1980s (Ring Group, 1981). The interactions among investigators from different disciplines were crucial to developing the inherent understanding of the ring phenomena as well as their biological and physical ramifications.

In an earlier time, oceanographers we hold in high esteem investigated across the boundaries of our present disciplines. Gordon Riley, a biological oceanographer, worked with Henry Stommel and Dean Bumpus, two physical oceanographers. Significant portions of their 1949 monograph (Riley at al., 1949) can still be used in an advanced undergraduate course (or a beginning graduate offering) in coupled biological-physical modeling. Walter Munk worked with the same Riley on nutrient transport in phytoplankton (Munk and Riley, 1952). A.C. Redfield's studies linking the chemical composition of seawater to biological characteristics of the organisms in the water column continue to inspire new investigations in both biogeochemistry and plankton ecology/organismal biology. Moreover, in our teaching, we inevitably pay homage to the "first" biological-physical model—the 1953 contribution of physical oceanographer Harald Sverdrup—that describes the initiation of a prominent biological feature, the spring bloom (Sverdrup, 1953).

Nevertheless, the era of true interdisciplinary oceanography began during the last 40 years (about the length of an ocean scientist's professional career). The oceanic literature in 1970 shows the stirrings of modern interdisciplinary endeavors. As a starting point, consider the content from one prominent publication, the *Journal of Geophysical Research* (*JGR*). In the last six months of 1970, the "Oceans and Atmospheres" section of *JGR* (then one year old as a separate section) was dominated by studies on physical phenomena in the ocean and atmosphere; there are also 11 short notes on chemical oceanography (though no articles addressing biological oceanography). These 11 back-to-back articles were the first contributions from GEOSECS (GEochemical Ocean SECtionS), a large, multi-investigator, global geochemical program steered by geochemists, along with several physical oceanographers (i.e., Joe Reid and Stommel). In the (nearly) 40 years that followed, the composition of the journals sponsored by the American Geophysical Union (AGU, the parent scholarly society of *JGR*) changed dramatically. In 2008, *JGR* has seven separate sections, including *JGR-Biogeosciences*, and one often finds many (> 10) articles addressing biological oceanography in a single issue of *JGR-Oceans*. Further, AGU now sponsors five additional journals, two of which are explicitly interdisciplinary, where a reader might find articles with oceanographic content. Furthermore, linked contributions from large, multi-investigator programs can be a prominent portion of any issue of *JGR-Oceans*.

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Climate, and the ocean's role in global change, generate the ultimate multidisciplinary questions. In the simplest terms, the zeroth-order consideration is the planet's energy balance under changing greenhouse gas concentrations, notably CO_2. The first-order problem concerns the changing constituents of the carbon cycle. However, the energy budget (zeroth-order) cannot be understood if the evolution of various carbon compounds (first-order) remains unclear. Further, the change in many carbon species also depends upon additional biogeochemical cycles through the biological uptake of other macro- and micronutrients like nitrogen and iron. Moreover, physical processes, like mixing and mesoscale motions, exert control on the amount of carbon removed from the upper mixed layer, thus affecting

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the carbon budgets. Everything seems to matter. Neither biology, nor geochemistry, nor physical processes can be neglected, even in this simple, broad-brush picture! We note that early climate programs, like CLIMAP (1981), were models of interdisciplinary activity, with atmospheric and oceanographic scientists from several subdisciplines participating.

Today, one can scarcely conceive of an oceanographic question that does not cut across disciplines. For example, let a biological oceanographer suggest a project on the links between populations of invertebrates up and down a coastline, and a physical oceanographic colleague will point to the importance of the details of long-shore coastal transport in these considerations (see the special issue of *Oceanography* on Marine Population Connectivity [2007]). Furthermore, some questions may cut across scales in surprising fashion. For example, feeding mechanisms involving hydrodynamics at the individual zooplankter scale (truly low Reynolds number; Koehl, 1998) may have large-scale consequences for plankton success (i.e., at the population level) and community structure. One generally associates these organizational levels with larger spatial scales related to the spatial extent over which the population or community is distributed, and hence with much larger Reynolds numbers. It is intriguing that processes involving fluid flows at one (very small) spatial scale may have important consequences for different biological phenomena at another (much larger) spatial scale.

Why have the interdisciplinary perspective, and the large interdisciplinary programs it bred, become so prominent during the last 40 years, in this one generation of oceanographers? A number of reasons present themselves. First, our society's focus has sharpened on several problems that may have grave consequences, and the ocean (its physical, chemical, biological, and geological processes) enters into considerations and possible solutions to these problems. The foremost of these is global climate change and the widely discussed consequences thereof. Another is declining marine fish stocks. Government bodies are willing to support studies that bear on these problems, and funding has been generous (though most agree not generous enough) and is likely to remain so. However, these bodies, and the citizens they represent, will only continue to support endeavors that address *all* (or, at least, most) of the categories that are thought of as significant problems. For example, the most respected climate change assessments, like those from the Intergovernmental Panel on Climate Change (IPCC), address freshwater resources, ecosystem properties, industry, sustainability, and many more problem areas. Such efforts will demand *all* ocean science disciplines, so the efforts must be interdisciplinary. It is no longer "maybe"; it is "essential."

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A second reason is the scale of the ocean, the largest surface feature on the globe. Earth is the blue planet, and the largest variations are the most energetic—big features (such as major storms) pack a larger "punch" than those of small extent. Thus, the "biggest" potential events (of planetary scale) need investigations by large teams. Unfortunately, large teams need large resources, so a "large team approach" can only be practical if participants from all ocean science disciplines are included as team members. One can no longer argue for the serial approach—first, a physics expedition, then a chemistry expedition, followed by biology cruises, and so forth. The scale of the questions we must address is just too large; investigations over the planetary scale will demand interdisciplinary approaches. Briscoe (this issue) argues that the large scale of the investigations is an important reason why multi-investigator collaboration is necessary…an identical conclusion as above, but from an entirely different perspective.

There may be other reasons for the rise of interdisciplinary studies of the ocean during the most recent 40 years that deserve a brief mention. One is that such studies provide a fertile field for timely intellectual challenge. Koehl (1998) describes the transfer of variance (energy? variability?) from small to large scale. It is an example of curious phenomena that may be linked to nonlinear interactions among nonconservative constituents. Curious, because one usually thinks of the transfer of energy, or variance, as proceeding from large to small scale (though this is not necessarily the case, for example, in two-dimensional flows). An excellent introduction to the fluid phenomena that bear on these questions is Müller and Garrett (2002). Another potential example of such "curiosities" may be the thin-layer phenomena that increasingly appear so ubiquitous (Focus on Thin Layers, 1998). Ocean studies seem to provide an excellent "laboratory" for the real-world investigation of nonlinear interactions of nonconservative "tracers." But, such studies must couple at least physical and biological processes, or physical and chemical phenomena, or, best of all, physical, chemical, and biological processes in the ocean (i.e., they must be inherently interdisciplinary). Further, the modern interest (obsession?) with nonlinearity is a post-1970 occurrence. In short, then, the recent fascination with nonlinear phenomena leads us inevitably to interdisciplinary studies in the sea.

The difficulties that scientists face when proposing, and pursuing, interdisciplinary projects are also not addressed in detail here. I refer the reader to a short article in the first volume of *Oceanography* where Olson (1988) considers three such difficulties. First, institutional barriers to obtaining information outside the range of activities normally fostered by a unit leading a specific investigation do exist. Second, flexible and tolerant funding sources are not easily found that can direct support to investigators, or groups of investigators, who lie in an entirely different discipline than others collaborating in the (interdisciplinary) project. Third, narrowly focused course work at the graduate level can restrict beginning students into a single discipline so that they (the narrowly trained students) do not have the background to participate in interdisciplinary programs. Olson (1988) raises the specter of "…a physical oceanographer who is at a loss about plankton, or a marine biologist with no concept of mixing processes or water masses." The obstacles that Olson addresses, and several more, will appear all too familiar to many. It gives one pause to realize that in 20 years, our community has made only meager progress in tackling these problems.

Setting these difficulties aside, I return to the question of why interdisciplinary studies have become as prominent as they are. There is one last reason for this prominence, and perhaps it is the most compelling of all. I introduce it with an anecdote. In 1986, while on sabbatical leave in England, I visited oceanographers at the University of Wales, Bangor (now School of Ocean Sciences, University of Bangor). One of the scientists with whom I had set up a meeting was biological oceanographer Paul Tett. When I arrived, Tett apologized, but we wouldn't have even a short time to meet. He was about to leave on a short cruise in the Celtic Sea with physical oceanographers Des Barton and John Simpson, and he was frantically packing. I asked what he would be doing on the cruise and he explained, "…if there's some feature that's interesting to them [Barton and Simpson], then it's bound to be interesting for me…" Ever since, I've taken that to be the best explanation for pursuing topics in an interdisciplinary fashion. There is bound to be something of value that an oceanographer would otherwise miss if he or she weren't with a colleague from a different discipline who might point it out. So, once the sketch of a phenomenon becomes available from initial observations, the drive for fuller understanding of the "whole picture" becomes irresistible. Most likely, that fuller understanding may involve the insights from another discipline. Our curiosity gets the better of us, and it's a good thing it does.

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