the early days of these instruments, no matter how much fun it was to see the currents directly for the first time; now such instruments are beginning to fill in our global picture of the eddies and circulation in a more extensive way. A central dynamic quantity, for example, is the rate at which heat is carried poleward by the oceans, a process tending to diminish the temperature difference between the poles and the equator. Niiler and his collaborators made key measurements in the Florida Straits many years ago, and these have now been used to give us reliable estimates of heat transport in the tropics.

J. Pedlosky and W. R. Young follow with lectures on the theory of the three-dimensional circulation. Pedlosky deals with thermocline theory, which describes the idealized, steady flow of a large-scale ocean in response to forcing by both wind and heating/evaporation at the sea surface. The equations governing the system, even if the average effects of eddy activity are not included, are nonlinear with respect to both horizontal and vertical advection. The difficulty is that one is trying to predict everything with one boundary-value problem. We now have reason to believe that natural discontinuities arise—rather like shock waves in a supersonic airflow—that make simple solutions of these equations unlikely to satisfy realistic boundary conditions at the sides, top, and bottom of the seas. The newer theories Pedlosky describes have the more modest goal of modeling limited elements of the circulation, rather than its totality. By specifying the winds and the surface density field, for example, one can integrate the conservative equations downstream, following the fluid as it descends to the ocean interior, and begin to see the shape of the wind-driven flow. It is these gyres of circulation, one or two to an ocean, that dominate the flow in the uppermost kilometer.

Young examines the morphology of the potential vorticity, which is the central dynamical variable describing the circulation. In this work the more global constraints on the recirculating gyres of flow become apparent. Flow tends to proceed along geostrophic contours (that is, curves of constant potential vorticity that cover the nearly horizontal, stable surfaces of constant potential density in the seas). Yet the flow itself reshapes the density surfaces and hence the geostrophic contours. For round-and-round flow characteristic of these gyres, the potential vorticity is determined by global integrals of eddy mixing. Eddy motions are crucial to these theories, in stirring the potential vorticity, sending momentum downward, and eventually shaping the mean "lens" of warm water that marks the subtropical gyre. Observations of the actual potential vorticity field of the oceans have been important in bringing these ideas close to reality, and this technique is described by Young.

M. C. Hendershott gives an account of the theory of circulation of a single layer of constant-density fluid. It was Stommel's use of this model that made analytical progress possible and produced the first "whole model" of an idealized ocean basin in motion. This, more than any other example, shows the spirit of geophysical fluid dynamics, where progress is made by simplification of the problem at the outset, rather than by mathematical approximation of the complete "gory mess." Hendershott's lectures take one from first principles, through the sequence of classical circulation models, to nonlinear and time-dependent one-layer flows. Rossby waves make their only appearance here; their key role in producing the "constitutive relation" that holds together the large-scale flow makes them important to studies of the development of the circulation as a time-dependent problem.

G. Veronis introduces the methods of inverse modeling, in which one aims to match a sparse set of observations to a model, either heuristic of dynamical, of the underlying continuous flow. Inverse modeling attempts both to map the fields between observed data points and to estimate unknown fields. The classic case is to infer velocity from observations of fluid density, using assumed global conservation properties and local force balance. Operationally it is an exercise in over- and underdetermined sets of linear equations. A difficulty is that assumptions used to select among a forest of possible solutions do not always have great strength. More powerful dynamical ideas are needed, either analytical or numerically implemented. Looking toward the future, one sees inverse models being combined with predictive dynamical models to yield a hybrid that takes whatever data are available and uses them to nudge the equations of motion in the right direction. In fact, K. Bryan and his collaborators at Princeton have been doing this less formally for some years. A decade ago physical oceanography had focused on the problem of the 100-kilometer-wide eddies that dominate the kinetic energy of the oceans. A result of that research has been an increasingly clear understanding of the way in which eddies can shape and distribute the global general circulation. In crucial ways the general circulation without these eddies is an underdetermined mathematical problem with no unique answer. A synthesis is now beginning to occur.

This volume would make a good textbook for a course on ocean circulation that includes basic derivations. A classical mechanicist might enjoy seeing how natural scientists approach their dynamics problems. A note of criticism is that although experimentation both in the laboratory and on the computer has acted as an essential intermediate step between dynamical ideas and observations, neither technique has an advocate in this book. We see increasingly that numerical models can help to develop theory and to forecast the state of the oceans. We are quickly moving to consider the complex behavior of the interactive ocean and atmosphere, and this campaign is more and more being waged on a numerical grid.

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Effects of Predation

Predation. Direct and Indirect Impacts on Aquatic Communities. W. CHARLES KERFOOT and ANDREW SIH, Eds. University Press of New England, Hanover, NH, 1987. viii, 386 pp., illus. $60. Based on a symposium, Fort Collins, CO, 1984.

The study of predation in aquatic communities has been a particularly fascinating and fruitful endeavor because predators often have effects that are both strong and far-reaching. Suppression of numbers in the immediate prey population is considered a direct effect. As a result of food web linkages, however, a predator's impact may extend well beyond the target species. In addition, many prey species have evolved defensive tactics that not only minimize predation risk but also affect the prey species' behavior or morphology, with consequences for its ecological role. It is these diverse, indirect effects that account for much of the current excitement in the field and most of this volume.

Just what is to be included under "indirect effects" of predation still seems to elude concise definition. The breadth of phenomena involved makes the grouping of chapters into sections somewhat arbitrary, and the redefinition of exploitative competition (that is, predation on a common resource) as an indirect effect does not strike me as helpful. One major theme clearly is the ramification of predation effects through the food web, and another is the variety of adaptations that have evolved in response to predation risk. However, the distinction blurs when, for instance, a prey species modifies its feeding behavior in the presence of a predator, with consequences for other species linked to it through the food web.

The food web perspective is nicely illustrated by several chapters on planktonic systems, where top-down predation frequently is a major force. Kerfoot summarizes the extensive field experimentation he and his students have carried out on a small Vermont lake, and Levitan contributes an original and impressively detailed stability analysis of the same lake, which should interest students of food web analysis. Surprisingly for a freshwater planktonic system, top-down predation effects appeared to be small. Levitan's analysis indicated a stable matrix of plant-herbivore interactions, sensitive to small changes in interaction coefficients yet insensitive to greater variation in coefficients adding the major invertebrate and fish predators into a larger web. Mills *et al.* summarize a long-term data set to provide a fine example of predator effects that cascade from the top to the bottom of the Lake Oneida food web. The abundance of young yellow perch is influenced both by climatic conditions during egg incubation and by walleye predation, while fluctuations in perch abundance strongly affect *Daphnia*, which in turn dictates the abundance of other grazers and (less obviously) phytoplankton. This is an excellent case study for an undergraduate ecology lecture. Together with the chapter by Kitchell and Carpenter, it also demonstrates that detailed understanding of food web interactions can provide valuable information for environmental management.

Any predator-induced reduction of a prey species may indirectly benefit other members of the food web linked to it. In one of the most explicitly theoretical papers, Abrams explores the variety of interactions between two prey that have a common predator. Other chapters report experimental evidence for indirect facilitation, including predatory suppression of a competitive dominant (Vanni) and the nutrient-regeneration link between plantivorous fish and the algae that nourish their prey (Threlkeld). Quite intricate linkages may result in indirect mutualisms, such as Dungan describes in an intertidal community.

Anti-predatory defenses are a widespread response to intense predation. Chapters by Sih and Havel provide general discussions, and Sih develops a major theme, namely that such adaptations may compromise life-style, habitat use, or other activities, with far-reaching consequences. Stemberger and Gilbert summarize the now extensive knowledge of rotifer defenses, including the chemically mediated morphological responses for which rotifers are justly famous. The potentially wide use of chemical defenses in freshwater beetles and bugs is perhaps underappreciated, as is indicated by Scrimshaw and Kerfoot's valuable review describing the substances carried, morphology of glands, and delivery mechanisms. Prey also reduce risk by minimizing their temporal or spatial overlap with predators. Some copepods undergo diapause during months when fish predation is intense but conditions are otherwise suitable for continued activity and reproduction, a response that appears to be genetically determined yet evolves rapidly in response to changes in predation intensity (Hairston). In contrast, behavioral flexibility in the use of high-risk habitats appears common in fish vulnerable to larger piscivores. This may have consequences for competitive interactions, described by Mittelbach and Chesson, and for lower trophic levels, discussed by Power. Finally, a paleontological perspective is added by two chapters that consider the habitat restriction over geological time of crinoids (Aronson and Sues) and the larger branchiopods (Kerfoot and Lynch), attributed to mid-Mesozoic changes in predation intensity.

The roots of the current volume lie in influential studies published in the 1960s on predator effects in small lake and rocky intertidal communities. An impressive level of understanding has been achieved in the last two decades of research, and this book provides a current and broad overview of the subject. The standard of quality (both science and presentation) is high, and although the setting is primarily lacustrine, some chapters are quite general and the insights gained into community interactions should be of broad interest.

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Quantum Gravity and Strings

Superstring Theory. Michael B. Green, John H. Schwarz, and Edward Witten. Vol. 1, Introduction. x, 469 pp., illus. $39.50. Vol. 2, Loop Amplitudes, Anomalies and Phenomenology. xii, 596 pp., illus. $49.50. Cambridge University Press, New York, 1987. Cambridge Monographs on Mathematical Physics.

In the last few years an ever-growing number of elementary particle theorists have become enamored of a subject called superstring theory. In a string theory the basic objects are tiny strings, 10^{-33} cm long, that propagate in a space-time generated by the theory itself. Each elementary particle is a specific vibrational mode of the string. The prefix "super" denotes the fact that the theory brings together the two broad classes of elementary particles found in nature, the bosons and fermions.

What superstring theory seems to provide is a mathematically consistent quantum theory of the gravitational force together with many new ideas for unifying gravity with the other forces. Direct effects of quantum gravity are probably negligible at energies less than 10^{19} GeV. This level is so far beyond current accelerator energies (10^4 GeV are planned for the new Superconducting Super Collider) that the theory will forever remain beyond experimental test. Conventional theories based on point-like elementary particles cannot predict quantum gravity effects even in principle, so gravity seems to be the arena of confrontation for the fundamental ideas of quantum physics. Further, many suspect that the correct theory of quantum gravity may answer questions about particle properties at lower energies that are left open by the current "standard model." Thus the enthusiasm of string theorists for the first consistent theory of quantum gravity is easy to understand. But it is worrisome that their ideas are so hard to test experimentally and that the highly mathematical nature of their research ignores the historical paradigm that progress in particle physics occurs through a partnership of theory and experiment in the exploration of a steadily increasing range of energy.

String theory was first developed in the late 1960s, but it was put aside by all but a few proponents about five years later, after other, more promising ideas emerged that led to the standard model. The second coming of the subject occurred in 1984 when it was shown that the symmetry group of particle forces could be almost uniquely predicted by superstring theory. It is clear that string theory is rich enough, whether right or wrong experimentally, to be a part of the graduate curriculum in particle physics. There is a genuine need for books that explain the early development and integrate it with the more modern mathematical view that has been developed largely in the last three years. This brings us to the two-volume work under review here.

The credentials of the authors are superb. It was Green and Schwarz who wrote the 1984 paper that led to the rebirth of the theory, and Witten immediately recognized the importance of that paper as indicating the potential solution to the problem of chiral fermions (in simple terms, why the weak interaction in nature is left-handed), a problem on which he had focused for years and developed many rich ideas. It is admira-