BOOK REVIEWS

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LERMAN, A., D. IMBODEN, AND J. GAT [EDS.]. 1995. **Physics and chemistry of lakes.** Springer-Verlag, Berlin. 334 p. $97.95. ISBN 0-387-57891-9.

It is widely accepted that lake systems are the result of a fragile ecological balance that is all too easily perturbed by human or natural intervention, but this was not always the case. In 1978 the publication of *Lakes: Chemistry, geology, physics,* edited by A. Lerman, coincided with a developing awareness of lakes as important, and sensitive indicators of environmental change. In particular, the potential consequences of the often dramatic transformations in lake ecology associated with human activities and the role of lake sediments as sensitive indicators of climate change over long and short timescales were only just beginning to be recognized. Since then things have moved on. *Physics and chemistry of lakes* is described by its editors as a sequel to the 1978 volume, which helped set the standard for many texts to follow but it is more than this, going further in the breadth and depth of its material. There are 10 chapters, contributed by 20 authors, and they address a wide range of physicochemical processes operative both in the water column and the underlying sediments. The interaction of lakes with their surrounding environments, including the atmosphere and the impacts of anthropogenic activities in particular, receive a much more in-depth coverage than in the previous volume, in recognition of the important roles that lakes fulfill in the global system.

The introductory chapter "Global distribution of lakes" by M. Meybeck, reviews the laws governing lake distribution and gives a quite detailed account of the global distribution of major natural lake types, according to such criteria as their size, mode of origin, major climatic features, and aspects of their geomorphological and geological history. Numerous examples are given, by way of exhaustive tables of lake statistics; for those interested in comparing the physical attributes of the world's major lakes, they can be found here.

The following four chapters focus on physical and hydrological aspects. Chapter 2, "Hydrological processes and the water budget of lakes," by T. C. Winter, identifies the major controls on lake hydrology by addressing water exchange with the major components of the hydrological cycle. Although the atmospheric and surface-water reservoirs are the dominant terms in bulk lake water exchange, these are afforded a comparatively brief treatment and the major focus of the chapter is the interaction of lakes with subsurface waters because of their importance as a conduit for chemical transport. Chapter 3, "Hydrological and thermal response of lakes to climate," by S. W. Hostetler, examines the relationships between lake size distribution and surface hydrology, and the role of lake–climate interactions in shaping internal lake processes. Formal mathematical descriptions of the hydrological budget are relatively straightforward and the section on modelling approaches and their value in predicting the physiochemical response to climate change is informative. In chapter 4, "Mixing mechanisms in lakes", D. Imboden and A. Wuest define the important time and space scales of fluid motions and present highly detailed mathematical descriptions of the hydrodynamics of mixing. At 56 pages this is the longest and, for nonmathematicians such as myself, the most demanding chapter in the volume. Nevertheless, I found the equations well laid out and clearly explained and the use of tables to summarize important variables and formulae was very helpful. Chapter 5, by J. R. Gat, describes the use of stable isotopes ($H_2{}^{18}O$ and HDO) as a fingerprinting tool for providing important information on the dynamics of lake interaction with the surrounding environment and gives examples ranging from simple homogeneous systems to more complex stratified ones.

Next come three chapters that deal with chemical aspects of human impacts on lakes. Chapter 6, "Exchange of chemicals between the atmosphere and lakes," by P. Viahos et al., describes the phenomena involved in air–water exchange and methods for quantifying the transfer rates of volatile anthropogenics. Case studies of the exchange of contaminants such as PCBs and cyclohexanes are very detailed, but I found the section on "mass transfer coefficients" (gas transfer velocities) a little lacking in some areas. For example, recent advances in the measurement of gas transfer rates using volatile traces were largely ignored. This is surprising because much of this work was pioneered in lakes; however, it was afforded only fleeting acknowledgment by way of citations in a figure reproduced from another source. Somewhat unfortunately, these citations were excluded from the reference list at the end of the chapter. The following chapter, on atmospheric depositions, by W. Stumm and J. Schnoor, deals with the generation of anthropogenic acidity and its partitioning into the terrestrial and aquatic reservoirs. The elementary concepts of acidification are described clearly and are followed by sections on transport mechanisms and consequences for the H^+ balance in receiving waters. Subsequent sections discuss the acid-induced mobilization of heavy metals, acidification effects on soil and watershed ecology, pollutant load evaluation, and finally, contrasting case studies of two lakes. I found this chapter extremely clearly written; concise yet comprehensive in its treatment of the subject. The following chapter on the redox-driven cycling of trace elements (W. Davison and J. Hamilton-Taylor) also was impressive. One message that clearly emerged from it is that redox cycling in lakes can be much more complex than it is in the oceans, and because of the dynamics of the processes and the time and space scales involved, a combination of approaches is required in order to understand it clearly. The use of "case study" elements to highlight important biogeochemical processes and pathways was especially good.

The final two chapters focus on the interactions of lake waters with their underlying sediments. Chapter 9, "Comparative geochemistry of marine and saline lakes," by F. Mackenzie et al., describes the major sediment–porewater reactions operative in two contrasting lakes, one a well-mixed temperate example characterized by organic-rich sapropelic sediments, the other an arid hypersaline lake with a mixture of evaporitic and biogenic sediments. Chapter 10 by P. Meyers and R. Ishiwatari, investigates the role of sedimentary organic matter as a recorder of past climate change and anthropogenic input and shows how the degree to which changes in the isotopic, elemental, and molecular compositions of sedimenting organic matter reflect such past conditions as vegetation cover, nutrient supply, and anthropogenic loading.

Overall, I found this an impressive book and the editors have done a good job in bringing it all together. In works of this format, with contributions from so many authors, some overlap between chapters is usually inevitable, but in this case the judicious selection of topics has restricted this to an absolute minimum. The production, editing, and layout are all generally excellent. I particularly like the A4, two-column format for text and the glossy print. There appear to be no substantive errors and typographic errors are relatively few, interestingly concentrated in the main into one or two chapters. The layout of figures and tables is consistently clear and the accompanying captions are informative. Chapters are comprehensively referenced, and in view of the typical production times of multicontributor works, the references are remarkably up to date. Many are from 1994 with one or two as late as 1995. Nevertheless, the missing references in chapter 6 remain an irritating oversight.

The editors contend that this book should appeal to a diverse readership and I think they are correct. It should serve as a valuable reference text, both for professional scientists and engineers and for the advanced student of limnology, although cost may be an issue in the latter case. I enjoyed reading it and it will make a welcome addition to my bookshelf.

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ANDERSEN, T. 1997. **Pelagic nutrient cycles: Herbivores as sources and sinks.** Ecological Studies, V. 129. Springer, Berlin. ISBN 3-540-61881-3. 280 p. $79.95.

What if there were something of critical importance to nutrient cycling and trophic dynamics, something unarguably fundamental to biological reality, something that had been *right in front our eyes,* but that had somehow been overlooked by ecologists? Such a situation seems almost impossible given the explosive growth of ecology over the past half century. Nevertheless, the new book by Norwegian limnologist Tom Andersen, *Pelagic Nutrient Cycles: Herbivores as Sources and Sinks,* formalizes the major consequences of a simple realization that has been dawning on a number of aquatic scientists over the past decade. That realization, put bluntly, is that animals are not made of pure energy (or pure phosphorus, for that matter). Instead, animals are constructed of multiple chemical elements (C, N, P, others) and to grow maximally must satisfy not only their energetic requirements for growth and maintenance but also their somatic requirements for major elements and biomolecules. (Reader alert! The author of this review has slowly arrived at this realization himself via various means and thus was predisposed to like this book.) Recent years have seen a flurry of laboratory and field studies examining various ramifications of this simple insight, from laboratory food quality assessments to field determinations of the stoichiometry of consumer-driven nutrient recycling. However, as noted by Robert MacArthur and quoted in chapter 1, "Scientists are perennially aware that it is best not to trust theory until it is confirmed by evidence. It is equally true . . . that it is best not to put too much faith in facts until they have been confirmed by theory." For aquatic scientists who have not yet brought themselves to trust the stoichiometric "facts" arrayed to date, here, in Andersen's brilliant book, is the theory.

The book, #129 in Springer's Ecological Studies series, is a direct transcription of Andersen's Ph.D. thesis at the University of Oslo (under the direction of E. Paasche). The writing is extremely clear and well edited. The book starts big (with an emphasis on P loading and the eutrophication problem; chapters 1–2) and ends big (connecting food webs with eutrophication; chapters 5–7) and in between moves methodologically through a mechanistic treatment of algal growth and nutrition, zooplankton growth and nutrition, and their reciprocal interactions via nutrient recycling. The theory development builds on sound physiological principles for both algae (chapter 3) and grazers (chapter 4), systematically considers size- and age-dependent grazer population models (chapter 4), and eventually leads to a synthetic treatment of the dynamic interactions among nutrients, algae, and grazers (chapter 5), adding bacteria in chapter 6. The model structure might be referred to as "stoichiometrically explicit." Let me explain. Ecology made a major advance with the development of "spatially explicit" ecological models that incorporate the constraints that space and rates of movement through space place on ecological dynamics. Similarly, a stoichiometrically explicit model captures the constraints that matter and energy (both!) place on ecological dynamics. As pointed out by Andersen, a number of influential models of nutrient cycling in food webs ignore such constraints and contain assumptions and formulations that generate model conditions that do damage to the first law of thermodynamics (e.g. grazers apparently synthesizing new P atoms within their bodies!).

In Andersen's model such absurd situations are impossible. The system of equations incorporates three key aspects of the stoichiometry of any autotroph–grazer–nutrient system. First, algal elemental composition (in terms of C : P ratio) is variable with algal nutritional state and scales with P supply rate and algal demand. Second, zooplankton grow maximally when both their energetic and somatic nutritional needs are met, with lower growth rates when food quantity is low but also when food quality is low and the animals are unable to meet their body P requirements. Third, release of limiting nutrient P is constrained by mass balance as the difference between ingested P and that incorporated into new biomass. Thus, there is a system of potentially complex interactions between P supply rate, algal growth rate and C : P ratio, and zooplankton growth and release of P. To my knowledge this is the first fully dynamic theory of trophic dynamics and nutrient cycling to include these three key realities.

What are the consequences of formalizing these biologically realistic assumptions? What happens when the wildly variable elemental composition of autotrophs interacts with the rigidly regulated, but species-specific, requirements of consumers? Andersen shows that the results are dramatic. In this system of equations, depending on model parameters, a limiting nutrient conceivably can cycle rapidly amongst dissolved, algal, and grazer pools, supporting high production with grazers as a key "source" of limiting nutrient, or spin off into a deteriorating syndrome in which P-limited algae develop high C : P ratios that induce slow, P-limited grazer growth with reduced P release rates (grazers are now a major "sink" of P), further accentuating algal P limitation. In other words, introducing stoichiometric reality to the interaction generates bifurcations in system behavior, bifurcations that are absent from single currency models. Chapter 6 ("Approaching Planktonic Food Webs: Competition, Coexistence, and Chaos") illustrates how complex indeed these interactions can become. While limitations of computer technology at the time that Andersen completed this work prevented him from formally assessing whether this system of equations generates true deterministic chaos, examination of the model output in this chapter leads a nonmathematician such as myself to conclude that it might as well be. In chapters 5 and 6 Anderson considers implications of his theory for food-web regulation of water quality (i.e. "biomanipulation" or the "trophic cascade") within the context of eutrophication, developing specific predictions for the feasibility of biomanipulation as a function of P loading and lake flushing rate. Remarkably, these predictions, developed from first principles, were accurate regarding the success or failure of six of seven well-documented biomanipulation experiments. Thus, we see it is only a short step to directly apply this theory to questions of considerable human concern.

Andersen's analyses show that, while in ecosystem ecology we have previously considered the primary influence of nutrient limitation on food webs to be in reducing the *quantity* of production available for consumers, a key effect of nutrient limitation on food-web dynamics, as yet largely ignored, may also be in altering the *quality* of that production in stoichiometric terms, with profound