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Comment

Diatom taxonomy for paleolimnologists

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Abstract

The present chaotic state of diatom taxonomy presents both significant difficulties and large opportunities for paleolimnologists. Lack of complete and generally available taxonomic treatises and rapid and substantial changes in nomenclature make it necessary for persons using diatom populations to infer environmental conditions to become more deeply and directly involved in diatom systematics, in the broad sense, than is generally realized. Paleolimnologists develop collections that are extremely valuable in addressing classic questions in evolution and biogeography, and should be encouraged to use these resources to advance diatom systematics, either themselves or in collaboration.

Commentary

The taxonomy and nomenclature of diatoms is undergoing very large and very basic changes at the present time. This is partially driven by growing concerns regarding global biodiversity, partially by improvements in technique, and very largely by increased awareness of the usefulness of diatoms in decoding many aspects of earth history (e.g., Dixit et al., 1992a,b; Stoermer & Smol, 1999). It is somewhat ironic that huge recent refinements in diatom taxonomy and nomenclature have raised considerable angst among colleagues whose primary research interests are in ecology and paleoecology. Probably because I have worked both in paleolimnology and in the more formal aspects of systematics I am besieged by questions:

- What do you think about the new taxonomy?
- Why do they change all the names?
- Who should I follow?
- Why can't we just ignore all this and stay with a system that works?
- What shall I do, What shall I do?

Of course it is possible to give a succession of snappy, short, and ultimately not very informative answers to such inquiries, i.e.

- Some of the changes are illuminating, some are misguided.
- Because our current system of scientific understanding demands it.
- You are responsible for your own decisions.
- Because that approach is eminently unscientific.
  - However, if you want to appear ignorant, go ahead.
- Get busy!

While the last answer may seem particularly unresponsive (most paleolimnologists consider themselves busy enough) it is really the essence of my remarks. As university administrators become ever more intrigued with new technologies and the gross financial rewards available from biomedical research, fundamental areas of biological research, such as systematics, become ever more restricted, and the flow of well trained students reduced. With a few notable exceptions, museums, which have *de facto* borne the brunt of systematic research and training in diatoms, have fallen dormant as their administrations attempt (usually futilely) to con-

vert them to 'contract ecology' profit centers. In truth, research and training in diatom systematics has never (at least in my lifetime) been very robust in any of these august institutions. The number of individuals studying diatoms who might be considered well trained systematists, according to the standards of better studied groups (those with fins, flowers or fur), has never been large. It is ironic that just when the enormous utility of diatoms in many types of environmental studies is being increasingly realized, the mechanisms which support quality research seem to be falling away. This problem is general in groups of organisms with poorly known taxonomy and a major concern for thoughtful researchers in all areas of ecology. This deficiency is increasingly being recognized at the national science policy level, at least in the United States, through programs such as the National Science Foundation's Partnerships to Enhance Expertise in Taxonomy (PEET) program. However it is unrealistic to believe that the neglect of decades will be remedied in the near future. In fact, the problem for ecological practitioners is certain to become worse as the full impact of problems such as climate change, nitrification, and the biodiversity crisis, is realized. The present small flurry of activity in the systematics and nomenclature of diatoms is almost certainly merely the tip of a much bigger iceberg. It seems a virtual certainty that the complexity and refinement of diatom classification will continue to grow very rapidly.

In her wonderful recent book Winston (1999) points out that it is increasingly the responsibility of ecologists, particularly those dealing with poorly studied groups of organisms, to shoulder the burden of systematic practice that has been previously assumed to be the province of taxonomic specialists. She then sets forth a succinct set of instructions on how to do so. Winston's book, and articles dealing directly with application of the Rules of Botanical Nomenclature to diatom names (Ross, 1993), provide the formalities of how to deal with diatom taxonomy. Here, I would like to talk more about the mechanisms for implementing advances in our general understanding of diatom relationships.

Consider how many of us were taught to do taxonomy as undergraduates. At least in my case, we were presented with some rather dry lectures about morphological characters, a brief outline of some general classification scheme, then presented with specimens and the latest authoritative tome and instructed to key them out. The specimens just appeared, usually from the field, but occasionally from some mysterious archive called the herbarium. Few students of my generation, and one must suspect even fewer of successive generations, were more than briefly introduced to the importance of collections, which form the ultimate basis of all systematic research At least we didn't have to worry about equipment. The naked eye sufficed for most key characteristics, and the rest could be adequately resolved with student microscopes of very modest sophistication. Although not particularly inspiring, this approach works quite adequately with well-known groups of organisms. All of the taxonomic work is done for us. We only have to apply it to our particular problem. There may be minor misunderstandings, but it is usually possible to resolve them by appealing to a local expert. Unfortunately, this venerable and well-practiced approach does not work at all well with diatoms.

Why not? In our example, the dry lectures were likely presented by a professional systematist who was privileged to devote his/her entire career to the study of a restricted group of organisms, usually a genus or a family. This individual was representative of literally thousands of similar specialists throughout the world who reviewed, criticized, and refined any publications our lecturer put forth. How many of you that had any formal instruction in diatom taxonomy received it from a person with this depth and tradition of training, taxonomic research experience, and degree of peer review? I would wager very few. There are simply not that many professional diatom systematists, and those that aspire to be often lack the background tradition, and certainly the depth and breadth of peer review and support assumed for better studied organisms.

The authoritative tome from our example would be the distillation of a very long history of research and refinement by many specialists over many years. One of the components would be systematic exploration of regions, eventually compiled into local, regional, national, and global floras. Local diatom floras are very rare. Regional floras are more common, but are often cursory – collected during a brief period without a detailed sampling plan. Regional coverage is quite poor, with little floristic information available for many regions. This situation has much improved recently, due to efforts of investigators such as H. Lange-Bertalot and his collaborators with the modern flora and several paleolimnologists, notably F. Gasse and J. Smol and his group.

An extremely important underpinning of our hypothetical tome would be revisionary studies, the careful reanalysis and rectification of previous identifications and distribution records. It is heartening to note that such important work has become more common re-

cently and has contributed greatly to the state of change in diatom taxonomy. A considerable part of the uncertainty amongst ecologists and paleoecologists results from the fact that these revisionary attempts have not yet been digested, in the sense of being codified and presented in comprehensive floras. Lacking these fundamental underpinnings, there is little wonder that the few major diatom floras available are an eclectic lot, at best.

The first part of Hustedt's (1927–1966) monumental tome, still held up by some as the ideal, was issued more than 70 years ago and died, still incomplete, more than 30 years ago. Cleve-Euler (1951–1955) realized that diatom diversity was greater than commonly thought at the time, but encapsulated this in non-standard nomenclature, supported by very brief descriptions and imperfect illustrations. Unfortunately, very few of the collections representing her work reached permanent repositories (Holmgren et al., 1990) and much of her work is now irretrievably lost to science. Patrick and Reimer (1966–1975) restricted their flora mostly to species reported from the United States before 1960. Even with this severe restriction, this flora has never been completed, and likely never will be. The latest major floristic work (Krammer & Lange-Bertalot, 1986–1991) has its own quirks. These authors attempted less of a formal revision than either Hustedt or Patrick and Reimer, hence reader's are often left to wonder precisely how names are applied. This problem is further compounded by the fact that the authors seem to have substantially changed their systematic viewpoints during the course of their work. The earliest volume contains a radically compressed species concept in which entities with minimal morphologic similarity are treated as the same taxon. Later volumes adopt a much more conservative approach with a higher degree of resolution. In some genera this extends to the informal separation of morphological races (Sippen), which may well prove to be species with further research (Mann, 1999). This more modern approach has certainly been followed in later publications by these authors and their co-workers. It is notable that Hustedt seemed to undergo a similar shift in outlook in his later years, when he apparently devoted most of his energies to description of new taxa.

Given these uncertainties, what is a paleoecologist to do? Because I have cited mostly problems to this point, I should probably first say, don't give up. At this point it has been adequately demonstrated that diatom studies, even in their present primitive state, are an impressively powerful tool. They should not be abandoned, nor should they be blunted by return to lowest common denominator approaches. They should be sharpened and improved.

I will give my ideas on how this may be accomplished at the end of this essay, but I think it would be useful to deal with some terms, as I understand them, first:

A species is a group of organisms more similar to themselves than they are to any other similar group. They share very similar (essentially the same) morphological, physiological, behavioral, and, of course, genetic, characteristics because of they share a more recent common ancestry among themselves than to other organisms. Species are the basic elements of taxonomic practice, however they are elements of a much different sort than the basic elements we are used to dealing with in physics and chemistry, our traditional models of scientific research. A hydrogen ion (sparing a few really esoteric physical arguments) was the same in the Cambrian as it is now, and will remain so as long as Earth exists. The International Meter will remain the same as it is today for at least millions of years. Species, on the other hand, are complex adaptive systems. Their membership and boundaries are constantly shifting. They can evolve into different species, or become extinct. Many of us deal, either knowingly or unknowingly, with species that change over the time course represented in our study sections. The concept of species is where most of the problems in understanding taxonomy arise, simply because our common model of science does not prepare us to deal very well with complex adaptive systems as objects.

A genus is a grouping of species that share a common ancestor at the next level of aggregation. Setting the precise boundaries for such groups is daunting, especially when we have only a vague notion of their potential membership. Higher levels of diatom classification are even more nebulous. The uncertainty, and some degree of inherent arbitrariness in generic, and higher, classifications have led some systematists to advocate creation of designation-free classification schemes, based entirely on nodes produced by cladistic analysis (Mishler & Brandon, 1987). Whatever the virtues of this approach may hold, it is unlikely that it can be applied to diatom classification in the foreseeable future.

A scientific name in biology is a hypothesis concerning descent of a species, postulating a terminal aggregation of like organisms and the membership of this species to a higher grouping, a genus. In botanical nomenclature, the authors of these hypotheses are

explicitly stated as authorities. It is **not** the logical or functional equivalent of a named chemical element or compound, or a natural or arbitrarily defined physical quantity. Because diatoms are complex evolved and ever evolving systems, the degree of proof of our name hypotheses cannot be complete.

The International Code of Botanical Nomenclature is an attempt to provide standard reference to plants as complex adaptive systems. Although it suffers from attempting to treat an array of organisms whose common ancestry is extremely remote, and setting forth its arguments in almost laughable pseudo-legalistic jargon, it actually achieves its primary function rather well in practice.

In order to make this highly developed system work for them, all paleolimnologists need do is cast aside the assumption that someone else has done the work, and embrace the system. In other words, we need to incorporate into our work on diatoms the elements of systematic practice that come 'pre-digested' for well-studied groups of organisms.

The first requirement is to develop and maintain a well-organized and curated collection. This is an absolute necessity to achieve internal consistency, becomes a valuable tool for comparability with other workers, and is the absolute foundation for progress. In the current state of diatom taxonomy, any name or other designation used as a category for analyses, or a designator for publication, should be linked to a physical specimen, **not (!)** to some concept extracted from the literature. If this practice is followed strictly, any errors that may occur become recoverable at any future date. Although maintaining a sizeable collection is a non-trivial task, it is essential to performing quality work in paleoecology at the present time. The general availability of fairly sophisticated databases certainly makes it much easier and less time consuming than it was in the past. A complete and well-ordered collection also has significant rewards in student training and publication preparation. Indeed, any University of substantial reputation has collections of well-known organisms that fulfill these functions. Ideally, such collections should be perpetual, so that accumulated knowledge is perpetuated. Unfortunately, the science and practice of collections-based research has failed us where we need it most. I know of no university in the United States that has a well organized and supported diatom collection and our country is now down to a single functioning permanent repository. Given these realities, the burden of these activities fall on the practitioners in our field. I argue this burden must be accepted if we are to fulfill the promise of diatom-based paleoecological interpretations. It is often argued we have to defer such obligations because they 'cost too much', and funding agencies won't support them. I would argue that funding agencies have no choice, if they wish to promote and sponsor quality research. Given that many agency managers are not particularly cognizant of the state of the art in diatom taxonomy, the implementation must occur through peer review. Any proposal which does not document adequate vouchering should be regarded as unfundable and any submitted manuscript that suffers the same deficiency should be regarded as unpublishable.

Appropriate equipment is another cost-related factor that needs attention in our work. Although the finest optical equipment available is, because of the laws of optics, barely adequate for diatom identification, few labs I am aware of are so equipped. Further, it becomes increasingly apparent that many morphological characters necessary for accurate identification are only available at magnifications achievable only with electron microscopy, although it is possible that once initial categorization is achieved, enumeration can still be accomplished with a light microscope. I fully appreciate the fact that access to adequate equipment is problematical. In my own case, as a graduate student I had to construct a useable microscope from 'liberated' components. In my present position, I initially found it necessary to get an alternate employment offer from another institution in order to persuade my Director to purchase an adequate microscope for my use. Although I fully appreciate the difficulty of finding funds for adequate equipment, and the fact that there is an all too human tendency to sacrifice such equipment before salaries are reduced in a competitive grant situation, the fact remains that it is essential to quality work. Again, the remedy exists in peer review. The level of all our research is raised if reviewers really insist that adequate instruments are available to accomplish the work proposed.

Similar stresses exist in literature resources. The current explosion in literature makes it most difficult to remain current and, unfortunately, many current publications are exploratory, unsummarized, and demonstrate a level of systematic understanding long abandoned in well-studied groups. Rather curiously, one of the regions of the world least well treated in the current literature deluge is North America, particularly west of the Rockies. Frankly, I see no immediate solution to this problem. It is certainly one that will yield to effort, but the type of monographic treatments that useful floras should be based upon will require a whole new gen-

eration of diatom taxonomists. In the interim, the internet and related technologies may constitute at least a partial solution to the 'never finished monograph' problem. Although its possibilities have not yet been fully exercised in diatom taxonomy, they offer the possibility of developing the sort of dynamic and flexible type of exposition that modern taxonomy demands. For the time being the best resorts are to work in an institution with a strong and continuing library system and/or periodic visits to institutions with extensive collections of specimens and literature.

The take home message is that paleolimnologists who wish to use diatoms (and other poorly studied organisms, for that matter) in their investigations should accept the fact that they need to become more deeply invested and engaged in the basic theory and practice of taxonomy than is commonly supposed. The current literature simply will not support the sort of 'look it up and key it out' paradigm that many ecologists, not only paleoecologists, have been trained to think of as taxonomy. While some may consider this sort of basic taxonomic research a diversion of effort and resources from what they consider their primary task, it is not without rewards. With minimal well-directed effort all those 'cf.'s' , aff.'s, and sp.'s can be converted to more certain, and perhaps new, knowledge. Besides looking good on your CV, taking the long view of science, the latter may be the most important contributions an individual can make. Certainly, paleolimnologists have the finest temporal records of diatom diversity obtainable at their disposal. Due to current interest in developing training sets from many parts of the world, many labs also have at hand fine-scale phytogeographic data that approaches those available for well-studied groups of organisms. In a world where species diversity, local extinctions, and invasion of exotic species are matters of great concern, paleolimnologically-based studies (e.g., Julius et al., 1998; Edlund et al., 2000) are a powerful, and indeed preferred, tool with which to address these questions. It is my sense of the situation that these resources are not presently being exploited to the extent they should be, to the detriment of both paleolimnology and classical diatom systematics. Wonderful opportunities exist in all these fields for those bold enough to seize them.

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