PROCEEDINGS OF THE CALIFORNIA ACADEMY OF SCIENCES

Volume 56, No. 14, pp. 156–161, 6 figs. April 29, 2005

Taxonomy and Ecology: An Inseparable Pair

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Some examples from the diatom genera *Gyrosigma* and *Pleurosigma* are presented to illustrate the following postulates: (1)the notion that taxonomy is an "old-fashioned" activity is a relict of the pseudo-progessive Seventies; (2) faulty taxonomy results in irreproducible pseudo-science, e.g., in unverifiable ecological conclusions; (3) ecological studies on diatoms should take account of the micro-sized biotope in which diatoms live and of the time factor; (4) phenotypically identical populations in widely different habitats may constitute different "ecospecies."

The central theme of this workshop is the synergy between taxonomy and ecology in the study of diatoms and the application of its results. To set the stage, I will try to illustrate what may happen if this synergy is disregarded with some examples from the genera *Gyrosigma* and *Pleurosigma* — not because they are particularly important in this respect, but as a result of personal interest. Call it a "travelogue" in which we travel from one taxon to another and from one issue to the next. In addition, I will offer some personal comments on the financial, political and societal context in which we have to study diatoms.

The Taxonomic Situation

In many countries including The Netherlands, the situation for diatom taxonomy is deplorable. No specific budgets are available and expertise in the practical application of diatom taxonomy is at risk of being destroyed by budget cuts that may lead to the closure of entire departments.

This is partly due to the fact that funding for basic research is becoming difficult to secure, because research may be at the mercy of leaders who think that Science can be profit-driven. But another factor involved is the widespread image of taxonomy as an unimportant activity, and this is a serious problem we must address.

The Image of Taxonomy

In the first place, the very nature of taxonomy is often unclear, even to some diatomists. Students think that the short courses they receive in identification of the more common diatoms constitute "taxonomy." Taxonomy, however, is the fundamental investigation of organisms aiming at a circumscription of their biological (that is, genetic) individuality.

Secondly, in some circles there is a strong aversion to what they *think* is "diatom taxonomy" because in their past experience this has resulted in long lists of names permitting no scientific conclusion whatsoever. A floristic inventory does not equate to taxonomy and it's the diatomists' own fault that this antipathy has arisen.

Thirdly, there is the widespread misconception that taxonomy consists of the description of new species or varieties. The realisation that taxonomy may instead have to start with the *elimination* of established but invalid "pseudospecies" may come as a surprise to workers not specialising in the subject.

Finally, the practice of taxonomy, with its careful procedure of literature research, tracing herbarium materials, determining synonyms and formal typification is dismissed as "old-fashioned" by some. Many biologists are unaware that the only permissible taxonomic procedure for diatoms (as for other algal groups and higher plants) must follow the rules of the ICBN (International Code of Botanical Nomenclature).

In this situation we must formulate convincing reasons why diatom studies involving taxonomy are important and should be supported. Unfortunately, the principal character separating humans from other animals — the Pursuit of Knowledge — is no longer regarded as sufficient *per se* by potential funders. Therefore, our arguments should in a sense also be "politically correct," fitting in with the societal-political issues of the moment. This may seem a mercenary attitude, but it merely recognises the reality that science is pursued in a societal — and thus political — context.

Taxonomy and Ecology: Inseparable

The examples given here relate to the diatom genera *Gyrosigma* and *Pleurosigma*. These diatoms illustrate the lack of taxonomic research very well, as evidenced by the amazing fact that of the many thousands of diatom illustrations published in the course of 85 years in Schmidt's *Atlas* (1875–1959) *not a single one* showed a representative of these genera!

Neglect of taxonomy violates the most basic rule of science. For human communication of *any* nature to make any sense at all, the entities under discussion must be unambiguously defined. If no proper taxonomic separation were made between *Canis lupus* and *Canis domesticus*, one would conclude that the development of human society since the Neolithic has been associated with an explosive increase in the population of wolves.

Only when the identity of an organism has been unambiguously fixed does it become possible to determine its biological characteristics: its physiology, nutritional requirements, habitat and biogeography. Only when these are known, the organism can become a source of information on the Earth's history. This is especially the case for diatoms, whose siliceous exoskeleton is both taxonomically informative and durable, permitting conclusions over many millions of years.

Example (Fig. 1): Published studies on the Dutch Wadden have described an abundant presence of *Gyrosigma spenceri* (Quekett) Griffith et Henfrey. The type material of this diatom indicates a freshwater environment, however. This would imply that either the Dutch Wadden Sea is subject to massive freshwater influx (which is not the case) or that *Gyrosigma spenceri* has an ecology ranging from freshwater to fully marine. Taxonomic studies have shown, however, that *Gyrosigma spenceri* — for 150 years one of the most frequently recorded members of the genus — is merely a later name for *Gyrosigma acuminatum* (Kützing) Rabenhorst, a purely freshwater diatom. In addition, it became clear that at least 6 different species with different ecologies ranging from freshwater to brackish and fully marine have been called "*Gyrosigma spenceri*," or varieties thereof. The previous studies thus presented irreproducible results because of taxonomic errors (Sterrenburg 1995, 1997; Sterrenburg and Underwood 1997).

The taxonomy of *Gyrosigma* and *Pleurosigma* species is a challenge, but their ecology is not particularly diverse. The freshwater species all avoid acidic, oligotrophic waters but do not appear to permit fine ecological distinctions. Also, especially in Holland there are major gradients in salinity from freshwater via brackish to fully marine and these show that some *Gyrosigma* and a few *Pleurosigma* species can tolerate a wide range of salinity. The genera clearly flourish best in the marine littoral and in general they favour the presence of organic detritus, but for really sensitive ecological indicators other diatom genera offer better candidates.

Example (Fig. 2): The most extreme case so far observed is *G. wormleyi* (Sullivant) Boyer, also on record as the illegitimate synonym *G. parkeri* (Harrison) Elmore. Its type material is definitely freshwater and I have indeed collected it in non-saline Dutch waters, but I have also found flourishing populations in the marine littoral of Cameroon, for instance. Also, Tiffany and I have verified that it grows abundantly in the Salton Sea, California, which is 30% saltier than seawater! Morphologically, the marine and the Salton Sea populations are completely identical to the freshwater type specimens so that identifications arrive at the same morphospecies. One could think of two different explanations: (1) *G. wormleyi* is very euryhaline by nature, any population being able to grow under widely different conditions of salinity; or (2) The populations from highly saline waters observed might not be genetically compatible with the type. The latter might apply to the Salton Sea populations in particular, because the Salton Sea is man-made and the result of an engineering mishap about a century ago. This caused the Colorado River to be dumped into a natural depression in the Californian desert and as the salinity of this artificial lake increased over time, an originally "freshwater population" from the Colorado River may have adapted and drifted apart genetically. One would need to verify whether these individuals can still cross with their parent line — if not, they should be considered a different "ecospecies."

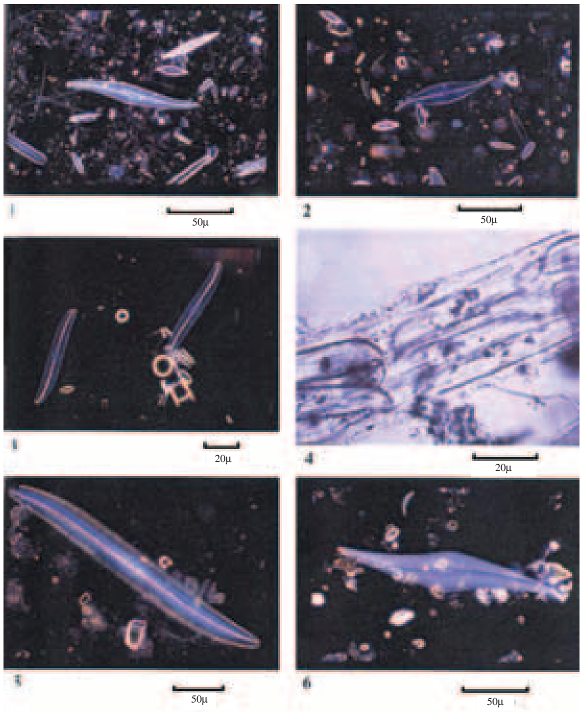

Figure 1. Specimen typical of "*Gyrosigma spenceri*" identifications in the literature: *G. acuminatum* from a ±freshwater ditch, North Holland. Bar = 50 µm.

Figure 2. *Gyrosigma wormleyi*, Salton Sea, California, USA. Morphologically this is a complete match for the freshwater type specimens. Bar = 50 µm.

Figure 3. Specimens matching the protologue of *Gyrosigma exilis* from the only population observed so far in The Netherlands (North Holland). Bar = 20 µm.

Figure 4. Live specimens of *Gyrosigma obliquum* in mucus tubes, Samoa, Pacific. Bar = 20 µm.

Figure 5. *Gyrosigma spectabile* from one of the "standing crops" in the Florianopolis area, Brazil. Bar = 50 µm.

Figure 6. Specimen fully matching the New Zealand type specimens of *Pleurosigma sterrenburgii*, from one of the rich populations seen in the Jadebusen, North Germany. Bar = 50 µm.

This shows that we may need to consider the species concept from the ecological as well as the traditional taxonomic perspectives (see Sterrenburg 1994; Sterrenburg, Tiffany, and Lange 2000).

Spatial and Temporal Factors

Examination of the literature of freshwater diatom surveys that include ecological data raises the question how reliable such "traditional" data really are. Typical sampling methods comprise too broad a scale for microscopic, rapidly dividing organisms such as diatoms, both spatially and temporally. Scaling down could reveal much more about the taxonomy and ecology of diatoms.

Suppose that physico-chemical analysis of a water column sample from a stagnant freshwater pool yields a certain pH and certain values for salinity, phosphate etc. Certainly, these values do not define the ecology of the bottom-dwelling as well as the epiphytic and planktonic species. Such a stagnant pool — because of the absence of mixing — shows a series of gradients in temperature, insolation, pH, mineral concentrations and organic compounds that may favour or inhibit the growth of certain species. When organic matter in the mud decays, this will lead to strong local physico-chemical gradients, which could lead to major changes in the diatom assemblage over very short distances. For micro-organisms we would need to scale down properly, using microsensing instead of analysing "a bulk water column sample."

Example: (Fig. 3): This small freshwater *Gyrosigma* matches the protologue for *G. exilis* Grunow. It had never been described for The Netherlands and the only locality where I have found it is a spot measuring only a few square meters: a sandy slope wetted by a trickle of freshwater in a reclaimed area called the Wieringermeer in the province of North Holland. In this tiny area, I have found that the species has continued to grow for about 20 years. Topological isolation is not involved, the physico-chemical conditions appear to be the same as everywhere else in the area and although some ecological factor is likely to be involved, I can offer no explanation.

For intertidal mudflats in the marine littoral, one does not expect to find major local ecological differences over short distances as intensive mixing is involved, but the time factor also needs to be considered.

Example: (Fig. 4): When this sample was collected from an intertidal mudflat on the coast of West Samoa, the temperature of the surface mud was near 50°C and evaporation had led to the appearance of salt crusts in some places — indicating a hypersaline habitat. A few minutes later, a torrential monsoon rain submerged the site ankle-deep in cool and only mildly brackish water. The diatom flora here has to be resistant against severe osmotic shock and probably for protection, *Gyrosigma obliquum* Grunow (like several other diatoms from such habitats) can develop thick mucus tubes. An ecological "snapshot" of the habitat may therefore be insufficient, one must consider the ecological extremes to which the diatom may be exposed during its lifetime (Sterrenburg 1989).

In other words, we may have to look at diatom ecology at the proper spatial and temporal scales. Such an integration of ecology and taxonomy could certainly yield valuable data from the purely scientific point of view, but I am not sure we could convince many politicians to finance it.

The Environment

Studies on the impact of human acitivites on the environment are certainly regarded as "politically correct." A previous generation of engineers and scientists was able to pursue a career studying acid rain and its effects. For this subject, diatoms have indeed contributed valuable data — provided there was a sound taxonomic basis for identification of species tolerant to low pH. But because electricity generation is now much cleaner, acid rain as a source of money has dried up in the developed countries.

Global warming was another good source of potential income for research but it may not be easy to find strong arguments for improved diatom taxonomy in support of short-term global warming studies — in contrast to long-term paleoclimatology, of course. And because of the recent political dissent over the Kyoto protocol, the immediate future for global warming studies looks somewhat chilly anyway in certain countries.

Water quality studies continue to be a modest but steady source of income for some diatomists, but it may not be easy to convince our paying customers of the necessity of further development of taxonomy here. Usually, customers want to hear simple and unambiguous answers to their questions. Customer relations would not receive a major boost if we told them that we'd have to spend lots of extra time and money to answer their question because we're not really sure our taxonomy is correct! Scientifically, this may be quite true, but we'd eliminate ourselves from the market.

Biodiversity

The situation becomes different, however, if we consider taxonomy and ecology in relation to studies on biodiversity. And "biodiversity" *has* become a word even government circles have become familiar with. It is certainly politically correct to express concern about the extinction of species due to human impact. Therefore, a taxonomically impeccable record of verified distribution patterns is highly valuable. The basic shortcoming in the concern about the loss of species diversity expressed by non-scientists is that we *should first know what there is in an area before we can determine what we are losing* — and that is far from being the case.

If we take the marine littoral as an example, a survey of the literature will immediately show that data on the diatom species diversity of many areas of the globe may amount to a single publication based on one or two poorly documented samples collected in the 19th century. This is especially true for tropical coasts, and there the situation is particularly serious for three reasons:

(1) these may be the areas where species diversity in certain diatom genera may be *particularly high*;
(2) they may be under severe human-related ecological pressure — for instance, the large-scale destruction of coastal wetlands and mangrove forests, or pollution by industrial effluents or sewage;
(3) but tropical and subtropical countries are often precisely the areas where funding for research is *minimal*!

Example: (Fig. 5): The total verifiable documentation of *G. spectabile* Grunow ex Peragallo consisted of a schematic drawing of a single specimen and minimal diagnosis published in 1891. De Souza-Mosimann, Fernandes, and I have verified that this presumably "rare and obscure" species, which had not been recorded for over a century, is actually an abundant member of the standing diatom crop of the coast of South Brazil to French Guyana (see Sterrenburg, de Souza-Mosimann, and Fernandes 2002)!

But even for our own backyard, great improvement in diatom biodiversity data is possible — and necessary before we can draw useful conclusions.

Example: (Fig. 6): Ten years ago, Stidolph described this diatom as a new species from New Zealand. I had never found it in samples from any other area, e.g., the Indian Ocean, Pacific, Caribbean, Arabian Gulf or Mediterranean until a few months ago when I found large populations in the German Jadebusen! This second, literally antipodal, record of *Pleurosigma sterrenburgii* Stidolph constitutes the greatest extension of biogeography possible, and, since then, it has been observed in large numbers in that area (Witkowski, pers. commun.; Stidolph 1993).

To illustrate the actual species diversity in *Gyrosigma* and *Pleurosigma* for The Netherlands: the Dutch flora of Van der Werff and Huls recorded about a dozen taxa for these genera. About half of these are synonyms or confused entities, so there remained only about half a dozen Dutch sigmoid diatoms whose identity was reasonably certain. So far, I have recorded about 60 species from these genera in the same area — and more continue to be found. With a Macchiavellian line of reasoning, it could be claimed that human activity does not harm Nature at all but can instead lead to a *ten-fold increase in species diversity.*

Although a combination of taxonomy and ecology properly scaled in space and time would be ideal, even a more modest effort to get an insight into the huge diversity of diatoms, with *verified* data on their biogeography and reliable information on their autecology, is necessary and can be argued to be compatible with the current societal-political trends. It can contribute to the challenge raised by the All Species Foundation (*www.all-species.org*) to catalogue all the World's living beings!

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