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Opinion Paper

Algal taxonomy in limnology: an example of the declining trend of taxonomic studies?

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Abstract

The recent decline in taxonomic studies is well recognized. Algae-related papers (390) published in five leading limnology journals (1971–2004) were consulted to assess similar trends in limnology by taking algae as a test aquatic group. The study showed a decrease of algae-only studies and an increase of multi-group studies (algae plus one or more aquatic groups). Identification of species decreased while mentioning of ecological groups (phytoplankton, epiphytes, etc.) increased while presenting results. Species identification, however, was not associated with number of aquatic groups or number of algal species included in a study. Problems probably lie with the old-fashioned image of taxonomy and it being threatened by the recent advancement in evolutionary and molecular biology. Issues like the changing research patterns in freshwater ecology, scope of limnological works, its workers and relevant journals are also shaping the status of traditional taxonomy in limnology. Practices such as giving of at least (algal) genera in community studies, and of the current names of studied species in physiological/molecular works and also in studies on particular supra-generic taxa (Class, Family, etc.), could help sustaining of taxonomy in limnology.

Introduction

For the last decade or so there has been an increasing concern for the substantial decline of traditional taxonomic studies (Bramley, 1994; Lhotský, 1998; Lee, 2000). This change is associated with an increasing attention to the applied disciplines of biology (e.g. biomedicine, gene manipulation, proteomics, etc.) than to those dealing with basic sciences (Lee, 2000; Boero, 2001). Increased funding for biological research is mostly controlled by the commercial returns to the funding agencies. Emphasis has been on specific species or groups because of their appealing economic benefits. This practice is also shaping the future of biological sciences by influencing the new generation of researchers. These trends are, however, more obvious in the developed countries than in the developing countries (Bramley, 1994; Disney, 1998; Wishart & Davies, 1998; Irfanullah, 2003).

Limnology is a multi-disciplinary subject by origin. Its advancement is closely associated with theoretical and applied development in its physical, chemical and biological elements. Biotic components of aquatic ecosystems encompass all natural groups: microorganisms, plants and animals. Because of the extreme variability among aquatic ecosystems in space and time, taxonomic identification of the studied organisms is necessary for the subsequent testing of a limnological notion or application of an understanding.

Given the worldwide decline in classical taxonomic interest, one can wonder, is limnological research an exception? In this account I try to understand this by taking algal taxonomy as an example. As limnology encompasses many different disciplines, it is a good field for testing taxonomic decline and revealing the possible causes. Papers published in five leading limnology journals over the last 34 years have been consulted. I test several hypotheses to reveal some trends in algal taxonomy in limnology and check: whether there is an increase in ecosystem-level studies and a decline in studies on a single aquatic group (in this case algae); whether there is an increase in studies involving mixed algal groups as opposed to single group studies (e.g. green algae, cyanophytes/cyanobacteria etc.); and whether there is a change in the number of algal species involved in a study. I also test whether these changes are associated with the practice of identifying an algal taxon to species level as species identification can be considered as the ultimate taxonomic element in a biological study. I discuss the limitations of taxonomy itself and also how limnology is influencing the use of taxonomy. Several suggestions are made for the practising of taxonomy in freshwater ecology in general.

Approaches taken

Issues published in five leading limnology journals (Table 1) in 1971, 1975, 1981, 1985, 1991, 1995, 2001 and 2004 (till August) were consulted. On average ca. 70 papers were checked for 10 algal papers published each year in each journal (i.e. around 2800 papers were browsed for a total of 390 algal papers). Here an algal paper is defined as a full limnology paper (original/standard work) where one or more members of the algae (non-embryonic, chlorophyll *a* bearing organisms and related groups including cyanobacteria, but not the macrophytic charophytes) have been dealt with either exclusively or with other aquatic organism(s). Freshwater, inland brackish and saline lakes, and lotic habitats are considered, but not estuaries. Special issues, supplements, review papers, applied papers or short communications/notes of a journal were not considered. Occasionally, volume(s) of a journal in the above-mentioned years did not contain 10 algal papers in one year. In such cases, papers published in the following year, but not later, (in the case of 2004 the preceding year) were also recorded. These selected papers were then read and classified according to several classification systems given in the Table 2. This table also contains the purpose of each system and associated hypothesis(es). In this account by identification I mean identification of species, if not mentioned otherwise.

In text, tables and figures, when more than one taxonomic category was mentioned, any category representing > 50% of the total mentioned taxa was considered for classification. For example, if a paper dealt with 10 taxa consisting of six genera and four species, this paper would be classified as a

Table 1. Journals consulted in the present study and their impact factors (IFs) in 2003 (Science Gateway, 2005)

Journal	IF (2003)
1. *Archiv für Hydrobiologie*	1.261
2. *Canadian Journal of Fisheries and Aquatic Sciences*	2.432
3. *Freshwater Biology*	1.936
4. *Hydrobiologia*	0.720
5. *Limnology and Oceanography*	3.329

genus paper. But if such clear estimation was not possible the lowest categories were registered. Where species diversity indices were mentioned, the paper was classified as a species paper. Often authors mentioned species names in the text then in the figures or tables used genera. In such cases I considered that species rather than genus had ultimately been used. Species names purely taken from previously published papers were not considered. In some works at ecosystem level no algal taxonomic group was mentioned. These were classified as 'mixed algal group'.

The total counts of five journals for each year in each category were used for statistical analyses. Normal distribution of the data sets was tested. Two sample *t*-tests or one-way analyses of variance (ANOVA) were made to determine significant differences among the categories under each category system. Pearson correlation coefficients (*r*) were calculated to show the association between two data sets.

Patterns revealed

Limnological studies involving only algae have decreased markedly over the last three decades, whereas, studies covering other aquatic groups in addition to algae have mounted gradually in recent years (Fig. 1).

Most of the algal papers dealt with more than five algal species, and this trend remained unchanged over the period studied (Fig. 2). Almost all of these papers involved natural communities with many species. There were no significant differences between the proportions of papers that included one algal species and two to five algal species.

Identification of the studied taxa down to species has decreased gradually since the 1970s (Fig. 3). It is accompanied by an increase in the use of ecological groups especially in the figures/tables (species papers versus eco-group papers, $r = -0.790$, $p < 0.05$). The mentioning of ecological groups, Classes and species names in the text showed positive correlations with mentioning them in the figures/tables ($r > 0.720$, $p < 0.05$). Hence, the identification of studied taxonomic ranks was similar in highlighting the research contents (in the text) and in presenting the data (in the figures/tables).

Studies on mixed algal groups have always been very common (Fig. 4). The proportions of papers in which only one major algal group (green algae, cyanophytes, diatoms, chromatophytes, etc.) was considered, did not vary much among themselves.

The specific mentioning of algae in the text or in the figures/tables was not correlated with the types of study (algae–only study or multi-group study) ($p > 0.1$). Such mentioning of algae was also not correlated with the number of species (1 sp., 2–5 spp. or > 5 spp.) considered in a study ($p > 0.10$). Both opposed the expected patterns.

The data analyses supported, however, two of the assumptions: (i) a decrease in the number of algae-only studies and (ii) a decrease in species identification over the last 30 years or so. If investigated similar trends might be found in other aquatic groups (e.g. ciliates, zooplankton and macroinvertebrates). But the data do not give a clear reason for this decline of taxonomic concerns in limnology. We need to look into the limitations of traditional taxonomy – whether it is responsible for such a decline. We also have to consider some limnological issues that probably can explain the changing patterns of taxonomy in freshwater ecology.

Limitations of taxonomy

The basic problem with taxonomy is its image of a tedious and laborious branch of biology. Identification of species is often time consuming, requires specialised literature and often demands expert assistance. A classification system based on morphology has its drawbacks due to scarcity of identifying elements (e.g. zygospores of Zygnemataceae species), high morphological variability (e.g. *Scenedesmus*, *Cladophora* and *Stigeoclonium* species), need for life-cycle study, and so on. Complex groups like diatoms and chrysophytes need to be identified with minute physical features. Thus, special procedures, such as electron microscopy, cultivation, biochemical and molecular techniques etc. have to be followed in many cases, which are not feasible for routine monitoring. Various opinions on naming a form and frequent changes in taxonomic ranking also make taxonomy subjected to criticism.

Table 2. Categorisation system used to classifying limnological papers included algae. Purpose and corresponding hypothesis(es) for each classification are also mentioned

Categories				
Type of study	Number of algal species studied	Level of identification in text	Level of identification in figures/tables	Broad algal groups
(1) Multi-group study: one or more groups studied in addition to algae	(1) 1 species	(1) Ecological group (as algae or as phytoplankton, epiphytes, etc.)	(1) Ecological group	(1) Mixed: more than one algal group
(2) Only on algae	(2) 2–5 species	(2) Supra-genus (from Family to Division)	(2) Supra-genus	(2) Green: Chlorophyceae, Prasinophyceae, etc.
	(3) > 5 species	(3) Genus	(3) Genus	(3) Cyanophyceae/ Cyanobacteria
		(4) Species	(4) Species	(4) Diatoms: Bacillariophyceae
				(5) Chromophytes: Euglenophyceae, Cryptophyceae, Xanthophyceae, Chrysophyceae, Dinophyceae, etc.
Purposes				
Indicates the degree of attention given to algae in an algal paper	Points out the number of algal species considered in a study	Important aspects of a study are mentioned in the text (Results sections). This categorisation suggests the usefulness of algal taxonomy in highlighting the research contents	Figures and tables present data concisely. This categorisation thus indicates the usefulness of algal taxonomy in presenting the findings	Suggests the occurrence of algal group(s) in a study
Hypotheses				
Multi-group studies increased (or algae-only studies decreased) over the period studied	Single species studies decreased over time	Papers mentioning eco-groups in text increased (or mentioning species decreased) over time	Papers mentioning eco-groups in figures/tables increased (or mentioning species decreased) over time	Studies on mixed algal groups increased (or on single group decreased) over time
Multi-group studies will have low species identification (or algae-only studies will have high)	If large number of algal taxa are studied in a single study, identification to species level decreases			

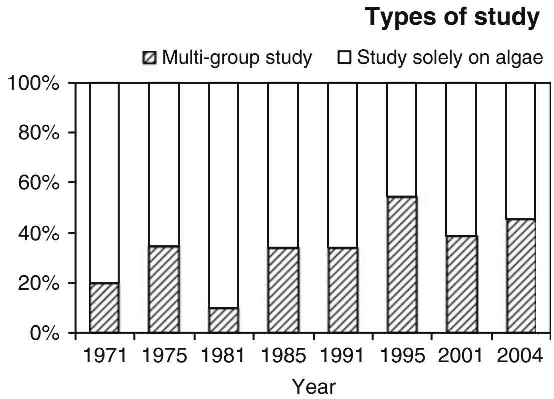

Figure 1. Percentages of multi-group studies (algae plus one or more groups) and studies solely on algae, 1971–2004.

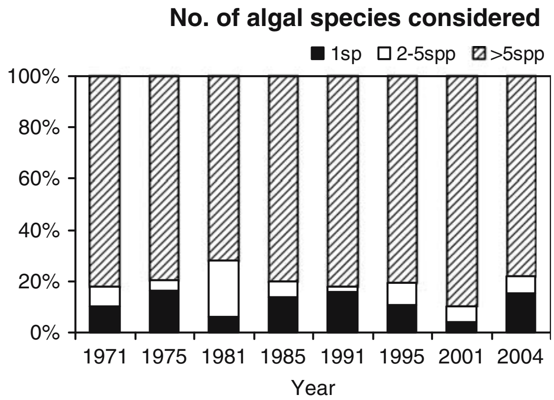

Figure 2. Percentages of algal studies involving 1, 2–5 or > 5 algal species in different years (1971–2004).

The second challenge taxonomy faces is from evolutionary biology. Whether guided by taxonomic authorities or regularly updated by new data, systematics are continuously evolving (e.g. algal systematics, Williams & Round, 1994). Despite the optimism that there is no conflict between classical (typological) species concept and the biological (reproductive isolation) species concept (Lewin & Newman, 1996), the status of 'species' as a taxonomic unit is now being questioned. The confusion in species concepts (typological, biological, ecological, etc.) and the inability of the Linnaean nomenclatural system to match with phylogenetic information has encouraged some workers to introduce new nomenclature systems for living organisms, e.g. PhyloCode (de Queiroz & Cantino, 2001), least-inclusive taxonomic unit (LITU) (Pleijel & Rouse, 2000) or molecular

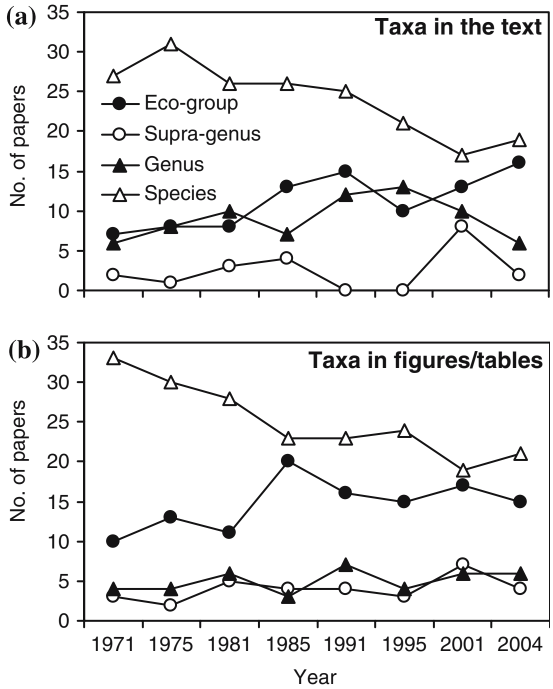

Figure 3. Yearly totals of algal studies where species, genus, supra-genus (Class, Family, etc.) or ecological-groups were mentioned (a) in the text and (b) in the figures/tables, 1971–2004.

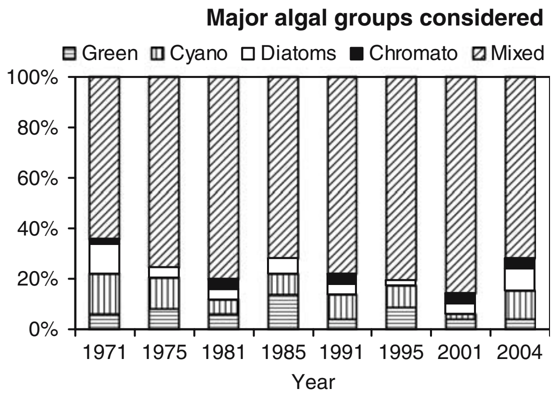

Figure 4. Percentages of algal studies involving major algal groups: 'Green' (Chlorophyceae), 'Cyano' (Cyanophyceae), 'Diatoms' (Bacillariophyceae), 'Chromato' (Chromatophytes: Euglenophyceae, Cryptophyceae, Xanthophyceae, Chrysophyceae, Dinophyceae, etc.) and 'Mixed' (more that one algal Class) in different years (1971–2004).

operational taxonomic unit (MOTU) (Blaxter, 2004). Additionally, for a quick assessment of biodiversity and minimising the pressure of taxonomic identification, the employment of parataxonomists and use of recognizable taxonomic unit (RTU) have also been proposed (Beattie & Oliver, 1994).

Thirdly, identification of species depends upon the judgement of the workers. Limnologists as non-taxonomists usually use only the literature they have in hand. Such reference materials may not represent the study area as most algal species are not cosmopolitan and most monographs are temperate world-based. Wide variability can be seen among the forms associated with a single species name. Repeated changing of taxonomic position also makes it difficult to name some algal material satisfactorily. On both occasions a worker has to choose a species name on his own accord. In addition, not considering ecological conditions while identifying a species could also lead to misidentification of a species (Lhotský, 1998).

Finally, the number of workers actively involved in taxonomy in general is decreasing rapidly as only a few experts are being created to replace the retiring ones (Cotterill & Dangerfield, 1997). Several reasons explain this. (1) Universities are now offering more and more molecular biology/genetics oriented biology courses (Lhotský, 1998; Boero, 2001). This is a response to the recent tremendous advancement in these fields of biology, but nonetheless, an example of the commercialisation of the education system. Taxonomy, especially identification of species, is fading away from biology curricula. (2) The pressure on researchers to publish papers is higher than ever, but journals publishing taxonomic papers have lower impact factors (IFs) (see later; Lee, 2000; Valdecasas et al., 2000). (3) Molecular or biotechnological skills are non-specific, flexible and with more funding, opposed to taxonomic expertise (Lee, 2000), thus offer better career prospects. Thus, very few young scientists are now entering into ecological research with sufficient knowledge about (plant/animal) identification. Limnology is not an exception.

Limnological issues

The changing trends

Because it is a multi-disciplinary endeavour, it is sometimes difficult to delineate the boundaries of limnology. It is often hard to determine where the concerns of nutrient loading on a lake end and the social and economic issues in the catchment begin; where the interest in lake-catchment ends and the arable land/forest management begin; or where the ecology of phytoplankton ends and algal taxonomy begins. It seems that limnology has been completing a full circle. It started its journey with the philosophy of understanding the whole lake system (Forbes, 1887, quoted by Elster, 1974). Over the last more than 100 years, a vast amount of information has been gathered on the components (organisms and processes) of aquatic ecosystems through direct observation and experimentation (Elster, 1974; Reynolds, 1998). Recently limnology has entered a phase where we are increasingly getting more concerned about the whole ecosystem putting its individual components into context. This is reflected by the generation of new notions (e.g. multiple states in shallow lakes), generalisation of complex ecosystem processes through modelling, approaches to restoring deteriorated ecosystems, water quality management schemes (sometimes driven by commitments at regional levels, e.g. the Water Framework Directive in Europe) and so forth. Studies now often involve wide boundaries of time and space. The past is now being re-constructed through paleolimnological investigations, while the future is being envisaged in climate change projects through simulation. Data are now collected at micro-scale as well as at regional scale using novel methods and advanced instruments. Publications are often enriched with statistical analyses (especially multivariate analyses) and mathematical modelling done with sophisticated software. Many studies now have direct economic, social or political concerns rather than are mere compilation of knowledge. Limnology has, thus, become more practical, more comprehensive, more technology-dependent and at the same time with wider perspective. Projects are now more multidisciplinary than ever, and done by researchers who are often experts on processes/events rather than individual species.

Scope of work and the workers

Taxonomic enumeration often depends upon the scope of a study and also on the choice and/or the ability of the researchers involved. In early limnological studies involving algae, a list of all common algal species encountered was a norm. But such trend has changed over the last few decades. Studies on the growth rates, nutrient requirements or responses towards pollutants of one or a few algal species are important in revealing patterns in a few representative taxa. In such studies, even if one pure algal culture is used, it is often referred to by genus. Studies on nutrient dynamics, primary productivity or heterotrophy in a system often involve whole phytoplankton/epiphytic communities, but frequently without species identification.

So one important question might be how much taxonomic knowledge is really required to describe a limnological phenomenon? For some assessments, such as bio-monitoring of water quality, determining species diversity or determining trophic indices using phytoplankton species identification is obligatory. Loss of information could be high when supra-specific taxa are used (Stubauer & Moog, 2000). It depends, however, upon the bio-geographical issues of an area and existing species diversity within the supra-specific taxa.

Although many algal species exist in an aquatic system, only the dominant ones influence the system, or conversely, are mainly controlled by the system. Tracking these few species can help us in understanding the system. So identifying all occurring taxa may not be practical for routine assessment. It is even tougher when a study handles several aquatic groups. Moreover, phytoplankters can be sorted into different functional groups on the basis of their habit and ecological concerns (Reynolds et al., 2002). For ecological modelling, we could rely on these functional groups rather than individual species (Harris, 1999).

At the beginning of limnology, studies on particular groups were usually done by researchers who were experts on the taxonomy of that group. Now-a-days limnologists should not be expected to be expert taxonomists. But they need to have certain level of taxonomic proficiency. But it seems that in recent years limnological studies on physiological, biochemical and molecular biological aspects of algae have increased and are done by workers not really critical about the taxonomy of the organisms.

The journals

The stance of a journal on taxonomy also influences the taxonomic resolution in its papers. Many journals are now available dealing with aquatic ecology. However, their IF is far below than that of other branches of biology. For example, in 2003 (Science Gateway, 2005) IF of *Cell* was 26.626, whereas the highest IF of an aquatic journal was 3.329 (*Limnology and Oceanography*). Important journals that publish taxonomic papers are with low IF (e.g. *Nova Hedwigia*, 0.819 and *Cryptogamie Algologie*, 1.044). The whole perception of publishing has changed drastically in recent years. Algal journals like *Journal of Phycology* (IF, 2.026) or *European Journal of Phycology* (IF, 1.446) now rarely publish a paper without biochemical/molecular concerns. With changing limnological interests, journals now seem to be relaxed about taxonomic citation in papers as they compete with other similar journals for papers on novel, interesting and imperative issues. This attitude in one sense quite practical as it appreciates the fact that most of the workers are no longer taxonomists *per se*.

The techniques

Many techniques exist and many are under development to assess the phytoplankton community structure in the water. But they are not without limitations. A quick estimation of phytoplankton community is possible by measuring pigment concentrations (e.g. (high-performance liquid chromatography) HPLC techniques, Havskum et al., 2004). But these are not sufficient. These have to be supplemented by microscopic examination of the communities (Irigoien et al., 2004), thus requires taxonomic knowledge. High-tech identification systems like computer assisted taxonomy (CAT), e.g. digital imaging (Gaston & O'Neill, 2004) or DNA taxonomy with bar-coding (Hebert et al., 2003) are still at early stage, and will take some time to be sufficiently accurate and commercially available. They will remain expensive for many of the countries that possess much of the world's freshwater.

The two 'Worlds'

Economic conditions of the workers and/or their country of origin may influence the degree of taxonomic works produced by them. In most of the developing countries limnological works are still largely descriptive with substantial taxonomic consideration. The reason is expense. Long-term data collection systems and experimental approaches are scarce in these countries (Wishart & Davies, 1998). Lack of long-term data and costly computer packages also prohibit them from carrying out projects on contemporary issues like climate change or modelling of ecological processes. By emphasising on taxonomy these countries try to over-come their deficit of advanced resources. Of course, unlike the First World countries, least is known about the ecosystems of many Third World countries. Taxonomy-dominated basic research is much appreciated in these regions and could also explain the distinction between limnological studies in these two Worlds.

Decline of taxonomy: should we be concerned?

Given the necessity of taxonomy in inventorying of biological resources, conservation biology, evolutionary and phylogenic studies and in every field of biology dealing with species, its overall decline is worrying. To pull taxonomy away from its present trend several strategies have been suggested: (i) more endowment for alpha taxonomy (Disney, 1998), (ii) changing the attitude of funding agencies towards non-transferable, unique, specialist subjects like taxonomy (Lee, 2000), (iii) establishing unitary taxonomy on the worldwide-web (Godfray, 2002), (iv) creating strong co-operation between molecular biology and traditional taxonomy (Boero, 2001; Godfray, 2002) and (v) strengthening taxonomic components in undergraduate biology courses (Bramley, 1994; Irfanullah, 2003) are a few.

I believe, however, that we should not panic over the present falling taxonomic practices in limnology. We should leave the job of identifying every species on earth, their naming and classification, and responding to the recent molecular/phylogenic advancement with the taxonomists. Nonetheless, limnologists should be aware of current taxonomic systems as they need them to explain ecological phenomena and make limnology a repeatable discipline. Until a new taxonomic naming or classification system becomes accepted by appropriate authorities (e.g. International Botanical Congress, International Commission on Zoological Nomenclature or International Union of Biological Sciences) limnology should follow traditional systems. Limnology is an applied window of pure sciences like taxonomy, and benefits from the development in those fields. So we cannot leave the decline in taxonomic interest in limnology in its present state. By adopting a few simple rules (by the authors and journals of freshwater ecology) limnology can also help taxonomy.

Following recommendations are prepared keeping algae in mind, but similar rules could be adopted for other aquatic groups with necessary modifications.

(1) In limnological works with algal communities, in addition to jotting them down in their ecological groups (phytoplankton/epiphyton/metaphyton) or just mentioning their supra-generic ranks (Classes/Orders) or classifying them in different size groups (nano-, micro- or mesophytoplankton), we should record all common/dominant algal taxa encountered in a study at least down to the genus level. This should be done especially when the papers are mainly concerned with algae.
    This approach will relax the pressure to identify species with available literature, as genera are far more cosmopolitan than species. It will provide a compromise between two extremes – identifying every species in the samples and the mentioning of eco-groups only. As algal species almost exclusively do not mean proven 'reproductive isolates' (biological species concept) but morphological variants – use of genera is more justified as they are the lowest morphological taxa by definition. Furthermore, genera are often sufficient for determining functional ecological groups of phytoplankton (Reynolds et al., 2002).
    Species, very common in a geographical area or cosmopolitan, however, should always be identified down to species.
(2) In physiological or molecular biological studies when a few species (say up to 10) are

studied it should be the norm that current species names are stated, and expert-advice should be sought if necessary. It is essential because important molecular variations may exist among different species of a genus, and it may help ecologists to use molecular data in interpreting ecological events.

(3) While focusing on a particular taxonomic group (Order, Class or Genus) identification of all the species studied should be obligatory. It is expected that all necessary facilities (expertise, literature and laboratory facilities) should be in hand while working on a specific taxonomic group.

(4) Ecological models including algae may mention broad algal groups, like classes, trophic levels, size groups, etc. wherever possible. This could be useful given the differences among ecosystems dominated by different algal groups.

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