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Ecological challenges for lake management

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Abstract

The need for management, in natural systems, and possibly in all systems, reflects an inability of the systems to operate in self-sustaining ways, due to interference, or damage to an extent that is beyond the capacities of the system for self-repair. Management need is thus a symptom of failure of the system. The more management needed, the greater the failure and management is always costly. Most freshwater systems have been seriously altered by human activities. We may wish to restore them to self-sustaining systems which provide conservation or amenity values, or products such as potable water or fish, with minimal management, or preferably none at all. This may not be possible in many cases; it is completely impossible without profound understanding of their functioning. The ecological 'challenges' in lake management are thus to remove blocks which impede this understanding. There are at least three groups of blocks: fundamental; those of approach and method; and political. The latter is no less ecological than the others; human beings and their behaviour are ecological phenomena like those of any other animal. Fundamental blocks include the complexity and stochasticity of natural systems, which may change faster than they can be dissected and understood. They include also the scarcity of complete systems for investigation. Lakes are parts of greater systems in the landscape and if these systems are no longer intact, through insensitive land use, such as drainage, it is not possible to understand interactions and influences which were not confined to the lake basin. Examples are given concerning fish and bird movements. Methodological blocks concern the scale of investigations. The need for statistical rigour confines many investigations to small scale, easily replicable phenomena. Lake systems, however, are influenced by larger scale, lakewide or more extensive effects. An example is given concerning the effects of piscivorous birds. Unless whole lakes and their catchments are subject to experimentation, these influences will remain obscure, though they may be at least as important as within-lake effects. Replication is difficult and areas with large numbers of broadly similar lakes are needed. Such areas exist, but the costs of such large scale and long-term experimentation are rarely met. Political blocks are the ultimate blocks. A society which chooses to continue exploiting natural resources in an unsustainable way is not particularly interested in the fundamental understanding which underlies sustainability. There are many symptoms that we are choosing to follow the imperatives of our selfish genes, rather than make the ethical choices of which we are alternatively capable. They include the greatly reduced support for fundamental research in the U.K., the failure to use, in the spirit in which it was intended, existing European legislation for environmental protection, and the decreased strength of imperatives for conservation in the Environment Act 1995, compared with the Water Act 1989 and the Water Resources Act of 1991.

Words and language

Words, no less than numbers, are precision tools. They can be used as fine probes to convey significant shades of meaning but, like all fine tools, they can also be easily blunted and made into bludgeons. William Shakespeare was one of our finest wordsmiths. His invectives alone are unsurpassed (Hill & Ottchen, 1991). You might disdain from being called the 'fount from which small brooks flow', a 'triton of the minnows', 'caddis garter', 'foolless gudgeon', or 'lily-livered boy', despite their connection with freshwater ecology.

Words can also be used to convey messages of subtler content, though equally forcibly intended. W.

H. Auden's poem seems to me to make an important statement, to which I will later return:

"We would rather be ruined than changed,
we would rather die in our dread
than climb the cross of the moment
and let our illusions die."

Those who use words well are keenly sensitive to the horrors of verbal debasement. One of Shakespeare's epithets was 'corruptor of words', and the Book of Job talks of 'he who multiplieth words without knowledge' (Job, 35,16). The odious Humpty Dumpty, in Lewis Carroll's 'Through the Looking Glass', used words to mean 'just what I choose it to mean – neither more nor less' and George Orwell articulated the current problem in his novel, '1984'. 'New speak' was the deliberately ambiguous and misleading language of bureaucrats and politicians. *Challenge, vision, relevant, target and management* are part of the new speak of today. And so I reach two of the key words in the title I was given, and accepted.

I suppose the intended agendum of the title is that lakes have to be managed, that they are complex, that there is inadequate understanding, that therefore there needs to be more research, that understanding is just a matter of time as a beneficent government and industry supports the relevant research to attain this target. The challenge, I presume, is to gain this understanding. And the word *challenge*, though it can have many shades of meaning, is intended in the context of aggressively meeting the problem, a throwing down of a gauntlet. It seems to me that such aggressive new speech is part of the problem, not of the solution.

Blocks to understanding

A more accurate term than *challenge* would be *block*. The word challenge is currently used in the hope of injecting zest into situations where, due to ignorance or dogma, support has been reduced, and motivation has been eroded. 'Management' is also a weasel word. The need for management, in natural systems, and perhaps in others, is a reflection that all is not well. It is a measure of a failing to conserve systems that could be self-sustaining. The more management that is needed, the greater the failure, and management is costly. Our aim should therefore be to restore systems to conditions where only minimal management, or none, is needed. To achieve this requires profound knowledge of how the systems function.

The title, in plain English, is thus translated to *What blocks are there to increasing our understanding of how lake systems function*? Unless function, with all its antecedents of evolution and biogeography, is understood, there cannot be sensible management nor predictable restoration. I see blocks to understanding that are fundamental to the systems themselves, those that are concerned with method and approach, and those that are political and imposed by government and its agencies.

The fundamental blocks concern the complexity of the systems themselves, and the current fragmentation of these systems in a landscape greatly influenced by human activities. The methodological blocks concern the scale on which we are able and willing to work. The governmental blocks concern the motives and aspirations of society as reflected, perhaps, in its government. We need to ask if it is really intended that the *challenges* be met?

They are all, even the latter, ecological blocks for, notwithstanding the real concerns of many non-biologists, human beings are biologically driven to a significant extent and their behaviour reflects the operation of the selfish gene no less than the beaver as dam builder (Diamond, 1991). The dominant themes of politics, as those of art and literature, are those of human behaviour, those largely of the selfish gene. There are differences from other animals, of course. The powers our particular genes have given for modifying the Earth's environment are stupendous on the one hand, but, on the other, we may choose not to use these powers. This is a choice given to no other organism.

Fundamental blocks – determinism, complexity and stochasticity

Criteria of a full understanding of an ecosystem might be that we know exactly what species are in it, and how many of each there are, why they are there, what they are doing, and why they are doing it. In some of the simpler Antarctic fellfield communities of a few species of bacteria, algae, mosses and mites, considerable understanding might be possible. In a lake system there are several thousands of bacterial (Torsvik et al., 1990a, b) and algal genotypes, several hundreds of those of invertebrates and several tens of vertebrates and higher plants. Detailed understanding will clearly be unlikely, if not impossible, even were the community completely deterministic – fixed by the conditions extant at that place and time.

A popular approach of British-trained plant ecologists in the middle of this century assumed that the ecology of plants depended on the plant's physiology and the physical and chemical properties of the soil, all seen in the context of the local microclimate. Given particular combinations of these environmental factors, the plant would be present and able to grow and reproduce. It was an approach I implicitly adopted in carrying out culture-based studies on the distribution of eutrophic and oligotrophic algae in the late 1960s (Moss, 1973).

Hutchinson (1957) began to upset this view by his definition of the fundamental and realised niches of organisms. The fundamental niche included, in a multidimensional hyperspace, all the possible combinations of circumstances in the habitat that an organism could tolerate. But, because the organisms themselves and their interactions with one another were also included as dimensions, the possibility of precise determinism receded. When it was realised that particular combinations of circumstances could be occupied by many different organisms and that competition for niche space was usual, a stochastic element was introduced.

In 1965, Hutchinson introduced the idea of the 'ecological theatre' and the 'evolutionary play'. The organisms evolve; they continually change in response to changes in the environment and the environment, being partly determined by the organisms, reciprocally responds. Environmental determinism became only a small part of ecological understanding. The realities of chance colonisation and chance extinction confound even further a simple predictability of community composition. For example, organisms can persist in habitats which they have not reached by natural means but to which they have been introduced. Their presence or absence may be randomly determined. Reynoldson (1966) provided a good example for flatworms. Four species of carnivorous flatworm are common in U.K. standing waters – *Polycelis tenuis*, *P. nigra*, *Dugesia polychroa* and *Dendrocoelum lacteum*. There was a degree of determinism in that *Dugesia* and *Dendrocoelum* declined in numbers with decreasing calcium concentrations and were usually absent from waters with less than 5 mg l^{-1} Ca. Northern Scottish waters were thus devoid of all but *Polycelis* species. However, all four species would persist indefinitely in waters of even the lowest calcium concentrations, if supplied with suitable food. The absence of all species from lakes on some Scottish islands, and of two of the four species from others, seems simply to reflect that in the comparatively short period of 10 000 years or so since deglaciation, there has simply not been time for natural colonisation to have occurred. British waters are similarly devoid of many fish species that were probably interglacial residents, and could be current ones, for similar reasons of prevention of colonisation by sea level rise following deglaciation, and isolation from sources in mainland Europe.

It is also well established that many alternative communities can occupy a given set of conditions and that there is a high degree of chance as to which particular collection is extant at a given time (McIntosh, 1995; Drake, 1989). The stochastic element in communities thus blocks a full understanding.

There are, for example, at least 30 submerged aquatic plant species that can persist in moderately fertile shallow lakes in the U.K. An average lake, however, might have almost any permutation of five, dependent on accidents of colonisation and local extinction over many years. The number of combinations of five from 30 is a little over 17 million. The number of possible interaction pairs in 5 is 20. At its simplest (ignoring within-habitat clonal differences among each species or any complications arising from the heterogeneous distribution of associated organisms such as invertebrates), understanding the ecology of submerged plant communities in shallow, fertile lakes at the species level thus draws on consideration of about 340 million potential interactions. With the additional thousands of bacterial and algal genotypes, and the invertebrates and vertebrates, this approach – building up the functioning of the community in a strictly reductionist way, clearly has no future. There is a fundamental block in the size and stochasticity of the problem.

To a large extent this has been recognised in the use of functional groups or guilds of various kinds. A good example has been the concept of shredders, scrapers, collectors and predators among stream invertebrates (Cummins, 1974). This approach has also been particularly useful in understanding phytoplankton dynamics, where the behaviour of small, easily grazeable cells can be contrasted with that of large rapidly sinking ones, such as diatoms or of buoyant cyanophytes. Specific studies on particular predominant species, such as the classic work of Lund (1964) on *Asterionella formosa* and species of *Melosira* (*Aulacoseira*) have also contributed much understanding of how the phytoplankton communities function.

There will always be limits to understanding through these approaches because there will always be deviation from the general models, but functional groups limit the number of interactions that have to be considered and define an attainable ceiling for understanding. The problem arises in that important subtleties will be missed if we select particular groups or species on the basis of our existing, inevitably prejudiced, concepts. Thus an unsuspected keystone predator or parasite, present at low biomass, may be of far greater importance than the much larger biomass of some organism influenced by it.

Fundamental blocks – incomplete systems

The second fundamental block to ecological understanding is that we rarely have systems on which to work that are not severely altered by human activity. It is thus difficult to reconstruct the workings of a pristine system so that a damaged system can be restored and managed. The original blueprints have been destroyed. I am arguing, however, that human beings, whatever they do, are still ecological agents, to be understood as part of the current systems rather than as something separate, so this may seem an untenable argument. The difficulty comes because we are unwilling to accept this. We still want lakes that have features recorded in the past when our activities were at much lower levels and we assume that we can, by judicious restoration and management still have this. It may not be possible.

For example, many lakes in lowland regions were parts of complex floodplain wetland systems. To understand the lake ecosystem it is, among other things, necessary to understand its interactions with the surrounding wetlands, and the rise and fall of the river flood. There are obvious chemical and hydrological implications for this, but perhaps less obvious biological ones, particularly where vertebrates are concerned. This is important because birds and fish, though traditionally conceived as separate or dependent on the functioning of freshwater systems, may be crucial in structuring such systems (Leah et al., 1978, 1980; Andersson, 1981; Moss & Leah, 1982; Hurlbert et al., 1986; Andersson et al., 1988).

Piscivorous birds, for example, may take as much fish prey as piscivorous fish (Winfield, 1990); pike, through feeding on chicks, may influence duck populations (Hill et al., 1987); ducks and fish may compete for invertebrate prey (Winfield et al., 1989); and piscivorous and zooplanktivorous fish are key players in determining the clarity of water and the ultimate growth of plants in shallow lakes (Irvine et al., 1989; Moss, 1989, 1990, 1991, 1994; Scheffer et al., 1993). Grazing birds, such as coot (*Fulica atra*), may devastate aquatic plant communities if the birds gather at high densities (van Donk et al., 1994; van Donk & Gulati, 1995). Many of these vertebrates would have moved freely over the various sub-habitats in an intact floodplain system.

Most such floodplain systems in Europe have been drained and the rivers canalised. The annual flood is not permitted and the complexity of the former floodplain system has been lost. Movements of fish are severely restricted and although birds may move, there may be little alternative habitat to which they may move. They too, are thus confined. Klinge et al. (1995) suggested that in the original system in Holland, the pike (*Esox lucius*) populations built up in the extended habitat of the floodplain at high spring water levels and then concentrated in the residual lakes of the floodplain in summer. There, at highly concentrated population densities, they may have controlled zooplanktivorous fish and helped maintain clear water and dominance by aquatic plants, rather than phytoplankton.

The residual lakes alone, now cannot support such populations because of lack of spawning and lurking habitat, and indeed the former high summer populations of pike could only be sustained for a short time – but a crucial one for the establishment of plants. If this is correct, we may not be able to maintain a stable, diverse, plant-dominated community in many isolated lakes, without continual intervention, such as the stocking of predators or the removal of zooplanktivores.

Isolation of lakes through removal of surrounding natural habitat may also result in concentration of migratory birds. This may occur if they provide suitable habitat and food and there are few, or no, neighbourhood alternatives. The birds, especially grazers like coot and swan, may then destroy the plant communities through overgrazing. This appears to have happened at Zwemlust, in the Netherlands, where restored plant communities in an isolated lake have been devastated by invasions of coot (van Donk & Gulati, 1995), which have no alternative habitat in the immediate area.

The implications of these findings are that sustainable restoration, with minimal continued management, of such lakes, is not possible without restoration of the greater system of which they were formerly a part. Countries such as Denmark (Madsen, 1995) have already taken considerable steps towards the restoration of floodplain ecosystems but other European countries have yet to do so.

Methodological blocks – the ecosystem concept and scale

Sir Arthur Tansley provided a great service to ecology in his articulation (Tansley, 1935) of the ecosystem concept – that there exist more or less self-contained collections of organisms and their detritus in a particular set of physical and chemical conditions. The concept had the idea of self regulation and balance; the ecosystem was something around which a boundary line, if a hatched one, could be drawn. It was a concept very much conditioned by the compartmentalisation of the English countryside, with which Tansley, an inveterate field worker, was deeply familiar. It still forms the base of much management of habitats in the U.K., where remaining fragments of natural and semi-natural systems do appear as apparently self-contained islands in a sea of agricultural and urban land. It might also seem highly appropriate to the distinctive boundary created by the lake water's edge.

The ecosystem concept, however, has undergone evolution since Tansley's time, though his original idea of more or less self-containment strongly persists among landscape and conservation ecologists, if not among population and evolutionary ecologists. Where freshwater systems are concerned, the original concept can now form a block to understanding. Lakes do not only have hydrological catchments, from which water and substances are drawn, and without consideration of which, any real understanding is impossible. They also are influenced by processes outside their hydrological catchment due to the movements of atmospheric gases and migratory animals. The example of acid precipitation is obvious; the linkages of remote systems by migratory species have been more recent insights. Any idea of self-containment of a freshwater system is illusory.

Thus the headwater lakes of many river systems depend for their nutrient supplies, their periphyton growth, their invertebrate production and their salmonid (or other anadromous fish) recruitment on the carcases of adult fish that have made much of their growth in the sea and died after spawning (Krokhin, 1975; Richey et al., 1975; Durbin et al., 1979; Kline et al., 1990). The retention of the carcases, and hence the nutrients, in a flowing system depends on obstructions in the streams provided by naturally collapsed timber. A further link with the terrestrial systems, comes with the feeding on the migrating fish by bears. The lake is thus ultimately influenced by downstream forested areas and the ocean, as well as its immediate catchment and riparian vegetation. Ultimately, the only system around which a boundary of sorts can be drawn is the entire biosphere.

This point has not been taken widely enough by limnologists. There is a block to understanding when too reductionist an approach confines work to what is going on only in the lake itself, and sometimes to laboratory abstractions of these processes. Few have been able or willing to carry out the more desirable whole lake experiments. This is partly because of limited opportunities, at least in the U.K., which, except for Scotland, is not so well endowed with lakes as in Scandinavia or Canada, where such experiments have been more common. Partly it is also because of the statistical difficulties of handling unreplicated manipulations, and an unwillingness sometimes on the part of peers to accept data from such situations.

Primarily, however, it is a problem of obtaining replicated, manipulable systems on which to work, unhampered by other contemporary users, and with sufficient resources to carry out the extensive sampling and measurement such approaches demand. It is regrettable that the Canadian government proposes to withdraw much of its support from one of the few such facilities, the Experimental lakes Area in Ontario, where much classic work has already been carried out.

It is also a function of a culture that is dominated by reductionist science, in which experiments that give precise answers to simple questions are valued over those that give more equivocal answers to more complex and perhaps more appropriate questions about large and complex systems. We are wont to assume that the results of a laboratory experiment can be applied to a larger system, but this is most unlikely to be the case. For example, in one lake, Little Mere in Cheshire, laboratory release rates of phosphorus from sediments have been found to be much higher than those calculated from mass balance studies in the lake itself. Concentrations found in the lake were consistent with the whole lake calculations not the laboratory experiments. Results from mesocosm experiments carried out in the lake, on the other hand, were consistent (Beklioglu & Moss, 1996). This raises questions about how large experimental mesocosms should be, for the smaller they are, the greater the possibilities of replication.

The results of laboratory experiments, for example with algal cultures, have been valuable in elucidating whole lake phenomena, such as the succession of phytoplankton species. But it is only when such data are considered, together with larger scale phenomena, such as washout rates, that they really explain what is happening in the lake. The case of the cyanobacteria is particularly revealing. There is an immense literature on the cyanobacteria because of their particular interest as prokaryotes containing chlorophyll a, their great antiquity, their production of toxins and blooms and their migratory behaviour in the water column. The results of many observations and experiments suggest that, given a suitable inoculum, their growth is favoured, *inter alia*, by high pH, low free carbon dioxide concentrations, low nitrogen to phosphorus ratios, the presence of grazers on other, potentially competing, algae, stratified conditions, microaerophilic habitats, high temperatures and high retention time of the water mass (Shapiro, 1990). In a given lake, however, with many of these conditions present, cyanobacteria populations may still fail to develop, despite abundant inocula from sources upstream (Beklioglu & Moss, 1995).

The need to realise the greater dimensions of lake processes, than those of the limits of the basin, or a subsample of water from it, and the availability of properly replicated experimental systems on which to investigate some of these dimensions, are thus blocks to understanding.

Political blocks

Political blocks may seem far removed from ecological challenges. Yet they constitute the greatest of these. In the past, there was considerable support for fundamental science and a growing official acknowledgement of the importance of environmental issues. Particularly since the mid-1980s, there has been a continual erosion of that support. Now, much of the funding that is described as research funding in the U.K., and increasingly elsewhere, is in fact funding for technological development work, descriptive survey and monitoring or literature review. None of this is likely to increase understanding. It may proliferate knowledge, but that is a different matter.

The opportunities for fundamental research have greatly diminished and the application of market principles of competitive tendering for research contracts, has dissolved the former efficient cooperativeness that existed between different research institutions and individuals. It has also greatly increased the time spent, and often wasted, by active scientists in the raising of funds and the production of large numbers of ephemeral reports. These are often not available to the community at large and have not been screened by peer review. The value of this system has not been proved. The absence of publication of material in support of it indeed suggests that such proof is not to be found; it must certainly have been sought.

It should not be necessary to have to make a case for fundamental research, yet it appears that such is needed. The case given by Victor Weisskopf in 1965, when the American government realised that its scientific endeavours were being eclipsed by those of the Soviet Union, is still valid:

> "The value of fundamental research does not lie only in the ideas it produces. There is more to it. It affects the whole intellectual life of a nation by determining its way of thinking and the standards by which actions and intellectual production are judged. If science is highly regarded and if the importance of being concerned with the most up-to-date problems of fundamental research is recognized, then a spiritual climate is created which influences the other activities. An atmosphere of creativity is established which penetrates every cultural frontier. Applied sciences and technology are forced to adjust themselves to the highest intellectual standards which are developed in the basic sciences. This influence works in many ways; some fundamental students go into industry; the techniques which are applied to meet the stringent requirements of fundamental research serve to create new technological methods. The style, the scale and the level of scientific and technical work are determined in pure research; that is what attracts productive people and what brings scientists to those countries where science is at the highest level. Fundamental research sets the standards of modern scientific thought; it creates the intellectual climate in which our modern civilisation flourishes. It pumps the lifeblood of idea and inventiveness not only into the technological laboratories and factories, but into every cultural activity of our time. The case for generous support for pure and fundamental science is as simple as that".

But the generous support is no longer there. There has been a systematic plundering of research institutes and universities by which the background support for fundamental research has been removed. The ability to update instrumentation through a disinterested public sector has been lost and there has ensued a dependency on government agencies and worse, private industry, to maintain most scientific work. It is not possible to sustain impartial investigation under these conditions.

Indeed the fundamental contribution to freshwater ecology by British scientists has dwindled, absolutely and proportionately. For five major freshwater ecological journals published between 1980 and 1991, Hildrew (1993) found a fall in contribution from the U.K. from about 10% to 6% of papers, whilst North American contributions stayed steady at about 60% and mainland Europe increased its contribution from 14 to 25%. In 1992, Britain was overtaken by Australasia. It is not a consolation that despite maintaining its paper contribution, the North American limnological community feels equally beleagured (Jumars, 1990; Kalff, 1991; Wetzel, 1991).

The funds directed at responsive mode (that in which choice of research topic is determined only by quality through extensive peer review) by the research councils have effectively dwindled (Motluk, 1996). More of the proportionately reduced total ‘pot’ has been diverted into directed programmes, referred to as relevant, but hardly innovative, and usually directed at wealth creation and therefore at exploitation.

It is tempting to attribute this to confusion and ignorance rather than conspiracy, but the signs are there that it represents a deliberate move to hamper progress in fundamental understanding, especially in the environmental arena, lest it conflicts with particular economic and political aspirations. The interesting aspect is that these aspirations can be predicted quite closely from the operation of selfish genes.

The evidence of deliberate undermining of fundamental inquiry can be seen in budget patterns, in the nature and weakening importance of ministerial support for science, in the undermining of environmental agencies like the former U.K. Nature Conservancy Council by reorganisation, and in the phraseology of legislation. Thus the U.K.’s Water Act of 1989 and the Water Resources Act of 1991, which respectively set up and consolidated the powers of the National Rivers Authority, spoke, in Sections 8 and 16, respectively, of the duty of Ministers and the Authority to further the conservation and enhancement of natural beauty and the conservation of flora, fauna and geological or physiographical features of special interest.

The Environment Act of 1995, ostensibly strengthening the powers of environmental regulation of a new body, the Environmental Agency, formed from an amalgamation of the National Rivers Authority with other bodies, speaks only (Sections 8 and 9) of the recognition of codes of practice, for which the Agency must have regard and puts the onus for notifying issues of conservation importance on other bodies. This harks back to the Water Act of 1984, which set up the Water Authorities, where again there was no duty to conservation, but simply a requirement to have regard for such issues. *Having regard* is much weaker phraseology than *duty*. The same weakening can be seen also in the ways in which the U.K. Department of the Environment, Transport and the Regions is failing to use environmental safeguards provided through the EU Urban Waste Waters Treatment Directive (Carvalho & Moss, 1995).

In a general disregard for environmental issues, recent U.K. governments essentially behaved like the members of any other species, produced by natural selection, and subject to the prerogatives of its genetic endowment. Its strategies are the maximising of resource acquisition (wealth creation) so as to promulgate its particular strategies as prolifically as possible. In doing this, it takes no future view. Natural selection responds to the current environment, not even the subsequent one in which the selected generation will live.

It is an interpretation of human behaviour which has been denied by sociologists, but for which there is increasing evidence, as the strategies of human behaviour are teased out and compared with those of other animals. On this biological interpretation, our present environmental problems – of lakes and everything else – are understandable. No more than the beaver, creating his lodge, cares for the upstream impacts of damming a stream and flooding a woodland community, does the human dam-builder worry about the ultimate morality of his actions. He may predict some consequences, and seek to mitigate them, but there is no real question that the structure is not in the human interest. To the dam builder, the creation of hydroelectric power or the storage of irrigation or drinking water clearly is.

The alternative side of this issue is the essence of being human. It is to decide against responding to the strategy of the genes, to make decisions on ethical grounds, to regard the biosphere as a collaborator rather than a slave; to understand first and control only after much reflection. To look ahead is to prolong the span of the human species and to create a more equitable world, where the selfish gene is not allowed its ruthless consequences. Part of such an approach is a return to more enlightened attitudes towards fundamental understanding of natural systems, and to the removal of the political blocks now being increasingly placed on our abilities to understand our world. The lesson of history is that suppression of new ideas ultimately always fails, but it is a lesson that has had continually to be re-learned.

The immediate, the proximate and the ultimate

The reasons for any phenomenon, boil down to the immediate, the proximate and the ultimate. With respect to understanding ecological issues in lake systems, fundamental issues might seem to be the ultimate blocks and political ones merely immediate. However, because the political ones are, in the final analysis, powerful products of biological phenomena, I believe that they are the truly ultimate ones. The immediate ones are the fundamental ones – those of the nature of the systems themselves and the material with which we have to work. Some of these can never be under our control and must be accepted, but the realisation of the importance of stochasticity is, in itself, a contribution to understanding. The proximate reasons are the blocks of methodology and scientific approach. They are dissoluble given sufficient support. Ecological science, no less than nuclear physics and biotechnology, has to be 'big science'. The pond net has now to be supplemented by the mass spectrometer, the large-scale controlled-environment chamber, and the system of replicated, instrumented experimental lakes or ponds.

Finally, the ultimate political blocks would be insuperable if we were completely governed by selfish genes, by the inherent ecology of one species, ourselves. But we are not. We can make choices. Frequently the behaviour of an individual as an individual, is much less selfish than that of the same individual competing in a group. Different choices are made. It is these choices to which Auden's poem, introduced at the beginning of this paper, refers.

The illusions of which he speaks are that we can continue to use resources as we do, and continue our present lifestyle, yet still expect to maintain a sustainable biosphere. We need to change in ways that are not palatable when it is felt that others in the group may steal a march, but which are otherwise reasonable and acceptable. The transition from being group-driven to being an individual is the cross to be climbed. It is a cross that many vested interests in the consumption of resources might wish were not there, whose existence they conspire to conceal. Tudge (1993) put it well:

> "Only when we are straight in our own heads, and have structured societies that are able to override their own innate tendency to be overtaken by hawks and hawkishness, can we hope to create the kind of world that can be sustained, for only the meek *can* inherit the Earth".

In the final analysis it is a very personal cross. I have not yet met any columbine professors.

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