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EUTROPHICATION IN LAKES

The art and science of lake restoration

Brian Moss

Abstract Science and art encompass understanding, through human hand and mind; both are applied in the form of creation by human hand and mind. Like Janus, the Roman god of doorways and bridges, they are two faces of the same thing. Great art requires great understanding and great understanding is wasted unless it is applied to create meaningful art, whether this is in the form of written works or paintings. These principles apply not least to the restoration of lakes and whole landscapes from the human-induced damage that is the antithesis of significant art and fundamental science. Because they lie at the lowest points of hydrologic basins, lakes reflect the balance of human activities in their catchments. If these activities are carried out well, they contribute greatly to the landscape and to the welfare of the human population. If carried out badly in the sole interests of exploitation of resources, both human and otherwise, they may become problems reflected, for example, in eutrophication, algal blooms and fish kills. Lake restoration involves first an understanding in a reductionist (scientific) way of the processes that drive lake ecosystems, but then of the ultimate reasons that create these proximate problems. Ultimate reasons lie in a much wider sphere of human nature and the organisation of society. Lake restoration, in its most trivial form, may be simply a form of gardening to allay the symptoms of problems and create the illusion of a solution. Lake restoration in its most profound form involves an understanding of cultural significance and the workings of human societies and forms an epitome for the solution of much greater, global problems. Only in this form does it become truly creative. Approval must come from both of the faces of Janus.

Keywords Eutrophication · Shallow lakes · Culture · China

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Eutrophication of shallow lakes with special reference to Lake Taihu, China

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Introduction

There has arisen a divide in the way that knowledge is perceived. It has been called the two cultures by the English novelist and physicist. Snow (1959) and it concerns the gulf between scientific perception and perception by artists, linguists, historians, social scientists and all those loosely grouped into the subject areas of the humanities. Science is perceived as objective, collects facts from survey and experiments, and interprets them in a way that is alleged to be value-free and objective. Scholars in the humanities also collect facts. The methodology of a historian is no different from that of an ecologist describing past and present ecosystems, but controlled experiments are not conceivable in the arts and thus determination of mechanism has to be left to the perception of the observer and therefore is regarded as subjective rather than objective. This simplified overview disguises the fact that there can be a great deal of subjectivity in the interpretation of information collected by scientists and that there are insights available to other scholars that are too readily rejected by some scientists because they are not amenable to controlled experiment. A better way of dividing approaches to understanding is to distinguish the reductionist from the holistic. Scientists and those in the humanities use both approaches, but current practice is for scientists to be more reductionist and humanities' scholars more holistic.

Where ecological restoration is concerned, there can be a harmony between the two approaches and the lessons of the humanities, indeed of fine art, can be applied to guide the process. Ecological restoration, for example, involves several stages. First there is a problem. A habitat has to be restored because it has been degraded to some extent. The reasons for the damage need first to be understood or otherwise restoration may be misguided. Secondly, the extent of the damage must be assessed and thirdly a target towards which restoration should be directed must be decided. Then, fourthly, the scientific understanding of the system is brought into play to determine how to achieve the target and lastly it is likely that maintenance of this new status will require management of some sort. The lessons of the humanities are applicable at all but the fourth stage of technical restoration.

The parallels with the conception and creation of fine art are considerable. Art exists to interpret society as much as to decorate it. Science likewise diagnoses problems as well as helps create the artefacts of comfortable life styles. The power with which artworks are expressed mirrors the degree of the problem just as scientific approaches assess the degree of damage. Restoration involves design and the parallels are obvious here and management may be both a scientific and aesthetic process if the results of the restoration are to be permanent and significant.

The existence of the problems

Lakes lie at the bottoms of catchment basins. Simply because of the operation of gravity, they will reflect activities in their catchments, manifested in changed water quality, but also in alterations to watercourses for the purposes of water storage, flood control, pollutant disposal and farming. A catchment covered by pristine ecosystems will pose no problems for the freshwater systems that drain it and indeed there is a seamless connectance between the terrestrial and freshwater systems. Intact ecosystems are parsimonious with nutrients and very little available nutrient leaches from the land to the water. Most key nutrients are held and recycled within the terrestrial biomass. Pristine freshwater systems thus have extremely low nitrogen and phosphorus concentrations, even when the catchment soils are made fertile from easily weathered rocks.

Pristine freshwater systems will also have considerable structure. They are not just masses of mixed water. Rivers have structures created by geomorphological processes (sand bars, riffles, floodplains, levees) and by woody debris entering from the immediate catchment. Lakes have littoral zones with a rich diversity of emergent and submerged plants. Maintenance of this structure may depend on the intactness of the diversity of the ecosystem. Top predators, wolves and bears, salmonids and other piscivorous fish and birds may exert considerable top-down effects (Ripple & Beschta, 2004a, b) that maintain both this structure and the efficiency of cycling of nutrients in a system where nutrients are naturally extremely scarce. There will also be a great connectivity between systems. A lake does not exist as an isolated system. It depends on organic matter washed in from the catchment through the inflow rivers for part of its productivity (Hanson et al., 2004). The surrounding wetlands may be crucial for fish and invertebrate life histories and in the interesting case of the functioning of northern rivers, nutrients brought from the ocean in the bodies of salmonid fish are recycled through the faeces of their brown bear predators into the riparian woodland. In turn tree debris retains carcases after spawning to provide the nutrients needed by the periphyton and micro invertebrates that sustain the hatched fish once they have used up their yolk sacs. Movements of pike (*Esox lucius*) between lakes and wetlands perform parallel roles (Klinge et al., 1995).

Parsimony of nutrients, preservation of structure, including appropriate biodiversity, and maintenance of connectivity are the three key elements that constitute the 'gold standard' for any ecosystem restoration. A system with these three characteristics intact is self-maintaining. Scientists comment on deviation from this state by recording the impacts on freshwater systems that damage these characteristics. Nutrient parsimony is eroded by eutrophication, which may also result in a loss of structure. Catchment management for efficient forestry may deny to rivers the structure provided by forest debris (Harmon et al., 1986) and connectance is easily lost through the construction of dams and the channelisation and embankment of lowland rivers so that they lose hydrological connection with their floodplains. Essentially, a long catalogue of impacts that damage freshwater systems ultimately boils down to damage to the three key elements.

The problems of freshwaters are ultimately the problems of how landscapes are managed and therefore of the way that human societies are controlled and managed. In the developed world the current philosophy is of maximising resource use in the interests of profit with rather little consideration of the sustainability of the resource. Early ecology contented itself with description of the workings of intact systems; now it is equally concerned with documenting the damage. Likewise fine art once celebrated the contemplative delights of pristine or lightly used landscapes. The traditions of Chinese scroll painting very much manifest this. But currently much of it is dedicated to protest and comment. Pablo Picasso's painting of *Guernica*, a horrific view of the bombing of a Spanish town in support of extreme right wing policies is a famous example. Peter Scott's painting. 'The Natural Environment of Man' (Fig. 1) uses art as a means of expressing environmental controversy.

Fig. 1 The Natural World of Man. Peter Scott, 1961. The painting is a comment on the dilemma faced by humans in contemplating the advances of technology, to the right of the picture and the consequent losses to ecosystems, represented by a selection of endangered mammals and birds to the left. The figure stands apart from the scene, representing philosophies that regard the natural world as something to be controlled by humans in their own interests but is also transparent and melds into the natural world. Humans are as dependent on the biosphere as all other creatures. The figure also holds his or her arms in a gesture of uncertainty, not knowing quite what to do about the problems being caused by human activities. By permission of Lady Scott, Wildfowl and Wetlands Trust, Slimbridge

The six artistic principles of Xi He and their equivalents in lake restoration

It is in the design of targets for restoration, however that the parallel approaches between art and science become most interesting. In the sixth century (Northern and Southern Dynasty) Xie He (Hsieh Ho), in his *Ku-hua p'inlu* (Acker, 1954; Tregear, 1997) posited, for the judgement of Chinese paintings, six principles, which have been so influential that they influenced Chinese painting into the twentieth century and may still influence it. These were:

Q'i yun sheng tung: The painter should endow his work with life and movement through harmony with the spirit of nature

Ku fa yung pi: Refers to structural power and tension of the brush stroke
Ying wu hsiang hsing: Fidelity to the object in portraying forms
Sui lei fu ts'ai: Conforming to kind in applying colours
Ching ying wei chih: Plan and design, place and composition
Ch'uan I mu hsieh: Transmission of ancient models by copying

Gombrich (1995) talks of a wonderful restraint in Chinese painting (Fig. 2). There is an economy of line, a sense of contemplation and inner feeling for the subject rather than a precise elaboration of details. Technique in brushwork is economical and firm and painted scrolls are usually adorned with philosophic comment, also elegantly executed in text characters. The long tradition of Chinese painting, adopted also by Japanese painters, has its dangers in that rigid tradition inhibits individual inspiration and innovation, but a balance between tradition and innovation often gives the best of both worlds and in such a balance lies the relevance of art to lake restoration.

Fig. 2 A characteristic Chinese painting by Sheng Mou, 1330–1369. Waiting for the Ferry on an autumn river (1351). Hanging scroll on paper. Palace Museum, Beijing

With some contraction of the third and fourth principles, which concern fidelity of form and colour, there are equivalents to Xie Hi's principles in the guidance that might be given for effective lake restoration, especially in the complex case of shallow lakes. There should be skill in carrying out the work and economy in resources and effort; there should be fidelity to the structures and nature of the system; there should be taste in reflecting the nature of the landscape; there should be wisdom in understanding the essence of the relationships by reference to pristine examples; and there should be harmony with the spirit of wise and sustainable use. It is not known whether there was particular significance in the order of Xie Hi's strictures on painting, except that the first was the most important. The logical parallels for lake restoration however might re-order the equivalents in terms of: Wisdom, Skill, Fidelity, Taste and Harmony.

Wisdom in understanding the essence of the relationships

Understanding of the functioning of shallow lake systems has advanced greatly since 1970. The natural state of all lakes is to have very low available nutrient concentrations, as discussed above. If the natural catchment vegetation is destroyed for urbanisation or agriculture of any kind, these mechanisms are destroyed and leaching losses increase greatly. Such eutrophication has been associated with the loss of clear water and submerged plant communities from shallow lakes and their replacement with filamentous algae and phytoplankton.

The idea that this was a process entirely driven by nutrient increase is still held by some workers, but was challenged by Balls et al. (1989) and Irvine et al. (1989) who found that adding large amounts of nutrients to such plant communities in experimental ponds did not displace the plants. Indeed they grew better. A switch to phytoplankton only occurred if the plants were independently damaged by mechanical removal. In subsequent years a range of switch mechanisms has been recognised, each of which, especially but not necessarily, in tandem with nutrient enrichment may displace the plants (Moss et al., 1996). These include herbicide application, grazing by introduced birds and fish like common carp (*Cyprinus carpio* L.), pesticide leachate and increasing salinity (both of which disturb the zooplankton grazer interactions that maintain clear water), rise in water level and violent storms. Thus over a large range of nutrient loadings, dependent on whether such a switch has occurred, shallow lakes may have alternative states of clear water and plant dominance and turbid water with phytoplankton dominance (Fig. 3). Sometimes, turbidity may be created through suspended sediment raised by wind or benthic fish in plant-devoid waters. This understanding has come from a range of approaches, including analysis of very large data sets (Jeppesen et al., 1999), mesocosm (Moss et al., 2004) and pond experiments (Balls et al., 1989; McKee et al., 2003), whole-lake experiments (Meijer et al., 1999) and theoretical treatments (Scheffer et al., 1993). The general model applies to small and moderate sized lakes (perhaps up to the order of 10^2–10^3 km^2 but is relevant also to very large shallow lakes though with very large wind fetches, the more exposed portions of these may behave differently.

Part of the understanding has also come from attempts to restore the plant communities to

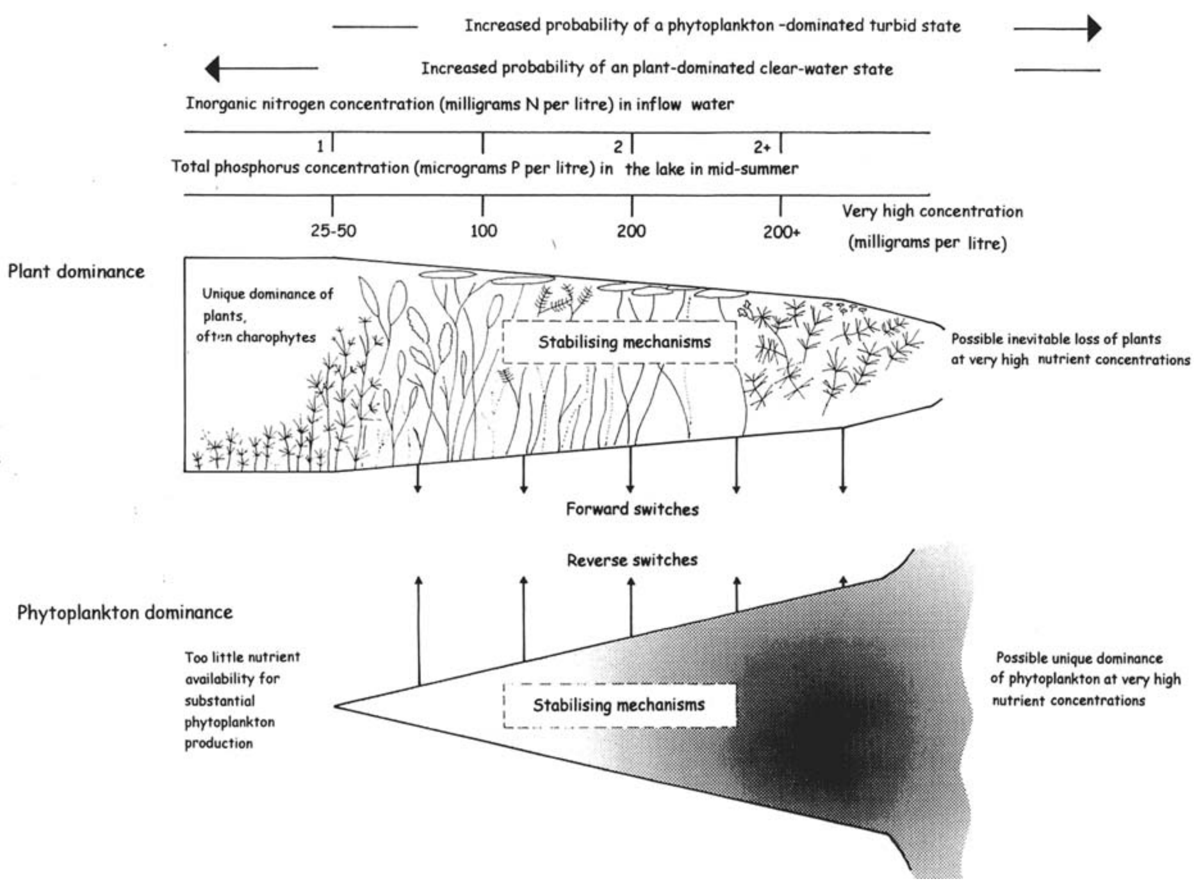

Fig. 3 Alternative states scheme for shallow lakes, illustrating alternative states, forward switches and restoration measures in the context of a range of nutrient loadings or concentrations (from Moss, 2002)

turbid lakes. Some cultures, not least those that have large populations to feed, may prize the turbid state for its ease of fishing and productivity of fish for food. The general presumption, however, is that the more desirable state of a shallow lake is to be plant-dominated, because this state is associated with the greatest biodiversity and aesthetic value and the least problems of smell, fish kills and toxicity of algal blooms. Plant communities use a number of mechanisms to maintain clear waters, including competition for nitrogen with algae, allelopathy, and reduction of eddy disturbance necessary for phytoplankton to remain suspended. Indirect, but equally important, mechanisms include provision of refuges against fish predators for zooplankton grazers on phytoplankton or macroinvertebrate grazers on periphyton (Moss et al., 1996; Scheffer, 1998).

Restoration attempts initially centred on reinstating the role of grazers by temporary removal of their fish predators, a process called biomanipulation. This resulted in clear water in which plants could grow, but protection against damage from grazing birds was sometimes necessary to establish self-sustaining communities. The communities were, however, usually of low diversity and vulnerable to slight disturbance that led to return of turbid conditions. Few restorations have been entirely successful in restoring diverse, stable plant communities (Moss et al., 1996; Meijer et al., 1999).

The reasons have perhaps been because the scale of restoration attempts has been too limited, that nutrients have not been adequately controlled or that only one of two important nutrients has been controlled. Shallow lakes have strong links in their natural states with surrounding wetlands that provide habitat for piscivorous fish that control zooplanktivorous fish and hence result in large zooplankton populations (Klinge et al., 1995). Extensive restoration of whole floodplains rather than just isolated lake basins is needed. Although alternative states exist over a wide range of nutrient loadings, it appears that the threshold for switches to act to remove plants is lower when nutrients are high and that biomanipulation is more effective if nutrients are reduced and that perhaps nutrient control should involve both phosphorus and nitrogen. Phosphorus may control algal production but the diversity of the plant community and hence its stability seems to be determined by nitrogen (James et al., 2005). Nutrient control is difficult especially when diffuse sources dominate and generally only phosphorus is controlled because point sources (for example, waste water treatment works) tend to be prominent and phosphorus can easily be precipitated at them.

Moss et al. (1996) developed a technical strategy for restoration, which forms an idealised basis for restoration attempts. First the target for restoration should be determined. The nature of the plant community is linked to the nutrient loading and generally diverse charophyte or isoetid communities require very low nutrient concentrations; mixed pondweed communities will persist over a middle range; and nymphaeid communities will still grow at very high concentrations and even when conditions are switching to turbid conditions. Once the target is decided, any existing or potential forward switches should be removed. There can be no success if this is not done. Thus, damaging fish or unusually high numbers of grazing birds need to be removed. Usually these are of introduced species and have built up to large numbers in the absence of natural predators. Risks from pesticide and herbicide contamination must be reduced and any damaging management such as mechanical clearance eliminated.

Nutrients should then be reduced, including both phosphorus and nitrogen. A range of methods exists for controlling point and diffuse sources but generally it is difficult to reduce concentrations to those that are likely to favour successful restoration. Restorations are most likely to be successful if total phosphorus concentration is reduced to winter values of less than 0.05 mg l^{-1} and total nitrogen to less than 1 mg l^{-1}. These suggestions are subject to much variability dependent on local circumstances however and emulation of the pristine condition of very low available nutrients should be the guiding principle. The fourth step is that of biomanipulation and a common source of failure is for too few fish to be removed. Successful restoration will be more likely if stocks are reduced to lower than 2 g m^{-2} and if some piscivores are left in the lake. This will allow daphnids and other zooplankters to increase and will clear the water, although if retention times are long and favourable to Cyanobacteria, there may be difficulties (Moss et al., 1991). Cyanobacteria can be controlled by grazing, but generally only if the proportion of such algae is low. Thick, surface blooms generally cannot. In the clear water, plants may spontaneously return from residual fragments but may have to be reintroduced. New plantings are vulnerable to bird damage and may need to be protected by caging. Thereafter, once plants have established vigorous beds, perhaps after two years, a fish community can be reintroduced, but should reflect the native community for the lake, should not include exotics and should always include piscivorous fish. Finally restoration projects should always be carefully monitored for several years afterwards. Many are not and valuable lessons as to why they succeed or fail will be lost. And in all things, patience is a virtue. It is not possible to replace over a year what may have been lost over a century.

Beyond this catalogue of necessary technicalities, however, is a philosophical basis for restoration and it is in this that the parallels with the principles of Xie He for painting become very relevant. Wisdom, skill, fidelity, taste and harmony are further contracted here into a hierarchy of skill, fidelity and taste, harmony and wisdom.

Skill in carrying out the work with economy of resources and effort

Lake restoration is often carried out by contractors, for whom it is simply a means of making profit. The results can then fall far short of the exquisiteness that Xie He would have expected of his painters and that sensitive ecologists would expect in the final result of a restoration. Mass-produced art is rarely prized. Skill comes in appreciating details and in minimising costs without compromise on the final result.

In one restoration attempt in which I was involved, at a lake in Wales (Moss et al., 2002), a detailed specification of what should be done was drawn up, including a strong proviso that certain plant species, like *Ceratophyllum demersum* L. should not be used, for they were likely to create dense beds that would interfere with angling. The use of plant stock bought from garden suppliers, which might include exotics and cultivars, was also precluded. In the event, the work was carried out by contractors who took the cheapest options of putting in any plant they could find, which included the very common *Ceratophyllum*, and at least effort, which meant they bought water lily stock from garden suppliers. The result was a lake choked by *Ceratophyllum* and fringed with an inappropriate, for the site, and probably non wild-type nymphaeid, *Nymphoides peltata* L. There was public protest at the *Ceratophyllum* choking and the result was that the local authority treated the lake with herbicide and effectively reversed the entire restoration after spending of a considerable sum of money ultimately to achieve nothing.

This however, is a small example of this particular precept. Skill involves choosing the right level of approach, and economy has to be considered in the long, not the short term. There are three levels of approach to restoration that correspond to different levels of cause of the problem. These are immediate, proximate and ultimate. For a shallow lake that has switched to phytoplankton dominance with troublesome, perhaps toxic cyanobacterial blooms, the immediate cause of the problem is the bloom. The immediate treatment is to use mixing methods or algicide. Both are cheap, temporary and ultimately ineffective in solving the problem for they treat only symptoms and the money spent on them is ultimately wasted.

The next level of treatment is to carry through the technical strategy outlined above. This deals with the proximate causes such as increased nutrient loading in the catchment, introduction of exotic fish or profligate use of herbicides and pesticides. It will cost much more but will be effective for a longer term. It may not be ultimately effective, however, for continuous control of nutrients will be needed and should funds become unavailable or should inappropriate fish be reintroduced for some new commercial intention, the money will have been wasted. What is really needed in this, as in all environmental problems, is a profound enquiry into the ultimate causes, which will be political, social and cultural. Treatment of the ultimate cause of the problem may have to be a change in agricultural policy so that large areas of the catchment are used as buffer zones to allow intensive agriculture to continue in the remainder. Or they may mean an enquiry into the relative rights of some parts of society to exploit the resources of the lake (for a fishery for introduced, very productive species for example), and the rights of other parts of society not to tolerate this in the interests of an environment that preserves biodiversity. Skill may come in realising these levels of approach and in aiming to tackle the problem as high up the hierarchy of causation as is possible.

Fidelity and taste in reflecting the nature of the landscape

Lakes that have been damaged are frequently incapable of being restored to anything remotely like their pristine equivalents. Shorelines often have been developed and damaged and may support building development that cannot be removed. Restoration may have to take on board such changes. A parallel aspect of restoration is re-creation of new lakes from quarries, gravel excavations and other such engineering activities. Pond creation is a widespread activity in Europe (Andrews & Kinsman, 1990; Williams, 1999; Moore, 2002) where former small ponds have often been filled in as a result of agricultural intensification to ease the use of large agricultural machines. Taste and design are very important in both these activities.

The guidance that Xie He would doubtless have given to lake restorers would have been that if natural structures such as emergent wetland margins cannot be restored, and hard edges have to be maintained, these should be of natural materials, appropriate to the area, especially its local geology, and not concrete or building stone of colours and textures that do not fit into the surrounding landscape. He would have spurned the artificiality of structures like fountains and artificial rafts for bird roosting. Fountains are particularly favoured by local government authorities, partly because the idea is rife that water needs continually oxygenating and partly by a perception that moving waters are tourist attractions. Water does not need artificially oxygenating, unless there has been such severe organic pollution that it is in danger of becoming permanently anaerobic and fountains are not good oxygenating devices anyway. Sub-surface circulation using powerful pumps is needed in such situations. Fountains may be appropriate to man-made pools in urban situations but not to natural or large lakes.

In designing new lakes, there is a tendency also to ignore the tenets of art in favour of the conveniences of engineering. Newly excavated lakes tend to have either geometric shapes, square or oblong, or exaggerated sinuosity in an attempt to avoid geometricity. Both are equally offensive to the eye. In natural lake basins the shape and outline are determined by the local geology and geomorphology. No general prescription can be given except that design should take account of the subtleties of the landscape and that this takes different talents from those needed for the engineering of earth movement and water retention. An appreciation of the nature of unmodified local lake basins and what gives them their particular characteristics is crucial to this. In an aerial photograph the ultimate results of lake creation or restoration should blend with the landscape and not stand out prominently as clearly different. One group of man-made lakes, the Norfolk Broads (Moss, 2002) formed in the 14th century in the United Kingdom, fits so well into the landscape that for many years their anthropogenic origin was not even realized.

Harmony with the spirit of wise and sustainable use

Xie He's first and most important stricture for painters is ultimately the most important one in lake restoration also. Problems in lakes reflect problems in society. An algal bloom is a symptom of a society that has not satisfactorily dealt with its immediate problems of waste disposal and food production in the best possible way. It reflects a dominance of some interests over others and generally these will have been the richest and most powerful interests. The current dominant philosophy of the human population of this planet is one of short-term exploitation of resources with rather little thought for ultimate consequences. Were this not the case we would not be facing severe climate change, heavily overfished seas, severe water shortages and polluted lakes.

There is acknowledgement of the problems in many political quarters but a policy of acknowledging problems but doing little and hoping that solutions will emerge spontaneously is a dangerous one. High quality lakes are set in high quality landscapes. High quality landscapes reflect sustainable values in society. Xie He taught that great art reflects great understanding, fundamental values and worthy objectives. Great lake restoration likewise reflects understanding and objectives worthy of a society that can be sustained, that reflects the needs of all people and that is not just a commercial activity. And if a Chinese art critic can be seen to offer guidance in lake restoration, perhaps ancient Chinese philosophy (Lao Tzu, approx. 500BC) can provide a solid basis for creating the sort of society that will sustain itself and its associated natural world, not least its freshwater resources. It defies all pleas above for connectedness, and a holistic and profound approach to quote a single passage to illustrate an entire philosophy, but Verse 67 will have to suffice:

> Some say that my teaching is nonsense.
> Others call it lofty but impractical,
> But to those who have looked inside themselves,
> This nonsense makes perfect sense.
> And to those who put it into practice,
> This loftiness has roots that go deep.
>
> I have just three things to teach:
> Simplicity, patience, compassion.
> These three are your greatest treasures.
> Simple in actions and in thoughts,
> You return to the source of being.
> Patient with both friends and enemies,
> You accord with the way things are.
> Compassionate towards yourself,
> You reconcile all beings in the world.
> (Translated by S. Mitchell, 1999)

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