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Conservation of salt lakes

W. D. Williams
Department of Zoology, University of Adelaide, G.P.O. Box 498, Adelaide, S.A. 5001, Australia

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Abstract

Salt lakes have a variety of important uses and values, including especially both economic and scientific ones. These uses and values have been and are increasingly subject to degradation from a variety of impacts: diversion of inflows, pollution, agricultural practices, and introduction of exotic species are among the more important. Recognition of these impacts upon salt lakes has led to some international and national measures for their conservation, but considerably more effort in this direction is needed. Against this background, Mono Lake, California, USA, and the Aral Sea, central Asia, are discussed as two localities which bring into sharp focus the various matters discussed in the paper. Finally, attention is drawn to the need to conserve the Akrotiri Salt Lake, Cyprus.

Introduction

There are many definitions of the term conservation. For present purposes, that used by the International Union for the Conservation of Nature (IUCN) is suitable and, despite the objections that can and have been raised against it, it is adopted here. It states that: 'Conservation is the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations' (IUCN, 1980). In the present context, the parts of the biosphere in focus are inland saline waters.

To a much greater degree than their abundance, distribution and importance would suggest, salt lakes – with only a few notable exceptions – have not attracted much attention from conservationists, and relatively few are the subject of active conservation. There is little doubt that this reflects the general lack of attention accorded salt lakes by limnologists – itself a reflection of the fact that salt lakes are often located far from where most limnologists live (Williams, 1986). Perhaps this relative inaccessibility itself has suggested that salt lakes need little protection (and therefore that most salt lakes need little protection).

But, despite the lack of attention given them, salt lakes are significant components of the biosphere (on a global basis, inland salt water is not markedly less in volume than inland fresh waters: according to recent estimates (Shiklomanov, 1990), 0.006 percent of total global water as compared with 0.007 percent), and they have a number of important uses and values. To a considerable degree, however, these uses and values have been and are being degraded. The agents causing such degradation are many and varied, and their impact is accelerating. Even so, the conservation of salt lakes has generally not been given high priority by governments, although, as indicated, some notable exceptions occur.

The present paper aims to draw attention to the need to conserve salt lakes more actively. It does this by outlining their values and uses, and the nature of destructive impacts upon them. The extent and type of protective measures which have been and can be put in place are briefly considered. Finally, to bring into sharper focus the general discussion, two salt lakes where significant changes have recently occurred following the impact of man, viz. Mono Lake, California, USA, and the Aral Sea, central Asia, are discussed in more detail. Brief attention is directed to Akrotiri Salt Lake, Cyprus, in an epilogue.

Uses and values of salt lakes

Seven reasons have been put forward in support of the conservation of particular aquatic systems: economic, cultural, aesthetic, recreational, scientific, educational and ecological. All of these, though at different degrees of applicability according to locality, can be advanced to support measures to conserve salt lakes. They are discussed *seriatim* below. More formal classifications and evaluations of uses and values exist to support the conservation of 'wetlands' in general, but the emphasis of these for the most part is upon fresh and coastal waters, and the more simple approach taken here will suffice for the present discussion. However, in any evaluation of a specific salt lake with conservation measures in mind, recourse to these more formal classifications and evaluations will be necessary. An introduction to them is provided by, for example, Adamus & Stockwell (1983), Claridge (1991), Dugan (1990), Foster (1978), Marble & Gross (1984) and Stone (1991).

Economic uses

An extensive account of the economic uses of salt lakes and their associated hydrological systems has been given by Hammer (1986) and Williams & Kokkinn (1988). Here, all that need be given is a summary listing of these uses.

1. As a source of minerals. Salt (NaCl) is particularly important, but others have become of increasing importance, such as uranium, lithium and zeolites.

2. As a source of fresh water by diversion of inflowing rivers.

3. As a source of power. Heliothermal ponds which involve an upper freshwater layer of water and a lower salt layer, and which trap incoming solar energy, have become increasingly important as sources of hot water from which power may then be generated.

4. In moderately saline lakes, as a source of fish of commercial importance.

5. As places where living organisms may be cultured for the production of fine chemicals, protein and other biochemicals. Of particular importance in this respect are *Dunaliella* (a source of β-carotene and glycerol), and *Spirulina* (protein).

6. As places where *Artemia* can be cultured. *Artemia* adults and cysts are important food items in the aquacultural industry.

Cultural values

Salt lakes have not had as large a cultural value for mankind as have fresh waters – reflecting their relative isolation –, but a number of important exceptions to that statement exist. Thus, the Aral and Caspian Seas figure prominently in the classical literature of central Asia, as does the Dead Sea in the history of the Middle East and eastern Europe (Nissenbaum, 1979). The Aral region in particular is one of the ancient centres where civilization and agriculture are presumed to have arisen. Primitive irrigation was practised in its basin as early as the sixth century B.C. No doubt many particular salt lakes of North and South America had special local cultural significance also. The cultural value of Mono Lake, California, to the indigenous Owens Valley Paiute Indians, for example, has been noted by Patten *et al.* (1987).

In this context, brief mention may be made of the cultural significance of flamingos, birds characteristically associated with salt lakes. Flamingo skins, flesh and eggs have long been trade items around the shores of the Mediterranean, and the ancient Phoenicians traded flamingo tongues which, according to the Roman Pliny, were a delicacy 'without which no Roman banquet was complete'.

Aesthetic values

Attitudes to the aesthetic values of salt lakes have been divided and have changed with time. Certainly, many early European explorers did not rate the aesthetic appeal of salt lakes highly when they first sighted them in remote areas. According to Serventy (1985), the Australian explorer Eyre, on first sighting Lake Eyre, stared in horror at 'one vast, low and dreary waste'. A later explorer, Warburton, noted that 'Lake Eyre was dry – terrible in its death-like stillness and the vast expanse of its unbroken sterility'. Modern perceptions are somewhat more progressive, as no doubt local perceptions have long been. Thus, Dulhunty (1975), writing of these early descriptions of Lake Eyre, said: 'But what damning descriptions they all are! No mention of the joy of experiencing its sea-salt freshness ... nothing of its scientific wonder ... no word of the unbelievable mirages ... nor of the exhilarating sight, and feel, of the beauty ...'

On another continent, Mono Lake, California, is perceived as a lake of outstanding beauty, a feature not lessened by the recently exposed tufa columns. Lake Nakuru, Kenya, and the Etosha Pan, Namibia, and their associated flamingo and wildlife populations, provide the focus of an important tourist industry drawing visitors worldwide who come to photograph and observe their beauty. Flamingos, both at Lake Nakuru and elsewhere, have long been regarded as birds of great beauty and grace.

Recreational values

The cultural and aesthetic values of many salt lakes mean that many are visited on a recreational basis to experience these values at first hand. But salt lakes have several recreational values in addition to those of a passive kind. Fishing, swimming and sailing are frequent recreational activities associated with lakes of moderate salinity. Perhaps, given the unproven therapeutic value of salt spas and lakes, the use of salt lakes in this way is better regarded as a form of recreation than as an economic use. The use of certain salt lakes when dry as the loci for attempts on land-speed records may also be regarded as a recreational value of salt lakes.

Scientific values

Salt lakes are of particular value to a number of disciplines. To ecologists, they are of value because of their habitat homogeneity, discreteness, low taxonomic diversity, and value as a source of material for microecosystem studies (Williams, 1972; Collins, 1977; Hammer, 1978; Vareschi, 1987). To physiologists, they are of interest because of the nature of biological adaptations to the environmental extremes operating within salt lakes (high salinity, low oxygen concentrations, high light exposure). To biochemists, they are of interest because of the enzyme mechanisms used by halophiles, and the mechanisms by which Halobacteria fix light energy. And to evolutionary biologists, they are of interest because, *inter alia*, stromatolites, a particular sort of microbial/ sediment assemblage, appear to be amongst the oldest known form of life on earth (3000 million years BP). The interest and value of salt lakes to non-biological science, especially geochemistry, is equally as wide. And, of course, the sensitivity of salt lakes to relatively small climatic changes means that palaeolimnological studies of salt lakes have also attracted considerable scientific interest, an interest recently catalysed by impending global climatic change.

Educational values

Closely allied to many scientific values of salt lakes, of course, are educational values. At a time of increasing global climatic change, this value should not be undervalued in regions where salt lakes are close to educational institutions. At my own institution, class exercises based on field observations of salt lakes are an important part of courses. And it is my opinion that microecosystems derived from salt lakes have the potential to play a most important rôle as teaching tools: their simplicity, ease of manipulation, and the wide range of experiments that can be undertaken using them are outstanding in this respect (Williams, 1991).

Ecological value

Not least amongst the values of salt lakes, though the most difficult to measure, is their value as an integral part of the biosphere. Their biological diversity and ecological processes cannot be excluded from global diversity and biospheric processes with any certainty that exclusion will not have profound repercussions. Changes in the nature of the Aral Sea referred to in more detail below are the most indicative evidence of this sort. Already, widespread unfavourable climatic and regional environmental changes have followed man-made alteration to this lake. One important ecological value of salt lakes that should receive particular mention is their rôle as feeding, refuge and breeding sites for many migratory or nomadic bird species. The loss of certain salt lakes of value in this respect may pose very serious threats to the continued viability of the bird species in question.

The impact of humans upon salt lakes

Our use of salt lakes and of resources in their drainage basins has had impacts upon them that are significant, diverse, comprehensive and mostly irreversible. Almost without exception, these impacts have been deleterious. In short, we have already irreparably damaged an important part of our biosphere.

Impacts have been many and diverse, of short or long-term duration, affecting part of the biota or the ecosystem as a whole, of limited extent or totally destructive. Effects have reflected this diversity, but with comprehensive overlap: that is, different impacts often have similar effects, in particular those, the most ubiquitous, resulting in increased salinities. Particular impacts are often site specific, but global generalities are easily discerned. Because of this comprehensive overlap, and in an attempt to avoid unnecessary repetition, the following discussion considers both impacts and effects without attempting to separate them too widely.

For ease of discussion, the impacts are considered as those which primarily (a) act upon the catchment or drainage basin, (b) involve diversion of inflowing waters, (c) result in the addition of unnatural waste products or pollutants, (d) directly affect the biota, (e) cause physical change to the nature of the lake basin, and (f) will follow global climatic and associated changes. Not discussed separately as an impact, though its importance (and thus effect) can scarcely be overestimated, is human ignorance: the perception that salt lakes have limited uses and values, are expendable 'wastelands', and do not merit serious consideration as sites of conservation interest (see Williams (1986) for an extended discussion of this subject).

Catchment/drainage basin activities

All lakes reflect catchment events, and in this respect salt lakes are particularly sensitive because their catchments are frequently in semi-arid regions where habitats respond quickly to perturbations. Two events of significance in the present context are grazing by wild and domesticated mammals, and more direct changes to the natural vegetation imposed by man.

The effects of grazing, particularly overgrazing, become manifest in changes to run-off patterns and increases in sediment loads in run-off (e.g. Grainger, 1990). In Australia, for example, overgrazing by the rabbit, an introduced species, has caused profound changes to both the biological and physical nature of lake catchments, and these changes compound those caused by the grazing of domesticated mammals (chiefly sheep and cattle). Most important of the physical changes are the formation of animal tracks and breakage of protective surface crusts; both events lead to mobilization of surface particles and erosion.

Changes to the nature of vegetation on catchments by more direct human activity have been equally if not more significant. The clearing of deep-rooted natural vegetation (trees) and its replacement by shallow-rooted grasses and crop species frequently has led to changes in local hydrology. These changes lead to changes in the salinity, composition and seasonality of run-off (e.g. Pereira, 1973; Holmes & Talsma, 1981). Thus, underlying groundwaters (often saline) may approach the land surface more closely and ultimately to a position where capillary action alone causes it to reach the surface. In certain regions, such as central Asia, capillary action may begin when the water table is as low as 10 m below the ground level. Evaporation then acts to increase salinity and subsequent run-off adds the saline water (or precipitated salts) to the local drainage terminus, that is, the lake. The obvious result, of course, is that lake salinity increases. Western Australia provides many examples of this phenomenon. Salinity increases are by no means confined to natural salt lakes, so that many previously freshwater lakes and rivers in areas where induced salinization is occurring now have elevated salinities (e.g. Lake Toolibin, Western Australia; Froend *et al.*, 1987). Clear evidence of this is to be seen in the dead stumps of trees both in and marginal to many Australian lakes now markedly saline (e.g. Lake Tallinga, South Australia) and in observed spatial and temporal patterns of salinity change in rivers draining cleared areas (e.g. Blackwood River, Western Australia).

Overgrazing, vegetation clearance and salinization frequently lead to severe erosion and overall 'desertification' (land degradation) in semi-arid catchments. Already, some $1–2.5 \times 10^6$ ha of the Aral Sea catchment is at hazard from this phenomenon, especially in the delta areas of the Amu- and Syr-Darya (Koust, 1991), and its catchment is far from unique in this respect.

In this context, it should also be recognised, as Stine (1991) has stressed recently, that a lake and its catchment are closely linked geomorphologically, so that a change in the lake can instigate secondary changes in the lake catchment. Thus, at Mono Lake California, the fall in water-level has forced the main inflowing streams to incise as much as 10 m. This incision, in turn, has resulted in a fall in the water-table over a considerable area with the consequential loss of many wetlands in the catchment. Stine also wrote that there are critical levels for geomorphological impact (akin to critical biological levels, for example, in salinity). These critical geomorphological levels may represent threshhold levels which, once passed, do not permit the restoration of original conditions should transgression (rather than regression) occur.

Diversion of inflows

Very large salt lakes frequently have more or less continuous inputs of fresh water. As indicated, this has long been recognized as a useful resource and considerable use of it has been made. As long as this use was of limited extent, no major impact upon the hydrological budget of the salt lake occurred. With increasing use, especially following the growth of human populations in semi-arid regions, major impacts followed. Some important lakes in this context are the Caspian, Aral and Balkash in central Asia, Lop Nor and Qinghai in China, and Pyramid and Mono Lakes in the USA. Diverted water is used for a variety of purposes: from Mono Lake, most is used for domestic purposes in Los Angeles; from other lakes, irrigation is often an important use.

A special case involving water diversion is provided by Kara-Bogaz-Gol Lake in Turkmenia. This was a large salt lake connected to the Caspian Sea by a narrow channel. Formerly, significant quantities of water flowed from the moderately saline Caspian Sea into the lake where it evaporated to create a large and highly saline water-body. Beginning in 1980, when the water level of the Caspian was at a very low level, an essentially 'blind' dam was built across the entrance to the Kara-Bogaz-Gol. Subsequently, the lake more or less disappeared. Following the expression of some concern on this matter, small amounts of water were and are now allowed to flow through to the lake, but the 'reconstituted' lake is smaller and different from the old one.

The diversion of water by direct drainage has also led to the disappearance of many interesting salt lakes. This is particularly so in agricultural areas, as for example, the Seewinkel pans in Austria (Metz & Forró, 1991) and pans in the Coto Doñana, Spain (Montez & Martino, 1987). Others have been destroyed by the excessive diversion (extraction) of underground water. The 'axalapazcos' of the Mexican plateau, whose existence largely depends or depended upon the existence of underground supplies, provide cases in point (Alcocer & Escobar, 1990).

Conversely, in some inland situations, water diversion may also give rise to salt lakes – though in the main such salt-water bodies are far from natural. (Left out of account here are solar salt ponds derived from diverted sea-water.) The most notable example is the Salton Sea in California. This was created when the Colorado River broke the banks of a man-made channel in 1905 and flooded a large depression in southern California (Stanley, 1966). The salinity of the lake has increased since 1905 and it now contains many introduced marine species, including barnacles. Less notable, but more numerous examples are provided by so-called 'evaporating basins' designed to reduce river salinities by diversion of saline agricultural drainage water. These basins may have been artificially created but are often flooded natural wetlands. There are many examples of such basins near the lower reaches of the River Murray, Australia, and also in California. They are far from natural, and may receive major inputs of water at times when natural salt lakes in the region are dry, and they may accumulate unnaturally high concentrations of toxic elements. Unnatural salt lakes of this sort are not further discussed here given the paucity of information on them (but see, for example, Chilcott *et al.*, 1990).

The primary effects of significant water diversion from salt lakes upon the lakes themselves are obvious and two-fold: water volume decreases, and salinity increases. Each has many consequential effects.

The decrease in volume is accompanied by a decrease in lake area, especially in shallow lakes, and this in turn may expose large areas of the former lake bed. Sometimes a significant transfer of salt and sediment particles from the bed to surrounding parts of the drainage basin occurs. Lower lake levels may also cause the destruction of shallow and deltaic areas which may have provided important refuge areas and otherwise have been of conservation significance. The delta of the Volga in the Caspian Sea, for example, is regarded as the most important site for waterfowl conservation in the region, with up to 750 000 waterfowl present in mid-winter (Finlayson, 1991). Lowered lake levels may lead to the destruction of islands which formerly served to protect breeding populations from terrestrial predators, and the emergence of formerly submerged objects such as the tufa at Mono Lake, California. In the case of the Aral Sea, where very large areas of the former lake bed now lie exposed, regional climatic change has been attributed to the decreased area and volume of the lake, and the increased area of exposed lake-bed.

Increases in salinity lead to several chemical, physical and biological changes. Thus, increased salinity values may exceed the solubility products of certain dissolved salts leading to their precipitation and thus an alteration in the ionic composition of the remaining solution. Increased salinities also cause decreases in oxygen solubility (Sherwood *et al.*, 1991). Increased densities may lead to changes in many physical phenomena, including seasonal patterns of thermal (and chemical) stratification (which, of course, are also influenced by decreased depths). Perhaps more obvious than physico-chemical changes are changes in the composition of the biota. Whilst salinity may not be as important as a direct determinant of the biota of highly saline lakes as once thought (Williams *et al.*, 1990), it is certainly true that good correlations exist between salinity and species composition, richness and diversity in moderately saline lakes. Thus, as the salinity tolerances of indigenous species are exceeded, these species are replaced by more tolerant species until their tolerance is exceeded.

Pollution

The fact that salt lakes are the termini of closed hydrological systems has not prevented the discharge of a wide variety of pollutants to rivers flowing into them or to the lakes themselves when it has been economically convenient to do so. Mostly, it seems that loadings relate more to criteria erected to protect open, freshwater systems, and thus pollutant concentrations in salt lakes often reflect progressive accumulation (Williams, 1981).

Almost the whole range of pollutants discharged to fresh waters is also discharged to salt lakes or their influent rivers. Little point is served by the provision of details, but a few examples will illustrate the general statement. Lake Colongulac, Victoria, Australia, receives the effluent from a sewage plant located on its bank, and adjacent salt lakes, nutrients in agricultural runoff (Williams, 1981). High concentrations of certain metals occur in some Bolivian salt lakes with nearby mining activities (Beveridge *et al.*, 1985). Lake Maryut, Egypt, has high concentrations of tin in its sediments (Aboul Dahab *et al.*, 1990). High concentrations of organochloride residues are found in Kenya's rift valley lakes (Lincer *et al.* 1981). And many salt lakes are used as dumps for domestic and other garbage.

There can be little doubt that the effect of these pollutants on salt lakes is essentially the same as it is on fresh waters – though the actual evidence is thin: additional nutrients promote algal growth, high organic loadings decrease diversity but increase biomass, and poisons decrease both diversity and biomass. The modifying effects of salinity have yet to be determined fully.

Direct impacts on the biota

In several salt lakes, the fauna largely represents purposive or serendipitous introductions. The Caspian, Aral and Salton Seas provide the most notable examples. In many more examples, individual components of the fauna have been introduced. Thus, fish have been introduced in several moderately saline Canadian (Rawson, 1946) and Bolivian lakes (Hammer, 1986). Fish have also been introduced into some moderately saline Australian lakes where they cannot breed but where populations are maintained by stocking. Not all attempts to introduce fish into saline lakes, of course, have proved successful. Of introduced invertebrates, various species and subspecies of *Artemia* have been spread worldwide. In the main, initial introductions were confined to coastal solar salt fields. There have been no attempts to control these largely *ad hoc* introductions either individually or at the governmental level despite the danger they pose to the regional genetic diversity of *Artemia* and the value of this. Geddes & Williams (1987) drew attention to the danger of these introductions, and the following motion was passed at a recent meeting of *Artemia* specialists (Sorgeloos *et al.*, 1987):

> 'the 2nd International Symposium on *Artemia*, meeting in Antwerp in September 1985, resolves that all possible measures be taken to ensure that the genetic resources of natural *Artemia* populations are conserved; such measures include the establishment of gene-banks (cysts), close monitoring of inoculation policies, and where possible the use of indigenous *Artemia* for inoculating *Artemia*-free waters'.

Persoone & Sorgeloos (1980), amongst others, had earlier pleaded for the conservation of all remaining natural habitats containing *Artemia*.

Leaving aside introductions, direct impacts on faunal species are few. However, exploitation of flamingo populations, either to provide meat or eggs, poses a direct threat to the survival of some South American species (Hurlbert & Flores, 1988).

Physical impacts on lake basins

Salt lake sediments, as noted, frequently contain minerals of commercial value (e.g. salt, soda, lithium, zeolites) and the mining of these frequently either physically damage the natural structure of the lake basin and/or indirectly lead to long-term changes in lake chemistry (and consequential biological effects). The derivation of useful salts from brines may also lead to physical change; often, this takes the form of dividing the basin into separate regions using low banks or levees separating waters of different salinity. Dredging activities may lead to the physical damage of some basins, as for example in the Caspian Sea.

Climatic and atmospheric changes

Finally in this consideration of hazards facing salt lakes, brief reference should be made to possible changes in global climatic patterns and to changes in the ozone concentration in the upper atmosphere. Because salt lakes represent a sensitive balance between many climatic parameters (e.g. evaporation, rainfall, temperature), relatively small changes in these will cause large changes to the natural character of salt lakes. This has already been recognised by workers in Canada (Hammer, 1990). The effects of climatic change could take various forms. Rising sea-levels would flood many coastally located athalassic salt lakes (e.g. those in southeastern South Australia). Particularly in danger in this respect are the many athalassic saline lakes occurring on small oceanic islands (e.g. Laysan Lagoon, Caspers, 1968). Increased aridity would lead to increased average salinities and ultimately to desiccation. Increased rainfall would lead to decreased average salinities and in extreme cases to the conversion of closed to open drainage systems. Changes to the seasonal patterning of climatic events would also lead to fundamental ecological changes. A major feature of this potential problem is that climatic changes are likely to occur, it is claimed, far too rapidly to permit the biota of salt lakes fully to adapt naturally to them (Parsons, 1990). On the other hand, it is possible that previous natural climatic changes have also been too rapid to permit tandem evolution. Certainly, there is evidence that some past climatic changes have been rapid, and a growing number of geologists are of the opinion that some significant global environmental changes occurred over relatively small periods of time (up to a few thousand years).

As for decreased ozone concentrations in the atmosphere, the problem here is that these allow more ultra-violet radiation to reach the surface of salt lakes and excessive exposure to such radiation is deleterious to living tissues. The plankton of lakes cannot stand increased exposure for any length of time (Traulich & Wagner, 1989). In deep lakes, however, avoidance is possible by sinking to lower depths, but this, of course, is not possible in shallow lakes. Since many salt lakes are shallow and already receive large amounts of ultraviolet radiation, the hazard is obvious.

Conservation measures

One of the essential first steps in the protection and conservation of any habitat is a recognition of its values, and the provision of a clear statement of these and the position of the habitat, its major features, hazards facing it, and knowledge available concerning it. A pioneer attempt to do this for inland waters (fresh and saline) worldwide formed the basis of 'Project Aqua' (Luther & Rzóska, 1971). 'Project Aqua' has been succeeded by more comprehensive wetland inventories amongst which those produced under the aegis of the International Waterfowl and Wetlands Research Bureau [IWRB] are notable. Comprehensive inventories of wetlands on all continents, however, do not yet exist. Even so, available inventories and similar publications have provided the basis for many important measures to conserve wetlands already. Several are important sources of information on salt lakes aside from any conservation value they may have (e.g. that by Scott, 1989, on wetlands of southeast Asia).

Measures to conserve salt lakes operate on a variety of organizational levels: at the local, regional (State, Province), national and international level; and at the non-governmental (public-interest) and governmental level. No comprehensive documentation of local, regional and national measures available to conserve salt lakes is given here, of course. However, it should be pointed out that regional and national governmental bodies with an interest in conservation are in general increasingly open to specific proposals on sites of interest. Pressure from non-governmental bodies is often an important catalyst in this context. To a not inconsiderable degree it is the responsibility of the scientific community to draw the attention of both sorts of body to particular salt lakes of conservation value.

It need scarcely be added that the responsiveness, sophistication and legislative power of regional and national governmental bodies, and the enthusiasm, credibility and the extent to which non-governmental bodies are informed, differ from country to country. In general, the more affluent countries have well-developed bodies of both types, so that in Australia, for example, the formal responsibility for conservation is vested in a variety of governmental bodies at State and Federal level (Bridgewater, 1991), and there are also various regional and national public-interest groups. Formal responsibility at the federal level is largely the province of the Australian National Parks and Wildlife Service; national non-governmental conservation bodies include the Australian Conservation Foundation and the Worldwide Fund for Nature (Australia). The value of non-governmental bodies should not be underestimated, and the Worldwide Fund for Nature (Australia) played an important rôle in promoting the publication of two influential books concerning Australian fresh and saline wetlands and supporting their conservation (McComb & Lake, 1988, 1990). Unfortunately, many salt lakes occur in countries that are not as affluent as Australia and lack well-developed conservation bodies and formal mechanisms to provide for conservation. Non-governmental bodies can be especially important in such countries. The Kalahari Conservation Society of Botswana, for example, has been active in drawing the attention of the international limnological community to threats to the Makgadikgadi pans posed by mining.

Of perhaps greater importance here is to note that international measures are now available promoting the conservation of wetlands. They should be used more effectively for salt lakes than they apparently have been. Measures which involve both non-governmental bodies and international agreements are important. Amongst the more influential non-governmental bodies with particular interests in wetland conservation rather than conservation issues in general, mention is made of the International Waterfowl and Wetlands Research Bureau (IWRB) (of which the Wetland Management Group is an active component), the International Association for Limnology (SIL) (of which the Working Group on Conservation specifically targets lake conservation issues), and the International Lake Environment Committee (ILEC).

The most important international measure for the conservation of wetlands (fresh and saline) is 'The Convention on Wetlands of International Importance Especially as Waterfowl Habitat'. The convention is widely known as the RAMSAR Convention after the name of the city in Iran where the Convention was adopted in 1971. At present (March 1991), there are 60 Contracting Parties with 508 listed sites of total area $> 30 \times 10^6$ ha. Australia was the first nation to become a party to the convention. In order for a wetland to be identified as a site of international importance, it must meet one of the following three general criteria (ANPWS, 1991):

(1) Be a representative or unique wetland
- be a particularly good representative example of a natural or near-natural wetland, characteristic of the appropriate biogeographical region;
- be a particularly good representative example of a natural or near-natural wetland, common to more than one biogeographical region;
- be a particularly good representative example of a wetland, which plays a substantial

hydrological, biological or ecological rôle in the natural functioning of a major river basin or coastal system, especially where it is located in a trans-border position;
- be an example of a specific type of wetland, rare or unusual in the appropriate biogeographical region.

(2) Be significant on the basis of contained biota
- support an appreciable assemblage of rare, vulnerable or endangered species or subspecies of plant or animal, or an appreciable number of individuals of any one or more of these species;
- be of special value for maintaining the genetic and ecological diversity of a region because of the quality and peculiarities of its flora and fauna;
- be of special value as the habitat of plants or animals at a critical stage of their biological cycle;
- be of special value for one or more endemic plant or animal species or communities.

(3) Be significant in the support of waterfowl
- regularly support 20000 waterfowl;
- regularly support substantial numbers of individuals from particular groups of waterfowl, indicative of wetland values, productivity or diversity;
- where data on populations are available, regularly support 1% of the individuals in a population of one species or subspecies of waterfowl.

Application of these criteria is made through a set of guidelines which enable the Conference of the Contracting Parties to assess the suitability of wetlands for inclusion on the List of Wetlands of International Importance. Whilst the RAMSAR Convention was originally formulated with the conservation needs of waterfowl in mind, its bailiwick has now been greatly extended to cover many wetlands of ecological but not necessarily ornithological significance. Nonetheless, the number of saline lakes listed is few, though many non-listed salt lakes clearly meet one or more of the criteria documented above. Thus, of the 39 Australian sites listed, fewer than five could be regarded as saline although saline lakes are widespread and important throughout the country.

Also of some value at the international level as a means of conserving salt lakes is the 'World Heritage Convention'. Parties to this Convention list national features that have outstanding and universal natural and cultural values. Whilst the Convention does not specifically target the conservation of wetlands, many listed features do include wetlands considered to be globally significant in a natural and cultural sense (*i.e.* of conservation significance). Once listed, parties to the Convention have a responsibility to protect the listed feature. Features proposed for listing must be comprehensively documented, have been the subject of national consultation, be nominated by the country (party) concerned, and be evaluated by IUCN. It may be added that Parties to the Convention have an obligation to protect, so far as possible, all features of World Heritage significance irrespective of whether they have been listed or not.

The sorts of national and international conservation measures indicated above, it may be added, have not yet adequately resolved the many special difficulties and problems associated with the conservation of inherently variable ecosystems (such as salt lakes). Maintenance of current conditions, the *status quo*, in a given locality may be a quite unnatural phenomenon.

Mono Lake, California

Many of the issues considered above are brought into sharp focus by a detailed consideration of Mono Lake, California. This lake has a variety of values and uses, a threat to its current status is present, some effects have already resulted from changes induced by man, and measures to protect and stabilise the lake are underway in response to the threat. The lake is relatively well-known scientifically, but a general discussion of it can be based upon Patten *et al.* (1987) and Stine (1991) who provide an authoritative summary of previous work.

Mono Lake is a large, deep lake in central California to the east of the Sierra Nevada (38° 00′ N, 119° 00′ W). In 1986, its altitude above sea-level was ~1,945 m, its area, ~150 km^2, and its mean depth, ~18 m. Surface salinity was ~84 g l^{-1}.

The values of the lake are many and diverse. The lake was of cultural significance to the Paiute Indians (for whom it also served as a food resource) and the past and present aesthetic appeal of the lake and its environs has attracted and continues to attract many sightseers. In addition to passive enjoyment of the lake, visitors also boat, swim, birdwatch and walk along its shores. Because of its high salinity and low taxonomic diversity, amongst other reasons, the lake continues to attract scientific and educational attention. A major invertebrate species inhabiting it, *Artemia monica* Verill, is endemic to the lake. The lake is an important feeding and breeding site for several bird species. It is particularly important as a feeding site on the migration pathway of Wilson's phalarope, the eared grebe and several other shorebirds. Economically, the lake is of value because of its production of *Artemia* and because its inflows are fresh.

It is this last value of the lake, the value of its inflowing fresh waters, which provides the only significant threat to the lake. Beginning in 1941, the water authorities for Los Angeles began diverting water from the lake for domestic supplies. As a result, the lake level began to drop steadily from 1956 m asl to its present level of ~1945 m asl, *i.e.* a drop of some 11 m. The effects have been an almost two-fold increase in salinity, from about 48 to ~95 g l^{-1}, the exposure of considerable areas of the former lake bed, and the connection of islands (e.g. Negit Island) to the mainland. The effects have had consequential impacts. The connection of the islands allowed predators (coyotes) access to the colony of California gulls. And the exposure of the former lake bed now causes alkali dust storms during windy conditions. The ecological impacts of the salinity increase have not been fully documented, but physiological studies have shown that over the full range of salinity increase already undergone in the lake growth and reproductive rates for much of the biota have been reduced (Dana & Lenz, 1986; Herbst, 1988; Herbst *et al.*, 1988). Further increases (e.g. to 120 g l^{-1}) are likely to lead to decreased phytoplankton and phytobenthic productivity, and reduced population densities of the major invertebrates in the lake (*A. monica* and *Ephydra hians* Say). Depending on the degree of decrease or reduction, this could reduce the value of the lake as a feeding station for migrating birds.

The past and predictable effects of water diversion have sparked considerable debate. In response to public concern on the fate of the lake, the California Department of Water Resources convened an 'Interagency Mono Lake Task Force' in 1978 charged with developing a plan of action to preserve the lake considering social and economic factors. The Task Force recommended that diversions be curtailed and the lake level raised. Further concern led to the formation, following a congressional directive, of the Mono Basin Ecosystem Study Committee (Patten *et al.*, 1987). After the passage of the California Wilderness Act in 1984, the Mono Basin National Forest Scenic area was established by Congress and the management of the basin placed with the U.S. Forest Service. The wider attention of the international limnological community was noted in 1982, when the following resolution was forwarded to President Reagan, governors and senators of respective states, and to the Mayor of Los Angeles.

> 'Because inland salt lakes are of interest to a variety of scientific disciplines;
> And because Mono Lake, California, [and Pyramid Lake, Nevada,] are of scientific interest, play critical rôles in the support of several bird, fish and other animal populations, but are seriously threatened as viable environments by continued water diversions in the States of California [and Nevada];
> We, participants of the Second International Symposium on Athalassic (Inland) Saline Lakes, meeting under the aegis of the Societas Internationalis Limnologiae urge responsible government agencies and municipalities in the

States of California [and Nevada], and the U.S. Federal Government to take into account scientific consideration about the value of these lakes when arriving at water resource decisions affecting them.'

The resolution was supported by summaries of the scientific value of Mono Lake.

The present position (1990) is that a local judge has ordered Los Angeles to limit its diversion of water from Mono Lake until the level of the lake has risen to an acceptable level, and a state agency (the State Water Resources Control Board) is studying whether changes need to be made in Los Angeles' licence to divert water from Mono Lake. Its ruling on Mono basin water rights is expected in 1993.

The Aral Sea

A consideration of the present situation in the Aral Sea, likewise, will serve to focus the earlier discussion. A considerable amount of material has recently been published on this lake, but much of it is of a general nature and rather little published material exists which documents the precise nature of limnological and wider ecological changes that have taken place since the lake began to change significantly in response to human activity. The primary scientific literature on the lake, moreover, is somewhat inaccessible to the international limnological community and most, of course, is in Russian. The necessarily brief account given here is drawn largely from the following recent references: Micklin (1988), Aladin & Khlebovich (1989), Glazovsky (1990), Anon. (1990, 1991), Williams & Aladin (1991), Aladin & Williams (in press), and various unpublished documents.

The lake lies in south central Asia (between 43°24′ and 46°53′ north and 58°12′ and 61°59′ east), and is fed by two major rivers, the Amu- and Syr-Darya. Prior to 1960, its major physico-chemical features had been more or less stable for a considerable time, with a water-level at ~53 m asl. At that time, the surface area of the lake was ~68000 km^2, its volume was 1090 km^2, its mean depth was 16 m, and its mean salinity was ~10 g l^{-1}. Lake level was maintained by an annual inflow of ~50 km^3 from rivers and 9 km^3 from rain.

In its natural state, the lake had a number of important uses and values (some evident only with hindsight). Although fish production was not high (~44000 ton per annum), commercial fishing was a significant activity for several lakeside communities. The moderate amounts of water diverted from inflowing rivers for irrigation and other uses was of great economic significance in the semi-arid regions through which the rivers flowed. The deltas of the Amu- and Syr-Darya were important habitats for resident and migrating birds, and these and other shallow parts of the lake were important foci of regional biodiversity (including terrestrial species able to use the only moderately saline water in marginal regions of the lake). As the fourth largest lake in the world, the Aral Sea was of considerable scientific value. It was also an integral part of central Asian culture and history. And, not least, the lake served to meliorate the severely continental climate of the region.

The major threats to the lake have been two-fold: the introduction of exotic species, and the excessive diversion of inflowing waters.

Since 1927, numerous introductions of animal species have taken place. Most of these have been on an *ad hoc* basis. Up to 1957, the introductions were entirely fish, but since then other groups have been introduced. Details need not be given, but it should be noted that the effects of these introductions have been greatly to change the nature of the Aral zooplankton, benthos and fish community. Biodiversity in the lake was never high; introductions simply decreased it.

The diversion of inflowing waters has been equally profound and certainly much more obvious. From its semi-stable state prior to 1960, the water-level has now dropped some 14 km (to ~39 m asl), the water surface has decreased to 37000 km^2, and lake volume has dropped to 340 km^3. Lake salinity, on the other hand, has increased to 30 g l^{-1}. The mean annual input to the lake for the period 1980–1989 was $\sim 7\ km^3$ (range: <1 to 22).

The effects of the changes brought about by water diversion have been marked. Falling water-levels have led to the loss of important shoal areas and islands in the south of the lake, destroyed the shallow deltas of the Amu- and Syr-Darya, converted islands elsewhere in the lake to peninsulas, and exposed large expanses of the former lake-bed. Each of these effects has had profound biological impacts (mostly involving loss in biodiversity), and in addition the newly exposed areas of former lake-bed are now the sources of salt and sand blown from the area in dust storms during windy conditions. The decreased area of free water, and increased area of lake bed, have caused local micro-climatic changes such that the climate is now a more 'continental' one.

Falling water levels have been accompanied by increasing salinities – from $\sim 10\ g\ l^{-1}$ in 1980, through $11.1\ g\ l^{-1}$ in 1970, $16.5\ g\ l^{-1}$ in 1980, and now $\sim 30\ g\ l^{-1}$ (1990). Many of the species present have been unable to tolerate such increases in salinity and have become extinct or are in the process of becoming so. This perhaps is not as devastating as it might first appear: recall that most of the fauna at least results from introductions.

Associated with these falls in water-level and increases in salinity have been several secondary impacts: pollution of groundwater from excessive use of pesticides and defoliants on irrigated cotton crops, medical problems (a general fall in public health, and an increase in child mortality and birth malformations), lowered crop productivity, and salinization of soils and rivers. It is these secondary impacts, taken with the primary ones, which are generally referred to as constituting the 'Aral Sea crisis'.

Predictions of what the end result of the water diversions will be depend upon the quantities of diverted water to be permitted in the future. Two scenarios advanced by P. P. Micklin (personal communication, 24 February 1991) for the year 2010 (~ 20 years hence) and based upon various Soviet sources are that: if only $16\ km^3$ of water is left to flow into the lake annually, then lake area will reduce to $\sim 22\,000\ km^2$, water-level will be 31.5 m asl, lake volume will be $140\ km^3$, and salinity will be $\sim 100\ g\ l^{-1}$; if $30\ km^3$ of water is allowed to flow into the lake annually, then lake area will reduce to $38\,000\ km^2$, water-level will be 37.5 m asl, lake volume will be $310\ km^3$, and salinity will be $\sim 40\ g\ l^{-1}$. Both scenarios, it may be noted, involve values of inflow water substantially greater than presently reach the lake (0–5 km^3 per annum), but still below that volume ($\sim 50\ km^3$ per annum) which reached the lake before its water-level began to drop. These scenarios, for simplicity of calculation, assumed a single water-body. However, the lake divided into two in 1988.

Widespread regional, national and international concern over the deteriorating ecological situation in the Aral Sea basin and in the lake itself has provoked a number of reactions at various levels. Of particular importance so far as international knowledge is concerned have been two recent symposia at which the 'Aral Sea crisis' was the main issue for discussion. The first was a joint USA/USSR meeting held in Indiana, USA, 14–19 July 1990; the second was a more open meeting held at Nukus, then in the USSR, 2–5 October 1990. A number of constructive resolutions and suggestions, as measures to conserve the lake, arose at these symposia. Additionally, the United Nations Environmental Programme, in cooperation with former Soviet scientists, has set up a working group of 'experts' to consider proposals which address various aspects of the crisis and which, it is hoped, will meliorate the more significant negative features of it. A plan incorporating an overall approach was recently put before the working party in Moscow (Anon, 1991). It will not be easy to implement this plan (and strong political decision-making will be necessary).

Epilogue

There are many salt lakes worldwide which have conservation significance, which are threatened by one or more hazards, but which are apparently not the object of any serious conservation effort.

Any attempt to document them is premature, but it would be remiss not to use this opportunity to draw attention to at least one of them. Accordingly, attention is drawn to the Akrotiri Salt Lake in Cyprus. Very little has been published on this lake despite its importance.

The Akrotiri Salt Lake occurs in southwestern Cyprus near Limassol. It has a maximum surface area (in winter) of 9.4 km^2, a maximum depth of 1 m, and the surface of the lake when full is 1.7 m below sea-level. Salinity varies from < 50 to > 200 g l^{-1} each year, and the lake dries in summer. It is separated from the sea in the east and west by a broad ridge of sand and shingle which in former times was breached by a channel. The last time there was a direct connection between the lake and the sea was in the early nineteenth century. Akrotiri Salt Lake is important as a refuge and resting place for migratory birds; as many as 150×10^6 birds pass through Cyprus in autumn, and a lesser number in spring, *en route* from the Palaeartic to Africa and *vice versa*. The lake, of course, is especially important for aquatic species, notably flamingos, the more so since it is one of a small and decreasing number of natural wetlands still left in the eastern Mediterranean. Note in this connection the extensive loss and degradation of Egyptian wetlands, particularly in the Nile delta. A major factor in the loss has been continuous land reclamation (Hollis & Jones, 1991); the addition of pesticides, heavy metals and nutrients (from sewage) is implicated in their degradation (Burgis & Symoens, 1987).

An important potential threat to the continued existence of the lake in its present condition is posed by the construction of a dam on the Kouris River, 5 km northwest of the lake, as part of a so-called 'Southern Conveyor Project'. The dam will store water to be used for the most part elsewhere on the island, and little water will be allowed to 'spill'. Below the dam, therefore, the Kouris River will dry up. The lake receives water from rainfall (annual mean ~ 0.5 m), groundwater, surface drainage (including a direct connection from the Kouris River), and the sea when small amounts are added by waves during storms. Inputs to local groundwater from the Kouris River will clearly change after the dam is complete, and this change will undoubtedly be reflected in the groundwater input to Akrotiri Salt Lake. Changes in this and the input from surface drainage may be expected to impact upon the lake. It is said that the influence of the dam on the lake 'is expected to be minor', but this seems far from certain and substantive hydrological data are not available to prove it.

The World Bank, the organization financing the 'Southern Conveyor Project', has called for a statement on the ecological implications of the scheme (in line with its normal procedures), and the preparation of this by a locally-based group is presently in hand. The importance of the lake is also recognized by the Cyprus Ornithological Society and the Association for the Protection of the Cyprus Environment. A recommendation has been made that the lake and its environs be declared a Nature Reserve. Thus, measures are in place which could provide for the conservation of the lake. These, however, may be less robust than they seem or than is desirable, and it is hoped that this epilogue, which will draw the attention of the international limnological community to the lake and the present situation there, will serve to strengthen any case to conserve the lake.

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References

Aboul Dahab, O., M. A. El-Sabrouti & Y. Halim, 1990. Tin compounds in sediments of Lake Maryut, Egypt. Envir. Pollut. 63: 329–344.

Adamus, P. R. & L. T. Stockwell, 1983. A Method for Wetland Functional Assessment: Vol. I. Critical Review of Evaluation Concepts. U.S. Department of Transportation, Federal Highway Administration, Office of Research and Management, Washington, D.C.

Aladin, N. V. & V. V. Khlebovich, 1989. [Hydrobiological Problems of the Aral Sea]. Proc. Zool. Inst. USSR Academy of Sciences, Leningrad, vol. 189. [In Russian]

Aladin, N. V. & W. D. Williams. The Aral Sea. Gleneagles Publishing, Adelaide (in press).

Alcocer, J. & E. Escobar, 1990. The drying up of the Mexican Plateau Axalapazcos. Salinet 4: 34–36.

Anon., 1990. The Aral Sea crisis and ways to meet this change. Supreme Soviet of the Union of Soviet Socialist Republics Committee on Ecology and Rational Use of Natural Resources. Moscow.

Anon., 1991. Outlines of the conception of conservation and restoration of the Aral Sea and normalization of the ecological, sanitary, medical, biological and socioeconomic situation in the Aral region. USSR Academy of Sciences/ USSR Committee for Conservation of Nature, Moscow. [Unpublished Report]

Australian National Parks and Wildlife Service [ANPWS], 1991. The Convention on Wetlands of International Importance Especially as Waterfowl Habitat. ANPWS, Canberra.

Beveridge, M. C. M., E. Stafford & R. Coutts, 1985. Metal concentrations in the commercially exploited fishes of an endorheic saline lake in the tinsilver province of Bolivia. Aquacult. Fish. Mgmt, 1: 41–53.

Bridgewater, P., 1991. Wetland conservation challenges in Oceania. In Proceedings of a Workshop on Wetlands Conservation and Management, Newcastle, Australia, 11–15 February 1991. Australian National Parks and Wildlife Service, Canberra.

Burgis, M. J. & J. J. Symoens, eds, 1987. African Wetlands and Shallow Water Bodies. ORSTOM, Paris.

Caspers, H., 1968. Biology of a hypersaline lagoon on a tropical atoll island (Laysan) Proc. Symp. Recent Adv. Trop. Ecol., 326–333.

Chilcott, J. E., D. W. Westcot, A. L. Toto & C. A. Enos, 1990. Water quality in evaporation basins used for the disposal of agricultural subsurface drainage water in the San Joaquin Valley, California, 1988 and 1989. California Regional Water Quality Control Board, Central Valley Region Report, December 1990, 1–48.

Claridge, G., 1991. An overview of wetland 'values': A necessary preliminary to wise use. In Proceedings of Workshop on Wetland Conservation and Management, Newcastle, Australia, 11–15 February 1991. Australian National Parks and Wildlife Service, Canberra.

Collins, N. C., 1977. Ecological studies of terminal lakes – their relevance to problems in limnology and population biology. In D. C. Greer (ed.), Desertic Terminal Lakes. Utah Water Res. Lab., Logan, Utah.

Dana, G. L. & P. H. Lenz, 1986. Effects of increasing salinity on an *Artemia* population from Mono Lake. Oecologia 68: 428–436.

Dugan, P. J., 1990. Wetland Conservation: A Review of Current Issues and Required Action. IUCN, Gland, Switzerland.

Dulhunty, R., 1975. The Spell of Lake Eyre. Lowden, Kilmore.

Finlayson, C. M., 1991. Conservation of the Volga delta. IWRB News, 5: 3.

Foster, J. H., 1978. Measuring the social value of wetland benefits. In P. E. Greeson, J. R. Clark & J. E. Clark (eds), Wetland Functions and Values: The State of Our Understanding. Proceedings of the National Symposium on Wetlands. Lake Buena Vista, Florida. Am. Wat. Resour. Ass. Minneapolis: 7–10 November 1984: 84–92.

Froend, R. H., E. M. Heddle, T. D. Bell & A. J. McComb, 1987. Effects of salinity and waterlogging on the vegetation of Lake Toolibin, Western Australia. Aust. J. Ecol. 12: 281–289.

Geddes, M. C. & W. D. Williams, 1987. Comments on *Artemia* introductions and the need for conservation. In P. Sorgeloos, D. A. Bengtson, W. Decleir & E. Jaspers (eds), *Artemia* Research and its Applications. Universa Press, Wetteren.

Glazovsky, N. F., 1990. [The Aral Crisis]. Academy of Science, Moscow. [In Russian]

Grainger, A., 1990. The Threatening Desert. Controlling Desertification. Earthscan, London.

Hammer, U. T., 1978. The saline lakes of Saskatchewan. I. Background and rationale for saline lakes research. Int. Revue ges. Hydrobiol. 63: 173–177.

Hammer, U. T., 1986. Saline Lake Ecosystems of the World. Dr W. Junk Publishers, Dordrecht.

Hammer, U. T., 1990. The effects of climatic change on the salinity, water levels and biota of Canadian prairie saline lakes. Verh. int. Ver. Limnol. 24: 321–326.

Herbst, D., 1988. Scenarios for the impact of changing lake levels and salinity at Mono Lake: Benthic ecology and the alkali fly, *Ephydra (Hydropyrus) hians* Say (Diptera: Ephydridae). Section 2, Appendix D-2. In Botkin, D. *et al.* (eds), The Future of Mono Lake. University of California Water Resources Centre Report No. 68.

Herbst, D., F. P. Conte &V. J. Brookes, 1988. Osmoregulation in an alkaline salt lake insect, *Ephydra (Hydropyrus) hians* Say (Diptera: Ephydridae) in relation to water chemistry. J. Insect Physiol. 34: 903–909.

Hollis, G. E. & T. A. Jones, 1991. Europe and the Mediterranean basin. In M. Finlayson & M. Moser (eds), Wetlands. Facts on File, Oxford: 27–56.

Holmes, J. W. & T. Talsma, 1981. Land and Stream Salinity. Elsevier, Amsterdam.

Hurlbert, S. H. & E. Flores, 1988. Nesting and conservation of flamingoes in the central Andes. Abstract of paper at IV Int. Symp. Salt Lakes, Banyoles, Spain, 28 May 1988.

International Union for the Conservation of Nature (IUCN), 1980. World Conservation Strategy. IUCN, Gland, Switzerland.

Koust, G. S., 1991. Evaluation of desertification in the south and east Aral region. Proceedings of Second Meeting of UNEP/USSR Working Group for the project 'Assistance for the Preparation of an Action Plan for the Conservation of the Aral Sea', Moscow.

Lincer, J. L., D. Zalkind, L. H. Brown & J. Hopcraft, 1981. Organochlorine residues in Kenya's rift valley lakes. J. appl. Ecol. 18: 157–172.

Luther, H. & J. Rzóska, 1971. Project Aqua: A Source Book of Inland Waters Proposed for Conservation. IBP Handbook, 21. Blackwell, Oxford.

Marble, A. D. & M. Gross, 1984. A method for assessing wetland characteristics and values. Landscape Planning 11: 1–17.

McComb, A. J. & P. S. Lake, 1988. The Conservation of Australian Wetlands. Surrey Beatty & Sons, Sydney.

McComb, A. J. & P. S. Lake, 1990. Australian Wetlands. Angus & Robertson, Sydney.

Metz, H. & L. Forró, 1991. The chemistry and crustacean zooplankton of the Seewinkel pans: A review of recent conditions. Hydrobiologia 210: 25–38.

Micklin, P. P., 1988. Desiccation of the Aral Sea: A water management disaster in the Soviet Union. Science 241: 1170–1176.

Montes, C. & P. Martino, 1987. La lagunas salinas espanolas. In Bases Cientificas para la Proteccion de los humendales en Espana. Dept. de Ecologia, Universidad Autonoma de Madrid.

Nissenbaum, A., 1979. Life in the Dead Sea – Fables, allegories, and scientific research. BioScience 29: 153–157.

Parsons, P. A., 1990. Biodiversity and climatic change. Proceedings of an International Conference on Conservation of Genetic Resources for Sustainable Development, Rxros, Norway, September 1990.

Patten, D. T. *et al.* [The Mono Basin Ecosystem Study Committee], 1987. The Mono Basin Ecosystem. Effects of Changing Lake Level. National Academy Press, Washington, D.C.

Pereira, H. G., 1973. Land Use and Water Resources. Cambridge University Press, Cambridge.

Persoone, G. & P. Sorgeloos, 1980. General aspects of the ecology and biogeography of *Artemia*. In G. Persoone, P. Sorgeloos, O. Roels & E. Jaspers (eds), The Brine Shrimp *Artemia*. Vol. 3: 3–24. Universa Press, Wetteren.

Rawson, D. S., 1946. Successful introduction of fish in a large saline lake. Can. fish. Culturalist, Nov. 1946.

Scott, D. A., 1989. A Directory of Asian Wetlands. IUCN, Gland, Switzerland & Cambridge, UK.

Serventy, V., 1985. The Desert Sea. The Miracle of Lake Eyre in Flood. Macmillan, Melbourne.

Sherwood, J. E., F. Stagnitti, M. J. Kokkinn & W. D. Williams, 1991. Dissolved oxygen concentrations in hypersaline waters. Limnol. Oceanogr. 36: 235–250.

Shiklomanov, I. A., 1990. Global water resources. Nat. Resour. 26: 34–43.

Sorgeloos, P., D. A. Bengtson, W. Decleir & E. Jaspers, 1987. *Artemia* Research and its Applications. Universa Press, Wetteren.

Stanley, M. de, 1966. The Salton Sea Yesterday and Today. Triumph Press, Los Angeles.

Stine, S., 1991. Geomorphic, geographic, and hydrographic basis for resolving the Mono Lake controversy. Envir. Geol. Wat. Sci. 17: 67–83.

Stone, A., 1991. Economic evaluation of wetlands. In Proceedings of a Workshop on Wetlands Conservation and Management, Newcastle, Australia, 11–15 February 1991. Australian National Parks and Wildlife Service, Canberra.

Traulich, B. & G. Wagner, 1989. Detektion von UV-B-Strahlung durch *Halobacterium halobium*. Akad. Natursch. Landschaftsplf. (ANL) Laufener Seminarbeiträge 3/88: 62–66.

Vareschi, E., 1987. Saline lake ecosystems. In E.-D. Schultz & H. Zwölfer (eds), Potentials and Limitations of Ecosystem Analysis. Springer Verlag, Berlin: 347–363.

Williams, W. D., 1972. The uniqueness of salt lake ecosystems. In S. Kajak & A. Hillbricht-Illkowska (eds), Productivity Problems of Freshwaters. Polish Academy of Science, Warsaw: 349–361.

Williams, W. D., 1981. Problems in the management of inland saline lakes. Verh. int. Ver. Limnol. 21: 688–692.

Williams, W. D., 1986. Limnology, the study of inland waters: A comment on perceptions of studies of salt lakes, past and present. In P. De Deckker & W. D. Williams (eds), Limnology in Australia. CSIRO & Dr W. Junk Publishers, Melbourne and Dordrecht.

Williams, W. D., 1991. Saline lake microcosms (microecosystems) as a method of investigating ecosystem attributes. Verh. int. Ver. Limnol. 24: 1134–1138.

Williams, W. D. & N. V. Aladin, 1991. The Aral Sea: Recent limnological changes and their conservation significance. Aquat. Conserv. 1: 3–23.

Williams, W. D., A. J. Boulton & R. G. Taaffe, 1990. Salinity as a determinant of salt lake fauna: a question of scale. Hydrobiologia 197: 257–266.

Williams, W. D. & M. J. Kokkinn, 1988. Wetlands and aquatic saline environments. AWRC Research Project 84/160, Completion Report. Dept. Resources and Energy, Canberra.