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Thematic Paper

Conservation and Management Challenges of Saline Lakes: A Review of Five Experience Briefs[†]

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Abstract

Saline lakes occur throughout the world and have significant economic, ecological, biodiversity, and cultural value. In addition to the wide array of human-caused impacts they experience in common with their freshwater counterparts, they are particularly vulnerable to changing hydrologic regimes due to climate change or water diversions. We review experience briefs addressing management issues at five lakes: Aral Sea (Kazakhstan/Uzbekistan), Issyk-kul (Kyrgyz Republic), Lake Nakuru (Kenya), Lake Poopó (Bolivia), and Chilika Lake (India). The Aral Sea experience illustrates the rapidity with which desiccation may occur and highlights the worldwide threat to all salt lakes with defined surface inflows as the demand for irrigated agriculture increases. It also shows the need for trans-boundary institutional structures for the management of water resources. All five experience briefs illustrate the linkage between lakes and their watershed and the need for basin-wide management. The role of international NGOs (e. g. Ramsar Bureau, Wetlands International, Birdlife International) in fostering an appreciation of non-economic values and promoting sustainable management is of particular importance to saline lake conservation; all five lakes considered here include Ramsar sites, "Wetlands of International Importance." The importance of stakeholder involvement in management is becoming widely recognized at all levels of governance (local to international). Experiences at Chilika Lake and Lake Nakuru provide examples of the success of stakeholder involvement.

Conservation and management issues of saline lakes are of particular interest as given the increasing demand for freshwater associated with population and economic growth, the fate of many salt lakes will be largely decided in the next several decades.

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Introduction

Inland saline lakes are found throughout the arid (25-200 mm annual precipitation) and semi-arid (200-500 mm) basins of the world. They include a vast array of lakes of different size, salinity, ionic composition, flora and fauna; and range in age from ephemeral playa lakes to ancient lakes (Hammer 1986, Williams 1996). The global volume of inland saline water (85,000 km^3) is only slightly less than that of freshwater (105,000 km^3) (Shiklomanov 1990). Locally they may be more abundant than freshwater, in which case they often dominate the landscape and provide critical habitat for endemic species, and breeding and migratory birds. Their size and salinity fluctuate whenever the balance between hydrological inputs (precipitation, surface runoff, and groundwater inflows) and outputs (evaporation and seepage losses) changes due to seasonal and climatic variation or anthropogenic activities. While the impact of water diversions for irrigated agriculture and urban consumption on several large salt lakes (Aral Sea, Dead Sea, Mono Lake) has been widely publicized, the global extent and rapidity with which saline lakes are being impacted throughout the world has yet to be fully appreciated (Williams 2002). In addition to inland saline lakes, coastal lagoons and solar pans constitute saline habitats of significant economic, cultural, and ecological value with many of the same issues arising in their management and conservation.

Here, we review case studies of three well-known salt lakes: Aral Sea, Issyk-kul, and Lake Nakuru; Lakes Poopó and Coipasa of the Titicaca-Desaguadero River system; and the large Indian coastal lagoon, Chilika Lake. These five “experience briefs” are a subset of 28 case studies of lake basin management initiatives sponsored by LakeNet to facilitate the dissemination and sharing of lessons learned in the management of a diverse array of lakes.

The Aral Sea

The desiccation of the Aral Sea in central Asia (Kazakhstan-Uzbekistan) first received international attention in the 1980s (Micklin et al. 1988). In 1960, the Aral Sea was the fourth largest lake in the world by area (67,000 km^2); only the Caspian, Superior, and Victoria were larger. Prior to 1960, the annual volume of inflows from the Syr Darya and Amu Darya rivers was 56 km^3; while following the increase in diversions for greatly expanded irrigated agriculture, the annual average inflows in the decades that followed were 43 km^3 (1961–1970), 17 km^3 (1971–1980), and 4 km^3 (1981–1990) (Letolle & Mainguet 1993). This led to the rapid desiccation of this immense water body to 17,000 km^2 by 2003 and caused a suite of environmental, social, economic, health, and cultural impacts.

The "Aral Sea Lessons Learned" brief focuses on the competing interests and difficulties of achieving transboundary cooperation on the management of the Amu Darya and Syr Darya among the seven countries with lands in the Aral Sea basin. While this focus may be appropriate and transboundary cooperation is critical to managing large river and lake systems, the brief does not adequately address a number of issues related to management of the Aral Sea basin. Most notable is the limited discussion of the continuing desiccation of the Large Aral Sea, biodiversity and the management of the large Syr and Amu Darya deltas, the Northern Aral Sea restoration project, and the roles of science and conservation NGOs. We briefly address these issues before considering the rest of the brief. We also note that poor overall organization of the brief decreases its effectiveness and include additional editorial comments in an appendix.

Continuing desiccation of the Large Aral Sea

The Aral Sea split into the smaller Northern Aral Sea and the Large Aral Sea in 1989. It is widely recognized that the Large Aral Sea will continue to shrink during the coming decades and restoration of the Aral Sea is economically and politically infeasible (World Bank 2001, Williams 1998). The brief describes impacts associated with the desiccation from 1960 to the present (desertification, dust storms, regional climate change, and health problems) but provides no discussion of potential impacts associated with further desiccation (indicated in Fig. 2 of the brief) and eventual stabilization. Williams (1998) suggests that management decisions regarding saline lakes are often based solely on easily quantified direct economic benefits, while the considerable non-economic values and diffuse economic impacts associated with degradation are rarely quantified. Discussion of the impacts associated with further desiccation of the Large Aral Sea is warranted including the splitting of the Large Aral Sea into three smaller lakes in the near future.

Deltas and Northern Aral Sea Project

The brief notes that "the extensive deltas of the Syr Darya and Amu Darya sustained a diversity of flora and fauna. They also supported irrigated agriculture, animal husbandry, hunting and trapping, fishing, and harvesting of reeds, which served as fodder for livestock as well as building materials." However, little information is presented on current or planned management of these deltas. Two projects are noted: a GEF-funded project including restoration of Lake Sudochje, a Ramsar site within the Amu Darya delta and a UNESCO project funding ecological research. However, discussion and analysis of these projects are lacking.

The Northern Aral Sea Project (World Bank 2001), which includes construction of a 12 km dike, has the potential for restoring biodiversity and fishery values to a portion of the Aral Sea resulting in considerable economic benefits to local populations. Dust storms and local climate changes may also be lessened. The dike would raise the Northern Aral Sea by several meters and maintain a lower salinity due to flushing effects of the Syr Darya. Although the resulting size of ~3,300 km^2 is small relative to the pre-1960 Aral Sea, it would still be the 15^{th} largest salt lake and 50^{th} largest lake by area in the world. A previously built dike (1992-1999) raised the lake by 3 m but was breached by large floods (Aladin et al. 1995).

The morphometry of the Aral Sea allows this partitioning to be done relatively inexpensively. Similar proposals have been made at other salt lakes and the design phase of a US$1-2 billion project to partition the Salton Sea, California is currently being implemented.

In 1960, the fish fauna of the Aral Sea consisted of a couple dozen native and introduced fishes while the invertebrate community included >200 species. When parted into the Northern and Large Aral Seas, only 7 species of fish, 10 common zooplankton species, and 11 common benthic species were present. Increased salinity of the Large Aral Sea has resulted in complete elimination of the fishes and of eleven invertebrate zooplankton species (Plotnikov et al. 1991). Re-colonization of a less saline restored Northern Aral Sea with fauna from the Syr Darya delta is likely and flounder and sturgeon fisheries are listed as economic benefits in an appraisal of the project (World Bank 2001).

The Aral Sea has experienced a long history of intentional exotic fish introductions beginning in the 1920s (Aladin & Potts 1992, Aladin et al. 1998). These should be reviewed so that the lessons learned can be applied to management of the restored Northern Aral Sea.

Roles of science and NGOs

Non-governmental organizations (NGOs) with missions directed toward conservation, biodiversity, and sustainable use have played a critical role in lake management. The Aral Sea brief does not adequately discuss the past, present, and potential roles of NGOs in Aral basin water management. NGOs are often critical to involvement of stakeholders and local support, and no mention of Aral Tenizi (www.aralsea.net), a local NGO is made. The brief does not discuss the involvement of stakeholders and capacity building at the local level except to state that 1) the region has very little experience in involving stakeholders and implementing integrated approaches to water management and 2) that "soft" components of projects (public awareness and developing institutional frameworks) were usually unsuccessful. In other case studies considered as part of the LakeNet's Lake Basin Management Initiative, NGOs played a significant role in developing stakeholder involvement. The Ramsar Bureau and other NGOs (e.g. LakeNet, Int. Wetlands, IUCN) could play significant roles in the Aral Sea basin. The Amu Darya delta contains a Ramsar site and a restored Northern Aral Sea, given its high biodiversity and conservation value, is a potential Ramsar site.

The Aral Basin has been the focus of an array of World Bank, UNESCO, UNDP, and USAID projects. Given the admitted failure of the "soft" components of many initiatives, an analysis of the effects of these failures on the overall success of various projects is strongly warranted. "Soft" components, including stakeholder involvement and the development of local institutional infrastructure, have been deemed critical to the success of many lake management initiatives.

The role of science in the decision-making process is not addressed although the Russian Academy of Sciences, the royal societies of the United Kingdom and Sweden, INTAS, and NATO have sponsored a wide array of research projects. A number of other foundations (e.g. MacArthur, Soros, Rockefeller) and corporations (e.g. Ford, Toyota) have also sponsored scientific studies. At one point the brief states “groundwater contribution to the Large and Small Aral is much bigger than it was considered before and this factor should be taken more seriously” but then provides no further information on the role or lessons learned regarding the use of scientific studies.

Institutional arrangements for trans-boundary cooperation

The main strength of the brief lies in providing an overall description of conflicting water interests and institutional arrangements among the seven countries which share the Aral Sea Basin (Afghanistan, Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, Uzbekistan and Iran). Given that all of the countries except Kazakhstan seek to increase irrigated lands and the differing priorities favoring irrigation in Kazakhstan and Uzbekistan versus winter power generation in Kyrgyzstan and Tajikistan, there is great potential for conflict. Plans to increase irrigated agriculture in Afghanistan may add further conflict and should be discussed in addition to the prominent role oil and gas exploration and development may have in the region. One example not discussed, which has potential for lessening conflict, is the recent effort to meet the needs of all states through trade in natural resources where Kazakhstan and Uzbekistan trade coal or oil for water rights with upstream states (Vinogradov and Langford 2003).

The brief highlights the existing difficulties of regional cooperation among newly independent countries and provides a list of 11 recommendations developed by different organizations. However, the brief provides little analysis of factors affecting the success or failure of past projects and initiatives.

In conclusion, the Aral Sea brief provides a good introduction to internationally-funded initiatives in the Aral basin and develops a compelling argument for the need to develop new institutional arrangements and agreements for basin-wide management. It proposes a European institutional model similar to that implemented around the Baltic Sea. The gradual development and trust in trans-boundary institutional arrangements for basin-wide management of water resources is essential to further progress and sustainable management in the Aral Sea Basin.

Issyk-kul

Issyk-kul, in the Kyrgyz Republic, is the 11th largest lake in the world by volume with an area exceeding 6,000 km^2 and a maximum depth of 700 m. It’s also among the most ancient lakes in the world with an age of ~25 million years. The population around the lake is about half a million people.

The Lake Issyk-Kul experience brief discusses threats to the sustainable use of the lake, fisheries, glacial retreat, agriculture, water diversions, biodiversity, tourism, and the Issyk-Kul Biosphere Reserve. While it focuses on the problems associated with management of the reserve, it does not provide an explicit section or enumeration of lessons learned. In comparison with other lake briefs, presentation of data on the structure and dynamics of the lake ecosystem is limited.

Issyk-Kul Biosphere Reserve/conservation priorities/lake management

The creation of the Issyk-Kul Biosphere Reserve is considered as one of the most important steps in government environmental policy. The primary goals of the reserve are protection of natural complexes from poachers and regulation of industries that currently pollute. It states that three experimental sites were chosen as typical for the region to serve as examples for implementation throughout the reserve although it is not clear as to what these sites include. Results of this experiment are not presented as most probably this project is at the stage of implementation. It is mentioned in the brief that many resolutions to protect the lake have been passed but in general have been poorly implemented or not implemented at all (p.20). However it is not clear what actions were proposed by these resolutions and what the reason was for poor implementation. Such information could serve as lessons learned.

The brief presents the list of agencies responsible for environmental management in Issyk-Kul oblast (administrative unit) but none of these agencies are specially focused on the management of Lake Issyk-Kul. Practically all these agencies are subordinated to the National Forestry Ministry. Thus, institutions responsible for lake (water) management are either not present in the region or not mentioned in the brief. It should also be mentioned that the Directorate General of Issyk-Kul Biosphere Reserve and the LakeNet Secretariat signed the memorandum on cooperation, which focuses on the management of Lake Issyk-Kul basin. This activity is not covered in the brief as the memorandum was signed after preparation of the brief.

Fish fauna/fishery/species introduction

The original fish fauna of the lake was severely changed by numerous introductions. These introductions were aimed in qualitative transformation of fish stocks. Such fish species as Sevan trout, bream, pike, perch, khramul, carp, and whitefish were introduced in different years into the lake to improve fishery resources. Sevan trout in the lake became an active predator on native species in the lake and high rates of predation led to a drastic decline in several endemic species and subsequently to the decline of the Sevan trout itself. The losses in yield were compensated for by introduction of planktivorous coregonids. Finally, as mentioned in the brief, the number of native species in the lake has diminished and others (e.g. the naked osman) are on the verge of disappearing. Paradoxically, the current strategy to preserve species diversity includes preservation of Sevan trout, which is endangered in its original lake, Lake Sevan (Savvaitova & Petr 1999). The most significant lessons learned from this are not discussed in the brief but as enumerated by Savvaitova & Petr (1999) include:

- Placement of additional fish species should depend on whether there is a vacant niche.
- Any new introduction should be capable of tolerating the harsh conditions of cold water high mountain lakes, as well as being a species with fishery value, either as food or for anglers.
- Newly introduced species should not compete with the indigenous, and especially endemic, fish species. In the case of Issyk-Kul the last condition was considered to be of

low importance. The introduction of the Sevan trout was done with full understanding of its character and with the purpose of better utilization of the existing fish stock, which were considered to be of low quality.

Radioactive contamination

Radioactive contamination of the lake is not covered in the brief but may be a significant problem. Uranium-carbon deposits may be contaminating the lake and the President of Kyrgyzstan, Askar Akayev, highlighted the need to speed up the reclamation of the Kadzhi-Say dump on the southern shore of Lake Issyk-Kul (BBC News). Previously, Kyrgyz newspapers reported a warning from the Emergencies and Civil Defence Ministry that if no action was taken heavy rains could wash radioactive particles into the Issyk-Kul basin, but the problem remains unsolved. A project to reduce this threat has reportedly attracted foreign funding. Russia is said to have given $160,000, and a further $400,000 has been made available by the USA. Now Russian Atomic Energy Minister Aleksandr Rumyantsev has presented an $8.8 m project to reclaim areas around former uranium mines. The structures built to contain the waste are in great need of renovation and under constant threat from mudflows, avalanches and flood waters, as well as people combing them for saleable waste and scrap metal (BBC News). It is worth mentioning that the Lake Issyk-Kul is characterized by increased natural uranium content. Within the project "Assessment and prognosis of environmental changes in Lake Issyk-Kul" (Program of the European Commission "Copernicus-2", 2001-2003) the water assays were sampled from different depths near the banks of the lake and from low-debit sources draining the dumping grounds of the uranium-carbon deposit. The results obtained demonstrated that the ecological status of the Lake Issyk-Kul is not damaged at present and wastewaters from the uranium-carbon mine do not make a decisive contribution into the natural radioactive background (Palesski et al., 2003) but the threat persists.

Water level/water diversion/salinity/ecosystem change

A 2.5 m drop in water level and subsequent salinity increase from 5.82 to 5.97 g/l during 1932-1984 is noted and the possibility of supplementing natural flows through diversions is being considered. The brief states "*any further drop in the level of Issyk-Kul will lead to change in the entire ecosystem*" (p.8) but scientific justification for this conclusion is lacking. Indeed, while there is ample evidence that large changes in salinity affect ecosystem structure and function (e.g. Schallenberg et al., 2003; Herbst & Blinn, 1998, Nielsen et al., 2003) the minor changes noted above in the range of 5.8 to 6.0 g/l are unlikely to produce marked effects especially when compared to those arising from fisheries management and basin activities. Also, current trends of water balance in Issyk-Kul are not obvious. According to Savvaitova and Petr (1999) since 1986 the lake level has started to rise again. On the basis of sediment studies (Ferronski et al., 2003) it was shown that the lake water level experienced considerable variations in the last 6000 years. Of course, global climate change will be the leading factor affecting the water balance of the lake. Predicted warming will lead to the melting of glaciers which will first increase but later decrease the water volume of the rivers fed by glaciers. Although diversions for irrigated agriculture are much less than those in the Aral Basin, water from a number of rivers has been diverted for irrigation before it enters the lake (Savvaitova & Petr 1999). Thus, the long-term dynamic of the water level of the lake is related to various natural and anthropogenic processes.

The much larger volume and smaller surface area of Issyk-kul compared to pre-diversion Aral Sea reduces the potential for a similar rapid desiccation and consequently the threat of salinization should not be overemphasized in support of diversion schemes. Any proposal of such activity should receive thorough examination and scientific justification.

Water quality

It is stated in the brief that the state of lake waters continues to worsen, however virtually no data is presented to support this general statement. It is clear from the brief that the main water quality threats are disruption of soils, terrain and water tables by mining operations; pollution from agricultural runoff, and illegal dumping or storing of toxic chemicals currently in use at the Kumtor gold mine. Kumtor gold mine was also responsible for the regional environmental disaster when more than 1.5 t of sodium cyanide were spilled during a truck crash in 1998. In spite of suspicion of illegal dumping (p. 4) and responsibility for the cyanide contamination, the environmental policy of Kumtor Operating Company is cited as an example of good environmental management (p. 6). Indeed, the company has banned grazing and hunting on outlying lands leading to regrowth of plants and increase in wildlife.

The reason for the degradation of water quality according to the brief is the decrease in water volume, which cites examples such as "*the color of the water has changed over time*", "*hydrobiologists …have noted an increase in numbers of phytoplankton and microorganisms*" (p.7). Such limited (anecdotal) examples of water degradation demonstrate that the lack of scientific data will be a serious problem for future environmental management. Also it is not clear how the "*fall in lake level brings with it a reduction in the volume of biogenic elements entering the lake from littoral silts, and thus with an increase of the biological productivity of the lake*" (p.7).

Unregulated camping is seen as an increasing anthropogenic source of wastewater and nutrient loading to the lake and the brief proposes possible solutions for this issue such as developing of tourist routes and ecotourism by Biosphere Reserve. It is impossible to assess the effectiveness of this proposal, as it is not implemented yet.

Lessons learned

It is clear the Lake Issyk-Kul faces an array of anthropogenic threats including toxic and radioactive waste contamination, eutrophication due to agricultural and other activities, loss of fish biodiversity due to overexploitation and introduction of nonnative species, tourism impacts, and possibly impacts due to long-term changes in the hydrologic balance of inflows and evaporation. Lake Issyk-Kul is a Ramsar site and has significant ecological and biodiversity value. However, according to information presented in the brief, the environmental management of Lake Issyk-Kul basin and surrounding territory is driven by the necessity to use natural resources of the lake in a way that is most beneficial to the local economy (fishery, recreation, etc.) and by the uniqueness of the high mountains territory where the preservation of terrestrial species sometimes may outweigh the lake priorities.

While not stated explicitly in the brief, several "Lessons Learned" are evident through careful reading.

1. It is stated that agencies charged with environmental protection are poorly organized and their work is for the most part limited to inspection – better organization and independent control will help in this case;

2. Decisions on social and economic issues were made without any consideration of environmental risks or eventual impact and without public participation – environmental impact and risk assessment should be an integral part of the decision-making process;

3. Low level of environmental education, ignorance of the laws and regulations, lack of information and limited access to information, no opportunity for the public to take part in decision-making on environmental issues – environmental education, dissemination of information, development and involvement of NGOs are obvious solutions. Taking into account the Issyk-Kul Biosphere Reserve and LakeNet memorandum of cooperation, institutional capacity-building activities of the Biosphere Reserve are expected to be strengthened. It might be a good strategy to link lake management activities with activities of Biosphere Reserve. The Biosphere Reserve, as a world-recognized organization in sustainable environmental management, has (or will) continue to develop infrastructure and resources. The main drawback of such a strategy is that the management of the lake basin should cover all basin territory and exceeds interests and responsibility of the Reserve. Thus the management of Issyk-Kul basin should be realized in cooperation and coordination with activities of Biosphere Reserve but separate management plans should be developed and adopted which deal with both specific problems of the lake, its' nature and local needs.

Lake Nakuru

Salient features of Lake Nakuru, in Kenya are described in the brief and several environmental threats posed by accelerated development in the lake's catchment are identified. Emphasis is placed on inputs of sewage, stormwater, sediments and toxic pollutants, such as metals and pesticides. A thorough and informative summary of government and NGO efforts to improve management practices in the catchment is provided.

The introductory material that describes the environmental setting of Lake Nakuru does not cite many relevant scientific studies and has numerous errors or simplifications. For this reason, we provide a section providing background on the ecology of Lake Nakuru (see Appendix). The references cited therein, and Melack (1996), in particular, are recommended as sources for information to improve the text. Examples of misstatements in the brief include: "alkaline water chemistry makes the lake a unique ecosystem", "lesser flamingoes are the principal primary consumers", and "semi-arid climatic regimes result in precipitation-evaporative deficit leading to hyper-eutrophication and accumulation of alkaline minerals leached from the catchment basin". Lake Nakuru is an example of a widespread type of lake with a characteristic ecology; it is not unique. Very abundant zooplankton and fish consume more algae than lesser flamingoes. While phosphorus enters from the catchment, nitrogen, prior to the addition of sewage, is more likely to be supplied by nitrogen fixation. The bicarbonate and carbonate entering the lake is a by-product of mineral weathering but is derived largely from carbon dioxide produced by microbial processes in soils, these anions plus cations released by weathering are concentrated as the water in the lake evaporates.

The section providing background on Lake Nakuru includes biophysical features, and political and socio-economic aspects of conservation and development. While much of the section on biophysical features is useful, the limnological aspects would benefit from inclusion of additional scientific references. However, the opening sentences of the section cite one area, depth and volume; clearly these values have changed considerably over the last few decades as the lake has waxed and waned in response to climatic conditions. One peculiar sentence suggests that *Arthropira fusiformis* contains unique bio-molecules. While it is true that this alga has received extraordinary attention because it is edible by humans and rich in several substances, none are unique. The discussion of political and socio-economic aspects is valuable because it traces the settlement history, noting the recent acceleration in the expansion of the city of Nakuru, and acknowledges the constraints on conservation posed by the political and socio-economic conditions. An especially sobering observation is the huge impact of the HIV/AIDS epidemic on all parts of Kenyan society.

Current ecological issues are described in a section called the biophysical environment; where results from recent and on-going studies are presented as tables and graphs. The text should be substantially revised to be a careful analysis of the available scientific evidence that the lake is actually less ecologically resilient and is undergoing human caused degradation. While it is obvious that the catchment has been substantially altered, the impacts of these changes on the lake are far from clear.

Several specific examples of points in the text that should be improved include the following: As noted earlier in the brief, humans have occupied the region for tens of thousands of years. The lack of baseline data on biodiversity, noted in the brief, makes it difficult to assert that there has been a “precipitous decline in biodiversity”. The implication that heavy metals and pesticide residues are at toxic levels needs to be evaluated carefully in light of the complex chemistry in alkaline-saline waters and difficulty of accurately measuring these substances. Bioassay experiments done with attention to the activity, not the concentration of the potential pollutants, are needed using organisms living in the lake. Evidence linking pollution by metals, such as lead, mercury, copper and arsenic, to massive deaths of flamingoes is weak; large numbers of dying birds suggests a disease as the cause. The possibility of algal toxins as a cause requires further study. The research by Vareschi was done from 1972 to 1975, and did not include much on water quality. The pH of the lake is closer to 10 than 10.5. Dissolved oxygen levels vary from supersaturation to near anoxia as a function of stratification and high biological activity of the productive, natural community living the lake. It is unclear how much more biological oxidation demand is added by the sewage and stormwater inputs. It is incorrect to write Spirulina *Arthrospira fusiformis.* It is not appropriate to suggest “normal” salinity levels for Lake Nakuru. Assessing impacts of increased sediment inputs because of deforestation in the catchment require measurements of sediment inputs and altered optical conditions in the lake.

The longest section of the brief, concerned with management of the resources, thoroughly summarizes a wide range of activities conducted by government authorities and NGOs. The objectives and the limitations of these efforts are treated in a balanced manner. Although considerable efforts are being made to increase public awareness and to implement actions that will improve water quality, it is very difficult to do so within the political and socio-political constraints of the region.

Lakes Poopó and Coipasa of the Lake Titicaca- Desaguadero River Basin

Introduction

The hydrological basins of Lake Titicaca, the Desaguadero River, Lake Poopó and the Salt Lake of Coipasa (TDPS) constitute a high altitude closed-basin shared between the republics of Peru, Bolivia and Chile. The closed-basin system's total surface is 143,900 km^2 and consists of territories of the sub-region of Puno (Peru) and the departments of La Paz and Oruro (Bolivia). The Desaguadero River connects Lake Titicaca to Lake Poopó. The Laca Jahuira River connects Lake Poopó with Coipasa Salt Lake through a channel 130 km long. Coipasa Salt Lake is connected in high water times to the salt lake of Uyuni through the Negrojahuira Channel. Coipasa Salt Lake has a 60,000 km^2 watershed and an average surface area of 12,000 km^2. Given the TDPS system's high altitude in the Andes Mountains (more than 3,600 m), the climate is cold at night (8-10 ^{o}C year-round average) and has a moderate climate during the daytime, with annual precipitation that varies from 200 mm in the south to 1,400 mm in the system's north, with the maximum values over Lake Titicaca. The system's main natural threats are climatic and include long, intense droughts, heavy rains, flooding, frequent hailstorms and freezes, all of which cause serious damage to the region's agriculture. The basin's characteristic ecosystem is the puna, a formation of rigid gramineae grasses and dwarf bushes with coriaceous leaves and forests of *quenoa* (Polylepis) and other trees in the sheltered sectors. The animals most characteristic of these ecosystems are condors and flamingoes; various camelids, including llamas, alpacas, vicunas and guanacos; and the world's largest known frog, of the genus *Telmatobius*. There is an impressive richness of animal species, and some are in danger of extinction. In addition, the special conditions created by Lake Titicaca and other highland lakes produce special aquatic vegetation, particularly the *totorale*s, or totora reeds, which are of great importance not only ecologically but also economically. The lakes host a great variety of aquatic birds, many migratory, and some native fish that still maintain a certain commercial importance.

Intensive exploitation of the natural resources in the area has produced a general degradation of the soil and the biological resources, with the exception of some areas of particularly difficult climatic conditions, where remnants of the native flora and fauna have managed to survive. Unsustainable use of resources has resulted in deforestation, extensive erosion, river sedimentation, soil salinization, silting up of lakes and water imbalances in watersheds, all contributing to extreme variations in water flows. In addition, lakes and rivers in the TDPS system have been polluted by chemicals from unsustainable and unregulated mining and from foundries producing metals for international exports. Finally, growing urban centers have added pollution due to inadequate sewage systems and intensive groundwater use. In addition to harming the flora and fauna of the area, unsustainable natural resource exploitation in the Lake Titicaca system has significantly impacted the basin's human settlements and the economy.

Compared to the other saline lake basin briefs (Aral Sea, Issyk-Kul, and Lake Nakuru), the Titicaca/Poopó brief provides the least amount of detail addressing specific issues in the basin. The Titicaca/Poopó brief is not well referenced and there are no maps provided to give the reader any sense of scale or geography.

Protection of saline lakes and habitats within the basin

Heavy metal contamination due to mining activity is a serious environmental concern. Contamination is probably worst at Lake Poopó because it is the terminal end of watercourses that are highly contaminated. Lead concentrations of lake water (from mine pollution) are 300 times higher than the average concentrations detected in other lakes in the world. Most of the fish such as Ispis, Carachis, etc, have disappeared except for the pejerrey, which has higher resistance. In addition, heavy metal residues are found in fish in these lakes (Cardoza et al. 2004). In spite of this problem, local consumption is evident.

Suggested protective measures include establishment of prohibited periods and protected areas as well as long term monitoring plans. As far as mitigation measures, it has been proposed to use the technologies described by ALT (1999), mining water recycling, including the reduction of the contaminate flows and liquid volume; and reprocessing of mining wastes that may still contain valuable metals with rejected waste being deposited in an environmentally sensitive manner.

Water shortages, as well as mining pollution, may cause the extinction of vegetation, native fishes and bird species. To prevent these problems urgent measures are required. However, the brief does not mention protective measures except in a broad way.

The Titicaca/Poopó brief does not treat the subject of protecting saline lakes and habitats at all. There is a very short mention of halophytic plant communities, but no mention of where they occur or if they are threatened. The brief is written in relatively general terms and covers a very large geographic area in less than 24 pages. The main focus of the brief is on Lake Titicaca, which has the largest human population and the largest hydrological and biological problems. In addition, Lake Poopó appears to have been largely neglected as a resource because it has been largely contaminated by mining activities for a long time (Adamek et al. 1998). Therefore, it is understandable that the saline habitats have been somewhat ignored. There is almost no mention of the salars in the brief at all.

Management issues not adequately addressed

The use of ground water resources in the basin as a whole is poorly documented. The brief states (pg 13) that: “Currently, water from the aquifers is largely not used.” It is not clear if the authors are only discussing the Lake Titicaca aquifers, but even so, it is clear from the work of Revollo (2001) and Adamek et al. (1998) that there is heavy local use of the ground water in the Oruro area. Adamek et al. (1998) stated that the aquifer supplying the town of Oruro is excessively utilized and its total capacity is limited. There has been a large drawdown of the water table here, and there is a risk of contamination from toxic discharges from mines. These impacts on the aquifer will also likely affect the river and lake systems. The risk of acid mine drainage discussed by Adamek et al (1998) is also not addressed in the brief.

Although the brief stresses the importance of an accurate water balance, it appears the ground water component has been largely ignored. The importance of including the ground water component of the hydrologic budget in saline basin water balances has been documented by Rosen (1994) and should not be ignored here.

In addition, the authors suggest that drawing down the water table in areas of high water table may have a beneficial effect on the area, but then they go on to say that plants and animals in the region depend on these high water tables to maintain their habitat. Therefore, these "beneficial" effects deserve fuller explanation. Lowering of the water table, in general, in this area would not be a good idea particularly because it is unknown what effect the change in ground water flow directions would have on delivering water to the lakes and rivers.

Another important omission from the brief is the mention of the oil spill that occurred in Lake Poopó in 2000. Newspaper reports indicated that '39,000 barrels of crude oil was spilled into Lake Poopó by Trans-redes, an oil company jointly owned by Dutch Shell and US-based Enron. The spill impacted the Uru Morato native community, which has lived on the lake's shore for 5,000 years. EcoNet reported (3 February 2000), that the Uru Morato "have not seen a single fish or bird on their lake and are in danger of starvation. For the first time in thousands of years, the flamingoes did not return to lay their eggs alongside Lake Poopó." While the Ministry of Environment has closed its investigation of this case, the impact and recovery from the spill and what, if any, actions were taken to prevent its reoccurrence should be discussed.

More background information could be included such as the chemical composition of the lakes and rivers and how the hydrological system works. Global climate change could markedly affect the entire system. Additional references to paleoclimate studies and limnology would also be helpful. References to the work of authors such as Guyot et al. (1990), Wirrmann and Mourguiart, (1995), and Baucom and Rigsby (1999) would be useful and informative.

Lessons learned

The most important lesson learned from the brief was that the key to success of any environmental programs in the Altiplano will involve raising the standard of living for the indigenous people either through new farming practices, or new "green" industries and tourism. The authors of the brief demonstrate that the people of the region are so poor, and the infrastructure so fragmented that environmental issues are not of concern to them unless it actually helps them raise their standard of living. The ability to achieve results in such a vast, remote region that has the added complications of multinational politics is daunting. It appears that some successes have been accomplished and future projects should consider these successful models. The brief does not adequately describe these or suggest successful strategies.

Research or management needs specific to saline habitats

The impacts that dramatically affect the Lakes Poopó and Uru Uru resources are as follows. Since 1992, the water inflows to these lakes were reduced through droughts and irrigation water for agriculture. In addition, following a project agreement between Peru and Chile the flow of the Mauri River has been diverted across the cordillera. This river is a main tributary of the Desaguadero River (Armando et al. 2004). Because of these water shortages all fishes except for the carachi fish, have disappeared at the Lake Uru Uru (Rocha 2002). With respect to salt concentrations in these lakes and, depending upon water inflows, they may range between 30 g/l to 70 g/l (Cardoza et al. 2004). Except for the fresh water beneficial effects that dredging on the Desaguadero River may have in the lakes Poopó and Uru Uru, there has not been any action taken relating to the preservation or protection of these lakes.

It is somewhat difficult to make further recommendations on what research and management needs are important in the Lake Poopó/Titicaca basins because so little of the brief describes the problems specific to these habitats. However, based on Adamek et al. (1998) and other sources, the main concerns at Lake Poopó are related to mining activities and water resources. These areas of exploitation in the basin have had profound and long lasting impacts on the flora, fauna and hydrology of the basin. The water balance and heavy metal contamination are the major management issues.

In addition to uses by indigenous people, Lake Poopó is ecologically significant and was recently (11 July 2002) designated a Ramsar site. The site harbors two endangered mammals, *Vicugna vicugna* and *Chaetophractur nationi*, and several endemic fish species in addition to being important to three species of flamingoes *(Phoenicopterus chilensis, P. andinus, P. jamesi*) (see Ramsar Site Description; www.ramsar.org). The Andean flamingo (*P. andinus*) is listed as declining and vulnerable to extinction while the other two, Chilean and James, are both declining and near threatened (Wetlands International 2002). Although the government designated the lake a national heritage and ecological reserve in June 2000, it is not part of the national system of protected areas and little has been done to assure its conservation and wise use. Given the limited resources in the region, it is likely that efforts will first be directed toward preventing further degradation of Lake Titicaca, rather than addressing issues at a terminal saline lake. However, Ramsar status may increase international attention and awareness of its ecological values.

Summary

Lake Poopó and Lake Salar of Coipasa are part of the Lake Titicaca-Desquadero River Basin (TDPS), a closed basin system that lies in the altiplano of Peru, Bolivia and Chile. The TDPS supports a population of almost 3 million people, most of who live at a subsistence level. The area is remote and historically there has been intense use of the landscape for agriculture and mining. The environment of the entire region, and these saline lakes in particular, has been seriously challenged and degraded as a result of water diversions for agriculture and drinking water, mining, agricultural pollution, and a major oil spill in 2000. Through legislative measures in both Peru and Bolivia since the 1950's, some degree of hydrologic management of the TDPS has occurred and some major works to control water flows have been emplaced, although most of this focuses on Lake Titicaca. There is very little information provided on these two lakes/playas and despite their ecological significance there appears to be little emphasis on the saline lake systems in this part of the world.

Chilika Lake

Introduction

Lake Chilika, located in the State of Orissa, India is about 1,100 km^2 in size, shrinking to about half that size during the dry season (1). It is the largest brackish lake in India, has marine and fresh water ecosystems with an estuarine character, and several islands. It is a natural, permanent, lake with a mean depth of 1.4 m and maximum depth of 6.0 m. It is connected to the Bay of Bengal by a 32 km long, 1.5 km wide outer channel and separated from it by a sandy ridge. Salinity levels vary seasonally and locally and reportedly dropped from 27-33 ppt to 1.38-6.3 ppt over 33 years (2) due to silting and blocking of the opening to the sea. Seasonal flooding of villages around the lake also seems to stem from this problem (3). In September 2000 an artificial, new opening was created by means of a major hydrological intervention with the expectation that it would resolve the more critical ecological problems of the lake (4, 4a).

The approximately 3,200 km^2 Lake Chilika watershed supports a population of about 500,000 people (5). The watershed includes about 2,300 km^2 of agricultural land, 500 km^2 of forests, 190 km^2 of permanent vegetation predominantly used for plantations, 70 km^2 of swamps and wetlands, and 90 km^2 of grassy mud flats. Only about 50 km^2 of the basin is occupied by human settlements, roads, railways, and other infrastructure (6). Reclamation of marginal land for agriculture, prawn farms, saltpans, and construction, as well as the natural siltation process, has contributed to the reduction of the lake area as well as a concomitant drop in the lake-water levels (7). Numerous temples (7a) and the Nalabana Wildlife Sanctuary (8) make Chilika both a religious pilgrimage and growing ecotourism destination (9), with thousands of visitors annually (2). The lake was declared a sanctuary in 1972 (10).

Lake Chilika is a LakeNet Biodiversity Priority site (11) and home to great biodiversity, including endangered species listed in the red data section of The Book of International Union for Conservation of Nature and Natural Resources red list (12). It is the wintering ground for more than 1,000,000 migratory birds, and breeding and staging ground for nearly three dozen water-bird species. About 200 bird species have been identified (13) of which, reportedly about 100 are intercontinental migrants. Several hundred fish species have been identified (14) (including commercially important species) and 40% are reportedly dependent on sea water migration. A 1980s survey claimed to have identified over 800 species of fauna (11). Rare species include the Limbless skink (*Barkudia insularis*), found only in Chilika (15), and the Irrawaddy Dolphin (*Orcaella brevirostris*) (15, 16). Nearly 400 species of flora were identified (17); with some having medicinal properties and others being used as vegetables, fodder, thatching, fish food, bird food and nesting material. Little is known about the microbial populations (18, 19). This data reflects a relatively small number of studies mostly conducted prior to the hydrological activities (20).

The Challenges

Degradation of the watershed area due to overgrazing, deforestation and cultivation along hill slopes has lead to erosion and siltation of the lake. In addition, rivers, streams and long shore sediment transport along the Bay of Bengal, have been reported to deliver about 365,000 tons annually (21). These are the likely causes of reduction of the lake and inlet channel size, as well as shifting of the mouth connecting to the sea (for Landsat images comparing the lake taken October 17, 1989 and September 12, 2000, see 21a). The result is an adverse effect on tidal exchange, ability of the lake to flush, and reduction in lake salinity and species diversity. Intrusion and rapid growth of invasive freshwater plants from nearly 20 km^2 in 1971 to about 650 km^2 in 2000 was observed (22). This, in addition to increased phosphorous and nitrogen levels from agricultural runoff, has altered the feeding, breeding, and spawning grounds of many fish and shellfish. Many species have disappeared due to their requirement to spend part of their life cycle in the ocean (2). As a result, Lake Chilika has seen a significant decline in fish, and shellfish productivity and biodiversity.

Encouragement of agricultural development exacerbated the effects of cultivation on the lake. The change in the Orissa Government's Chilika Fishing Regulation Bill called for 30% of prawn-culturing lease space to go to non-fishermen (23) and was implemented by the State Revenue Department, which has complete administrative control of land area - including wetlands. The Supreme Court order treating a 1 km zone around the lake as a "No Activity Zone" has not been enforced. These policies, and reductions in their catches, led some fishermen to collect and sell rare bird eggs and poach birds (24). It also led to complaints and protests (25), demanding abolition of unauthorized prawn culture. Police shootings at protests and rallies caused loss of life (26, 27), and ultimately, the Orissa High Court directed the Orissa Government to modify leasing policy in favor of safeguarding the interests of the local fishermen. However, large companies continue to be a threat to local fishermen (28).

Industrial pollution seems not to be a problem due to a law banning factories in the lake vicinity (2). However, agricultural pollution due to runoff of fertilizer and pesticide residues in the north doubled from 1986 to 1998. Also untreated wastewater from surrounding villages and the state capital is an ongoing problem. Reportedly, there is a pollution abatement proposal under discussion using an Integral Sewage and Waste Disposal Scheme (29) and a 1995 project (30) to control runoff water with fertilizers, has yet to be completed (31).

The Responses

The Government of India became a Contracting Party to the Ramsar Convention on Wetlands in 1981 (32). In 1993, Lake Chilika became one of the first Ramsar sites in India (33) and was added to the Montreux Record (34). The Chilika Development Authority (CDA) was established in 1992 (35) and since 1997, has obtained multiple grants to protect, survey, study the root cause of degradation of the lagoon ecosystem and to launch restoration measures and develop the lake region (2) as well as provide an extensive, searchable website (36) covering many aspects of the lake. A 1998 workshop of the CDA along with partnering agencies (37), led to plans to minimize polluting industry in and around the lake, stop agricultural land expansion along the lake's periphery, increase active land management in the watershed area, divert early monsoon flow in the river system, desilt the channel linking lake and sea, and improve the Nalabana Bird Sanctuary and socio-economic conditions in villages.

The Government of Orissa authorized a study of the flow of marine water and its mixing pattern in the lake in order to restore appropriate salinity levels (38). As a result, on September 23, 2000, there was an opening of an outer mouth made in the sand ridge, along the channel, 11 km from the lake (4), reducing the distance between lake and sea by 18 km (2). Additionally, desiltation of the lead channel over a length of 3.2 km at Magarmukh considered a gateway between the outer channel and the sea (39) increased the maximum depth from 480 cm (1988) to 586 cm (2003). The dredged material was deposited on to an existing island and planted with species suitable for migratory bird perching. This has led to improved water flow and salinity gradient, auto-recruitment of marine species, and resulted in a substantial improvement of fish, prawn and crab yields (2). Fish and prawn landings have reportedly increased from 1269 (1995) to 11-12000 metric tons (2001-2002) (45a). Reappearance of 8 aquatic species (45a) including *Paenaeus indicus* (which has come to make up 50% of total prawn population) (2) and spread of the Irrowady Dolphin to Central and Southern sectors of the lake is also attributed to the hydrological and clearing efforts (40). Devastating village flooding and water logging (3) has also declined since 2001. The reduction is being attributed to the increase in lake depth and drainage (2).

Watershed treatment includes implementation of participatory micro-watershed-based soil and moisture conservation programs and income generation through proper natural resource management areas. This has led to increased productivity and income (2). Training and holistic management along with aforestation programs has led to reduction of silt flow to the lake (2). Plant restoration programs and weed management has led to improved biomass and diversity of seagrass meadows and a decline in freshwater invasive plants (2). There have been various economic development plans implemented including restoration of the Nalabana island bird sanctuary ecosystem and development of alternatives for villagers to prevent poaching (through the efforts of CDA, commercial Banks and local NGOs). Communication network improvements have involved fishery resource development and voluntary participation by fishermen in spreading information on importance of correct mesh-size nets, ill effects of "zero mesh nets" and ban on juvenile catches. This has lead to higher yields, improvement of local economic conditions and reinforcement of the programs (2). Ecotourism resources have grown 30% from 1987 to 1997 (2). Introduction of motorized boats for ecotourism and lack of a demarked channel to Nalabana has adversely impacted the lake conditions. Also, uncontrolled tourism has led to Wetland International recommending the need for implementation of a Community-based Ecotourism Program and more dialogue between CDA and the State Tourism Department (2). This has led to an orientation training program for boat men transporting tourists, making the boatmen more responsive to efforts by the Tourism Department to develop an ecotourism master plan.

A federation of Non Governmental Organizations (NGOs) and Community Based Organizations (CBOs) has led to the Campaign for Conservation of Chilika Lagoon. CDA, in collaboration with the Center for Environment Education Ahmedabad has developed the "Lake Science Centre" visitor center at Satapada, a major gateway to Chilika for tourists. They have also developed wetland education programs for schools (41). Ten Centers for Environment

Awareness and Education, in local villages are being run by local NGOs. Each has a small museum, library and environmental programs for children (43). They provide non-formal education by trained facilitators (mainly local women) and formal education through school textbooks (in local languages) on flora and fauna (2). There are several quarterly newsletters, some in local languages, with most articles written locally (40). An ecological adventure book for children about Chilika was also published (43).

A request was made in 2001 by the Government of India to remove Chilika from the Ramsar list of endangered sites (Montreux Record) and a Ramsar Advisory Mission visited Chilika Lake to review management actions undertaken and improvements made. In 2002 Chilika was removed from the Montreux Record, contingent on commitments from the Government of India and CDA to integrate management planning, including continuation and extension of local community participation, and monitoring of the lake, sea outlet, siltation, aquatic weeds, fishery yield, prawn aquaculture, and tourism. In 2002, the Chilika Development Authority received the Ramsar Wetland Conservation Award for "outstanding contributions to wetlands conservation and sustainable use", as well as the Evian Special Prize (44).

Future Plans and Recommendations

One of the most important future plans at Chilika involves the use of scientific databases, remote sensing technology, global positioning systems mapping and development of mathematical modeling (2). Also, further monitoring and expanding plans for ecotourism and pilgrimage-related tourism exist. Work is being done to improve the flow of money and funding lake work through self-financing through fishery and ecotourism. The State Government is planning a Chilika Fishery Regulation Act, including a complete ban of fishery culture and posting of severe penalties, reinforcing the ban on prawn culture by the Revenue authority of Orissa (2, 45). The Orissa Fishing in Chilika (Regulation) Bill 2002 transfers the right of the District of Collector to grant leases to the Orissa State Fishermen Cooperative Federation Ltd., making it mandatory to involve the CDA, empowering it to prosecute violators and to destroy illegal structures using police support.

Several steps that can be taken to further improve the lake and watershed ecology and economic conditions include continued hydrological and biological monitoring of the lake management, better monitoring and reporting of pollution by non-involved parties (33) and revival of, and better communication with, the Primary Fishery Co-operative Societies (2).

Inclusion of more complete scientific and regulatory information on projects involving Chilika on the CDA and LakeNet websites is highly desirable. In particular, a web site providing goals and outlines of past, present, and future projects concerning Lake Chilika would be valuable. There needs to be improvement in establishing the actual chronology of events – which laws and plans have been enacted and when they were established or completed? The LakeNet site (21) would benefit from more links to the actual ecological projects at Chilika, including a listing of species of concern listed on the CDA website. It will be valuable to analyze the results of hydrological and biological studies post dredging and opening of the new mouth to the sea. Though there is surely room for improvement in documentation, available information and the awards bestowed indicate that the CDA along with the Governmental, NGOs and CBOs have worked hard at improving the general welfare of all the species in the Chilika environment, including humans. No doubt that continuing efforts to abate pollution and regulate fishing practices, monitor reforestation projects and land use management, and improve tourism practices are all essential to the future success of the Lake Chilika region. The brief also illustrates that a clear understanding of the coastal process and the river basin is essential for restoration of a coastal wetland. Continued hydrological and biological monitoring of the lake environment is strongly recommended. The Chilika Lake restoration project provides an excellent case study illustrating the utility of adopting the principles of wise-use, integrated management, and emphasizing the participation of the local community in shared decision-making.

The conservation and management of other salt lakes

Salt lakes are subjected to a variety of anthropogenic impacts in common with their freshwater counterparts. Many of the lessons learned during the conservation and management efforts of freshwater lakes are generally applicable. However, the impacts of varying hydrologic regimes due to climate change or water diversions is often greatly magnified in salt lakes compared to freshwater lakes. Ever-increasing populations in semi-arid regions and expansion of irrigated agriculture will make conservation of salt lakes extremely difficult. An imminent freshwater crisis is widely forecast (Cosgrove and Rijsberman 2000) and plans for infrastructure improvements (dams, diversions, and irrigation) are being made with little attention to the environmental impacts on salt lakes. Also, excessive groundwater pumping is over-drafting aquifers in China, India, US, Pakistan, Mexico, Iran, South Korea, Morocco, Saudi Arabia, Yemen, Syria, Tunisia, Israel, and Jordan. A significant portion of increased world agricultural output observed over the past 50 years is directly dependent on over-drafting of groundwater aquifers Brown (2003) and, as these are depleted, additional increased demand for surface water will occur.

In some cases, the economic values associated with fisheries, tourism, or other uses may be substantial. The abundant birdlife and dramatic settings of many salt lakes (e.g. Lake Nakuru, Kenya and Mono Lake, USA) make tourism economically important and provides conservation incentives. In lakes of low to moderate salinity, recreational and commercial fisheries may be important and brine shrimp “fisheries” in more saline lakes (e.g. *Artemia* cyst harvest from Great Salt Lake, USA) are of considerable value. Recently, the brine shrimp A*rtemia* was detected in the Large Aral Sea and harvesting of *Artemia* cysts is under consideration (NATO Advanced Research Workshop 2002). In specific cases, the medicinal properties of saline waters have been developed as an economic resource. The economy of Shira district in Khakasia (South Siberia, Russia) is mostly based on recreational activities stimulated by numerous curative lakes.

Salt lakes often provide critical habitat in arid and semi-arid regions and appreciation of their ecological values has been increasing. Nominal protection for many salt lakes has been achieved through the International Treaty of Wetlands of International Importance (Ramsar Treaty) and the efforts its partner organizations (Wetlands International, the IUCN, Birdlife International, Worldwide Fund for Nature) and many small NGOs dedicated to conservation of individual salt lakes. There are currently 138 countries party to the Ramsar Convention (“Treaty”) with 1308 wetland sites of which 139 include inland salt lakes and 251 coastal brackish to saline lagoons.

While the current number is only a small fraction of important salt lakes worldwide, more are being listed each year.

Despite the economic value and growing awareness of the considerable ecological value of salt lakes, continued desiccation of most salt lakes with defined surface inflows is likely. Of all the large salt lakes, very few, most notably Issyk-Kul and the Caspian Sea, have avoided significant decreases in volume and increases in salinity due to water diversions. The Aral Sea brief illustrates the general case that the economic value of freshwater for irrigated agriculture will often outweigh the economic values of salt lakes and non-economic values (i.e. conservation, biodiversity, ecological, and cultural) are often given little weight in management decisions.

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Appendix 1: Lake Nakuru: Ecological Background

Lake Nakuru is one of several shallow, alkaline-saline lakes lying in closed hydrologic basins in the eastern African Rift Valley that stretches from northern Tanzania through Kenya to Ethiopia (Livingstone & Melack 1984). As is typical of shallow, saline lakes, worldwide, climatic variations have caused large changes in depth and salinity on annual, decadal and longer time scales and have had major consequences for the ecology of the lake. Daily fluctuations in heating and cooling result in strong diel cycles of stratification and mixing (Melack & Kilham 1974). High insolation and adequate supply of nutrients usually support abundant phytoplankton (Peters & MacIntyre 1976, Melack et al. 1982, Vareschi 1982). Supersaturation of dissolved oxygen in the upper waters during the day often results from the high rates of photosynthesis (Melack & Kilham 1974, Vareschi 1982).

Alkaline-saline lakes rich in bicarbonate and carbonate and usually called soda lakes, such as Lake Nakuru, are among the world's most productive, natural ecosystems (Livingstone & Melack 1984, Melack 1996). A conspicuous feature of these lakes is often the presence of enormous numbers of Lesser Flamingoes (*Phoeniconaias minor*) grazing on thick suspensions of phytoplankton. Low species diversity but abundant populations of aquatic organisms make soda lakes especially suitable for the study of trophic dynamics and ecosystem processes (Vareschi & Jacobs 1985).

Biological communities in shallow, tropical saline lakes are susceptible to slight variations in water balances and salinities. Paleoecologists have long exploited the salinity-driven shifts in aquatic communities of saline lakes to decipher the climatic history of tropical Africa (Livingstone 2000). In the 1970s, intensive limnological studies in the soda lakes of Kenya documented striking changes in association with climatic variations (Melack 1996). During a period of low rainfall and abrupt increase in salinity in Lake Elmenteita (Kenya, 0^{o} 27' S, 36^{o} 15' E) and Lake Nakuru (Kenya, 0^{o} 22' S, 36^{o} 5' E), the abundance of phytoplankton dropped and the species composition of zooplankton changed (Melack 1979, 1981, 1988, Vareschi 1982, Vareschi & Vareschi 1984). As species of phytoplankton, such as *Spirulina platensis*, were replaced by much smaller phytoplankton, the abundance of Lesser Flamingoes decreased markedly (Vareschi 1978, Tuite 1979). At Lake Nakuru, the birds declined from over one million to a few thousand after the salinity rose about 25% (20 to 25 g/L from September 1973 to March 1974, Vareschi 1982), and the phytoplankton abundance declined and species switched to ones too small for the flamingoes to filter from the water. Although demonstrating the sensitivity of these ecosystems to modest changes in salinity, the underlying mechanisms for the multiple responses could only be surmised (Melack 1988).

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Appendix 2: Chilika Lake Web References

Saline lakes have become the subject of active scientific research relatively recently beginning in the 1970s and except for some well-known examples (eg. Aral Sea, Dead Sea, Mono Lake, and Great Salt Lake) they are grossly under-represented in the English language peer-reviewed literature. For instance, a search of WebOfScience which abstracts over 8,000 leading scientific journals provided only two references on Chilika Lake; a 2-page 1989 article on desilting the lagoon and a recent article on the eradication of malaria. For this reason, the lead reviewer of the Chilika brief was forced to rely heavily on web documents which are referenced below.

1. http://indoexpedition.com/chilika.html
2. http://www.worldlakes.org/uploads/Chilika_10.22.03.pdf
3. http://www.chilika.com/about.htm
4. http://www.ramsar.org/key_awards2002_interview_chilika.htm, http://www.chilika.com/mouth.htm
5. http://www.worldlakes.org/lakedetails.asp?lakeid=8607
6. http://photos.panda.org/downloads/policy/rcindia.doc
7. http://www.gpa.unep.org/documents/PADH/Legislation_Study_FINAL_Report_2003.pdf
7a. http://www.chilika.com/eco.htm
8. http://www.indiatouristoffice.com/East/chilka_lake.htm
9. http://puri.nic.in/chilika.htm
10. http://www.sanctuaryasia.com/travel/detailtravel.php?id=27
11. http://www.worldlakes.org/docs/Report2/Report2AIII_Biodiversity.pdf
12. http://www.chilika.com/about.htm but unverified by us
13. http://www.chilika.com/bird.htm
14. http://www.chilika.com/fish.htm
15. Included in Schedule I of the Indian Wildlife Protection Act http://www.itechnology.co.za/index.php?click_id=588&art_id=qw1064819161507B253&set_id=1
16. http://www.wcmc.org.uk/cms/reports/small_cetaceans/data/O_brevirostris/O_brevirostris.htm)
17. http://www.chilika.com/plant.htm
18. http://www.chilika.com/algaflora.htm
19. http://www.chilika.com/zoo.htm
20. http://www.chilika.com/wetland.htm
21. www.worldlakes.org/lakedetails.asp?lakeid=8607
21a. http://home.iitk.ac.in/~ramesh/chilika.html
22. http://www.indianjungles.com/111202.htm
23. http://www.learningchannel.org/external/?url=http%3A%2F%2Finfochangeindia.org%2FLivelihoodsItop.jsp%3Fsection_idv%3D8%231934
24. http://forests.org/articles/reader.asp?linkid=19559
25. Including formation of the Chilika Matsyajivi Mahasangh - Chilika Fishermen's Federation
26. http://www.indianjungles.com/flasjun1_99.htm
27. http://www.earthisland.org/takeaction/actionalert_map6.html
28. Ref.Sec.6.1.7.2 C.D.A. http://sdnp.delhi.nic.in/nbsap/nbsapplan/chapter6.htm

29. Orissa Water Supply and Sewage Board, Government of Orissa
30. Orissa Water Resources Consolidation
31. http://www.orissagateway.com/news/daily/23042003/Orissa/Island_irrigation_project_.html
32. The convention, started in 1971, is an intergovernmental treaty providing the framework for national action and international cooperation for conservation and wise use of wetlands and their resources http://www.ramsar.org/
33. http://ramsar.org/wwd2000_rpt_india1.htm
34. A list of Ramsar sites where changes in ecological character "have occurred, are occurring or are likely to occur" http://www.ramsar.org/key_montreux_record.htm
35. The Ministry of Environment and Forests is the Administrative Authority for Ramsar implementation. Ramsar, and grants from the Ministry of Finance helped form the autonomous Chilika Development Authority (CDA) in 1992. Chief Minister of the State is the Chair Person, but CDA is under control of the State Environment Department and has no statutory powers and until 1997, did not play a significant role in major policy making activities.
36. http://www.chilika.com
37. Department Water Resources of Orissa, Indian Institute of Tourism and Travel Management and the Orissa Environmental Society and Wetlands International, South Asia in Bhubaneshwar
38. http://www.ramsar.org/cop7_nr_india.htm
39. http://www.chilika.com/restore.htm
40. http://www.chilika.com/publication1.htm
41. http://www.chilika.com/visitor.htm Though it is unclear as to its state of completion or exact location (see 29).
42. Funded by Japan fund for Global Environment Ramsar Centre Japan-Asia
43. http://www.cseindia.org/html/eyou/envedu/eeprod.htm#childbooks
44. http://www.chilika.com/news.htm
45. It is under active consideration by a committee of the Orissa Legislative Assembly

45a. http://www.chilika.com/reappear.htm