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Chapter

The Likely Status of Inland Salt Lake Ecosystems in 2050: Reminiscing and Revisiting Bill Williams

Francisco A. Comín

Abstract

The classical management approach of inland saline lake ecosystems focused on ecological issues, including conserving their biological communities and physical-chemical characteristics. However, the peculiarity of saline lake ecosystems is that they are in a limited watershed, in many cases a closed watershed. So, its management should be planned and performed at watershed scale, which has been frequently neglected. W.D. (Bill) Williams was one of the key persons rising awareness for conservation and promoting their rationale management based on scientific research results. This work shows, through a literature review, that classical management approaches included returning impacted salt lakes to initial conditions through, mostly, eliminating the processes impacting them. At the turn of the century, a wider approach emerged. In addition to focusing on watershed scale management, the integration of social, economic, and environmental issues was incorporated into management proposals by different authors. Lake Gallocaanta case study is described and discussed as a paradigm of inland salt lake management. The status of inland salt lakes will improve in the future if land cover reparation, and rationale uses of water in the watershed are incorporated, considering adaptive practices to climate change impacts and a balanced provision of ecosystem services.

Keywords: management, watershed, climate change, fluctuations, inland salt lakes

1. Introduction

The conservation of inland salt lakes (ISL) has been a matter of interest for the last four decades [1, 2]. Although scientific aspects of ISL have been investigated since long ago [3, 4], their management focused on the extraction of minerals for a long time during the last century and before [5, 6]. The improvement of their knowledge of ecosystems [7] increased the interest for their conservation since the last decades of the twentieth century [8, 9]. The triennial conference series on inland salt lakes started in Australia [10] and followed under the auspices of the International Society for Salt Lake Research was instrumental in extending the interest and knowledge
on inland salt lakes. William (Bill) D. Williams early realized the relevance of ISL as a unique ecosystem and encouraged both their study from the scientific point of view and their conservation in a good ecological state [11, 12]. All around the world, many others contributed to increasing the information on the biological components, comprehending the hydro-geochemical processes regulating ISL dynamics, and the interest in their conservation [13, 14].

By the end of the last century, most interests was devoted to classical issues as species conservation and hydrology-related impacts. The desiccation of ISL because of human land uses in their watershed, called anthropogenic drought, was a challenge for their conservation. Hydrological modeling was used as a tool to show the relationships between water flows in their watersheds and water level changes in the ISL. Many detailed studies were dedicated to knowing the trophic webs and their dynamics in relation to chemical characteristics of the water. However, their conservation and management received much less attention by the scientific community.

Early this century, several authors claimed the global trend of degradation affecting lakes [15, 16]. This reflected the previous alarm calls that arose by scientists all around the world to be aware of the causes of the degradation of lakes [17]. ISL were one of those most negatively affected by desiccation due to water diversion and abstraction in their watersheds. Other negative impacts included pollution, salinization, direct occupation of the lake’s shores by urban developments and mining activities. Also, global climate change has been reported as a major factor causing a general decrease in the water level of many lakes [18].

In some way, these papers reflected the ideas of others who described the degradation of salt lakes globally during the last decades of the twentieth century and anticipated a deficient ecological state for the first decades of the twenty-first century [19, 20]. During the last two decades, concern about the state of ISL increased simultaneously with the awareness of the environment in general after the Rio Declaration on Environment and Development and the Sustainable Development Declaration of the United Nations in 1992 and 2015, respectively, and the successive reports of the International Panel for Climate Change, all of them demonstrating the relationships between human activities and degradation of the environment and suggesting new models of development based on the preservation of natural resources.

This work follows a similar trail as in the above-mentioned papers to discuss the likely status of salt lakes by the mid-twenty-first century. The projection to 2050 is an ideal figure just to define a period long enough to observe changes in the status of salt lakes. A literature review is done to ascertain major topics of interest of authors with respect to the conservation and management of salt lakes. Then, following Bill’s footprints, the likely status of salt lakes is discussed after a driver-pressure-state-impact-response route. Finally, new paradigms for the management of salt lakes are presented using a few well-known lakes as case studies. Here, we focus on athalassic inland salt lakes, although a few inland thalassic lakes are quoted as examples of the specific issue. Coastal lagoons are not considered here, as they are driven by processes linked to coastal and marine hydrodynamics, which are quite different from those regulating inland salt lakes.

2. Literature review

Vosviewer, a visualization software [21], was applied to a series of 299 documents (papers published in scientific journals and proceedings of congresses) obtained from Web of Science using the searching terms “salt lakes”, “conservation” and
The revision of scientific publications showed that just a few words were most frequently used to refer the topics of interest: salinity (and its related words plants, water, diversity, growth, wetland and salt), saline and salt lakes (and its related words

“management” on 15 July 2021 for the period 1992–2020 after removing from the initial list of 432 documents obtained those not related to inland salt lakes.

The revision of scientific publications showed that just a few words were most frequently used to refer the topics of interest: salinity (and its related words plants, water, diversity, growth, wetland and salt), saline and salt lakes (and its related words

Figure 1. Visualization maps generated by Vosviewer showing: Six major clusters of topics of interest in the study of inland salt lakes after the literature review (above); relationships between authors and papers published by most cited authors (below). Each cluster is represented with a different color; the font size of the nodes in the graph represents the relative frequency of occurrence or both topics, above and authors, below.
biogeography, zooplankton, crustacea, tolerance and biomass), evolution (and its related words basin, origin, groundwater, system and geochemistry), inland waters (and its related words shallow, climate change and remote sensing). A few other words – taxonomy, genus nov., sp. nov., prokaryotic diversity, gradient – were also less frequently used as representative of topics of interest in papers on inland salt lakes. Many other words were much less frequently used to simplify the relevant subjects of scientific papers dealing with inland salt lakes (e.g. nutrient, salt tolerance, eutrophication, branchiopoda, habitats, identification, desert, archaea and hypersaline environments).

These six groups of words corresponding to topics of interest in the study of ISL are represented in the Vosviewer visualization map in Figure 1. It is remarkable that the most outstanding author in the set of publications selected with this literature review is (Bill) Williams (Figure 1), pioneer in the study of inland salt lakes who was promoting their knowledge and conservation all around the world for many years. Following his wake, many other authors later reviewed the state of inland salt lakes.

3. The conservation of inland salt lakes and their status in 2025

The driver-pressure-state-impact-response (DPSIR) approach is a causal framework to describe the interactions between society and the environment developed by the European Environment Agency [22]. Data and information on the five steps are collected from the scientific literature, official conservation departments and Internet linked. Here, the DPSIR analysis is applied generically for ISL in general (Table 1). A special emphasis is devoted to lakes previously reviewed by Bill Williams [20] and other authors to comment on their management progress and their likely status in 2050.

Burning fossil fuels, which is the major cause of global climate change, is related to the decrease of the water level of many lakes and, consequently, increased desiccated periods (both frequency and duration) and related impacts as increased penetration of ultraviolet radiation. A few lakes in Pakistan are examples of this case, with reduced habitat representativeness and biodiversity and altered life cycles of aquatic species [23]. Many other ISL have been referred to with decreasing water levels related to climate change [18, 24–26]. The relationship between climate change and inland water shrinking is common in many lakes around the world [27, 28]. However, a detailed water budget is needed to discern the relative contributions of climate variability and human impacts on lake inflows [14].

Land cover and land use changes in the watershed are major drivers of changes in the state of ISL. Their pressures include alteration of surface and groundwater flows and, consequently, affect the water cycle and impact both the quantity and the quality of the water in the lakes, as well as alter its salinity and habitats. The expansion of irrigated agriculture is the origin of decreased water levels, water quality degradation and biodiversity loss in many lakes around the world. Aral, Mono, Dead Sea, Qinghai, Corangamite, Winnemuca and Owens are ISL submitted to these impacts caused by changes in land cover and land use changes in their watersheds with changes in water uses.

The Aral Sea has been one of the most cited closed lakes impacted by diversions of surface freshwater inputs to irrigate new developments of agriculture, which caused a catastrophic water level decrease and took the lake state to collapse. In contrast,
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<table>
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<td></td>
<td>Increased water levels and salinity</td>
<td>Altered water cycle Reduction of characteristic habitats.</td>
<td>Lowered water level. Increased salinity. Water hyper-salinization</td>
<td>Aral, Mono, Pyramid, Dead Sea</td>
</tr>
<tr>
<td></td>
<td>Increased sediment loads</td>
<td>Increased salinity. Addition of halotolerant community one</td>
<td>Secondary (anthropogenic) salinization Replacement of biological communities Decreased biodiversity</td>
<td>Lake Pyramid</td>
</tr>
<tr>
<td></td>
<td>Loss of lake area and habitats</td>
<td>Decreased esthetic, scientific values Pollution</td>
<td>Loss of lake area</td>
<td>Great Salt Lake</td>
</tr>
<tr>
<td></td>
<td>Biological disturbances</td>
<td>Altered trophic structure Elimination of species, changed community</td>
<td>Rottnest Island and Lake Hayward// Caspian Sea</td>
<td></td>
</tr>
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</table>

Table 1. The DPSIR approach applied to ISL reminiscing some of the lakes discussed by Bill Williams.
the water level of the Caspian Sea, the largest in the world endorheic saline lake, has steadily increased. These two lakes are just 500 km far from each other. However, they contrast with respect to water management in the watershed. The withdrawal for irrigation is 90% of the water resources of the Aral watershed, which occupies a semiarid territory, and just 10% of the water resources in the watershed of the Caspian Sea, which occupies a temperate territory [29].

Clearance of the natural vegetation is another driver who causes increased sediment loads and altered runoffs in ISL. A management strategy is being developed in the Truckee River Watershed (Nevada, USA) to reduce sediment loads and improve the water quality of the water inflowing Lake Pyramid. It includes the restoration of riparian, aquatic and wetland habitats and planning new urban and rural land cover changes to avoid easily erodible areas [30].

Urban development in the lake shores and watershed is a driver causing decreased lake area. This is also a relevant driver-pressure factor affecting Great Salt Lake since the early 1900s. Diversion of water inflows, constructed infrastructure in the lake, and dust storms from desiccated areas are also key pressures not only for the lake state but also for the human population living near the lake [31]. Similar actions dominated the degradation of Salton Sea (California, USA), an artificially created ISL over old marine deposits which receives huge amounts of pollutants (nutrients, pesticides) used in agricultural activities in its watershed [32].

Mining is also a major driver in those ISL where mineral extraction, mostly linked to evaporative deposits, takes place. Extraction of salt deposited in the lakebed to obtain salt itself or metals associated with the salt (e.g. lithium) causes loss of the water quality. This is the case for the lakes located in the Qaidam Basin in Tibet and Qinghai Basin in China and in the Andean’s plateau [33, 34].

Invasive alien species trigger biological disturbances and alter lakes’ trophic structure, as it happened in Caspian and Aral Seas after the introduction of fish for commercial purposes [27]. The consequence is a changed biological community, including the disappearance of key species. In many cases, the introduction of alien species was not successful because they did not adapt to the environmental conditions of salt lakes. However, some species were able to acclimatize and had significant impacts on native populations. This is a major aspect to consider while trying to manipulate the water level and inland salt lakes’ water salinity.

The conclusion is that there are big differences between ISL with respect to their ecological states. In those countries where their natural resources are highly appreciated, the status is good or, at least, there is a major concern to preserve all their values and to establish regulations to combine a rational use of their resources. In Europe, where ISL are relatively small, there are European regulations to preserve their biological populations and their habitats. They all are part of the network of sites so-called Natura 2000. Similarly, the status of those ISL under a formal protection regulation is good, although some threats persist. This is the case of many lakes in North America and South America: Mono Lake (California, USA), Lake Manitou (Saskatchewan, Canada), Laguna Colorada (Potosi, Bolivia), Mar Chiquita (Cordoba, Argentina), Alchichica (Puebla, Mexico). Advisory or management committees and plans have been established, and some actions are already planned and/or implemented to improve the ecological state of many ISL lakes and their human populations living in the lake shores and watersheds. Nevertheless, the general feeling is that the process of improving their ecological state has been too long for many ISL and that a successful implementation of actions remains to be seen.
4. The likely status of inland salt lakes by 2050 and beyond

A major challenge for improving ISL’s ecological state is integrating economic, environmental and social aspects under an efficient governance plan for their management. Such type of plans has been written and implemented for a few lakes but are still missing for many others.

Mono Lake (California, USA) is an excellent example of this approach. Legal protection as a nature reserve was established in 1981, and as scenic area in 1984. A regulatory programme to decrease water diversion from the lake basin was established, and the lake water level was recovering. Also, restoration of degraded streams and lake habitats was performed and, even more, Los Angeles City started a programme to use water more efficiently. The groups promoting the conservation of Mono Lake extended similar programmes for the rational use of water throughout California. However, recovery of the original water level did not proceed as predicted by the hydrologic model, and large areas of the lake shore remain dry. Then, windblown dust causes health problems because of the high concentration of particles in the air, which do not meet the federal PM-10 standard (as in other ISL in North America, Asia and Australia). The challenge now is updating the hydrologic model to achieve a lake water level that does not cause this impact, which will also improve the lake shore habitats and the ecological state of the lake [35].

Aral Sea (Kazajistan/Uzbekistan) still shows a high degradation since the diversion of water from the two major rivers (which also drain areas of other five countries) inflowing water to the lake started promoted by the old URSS before the 1960s. At that time, the natural resources of the Aral Sea were not considered valuable to be protected, neither those in the central Asia desert which was irrigated with the diverted water for agricultural production. After the 1990s, two countries are responsible for the administration of the lake: Kazajistan for the North part and Uzbekistan for the South part. The Kazajistan Government constructed a dam separating both parts of the lake in 2007, and the water level is recovering with improvements in the irrigation system. Further efforts of local groups and international collaboration (both scientific and financial) are contributing to the recovery of fisheries and habitats of the lake. However, corresponding actions have not been implemented in the south part, and degradation progresses with the full desiccation of most of this south part of the lake. Despite the orientations provided by scientists for possible restoration actions to improve the state of Aral Sea [36], the lack of agreement between the two countries managing the lake watershed and others in its watershed is a handicap for the recovery of the Aral Sea. A common plan for these territories could contribute to their sustainable development if the preservation of the Aral Sea values is included.

In 2000 an intergovernmental agreement was signed between two Australian states to maintain the important environmental, social and economic values of Lake Eyre. Later, a collaborative work participated by authorities, environmental groups, local communities and scientists extended the agreement for the sustainable development of the whole lake watershed. All the drivers and pressures listed in Table 1 are present in Lake Eyre Basin. A very comprehensive plan is applied and renewed every 5 years. It includes the preservation of water flows in the watershed and integrating aboriginal culture and knowledge, promoting a diverse economy adaptable to the effects of climate variability and change [37]. An important point of this plan is that reports of the monitoring and evaluation of the plan actions and
lake and basin status will be delivered regularly under the intergovernmental agreement established. These are three examples of the great variety of management practices of inland salt lakes. Those ISL with an integrative management plan and a governance structure for its implementation will have more changes to improve their ecological state.

In any case, climate change impacts and will continue impacting ISL. As they are in arid and semiarid zones, the increasing global temperature enhances evaporation and evapotranspiration. So, a long-term decreasing trend for the water level is observed in many ISL [18, 27, 38]. However, the rainfall pattern is also changing all around and more intense seasonal and interannual patterns (heavier and shorter rainfalls) are being observed in contrast to previous regular longer rain seasons [39]. This climate change feature can negatively affect the biota of a temporary ISL if it dries soon after the rain and there is not enough time for the biota to develop its life cycles, as suggested previously [20]. Also, it can affect positively to temporary ISL with a marked desiccation trend because they will stay flooded for longer periods of time or more frequently within the framework of the long-term water level decreasing trend. However, background climate variation often masks long-term trends in environmental variables, which must be disentangled through robust statistical analysis to attribute lake water level variations to different causes [40].

Revisiting some of the suggestions by Bill Williams and others, Table 2 shows a few examples of drivers of change for ISL and the responses which would be useful for the improvement of their ecological status.

The first and most important aspect for the management of ISL is considering the management of the lake and its watershed as just one ecosystem. Most of the impacts originated after actions in the lake basin. So, the solution must start by acting in the watershed. Planning and implementing a balanced provision of different ecosystem services in the watershed, covering the human population demands and developing the plan with the information and participation of the population is the first step for the sustainable development of the territory preserving the lake. If this is not incorporated in the management of ISL watersheds, the impacts of land cover and water use changes will continue, and the improvements derived from actions in the lake will not be successful in preserving the natural values of the whole ecosystem.

The perception of the functions and values of ISL is changing all around the world with status of protected sites and conservation and restoration measures already established in many countries of Europe, America and Australia. Even more, many inland salt lakes already have a strategic management plan which includes the ordination of land cover and efficient water use in the watershed. Obviously, this type of plans requires establishing benefits for the local population or facilities to incorporate environmental practices in their current activities. In addition to those cases mentioned above, there are examples of these management practices in China (Lake Qinghai) and Africa (Lake Bogoria). However, one additional requirement for the successful implementation of such type of plans is good communication between stakeholders. This requires mechanisms of participation of local communities to set up the management plan and transparency for the implementation. If all these aspects are not considered in the management plan, the improvement of the ecological state of the lake will not be ensured.

There are examples of ISL with protected status where conservation actions did not progress because of failings to agree such management plan. In Lake Torrens (Australia), an episodic closed lake declared national park, mining operations approved by a local authority were prohibited by the Court of Justice under demand
from a local aboriginal community because of damages to cultural sites. This is an example of the need to integrate social aspects while managing ISL. In this case, the conservation of the ISL will benefit from the resolution of the conflict of interests.

Lake Nakuru (Kenya) is well-known for its impressive populations of hippos and flamingoes, which thrive on a simple and very productive trophic web based on micro-algae and microcrustaceans. It has been a national park since 1961 but also well-known after the dramatic decrease in flamingoes and fish mortality caused by contamination alerted in the 1970s [41]. Pollution by non-treated wastewater from increasing tourism and the local population, heavy metals from a growing industry and pesticides from expansive agricultural activities [42] jeopardize the conservation of the lake values. Furthermore, siltation caused by deforestation (the basin area covered by natural forest decreased from 47% in 1970 to 8% in 2021) and bad farming practices increased the lake water level, which expanded 60% of the area flooded, impacting the riparian ecology and displacing wildlife, the road network, staff houses, office blocks, electric fences and campgrounds, as well as increasing occurrences of human-wildlife conflict.

The watershed approach – most of the environmental threats are originated in the watershed – is not included yet for the management of many ISL. New delimitations of protected areas incorporating key functional zones of the lake’s watershed must be integrated for protection and restoration. For this purpose, integrating the evaluation of ecosystem services [43] is a practical tool to define zones of interest for the ordination of land cover and land uses in spatial planning at a watershed scale. The conservation and management of an ISL can have success if the social, economic and environmental requirements of the whole watershed are satisfied in an integrative way, as socio-ecological system. Additionally, a governance structure must facilitate the participation of stakeholders based on an excellent information system of the lake values and watershed capacities.

The scenarios for the ecological state of inland salt lakes in the future can be outlined by contrasting the effects of climate change (only alternative rainfall is considered as the prediction for temperature is a global increase for the next 30 years, at least) and land cover and water use in the watershed, the two main drivers for the ecological functioning of the lakes (Table 3). In general, increased rainfall is not predicted to occur in semiarid and arid zones, but more intense rains and snow events have been observed affecting inland salt lakes [39]. However, warm temperature extremes have also increased, while cold temperature extremes decreased, enhancing evaporation and evapotranspiration, diminishing the water in both the watershed and the lake. Intensification of land cover change and water use diminishing natural habitats will continue the degradation of the lake, whatever the rainfall pattern change. In contrast, a rationale distribution of land cover and water use in the watershed will buffer the impacts of climate change in the lake and, consequently, a relative improvement of the ecological state of the lake will be observed if rainfall decreases or a clear improvement will take place if rainfall increases.

Under these circumstances, the only way to improve the ecological state of an ISL is implementing a sustainable development programme to re-organize watershed land covers and water uses reducing the driver-pressures causing negative impacts in the lake. If this is implemented, restoration of degraded sites in the lake can proceed successfully.

During the present century, new paradigms and approaches have been developed for the management of ecosystems, which are useful for improving the ecological state of ISL. Integrative management plans are useful if implemented at watershed-lake scale with the participation of local communities. For this purpose,
The evaluation of ecosystem services let to define land cover and uses and, finally, a watershed land cover consolidation providing benefits for socio-economic interest and for conservation purposes satisfying the interest of all the stakeholders [44].

A good knowledge of the natural values and processes in the lake and watershed is essential for its management. The essential point is to have a detailed water budget because it lets us know the key inflows and consumption processes of water in the watershed and the lake. Then, management decisions can be taken accordingly to the critical points of the water budget [14]. However, both a short and long-term perspective of the water level changes must be considered as the relative importance of background climate oscillations in ISL remains uncertain and often masks long-term trends in environmental variables but can be accounted for through more comprehensive statistical analyses [40].

<table>
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<th>Responses</th>
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<tbody>
<tr>
<td>Climate change</td>
<td>ISL in general</td>
<td>Adaptive management of land and water use in the watershed</td>
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<tr>
<td>Expansion of irrigated agriculture &amp; other water uses in the watershed (urban wastewater discharges)</td>
<td>Aral, Mono, Pyramid, Dead Sea Qinghai, Corangamite, Winnemuca, Owens</td>
<td>Inter-basin collaboration for socio-ecological development. Spatial re-ordination of land covers &amp; land uses. Afforestation (reduced water consumption)</td>
</tr>
<tr>
<td>Agriculture irrigation by groundwater pumping in the watershed and inter-basin water exchange</td>
<td>Lakes in Salt Range (Pakistan)</td>
<td>Land cover &amp; Land use reclassification</td>
</tr>
<tr>
<td>Clearance of the natural vegetation and other land use changes in the basin</td>
<td>Lake Pyramid</td>
<td>Reforestation/Restoration</td>
</tr>
<tr>
<td>Soil erosion in the catchment after deforestation and land consolidation</td>
<td>Lake Gallocanta</td>
<td>Restoration</td>
</tr>
<tr>
<td>Urban development in the catchment and lake shores</td>
<td>Great Salt Lake, Lake Nakuru</td>
<td>Urban planning at watershed scale, avoiding taking up the shores of the lake.</td>
</tr>
<tr>
<td>Mining</td>
<td>Lake Poopo (water diversion for mining and agriculture &amp; climate change)</td>
<td>Socio-ecological plan after ecosystem services evaluation &amp; adaptation</td>
</tr>
<tr>
<td>Exotic species in the lake</td>
<td>Caspian Sea (fish species, invertebrates, introduced)</td>
<td>Removal of invasive species/ Restoration of degraded habitats</td>
</tr>
</tbody>
</table>

Table 2.
Revisiting some of the ideas by bill Williams and others suggesting actions to improve the ecological status of ISL.

<table>
<thead>
<tr>
<th>Intensification</th>
<th>Rationalization</th>
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<tbody>
<tr>
<td>Climate change</td>
<td>Decreased rainfall</td>
</tr>
<tr>
<td></td>
<td>Increased rainfall</td>
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Table 3.
Likely trends of the ecological state of ISL under different scenarios.
Of course, trophic web changes in relation to the water level fluctuations are essential information to know the full spectrum of biodiversity of ISL [45]. This includes the distribution of habitats and communities on the shores of the lake, which also fluctuate as the water level markedly changes [46]. This is fundamental information to anticipate climate change and adopt a strategy to counteract its impacts.

5. Lake Gallocanta as a case study

Lake Gallocanta (22 km², watershed 520 km², located at 1000 m.a.s.l. at 40° 50’ N, 20 11’ W in Central Spain) is a closed temporary (maximum water column recorded 250 cm in 1974) salt lake characterized by seasonal and interannual fluctuations of the water level with a return period of 0.3–2.4 years [47]. The lake and 15% of its basin around it were declared protected (Natural Reserve) by the regional Government in 2006. It is a site with natural habitats, vegetation, and animals, protected by the European Union and a Ramsar site.

Lake Gallocanta has two major drivers-pressures in common with many other ISL. Climate change is the major pressure as it has been observed a long-term water level decrease [48], including more frequent desiccated periods during the second half of the twentieth century [49]. Only 1% of the potential water input to the lake is used for irrigation in the watershed [50]. Deforestation for agricultural purposes took place in the mountains surrounding the watershed five decades ago. During the last years, land reparation promoted to favor agricultural production has been implemented in most of the municipalities around the lake eliminating hedges and banks, and favoring soil erosion. Also, most of the groundwaters are contaminated by nitrates after years of fertilizing agricultural crops with pig slurry.

The lake maintains a good ecological state, although there is not a current evaluation beyond bird census and reports about the spatial distribution of species and habitats of interest. Recently, an increasing frequency of filamentous algae blooms and oxygen depletion in some parts of the lake bottom linked to heavy rains inflowing suspended solids and nitrates to the lake has been observed. The recently changed rainfall pattern [51] with more intense rainfall events maintains the water fluctuating at a critical intermediate level and salinity. At this stage, a short water level fluctuation significantly changes the trophic structure, which is part of the lake dynamics. The key point is to value all the facies of the lake and their fluctuations in accordance with the natural lake

Figure 2.
Changes in the major aspects considered for the management of Lake Gallocanta and its watershed since mid-twentieth century.
dynamics, which in the case of Lake Gallocanta requires desiccation periods following Langbein hydro-ecological model [52] to show all its biodiversity through time.

In the case of Lake Gallocanta, while most of the management attention is devoted to bird populations and bird-watching activities by visitors, a management action plan has not been established yet because of disagreements between farmers and regional Governmental administrators. An erratic management has been taking place with alternative emphasis on different aspects and controversial practices between agricultural and biodiversity measures, although funds provided by the European Union have been given to stimulate agricultural practices in accordance with nature since the mid-twentieth century and for the restoration of natural habitats recently (Figure 2).

The history of management of Lake Gallocanta is a paradigm for other lakes. The lack of integration of environmental, social, economic aspects and, overall, lack of governance capacity is a handicap for the conservation of the lake values in the long term. The human population has decreased strongly since the mid-twentieth century, but the economic status of the remaining population did not improve compared to those living in cities. Alternative activities such as tourism or manufacturing did not start up significantly. In addition to specific restoration actions to recover and maintain natural habitats, a management plan integrating the three aspects for the sustainable development of the watershed, including lake conservation, with the participation of local people in the governance programme, is required for the improvement and conservation of the ecological state of the lake.

6. Conclusions

Degradation of ISL progresses all around the world as a consequence of, mostly, impacts originated by land cover and water use changes in the watershed, mining operations and urbanization of lake shores. The status of ISL will improve if management plans are established integrating environmental, social and economic aspects at watershed scale and an efficient governance protocol to implement the management plan. Land cover reparcelling and a rational distribution of water should be part of the management plan. Adaptive management practices in the watershed are required to buffer climate change impacts. Continuous control of the lake’s physical, chemical and biological conditions will provide the required information for the evaluation of their status and innovation of the management plan.
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