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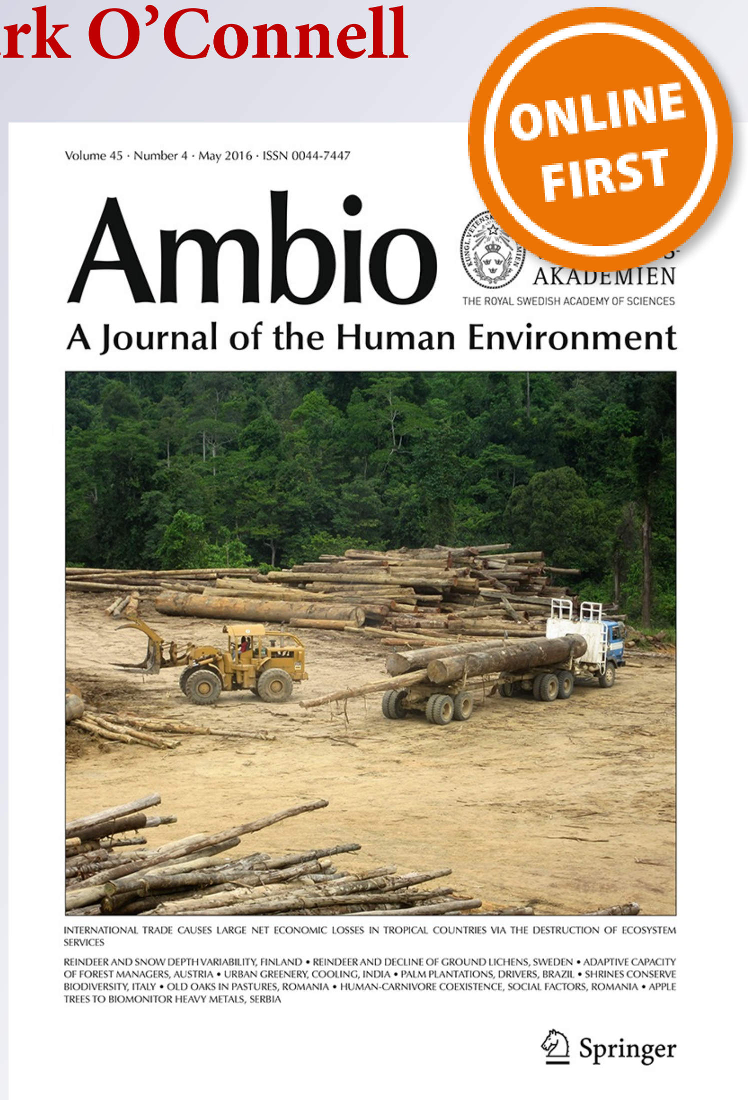

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PERSPECTIVE

An overview of wetlands of Saudi Arabia: Values, threats, and perspectives

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Abstract The wetlands of Saudi Arabia are located in a water-stressed region that is highly vulnerable to climate and other global changes. Sebkhas, mudflats, mangroves, and wadis are the dominant wetlands in the arid regions of North Africa and the Arabian Peninsula. These unique wetlands are recognized as a sanctuary for biodiversity and for their economic services generated from mineral extraction, agriculture, and grazing. Despite their ecological values and societal services, the long-term permanence of Saudi Arabia's wetlands faces strong challenges resulting from human activities associated with sustained population growth, habitat degradation, and coastal development. This paper consolidates a literature review of Saudi Arabia's wetlands from local to global importance, highlights their biodiversity, and identifies threats and evolution of these vulnerable ecosystems in the arid Arabian Peninsula by focusing on the status of key freshwater taxa (Odonata, freshwater fishes, amphibians, and waterbirds) and documenting changes affecting important wetlands.

Keywords Conservation · Environment · Global changes · Management · Saudi Arabia · Sustainable use · Wetlands

INTRODUCTION

Changes to the global environment are being mediated through multi-scale alterations to climate and land use (Chapin et al. 2000; Oliver and Morecroft 2014). Habitat loss, degradation, and fragmentation, in addition to invasive species and pollution, are significantly impacting ecosystem services and human health and well-being (Brook et al. 2008; Willis and Bhagwat 2009). Habitat loss and degradation are major drivers of biodiversity erosion, and a warming climate and changes in rainfall patterns are expected to impact a broad range of current ecosystem services and significantly reduce biodiversity as species fail to adapt to climate change (Barnard and Thuiller 2008; Ohlemüller et al. 2008).

Among ecosystems, wetlands are recognized as being essential to sustainable development and human welfare due to their environmental, social, and economic value. Wetlands are also highly vulnerable to global environmental changes through alterations of their hydrological regimes, and these changes can threaten the conservation of wetland-dependent species and their associated habitats (IPCC 2007). Global changes will most likely induce significant modifications to wetlands over the coming decades (Long et al. 2007). Mangroves, intertidal mudflats, and saltmarshes are coastal ecosystems under increasing pressures from rising sea levels, overexploitation, and habitat destruction (Linden and Jernelov 1980; Valiela et al. 2001; Adam 2002; Bromberg Gedan et al. 2009). These natural infrastructures provide many ecosystem services such as extreme weather buffering and nurseries for fish (Ronnback 1999). Through changes in land use, pollution, the burning of fossil fuels, and the spread of exogenous species, human activity is gradually modifying the Earth's climate, and these modifications have dire consequences for biodiversity and human health and welfare (Daily and Ehrlich 1996; Ricciardi 2007; Mooney 2010).

In the Arabian Peninsula, water is scarce and valuable, and Saudi Arabia has undergone substantial changes in land use over the past few decades. These changes have been driven by sustained high economic growth and unparalleled levels of population growth and urbanization (Collymore 2003, UN Population Division 2016). These changes have heavily impacted and degraded many of the Kingdom's natural habitats, posing a challenge to the sustainable use of natural resources (Sheppard et al. 2010). At present, there is no general information regarding the overall status and trends of wetland resources and biodiversity in the Kingdom of Saudi

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Arabia, nor a quantitative and spatially referenced baseline against which to measure future change. Little research has been undertaken to understand and communicate the essential services provided by Saudi Arabia's wetlands and the need for their sustainable use and conservation. Previous surveys of particular taxonomic groups are in urgent need of updating (Tinley 1994; Newton 1995). Some data exist for individual sites and areas or taxonomic groups, but such information is often not accessible. Yet, there is a growing awareness of the importance of conserving these ecosystems in the context of rapid global changes. By becoming signatory to the Convention on Biological Diversity (CBD), the Ramsar Convention and numerous other multi-lateral treaties and protocols, the Kingdom of Saudi Arabia has taken steps to prevent the abuse of its limited stock of natural resources and to sustain them and their benefits for the future. Whereas these ecosystems have elsewhere attracted a wide body of research, very few investigations have been carried out locally. This review, focused on the wetlands of Saudi Arabia, attempts to fill this gap.

VALUES AND ECOLOGICAL SERVICES OF WETLANDS

For thousands of years, people have depended on wetlands which may constitute important archeological archives (Coles and Coles 1989). According to the Ramsar Convention (1971), "wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters."

Wetlands provide essential habitats for many plant and animal species and sustain numerous commercial and recreational fisheries; thus, wetlands and in particular, coastal systems, have been considered among the most productive and valuable ecosystems on Earth (Keddy 2000). Wetlands have also played a major role in the subsistence agriculture of oases, which have a long history of date palm cultivation (Newton 1995). Humans have constructed reservoirs for thousands of years for water supply and irrigation. Dams play also key roles by generating hydropower, controlling floods, and providing fishing and recreational activities (Lehner et al. 2011).

SAUDI ARABIA'S WETLANDS

A typology of Saudi Arabia's wetlands

Despite its extremely arid climate, the Kingdom of Saudi Arabia, which is the largest country on the Arabian Peninsula, harbors a broad spectrum of wetland types (Newton 1995), which have been classified into eight distinct wetland systems (Tinley 1994):

1. Coastal systems, including freshwater marshes, mangroves, coral islands, and mudflats.
2. Dunefield systems, including minor aquifer seeps.
3. Sebkha systems, including continental lagoons or salt lakes.
4. Karst systems, which are aquifer-fed karst crater lakelets.
5. Mountain systems, including various seeps and marshes in volcanic areas.
6. Geothermal systems, including springs confined to southern Tihamah.
7. Wadi systems, including intermittent streams and perennial rivers.
8. Man-made systems, including dams and reservoirs as well as outflows from sewage treatment plants.

Some of the wetlands in Saudi Arabia, such as coastal areas surrounding the Arabian Peninsula, are considered to be among the most productive and diverse marine ecosystems in the world. They support major fisheries as well as internationally important populations of breeding seabirds and wintering shorebirds (Ormond et al. 1984; Symens and Evans 1993; Perennou et al. 1994; Newton and Al Suhaibany 1996; Wetlands International 2012). They play a key role in ecological processes, and they have provided local communities with goods and services (e.g., food and protection against floods) for millennia. The biological diversity of these ecosystems has supported numerous civilizations in and around the Arabian Peninsula, and this natural resource has spun a delicate web of inter-dependence among people and other living organisms. Despite this inter-dependence, the Arabian Gulf (from now on referred as the Gulf) and, to a lesser extent, the Red Sea coasts are among the most threatened ecosystems in the region and are subject to many pressures associated with modern development (Sheppard et al. 2010; Sale et al. 2011). In arid regions, agricultural extension and intensification often lead to an overuse of the ground water due to the multiplication of boreholes (Demnati et al. 2012). Noteworthy is the loss of the Laila Lakes at Al-Aflaj in central Arabia, the last Pleistocene lakes in Arabia. This lake complex, fed by an underground karst system, was a sanctuary for breeding waterbirds and a stopover for migrant birds crossing Arabia (Jennings 2010). Starting from the late 1970s, the water levels of the lakes dropped following the increase of water wells drilled for irrigation schemes. By 1995, the lakes dried up completely and, with their demise, went the damselfly *Azuragrion vansomereni*, known from only that locality in Saudi Arabia and now considered Regionally Extinct (RE) in the

Arabian Peninsula (Krupp et al. 1990; Kempe and Dirks 2008; Jennings 2010; Schneider and Samraoui 2015).

Focus on specific wetlands

Jizan (16°55′01″N, 42°32′33″E), on the southern Saudi Arabian Red Sea coast

Along the coastline of the Gulf and the Red Sea, especially the sheltered areas around Jizan, there were vast expanses of mudflats which were highly productive intertidal habitats composed of microbial mats, plankton, molluscs, polychaete worms, crabs, fish, and animal detritus (Raffaelli and Hawkins 1996). These large expanses of highly bio-productive mudflats are used by millions of waders for migration refueling and roosting (Wolff 1969; Baker and Baker 1973). Over the past decades, Saudi Arabia, like other Gulf countries, has experienced extensive coastal development leading to the disappearance of coastal ecosystems (Fig. 1) or to their degradation by numerous anthropogenic stressors (Sheppard et al. 2010). These extensive habitat alterations have coincided with other global changes and have concurred to a worldwide decline of waders (Rehfish and Crick 2003; Baker 2006).

Wadi Hanifa (24°35′36″N, 46°42′33″E), El Hair, Riyadh

Rapid urbanization and population growth have characterized the relatively recent history of Riyadh, the Kingdom's capital located in the arid Najd Plateau, and this trend is likely to persist in the future (UN Population Division 2016). Wadi Hanifa, the major river of the region, drains the eastern slopes of the Tuwaiq Mountain and is the receptacle of the treated waste water and industrial effluents. The wadi is an important sanctuary for wildlife, especially migratory birds which use this wetland as a stopover during their journey through the Arabian desert (Stagg 1991). In recent years, the worsening of the ecological integrity of Wadi Hanifa has spurred authorities to initiate a large-scale environmental rehabilitation program with the construction of a Bio-remediation Facility aimed at improving the water quality of the wadi through natural processes (Fig. 2). The facility includes bio-remediation cells, aerating pumps, artificial periphyton, and fish. As part of the same project, a series of parks have been set up, supporting recreational activities (Moosavi et al. 2015). This wetland landscape is possibly an architectural success, having won the prestigious Aga Khan Award for architecture; it is, however, a river restoration remote from Hogarth's line of beauty (Podolak and Kondolf 2015), and wildlife was certainly left at the losing end (Jennings 2010).

Wetland biodiversity of Saudi Arabia

Focus on indicator taxa

Considerable information regarding the biodiversity of the Kingdom of Saudi Arabia has been accumulated over the last several decades (Krupp et al. 1990; Waterston and Pittaway 1991; Perennou et al. 1994; Jennings 2010), but more discoveries are expected in the future. An adequate baseline knowledge of the status of the biodiversity of wetlands and services will be invaluable, as the implementation of sustainable development strategies requires a complex combination of ecological, social, and economic considerations. Regional and national databases, atlases, and Red Lists are useful management tools in need of development. Odonata, waterbirds, amphibians, and fish are intimately linked to wetlands and relatively easy to survey and monitor; thus, they are appropriate candidates as indicators for use in monitoring the effects of climate or other changes on population dynamics. These changes may reflect population declines in wetland species that lack adaptability. Species that lack phenological adaptability and resilience, behavioral changes, or fail to respond through dispersal due to habitat fragmentation will experience greater stress and may eventually become extinct. Here, we will briefly survey the state of current knowledge for these four taxa (Odonata, freshwater fishes, amphibians, and waterbirds):

Odonata

Dragonflies have been called "*guardians of the watershed*" (Clausnitzer and Jödicke 2004), as they are dependent on water and highly sensitive to changes in their habitats. Anthropogenic alterations of wetlands in an arid region such as the Arabian Peninsula are likely to affect the community structure of dragonflies. Regular surveys can provide baseline data for long-term monitoring of ecological changes and prove invaluable in the development of any future conservation strategies. The Odonata fauna of the Arabian Peninsula was hardly known to science before the mid-twentieth century, and the first specimens were collected by Bertram Thomas before he made his historical crossing of the Rub' Al Khali (Longfield 1932). Knowledge was accumulated gradually during the second half of the past century, and the Odonata fauna of Saudi Arabia received increased attention following a series of expeditions (Buttiker and Wittmer 1979; Abo-Khatwa et al. 1980; Buttiker 1979, 1980a, b, 1981, 1983) and dedicated endeavors by various odonatologists (Waterston 1980, 1984; Schneider 1987; Waterston and Pittaway 1991; Schneider and Krupp 1993). A total of 41 species of Odonata have been recorded for Saudi Arabia with one

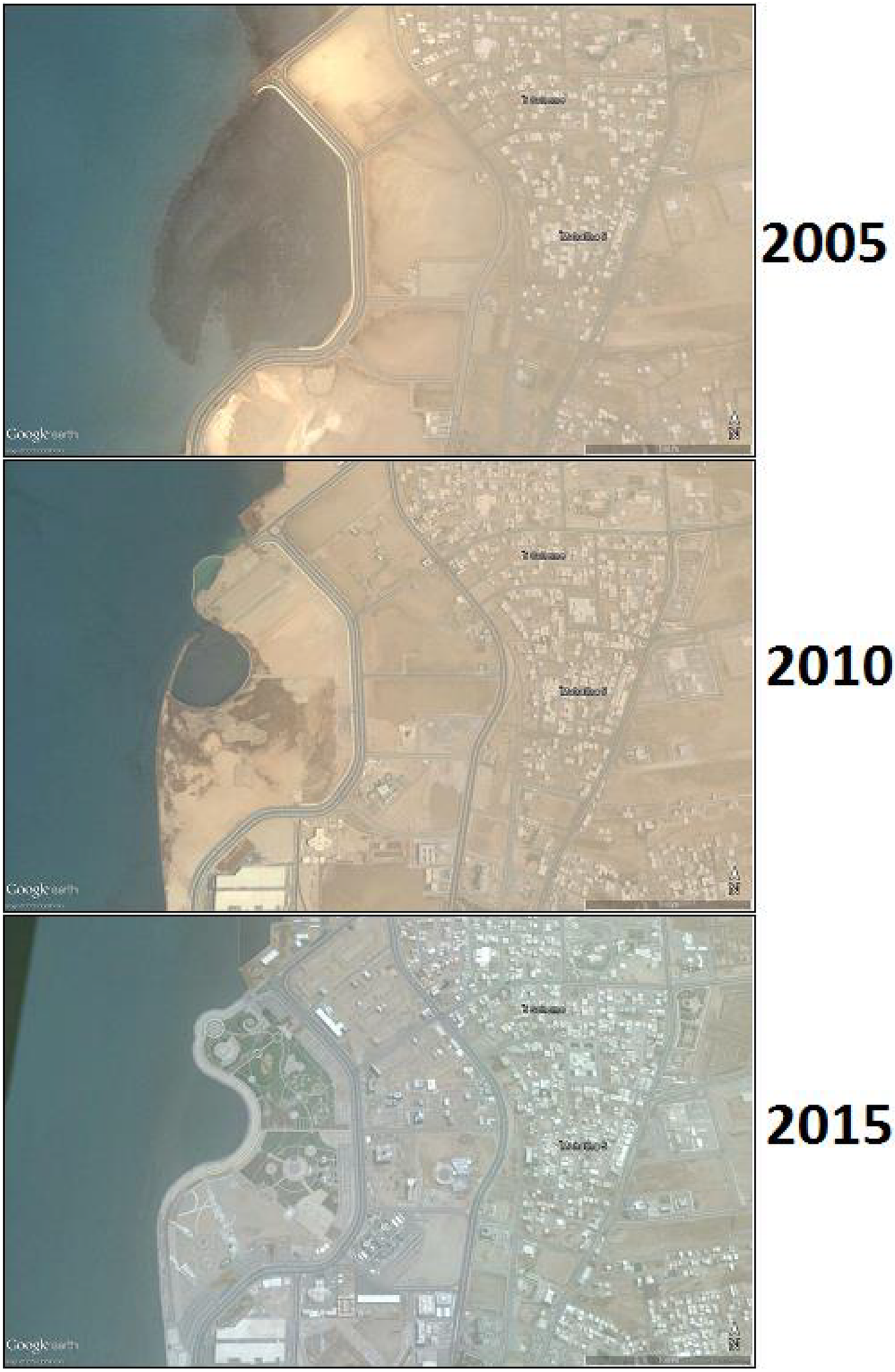

Fig. 1 Satellite view (Google Earth 2016) of the development of Jizan coastal wetlands on the southern Red Sea coast, illustrating the construction of the North Corniche Park, 2005 to 2015

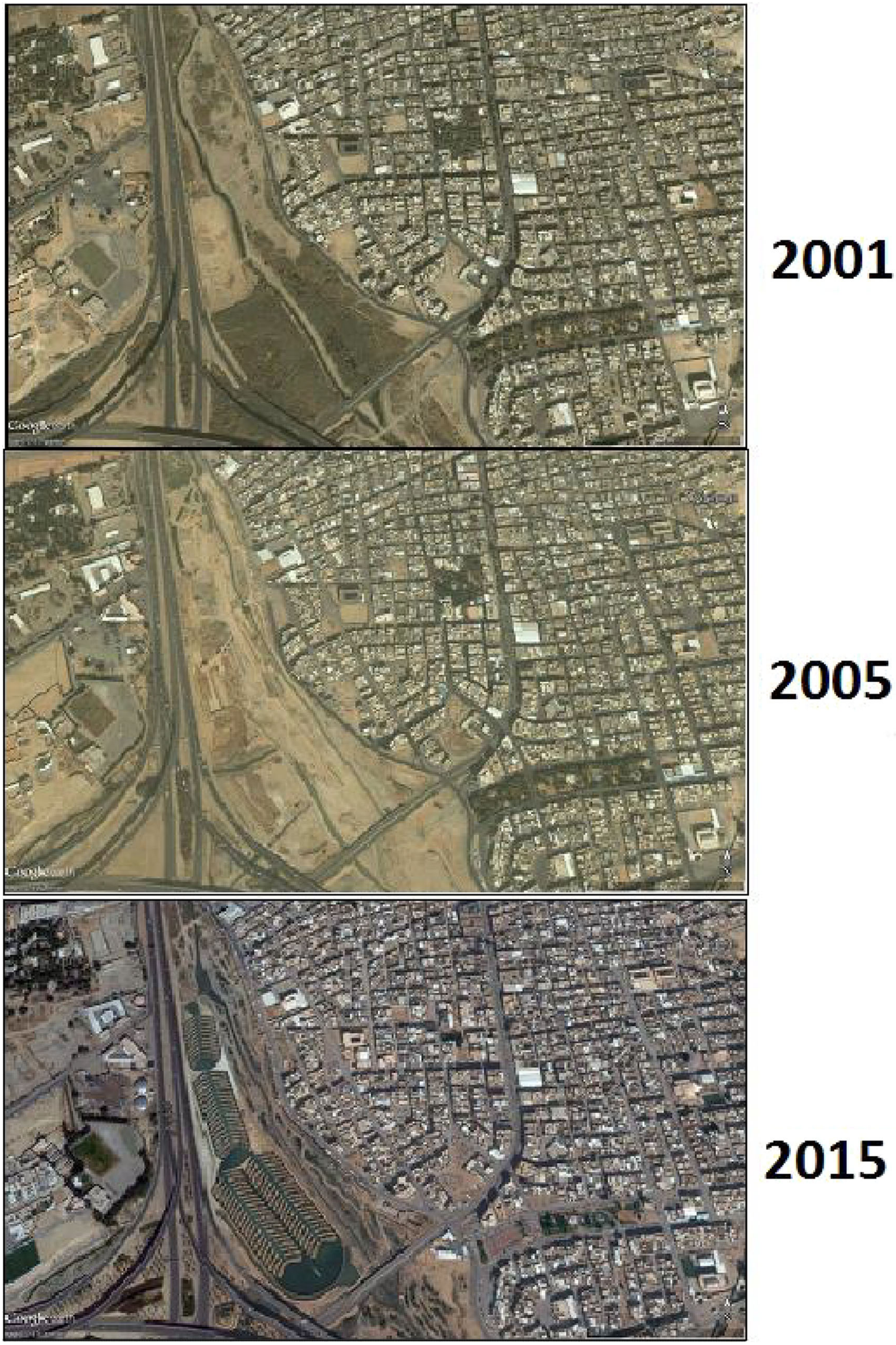

Fig. 2 Satellite view (Google Earth 2016) of part of Wadi Hanifa, Riyadh, where the Bio-remediation Facility was constructed, 2001 to 2015

known Arabian endemic, *Pseudagrion arabicum* (Schneider and Samraoui 2015). Recently, interest in the conservation of dragonflies and their habitats has increased (Jödicke et al. 2004; Schneider and Samraoui 2015), and as part of a IUCN Red List of the Odonata of the Mediterranean and North Africa, a distribution atlas was compiled, which included the northern part of the Arabian Peninsula (Boudot et al. 2009).

Freshwater fish

The freshwater ichthyofauna of Saudi Arabia attracted little attention until a comprehensive study was performed by Banister and Clarke (1977). Knowledge increased significantly following the several zoological expeditions of Büttiker (1979–1983) across Saudi Arabia. Büttiker's extensive findings were extended by Krupp (1983), who added numerous new taxa to the modest list of 10 species known at the time. Around the same time, Ross (1985) researched the oasis fish of Eastern Saudi Arabia and found a single secondary freshwater fish and seven introduced species. To date, eight species of primary and one species secondary native freshwater fish are known from Saudi Arabia (Freyhof et al. 2015). All primary native freshwater fish species belong to the family Cyprinidae. In Saudi Arabia, they are restricted to the western mountainous areas of the country. All are endemic to the Arabian Peninsula, and three species are endemic to Saudi Arabia: *Acanthobrama hadiyahensis*, *Cyprinion mhalensis*, and *Garra buettikeri*. *Acanthobrama hadiyahensis* is particularly threatened, because of its very small population size. In many wadis, indigenous freshwater fishes are threatened by the introduction of tilapias (Freyhof et al. 2015). Almost nothing is known of the natural history of these recorded species, which may be at considerable risk from introduced species, water extraction, and hydrological changes.

Amphibians

Despite recent progress, data on the distribution and abundance of the amphibian fauna of the Arabian Peninsula remains scarce (Balletto et al. 1985; Briggs and Ault 1985; Schätti and Gasperetti 1994; Al-Johany et al. 2014). This situation will be helped by current significant progress in molecular taxonomy, ecology, behavioral ecology, and phylogeography. The known amphibian fauna of Saudi Arabia includes seven species, four of which are endemic to the Arabian Peninsula (*Amietophrynus arabicus*, *A. tihamicus*, *Duttaphrynus dhufarensis*, and *Euphlyctis ehrenbergii*), and three of which have a wider distribution (*Bufotes viridis* (*Bufo cf. variabilis*), *Hyla savignyi*, and *Pelophylax ridibunda*) (Balletto et al. 1985). Many of these taxa are part of species complexes and, therefore, present a considerable taxonomic and biogeographic challenge (Stöck et al. 2006; Portik and Papenfuss 2015).

Waterbirds

The ornithological literature of Saudi Arabia has been relatively scant until fairly recently, with the first studies published in the twentieth century (Bates 1935a, b, 1937). Meinertzhagen (1954) conducted a seminal study when he visited Jedda and the Hijaz. In the 1970s, ornithological accounts relating to this area substantially increased (Jennings 1976, 1980a, b, 1988; Stagg 1991; Newton and Symens 1996), culminating in the'Atlas of the breeding birds of Arabia' (Jennings 2010). Since 1990, there is an International Waterbird Census (IWC) led by Wetlands International (Perennou et al. 1994). Further research was carried out on the distribution of wetland birds (Almalki et al. 2014) and to identify suitable habitat for internationally important populations of Kentish Plover (Al Rashidi et al. 2011).

Threats to wetlands

Climate change will affect the hydrology and community structures of wetlands, primarily through changes in precipitation and temperature regimes (and in some cases through species range expansion). It will also seriously impact wetland ecosystem services (e.g., fisheries, water quality and supply, recreational activities, and wildlife habitats). A global consensus now exists that human-induced climate change is causing physical and biological impacts worldwide (IPCC 2007). Managing those impacts requires that we adapt human activities so that crucial resources such as wetlands continue to function effectively. Prompted by a burgeoning water demand for agricultural, industrial, and domestic use, Saudi Arabia has been very keen to exploit rain and flood waters by constructing dams (Table 1). The pace of dam construction has been going on unabated for the last fifty years (Alsharhan et al. 2001; Vincent 2008; Al-Zahrani 2009). However, the construction of dams in the western part of Saudi Arabia has already altered flow regimes, water chemistry, and biotic

Table 1 Progress of dam construction in the Kingdom of Saudi Arabia (sources are cited in the text)

Year	Number of dams	Storage capacity (M m^3)
Before 1975	16	N/A
1984	180	N/A
1993	184	482
2000	190	850
2006	230	1138

communities of many wadis; thus, raising serious concerns over irreversible environmental changes as is known elsewhere (Dugan et al. 2010; Ziv et al. 2012; unpublished). The construction of dams is often controversial and large reservoirs are often associated with displacement of rural communities and resettlement.

Coastal wetlands have been identified as the ecosystem most vulnerable to the direct, large-scale impacts of climate change, primarily due to their sensitivity to rising sea levels (IPCC 2007). Large tracts of mudflats and mangroves, located on the Gulf and the Red Sea coasts, have been transformed into marinas, shrimp farms or have been encroached by urban sprawling. There is little disagreement that the loss of these wetlands and their associated services will involve huge costs to and social upheaval of their stakeholders. Owing to loosely enforced fisheries regulations, the most important natural resource after oil may be at considerable risk (Grandcourt et al. 2004). Domestic and industrial wastewater as well as pollution due to oil exploration, production and transport may also constitute a persistent threat to the ecological integrity of the coastal waters of the Gulf (Krupp and Abuzinada 2007; Sheppard et al. 2010).

PERSPECTIVES

This review has shown that there is a real need for a quantitative evaluation of the status of Saudi Arabia's wetlands. The highest priority task is to establish a baseline by collating all currently available data and assess the resilience of the wetlands to change by quantifying local trends. These analyses and information can then be used to support the development of solutions to ameliorate adverse anthropogenic effects, which can be accomplished by measuring and mapping factors that might have the greatest impact on the ecological integrity of the wetlands. It is likely that these factors will include the following: human encroachment (e.g., urban expansion and fragmentation), overfishing, overgrazing, hydrological changes, fires, and pollution. To stem the increasing erosion of local biodiversity and sustain the wetlands' resilience, specific plans will need to be elaborated, integrated and implemented to provide capacity building for local managers, increase between-site connectivity, maintain local hydrology, reduce current and future pollution, and control invasive species (Krupp et al. 2006).

The search for anthropogenic climate fingerprints is complex as most studies, including those carried out sporadically in Saudi Arabia, are largely correlational and involve distributional shifts, behavioral plasticity, and life history changes (Parmesan and Yohe 2003). It should be born in mind that although a wide range of taxa have been shown to respond to climate change (Crick et al. 1997; Parmesan et al. 1999; Thomas and Lennon 1999; Pounds 2001; Fitter and Fitter 2002), most short-term local changes are provoked by land-use modifications or by stochasticity in the abundance and distribution of species; thus, the assignment of causality is mainly inferential. Importantly, the negative effects of climate change will thus merely be 'additive' to ongoing and increasing human-induced pressures. Ectotherms such as amphibians (Beebee 1995; Gibbs and Breisch 2001) and Odonata (Hassall et al. 2007; Parr 2010; Dingemanse and Kalkman 2008) are closely linked to climatic factors, and their biology is driven by weather patterns (Blaustein et al. 2001).

In the context of global changes, identifying the current location and the extent of aquatic resources is an important tool for the conservation of the natural environment. Therefore, preserving the biodiversity of Arabian wetlands requires a substantial understanding of the location, extent, and conservation status of these habitats. As the Kingdom of Saudi Arabia embraces the principles of sustainable development (Brundtland Commission) to secure the welfare of its citizens without compromising their future well-being, it must successfully implement and integrate cohesive management mechanisms that allow for economic growth, social development, and environmental conservation. The conservation and sustainable use of wetlands in the region can only be achieved by focusing on the following four core objectives:

(1) Assessing the relative conservation status of Saudi Arabia's wetlands by identifying key taxa most sensitive to global change, monitoring the ecological integrity of water or looking for trends related to wetland surface area, (2) providing management tools and capacity building with skills including the ability of carrying field monitoring, mapping and analysis, and conveying biodiversity objectives into policy development, (3) increasing public awareness regarding the sustainable use of wetlands, and (4) assisting in improving the health and welfare of local communities by increasing wetland resilience (e.g., maintaining hydrology, increasing connectivity, reducing pollution, and controlling invasive species) and preserving their heritage.

Animal and plant populations already face several difficult challenges, including a reduction in the surface area of wetlands, changes to their function, pollution, exploitation, and competition from or predation by invasive species. 'Snap-shots' of the distribution of different taxa through surveys and census are valuable in understanding the spatial ecology of different species. However, sustainable strategies need to be based on long-term, repeated assessments, which can be accomplished using established 'badged' monitoring schemes like the IWC monitoring program (https://www.wetlands.org/casestudy/international-waterbird-census/). The conservation of these populations relies on a better understanding of demographic processes and their interactions with natural and anthropogenic factors and the implementation of management measures. The primary scientific objective in need of implementation should focus on a good understanding of the responses of wetland populations to environmental variability, including anthropogenic constraints such as exploitation and the limits of these responses.

The rational management of wetlands will yield a wide range of socio-economic benefits (including capacity building, biosurveillance, sustainable fisheries, wildlife conservation, management of the water supply, and flood protection) to a broad range of stakeholders. The Kingdom of Saudi Arabia has established a number of natural reserves managed by the National Commission for Wildlife Conservation and Development (NCWCD, now the Saudi Wildlife Authority) and has provided support for biodiversity research and conservation (Gladstone et al. 1999; Gladstone 2000; Abuzinada 2003). However, as rates of environmental change increase, there is a greater need to proactively monitor and foster biological diversity. Recent advances in molecular biology and genetic engineering have created new opportunities to identify and promote biodiversity.

CONCLUSION

Saudi Arabia faces many future challenges, including the identification of the causes of overexploitation and depletion of natural resources, the development of innovative methods to integrate economic prosperity and environmental protection, and the implementation of management strategies that lead to functioning ecosystems that benefit Saudi Arabia's citizens. Well-managed ecosystems should also be resilient in response to future uncertain events. The conservation strategy of Arabian wetlands must be included within a framework of integrated management which includes keystone and umbrella species.

The analysis of the status, spatial and temporal trends, and priorities of wetland resources as well as the dissemination of this information are essential for mobilizing and supporting the conservation and sustainable management and use of aquatic ecosystems. These efforts should lead to the adoption and implementation of national wetland policies across a range of stakeholders, action plans, and best practices. In addition to conserving biodiversity, the sustainable use of wetlands will contribute to the preservation of water resources, reduce the impact of climate change (through the carbon sink and reservoir functions of wetlands), and alleviate community-level economic hardship.

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AUTHOR BIOGRAPHIES

Sami Al-Obaid is a research scientist at King Saud University with a Ph.D. in environmental science. He is interested in ethnobotany and impact of anthropogenic changes on biodiversity.
Address: Department of Botany and Microbiology, College of Science, King Saud University, P.O. Box-2455, Riyadh 11451, Saudi Arabia.

Boudjéma Samraoui (✉) is Professor at the University of Annaba and is a Distinguished Scientist Fellow at the Center of Excellence in Research in Biodiversity, King Saud University. He received a D.Phil. in structural molecular biology from Oxford University, U.K, and he is interested in the ecology and conservation of Biodiversity, especially wetland biodiversity.
Address: Laboratoire de Conservation des Zones Humides, University of Guelma, Guelma, Algeria.
Address: Department of Biology, University of Annaba, Annaba, Algeria.
Address: Center of Excellence for Research in Biodiversity, King Saud University, Riyadh, Saudi Arabia.
e-mail: bsamraoui@gmail.com

Jacob Thomas is a research scientist at King Saud University, and he received a Ph.D. in botany. He is specializing in plant taxonomy and impact of global changes on biodiversity.
Address: Department of Botany and Microbiology, College of Science, King Saud University, P.O. Box-2455, Riyadh 11451, Saudi Arabia.

Hamed A. El-Serehy is Professor at King Saud University, and he received a Ph.D. in Zoology from Southampton University, U.K. He is specialized in marine biology and coastal zone protection and management.
Address: Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia.

Ahmed H. Alfarhan is Professor at King Saud University, and he received a Ph.D. in botany from Reading University, U.K. He is specialized in plant taxonomy, sustainable development, and biodiversity conservation.
Address: Department of Botany and Microbiology, College of Science, King Saud University, P.O. Box-2455, Riyadh 11451, Saudi Arabia.
Address: Center of Excellence for Research in Biodiversity, King Saud University, Riyadh, Saudi Arabia.

Wolfgang Schneider is a research scientist, he received a Ph.D. in Zoology from Mainz University, Germany. He specialized in freshwater and terrestrial entomology, the conservation of freshwater in arid ecosystems, and museum management.
Address: Senckenberg Research Institute, Entomology II, Senckenberganlage 25, 60325 Frankfurt, Germany.

Mark O'Connell is a research scientist, and he received a Ph.D. in ecology from Durham University, U.K. He is also director of Ecological Research & Training (ERT) specializing in Biodiversity Conservation and capacity building.
Address: ERT Conservation, Stroud, Gloucestershire GL5 1TP, UK.