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Springs: Conserving perennial water is critical in arid landscapes

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ABSTRACT

Arid landscapes are highly water-limited environments and all water (surface and groundwater) is environmentally, culturally and economically important. Springs, sites where groundwater discharges at the Earth's surface, are often the only perennial aquatic environments in arid regions. By providing habitats for aquatic biota, as well being an essential water resource for terrestrial species and human settlements, they are small natural features that make a contribution to ecological processes and biodiversity that extends far beyond their area. Many contain endemic, rare or relictual species of plants, fishes and invertebrates and are recognized as globally important biodiversity hotspots and evolutionary and ecological refugia. However, water resource development and invasive species are major threats to these systems. Future climate scenarios indicate that extended droughts may become more common in some arid regions. Such droughts will increase the pressure to extract groundwater for human uses. Increasing aquifer drawdown will result in the loss of some spring habitats and the endemic and dispersal-limited species they support. Conservation challenges include addressing the additive impacts of water extraction and exotic and invasive species and managing recreational activities. Although the isolation and small size of arid land springs makes them extremely vulnerable to anthropogenic impacts, it also means that protection and management may be more feasible and cost effective than for larger aquatic ecosystems. However, multiple approaches and ongoing actions will be required to address additive impacts. Examples of current conservation measures include fencing to exclude feral herbivores, removal of alien aquatic species and assisted re-colonisation of dispersal-limited, endemic species. The fundamental conservation priority is the protection of the groundwater resource (aquifers) on which arid land springs depend.

1. Introduction

Springs are sites where groundwater discharges at the Earth's surface. They are often the only perennial or long lasting aquatic habitats in arid regions (Fig.1a–d). They can range from the classic 'oases' associated with sandy deserts (Fig. 1a) to highly shaded systems sheltered within rocky arid land gorges (Fig. 1c). Although small in area, and usually spatially isolated, they are highly productive and diverse habitats that are recognized globally as biodiversity hotspots (Bogan et al., 2014). They are an archetypal example of a small natural feature (SNF) with an ecological role that extends far beyond their area (Hunter, 2017). Unlike many other SNFs, for example, rocky outcrops (Fitzsimons and Michael, 2017) and large old trees ((Lindenmayer, 2017), many springs are recognized as important, rare, and globally threatened ecosystems. However, there is still much that we do not know about these systems. For example, Springer and Stevens (2008) noted that there was no consistent or comprehensive classification system for springs. Springer and Stevens (2008) described 12 spheres of discharge of springs that included the hydrogeology of their occurrence and the microhabitats and ecosystems they support. Their classification provides a common understanding of spring types that offers guidance for spring ecosystem conservation, management, and restoration.

The main goal of this paper is to discuss the importance of springs in arid landscapes as SNFs and highlight the many conservation challenges and solutions that they share with other SNFs (see Hunter et al., 2017). Springs may also occur in non-arid environments (e.g. spring soaks in temperate regions) and these can also have SNF roles (see Calhoun et al., 2017).

2. Why are arid land springs important, both ecologically and economically?

Arid landscapes are highly water-limited environments and water (surface and groundwater) is environmentally, culturally and economically important. The importance of arid land springs in supporting unique assemblages of aquatic species, especially dispersal-limited endemics, has been documented for North America (Stevens and Meretsky, 2008; Bogan et al., 2014), Europe (Cantonati et al., 2012),

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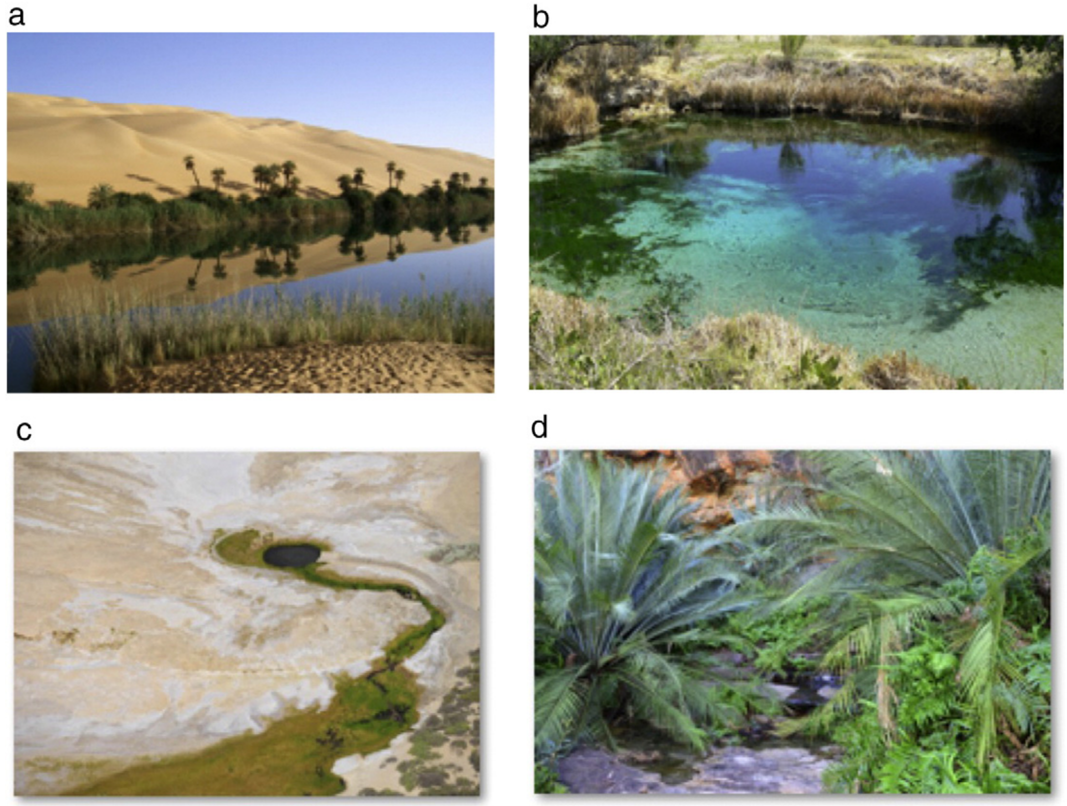

Fig. 1. (a) Upper left: Ubari Oasis, southwest Libya. Photo credit: Sfivat Wikimedia Commons. (b) Upper right: Crystal Spring, Ash Meadows National Wildlife Reserve, USA. Photo: Stan Shebs Creative Commons. (c) Lower left. The Bubbler mound spring, South Australia. Photo credit: Jenny Davis. (d) Lower right: Penny Springs, central Australia. Photo credit: Jenny Davis.

Africa (Suhling et al., 2006) and Australia (Fensham et al., 2011; Davis et al., 2013; Murphy et al., 2015).

Springs in arid areas are ecologically analogous to islands, as the fauna and flora that inhabit them are effectively marooned. The isolation of arid zone springs and their limited (and sometimes very shallow) areal extent creates conditions that are often unsuitable for aquatic species from riverine habitats, and as a consequence the biota in springs have evolved to benefit from the unusual environments. As a consequence, the majority of biota are very small and endemic. The high numbers of pupfish species associated with North American desert springs and species of hydrobiid snails associated with Australian springs provide examples of endemic faunas that have evolved and diversified in order to capitalize on unique habitats (Minckley, 1999; Ponder, 2003).

Arid land springs provide one the few sources of water for terrestrial vertebrates to drink (and bathe in) and can act as mesic refugia within a xeric landscape (Antos and Dann, 2014). In this way, arid land springs can influence an area far beyond their small size (a key attribute of a SNF).

Arid land springs present unique research opportunities in areas such as adaptation, evolution, island biogeography, conservation, modelling, genetics and the development of new monitoring techniques (Kodric-Brown and Brown, 2007; Kerezsy and Fensham, 2013; Murphy et al., 2015; Nicol et al., 2015; Rossini et al., 2015; Faulks et al., 2016). The spatially contained nature of spring environments provides a bridge between laboratory studies and natural environments, and springs are essentially 'natural laboratories' for any research work associated with their ecology (Shepard, 1993; Unmack and Minckley, 2008).

3. What are the current management challenges?

Although the environmental importance of spring ecosystems, and groundwater-dependent ecosystems (GDEs) more generally, is gaining increasing recognition, these habitats are at risk from various anthropogenic activities, particularly those that involve the extraction of groundwater (Boulton et al., 2014). A recent study found that 13 of the world's 37 biggest aquifers are being depleted by irrigation, and other uses, much faster than they can be recharged by rain or runoff (Richey et al., 2015). Global population growth is driving a demand for groundwater for direct human consumption and the production of food, fibre and energy. This demand is elevated in arid regions where surface waters are naturally scarce.

Projections for the arid and semi-arid Australian rangelands indicate that mean, maximum and minimum air temperatures will continue to increase and the time spent in drought will increase (Healy, 2015). A likely scenario linked to these projections is that the pressure to extract groundwater for human use in arid regions will increase. Declining groundwater levels will ultimately result in the loss of spring habitats and the endemic and dispersal-limited species they support. Mining and fracking (unconventional gas extraction) also pose significant risks to many arid land springs and GDEs (Boulton et al., 2014). Fracking produces disposal water with high concentrations of various impurities that can pollute arid land aquifers. Additionally, the complexity of surface water–groundwater interactions means that the exact effects of fracking at a specific site may be hard to predict.

Similar to the situation for other SNFs, the isolation and small size of spring habitats makes them extremely vulnerable to anthropogenic impacts. Additional management challenges include the impacts of exotic and invasive species and unmanaged recreational activities. Invasive plant and animal species compete with endemic spring biota by habitat alteration (i.e. non-native plant species) (Fensham et al., 2007), competition and predation (Meffe et al., 1983; Rosen and Schwalbe, 1995). The colonisation of the Edgbaston spring group in central western Queensland, Australia, by the invasive mosquitofish, *Gambusia holbrooki*, is a prescient example of the negative impact of an exotic and invasive aquatic species. Populations of the endemic and critically endangered