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Review

Anthropogenic refuges for freshwater biodiversity: Their ecological characteristics and management

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ABSTRACT

We reviewed literature describing the potential for freshwater anthropogenic waterbodies to act as refuges from disturbance. We identified research related to the refuge potential of a wide range of waterbodies, using waterbody names as keywords along with 'artificial' and 'freshwater'. Potential freshwater anthropogenic refuges were more often standing than running waters. Agricultural ponds, rural and urban drainage ditches and transport canals were the most diverse for all aquatic taxa, whereas irrigation infrastructure was least diverse. Comparatively little is known about the refuge role of fire dams, urban artificial ponds, golf course lakes, disused industrial ponds and retaining walls. Local-scale attributes associated with high biodiversity were: presence of macrophytes (for animals), absence of fish (for amphibians, invertebrates), natural bed materials and hydroperiod (all biota). Landscape variables associated with high biodiversity were proximity to and connectivity with other waterbodies and to natural terrestrial vegetation. Moderate levels of management intervention were also associated with higher biodiversity. Many knowledge gaps about the function of anthropogenic refuges within landscapes exist and require further research. One of the most important limitations to the provision of refuges for freshwater biodiversity by anthropogenic waterbodies is the lack of recognition of their actual or potential biodiversity value. Anthropogenic waterbodies need to be recognised for their potential to support biodiversity conservation and climate change adaptation for freshwater species, while being managed to prevent the spread of invasive species.

Contents

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1. Introduction

Biodiversity conservation cannot rely solely on protected areas; and the pervasive nature of climate change is reinforcing that view (e.g. the problem of the 'summit trap': Sauer et al., 2011). Also, there is emerging evidence that freshwater biodiversity can persist alongside intense human activity (e.g. in Hong Kong: Dudgeon, 2003; and Asia more generally, Gopal, 2013), and an increasing interest in determining how this can occur. The term that has been adopted for biodiversity conservation in conjunction with human activities is reconciliation ecology (*sensu* Rosenzweig, 2003; Dudgeon et al., 2006). One aspect of reconciliation ecology is the utilisation of anthropogenic (human-created) or heavily modified ecosystems to support biodiversity (Lundholm and Richardson, 2010), whereas restoration ecology focuses upon recovering lost ecosystem attributes (Robson et al., 2011). Anthropogenic habitat may include areas formerly created for human purposes and later abandoned, but not degraded natural ecosystems that are being restored.

Many studies of anthropogenic ecosystems have focused on their capacity to promote the spread of invasive species (e.g. review by Rahel (2002)). For example, large reservoirs provide perennial lentic habitat that may facilitate populations of invasive species and promote homogenisation of faunas across large areas (Rahel, 2002; Clavero and Hermoso, 2011; Lapointe et al., 2012). Stormwater ponds may harbour an invasive species of toad (as well as native amphibians) and may facilitate its dispersal (McCarthy and Lathrop, 2011). While natural processes such as dispersal via drifting in currents can be assisted by the construction of channels that artificially connect waterbodies, they may also facilitate the spread of invasive plants and animals (Nilsson et al., 2010).

Recently, there are more studies recording biodiversity in anthropogenic waterbodies and the factors that support biodiversity within them (e.g. Davies et al., 2008a,b; Vermonden et al., 2009). Studies focused on birds, amphibians, fish, macroinvertebrates and aquatic macrophytes, with few studies of plankton, although zooplankton have received some attention (e.g. planktonic crustaceans in Mexican 'bordos' (artificial ponds), Dodson and Silva-Briano, 1996). Recognition is increasing that the role of anthropogenic waterbodies goes beyond facilitating the spread of invasive species. For example, while impoundments were associated with the spread of invasive fish, the proportion of artificial channels in a catchment was not (Lapointe et al., 2012), suggesting different roles for these two types of anthropogenic waterbodies.

The present article reviews the potential of anthropogenic freshwater waterbodies to act as refuges for native species, including those of conservation interest, from disturbance; especially from those disturbances that will be intensified by climatic change. Some anthropogenic ecosystems are recognised in the literature as refuges for native species, but others could potentially become refuges with alterations in their management, despite, for example, their small size (e.g. Davies et al., 2008a; Lundholm and Richardson, 2010). As the concept of refuges from disturbance is relatively recent, this review necessarily focuses on recent literature (i.e. 'electronic era'). However, it is important to note that many studies of artificial ecosystems were published in the pre-electronic era, including assessments of biodiversity and environmental impacts, so there is a larger body of knowledge about artificial ecosystems than reviewed here cited in Baxter (1977), Paul and Meyer (2001), Herzon and Helenius (2008) and Gopal (2013).

1.1. Defining anthropogenic freshwater refuges

The essential components of a refuge are that it is a physical place secure from one or more disturbances, and that it can act as a source of colonists for habitat in the wider landscape after disturbance has ceased (Robson et al., 2008). Therefore, the processes of retreat into and recolonisation out from refuges are an important part of refuge function. Lake (2011) and Keppel et al. (2012) make the distinction between refuges (which exist at ecological temporal and spatial scales) and refugia (which exist at evolutionary scales), and we follow this terminology here, focussing on refuges and disturbances at ecological scales of time and space. That is, those constraints in time and space within which an organism directly experiences a disturbance event and its consequences. Natural refuges may be conceptualised as part of a matrix of habitats within a landscape subject to disturbances (Robson et al., 2008). Anthropogenic refuges may act in ways similar to natural refuges, but might also provide new opportunities for species to resist (potentially also previously unknown) disturbances. Importantly, places that do not necessarily contain high biodiversity (or in the case of anthropogenic habitat, a representative biodiversity) may still provide critical habitat for species during their life cycle or during unpredictable catastrophe.

In some cases, refuges may occur in secondary habitat. Secondary habitat is sub-optimal and species may use it seasonally (e.g. Taylor et al., 2012) or once optimal habitat is lost due to human impacts (Chazdone et al., 2009; Costello et al., 2013). The distinction between secondary and refuge habitat is that refuges are not necessarily sub-optimal habitat (e.g. dryland river waterholes are natural refuges for species and are not sub-optimal for most; Sheldon et al., 2010), and their use arises during disturbance, whether sought actively or not. In contrast, secondary habitat may be used by individuals once primary habitat is fully occupied, termed the "mass effect", leading to increased species richness (Robson and Chester, 1999). As Loehle (in press) points out, when population sizes are large, secondary habitat may not always be occupied by poor competitors and these habitats may become source patches. Importantly, when populations are small (such as when species are endangered) failure to protect secondary or sink habitat may lead to loss of necessary habitat to enable species recovery (Loehle, in press). This applies equally to refuge habitats, which may be essential to surviving disturbance but may not be protected by conservation management because they may appear to be secondary or sink habitats if no reproduction is observed there.

Created habitat is most likely to occur within a landscape heavily modified by human activities, where there is a loss of natural support for biodiversity. Hence anthropogenic refuges will generally be refuges from disturbances associated with loss of habitat and human activities (these will almost certainly be of a "press" nature; Lake, 2000), although habitat modified by humans may also provide refuges in predominantly undisturbed environments. For example, fire dams in forested landscapes may act as wetland analogues if they retain water during drought. There is clearly the potential to at least partially compensate for habitat lost elsewhere (Dodson, 2008). For example, erosion and sedimentation in the Glenelg River has led to sand blocking tributary junctions and creating wetlands instead of the pool-run habitat that preceded it (Lind et al., 2009). These 'junction plug wetlands' harbour a high taxonomic richness of invertebrates and at least partially compensate for the large area of wetlands lost from the catchment (Lind et al., 2009). We may see analogues with refuge function in natural habitat with, for example, shelter from seasonal disturbance events; but the amplitude and frequency of such disturbances will almost certainly also be modified by human activities, so that functioning, in terms of resistance to those disturbances, may not directly mimic that of natural ecosystems. Patterns of movement in and out of different refuges are likely to differ strongly because they will vary in their representativeness of the pre-existing biodiversity. Chance and the intensity of disturbance also play a role (Robson et al., 2008) as does the dispersal capacity of species