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Influence of Catchment Condition and water resource development on waterbird assemblages in the Murray-Darling Basin, Australia

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ABSTRACT

River regulation and water resource development have resulted in significant deterioration in aquatic ecosystems worldwide, including reductions in wetland extent, changed flow regimes, and declines in biodiversity. The impacts on the composition and distribution of waterbird assemblages has not been studied previously at the scale of a major river basin. We investigated the relationship between waterbird assemblage composition and ecosystem health across the 21 catchments of the Murray-Darling Basin in south-east Australia, which contains major wetlands that have been adversely affected by river regulation and over-allocation of water for irrigation. We allocated 51,000 surveys of 96 waterbird species, obtained from the New Atlas of Australian Birds database, to 117 one-degree grid squares for multivariate statistical analysis (MVA). Hierarchical clustering showed five main groups of squares reflecting strong biogeographic gradients. Pronounced spatial autocorrelation in the waterbird assemblage data was found. Unequal survey effort across grid squares and varying taxonomic scope also hindered conventional MVA and interpretation. To circumvent these constraints, survey data were recompiled at the half-degree square resolution after removing surveys with few waterbird records, leaving 17,448 surveys of 80 species. A novel sequential approach of multivariate regression of distance matrices, ordination of Bray–Curtis residuals, and *post hoc* correlation of the independent variable was used to test the hypothesis that assemblage composition varies systematically with Catchment Condition, after controlling for spatial autocorrelation, biogeographic trends and unequal survey effort. Ordination of the residuals of the half-degree square Bray–Curtis association matrix revealed a strong relationship between a nine-point index of Catchment Condition and waterbird assemblage composition. The colonial nesting waterbird guild (egrets, herons, ibis and spoonbills), was uniquely identified as being aligned with catchments in moderate to good condition. Waterbird assemblage composition shows significant spatial variation throughout the Murray-Darling Basin, influenced by the hydrological and ecological condition of catchments as well as by natural biogeographic factors. The least degraded catchments offer the best habitat for the colonially nesting waterbird guild, the group most adversely affected historically by river regulation and water diversions. These catchments require protection from water resource development if such habitat is to be maintained. Our results support the conservation objective of improving wetland health in degraded catchments through delivering environmental flows to ensure breeding and population maintenance of colonial nesting waterbirds.

1. Introduction

Wetlands and floodplains are in declining health throughout the world due to increasing human pressures on water resources (Lemly et al., 2000; Vörösmarty et al., 2010). For example, over 80% of wetlands in South-east Asia are threatened by population growth and economic development (International Wader Study Group, 2003). As a consequence, waterbirds are under significant threat (Crozier and Gawlick, 2003; Fox et al., 2010; Ma et al., 2010). Of 1138 waterbird populations whose trends are known, 41% are in decline (Millennium Ecosystem Assessment, 2005). Concerns over such declines have led to international conservation agreements such as those between Australia, Japan, China and Korea for migratory waterbirds using the East Asian–Australasian Flyway (Amano et al., 2010).

Flow regimes are the main drivers of the ecology of rivers, wetlands and floodplains. Rainfall, topography, vegetation and land use modify ecological responses and patterns at various scales and ecological responses to flows reflect these factors (Walker

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et al., 1995; Puckridge et al., 1998, 2010). The Murray-Darling Basin occupies 1,040,000 km^2 and contains some of the most ecologically important wetland ecosystems in Australia, of which 16 are Ramsar sites and over 200 are deemed to be of National Importance (DSEWPaC, 2011; MDBA, 2010). Changes to flow regimes due to river regulation and water resource development have resulted in declining ecological condition (Kingsford, 2000) with major implications for floodplain ecosystem resilience (Colloff and Baldwin, 2010). The extent of water resource development varies across catchments and few are not impacted (CSIRO, 2008; Sims et al., 2012). The ecological consequences of hydrological change remain hard to predict (Poff and Zimmerman, 2010) but declining waterbird populations have been reported from major breeding sites (Kingsford and Johnson, 1998; Leslie, 2001; Kingsford and Thomas, 1995, 2004; Paton et al., 2009; Brandis et al., 2011; Wen et al., 2011), exacerbated by a thirteen year-long drought (1997–2010). Floodplain productivity is enhanced by sequential flooding and drying, and river regulation has affected productivity 'booms' by reducing flood frequency and extent or by permanently inundating some areas. Imposition of hydrological stability through river regulation is associated with lower abundance and diversity of waterbirds compared with non-regulated rivers (Kingsford et al., 2004).

Waterbirds represent indicators of environmental change at a variety of spatial scales (Kushlan, 1993; Paillisson et al., 2002; Hanowski et al., 2007; Celdrán and Aymerich, 2010; Everard and Noble, 2010). They are speciose – >120 species have been recorded in the Murray-Darling Basin – easy to identify, long-lived and, due to their size and mobility, require large areas of habitat. Waterbirds as a group consume a wide range of food sources, so changes in assemblage composition and abundance ought to reflect changes to aquatic food web structure (Fox et al., 2010; Stillman et al., 2010). Various waterbird guilds have different feeding and breeding requirements, and healthy diverse communities require a range of habitats that enable both breeding and survival between breeding events (Leslie, 2001). Waterbirds are readily surveyed and the efforts of amateur enthusiasts have been harnessed to assemble large, long-term databases of structured bird observations throughout Australia (Blakers et al., 1984; Barrett et al., 2003).

Research on waterbird conservation and management needs to include studies at appropriate large spatial scales because knowledge of patterns of spatial and temporal abundance and diversity help in prioritising conservation objectives and resources (Haig et al., 1998; Maclean et al., 2011). The availability of waterbird breeding habitat and food resources in Australia is closely linked to highly variable patterns of floodplain inundation, so the habitats that support waterbirds vary considerably in time and space. Thus waterbirds may have to travel long distances to access suitable resources (Roshier et al., 2001a,b; Kingsford et al., 2010). Most waterbird species in the Murray-Darling Basin are distributed across the Australian continent and individuals are likely to be able to disperse at this scale (Kingsford et al., 2010). Successful management of waterbird populations must therefore consider local, catchment, basin and continental scales, over short to long time scales.

The unpredictability of floodplain and wetland inundation and the high mobility of most Australian waterbirds means that the drainage basin scale may be the most appropriate for consideration of waterbird distribution, abundance and diversity (Maher and Braithwaite, 1992). Previous analyses at this scale (Roshier et al., 2002; Kingsford et al., 2004) focussed on abundance and species richness of waterbirds collectively or by functional groups but did not address whether there is systematic variation in the composition of waterbird assemblages that reflects the spatial variation in the capacity of river catchments to provide habitat and resources. Broad-scale spatial trends in assemblage composition may relate to diverse ecological factors, as well as to water resource development, but with the focus here at the catchment scale we show that simple biogeographic gradients can adequately represent the former, and so allow the anthropogenic impacts to be modelled. Our objectives were to determine the patterns of distribution of waterbird species and assemblages within the Murray-Darling Basin and to test the hypotheses that (1) species composition differs between catchments; and (2) compositional change is related to catchment condition, reflecting river regulation and water resource development, assessed independently of waterbird data using the Sustainable Rivers Audit ecosystem health index (Davies et al., 2010). In doing so we present a novel combination of multivariate statistical analyses (MVA). Ultimately our goal is to inform policy regarding the allocation of environmental flows at the basin scale by demonstrating the links between river health and changes in waterbird assemblages.

2. Methods

The Murray-Darling Basin (Fig. 1) is characterised by its inland draining nature, with high discharge losses over the lengthy floodplain traverses of the major rivers, many of which terminate in extensive wetlands. In the northern Basin, tropical influences are apparent with rainfall mostly during summer and the occurrence of some northern Australian (Torresian) waterbird species, contrasting with mostly winter rainfall in the south. Across the entire Basin, species with predominantly southern (Bassian) or Australia-wide distributions dominate waterbird assemblages, but in the semi-arid north-west (e.g. Paroo River) inland Australian (Eyrean) species are more prominent. A number of shorebird species are largely confined to the Lower Lakes and the estuarine Coorong wetlands in the south-west of the Basin.

We acquired data from the New Atlas of Australian Birds Scheme (Barrett et al., 2002, 2003), comprising *ca*. 51,000 bird surveys conducted in the Murray-Darling Basin from 1987 to 2009 and which included observations of waterbirds (see Fig. 1 for locations). The survey types we included were 20 min 2 ha searches, area searches within a 500 m radius and area searches within 5 km (Barrett et al., 2003). Incidental surveys were excluded. We sorted the surveys into squares defined by whole degrees of Latitude and Longitude, consistent with the one-degree grid used for distribution maps in the Atlas of Australian Birds. We eliminated eight marine and vagrant species that were not typical waterbirds of Australian inland waters, plus a further 11 migratory shorebirds that only occurred in one coastal one-degree square, leaving 96 species. We removed eight one-degree squares with less than 11 species leaving 117 squares for exploratory MVA. The list of waterbird species is presented in Table S1 (Supporting information). Taxonomy and nomenclature follow Christidis and Boles (2008).

2.1. Classification and ordination of one-degree squares

For each square we combined surveys and cumulatively tallied species. The input *q*-mode data matrix to the MVA package PATN (Belbin, 1995) comprised 117 squares, with observations of the 96 species being the natural log. of percentage reporting rate (+1), where reporting rate is the proportion of surveys with records of the species. An association matrix between squares was formed with the Bray–Curtis distance measure. We used the UPGMA routine in PATN (dilation factor −0.1) to generate a dendrogram of the relatedness of groups according to their species composition. We then used the semi-strong hybrid (SSH) form of non-metric multi-dimensional scaling (NMDS) in PATN (Belbin, 1991) and retained the solution that minimised stress in two and three dimensions, using 50 random starts. Species vectors (a multiple correlation