Biological Conservation 177 (2014) 64–73

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

# River birds' response to hydrological extremes: New vulnerability index and conservation implications

Alexander Royan [a,*], David M. Hannah [a], S. James Reynolds [b], David G. Noble [c], Jonathan P. Sadler [a,b,*]

[a] School of Geography, Earth & Environmental Sciences, College of Life & Environmental Sciences, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom
[b] Centre for Ornithology, School of Biosciences, College of Life & Environmental Sciences, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom
[c] The British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU, United Kingdom

ARTICLE INFO

*Article history:*
Received 11 March 2014
Received in revised form 27 May 2014
Accepted 19 June 2014

*Keywords:*
Avian conservation
Biogeography
Climate change
Demography
Extreme events
Hydrology

ABSTRACT

There is growing evidence that as a consequence of climate change the frequency of extreme hydrological events will increase. Predicting the impacts of these extreme events on ecological systems is a major research challenge. It is predicted that change in future river flows, characterised by greater occurrence of floods and droughts, will have profound impacts on aquatic invertebrate communities by removing sensitive species and restructuring food networks. However, it remains unclear how an increase in these hydrological extremes will impact on riparian communities and species at higher trophic levels. Here, we describe a new methodology that facilitates the integration of quantitative outputs of species' distribution models with the expert knowledge of conservation practitioners to produce a species' vulnerability index (SVI). Using our SVI framework, we assessed and ranked the vulnerability of 16 river bird species to a potential climate-induced shift in the frequency, duration and magnitude of flood and drought events. Vulnerability was associated primarily with ecological traits that restrict species to in-channel riverine habitat. Whilst the SVI was developed to assess species' vulnerability to hydrological extremes on rivers, it is equally applicable to other environmental domains as well as a range of avian and non-avian taxa. Furthermore, this original methodological approach provides researchers and managers with a valuable conservation tool that allows them to identify the species most vulnerable to climate change impacts and plan mitigation and adaptation strategies.


## 1. Introduction

There is increasingly robust evidence that global warming and the associated increase in climatic variability will lead to more extreme climatic events (Hansen et al., 2012; Min et al., 2011; Seneviratne et al., 2014). Given their potentially profound impacts, understanding the role of extremes in shaping ecological systems has gained increasing importance and momentum (Smith, 2011a,b). Climate change is predicted to result in the intensification of key processes in the water cycle such as precipitation, evaporation and runoff (Durack et al., 2012). As river flows are coupled closely to atmospheric drivers (Laizé and Hannah, 2010), shifts in the distribution of precipitation will result in modified hydrological regimes characterised by increasing trends in the frequency, duration and magnitude of hydrological extremes, including floods and droughts (Pall et al., 2011; Prudhomme et al., 2013).

River flow is regarded as the 'master variable' (Power et al., 1995) in riverine environments as flow not only structures physical habitats (e.g. channel width and stability), but also determines the physicochemical properties (e.g. water temperature, dissolved oxygen concentrations) of in-channel habitats which, in turn, regulate a range of environmental processes (e.g. production, nutrient retention) (Ward et al., 2002). Subtle changes in the spatio-temporal heterogeneity of river flows can determine the distribution and abundance of certain taxa (e.g. aquatic invertebrates, fish) (Bunn and Arthington, 2002), while extreme high and low flows can exclude sensitive species and restructure food webs by simplifying the network architecture and reducing species' richness at higher trophic levels (Ledger et al., 2012). Thus, an increase in climate-induced hydrological extremes is likely to have dramatic impacts on riverine biodiversity. Yet, incorporating extreme events into the experimental design of ecological studies remains a considerable challenge (Thompson et al., 2013).

* Corresponding authors. Address: School of Geography, Earth & Environmental Sciences, College of Life & Environmental Sciences, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom. Tel.: +44 (0)121 414 5528.
*E-mail addresses:* axr196@bham.ac.uk (A. Royan), j.p.sadler@bham.ac.uk (J.P. Sadler).

http://dx.doi.org/10.1016/j.biocon.2014.06.017
0006-3207/

Variability in river flows influences the spatio-temporal distribution of riparian consumers such as river birds (Royan et al., 2013). Flooding influences the habitat occupancy (Reiley et al., 2013), abundance (Chiu et al., 2008), breeding success (Strasevicius et al., 2013), breeding timing (Arthur et al., 2012), and survival (Chiu et al., 2013) of river birds. Moreover, changes in the quality of foraging habitat can determine the timing of foraging activities (Cumming et al., 2012). The maintenance of unregulated (near-natural) riverine hydrological variability, including the occurrence of flooding and drought events, can be beneficial to river birds, with both diversity and abundance declining on rivers where anthropogenically-regulated, stable flow regimes exist (Kingsford et al., 2004). The impact of river regulation can be highest for those bird species (e.g. European pied flycatchers *Ficedula hypoleuca*) adapted to feeding on emergent aquatic invertebrates (Jonsson et al., 2012; Strasevicius et al., 2013). However, extreme flow events can also have dramatic negative impacts on river-obligate birds through marked shifts in surface flows (Hinojosa-Huerta et al., 2013).

Our understanding of the vulnerability of river bird communities to hydrological extremes is limited because of a failure to focus on multiple species' responses to a range of hydrological extremes across large geographical areas. This may partly be explained by the low probability of occurrence of hydrological extremes but also by the lack of conceptual frameworks for studying extremes, given that the description of an event as "extreme" is catchment-specific and depends on previous flow conditions (Smith, 2011a,b). Consequently, a study of this type may be best achieved using long-term, large-scale, multi-species data as these will facilitate the investigation of species' ecological responses to hydrological parameters across a range of 'extremes' (e.g. statistical quantiles) and across a range of ecosystems which vary in their sensitivity to hydrological extremes.

Two tools used regularly to evaluate the effects of climate change on biodiversity are: (1) species' distribution models (SDMs), which relate data on species' occurrence (Jones et al., 2013) or abundance (Renwick et al., 2012) to environmental drivers, and (2) assessments of species' sensitivity and exposure to climate change effects to determine the vulnerability of species to climate change (Davison et al., 2012). We combined aspects of both of these approaches to define a new methodological framework for the development of a species' vulnerability index (SVI) to hydrological extremes. River bird data from the British Trust for Ornithology's (BTO's) Waterways Breeding Bird Survey (WBBS) were combined with mean daily river flow data from the UK National River Flow Archive (NRFA) to investigate the vulnerability of 16 river bird species to a potential climate-induced increase in the frequency, duration and magnitude of hydrological extremes (floods and droughts) across 117 river locations. We used the IPCC (2012) statistical definition of an "extreme" as being a statistically rare event (i.e. events outside a defined percentile under current climate conditions) and investigated the relationship between species' abundance and flow parameters measured across a range of extremes (e.g. 95th, 90th and 75th percentiles for low flows and 5th, 10th and 25th percentiles for high flows).

Vulnerability to climate change impacts is comprised of two separate facets: sensitivity and exposure (Williams et al., 2008). Sensitivity is mediated by the resilience and adaptive capacity of the species, as determined by factors such as specific ecological traits (Williams et al., 2008). Exposure depends on the degree of buffering offered by species' occupied habitat and species' behaviour that reduce future exposure to the specific climate effects (Williams et al., 2008). Following the methodology of other SVIs (Furness and Tasker, 2000; Garthe and Huppop, 2004; Williams et al., 1995), we obtained exposure scores by providing relative numerical scores to a set of key qualitative questions. These scores were then combined with quantitative outputs from an ensemble of SDMs to provide a framework for assessing species' vulnerability. SVIs offer researchers and managers a valuable conservation tool that allows them to identify priority species for conservation action (Davison et al., 2012).

The specific objectives of this study were to:

1. Identify species of river birds most sensitive to changes in the variability of high (flood) and low (drought) river flows.
2. Combine quantitative analyses of species' sensitivity with assessments of species' exposure to a potential future increase in hydrological extremes in order to develop an index of species' vulnerability.
3. Identify priority riverine locations that support greater abundances of species of high vulnerability.

## 2. Methods

### 2.1. Data

River bird data were obtained from the BTO's WBBS: a large-scale annual survey of UK breeding birds on rivers and canals (canals were excluded from this study). Each survey location comprised a single river within a random $2 \times 2$ km tetrad that was stratified to target accessible locations across UK regions and provide extensive national coverage. The survey location represented the nearest waterway to a randomly selected point within the tetrad. The WBBS protocol requires two visits to the survey location during the birds' breeding season – one in early April to mid-May and the second in mid-May to late June. Each location comprised a number of continuous 500 m-long linear transects positioned along one bank beside the river. During both visits, observers recorded all birds within 100 m of the transects and noted the number of 500 m transects surveyed so that the total sampling effort was quantifiable (up to 10 transects in a row [5 km] could be surveyed).To determine the response variable (relative abundance), we pooled species' counts across all transects in the sample year and then used either the sum of counts for the first or second visit depending on which was higher. This count was then divided by the number of transects to ensure that that variability in abundance was not confounded by heterogeneity in sampling effort.

The procedure used to select WBBS survey locations for analyses was as follows. First, survey locations within 10 km of a river flow gauging station were selected. To ensure the relevance of flow variables to survey locations, gauging station-survey site pairings were not used where a major tributary inflow or anthropogenic barrier occurred between the gauging station and survey location. Survey locations with a minimum of four repeated visits were then selected as datasets that involve multiple visits to sample sites provide more reasonable estimations of species' occupancy and abundance by reducing bias associated with detection probability (Royle and Nichols, 2003). Survey data between 1998 and 2011 (inclusive) were used but excluding data from 2001 as few sites were surveyed due to the foot-and-mouth outbreak when access to rural areas was restricted by the UK Government. Lastly, for each bird species in turn, we then selected survey locations where a species was recorded in at least 80% of survey years. This reduced the likelihood of including sites that had been newly colonised or sites where populations were extirpated during the survey time series in the analyses (Oliver et al., 2012). This final criterion also served to remove false zeros, caused by sampling outside species' habitat range, from datasets as well as limiting overdispersion and associated model parameter and standard error bias (Zuur et al., 2012). In total, 117 WBBS survey locations were used (Fig. 1), although the number of sites varied between species.