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Island refuges: Conservation significance of the biodiversity patterns resulting from 'natural' fragmentation

L.A. Gibson[a,b,*], M.A. Cowan[a], M.N. Lyons[a], R. Palmer[c], D.J. Pearson[c], P. Doughty[d]

[a] Science and Conservation Division, Department of Parks and Wildlife, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983, Australia
[b] Western Australian Biodiversity Science Institute, WA Trustees Building, Level 2, 133 St Georges Terrace, Perth 6000, Australia
[c] Science and Conservation Division, Department of Parks and Wildlife, PO Box 51, Wanneroo, Western Australia 6946, Australia
[d] Department of Terrestrial Zoology, Western Australian Museum, 49 Kew Street, Welshpool, Western Australia 6106, Australia

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ABSTRACT

The near-pristine continental-shelf islands along the remote and rugged Kimberley coast of north-western Australia are important natural refuges that have been isolated from many of the threatening processes affecting the adjacent mainland. Between 2007 and 2014, 27 of the largest of these islands were sampled for non-volant mammals, bats, reptiles, birds and vascular plants. Here, we evaluate the congruent patterns in species richness and composition among the taxonomic groups and relate these to island-wide attributes. We consider the conservation implications of the observed biodiversity patterns in the context of species replacement, nestedness and the minimum number of islands required to represent all species. While the species-area relationship was consistently supported, the effect of island isolation was observed for the non-volant mammals only. Environmental heterogeneity and spatial arrangement of islands strongly influenced species compositional patterns. We show that this pattern was largely due to species replacement among islands, rather than nestedness. These patterns reflect the greater diversity of regionally endemic species that are largely restricted to the more mesic and extensively rocky islands; whereas the drier islands typically support more widespread generalists. The combined measures of biodiversity patterns we observed indicate that all of the sampled islands have high conservation value. The conservation implications of the apparent lack of nestedness in this island system have relevance for other similar systems including fragmented landscapes.

1. Introduction

Due to the unique and divergent evolutionary histories of their biota, islands hold a disproportionate percentage, by area, of global biodiversity (Whittaker and Fernández-Palacios, 2007; Kier et al., 2009). Islands are also centres of endemic richness (Kier et al., 2009) and can act as conservation refuges from threatening processes affecting mainland populations (Clout, 2001; How et al., 2009; Harradine et al., 2015). Unfortunately, islands are also particularly susceptible to dramatic ecosystem changes if they are exposed to environmental disturbances (Laurance et al., 2011; Walshe et al., 2011). Species on islands are also disproportionately threatened, with 61% of all extinct species and 37% of all critically endangered species confined to islands (Tershy et al., 2015). The vulnerability of islands to disturbance, in combination with their high biodiversity values, has highlighted the need to increase targeted conservation efforts, including expanding protected areas to encompass more islands (Kier et al., 2009; Nias et al., 2010; Aslan et al., 2015). However, basic biodiversity inventories to inform island conservation priorities are few and tend to be biased toward conspicuous taxa or particular geographic areas (Brooks et al., 2006; Ahrends et al., 2011; Aslan et al., 2015).

Australia's islands have long been recognized as important refuges for native mammals that have suffered extensive contractions of their mainland distributions (Burbidge, 1999; Woinarski et al., 2011). Around a third of Australia's islands occur off the remote Kimberley coast of north-western Australia (CCWA, 2010). The Kimberley region is significant for its rich diversity of flora and fauna, including endemic species, justifying its status as a National Biodiversity Hotspot (Department of the Environment and Energy, 2017). Recent studies examining phylogenetic patterns have also indicated that this region harbors an inordinately high level of cryptic diversity that is observed nowhere else on the Australian continent (e.g. Oliver et al., 2012; Pepper and Keogh, 2014; Moritz et al., 2016). Changes in land use practices in the Kimberley over the last century have coincided with a wave of local extirpations among medium-sized mammals, and reductions in the abundance of some small mammal and granivorous bird

* Corresponding author at: Science and Conservation Division, Department of Parks and Wildlife, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983, Australia.
E-mail address: lesley.gibson@dpaw.wa.gov.au (L.A. Gibson).

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species (Franklin et al., 2005; Start et al., 2012). The arrival of the exotic cane toad (*Rhinella marina*) is likely to add further pressure to already modified and vulnerable ecosystems. As such, escalating threatening processes on the Kimberley mainland has raised the profile of its off-shore islands as important natural sanctuaries (CCWA, 2010). A major Western Australian state government initiative, *The Kimberley Science and Conservation Strategy* (Department of Parks and Wildlife, 2011), has been implemented to conserve the Kimberley's unique environment, and a component of this strategy is to protect priority Kimberley islands through reservation and joint management with Traditional Owners.

Formed as a result of rising sea levels, the > 2500 continental-shelf islands along the Kimberley coast are thought to have last been part of the mainland as recently as 8000 to 10,000 years ago (Burbidge and McKenzie, 1978). Of these, only 145 islands are at least 100 ha in area and just 20 are > 1000 ha; only 12 are reserved for conservation (CCWA, 2010). Coastal aboriginal people possessed watercraft in this region so these islands have a history of seasonal occupation and use (Vigilante et al., 2013). With a few exceptions, these islands have remained largely free of invasive species and are less altered by contemporary fire regimes than the adjacent mainland (McKenzie et al., 2009; Gibson and McKenzie, 2012). Collectively, the islands are near-pristine examples of the coastal Kimberley's geology and vegetation (Gibson and McKenzie, 2012). Like the mainland, the islands also demonstrate a high level of cryptic diversity (Köhler, 2011; Oliver et al., 2012; Moritz et al., 2016). In the last decade or so, the coastal region of the Kimberley has increasingly been exposed to disturbances associated with tourism, fishing, aquaculture, mining, and oil and gas exploration (Carwardine et al., 2011). While these industries bring economic benefits to the region, they also pose potential risks to the biodiversity values of the islands.

To help inform the setting of conservation priorities for these important refuges, we systematically sampled the occurrence of mammal, bird, reptile and vascular plant species on 27 of these islands. Biodiversity patterns on continental-shelf islands are a function of species assemblages at the time of isolation, species persistence since isolation and accumulation of species through time via over-water colonization (Losos and Ricklefs, 2010). Geographical factors and regional environmental conditions of islands such as area, isolation, topographic complexity, habitat heterogeneity and climate, as well as intrinsic factors such as dispersal capability and ecological tolerance of species are likely to influence the relative importance of these processes (Cabral et al., 2014; Triantis et al., 2015). Given that the permeability of these continental fragments is more likely to be akin to habitat islands on the mainland than oceanic islands, particularly for high dispersal taxa, the biogeographic patterns observed are likely to offer some insight into the long-term consequences of fragmentation on the mainland (Tscharntke et al., 2012). Additionally, the relative lack of contemporary anthropogenic disturbance in this island system makes it an ideal model to examine the consequences of 'natural' fragmentation minus the confounding effect of human disturbance.

Here we specifically evaluate the level of cross-taxon congruence in both species richness and composition among the Kimberley islands sampled. Common biogeographic patterns among multiple taxonomic groups helps to prioritize areas for conservation effort, as conservation actions for one group are also likely to benefit the others (Heino, 2010). We then determined what biogeographical and environmental factors (e.g. island area and isolation, topography and climate) correlate with patterns in both species richness and composition. Finally, we examined the conservation implications of the observed biodiversity patterns in the context of the richness of regional endemic species, and the level of species replacement, nestedness and the minimum number of islands required to represent all species.

2. Material and methods

2.1. Study area

We selected a subset of the largest islands for sampling, targeting those with a variety of geological surfaces, as well as ensuring geographic coverage (Fig. 1). Although many islands are separated from the mainland by narrow channels, those connected to the mainland by mangroves, littoral mudflats or reef exposed at low tide were avoided. All 27 islands were uninhabited and there is no agricultural activity on the islands. The geomorphology of the islands resembles that of the adjacent mainland (Burbidge et al., 1991). Sandstone and volcanic strata comprise most of the structural elements of the island landscapes. The sandstone units tend to give rise to rugged, dissected terrains, while the volcanics usually produce more rounded and undulating topography.

Broad vegetation communities on the islands include eucalyptus savannah woodlands, hummock grassland, monsoonal rain forest, coastal tussock grassland, riparian paperbark woodland and mangroves. The area experiences a tropical monsoon climate with a pronounced dry season extending from around April to October, and a wet season from November to March when almost all rainfall occurs. Cyclonic activity is also a feature of the climate, with an average of two cyclones crossing the northwest Australian coast each wet season. Average annual rainfall ranges from 1500 mm in the northwest to 800 mm in the southeast and northeast, and average maximum temperature ranges from 25 °C to 35 °C. Aside from the wet season, freshwater is limited on the islands and their wetlands are almost all ephemeral.

2.2. Sampling strategy

We selected sites on the islands based on geology and vegetation associations, satellite imagery and a reconnaissance flight (see Gibson and McKenzie, 2012). Two sites were needed to access the environmental variation of the largest islands. Wanjina-Wunggurr Uunguu, Wanjina-Wunggurr Dambimangari, Balanggarra and Bardi-Jawi native title determinations and the Mayala native title claim together cover all of the islands sampled (Vigilante et al., 2013). Accordingly, we gained approval from Traditional Owners (TOs) to access the islands, and TOs joined the field teams. In the dry season, sites were accessed by a helicopter and sampled over a six-day period. Sites were then revisited in the wet season using a combination of charter boat and helicopter, and sampled opportunistically over a single day and night. In total, 34 sites were sampled over five dry and three wet seasons from 2007 to 2014.

Sampling strategies used were specific to each of the targeted taxonomic groups (see *Supplementary methods* in Supplementary material (Appendix A)). We aimed to sample each of the taxonomic groups as systematically as possible within each of the selected habitat types. However, birds were sampled opportunistically due to time constraints and search emphasis for bats was placed on specific habitats. We combined occurrence data across habitat type and sampling occasion for each island. To increase the comprehensiveness of these lists, we supplemented the data with verified records from previous surveys (e.g. Burbidge and McKenzie, 1978), with the exception of the plants due to overwhelming sampling bias (i.e. greater sampling effort on larger islands), and constituted a best-available species list for each of the islands sampled. We excluded marine birds and reptiles from the analysis. See Table S1 in Supplementary material (Appendix A) for source of the datasets for each taxonomic group and details regarding sampling effort. The species by island data matrix is provided in Supplementary material (Appendix B).

2.3. Island attributes

Given a sample size of 27 islands, we were restricted in the number