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# Predicting island biosecurity risk from introduced fauna using Bayesian Belief Networks

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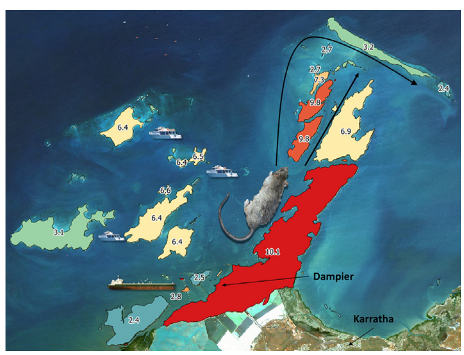
## HIGHLIGHTS

- The biosecurity problem for many regions is one of prioritizing surveillance sites.
- Bayesian Belief Networks (BBNs) link five invasive species (NIS) dispersal pathways.
- Dispersal by ocean current, flood plume, land bridge, swimming, or human-mediated.
- We estimate the number of arrivals and probability of establishment for 11 species.
- We automated the computation of species- and site-specific biosecurity BBNs.

## GRAPHICAL ABSTRACT




Number of black rats (*Rattus rattus*) expected to arrive on islands within the Dampier Archipelago each year. The Burrup Peninsula (red) is connected to the mainland via a causeway which crosses industrial salt evaporation ponds. Travelling north-east, rats may swim or cross tidal land bridges. Rats may stowaway on recreational or industrial boats to outer islands.

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## ABSTRACT

Around the globe, islands are the last refuge for many threatened and endemic species. Islands are frequently also important sites for recreation, cultural activities, and industrial development, all of which facilitate the establishment of invasive species. Surveillance is employed on islands to detect the establishment of invasive species after their arrival, leading to decisions about follow-up actions. Unless surveillance is prioritised according to risk of establishment of invasives, it may be infeasible to implement efficiently over large tracts of publicly accessible land, especially in data-deficient areas. The key biosecurity problem for many regions is one of prioritizing sites for surveillance activities and identifying invasive species most likely to disperse to, and establish, and proliferate on those sites. We created a series of Bayesian Belief Networks (BBNs), linked by Java computing code and the freely available GeNIe application to automate the creation and computation of species- and site-specific biosecurity BBNs. The BBNs require data on island attributes, recreational or industrial visitor load, infrastructure, habitat availability, and animal behaviour and dispersal via swimming, flying, human movement, land bridges, or flood plumes. We used this biosecurity BBN to estimate the risk of 11 invasive faunal species arriving and establishing on 600 islands along the Pilbara coastline, Western Australia. Sensitivity analyses were conducted to identify nodes within the BBNs that required refined data inputs. Propagule pressure was the node with the greatest influence over the number of arrivals. Other nodes such as the number of visitors to islands and swimming

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capabilities of invasive animals greatly influenced the model results. Across the 11 species studied, our models predicted one arrival per 300 visitors. The biosecurity BBN can be used to identify the islands at highest risk from establishment of invasive species within any archipelago/s, and the invasive species most likely to establish on each island.



## 1. Introduction

Invasive species are one of the leading causes of animal extinctions globally (Clavero and Garcia-Berthou, 2005). The introduction of invasive non-indigenous species (NIS) to natural environments can affect the structure and function of established ecosystems. Ecological interactions between native and invasive species may be direct (e.g., predation, herbivory, parasitism, competition, mutualism) or indirect (e.g., habitat alteration and nutrient cycles, cascading trophic interactions) and result in severely disrupted ecosystem dynamics (Ives and Carpenter, 2007; Sakai et al., 2001). While the small size and relative isolation of islands buffer them from global NIS transport (Cope et al., 2016), islands remain particularly prone to NIS because their low diversity of native species compared with continents means that they are poorly protected by biotic barriers to naturalization and invasion (Mack and Lonsdale, 2002).

Quarantine and surveillance are two tools employed to restrict the spread of invasive species to islands. Quarantine programs aim to reduce the risk of NIS arriving on islands and typically focus on the most likely source populations of NIS or dispersal pathway (Cope et al., 2016; Faulkner et al., 2017). Quarantine programs are difficult to implement on publicly accessible natural lands because, as the number of source populations and dispersal pathways available to NIS increases, so too does the area to be searched and treated, which quickly makes quarantine cost-prohibitive. Domestic quarantine programs tend to rely heavily on education and outreach to raise awareness among the users of natural lands of the potential to spread NIS (Boser et al., 2014). Surveillance programs, on the other hand, aim to find NIS after their arrival but before their populations become large and potentially uncontrollable, and hence are designed to search high-risk areas more often (Moore et al., 2010; Whittle et al., 2013).

The key biosecurity problem for most islands is one of prioritizing islands for surveillance activities and identifying NIS most likely to disperse to, establish, and proliferate on islands. Biosecurity risk assessments frequently appear in the form of ranked lists of species that identify the greatest threats for an area (Gordon et al., 2011; Lohr et al., 2015; Pheloung et al., 1999). Many risk assessments, however, are built on limited data, and a limited number of poorly defined species, characteristics, or measures related to NIS dispersal (Dahlstrom et al., 2011). Pest risk maps are a recommended tool for identifying high risk NIS and surveillance sites (Venette et al., 2010) because modern computational power allows analysts to combine complex models with spatial data sets to produce refined risk-assessment results (Koch et al., 2013). Unfortunately, these pest risk maps are frequently not designed to be used in data-deficient areas, on poorly studied NIS, or by land managers. Many of these maps are also generated for entire continents, and hence produce results at a resolution that is uninformative for site-specific surveillance programs. Additionally, classical two-dimensional spatial spread models usually depict the spread of invasive species as a diffusion across the landscape, which has limited applicability to long-distance dispersal events which are better depicted by networking models (Koch et al., 2013), especially across a hostile matrix. These deficiencies may explain some of the failures to implement risk assessments (Dahlstrom et al., 2011).

In this manuscript we describe a new pest risk mapping system built using a series of generic Bayesian Belief Networks (BBNs), which are linked by Java computing code and the freely available GeNIe application to automate the creation and computation of species- and site-specific biosecurity BBNs. The BBNs have been designed to produce high-resolution estimates of biosecurity risk. Specifically, the models estimate for each island, the number of individuals of multiple species arriving, the number of individuals using each dispersal pathway, and the annual risk of NIS establishment for each species, despite uncertainty in data inputs. We have used this biosecurity BBN to estimate the risk of 11 invasive faunal species arriving via five dispersal pathways and establishing on 600 islands along the Pilbara coastline, Western Australia. We hypothesised that common household pests (*Rattus rattus* and *Mus musculus*) would be the most likely NIS to disperse to islands, and that recreational boats would be greatest contributor to NIS dispersal because most long-distance introductions of NIS to new areas are the direct or indirect result of human activities (Sakai et al., 2001; Clout and Veitch, 2002). Industry is subject to far stricter quarantine protocols than recreational island users. The automation of the creation of high-resolution biosecurity risk estimates using relatively little data to describe surveillance sites and NIS of interest means our BBN code is flexible and applicable to any archipelago globally.

## 2. Material and methods

### 2.1. Study area

In the Pilbara region of Western Australia there are 601 islands spread out over 30,000 km$^2$ of ocean with an approximate total land area of 500 km$^2$ (Fig. 1).The isolation of the Pilbara islands, with only 45,000 people (ABS Stat, 2015) living along 740 km of Pilbara coast, makes them good refuges for threatened and endemic species including mala (*Lagorchestes hirsutus*) translocated from the mainland, Shark Bay mouse (*Pseudomys fieldi*), translocated from Shark Bay islands, Rothschild's rock-wallaby (*Petrogale rothschildi*), Northern quoll (*Dasyurus hallucatus*), four species of nesting turtles and numerous seabirds species. Even with their isolation, however, the islands are poor candidates for protection through quarantine. Twenty-two (3.6%) of these islands have some form of industrial activity or marine navigational equipment and are subject to quarantine programs. A large number of other islands are used for recreational activity with little or no biosecurity programs. Approximately one in ten people in the Pilbara own a boat (ABS Stat, 2015; Department of Transport, 2014), any of which may be launched from one of four marinas or numerous small boat ramps along the coast. The remoteness of the islands and their sheer number mean that data on biotic and abiotic characteristics and patterns of human use are scarce (Lohr et al., 2015).

We used BBNs to estimate the probability of 11 faunal NIS arriving and establishing on each island: cow *Bos taurus*, dog *Canis familiaris*, pigeon *Columba livia*, horse *Equus caballus*, cat *Felis catus*, Asian house gecko *Hemidactylus frenatus*, mouse *Mus musculus*, rabbit *Oryctolagus cuniculus*, black rat *Rattus rattus*, cane toad *Rhinella marina*, and red fox *Vulpes vulpes*. These NIS species are already present on Pilbara islands or are present on the nearby mainland and were identified by experts as having the potential to disperse to islands. Five dispersal pathways were identified by experienced island managers for this suite of species: swimming or flying; crossing temporary tidal land bridges; rafting on flooded river plumes; and human-facilitated dispersal via recreational visitors or industrial workers.