RAFFLES BULLETIN OF ZOOLOGY Supplement No. **30**: 17–23
Date of publication: 25 December 2014
http://zoobank.org/urn:lsid:zoobank.org:pub:9EC32B64-5B91-419E-B423-8A6FF32B7297

Conservation management of the terrestrial biodiversity of Christmas Island: challenges and perspectives

Michael Misso[1*] & Judy West[2]

Abstract. Christmas Island is a tropical oceanic island with biodiversity of immense international conservation significance. Like other remote oceanic islands, it is a significant seabird rookery and has a high degree of species endemism. The island's tropical rainforests are characterised by the most diverse and abundant land crab community on earth, particularly the endemic red crab (*Gecarcoidea natalis*) which significantly influences the ecology of the island's rainforests. The island also has two wetlands, The Dales and Hosnies Spring, listed as wetlands of international importance under the Ramsar Convention. Components of Christmas Island's biodiversity are under significant threat and some species have become extinct since human settlement in 1888 while others are in decline. These declines are primarily due to the island's intrinsic ecological vulnerability, combined with invasive species, particularly yellow crazy ants (*Anoplolepis gracilipes*), and human impacts, including through clearing of a quarter of the island's rainforest since settlement. Biosecurity threats also place additional potential pressures on the island's biodiversity. Despite the threats facing Christmas Island's biodiversity, populations of several threatened species are stable and a range of conservation actions are being implemented which, if continued and/or expanded, will support the recovery of Christmas Island's unique and internationally significant biodiversity.

Key words. Christmas Island, conservation management, terrestrial

INTRODUCTION

Christmas Island (10°30'S, 105°39'E) is a tropical oceanic island of 135 km^2 with 73 km of coastline, located about 2800 km west of Darwin (Australia) and 500 km south of Jakarta (Indonesia) (Director of National Parks, 2014). The island is composed of limestone on the top of a basaltic volcanic seamount and is step-terraced (reflecting its origin and changing sea levels over the past several million years) and is fringed by coral reefs (Beeton et al., 2010). About one quarter of the tropical rainforest that originally covered the island has been cleared since it was first settled in 1888 (Director of National Parks (DNP), 2014).

Most residents were born in Australia or Malaysia and are of Chinese, Australian European or Malaysian descent and in 2011 the resident population was 2072 (Australian Bureau of Statistics, 2013). The main economic activities are mining of low-grade phosphate, some tourism and provision of government services, including operation of an immigration detention centre (Department of Infrastructure and Regional Development, 2014a). Christmas Island is administered in accordance with Australian Government legislation (the Christmas Island Act 1958*)* which provides the legislative basis for the Territory's administrative, legislative and judicial systems (Department of Infrastructure and Regional Development, 2014b); certain other Australian Government legislation and laws of the State of Western Australia also apply. The Shire of Christmas Island is responsible for the delivery of municipal services to island residents.

Of the island's land area, major land uses and allocations include mine lease (13.7%); uncommitted Crown Land (19.2%); other committed land (4.1%) and national park (63%) (DNP, 2014). Christmas Island National Park is managed by the Australian Government Director of National Parks (DNP) and covers approximately 63% of the Territory's land-mass, as well as a marine zone extending 50 m seaward of the national park's low water line (DNP, 2014). The national park is a Commonwealth reserve under Australian Government legislation (the Environment Protection and Biodiversity Conservation Act 1999—EPBC Act) declared for the preservation of the area in its natural condition and the encouragement and regulation of the appropriate use, appreciation and enjoyment of the area by the public (DNP, 2014).

SUMMARY OF CHRISTMAS ISLAND'S BIODIVERSITY VALUES

For the purpose of this paper, only Christmas Island's terrestrial biodiversity values will be described. This is primarily because terrestrial biodiversity is most under threat, and a more detailed paper would be needed to adequately

[1]Manager, Christmas Island National Park, Parks Australia, PO Box 867 Christmas Island Indian Ocean 6798 Australia, Department of the Environment; Email: Michael.Misso@environment.gov.au (*corresponding author)

[2]Executive Director, Australian National Botanic Gardens; and Assistant Secretary, Parks Australia, Island and Biodiversity Science, Department of the Environment; Email: Judy.West@environment.gov.au

ISSN 2345-7600 (electronic) | ISSN 0217-2445 (print)

describe the biodiversity values of the island's less well-known marine and subterranean environments.

Similar to other emergent oceanic islands, Christmas Island's native species are derivatives of colonisers from distant land masses that arrived naturally by air or ocean currents, leading to the formation of unique ecological communities (Beeton et al., 2010). For instance, Christmas Island supports more than 200 endemic species and subspecies of flora and fauna (DNP, 2008), as well as unique rainforest ecosystems.

Christmas Island's vegetation comprises four primary types (Claussen, 2005). Most common is evergreen tall rainforest which occurs in areas with deep soils on the plateau, and is also found on deep soil terraces. Semi-deciduous rainforest occurs on shallower soils and is common on terraces and slopes and on shallow soil plateau areas. Deciduous scrub is restricted to areas with less soil on terraces, steep slopes and inland cliffs. Herbland is the least common vegetation type and exists occasionally between the scrub and the coastal cliffs in more exposed areas.

Flora species diversity and composition is relatively low, largely reflecting the island's geological and geographical isolation and remoteness; endemic species include *Pandanus elatus*, the Arenga palm (*Arenga listeri*) and the threatened Christmas Island spleenwort (*Asplenium listeri*). As with oceanic islands generally, many plants have been deliberately or accidentally introduced as a result of human settlement, with more than half of the recorded flora now exotic including many that pose a significant weed problem (DNP, 2014).

One of the island's most ecologically conspicuous features, which characterises and influences the ecology of its rainforest, is its land crab fauna. The island has the largest and most diverse land crab community in the world (DNP, 2008) and notable species include the freshwater-inhabiting blue crab (*Discoplax celeste*) previously known as *Discoplax hirtipes* but now recognised as a distinct endemic species (Ng & Davie, 2012); the world's largest terrestrial arthropod, the robber crab (*Birgus latro*) which, although widespread throughout the Indo-Pacific, has its largest and best protected population on Christmas Island (Beeton et al., 2010; Orchard, 2012); and the endemic omnivorous red crab (*Gecarcoidea natalis*).

Red crabs are the most abundant of the land crab species, with an estimated population of 40 to 47 million (DNP, 2011) and they dominate the forest floor of intact rainforest, consistently controlling the dynamics of seedling recruitment (Green et al., 2008). The ecological role of red crabs shaping the floor and lower strata of the forests is a unique feature of the island and is internationally significant (Beeton et al., 2010). Also internationally significant is the annual migration undertaken at the beginning of the wet season, when tens of millions of red crabs emerge from their burrows and make their way to the sea to breed in one of the world's most spectacular breeding migrations and natural wonders (Ng & Davie, 2012; Orchard, 2012).

Along with its highly conspicuous crab fauna and unique crab-dominated rainforests, the island's natural environment is most strongly characterised by its bird fauna (Beeton et al., 2010). Like many oceanic islands, Christmas Island is an internationally significant seabird rookery (Beeton et al., 2010) and has been declared an Endemic Bird Area by BirdLife International (BirdLife International, 2013). There are seven endemic land bird species and eight species and one subspecies of seabird that breed on the island (DNP, 2014). Seabirds of conservation significance include two endemic species listed under the EPBC Act as threatened—Abbott's booby (*Papasula abbotti*), a large, long-lived seabird with the only known extant nesting colony on Christmas Island (Department of the Environment and Heritage, 2004); and the Christmas Island frigatebird (*Fregata andrewsi*), the island's rarest seabird (Hill & Dunn, 2004)— and the endemic subspecies of the white-tailed tropicbird (*Phaeton lepturus fulvus*) listed as threatened under the IUCN Red List (Garnett et al., 2010). Endemic forest birds listed as threatened are the Christmas Island goshawk (*Accipiter hiogaster natalis*), the rarest endemic bird (Hill, 2004a); the Christmas Island hawk-owl (*Ninox natalis*), mostly found in primary and marginal rainforests (Hill, 2004b); the Christmas Island emerald dove (*Chalcophaps indica natalis*); and the Christmas Island thrush (*Turdus poliocephalus erythropleurus*).

Two of the island's wetlands, The Dales and Hosnies Spring, are listed under the Ramsar Convention as Wetlands of International Importance. The Dales is a series of seven small freshwater streams predominantly surrounded by semi-deciduous forest and a range of karst features. The combination of the variety of habitats and permanent surface water provides the physical habitat that supports a wide diversity of endemic and listed threatened species including the hawk-owl, thrush and goshawk (Hale & Butcher, 2010). The site plays host to the annual red crab migration, provides critical habitat for blue crabs and supports a diverse community of tree species and epiphytes. At Hughs Dale, and in parts of Anderson Dale and Sydneys Dale, there are mono-dominant stands of Tahitian chestnut (*Inocarpus fagifer)* and the rare epiphytic ribbon fern (*Ophioglossum pendulum*); the endemic arenga palm and Ridley's orchid (*Brachypeza archytas*) are also common.

Hosnies Spring is a small permanent, shallow freshwater wetland, fed by a natural spring system located approximately 30 me above sea level and 120 m inland of the seaward cliff. The wetland is covered by a stand of mangroves, including *Bruguiera gymnorhiza* and *B. sexangula*, which is estimated to be 120,000 years old (Woodroffe, 1988). The site is remarkable because of the length of persistence of the mangrove stands and their occurrence at an elevation not recorded elsewhere in the world. The site also supports red, robber and blue crabs, as well as endemic and/or listed threatened species such as the Christmas Island imperial pigeon (*Ducula whartoni*) and the Christmas Island flying fox (*Pteropus melanotus natalis*) (Hale & Butcher, 2010).

Only the most conspicuous and characteristic aspects of Christmas Island's terrestrial biodiversity have been described

but it is clear that Christmas Island's unique biodiversity is of immense international conservation significance.

CONSERVATION MANAGEMENT CHALLENGES

The management challenges facing the conservation of Christmas Island's terrestrial biodiversity are largely due to the island's intrinsic ecological vulnerability, combined with the impacts of invasive species and human activities, as well as biosecurity threats.

As a result of the serious decline of the Christmas Island pipistrelle (*Pipistrellus murrayi*), in 2009, the then Australian Government Minister for the Environment, Heritage and the Arts established a scientific Expert Working Group to review threats to the biodiversity of Christmas Island. In its final report (Beeton et al., 2010), the Expert Working Group described the uniqueness of the island's biodiversity and its close links to the island's geographic and geological isolation which greatly affects its vulnerability. Because of small founder numbers, populations on isolated islands usually have little genetic heterogeneity and limited ecological resistance to perturbations (Beeton et al., 2010). Christmas Island is no exception as its biodiversity is threatened by introduced species and human-related landscape changes (Beeton et al., 2010; DNP, 2008).

The vulnerability of Christmas Island's biodiversity is reflected through the listing of 17 terrestrial species as threatened; invasive species are directly implicated in several species declines. The island's two endemic rats, Maclear's rat (*Rattus macleari*) and the bulldog rat (*R. nativitatis*), were likely to have become extinct by the early 1900s as a result of an exotic pathogen (*Trypanosoma lewisi*) carried by introduced black rats (*R. rattus*) (Wyatt et al., 2008). Cats (*Felis catus*), also introduced during settlement, are numerous and widespread (Algar & Johnston, 2010); species that may be at risk from cats (at least in part) include the emerald dove, the hawk-owl, the thrush, Lister's gecko (*Lepidodactylus listeri*), the blue-tailed skink (*Cryptoblepharus egeriae*), the forest skink (*Emoia nativitatis*) and the red-tailed tropicbird (*Phaethon rubricauda*) (Algar & Johnston, 2010). Accordingly, the Expert Working Group recommended immediate measures to exclude cats from red-tailed tropicbird nesting areas and the coordinated eradication of cats and rats (Beeton et al., 2010).

The island's iconic red crabs are threatened by highly invasive introduced yellow crazy ants (*Anoplolepis gracilipes*) which form dense super-colonies. It has been estimated that the red crab population has been reduced by a quarter to a third (O'Dowd et al., 2003). In addition to their keystone species role, red crabs also provide biotic resistance to invaders, including some introduced plant and mollusc species, and accelerated rates of spread may occur following elimination of red crabs from invaded rainforests (O'Dowd et al., 2003).

Christmas Island's terrestrial native reptile fauna has suffered major declines since the early 1990s, most likely in response to the impacts of introduced reptiles and other invasive species. Three endemic native reptiles may already be close to extinction in the wild and a captive breeding programme is underway with the goal to release individuals back into the wild once threatening processes have been understood and mitigated (DNP, 2014).

Because of the impacts of introduced invasive species, Beeton et al. (2010) identified a lack of biosecurity management for much of Christmas Island's history as the major cause of biodiversity decline. The Australian Government Department of Agriculture manages the island's biosecurity systems to minimise the risk of introduction of exotic pests and diseases (Department of Agriculture, 2013). Nevertheless, despite these efforts, biosecurity threats remain a major management challenge and there have been additional biosecurity pressures in recent years. For instance, the number of Suspected Illegal Entry Vessels (SIEV) carrying asylum seekers to Christmas Island significantly increased. Correspondingly, the resident population increased from 1349 in 2006 to 2072 in 2011 (Australian Bureau of Statistics, 2013) and numbers of fly-in and fly-out workers have also risen. Consequently, there has been an increase in freight shipments, mainly associated with the need to expand accommodation and infrastructure due to detention activity (Beeton et al., 2010).

The increase in the island's population may not necessarily pose a direct biosecurity threat but the increase in freight and SIEV entries may. For example, on 21 January 2013 an unoccupied SIEV freed its moorings at the island's principal wharf (Flying Fish Cove) during high swells and broke up on the shoreline, releasing at least three rats and hundreds of exotic invertebrates; and in early 2013 two exotic microbats were found around shipping containers. Not surprisingly, the Expert Working Group identified as a priority recommendation that biosecurity management be upgraded urgently to a standard commensurate with Christmas Island's biodiversity values (Beeton et al., 2010).

While there is no doubt that existing invasive species and biosecurity pressures pose major threats to Christmas Island's biodiversity, human activities also pose a direct threat. There have been large increases in vehicle numbers and activity associated with the increase in the island's population. For instance, traffic activity count data on Murray Road showed a 480% increase between 2001 and 2012, from 86.2 average daily traffic trips to 499.6 average daily traffic trips (Shire of Christmas Island, 2012). This increase in traffic has led to significant increases in robber crab mortality from vehicles. In response, the DNP initiated a programme to monitor mortality rates, which has recorded 2575 deaths from January 2010 to June 2013, with the highest monthly tally of 113 deaths in May 2013 (DNP, 2013). Similarly, each year, during their annual breeding migration, thousands of red crab are killed by vehicles—for example 425,000 deaths were estimated in 2005–2006 (DNP, 2008) and at least 400,000 in 2010 (Robert Muller, pers. comm., 2010). These numbers are about one percent of the estimated 2011 red crab population of 40 to 47 million (DNP, 2011). Cumulative losses to vehicles over several years could have a major impact on the red crab

population including by reducing ecological resilience to other threats (particularly crazy ants) and poor recruitment processes.

Another direct human impact has been the clearing of approximately 25% of the island's original rainforest for mining, infrastructure and settlement, which has resulted in some species declines through direct habitat loss. For example, the Abbott's booby population has primarily declined due to clearing of a third of its original primary rainforest nesting habitat for phosphate mining (Garnett et al., 2010) and clearing of hawk-owl habitat has decreased its total population size (Hill, 2004b). While phosphate mining still occurs (on sites with secondary re-growth vegetation), clearing of the island's original rainforest has effectively ceased. Actions that may or are likely to have a significant impact on a matter of national environmental significance (e.g., listed threatened species) need to be assessed and approved under the EPBC Act. This requirement has, to date, protected original remaining rainforests from clearing. Additionally the clearing of native vegetation, including secondary re-growth on previously cleared sites, must be assessed (and where appropriate may be approved) under applied Western Australian legislation. These legislative requirements lessen the likelihood that vegetation clearing poses a significant current threat to biodiversity. Undoubtedly, however, past rainforest clearing has reduced the area of critical habitat available for some threatened species (particularly the Abbott's booby) and has lowered population recovery potential, as well as exacerbated impacts from other threats such as invasive species and stochastic events like storms or cyclones.

While it is clear that invasive species and human activities threaten the island's biodiversity, with some exceptions (particularly crazy ants, vehicle mortality on land crabs and cat predation of ground-nesting seabirds), the specific reasons for the decline of many species are not known. Beeton et al. (2010) hypothesised that declines were related to disease, predation or ecological shifts, leading to increased predation, physiological disruption, habitat change or changes in food availability. Yet Beeton et al. (2010) only identified two cases (in addition to those above) where the specific cause of the decline of endemic species is definitely known, namely Maclear's rat and the bulldog rat. Likewise, of the nine recovery plans prepared for the listed threatened species on the island, few clearly identify the threats causing species declines and most include research actions to identify threats. In the case of the pipistrelle, its recovery plan states that population decline was caused by unidentified threatening processes, most likely invasive species, habitat loss and alteration, climatic conditions and decreasing population size (Schulz & Lumsden, 2004). Notwithstanding the substantial actions undertaken to research and monitor threats (e.g., DNP, 2008; Lumsden et al., 2007) and ongoing management actions of national park staff, the pipistrelle continued to decline—either because its principal threat evaded identification or effective management or due to the complexity of multiple threats (Beeton et al., 2010).

The decline of the pipistrelle highlights several conservation management challenges. Firstly, despite relevant scientific expertise and considerable effort, it can be difficult to determine the specific threatening processes causing declines. Secondly, management decisions and recovery actions need to be undertaken in the absence of adequate knowledge of the prevailing threats. And thirdly, difficult choices may be required in the allocation of available conservation resources, especially if threats are not known or quantified.

Triage in a conservation context is the process of prioritising the allocation of resources to maximise conservation returns, relative to the conservation goals, by explicitly accounting for the factors of cost, benefits and likelihood of success of alternative conservation actions (Bottrill et al., 2008). For some species recovery actions (e.g., red crabs) these factors are clear but for other species they are not. In the case of the island's declining native reptiles, multiple threats are likely to be responsible, particularly predation by a range of invasive species (Cogger, 2006; Schultz & Barker, 2008; Beeton et al., 2010; Smith et al., 2012). Assuming threats can be determined for declining species (which itself can be difficult), developing, resourcing and implementing feasible threat mitigation actions may be a considerable management challenge.

An underpinning management challenge is the need for holistic and collaborative approaches to address the threats causing biodiversity decline. Conservation problems are island-wide and accordingly management responses need to also be island-wide and beyond just the jurisdictional span of the national park. Beeton et al. (2010) identified several immediate high priority island-wide recovery actions including biosecurity improvement, eradication of cats and rats and the further escalation of biological control of crazy ants. Another high priority recommendation was the establishment of more effective environmental governance and management frameworks. The Australian Government response to the Expert Working Group report did not support this recommendation but instead supported improved coordination and collaboration among agencies in relation to environmental management (Parks Australia, 2011). As described below, such coordination and collaboration is occurring and, if continued and enhanced, should significantly contribute to recovery of Christmas Island's biodiversity.

THE FUTURE FOR CHRISTMAS ISLAND'S TERRESTRIAL BIODIVERSITY

Given several species extinctions and declines of other species (particularly the Christmas Island flying fox, Christmas Island frigatebird and terrestrial reptiles) it may appear that the future for Christmas Island's biodiversity is not promising with little likelihood of halting these declines and recovering the island's remaining biodiversity. However, some listed threatened species remain in a healthy state and there are indications that others are recovering or have the potential to do so with active management.

While crazy ants have caused significant declines in red crab numbers, these declines may be halting. An island wide survey (IWS) is carried out every two years to map crazy ant super-colonies and collect population data for the red crab. The 2011 IWS showed that the red crab population has increased by 3 to 8% since 2009 (DNP, 2011). If a halt in declines is occurring, it may be linked to aerial baiting of crazy ants carried out in 2002, 2009 and 2012; baiting of super-colonies with 'AntOff' has been demonstrated to reduce crazy ant densities by 99.4% (Green et al., 2004; Boland et al., 2011) and crab numbers appear to be slowly increasing in some sites baited in 2009 (DNP, 2011). While baiting is effective and pre and post-baiting studies provide no evidence that the active ingredient of AntOff (fipronil) is accumulating in the environment (CESAR, 2013), baiting is not viewed as a viable long-term control method. In 2009, the DNP funded La Trobe University to investigate the indirect biological control of crazy ants as an alternative long term control method. The results of this research indicate that long-term, sustainable suppression of crazy ant super-colonies could be achieved through a host-specific biological control agent that would indirectly affect crazy ants by reducing carbohydrate supply provided by scale insects, a key resource implicated in super-colony dynamics.

Based on the results of the biological control research, in July 2013, the DNP and La Trobe University agreed to trial, implement and monitor a biological control programme, subject to relevant environmental assessments and approvals. Crazy ant management activities carried out by the DNP are advised by the independent Crazy Ant Scientific Advisory Panel (CASAP). Thus a conservation outcome focused research and management approach, through collaboration between CASAP, La Trobe University and the DNP, is helping to address the greatest single known threat to Christmas Island's biodiversity. The efforts to control crazy ants have been possible due to the allocation of considerable Australian Government funding since 2007–2008 and which is committed until at least 2015–2016. Undoubtedly, the scientific evidence and approach, and the ability for CASAP members to provide independent advocacy and advice, have been major factors influencing the commitment of such funds. This provides but one example demonstrating the benefits that collaboration between the DNP, scientists and management agencies is achieving.

Like crazy ants, vehicles are a threat to red crabs. To reduce mortality, the DNP, in collaboration with key stakeholders and the community, implements a range of coordinated cross-tenure mitigation activities. Specially designed grid-style underpasses and fences are installed on several roads with high numbers of migrating red crabs to channel crabs under the road during their migration (Orchard, 2012). With the support of the Shire of Christmas Island, selected roads are closed both inside and outside the national park during peak crab migration periods and community awareness activities are also conducted.

Many community members and organisations actively support and are strong advocates of DNP efforts to protect crabs. For example, some community members use rakes to remove red crabs from roads in settled areas during the migration and the Christmas Island District High School has adopted the red crab as its icon and has painted a robber crab and the slogan 'slow down drive around' on a school vehicle. The school and Island Care, a local environment group, have also prepared road signs using student's art work to encourage people to avoid driving over red crabs. The combined efforts of the DNP, stakeholders and the community have resulted in significant reductions in red crab mortality over recent years (DNP, 2013). Through these efforts not only are red crab mortality rates reducing, there are direct community connections to conserving Christmas Island's biodiversity, thereby providing opportunities to foster greater advocacy for its conservation.

There has been similar stakeholder and community support in relation to cat and rat control. From 2010 the DNP and the Shire, in collaboration with other stakeholders (particularly the Australian Government Department of Industry and Regional Development and Phosphate Resources Limited) and based on the scientific expertise of the Western Australian Department of Parks and Wildlife, have implemented an extensive cat and rat control programme. From May 2011 to August 2012 between 417 and 469 feral and stray cats were removed (Algar & Hamilton, 2012). Significantly, this has led to the recovery of red-tailed tropicbirds at their Settlement nesting colony (Algar et al., 2012). While cat and rat control has proven to be successful, a major management challenge is providing ongoing resources to continue these efforts across the island to ensure the outcomes achieved and resources committed to date have not been in vain. Nevertheless, the ongoing collaboration of stakeholders and support of the community increases the likelihood that the recommendations of Beeton et al. (2010) in relation to cat and rat management may eventually be achieved.

While cats may pose a direct threat to forest birds, so do crazy ants. The nesting and foraging success of several listed threatened forest bird species (e.g., the emerald dove and thrush) is affected by crazy ant super-colonies (Davis et al., 2008). However, populations of both species as well as the non-listed Christmas Island white eye (*Zosterops natalis*) are considered relatively abundant and not at risk (Garnett et al., 2010; Smith et al., 2012). This may suggest the potential for these birds to be de-listed as threatened, especially if the biological control of crazy ants proves successful and cat and rat control is implemented across the island. Likewise, population surveys of the hawk-owl in 2012 indicate that there is no immediate concern for its conservation (Woinarski et al., 2012). Similarly, the population of the listed endangered Abbott's booby appears to be stable, based on an analysis of comparative nest occupancy surveys from 2009 to 2011 (DNP, 2012a) and nesting success surveys from 2010 and 2012 (Janos Hennicke, unpublished data).

Actions are also being implemented to enhance and restore Abbott's booby habitat and habitat for other species; the Abbott's booby recovery plan identifies forest rehabilitation as a major recovery action (Hill & Dunn, 2004). Since

2005 the DNP, through agreements with the Department of Infrastructure and Regional Development and funds from a conservation levy paid by Phosphate Resources Limited, has rehabilitated 92 hectares of rainforest through the Christmas Island Mine-site to Forest Rehabilitation Program (DNP, 2012b). The programme currently operates under the Christmas Island Mine-site to Forest Rehabilitation Program Plan 2012–2020 (DNP, 2012c). The ecological benefits resulting from forest rehabilitation will be long-term and will not address the immediate high priority biodiversity threats identified by Beeton et al. (2010). However, when integrated with other recovery actions (especially invasive species control), forest rehabilitation is expected to increase the population recovery potential and ecological resilience of species such as Abbott's booby, forest birds and red crabs; several forest bird species and red crabs are known to inhabit planted forests after several years (DNP, 2012c).

Indirectly, the recovery of Christmas Island biodiversity may be supported through nature-based tourism. The island's biodiversity and natural environment are major tourist attractions (Beeton et al., 2010; Christmas Island Tourism Association, 2013a). A sensitively expanded and promoted nature-based tourism industry may not only provide socio-economic benefits for the community but would also help promote the island's biodiversity values, as well as be a potential advocacy for their conservation. For example, the Christmas Island Tourism Association coordinates the annual Bird and Nature Week, a tourism product focused on the island's biodiversity attractions, involving researchers as guides (Christmas Island Tourism Association, 2013b) with DNP staff providing presentations of conservation management programmes. The Association also engaged Australian Geographic in 2012, with funding from the Department of Infrastructure and Regional Development and with DNP's support, to prepare a documentary showcasing the island's natural attractions as a means of enticing nature-based tourists to the island. The key, however, to a successful nature-based tourism product is an environment that is sufficiently conserved and restored (Beeton et al., 2010; Christmas Island Phosphates, 2010).

To help conserve and recover Christmas Island's biodiversity, a draft multi-species recovery plan for Christmas Island's threatened species has been prepared in accordance with the EPBC Act. The recovery plan incorporates relevant actions from nine existing species-specific recovery plans for listed threatened species, as well as priority Expert Working Group recommendations. The draft plan provides objectives and holistic and cross-tenure actions for conserving Christmas Island's biodiversity. This, combined with effective and collaborative implementation, will provide a foundation to halting the decline in Christmas Island's biodiversity and promote its recovery.

CONCLUSION

Despite over 100 years of impacts of invasive species and clearing of a quarter of its original rainforest, Christmas Island's biodiversity remains an internationally unique and significant attribute of Australia's and the world's natural heritage. Because of the intrinsic vulnerability of the island's biodiversity, addressing current threats and reducing the risks of future ones (particularly biosecurity threats) will be a major and ongoing management challenge. However, while some components of Christmas Island's biodiversity are clearly declining or are threatened, other components remain healthy; and there is potential for recovery of a range of species if priority recovery actions are implemented. Given Christmas Island's significant international conservation, scientific and nature-based tourism values, it is fitting and proper that the island's biodiversity is conserved for future generations.

ACKNOWLEDGEMENTS

The authors would like to thank all of those people past and present who have contributed to the conservation of Christmas Island's biodiversity. This particularly includes current and former Christmas Island National Park staff; external researchers and natural resource management experts; scientific advisors including the Crazy Ant Scientific Advisory Panel and the Christmas Island Reptile Advisory Panel who freely provide their advice and expertise; and Christmas Island stakeholders and community for their support and engagement in national park efforts to recover Christmas Island's biodiversity.

LITERATURE CITED

Algar D & Hamilton N (2012) Report of Stage 2 of the Christmas Island Cat and Black Rat Management Plan – Report to the Shire of Christmas Island and Christmas Island National Park. Department of Environmental and Conservation, Wanneroo Western Australia, 33 pp.

Algar D & Johnston M (2010) Proposed Management Plan for Cats and Black Rats of Christmas Island. Western Australian Department of Environment and Conservation, 71 pp.

Algar D, Hamilton N, Holdsworth M & Robinson S (2012) Eradicating cats and black rats from Christmas Island. Landscope, 27(4): 43–47.

Australian Bureau of Statistics (2013) http://www.abs.gov.au/websitedbs/censushome.nsf/home/data (Accessed 14 April 2013).

Beeton B, Burbidge AA, Grigg G, Harrison P, How RA, Humphries B, McKenzie N & Woinarski J (2010) Final Report, Christmas Island Expert Working Group to Minister for the Environment, Heritage and the Arts, 245 pp.

BirdLife International (2013) Endemic Bird Area factsheet: Christmas Island. Downloaded from http://www.birdlife.org (Accessed 27 April 2013).

Boland CRJ, Smith MJ, Maple D, Tiernan B, Barr R, Reeves R & Napier F (2011) Heli-baiting using low concentration fipronil to control invasive yellow crazy ant supercolonies on Christmas Island, Indian Ocean. In: Veitch CR, Clout MN & Towns DR (eds.) Island Invasives: Eradication and Management. Proceedings of the International Conference on Island Invasives. IUCN, Gland and CBB, Auckland, xii +542 pp.

Bottrill MC, Joseph LN, Carwardine J, Bode M, Cook C, Game ET, Grantham H, Kark S, Linke S, McDonald-Madden E, Pressey RL, Walker S, Wilson KA & Possingham HP (2008) Is conservation triage just smart decision making? Trends in Ecology & Evolution, 23(12): 1–6.

CESAR Consultants (2013) Monitoring of the 2012 Aerial Baiting of Yellow Crazy Ants (*Anoplolepis gracilipes*) on Non-Target Invertebrate Fauna on Christmas Island. Report to the Director of National Parks, Melbourne University, 37 pp.

Christmas Island Phosphates (2010) Christmas Island Business Community Function—Introductory remark by the Chairman of Phosphate Resources Limited to the Christmas Island Business Community on 14 May 2010, 4 pp.

Christmas Island Tourism Association (2013a) http://www.christmas.net.au/ (Accessed 22 June 2013).

Christmas Island Tourism Association (2013b) http://www.christmas.net.au/experiences/bird-watching/bird-n-nature-week.html (Accessed 22 June 2013).

Claussen J (2005) Native Plants of Christmas Island. Flora of Australia Supplementary Series Number 22. Department of the Environment and Heritage, Canberra, 146 pp.

Cogger H (2006) National Recovery Plan for Lister's Gecko *Lepidodactylus listeri* and the Christmas Island Blind Snake *Typhlops exocoeti*. Department of the Environment and Heritage, Canberra, 10 pp.

Davis NE, O'Dowd DJ, Green PT & MacNally R (2008) Effects of an alien ant invasion on abundance, behaviour, and reproductive success of endemic island birds. Conservation Biology, 22: 1165–1176.

Department of Agriculture (2013) http://www.daff.gov.au/biosecurity/quarantine/australias-indian-ocean-territories (Accessed 26 June 2013).

Department of the Environment and Heritage (2004) National Recovery Plan for the Abbott's Booby *Papasula abbotti*. Department of the Environment and Heritage, Canberra, 14 pp.

Department of Infrastructure and Regional Development (2014a) http://www.regional.gov.au/territories/christmas/economics.aspx (Accessed 12 February 2013).

Department of Infrastructure and Regional Development (2014b) http://www.regional.gov.au/territories/christmas/governanceadministration.aspx (Accessed 12 February 2013).

Director of National Parks (2008) Christmas Island Biodiversity Monitoring Program: December 2003 to April 2007. Report to the Department of Finance and Deregulation from the Director of National Parks, 132 pp.

Director of National Parks (2011) The 2011 Island Wide Survey Report on Yellow Crazy Ants and Red Crabs, Christmas Island National Park. Unpublished report, Director of National Parks, Canberra, 19 pp.

Director of National Parks (2012a) Annual Report 2011–12. Director of National Parks, Canberra, 162 pp.

Director of National Parks (2012b) Annual Report for the Christmas Island Minesite to Forest Rehabilitation (CIMFR) Program July 2011 – June 2012. Director of National Parks, Canberra, 33 pp.

Director of National Parks (2012c) The Christmas Island Minesite to Forest Rehabilitation Program 2012–2020 Plan. Director of National Parks, Canberra, 53 pp.

Director of National Park (2013) Annual Report 2012–13. Director of National Parks, Canberra, 160 pp.

Director of National Parks (2014) Christmas Island National Park Management Plan 2014–2024. Director of National Parks, Canberra, 1–166 pp.

Garnett S, Szabo J & Dutson G (2010) The Action Plan for Australian Birds. CSIRO Publishing, Collingwood, 442 pp.

Green PT, Comport S & Slip D (2004) The Management and Control of the Invasive Alien Crazy Ant (*Anoplolepis gracilipes*) on Christmas Island, Indian Ocean: The Aerial Baiting Campaign September 2002. Unpublished Final Report to Environment Australia and the Crazy Ant Steering Committee, 79 pp.

Green PT, O'Dowd DJ & Lake PS (2008) Recruitment dynamics in a rainforest seedling community: context-independent impact of a keystone consumer. Oecologia, 156: 373–385.

Hale J & Butcher R (2010) Ecological Character Description for Hosnies Spring Ramsar Site. Report to the Department of Sustainability, Environment, Water, Population and Communities, Canberra, 61 pp.

Hill R (2004a) National Recovery Plan for the Christmas Island Goshawk *Accipiter fasciatus natalis*. Commonwealth of Australia, Canberra, 18 pp.

Hill R (2004b) National Recovery Plan for the Christmas Island Hawk-Owl *Ninox natalis*. Commonwealth of Australia, Canberra, 16 pp.

Hill R & Dunn A (2004) National Recovery Plan for the Christmas Island Frigatebird *Fregata andrewsi*. Commonwealth of Australia, Canberra, 18 pp.

Lumsden L, Schulz M, Ashton R & Middleton D (2007) Investigation of Threats to the Christmas Island Pipistrelle. A report to the Department of the Environment and Water Resources. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria, 88 pp.

Ng PKL & Davie PJF (2012) The blue crab of Christmas Island, *Discoplax celeste*, new species (crustacean: Decapoda: Brachyura: Gecarcindae). Raffles Bulletin of Zoology, 60(1): 89–100.

O'Dowd DJ, Green PT & Lake PS (2003) Invasional 'meltdown' on an oceanic island. Ecology Letters, 6: 812–817.

Orchard M (2012) Crabs of Christmas Island. Christmas Island Natural History Association, 288 pp.

Parks Australia (2011) Australian Government Response to the Recommendations of the Christmas Island Expert Working Group Report. Parks Australia, 12 pp. http://www.environment.gov.au/parks/publications/christmas/pubs/ewg-report-response.pdf

Schulz M & Barker C (2008) A Terrestrial Reptile Survey of Christmas Island, May–June 2008. Consultancy report for Parks Australia North, Christmas Island, 67 pp.

Schulz M & Lumsden LF (2004) National Recovery Plan for the Christmas Island Pipistrelle *Pipistrellus murrayi*. Commonwealth of Australia, Canberra, 56 pp.

Shire of Christmas Island (2012) Traffic Count Data, unpublished.

Smith MJ, Cogger H, Tiernan B, Maple D, Boland C, Napier F, Detto T & Smith P (2012) An oceanic island reptile community under threat: the decline of reptiles on Christmas Island, Indian Ocean. Herpetological Conservation and Biology, 7: 206–218.

Woinarski J, Flakus S & Tiernan B (2012) Results from a Monitoring Program for the Christmas Island Hawk-Owl *Ninox natalis*. Parks Australia unpublished report, 17 pp.

Woodroffe CD (1988) Relict mangrove stand on last interglacial terrace, Christmas Island, Indian Ocean. Journal of Tropical Ecology, 4: 1–17.

Wyatt KB, Campos PF, Gilbert MTP, Kolokotronis S-O, Hynes WH, DeSalle R, Ball SJ, Daszak P, MacPhee RDE & Greenwood AD (2008) Historical mammal extinction on Christmas Island (Indian Ocean) correlates with introduced infectious disease. PLoS ONE, 3(11): 1–9.