Confirmation of the extinction of the Bramble Cay melomys *Melomys rubicola* on Bramble Cay, Torres Strait:

results and conclusions from a comprehensive survey in August–September 2014

Queensland Government

The University Of Queensland
AUSTRALIA

Ian Gynther, Natalie Waller & Luke K.-P. Leung

June 2016

This report should be cited as:

Gynther, I., Waller, N. & Leung, L.K.-P. (2016) Confirmation of the extinction of the Bramble Cay melomys *Melomys rubicola* on Bramble Cay, Torres Strait: results and conclusions from a comprehensive survey in August–September 2014. Unpublished report to the Department of Environment and Heritage Protection, Queensland Government, Brisbane.

Author affiliations:

Ian Gynther (to whom correspondence should be addressed) –
Threatened Species Unit, Department of Environment and Heritage Protection, PO Box 64, Bellbowrie Qld 4070, Ian.Gynther@ehp.qld.gov.au

Natalie Waller and Luke Leung –
School of Agriculture and Food Sciences, The University of Queensland, Gatton Qld 4343

Photographs:

Front cover –
Top: Eastern end of Bramble Cay between October 1979 and March 1980 (David Carter)
Bottom: Same view of eastern end of Bramble Cay in September 2014 (Ian Gynther, EHP)
Inset: Bramble Cay melomys *Melomys rubicola*, November 2002 (Ian Bell, EHP)

Inside front cover –
Bramble Cay melomys *Melomys rubicola*, with single young attached to a teat, climbing on an anemometer, October 1979–March 1980 (David Carter)

Report prepared for the Department of Environment and Heritage Protection, June 2016

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The endangered Bramble Cay melomys *Melomys rubicola* is known only from the very small (approximately 4 ha) Bramble Cay in the north-east Torres Strait, Queensland. Because a limited survey in March 2014 failed to detect the species, Bramble Cay was revisited from 29 August to 5 September 2014, with the explicit aims of establishing whether the Bramble Cay melomys still persisted on the island and enacting emergency measures to conserve any remaining individuals. A thorough survey effort involving 900 small mammal trap-nights, 60 camera trap-nights and two hours of active daytime searches produced no records of the species, confirming that the only known population of this rodent is now extinct. Anecdotal information obtained from a professional fisherman who visited Bramble Cay annually for the past ten years suggested that the last known sighting of the Bramble Cay melomys was made in late 2009.

During the August–September 2014 survey, we documented the cay's physical environment, measured the extent of the herbaceous vegetation and gathered evidence of physical processes that may have impacted adversely on the Bramble Cay melomys. The key factor responsible for the extirpation of this population was almost certainly ocean inundation of the low-lying cay, very likely on multiple occasions, during the last decade, causing dramatic habitat loss and perhaps also direct mortality of individuals. Available information about sea-level rise and the increased frequency and intensity of weather events producing extreme high water levels and damaging storm surges in the Torres Strait region over this period point to human-induced climate change being the root cause of the loss of the Bramble Cay melomys.

Because exhaustive efforts have failed to record the Bramble Cay melomys at its only known location and extensive surveys have not found it on any other Torres Strait or Great Barrier Reef island, the assertion that Australia has lost another mammal species can be made with considerable confidence. On this basis, the Bramble Cay melomys qualifies for listing as extinct in the wild under both state and federal legislation. Significantly, this probably represents the first recorded mammalian extinction due to anthropogenic climate change. However, new information is provided in support of a previously presented hypothesis that the Fly River delta of Papua New Guinea is a possible source of the original melomys population on Bramble Cay, which would imply that the Bramble Cay melomys or a closely related species may occur in the Fly River region, an area that has received relatively little mammal fauna survey effort to date. Consequently, at this stage, it may be premature to declare the Bramble Cay melomys extinct on a global scale.

KEY RECOMMENDATIONS

- Amend the conservation status of the Bramble Cay melomys from endangered to extinct in the wild within Queensland's *Nature Conservation (Wildlife) Regulation 2006* under the *Nature Conservation Act 1992*.
- Amend the conservation status of the Bramble Cay melomys from endangered to extinct in the wild based on definition (2)(b) under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*.
- Encourage external agencies and institutions to conduct targeted terrestrial mammal surveys of the Fly River region of Papua New Guinea, with the goal of locating an extant population of the Bramble Cay melomys.
- Advocate for the collection of DNA samples and morphological data from all melomys encountered during surveys of the Fly River delta and encourage the taking of representative voucher specimens for lodgement in New Guinean and Australian institutions to enable future taxonomic and genetic investigations of this rodent group.
- Because it may be premature to declare the Bramble Cay melomys extinct at a global level until such surveys of extralimital areas are conducted, amend the current Critically Endangered categorisation of the species on the IUCN Red List by adding the tag 'Possibly Extinct'.
- Examine current threats to Bramble Cay more closely so that practical, cost-effective actions to prevent future losses of important turtle and seabird rookeries on the island due to ongoing, climate change-induced sea-level rise and ocean inundation events may be devised and implemented.

INTRODUCTION

Bramble Cay, known also by its traditional name of Maizab Kaur, is a very small (about 4 ha) island with surrounding oval reef measuring 1.8 km x 0.9 km in the north-east Torres Strait. Its comparatively isolated location (9°08’32”S, 143°52’33”E), approximately 53 km south-east of Papua New Guinea’s Fly River delta and 227 km north-east of Cape York Peninsula, Queensland, lies only some 4 km inside Australian waters (**Fig. 1**). Bramble Cay and its associated reef formed around a basalt outcrop produced by Pleistocene volcanic activity (Willmott *et al.* 1969, Dennis & Storch 1998, Ellison 1998), with a basalt exposure still visible at all tides in the reef lagoon, south-east of the cay. The island, which has a maximum elevation above high tide of 3 m (Elvish & Walker 1991), is composed of foraminiferal sand, compacted guano and, at its south-eastern end, a low phosphatic rock platform, and supports only patchy herbaceous vegetation (Ellison 1998, Latch 2008). The cay is highly dynamic, undergoing constant changes in size, shape and orientation due to competing erosional and depositional forces from wind, waves and tides (Limpus *et al.* 1983, Dennis & Storch 1998, Latch 2008). Bramble Cay is the most important rookery in Torres Strait for green turtles *Chelonia mydas* and a variety of seabirds (Elvish & Walker 1991, Ellison 1998, Limpus *et al.* 2001, Latch 2008). As a result, the island’s vegetated areas are subjected to seasonal disturbance, particularly by adult green turtles that come ashore to lay eggs during the nesting season (Dennis 2012). The Erubam Le (Erub or Darnley Islanders) are the traditional custodians of Bramble Cay and were granted native title rights over most of the island in 2004 (Latch 2008). They have long visited the cay and its reef to harvest the rich fish, turtle and bird resources (Johannes & MacFarlane 1991, P. Sagiba in Dennis & Storch 1998). Extensive European exploitation of the island’s biological and phosphatic rock resources has occurred from around the mid-19th century (Ellison 1998). Due to its location at the northern entrance to the Great North East Channel through the Torres Strait, Bramble Cay has borne a succession of navigational beacons and lighthouses since the early 1900s, with one temporary structure erected at the south-eastern end of the island in 1958 needing to be replaced because of severe ocean erosion of its foundations (Limpus *et al.* 1983, Ellison 1998). The existing lighthouse, constructed in a new site in 1973, is maintained by the Australian Maritime Safety Authority (Limpus *et al.* 1983, Latch 2008).

Adding to Bramble Cay’s biodiversity and conservation values is that the island is the only known location of a terrestrial mammal, the Bramble Cay melomys *Melomys rubicola* (Latch 2008, Dennis 2012, Woinarski *et al.* 2014). This rodent is remarkable in possessing the most isolated and restricted distribution of all Australian mammals (Latch 2008). It is also ecologically unique and considered to be the Great Barrier Reef’s only endemic mammal species (Limpus *et al.* 1983).

Fig. 1. The location of Bramble Cay and other Torres Strait islands mentioned in this report in relation to Papua New Guinea and Cape York Peninsula, Queensland.

Current conservation status of the Bramble Cay melomys

The official conservation status of the Bramble Cay melomys is endangered under both Queensland's *Nature Conservation (Wildlife) Regulation 2006* (subordinate legislation to the *Nature Conservation Act 1992*) and the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), although the International Union for Conservation of Nature (IUCN) lists it as Critically Endangered (Leary *et al.* 2008). *The Action Plan for Australian Mammals 2012* (Woinarski *et al.* 2014) takes into account more recent information in listing the Bramble Cay melomys as Critically Endangered (Possibly Extinct).

A recovery plan was produced for the species in 2008 (Latch 2008). This plan, prepared by the Queensland Government on behalf of the Commonwealth, summarises the biology of the Bramble Cay melomys, describes known threats to the species and outlines recovery objectives and specific recovery actions, with associated costs, to secure and enhance the conservation status of the Bramble Cay melomys.

Known history of the Bramble Cay melomys

The Bramble Cay melomys was first discovered by Europeans when, in April 1845, Lieutenant Yule, Commander of the HMS *Bramble*, and his crew encountered the cay supporting this rodent population (Limpus *et al.* 1983, Ellison 1998). The species was then apparently in high densities and seamen from aboard this vessel sought recreation by shooting the "large rats" with bows and arrows (Sweatman, unpublished). It was not until the first part of the following century that the species was formally described as *Melomys rubicola* (Thomas 1924), based on a specimen collected by MacGillivray from aboard the HMS *Fly* in May 1845 (Dennis & Storch 1998, Ellison 1998).

In December 1978, Limpus *et al.* (1983) estimated the population on Bramble Cay to comprise at most several hundred individuals. The first formal population census of the Bramble Cay melomys was not conducted until 1998, when a population size of 93 (±36 SE) was estimated from the capture of 42 individuals (Dennis & Storch 1998). Surveys in November 2002 and 2004, adopting the same methodology as the 1998 census, captured only 10 and 12 individuals, respectively (Latch 2008, P. Latch pers. comm.), indicating a declining population. A brief survey conducted in December 2011 found no animals at all, but the monitoring effort was hampered by the numerous nesting green turtles that damaged, moved or buried traps (Waller *et al.* 2014, N. Waller pers. obs.).

In March 2014, a three-night survey conducted jointly by staff from the Department of Environment and Heritage Protection (EHP) and the Torres Strait Regional Authority also failed to capture any Bramble Cay melomys or detect signs of the species' presence on the island (Gynther *et al.* 2014a). While the outcome of this survey suggested it is unlikely that the Bramble Cay melomys still occurred on Bramble Cay, uncertainty remained because of the relatively low trap effort employed (a result of the short survey duration and a necessity to restrict transects to areas where traps would not be crushed by nesting turtles). Nevertheless, a worrying finding from the March 2014 assessment was that due to erosion by wind, waves and tides impacting on the island (refer to Limpus *et al.* 1983, Dennis & Storch 1998) the cay's area above high tide had decreased from the approximately 4 ha reported in 1998 to only 2.5 ha, apparently the smallest size documented for the island to date (Dennis & Storch 1998, Ellison 1998, Latch 2008). Furthermore, the herbaceous vegetation on Bramble Cay, which provides both food and shelter for the Bramble Cay melomys (Dennis & Storch 1998), declined dramatically from approximately 2.2 ha in 2004 to only 0.065 ha, equivalent to a 97% loss over a decade (Gynther *et al.* 2014a). Birds roosting amongst this vegetation in March 2014 further reduced habitat availability for the Bramble Cay melomys because the species is known to avoid areas in which numerous seabirds roost at night (Dennis & Storch 1998, Gynther *et al.* 2014a).

Given the combination of factors at play, namely the declining trend in abundance of the Bramble Cay melomys (from a very low base) since the 1970s, the absence of records from the December 2011 and March 2014 surveys, the very small size of the species' location and the extremely small and diminishing extent of habitat at that location, as well as the likelihood of ongoing severe threats, possibly worsening with time, the species was evidently in severe peril, if not already extirpated (Gynther *et al.* 2014a). Consequently, an emergency response for the Bramble Cay melomys was implemented in the second half of 2014 and involved: a) conducting a comprehensive sampling effort on Bramble Cay adequate to establish whether the species was still extant, and b) if found to be present, the objective of securing all Bramble Cay melomys individuals trapped for a captive population. To achieve these two main objectives, an expedition to Bramble Cay was conducted in August–September 2014, coinciding with the time when turtles are absent from the island. The results of the survey carried out during this expedition, together with other observations pertinent to the Bramble Cay melomys made while visiting the island, are reported here.

METHODS

Groundwork: permits, approvals and preparations

Given that a goal of the August–September 2014 survey was to retain any Bramble Cay melomys individuals captured for transfer to a captive facility on the mainland, a set of relevant approvals was required. To enable the emergency plan to be implemented, the following actions were carried out during the five-month period between the conclusion of the March 2014 survey and departure on the present expedition:

- Permission to remove any captured Bramble Cay melomys individuals from Bramble Cay was sought from the Erubam Le Traditional Land and Sea Owners (Torres Strait Islanders) Corporation Registered Native Title Bodies Corporate (RNTBC), the Traditional Owners of Maizab Kaur. To assist in gaining this approval, Mark Geyle (Land and Sea Management Unit, Torres Strait Regional Authority), on behalf of the authors, delivered a presentation to the Traditional Owners during a meeting on Erub (**Fig. 1**) on 21 August 2014, explaining the need for such action. While receptive to our request, formal approval was not given at the time of this meeting because the Traditional Owners wished to discuss the issue with other community members. Formal approval was to be sought during the planned survey trip upon capture of any Bramble Cay melomys.
- A proposal for a captive breeding agreement to secure the Bramble Cay melomys as an insurance population at The University of Queensland's Gatton Campus was developed and an associated captive breeding agreement between EHP and the university was formulated and signed by representatives of the two participating parties.
- In conjunction with the captive breeding proposal and agreement, an application was submitted to, and approved by, the university's Animal Ethics Committee to house and breed the Bramble Cay melomys in captivity at the Gatton Campus.
- An exemption was sought under section 158 of the EPBC Act to remove individuals of the endangered Bramble Cay melomys from Bramble Cay for the purposes of establishing a captive colony on the mainland. This exemption was granted by The Hon Greg Hunt MP, Federal Minister for the Environment, on 3 September 2014 on the basis that the proposed action was in the national interest.
- An application was made to the Commonwealth Department of Agriculture through its Northern Australia Quarantine Strategy office in Cairns for a permit to move live Bramble Cay melomys out of the Torres Strait Protected Zone and through the Special Quarantine Zone to the mainland. This permit was issued on 25 August 2014.

- Relevant approvals were obtained from commercial airline carriers to transport live Bramble Cay melomys individuals from Torres Strait to Brisbane and arrangements were made with a commercial supplier of pet transport containers for the necessary equipment to be available at the airport at Ngurupai (Horn Island; **Fig. 1**) on the final day of the planned survey trip.
- All necessary holding cages, bedding, food supplies and water bottles to enable the short term maintenance and transportation of any captured melomys were prepared and freighted to Seisia, Cape York, the planned point of departure of the sea voyage to Bramble Cay, prior to the trip's start date.

Fieldwork

The spring 2014 survey of Bramble Cay was conducted by two of the authors (Ian Gynther and Natalie Waller) from 30 August to 5 September 2014, inclusive. Transport to the cay and accommodation at the island during the survey period were provided by Carpentaria Seafaris' live-aboard vessel MV *Tropic Paradise*. Although surveying for the Bramble Cay melomys was the primary goal of our visit to the island, other participants on the expedition (comprising staff from the Australian Institute of Marine Science, Torres Strait Regional Authority, including Rangers from Erub, and a researcher from James Cook University in Townsville) conducted independent project work related to evaluating green turtle nesting success, installing a remote weather station and deploying water quality monitoring equipment in the surrounding reef waters. The methodology and results of these separate projects are not included in this report. All trip participants assisted the authors with various tasks during the survey for the Bramble Cay melomys.

Survey program

Trapping for the Bramble Cay melomys was conducted over the six nights from 30 August to 5 September 2014. Because the two preceding surveys for this species in December 2011 and March 2014 failed to capture any individuals (Gynther *et al.* 2014a, Waller *et al*. 2014, N. Waller pers. obs.), it was assumed that the population on the cay during the current visit would, at best, be very low. Consequently, we chose not to repeat the monitoring methodology of Dennis & Storch (1998) in terms of trap effort and layout, but instead to adopt an approach involving saturation trapping of all potential Bramble Cay melomys foraging habitat, while also targeting any terrain features that may have provided shelter for the species. This strategy was considered to provide the best means of detecting any remaining individuals. Accordingly, 75 Elliott traps (size A, Elliott Scientific, Upwey, Victoria) and 75 Sherman traps (H.B. Sherman Traps, Tallahassee, Florida, USA), baited with a mixture of rolled oats, peanut butter, peanut oil and golden syrup, were deployed across the cay, focusing particularly on all areas of remaining habitat (**Fig. 2**). This gave a total survey effort of 900 trap-nights for the survey, appreciably greater than any previous sampling effort. Traps were set amid and around the edges of all except the smallest patches of remnant vegetation (**Appendix 1a** & **b**), as well as adjacent to logs (**Appendix 1c**) and beneath exposed outcrops of phosphatic rock at the south-eastern end of the island, where a limited number of undercut ledges offered potential daytime refuges for the Bramble Cay melomys (**Appendix 1d**). All trap positions were recorded with a GPS. Traps were opened just prior to sunset and were checked and closed soon after dawn each day.

To augment the overall survey effort and provide an alternative sampling strategy with the potential to increase the chances of detecting a species existing at a very low abundance on the cay, camera traps were also used. Ten infrared camera traps (RECONYX HyperFire HC600, RECONYX Inc., Holmen, Wisconsin, USA), placed 20 m apart, were deployed over the six-night survey (i.e., a total effort of 60 camera trap-nights). Most were deployed around the periphery of the island's vegetated area (**Fig. 2**, **Appendix 1e**), where Dennis & Storch (1998) had previously indicated activity of the Bramble Cay melomys is most concentrated. At each station, a camera trap was positioned approximately 34-40 cm above the ground, fixed to a star picket using a bungee cord. To provide a lure for melomys, a bait ball consisting of the same mixture of ingredients used for Elliott and Sherman trapping was placed inside a spring-loaded, stainless steel tea strainer. The tea strainer was anchored in place with a large, U-shaped metal peg hammered into the sand approximately 1m from the camera trap. To maintain bait freshness, the bait was changed every two days. To maximise the chance of detecting the nocturnal Bramble Cay melomys, camera traps were activated just prior to sunset and were set with high sensitivity to take three images per trigger event, without a quiet period. Following the check of the small mammal traps early every morning, the cameras were deactivated and their SD cards were removed and replaced. Subsequently each day, the photos recorded during the preceding night were examined independently by two observers, frame by frame, on a laptop computer to search for any images containing Bramble Cay melomys.

Additional survey effort consisted of a total of two person-hours of active daytime searches conducted in an attempt to detect living Bramble Cay melomys or signs of the species' current or recent presence, such as tracks, scats and skeletal material. Pieces of driftwood, beach-washed logs, human-derived building material and crevices and overhanging caves in the phosphatic rock ledges were all searched thoroughly (**Appendix 1f**). Headlamps were used to illuminate dark recesses in which animals may have been sheltering or evidence of their former occupation located. A deliberate decision not to search the cay during the hours of darkness was made so as to minimise the chances of disturbing any foraging Bramble Cay melomys in case this prevented them from entering traps. Consequently, nocturnal active searches for Bramble Cay melomys using headlamps or spotlights were not undertaken during the current survey.

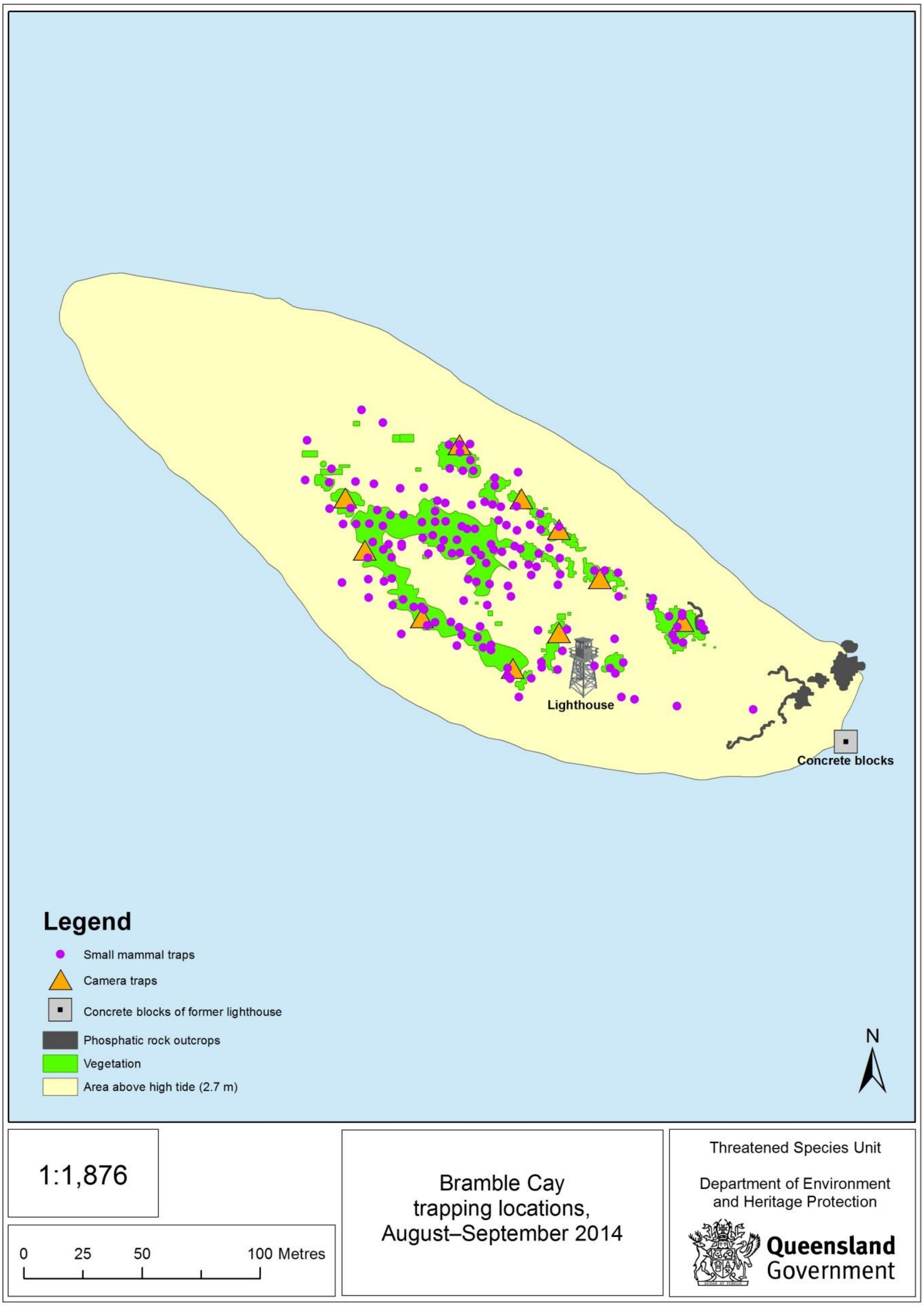


Fig. 2. Map of Bramble Cay showing the location of Elliott and Sherman traps (not differentiated) and camera traps in relation to areas of living vegetation. The position of the existing lighthouse tower, concrete foundations of the former (1958) lighthouse structure and exposed outcrops of phosphatic rock are also indicated.

While visiting Bramble Cay to implement the melomys survey program, the opportunity was also taken to conduct a census of the island's bird population. A brief summary of the methods and results of this bird census are provided in **Appendix 3**.

Physical features of Bramble Cay during the August–September 2014 expedition

On the morning of 4 September 2014, after a high tide of 2.7 m at 1825 hrs the previous evening (the highest tide to that point of the visit), the cay was circumnavigated on foot along the high water mark to record a track using a handheld GPS unit (a Garmin GPSMAP 76CSx). At 1240 hrs the same day, a similar track was recorded by walking along the edge of the cay on the reef flat (as per the methodology of Dennis & Storch 1998) during the low tide of 0.7 m. In this way, outlines of the island at high and low tides were stored. Similarly, GPS tracks were recorded along the exposed bands of phosphatic rock and around the perimeters of free-standing outcrops of this rock at the south-eastern end of the cay. For completeness, positional fixes of key permanent features of Bramble Cay, namely the current lighthouse tower and the four concrete blocks that formed the base of the original (1958) lighthouse tower at the south-eastern end of the cay, were also taken using a GPS. A tape measure was used to record the distance between the centre point of the four concrete blocks and the 2.7 m high tide line, as well the distance to the nearest outcrop of phosphatic rock, measured perpendicularly to the shoreline.

Vegetation composition and extent

Because a detailed floristic survey of the island was conducted five months earlier during the March 2014 visit to Bramble Cay (Gynther *et al.* 2014a), a second such census was considered unnecessary on this occasion. Instead, plant species present were simply noted while undertaking various fauna survey and habitat assessment activities.

Considerable effort was made to map the location, boundary and area of individual patches of herbaceous cover present on the cay so that an accurate estimate of the total extent of vegetation could be determined. Similar to the methodology described above for measuring the cay's total area, a handheld GPS unit was used to record the perimeters of the major patches of vegetation. Subsequently, GIS was used to calculate the areas of the resulting polygons (see 'Mapping and spatial analysis'). For smaller patches and clumps of vegetation, the dimensions were recorded with a tape measure, the shape of the area being measured was noted (e.g., whether it was oblong or round), and a GPS fix taken at the centre point of each patch. For all vegetation polygons recorded, whether using GPS or tape measure, the estimated percentage vegetation cover and the dominant plant species contributing to this cover were both recorded. The actual vegetation cover for each individual patch was then calculated by multiplying the estimated percentage cover by the total area of the patch.

Finally, figures for all patches were summed to provide an overall estimate of the vegetation cover present on the cay.

Collection of anecdotal information about Bramble Cay and the Bramble Cay melomys

During the present survey, an opportunity was taken to interview two mackerel fishermen, who were based temporarily near Bramble Cay aboard the vessel *New Traveller*. These fishermen, Mr Egon Stewart and his grandfather, Mr Al Moller-Nielsen, had between them visited the island for 40 years. On 3 September 2015, they shared their memories of Bramble Cay, its fauna and flora, and the weather patterns and events in this section of the Torres Strait. The recollections of Erub-based Torres Strait Regional Authority Land and Sea Ranger, Aaron Ketchell were also recorded during the current field work.

Mapping and spatial analysis

After the trip concluded, David Woolsey and Kirsten Wallis (both of EHP) employed GIS (ArcMap10.1) to create maps of the island and calculate areas bounded by the various GPS tracks and waypoint-based polygons that were recorded or measured in the field. In this way, the area of the island above high water mark, the total area of the cay on the reef flat, and the total extent of vegetation were determined.

RESULTS

Bramble Cay melomys survey

The Bramble Cay melomys was not recorded during the survey – no individuals were captured in small mammal traps or detected by camera traps, and active daytime searches failed to produce sightings of the species or discover signs of this rodent's current or former presence on Bramble Cay in the form of tracks, scats and mummified or skeletal remains.

The only fauna caught in the Elliott and Sherman traps over the six-night survey were ghost crabs *Ocypode* spp. In total, 35 captures of *O. cordimana* and three captures of *O. ceratophthalmus* were made, although the number of individuals involved was not determined. From 30 August to 5 September 2014, the camera traps recorded a total of 7761 images during the hours of twilight and darkness, but almost all of these (99.4% or 7712 images) were of roosting adult or immature sooty tern *Onychoprion fuscata* individuals (**Appendix 1g** & **h**), with the remainder detecting ghost crabs or no fauna at all.

Features of Bramble Cay during the August–September 2014 visit

The shape and size of Bramble Cay in August–September 2014 is illustrated in **Figure 3**. The area of the cay above high tide was 3.44 ha, excluding outcrops of phosphatic rock that rise above high tide level in the intertidal zone at the south-eastern end of the island. A separate measurement of the island's size based on the area bounded by the edge of the cay on the reef flat (i.e., the point where the toe of the sloping beach meets the reef flat) was 4.86 ha. This second figure exceeded the area above high tide because it also includes the intertidal zone surrounding the cay (**Fig. 3**).

The island was oriented along a north-west–south-east axis, with a sandy promontory present at the north-western end of the cay. The four concrete blocks that once provided the foundations for a temporary navigation light tower at the south-eastern end of the cay (Limpus *et al.* 1983) were situated in the intertidal zone, 6.3 m straight line distance below the high tide mark (measured to the centre point of the blocks) and were immersed at high tide. These blocks were 21.0 m from the nearest band of exposed phosphatic rock situated at the edge of the elevated area that forms most of the cay's interior plateau.

By overlaying the high tide outlines of Bramble Cay documented during the March 2014 (Gynther *et al.* 2014a) and current visits, it is apparent that the island has undergone the marked changes in size and shape during the intervening five-month period (**Fig. 4**). As well as the cay now being larger (3.44 ha cf. 2.48 ha) and more elongate (370 m long in August–September 2014, but only 253 m in

March 2014), the prominent sand spit that extended from the southern side of the cay and the sandy, hooked projection on the northern shoreline present in March 2014 no longer existed. Furthermore, the steep sand banks that bordered the beach along the north-eastern and south-western shorelines during the previous trip had disappeared prior to this second visit so that gently sloping beaches surrounded the entire circumference of the cay in August–September 2014. A significant amount of sand had accumulated at each end of the island and along the north-eastern shoreline between March and August–September 2014, and this was probably the reason why much less phosphatic rock, particularly that forming linear ledges and cliff bands, was exposed at the south-eastern end of the island on the second visit (**Fig. 4**). The location of what was a shallow lagoon to the north-west of the existing lighthouse tower in March 2014 (**Fig. 4**; Gynther *et al.* 2014a) was a bare area of cracked or cracking peat by August–September 2014 (**Appendix 2a**).

Vegetation assessment

Only two plant species were recorded on Bramble Cay during the current visit: the succulent perennial herb *Portulaca oleracea* and an unidentified sedge *Cyperus* sp., possibly *C. stoloniferus*, both of which were present in March 2014 (Gynther *et al.* 2014a). The sedge represented only a minor component of the flora and, in the few places where it did occur, appeared to be regenerating because new shoots were just visible above the sand.

The extent of vegetation on Bramble Cay in August–September 2014 was small, with a total area of only 0.19 ha (**Table 1**). Vegetation cover was patchy (**Fig. 2**; **Appendix 2a** & **b**), with only one area of *P. oleracea* forming a near-contiguous arc to the west and north-west of the former lagoon. **Figure 5** illustrates the vegetation cover on Bramble Cay in August–September 2014 as compared to March 2014 (when the total vegetated area was 0.065 ha; **Table 1**; Gynther *et al.* 2014a). Over the five-month period between the two surveys in 2014, the vegetation cover had approximately tripled, although not all sections of the cay with herbaceous growth in March still supported living vegetation at the time of the August–September 2014 visit. In one case, a section of what had been the largest patch of vegetation on the island in March (an area once dominated by *P. oleracea* on the western margin of the lagoon – see the greyish band in the centre region of the image in **Appendix 2a**) had thinned significantly, most likely due to trampling by nesting and roosting birds. On an island-wide scale, however, disturbance by birds had not caused a significant reduction in overall vegetation extent (see **Appendix 3**, **Photos B** & **D**). Nesting turtles were absent during August–September 2014 and so had not contributed to any deterioration of vegetation cover. In other examples of recent vegetation loss, areas of *Cyperus* sp. documented in March 2014 were now dead. These were a formerly 40 m^2, almost linear patch south-east of the lighthouse tower (**Fig. 5**; **Appendix 2c** & **d**) and a clump originally of about 4 m^2 growing in firm, guano-rich sand on a phosphatic rock outcrop at the south-eastern corner of the island (**Fig. 5**; **Appendix 2e** & **f**). At each location, the clumps were found to be lying flat and with all the sedge blades aligned in one direction, pointing away from the nearest shoreline. In addition, at the cay's south-eastern corner, the outcrop that had supported the sedge stand was now missing its cover of peaty sand. Indeed, all rocks in this vicinity no longer had overlying substrate, as is evident by comparing the inset image with the main photo in **Appendix 2e**.

Table 1. Chronology of vegetation extent on Bramble Cay from assessments made since 1998.

Time Period	Vegetated Area (ha)	No. of Plant Species Present	Reference
July 1998	2.43	4	Dennis & Storch (1998)
Nov 2004	2.16	4	Latch (2008); P. Latch (pers. comm.)
Dec 2011	1.1	3	Waller *et al*. (2014); N. Waller (pers. obs.)
Mar 2014	0.065	6	Gynther *et al*. (2014a)
Aug–Sep 2014	0.19	2	This study

Of the vegetation that had regenerated since March 2014, a large swathe lying in a band parallel to the north-eastern shore of the cay was brown and clearly dead (**Appendix 2g–j**). The broad area of affected vegetation, which mostly comprised *P. oleracea*, was confined to a swale or low-lying area, as was especially evident when viewed from the lighthouse tower (**Appendix 2i** & **j**). The boundary between the living and dead areas of this vegetation was sharply demarcated and, in some situations, only the plants growing on the crests of small knolls or rises remained healthy while those on the surrounding slopes and depressions were dead (**Appendix 2h**). Drifts of dead bird eggs, mixed with feathers and assorted beach wrack (**Appendix 2k** & **l**), and jumbled piles of dead bird eggs, beach-washed timber and pumice (**Appendix 2m** & **n**) were located at various points along the swale but, in particular, at the north-western end of the cay.

The distribution of logs and other larger pieces of beach-cast timber on the island was noticeably different during the two visits made to Bramble Cay in 2014. By comparing images taken in March and September 2014 of the area south-east of the lighthouse tower, it is evident that individual pieces of timber had moved from their original positions or were missing altogether, and new logs had appeared in the cay's interior (**Appendix 2o**).

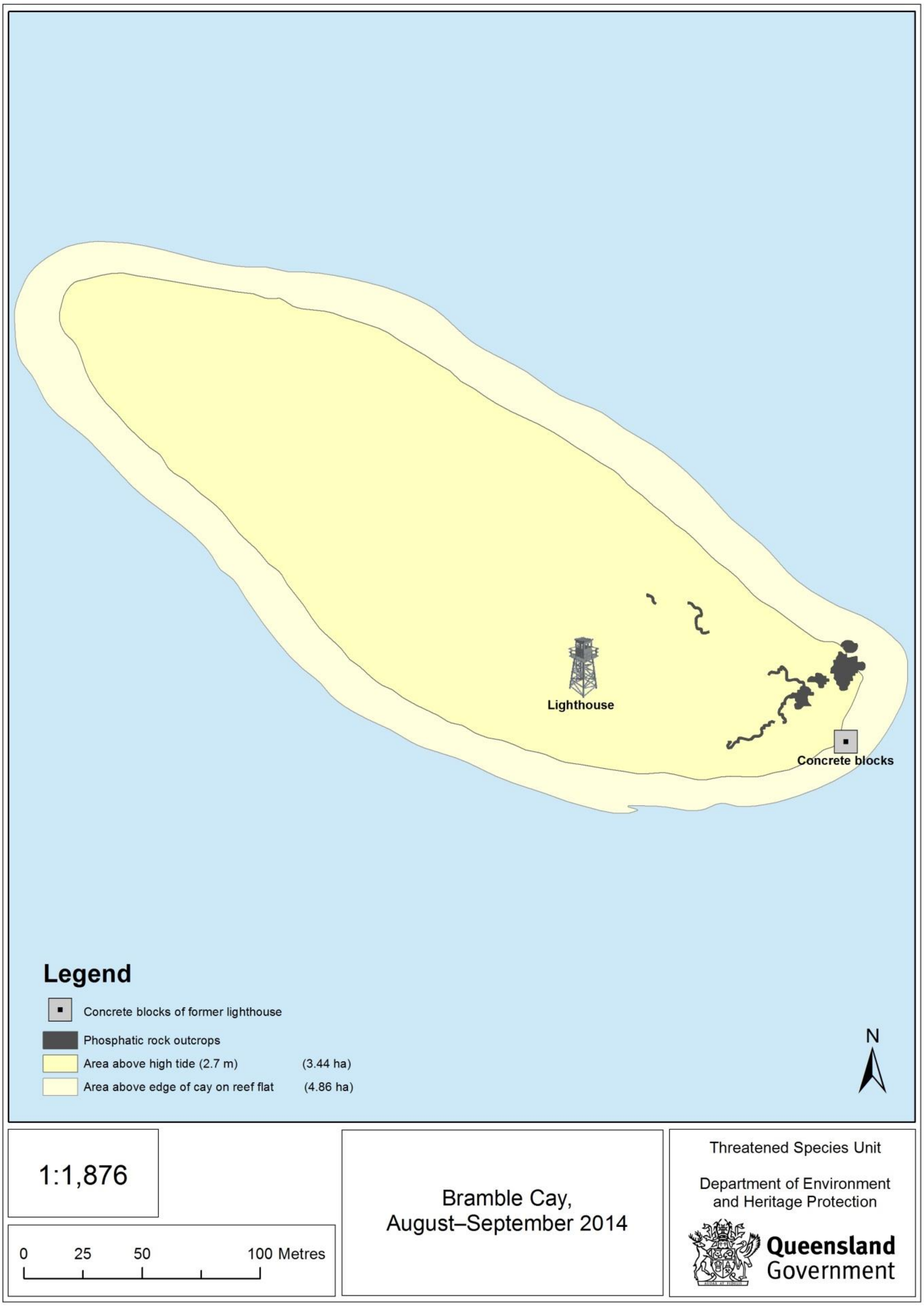


Fig. 3. Map of Bramble Cay showing both the island's area above the high tide line and the area bounded by the edge of the cay on the reef flat in August–September 2014. The location of the current lighthouse tower, concrete foundations of the former (1958) lighthouse structure and exposed outcrops of phosphatic rock are also depicted.

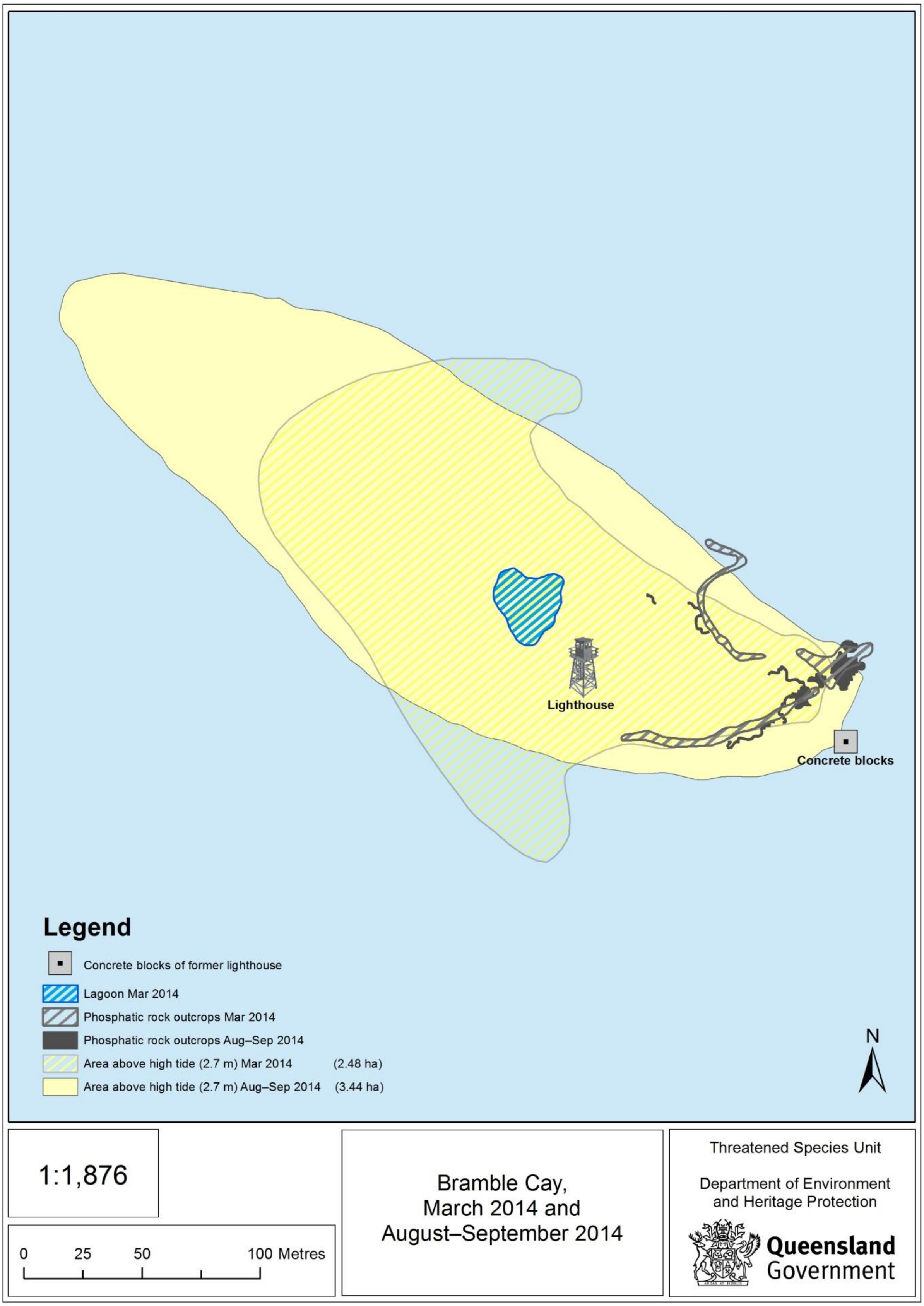


Fig. 4. Maps of Bramble Cay comparing the areas above the high tide line in March 2014 and August–September 2014. The extent of the exposed outcrops of phosphatic rock on each visit is also depicted. The lagoon depicted was only present in March 2014.

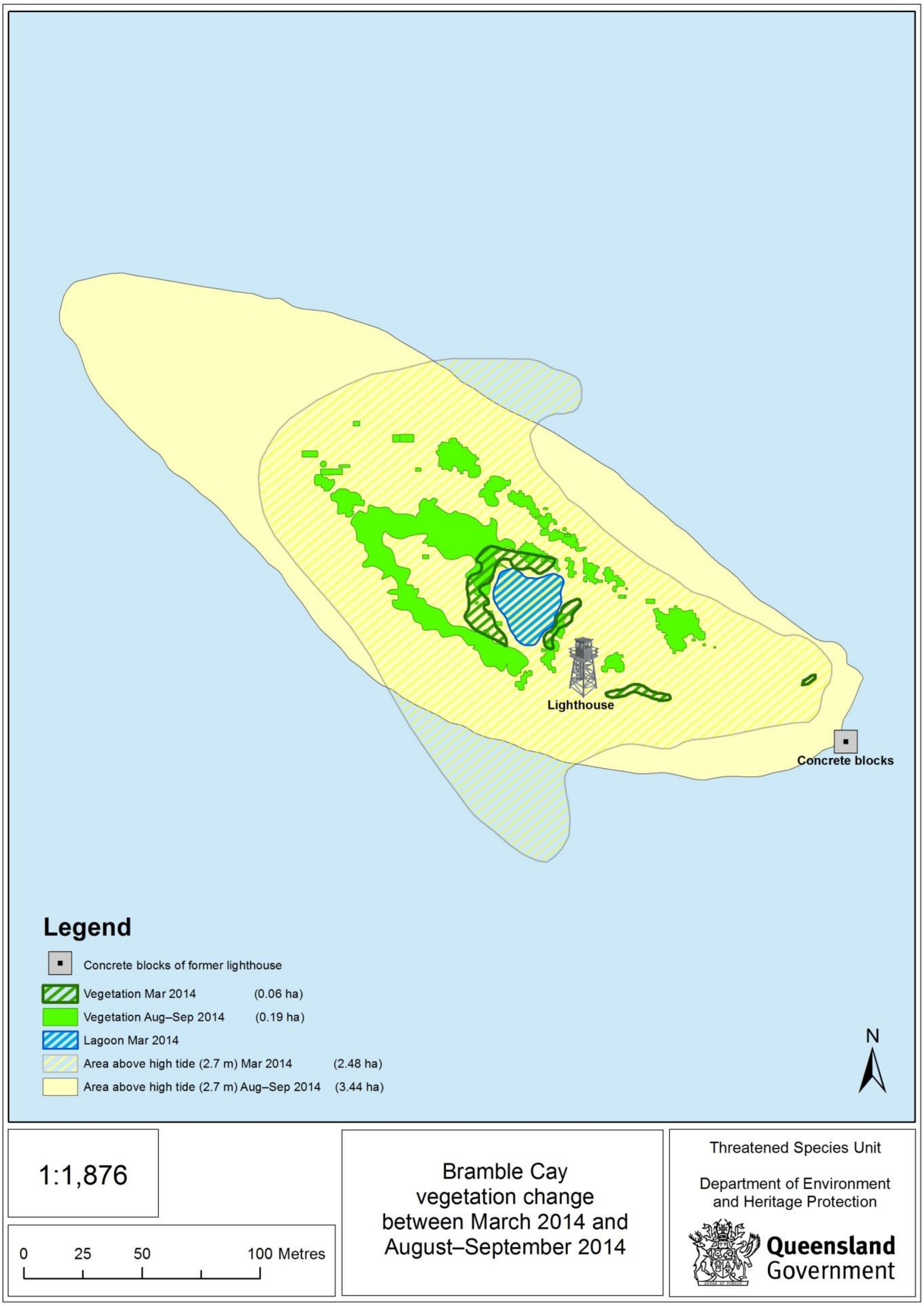


Fig. 5. Maps of Bramble Cay's area above the high tide line in March 2014 and August–September 2014, comparing the extent of living vegetation present during the two visits. The lagoon depicted was only present in March 2014.

Anecdotal information about Bramble Cay and the Bramble Cay melomys

Mr Aaron Ketchell, a Land and Sea Ranger from Erub, recalled that an 'old timer' on Erub had told him about finding at least one indigenous Papua New Guinean on Bramble Cay during a visit to the island in the late 1970s. It was assumed these visitors were collecting tern eggs and would simply flee when the boat from Erub came ashore. However, they didn't and were instead observed catching 'rats' (i.e., melomys) for food by hitting them with sticks. No information was provided about how many Bramble Cay melomys were taken during this particular episode.

Mr Ketchell also remembered accompanying his father on a day trip to Bramble Cay to collect tern eggs in 1983 or 1984, when he was an 11-year old boy. He described seeing several melomys during the daytime on this occasion. The animals were disturbed from their shelter sites amidst low vegetation and jumped over clumps of vegetation as they fled. At this time, the vegetated area extended over much of the cay to the west of the lighthouse, with 'grass' forming a ring outside of this (A. Ketchell pers. comm.).

An interview with Mr Egon Stewart, a mackerel fisherman who has visited Bramble Cay annually over the previous decade, ascertained that he was familiar with the Bramble Cay melomys from time spent ashore on the cay during daylight hours over this period. Mr Stewart said that the melomys (which he referred to as 'rats') were often observed fleeing when beach-washed debris or other material on the island was lifted or overturned. He recalled that it was approximately five years earlier (i.e., around 2009) when he last saw the rodents in this way (**Table 2**). On this occasion, there had been "a heap of sticks and a smashed up dug-out canoe at the north-western end of the island". When this material was upturned, one or two rats ran out from under it.

Mr Stewart's grandfather, Mr Al Moller-Nielsen, has fished for mackerel in the waters around Bramble Cay over a period of 30 years. He described seeing dead seabirds with chewed wings on the island and had assumed the 'rats' were responsible. Mr Moller-Nielsen explained that crew members from more than one boat in the small fishing fleet that anchored in the lee of the cay would let dogs (including Jack Russell terriers) loose to chase melomys for exercise and to protect the birds. He said "they'd always get a few" and recalled seeing dead rats during his visits to the island. The exact dates of these observations were not available, although apparently they were made during the first half of his long fishing career at Bramble Cay, which commenced in 1983.

Mr Moller-Nielsen described how the sea breaks over the south-eastern end of Bramble Cay during high tides of 3.5–4 m, and recalled that this happened in the late 1980s or early 1990s, resulting in water lying in the middle of the cay. He said that in the last ten years "there had been big tides and it's been a bit rough" during the annual mackerel season, which runs for approximately six months over the last half of each year (June or July to November or December). Mr Stewart also reflected that the weather had worsened over the previous decade, in particular "getting rougher and rougher over the last four or five years". He recalled that in former times "there would be strong winds for a few days, but then it would ease off, becoming calm for periods, but this doesn't seem to happen recently". Instead, he said there were "big seas and 30 knot winds lasting for longer periods of ten days to three weeks" and now "they practically live in wet weather gear".

Anecdotes about unusual flotsam observed in the seas around Bramble Cay were provided. Mr Moller-Nielsen recalled on one occasion taking his fishing boat to investigate what looked like a vessel in distress, but found the object to be a large (6 m x 6 m), floating piece of land that supported an upright palm tree. Another time he observed an intact hut adrift at sea on a section of earth.

Table 2. Chronology of Bramble Cay melomys abundance from assessments made on Bramble Cay since the 1970s.

Time Period	Sampling Effort	No. of Individuals Recorded	Reference
Dec 1978	Spotlighting	Estimated max. of several hundred	Limpus *et al*. (1983)
July 1998	444 trap-nights	42 (estimated pop. of 93)	Dennis & Storch (1998)
Nov 2002	444 trap-nights	10	Latch (2008); P. Latch (pers. comm.)
Nov 2004	444 trap-nights	12 (last known capture)	Latch (2008); P. Latch (pers. comm.)
Late 2009	Casual searching	1-2 **(last known record)**	E. Stewart (pers. comm.)
Dec 2011	150 trap-nights Spotlighting Daytime searching	nil	Waller *et al*. (2014); N. Waller (pers. obs.)
Nov–Mar 2013	3 camera trap-nights	nil	S. Preston (pers. comm.)
Mar 2014	120 trap-nights Spotlighting Daytime searching	nil	Gynther *et al*. (2014a)
Aug–Sep 2014	900 trap-nights 60 camera trap-nights Daytime searching	nil	This study

DISCUSSION

Confirmation of the extirpation of the Bramble Cay melomys from Bramble Cay

This August–September 2014 survey that yielded no records of the Bramble Cay melomys despite a thorough program of trapping and searching served to confirm recently expressed fears that the species may have been extirpated from Bramble Cay (Gynther *et al.* 2014a, Waller *et al*. 2014, Woinarski *et al*. 2014). Adding weight to this conclusion, the effort employed in this most recent survey (900 small mammal trap-nights, 60 camera trap-nights and 2 hours of diurnal active searches) was significantly greater than that used during the last successful surveys conducted in 1998, 2002 and 2004, when between 10 and 42 individuals were captured using a consistent effort of 444 trap-nights per survey (**Table 2**; Dennis & Storch 1998, Latch 2008, P. Latch pers. comm.). The present level of survey effort also far exceeded what is recommended in the Commonwealth's survey guidelines for threatened mammals (SEWPaC 2011) for an area of this size (<5 ha). Moreover, considering that the island is a closed system, there appears little chance of the nil result obtained during the current assessment being a false negative. A combined trap effort of 1,170 small mammal trap-nights, 8 person-hours of nocturnal searches and 5 person-hours of diurnal searches has now been employed on Bramble Cay over the three most recent surveys (December 2011, March 2014 and August–September 2014) without detecting the Bramble Cay melomys (Gynther *et al.* 2014a, Waller *et al*. 2014, this study). Also, the fact that the recent surveys focused on a reduced area of available habitat for the Bramble Cay melomys (on two occasions, dramatically so) as compared to the assessments undertaken over the two preceding decades further demonstrates that the species is no longer extant on Bramble Cay.

As summarised in **Table 2**, although the last documented occurrence of the Bramble Cay melomys (a capture record) was in November 2004 (Latch 2008), anecdotal information obtained from a fisherman during the current work indicated the species persisted on Bramble Cay, albeit in low numbers, at least until around 2009 (E. Stewart pers. comm.).

In conclusion, more than 25 years after Limpus *et al*. (1983) warned that the survival of the Bramble Cay melomys was in jeopardy, the population has been lost. It appears likely that numbers declined from around the late 1970s, with the species eventually disappearing from the island at some point between late 2009 and December 2011, an event that represented the extinction of the only known population.

Causes of the extirpation of the Bramble Cay melomys from Bramble Cay

The extirpation of the Bramble Cay melomys from Bramble Cay merits a thorough consideration and analysis of the factors most likely responsible for this extinction event. Key threatening processes that potentially impacted on this unique rodent population are examined in detail here.

Direct mortality of Bramble Cay melomys individuals due to predation by domestic dogs brought ashore from fishing vessels (A. Moller-Nielsen pers. comm.) and hunting by visiting indigenous people from Papua New Guinea (A. Ketchell pers. comm.) would have contributed to pressures on this isolated rodent population. However, such events were probably sporadic and relatively limited in their overall impact.

Cay erosion has long been held as the most significant threat to the continued survival of the Bramble Cay melomys (Limpus *et al.* 1983, Latch 2008). Erosion has even been considered to be a more important threat than intrinsic factors relating to the species' small population, such as its high level of inbreeding (Dennis & Storch 1998; Elphinstone & Baverstock, Appendix 2 in Dennis & Storch 1998; Dickman *et al.* 2000). Although initial fears were that erosion would result in the outright loss of the cay as it 'dropped off' the north-western edge of the reef flat (Limpus *et al*. 1983), this scenario has not eventuated. Rather, the cay's physical environment is recognised as being in a state of flux, changing seasonally in accordance with the prevailing weather patterns (Latch 2008). In the Torres Strait, strong north-westerly winds that blow during the monsoon season (November to March) create considerable erosion of the cay, as well as movement of sediment on the reef, while the predominantly south-easterly trade winds from March to November cause sand to accumulate on the island, particularly at its north-western end (Elvish & Walker 1991, Dennis & Storch 1998, Ellison 1998, Latch 2008, Duce *et al.* 2010, D. Carter *in litt*.). Observations made during August–September 2014 support the occurrence of such seasonal fluctuations. The cay's size had increased during the five-month interval since March 2014, although both the area above high tide (3.44 ha) and total cay area (4.86 ha) were less than the corresponding figures recorded during 1998, 2002 and 2004 (Dennis & Storch 1998, Latch 2008). Nevertheless, the current area above high tide matched that documented for the island in 1987 (Walker 1988), demonstrating that the cay's size is not diminishing continuously. Similarly, the island's shape, orientation and beach profiles also changed radically between the March and August–September 2014 visits, and now more closely resembled those documented in November 2002 and 2004 (Latch 2008).

Despite this evidence for Bramble Cay's physical environment fluctuating over time, phases of significant erosion clearly could have impacted directly on the Bramble Cay melomys by limiting the amount of area available for the species to occupy. For example, in March 2014 the island was at its smallest documented size of approximately 2.5 ha (Gynther *et al.* 2014a), a figure representing around half of the maximum area ever recorded for Bramble Cay (Dennis & Storch 1998). The availability of potential refuge sites for the Bramble Cay melomys in rock caves, crevices and overhangs also appears to change seasonally with the movement of sand caused by prevailing patterns of wind, waves and currents. Much less phosphatic rock was exposed at the south-eastern end of the island during the August–September 2014 visit than in March 2014. Added to this, the ongoing erosion of phosphatic rock from the cay's south-eastern end, as demonstrated by the relative shift in the position of the former lighthouse foundations from on top of the cay's plateau to the intertidal zone since 1958 (Limpus *et al.* 1983, Dennis & Storch 1998, Ellison 1998, Latch 2008, Gynther *et al.* 2014a, this study), may have increased the vulnerability of any Bramble Cay melomys that relied on such landscape features for shelter. Although likely to be contributing factors, it remains unclear whether such spatial bottlenecks and loss of refugia could, in themselves, account for the extirpation of the melomys population on Bramble Cay.

The vegetation on Bramble Cay, particularly the succulent *P. oleracea*, provides both food and shelter for the Bramble Cay melomys (Dennis & Storch 1998) and, consequently, any reduction in the island's herbaceous cover is likely to have had deleterious impacts on this rodent species. Although the total area of vegetation (0.19 ha) present on Bramble Cay during August–September 2014 had increased almost threefold since March 2014, it was nevertheless very small, and notably smaller that the areas recorded during earlier assessments of the island (**Table 1**). For example, the current vegetated area represented just 7.8% of the herbaceous cover present on Bramble Cay in July 1998 (2.43 ha) and 8.8% of the November 2004 figure (2.16 ha), both occasions when the Bramble Cay melomys was still present on the island (Dennis & Storch 1998, Latch 2008), and 17.3% of the 1.1 ha coverage measured in December 2011 (Waller *et al.* 2014). Floristic diversity was also very low (**Table 1**), with just two plant species present in August–September 2014, as compared to six species (two of which were seedlings) in March 2014 (Gynther *et al.* 2014a) and a total of 11 species recorded from the island prior to that (Elvish & Walker 1991, Ellison 1998, Latch 2008). The overall decline in vegetation cover and diversity from 2004 (when the Bramble Cay melomys was last trapped on Bramble Cay) until 2014 dramatically reduced foraging and sheltering resources for the species and this most likely played a major role in the extirpation of the Bramble Cay melomys from the island. The question remaining to be answered is: what caused such a rapid and significant loss of habitat during the preceding decade?

A change in climatic conditions over this period is one factor that may have driven a decline in herbaceous cover on Bramble Cay. However, data from Waiben (Thursday Island; **Fig. 1**) and Ngurupai (Horn Island), located in the southern Torres Strait, some 234 km to the south-south-west, indicate that annual rainfall up until the late 2000s shows strong variations on inter-annual and inter-decadal time scales, with the 1990s being dry and the 2000s relatively wet, but no clear overall trend (Suppiah *et al.* 2010). Similar variations in annual rainfall data are recorded at Daru, Papua New Guinea (**Fig. 1**), situated just 74 km west of Bramble Cay, indicating that the rainfall data from the northern and southern Torres Strait are strongly correlated (Suppiah *et al.* 2010). El Niño/Southern Oscillation events strongly influence the climate of the Torres Strait region and largely account for the year-to-year variability in rainfall (Suppiah *et al.* 2010), while a long term cycle of rising and falling sea surface temperatures in the Pacific, referred to as the Inter-decadal Pacific Oscillation (or Pacific Decadal Oscillation), may be involved in producing the variability in measurements between decades (Suppiah *et al.* 2010, Harper 2013).

Annual mean air temperatures at Waiben–Ngurupai show a positive trend, but with strong inter-annual variability – mean temperatures increased by 0.25°C per decade from 1960 to the mid-1990s and by 0.51°C per decade from then until 2009 (Suppiah *et al.* 2010). A positive trend in annual mean temperatures with marked variability between years is also apparent at Daru, although the increases recorded in the northern Torres Strait were less than those in the southern part of the region (Suppiah *et al.* 2010). Although the climatic data from these weather stations may reflect continental influences from the adjacent Australian and New Guinea mainlands such that they do not accurately record the maritime conditions experienced on Bramble Cay, they probably illustrate regional patterns across the Torres Strait. Moreover, a limited set of maritime climatic data from Poruma (Coconut Island; **Fig. 1**), lying 134 km south-west of Bramble Cay in the Central Torres Strait, also indicate that annual rainfall in the Strait has remained relatively stable during the period over which the extent of vegetation on Bramble Cay has diminished, while annual mean maximum temperatures show an overall increase from 1998 to 2014 (BOM 2015).

With no trend in the annual rainfall data apparent over recent decades, this climate variable is unlikely to be a causative factor in the decline in vegetation cover on Bramble Cay during the decade prior to 2014. By contrast, the small, gradual increase in air temperature evident in the climatic record for Torres Strait could conceivably have affected plant health on Bramble Cay negatively over the past ten years, perhaps contributing to a reduction in the area of vegetation on the island. However, the relatively small change in average temperatures is unlikely to account for the large magnitude of change in vegetation extent that has taken place over such a relatively short time span.

A more likely cause of the marked decline in vegetation cover is ocean inundation. With a maximum elevation of only 3 m (Elvish & Walker 1991), Bramble Cay is particularly vulnerable to sea-level rise and the impacts of extreme high water events. Seawater inundation as a result of storms and high tides has previously been identified as a threat to the Bramble Cay melomys because it kills vegetation and reduces the area of habitat present (Dennis 2012). Climate change-induced sea-level rise is also recognised as a potentially catastrophic threat to the species because it may erode away Bramble Cay or lead to inundation of the entire range of the Bramble Cay melomys (Turner & Batianoff 2007, Woinarski *et al.* 2014).

Events involving at least the partial inundation of Bramble Cay have been documented on several occasions over the last quarter century (Dennis & Storch 1998, Latch 2008, Gynther *et al.* 2014a). Dennis & Storch (1998) record a partial inundation event occurring shortly before 1991. This may correspond to the anecdotal report obtained during the present field work of seas breaking over the south-eastern end of Bramble Cay in the late 1980s or early 1990s, resulting in water lying in the island's interior (A. Moller-Nielsen pers. comm.). A significant weather system in July 2005 during which "waves were reported being thrown up over the cay as a result of gale force winds pounding the cay for several days coupled with very high tides" (G. Romano & K. Gutchen in Latch 2008) was probably responsible for, or at least contributed to, the 49% reduction in vegetation cover on the island in December 2011, as compared to the previous assessment in November 2004 (**Table 1**; Latch 2008, Waller *et al.* 2014). Gynther *et al.* (2014a) proposed seawater inundation resulting from one or more extreme weather events over the two and a quarter years following December 2011 as the most likely cause of the further 94% loss of vegetation cover that occurred by March 2014 (**Table 1**).

Observations made during the August–September 2014 visit provided strong evidence of additional episodes of seawater inundation or wave penetration of the cay's interior during the five-month period between the two trips made to the island in 2014. Two areas of living sedge growing on the southern and south-eastern sides of Bramble Cay in March 2014 were found dead and unidirectionally-flattened in August–September, strongly suggesting that waves had washed over them. Furthermore, the loss of soft substrate overlying rocks at the south-eastern end of the island suggested the area had been subjected to significant scouring by the ocean. Although *P. oleracea*, the most common plant species on the cay, is considered salt-tolerant, increased exposure to large salt concentrations can cause reduced germination and growth (Yazici *et al*. 2007). The distribution of dead *P. oleracea* in the swale parallel to the north-eastern shoreline demonstrated that the ocean had breached the island's perimeter, with the seawater killing vegetation growing in areas of low elevation as it flowed north-west over the cay with sufficient force to carry along hundreds of birds' eggs, timber, pumice and other items, depositing them in drifts along the way. Finally, differences in the number and location of logs and other large pieces of beach-cast timber between the two visits in 2014 could only have been the result of wave action across the cay during the intervening five months. These new observations serve to bolster the evidence previously gathered that Bramble Cay has been subjected to repeated episodes of seawater inundation, which directly impacted on the vegetation by killing or damaging it, thereby reducing the extent and diversity of the herbaceous cover. The recent record of inundation events, together with the observations concerning the significant degree of vegetation loss on the island during the last decade, also provide a credible case for Bramble Cay having experienced flooding by the ocean at an increased frequency and, perhaps, severity during this period. Observations by fishermen, reported here, of high tides and worsening weather conditions (e.g., large waves and strong winds lasting for longer periods) at Bramble Cay over the same time period (A. Moller-Nielsen & E. Stewart pers. comm.) support this conclusion.

Ocean inundation is an anticipated climate change-driven impact on low-lying reef islands caused by changing weather and oceanographic regimes, a greater frequency and intensity of cyclones and rising sea levels (Mimura 1999, Church *et al*. 2006, Mimura *et al.* 2007, Department of Climate Change 2009, Webb & Kench 2010). In the Torres Strait, information on recent changes in weather regimes and their associated effects supports the proposal that Bramble Cay has been subjected to seawater inundation with greater regularity since 2004. This region "experienced a spate of inundation events" over the four years prior to 2011 (J.J. Callaghan, Appendix H in Harper 2013), all involving storm surges that resulted in inundation of low-lying areas and damage to coastal communities. Tropical cyclones produce the most damaging storm surges, although the direct impacts of these are typically limited to within 100 km of the centre of the system and last less than 12 hours (Harper 2013). Since 2003, an increase in cyclonic impacts has occurred on the east coast of Queensland, contrasting with a period of reduced impacts from around 1977 to 2003 (J.J. Callaghan, Appendix H in Harper 2013). Although tropical cyclones are relatively rare in the Torres Strait, with most such systems tracking further south (Green *et al*. 2009, Duce *et al.* 2010), the indirect storm surge impacts of even low intensity, relatively distant cyclones or low pressure systems (e.g., those in the Gulf of Carpentaria or crossing Cape York Peninsula) can be significant for low-elevation Torres Strait islands during the regular season of prevailing monsoonal north-westerly winds (particularly in January and February) when they occur in conjunction with the astronomical high tide (Green *et al*. 2009, Parnell & Smithers 2010, Suppiah *et al.* 2010). This is because the monsoon, in contrast to tropical cyclones, affects much wider areas and persists for days at lower levels of impact (Harper 2013). These systems produce high energy waves during the storm tides, leading to severe coastal erosion and inundation (Green *et al*. 2009, Duce *et al.* 2010). Outside of the monsoon and cyclone season, when the Torres Strait experiences a season of reversed wind direction, damaging storm surges and storm tides during the high tide period can still be produced by the strong, sustained south-easterlies in winter (Green *et al*. 2009).

Examples of recent meteorological events involving high water impacts in the Torres Strait region include Tropical Cyclone (TC) *Ingrid* in March 2005, a very intense, westward-moving system just south of the Torres Strait that generated southerly swells and storm surges and caused significant damage to villages along the southern coast of Papua New Guinea to the south-east of Port Moresby. The following month, a rapidly developing, eastward-moving cyclone tracked off New Guinea into the Gulf of Papua, passing close to the north of Bramble Cay with gale to storm force winds (J.J. Callaghan, Appendix H in Harper 2013). In July 2005, sustained winter-time south-easterly gales produced a large storm surge that impacted broadly across the Torres Strait region, destroying hundreds of homes in Papua New Guinea's Western Province and on Daru, producing significant inundation on Mer (Murray Island), north-east Torres Strait, and causing erosion of land on Warraber (Sue Island), central Torres Strait (**Fig. 1**; Green *et al*. 2009; J.J. Callaghan, Appendix H in Harper 2013). Reported impacts of this same weather system on Bramble Cay provided by Latch (2008) are described above. The damage inflicted by this weather system was compounded in January and February 2006 by large storm surges across the Torres Strait caused initially by an intense monsoon low in the Northern Territory, followed by the formation of TC *Kate* (J.J. Callaghan, Appendix H in Harper 2013). Finally, two large cyclonic systems in the southern Gulf of Carpentaria (ex-TC *Helen* in January 2008 and TC *Charlotte* in January 2009) produced extensive areas of strong to gale force winds across the Arafura Sea and generated large waves, elevated sea levels and damaging storm surges across the Torres Strait (J.J. Callaghan, Appendix H in Harper 2013).

Seawater inundation events associated with the weather systems of January and February 2006, January 2009 and an additional system that impacted in 2012 were documented for as many as seven inhabited islands across the Torres Strait (Green *et al*. 2009, Duce *et al*. 2010, Parnell & Smithers 2010, DERM 2011, Kelly 2014) and gained significant media coverage as a result of damage caused to sea walls and other human infrastructure, as well as culturally important sites (Minchin 2006, Michael 2007, Cohen 2012, Bagnall 2014, Garrett 2014, Kelly 2014). Additional significant flooding and erosion events were noted for inhabited Torres Strait islands during 2010 and 2014 (Steffen & Hughes 2013, Torres Strait Regional Authority 2014). For the period 1998–2008, a tidal gauge at Palilug (Goods Island; **Fig. 1**) in the southern Torres Strait, approximately 245 km south-west of Bramble Cay, recorded anomalies between measured and predicted tides of as much as 1.15 m, demonstrating that surge effects can exert significant influences on sea levels in the region (Duce *et al.* 2010).

The increase in cyclonic activity on the east coast of Queensland since 2003 has been attributed to an alteration in the occurrences of El Niño and La Niña events under the influence of the Inter-decadal Pacific Oscillation (J.J. Callaghan, Appendix H in Harper 2013). An analysis of three decades of data from across the entire Pacific Ocean basin determined that occurrences of coastal erosion and flooding are most closely tied to the El Niño/Southern Oscillation, with the Southern Hemisphere, including Australia, experiencing more severe conditions during La Niña due to increases in cyclonic activity, wave energy and sea surface elevation (Barnard *et al.* 2015). The Torres Strait also experiences higher sea levels during La Niña years, whereas lower sea levels occur during El Niño years (Suppiah *et al.* 2010). Clearly, the damaging impacts exerted on coastal areas by the changing weather regimes are being driven by climatic oscillations (Barnard *et al*. 2015). The trend towards a strengthening in the intensity of La Niña conditions until at least 2012 has been linked to climate change, specifically the increase in global mean temperature (L'Heureux *et al.* 2013), with the frequency of extreme La Niña events predicted to increase (almost doubling) with greenhouse warming during this century (Cai *et al*. 2015).

For low-lying islands like Bramble Cay, the destructive effects of extreme water levels resulting from severe meteorological events are compounded by the impacts from anthropogenic climate change-driven sea-level rise (Mimura 1999, Mimura *et al*. 2007, Department of Climate Change 2009, Green *et al.* 2009). Globally, the mean sea level has risen by almost 20 cm between 1901 and 2010 (Church & White 2006, Church *et al.* 2013), a rate unparalleled in any period during the last 6000 years (Lambeck *et al*. 2014). The average rate of rise over that time has been 1.7 mm/year, and approximately 3.2 mm/year between 1993 and 2014, with these rates being mostly attributable to anthropogenic climate change (Jevrejeva *et al.* 2009, Church *et al.* 2013, Hamlington *et al.* 2014, Greenhalgh 2015). Regional variation in rates of sea-level rise exist (Church *et al.* 2006, Mimura *et al.* 2007, Church *et al.* 2013), and northern Australia has experienced some of the most rapid rates recorded in the world (Church *et al.* 2010). Tidal gauge and satellite data from the Torres Strait and Papua New Guinea indicate mean sea level has risen 6 mm per year between 1993 and 2010 for the region, a figure that is twice the global average (Suppiah *et al.* 2010). The Torres Strait islands are particularly vulnerable to rising sea levels and low-lying communities here are already subjected to regular inundation by the sea, with spring tides each year causing increasing extents of flooding and erosion (Steffen & Hughes 2013, Torres Strait Regional Authority 2014). Overall, the frequency at which such ocean inundation events occur will increase with rising mean sea levels (Department of Climate Change 2009), perhaps resulting in permanent inundation of the areas of lowest elevation on Torres Strait islands (Duce *et al.* 2010).

From the foregoing consideration of the range of threatening processes that potentially impacted on the Bramble Cay melomys, information about the various meteorological and oceanographic influences on the Torres Strait provides a compelling case that repeated ocean inundation driven by anthropogenic climate change posed the most severe, immediate and all-pervasive threat to this rodent population, ultimately sealing its fate. Specifically, the climate change-induced impacts of sea-level rise, coupled with an increased frequency and intensity of weather events that produced damaging storm surges and extreme high water levels, particularly during the last decade, were most likely responsible for the extirpation of the Bramble Cay melomys from Bramble Cay. This may have been due to one severe event or, consistent with the observed pattern of decline, a series of acute episodes of partial inundation. In this light, speculation by Dennis & Storch (1998) that "*M. rubicola* will not necessarily persist after a cyclone event that entirely inundates the cay even if the cay persists" and by

Turner & Batianoff (2007) that a severe cyclone may destroy all of the island's vegetation now appear prophetic. It is a matter for conjecture whether the eventual demise of the Bramble Cay melomys was caused indirectly by seawater destroying the herbaceous vegetation upon which the species depended or directly by wave action drowning remaining individuals and washing them from the island, but most likely both consequences would have arisen from a severe inundation event. Certainly, waves with sufficient power to move logs across the cay surface would be expected to have been lethal for a population of terrestrial rodents.

The IUCN Red List of Threatened Species (IUCN 2015) currently indicates that climate change and severe weather were implicated in the relatively recent (1950s) extinction of one other mammal, the Little Swan Island hutia *Geocapromys thoracatus*, a rodent that was endemic to a coral atoll in Honduras. Although a single, very strong hurricane in 1955 may have contributed to the population's decline, Turvey & Helgen (2008) identified predation by introduced cats as the main extinction driver for this species. Consequently, the conclusion here that the extirpation of the Bramble Cay melomys from Bramble Cay occurred because of rising sea levels and an increased incidence of extreme weather events over preceding years is significant in that it probably represents the first documented mammalian extinction due solely (or primarily) to anthropogenic climate change.

Worryingly, losses of breeding populations of additional vertebrate species from Bramble Cay are to be expected. Global climate change predictions for the remainder of this century and beyond are dire, with some modelling predicting a sea-level rise of nearly 1 m by the year 2100 (Church *et al*. 2013). Superimposed on any effects caused by this rise in sea level, the predicted increases in the frequency and intensity of La Niña events for the 21st century driven by global warming will greatly exacerbate the impacts of coastal erosion and flooding (Barnard *et al*. 2015, Cai *et al*. 2015). Even with only a mid-range sea-level rise of 0.5 m, extreme weather events that now occur every ten years would be expected approximately every ten days by the end of this century (Department of Climate Change 2009). Because small, low-lying reef islands are especially vulnerable to sea-level rise and the increasingly intense storm surges produced by more extreme weather events, future prospects for the regionally important seabird and green turtle rookeries on Bramble Cay, and for the cay itself, are grim. Other islands supporting breeding populations of turtle and bird species in the Torres Strait and northern Great Barrier Reef may be impacted similarly in coming years if the current trends continue.

Extinct or not?: does the Bramble Cay melomys occur elsewhere in Torres Strait?

Extinction can be an unexpectedly difficult state to demonstrate. The results reported here, from thorough survey, confirm that the Bramble Cay melomys no longer occurs at the only site from which it has ever been reliably reported. The IUCN (IUCN 2001) defines extinction as follows:

> "A taxon is Extinct when there is no reasonable doubt that the last individual has died. A taxon is presumed Extinct when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form."

Under the Commonwealth's EPBC Act, definitions for the categories of extinct and extinct in the wild are:

> (1) A native species is eligible to be included in the extinct category at a particular time if, at that time, there is no reasonable doubt that the last member of the species has died.
> (2) A native species is eligible to be included in the extinct in the wild category at a particular time if, at that time:
>> (a) it is known only to survive in cultivation, in captivity or as a naturalised population well outside its past range; or
>> (b) it has not been recorded in its known and/or expected habitat, at appropriate seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.

Queensland's *Nature Conservation Act 1992* prescribes native wildlife as being extinct in the wild if:

> (a) there have been thorough searches conducted for the wildlife; and
> (b) the wildlife has not been seen in the wild over a period that is appropriate for the life cycle or form of the wildlife.

In this particular case, the recent surveys of Bramble Cay were both 'thorough' and 'exhaustive' and sampled all 'known habitat' at appropriate times, and represented the full extent of the known historic range of the Bramble Cay melomys. What follows in this and the subsequent section relates to those parts of the above IUCN and EPBC Act definitions concerning 'expected habitat'.

Although it is now certain that the Bramble Cay melomys is no longer extant on Bramble Cay, the possibility that the species occurs elsewhere on islands in the Torres Strait deserves serious consideration. Arguing against such a notion, it is now 170 years since the existence of the species on Bramble Cay was first reported (Sweatman unpublished), and more than 90 years since the Bramble Cay melomys was formally described (Thomas 1924), and yet in all that time no other population has been discovered. Lee (1995) stated:

> “Extensive surveys by Limpus (Qld Department of Environment and Heritage), Miller (Qld Department of Environment and Heritage), and Heatwole (Australian Museum) in the Torres Strait and the Northern Great Barrier Reef have failed to locate this species anywhere but Bramble Cay, Torres Strait.”

Limpus *et al.* (1983) reported the only melomys found during their surveys of other islands was the grassland melomys *M. burtoni*.

Since such survey work was conducted, additional trapping effort targeting vertebrate fauna of Torres Strait islands situated close to Bramble Cay has been made, also without detecting the Bramble Cay melomys. Gynther *et al*. (2014a) undertook two-night trapping surveys of three uninhabited, vegetated coral cays within a radius of 81 km of Bramble Cay, namely Tappoear (Campbell Island; 9°34’00”S, 143°29’30”E), Attagoy (Nepean Island; 9°34’05”S, 143°39’20”E) and Damut or Damuth (Dalrymple Islet; 9°36’50”S, 143°18’10”E), with the grassland melomys being the only ground-dwelling mammal located on the last of these islands (**Fig. 1**). Extensive surveys of the two nearest islands to Bramble Cay that possess any topographic relief, namely Ugar (Stephens Island; 9°30’27”S, 143°32’43”E) and Erub (Darnley Island; 9°35’16”S, 143°46’09”E), human-inhabited islands of volcanic origin situated 54 km south-west and 50 km south-south-west of Bramble Cay, respectively (**Fig. 1**), also found no Bramble Cay melomys. Instead large populations of grassland melomys and, on Erub, the introduced house mouse *Mus musculus* and black rat *Rattus rattus* were discovered (Diete 2010, Lavery *et al.* 2012). Furthermore, over the last decade, considerable survey work has focused on the Torres Strait’s 15 other human-inhabited islands (Ingram & Caneris 2004a; Ingram 2008; Diete 2010; Lavery *et al*. 2012; Watson 2012; Gynther *et al*. 2014b; Reis *et al.* 2015), as well as a number of uninhabited islands (Ingram & Caneris 2004b; Watson 2009, Hitchcock 2012, Fell & Watson 2014; J. Watson pers. comm.), but the Bramble Cay melomys has not been detected. This recent work assessed vegetated coral cays, as well as mud islands, basaltic lava islands and continental islands, from across all five of the Torres Strait’s geographically classified island groups, namely the Northern, Eastern, Western, Central and Southern Divisions (refer to Lavery *et al*. 2012, Torres Strait Regional Authority 2014).

Only one other island has previously been mentioned as a possible location for the Bramble Cay melomys. This is Sassie (Long Island; 10°01’56”S, 142°50’55”E), a large mud and mangrove island that formed on a platform reef (Willmott *et al.* 1969) after the ocean flooded the Australia–New Guinea land bridge. Sassie lies in the Central Division of Torres Strait, 149 km south-west of Bramble Cay, approximately 160 km south-west of the Fly River mouth, and equidistant (80 km) from the nearest sections of the Cape York and Papua New Guinea coastlines (**Fig. 1**). In his description of the

Bramble Cay melomys, Thomas (1924) referred to a single specimen resembling this species that was collected from this location, presumably in 1845 (Limpus *et al.* 1983), but which could not be identified conclusively due to its poor condition. Limpus *et al.* (1983) reported that no melomys were found during a brief assessment of the "sand and shingle ramparts" on the western side of Sassie. Thomas's tentative record of the Bramble Cay melomys from Sassie has never been substantiated and indeed appears to have been discounted because all recent authors state that the species is restricted to Bramble Cay (Dennis 2008, Latch 2008, Dennis 2012, Woinarski *et al.* 2014). Furthermore, as neither of the two hypotheses proposed to explain the origin of the Bramble Cay melomys population on Bramble Cay (see following section) could account for an isolated occurrence of the species on Sassie, it seems very doubtful that a population ever existed on this second Torres Strait island.

Given the long history of knowledge of the Bramble Cay melomys, the lack of substantiation of the Sassie specimen, as well as the absence of records of the species from other islands in the region despite considerable survey effort, the conclusion that the Bramble Cay melomys does not occur elsewhere in the Torres Strait appears well justified. As a result, the now confirmed extirpation of the only known population of the species from Bramble Cay has heightened importance because it constitutes the almost certain extinction of another of Australia's mammals.

Extinct or not?: does the Bramble Cay melomys occur outside Australia?

The origins of the Bramble Cay melomys population on Bramble Cay are uncertain (Dennis & Storch 1998, Latch 2008), with two hypotheses having been presented to explain how the species came to have such a tiny, restricted distribution. The first is that it represents a relictual population of a species previously inhabiting the low-lying Sahul Plain that once connected the land masses of Australia and New Guinea, but was left stranded on Bramble Cay (an island with ties to a volcanic past) following sea-level rise between 9000 and around 5800 years ago when the present day island formations were established (Dennis & Storch 1998, Barham 1999, Woodroffe *et al.* 2000, Lavery *et al.* 2012). The second hypothesis is that the species is of New Guinean origin, and that colonising individuals rafted across to Bramble Cay on flood debris emanating from the mouth of the Fly River, located just over 50 km from the island (Dennis & Storch 1998, Latch 2008). This idea has been proposed even though the Bramble Cay melomys is not known from New Guinea (e.g., Flannery 1995, Menzies 1996, Dennis & Storch 1998). Available genetic and biochemical evidence shows the species has closest affinity with Australia's Cape York melomys *M. capensis* (Limpus *et al.* 1983; Dennis & Storch 1998; Elphinstone & Baverstock, Appendix 2 in Dennis & Storch 1998; Bryant *et al.* 2011), from which it is estimated to have diverged at around 900,000 years ago, also during a period when land bridges occurred between Cape York and New Guinea, including the region in which Bramble Cay now lies (Bryant *et al.* 2011). This evidence is used to provide support for the former hypothesis, however, little fauna survey work and genetic sampling of melomys from the Fly River delta of Papua New Guinea have been undertaken (Dennis & Storch 1998, Latch 2008, Bryant *et al.* 2011, Lavery *et al.* 2013). Consequently, the possibility exists that the Bramble Cay melomys (or a related species with even closer taxonomic affinity with the Bramble Cay melomys than the Cape York melomys) has been overlooked or remains to be discovered in this region of Papua New Guinea (Bryant *et al.* 2011, Dennis 2012).

Favouring the second hypothesis, some evidence is available to support the potential colonisation of Bramble Cay by melomys individuals rafting across from Papua New Guinea on flood-borne debris. The shoreline of Bramble Cay is frequently littered with beach-washed nypa palms *Nypa fruticans*, logs of pandanus *Pandanus* spp., mangrove plant parts and large pieces of other vegetation of New Guinean provenance, primarily originating from the Fly River (Smith 1994, Dennis & Storch 1998, Ellison 1998, Gynther *et al.* 2014a). The dug-out canoe that provided shelter for the last known Bramble Cay melomys individuals on the island around 2009 (E. Stewart pers. comm.; **Table 2**) very likely also washed ashore from New Guinea. In this regard, the observations supplied by Mr David Carter (*in litt.*), a turtle researcher who lived on Bramble Cay for six months during the 1979–80 wet season, are particularly pertinent. He wrote:

> "One of my strongest recollections is dawn light revealing a sea dotted with flood debris right to the horizon in every direction: trees, great rafts of nipa [sic] palms and tangles of grass and reeds from the Fly River we presumed. Some of these washed up on the Cay or stranded in the reef lagoon. As with every new feature, there were always rats climbing around on these beach washed items even as they tossed in the surf."

Anecdotal reports collected during the present fieldwork indicate flood debris, undoubtedly from the Fly River delta, may at times be large enough to support upright palm trees or entire human structures (A. Moller-Nielsen pers. comm.). In light of this and given the evident arboreal tendencies of the Bramble Cay melomys[1], trees and other large items of flood debris would clearly be sufficient to support the Bramble Cay melomys on the relatively short ocean crossing from Papua New Guinea to Bramble Cay. Colonisation of the island by just a single pregnant female or a female nursing young may have been all that was required to establish this population. Such a scenario would concur with the results of genetic investigations demonstrating that the Bramble Cay melomys population possessed only one mtDNA genotype, suggesting that a single colonisation event took place on the cay (Elphinstone & Baverstock, Appendix 2 in Dennis & Storch 1998).

[1]Bramble Cay melomys individuals were observed climbing any upright structure that was erected on Bramble Cay, even clambering up an anemometer (see photograph on inside front cover) and throughout the small hut that provided the turtle researchers with shelter from October 1979 to March 1980 (D. Carter *in litt.*).

Together, these observations and associated evidence suggest a New Guinean origin of the Bramble Cay melomys is not only plausible but perhaps the more likely of the two hypotheses. Importantly, the implications of this conclusion are that the former isolated and restricted distribution of the species on Bramble Cay was actually anomalous and that the species originated from (and may still occur in) Papua New Guinea, thereby providing some hope that outright extinction of the Bramble Cay melomys has not occurred. However, there is no direct evidence for this supposition. Confirming any occurrence in Papua New Guinea will require targeted surveys of habitats lining the Fly River, particularly within the delta, as has previously been advocated by Dennis & Storch (1998), Latch (2008), Dennis (2012), Gynther *et al.* (2014a) and Woinarski *et al.* (2014). Given the level of global conservation concern for the Bramble Cay melomys (Leary *et al.* 2008), funding such survey work should be a high priority to resolve questions about the continued existence of the species.

It is reasonable to conclude that the Bramble Cay melomys is 'Presumed Extinct', given that exhaustive surveys have failed to record it at its only known location. However, this category is no longer available under IUCN or EPBC Act classifications. Some case may be made for the occurrence of the species in locations from which it has never before been recorded. This appears to be unlikely for other islands in the Torres Strait and, consequently, the species should be considered regionally extinct in Queensland and nationally, i.e. extinct in the wild under both Queensland's *Nature Conservation Act 1992* and the Commonwealth's EPBC Act, based on definition (2)(b) for the latter. However, a possibility exists that the Bramble Cay melomys occurs in the Fly River delta area of southern New Guinea and so, until this area is adequately surveyed, it may be premature to formally declare the species extinct. In view of this, the most appropriate action would be to retain the IUCN listing of Critically Endangered for the Bramble Cay melomys, but to add the tag 'Possibly Extinct' in accordance with the Red List Guidelines (IUCN Standards and Petitions Subcommittee 2014) because of the small chance the species is extant outside Australia.

RECOMMENDATIONS

With the extirpation of the Bramble Cay melomys from Bramble Cay and the near certain absence of this rodent on all other islands within Australian territory, the status of the species should be amended to extinct in the wild under Queensland's *Nature Conservation (Wildlife) Regulation 2006* (subordinate to the *Nature Conservation Act 1992*) and extinct in the wild, based on definition (2)(b), under the Commonwealth's EPBC Act.

Because of the small chance the Bramble Cay melomys occurs outside Australia, it would be appropriate to amend the current IUCN listing for the species to Critically Endangered (Possibly Extinct).

To resolve the global conservation status of the Bramble Cay melomys, the highest priority action required is to clarify whether this species is extant in Papua New Guinea's Fly River region. Because Queensland has a special interest in the status of the Bramble Cay melomys, being the former sole jurisdiction under which the species was known to occur, it is recommended that EHP actively encourage external organisations and agencies to conduct targeted surveys for the Bramble Cay melomys in the Fly River delta. This work should incorporate a comprehensive genetic sampling program for all species of melomys encountered to assist in elucidating the taxonomic and phylogenetic relationships of the Bramble Cay melomys.

Although purely speculative, should surveys in New Guinea prove to be successful in discovering an extralimital population of the Bramble Cay melomys, the potential future translocation of individuals of this species back into Queensland (i.e., Australian) territory from Papua New Guinea could be contemplated. However, notwithstanding the international agreements and cooperation this would require, any such action would demand very careful consideration. Ideally, the genetic composition of the founder population should match that of the former Bramble Cay population, but this may not be the case if genetic drift had occurred in the latter over the period spent in isolation. Regardless, with the extirpation of the Bramble Cay melomys from Bramble Cay and the whereabouts of the DNA samples previously collected from this population now unknown (S. Fuller pers. comm.), such genetic matching is probably no longer possible. Of greater concern for any potential translocation program are the ongoing and apparently worsening climate change-related threats to Bramble Cay and other reef islands of the Torres Strait, suggesting the introduction of founders to such locations would be inadvisable. A number of candidate islands for translocations exist further south in the Great Barrier Reef (Gynther *et al*. 2014a), although the suitability of these has yet to be evaluated and utmost care would be needed to ensure no damage occurred to the existing ecology of these islands through any conservation management action taken on behalf of the Bramble Cay melomys.

ACKNOWLEDGEMENTS

We are deeply indebted to the Erubam Le for granting us permission to access the island and conduct this survey. Special appreciation goes to Torres Strait Regional Authority and Australian Institute of Marine Science for arranging trip logistics and sharing the costs of boat and aircraft charters with EHP, and also for accommodating our need for a 6-night visit early in spring, before the turtle nesting season. We thank Scott Bainbridge, Scott Gardner and Ray Boyes (all Australian Institute of Marine Science), Tristan Simpson, Aaron Ketchell and David Ghee (all Torres Strait Regional Authority), Collette Thomas (James Cook University) and Ryan Moss for help with the trapping program, as well as with trap washing under less than ideal conditions. We are extremely grateful to professional fishermen, Al Moller-Nielsen and Egon Stewart for offering their recollections of events pertinent to Bramble Cay and its melomys from their long association with the island. Peter Davie (Queensland Museum) kindly identified crab species captured and photographed during this field trip. Particular thanks go to Kirsten Wallis and David Woolsey (both EHP) for undertaking GIS analyses of cay areas and vegetation extent. David also prepared most of the figures in this report. Figure 1 was produced by Emma Gatehouse and Brooke Taylor (both EHP). We are grateful to Gillian Carter for supplying contact details for her brother, David Carter, who offered invaluable insights into the behaviour of the Bramble Cay melomys, as well as events on and around Bramble Cay and photographs of the island from 1979–80. Many people provided considerable efforts, under extremely tight timeframes, to ensure that the various approvals necessary for this project were in place prior to the survey starting. They include Peter Latch, Natalie Cummings, Claire Sim, Ben Phillips, Sam Dutton and Sebastian Lang (all Commonwealth Department of the Environment), Peta Maidens (EHP) and Mark Geyle (Torres Strait Regional Authority). We thank Col Limpus for helpful discussions and provision of valuable information about survey work conducted in the Torres Strait and northern Great Barrier Reef, as well as details concerning Bramble Cay melomys kept briefly in captivity in the 1980s. John Clarke (CSIRO) kindly provided climatic data for Poruma, as well as contact details for the PNG Met Service. Finally, the staff of Carpentaria Seafaris, namely Greg Bethune (Skipper of MV *Tropic Paradise*), Andrew Barry (First Mate) and Naomi Chan (Cook), were a vital part of this expedition. They assisted in innumerable ways, including loading and unloading field equipment, transporting us and our gear to and from Bramble Cay, facilitating all aspects of the survey program while at the island, introducing us to the professional fishermen who were also present at the time, and providing exceptional meals and entertainment on board to nourish body and soul in the face of each day's gloomy trapping results. Thanks go to Katrina Prior and Rich Seaton (both EHP) for their comments on an earlier version of this report. Last but not least, we are indebted to external reviewers John Woinarski and Tim Flannery for generously giving up their time to provide numerous helpful edits and comments that greatly improved this survey report.

REFERENCES

Bagnall, G. 2014. Torres Strait fears climate change. *The Stringer*, Independent News. 10 October 2014. <thestringer.com.au/torres-strait-fears-climate-change-8790>. Accessed 10 October 2014.

Barham, A. 1999. The local environmental impact of prehistoric populations on Saibai Island, northern Torres Strait, Australia: enigmatic evidence from Holocene swamp lithostratigraphic records. *Quaternary International* 59: 71–105, doi:10.1016/S1040-6182(98)00073-1.

Barnard, P.L., Short, A.D., Harley, M.D., Splinter, K.D., Vitousek, S., Turner, I.L., Allan, J., Banno, M., Bryan, K.R., Doria, A., Hansen, J.E., Kato, S., Kuriyama, Y., Randall-Goodwin, E., Ruggiero, P., Walker, I.J. & Heathfield, D.K. 2015. Coastal vulnerability across the Pacific dominated by El Niño/Southern Oscillation. *Nature Geoscience* 8: 801–807, doi:10.1038/ngeo2539.

BOM. 2015. Climate Data Online. Monthly rainfall. Coconut Island. <www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=139&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=027054>. Accessed 13 Aug 2015.

Bryant, L.M., Donnellan, S.C., Hurwood, D.A., & Fuller, S.J. 2011. Phylogenetic relationships and divergence date estimates among Australo-Papuan mosaic-tailed rats from the *Uromys* division (Rodentia: Muridae). *Zoologica Scripta* 40: 433–447, doi:10.1111/j.1463-6409.2011.00482.x.

Cai, W., Wang, G., Santoso, A., McPhaden, M.J., Wu, L., Jin, F-F., Timmermann, A., Collins, M., Vecchi, G., Lengaigne, M., England, M.H., Dommenget, D., Takahashi, K. & Guilyardi, E. 2015. Increased frequency of La Niña events under greenhouse warming. *Nature Climate Change* 5: 132–137, doi:10.1038/nclimate2492.

Church, J. A. & White, N. J. 2006. A 20th century acceleration in global sea-level rise. *Geophysical Research Letters* 33: L01602, doi:10.1029/2005GL024826.

Church, J.A., White, N.J. & Hunter, J.R. 2006. Sea-level rise at tropical Pacific and Indian Ocean islands. *Global and Planetary Change* 53: 155–168, doi:10.1016/j.gloplacha.2006.04.001.

Church, J.A., Woodworth, P.L., Aarup, T. & Wilson, W.S. (eds.) 2010. *Understanding Sea-Level Rise and Variability*. Wiley-Blackwell, Hoboken, NJ, USA.

Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S., Levermann, A., Merrifield, M.A., Milne, G.A., Nerem, R.S., Nunn, P.D., Payne, A.J., Pfeffer, W.T., Stammer, D. &

Unnikrishnan, A.S. 2013. Sea Level Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Eds T.F. Stocker, D. Qin, G-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P.M. Midgley), pp 1137–1177. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Cohen, H. 2012. A sinking feeling in the Torres Strait. Background Briefing. ABC Radio National, Australian Broadcasting Corporation. <www.abc.net.au/radionational/programs/backgroundbriefing/2012-03-04/3857272>. Accessed 27 November 2014.

Dennis, A.J. 2008. Bramble Cay Melomys *Melomys rubicola*. In *The Mammals of Australia*, Third Edition (Eds S. Van Dyck & R. Strahan), pp 673–674. New Holland Publishers, Sydney, NSW.

Dennis, A.J. 2012. Bramble Cay melomys *Melomys rubicola*. In *Queensland's Threatened Animals*. (Eds L.K. Curtis, A.J. Dennis, K.R. McDonald, P.M. Kyne & S.J.S. Debus), pp 398–399. CSIRO Publishing, Collingwood, Vic.

Dennis, A. & Storch, D. 1998. *Conservation and Taxonomic Status of the Bramble Cay Melomys, Melomys rubicola*. Unpublished Report to Environment Australia Endangered Species Program Project No. 598. Queensland Department of Environment, Atherton, Qld.

Department of Climate Change. 2009. *Climate Change Risks to Australia's Coasts. A First Pass National Assessment*. Australian Government, Canberra, ACT.

DERM. 2011. *Queensland Coastal Processes and Climate Change*. Queensland Climate Change Centre of Excellence, Department of Environment and Resource Management, Brisbane, Qld.

Dickman, C.R., Leung, L.K.-P. & Van Dyck, S.M. 2000. Status, ecological attributes and conservation of native rodents in Queensland. *Wildlife Research* 27: 333–346.

Diete, R. 2010. *The ecology of exotic rodents and non-target species on Torres Strait islands: implications for exotic rodent eradication*. Bachelor of Applied Science (Animal Studies) (Honours) thesis. University of Queensland, St Lucia, Qld.

Duce, S.J., Parnell, K.E., Smithers, S.G. & McNamara, K.E. 2010. *A Synthesis of Climate Change and Coastal Science to Support Adaptation in the Communities of the Torres Strait*. Synthesis report prepared for the Marine and Tropical Sciences Research Facility (MTSRF). Reef & Rainforest Research Centre Limited, Cairns, Qld.

Ellison, J.C. 1998. Natural history of Bramble Cay, Torres Strait. *Atoll Research Bulletin* 455: 1–33.

Elvish, R. & Walker, T.A. 1991. Seabird Islands. Bramble Cay, Great Barrier Reef, Queensland. *Corella* 15: 109–111.

Fell, D.G. & Watson, J.J. 2014. *Biodiversity Values of the Warraberalgahl and Porumalgal Indigenous Protected Area, Central Torres Strait*. Unpublished Report to Torres Strait Regional Authority. David Fell Environmental Pty Ltd, Alstonville, NSW & Gondwana Ecology Group, Kenmore, Qld.

Flannery, T. 1995. *Mammals of New Guinea*. Reed Books, Chatswood, NSW.

Garrett, J. 2014. Torres Strait receives $26.2m funding for coastal protection. Pacific Beat. ABC News, Australian Broadcasting Corporation. <www.abc.net.au/news/2014-02-26/an-australia-gives-funding-for-torres-strait-coastal-protection/5286732>. Accessed 27 November 2014.

Green, D., Alexander, L., McInnes, K., Church, J., Nicholls, N. & White, N. 2009. An assessment of climate change impacts and adaptation for the Torres Strait Islands, Australia. *Climatic Change* 102: 405–433, doi:10.1007/s10584-009-9756-2.

Greenhalgh, E. 2015. *2014 State of the Climate: Sea Level*. National Oceanic and Atmospheric Administration. <www.climate.gov/news-features/understanding-climate/2014-state-climate-sea-level>. Accessed 16 December 2015.

Gynther, I., Fell, D.G. & Freeman, A. 2014a. *Results of a March 2014 Survey of Bramble Cay and Three Other Uninhabited Islands in the North-eastern Torres Strait, with Particular Reference to the Bramble Cay Melomys*. Unpublished report to the Department of Environment and Heritage Protection, Queensland Government, Brisbane.

Gynther, I., Fell, D.G. & Freeman, A. 2014b. *A Terrestrial Vertebrate Fauna Survey of Mua (Moa Island), Torres Strait, Queensland*. Unpublished report to Torres Strait Regional Authority. Department of Environment and Heritage Protection, Brisbane & David Fell Environmental Pty Ltd, Alstonville, NSW.

Hamlington, B.D., Strassburg, M.W., Leben, R.R., Han, W., Nerem, R.S. & Kim, K-Y. 2014. Uncovering an anthropogenic sea-level rise signal in the Pacific Ocean. *Nature Climate Change* 4: 782–785, doi.org/10.1038/nclimate2307.

Harper, B.A. 2013. *Torres Strait Extreme Water Level Study. Final Report, July 2011*. Report to the Torres Strait Regional Authority, revised April 2013. Systems Engineering Australia Pty Ltd, Newstead, Qld. <www.tsra.gov.au>.

Hitchcock, G. 2012. *Warul Kawa Indigenous Protected Area Plan of Management.* Arafura Consulting, Melbourne, Vic.

Ingram, G.J. 2008. The terrestrial vertebrates of Mua, Western Torres Strait. *Memoirs of the Queensland Museum, Cultural Heritage Series* 4: 495–504.

Ingram, G. & Caneris, A. 2004a. *Fauna Assessment Report: High Frequency Surface Wave Extended Coastal Area Radar (SECAR) and DSTO Projects, Dauan Island, Torres Strait*. A report prepared for Daronmont Technologies. Biodiversity Assessment and Management Pty Ltd, Cleveland, Qld.

Ingram, G. & Caneris, A. 2004b. *Fauna Assessment Report: High Frequency Surface Wave Extended Coastal Area Radar (SECAR) and DSTO Projects, Koey Ngurtai (Pumpkin Islet), Torres Strait*. A report prepared for Daronmont Technologies. Biodiversity Assessment and Management Pty Ltd, Cleveland, Qld.

IUCN. 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK.

IUCN. 2015. The IUCN Red List of Threatened Species. Version 2015-4. <www.iucnredlist.org>. Accessed 2 June 2016.

IUCN Standards and Petitions Subcommittee. 2014. Guidelines for Using the IUCN Red List Categories and Criteria. Version 11. Prepared by the Standards and Petitions Subcommittee. Downloadable from http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Jevrejeva, S., Grinsted, A. & Moore, J.C. 2009. Anthropogenic forcing dominates sea level rise since 1850. *Geophysical Research Letters*, 36: L20706, doi:10.1029/2009GL040216.

Johannes, R.E. & MacFarlane, J.W. 1991. *Traditional Fishing in the Torres Strait Islands*. CSIRO Division of Fisheries, Hobart, Tas.

Kelly, E. 2014. Rising seas pose a cultural threat to Australia's 'forgotten people'. *The Conversation*. 27 November 2014. <theconversation.com/rising-seas-pose-a-cultural-threat-to-australias-forgotten-people-34359>. Accessed 27 November 2014.

Lambeck, K., Rouby, H., Purcell, A., Sun, Y. & Sambridge, M. 2014. Sea level and global ice volumes from the Last Glacial Maximum to the Holocene. *Proceedings of the National Academy of Sciences (USA)* 111: 15296–15303, doi:10.1073/pnas.1411762111.

Latch, P. 2008. *Recovery Plan for the Bramble Cay Melomys Melomys rubicola*. Environmental Protection Agency, Brisbane, Qld.

Lavery, T.H., Watson, J.J. & Leung, L.K.-P. 2012. Terrestrial vertebrate richness of the inhabited Torres Strait Islands, Australia. *Australian Journal of Zoology* 60: 180–191.

Lavery, T.H., Fisher, D.O., Flannery, T.F. & Leung, L.K.-P. 2013. Higher extinction rates of dasyurids on Australo-Papuan continental shelf islands and the zoogeography of New Guinea mammals. *Journal of Biogeography* 40: 747-758, doi:10.1111/jbi.12072.

Leary, T., Singadan, R., Menzies, J., Wright, D. & Thomson, B. 2008. *Melomys rubicola*, In: The IUCN Red List of Threatened Species 2008: e.T13132A3412635, doi.org/10.2305/IUCN.UK.2008.RLTS.T13132A3412635.en. Accessed 25 June 2014.

Lee, A.K. 1995. *The Action Plan for Australian Rodents*. Australian Nature Conservation Agency, Canberra, ACT.

L'Heureux, M.L., Lee, S. & Lyon, B. 2013. Recent multidecadal strengthening of the Walker Circulation across the tropical Pacific. *Nature Climate Change* 3: 571–576, doi:10.1038/nclimate1840.

Limpus, C.J., Parmenter, C.J. & Watts, C.H.S. 1983. *Melomys rubicola*, an endangered murid rodent endemic to the Great Barrier Reef of Queensland. *Australian Mammalogy* 6: 77–79.

Limpus, C.J., Carter, D.C. & Hamann, M. 2001. The Green Turtle, *Chelonia mydas*, in Queensland, Australia: the Bramble Cay rookery in the 1979-1980 breeding season. *Chelonian Conservation and Biology* 41: 34–46.

Lyu, K., Zhang, X., Church, J.A., Slangen, A.B.A. & Hu, J. 2014. Time of emergence for regional sea-level change. *Nature Climate Change* 4: 1006-1010, doi:10.1038/nclimate2397.

Menzies, J.I. 1996. A systematic revision of *Melomys* (Rodentia: Muridae) of New Guinea. *Australian Journal of Zoology* 44: 367–426.

Michael P. 2007. Rising seas threat to Torres Strait Islands. *The Courier-Mail*, Brisbane, Qld. 2 August 2007. <http://www.couriermail.com.au/archive/news/rising-seas-threaten-isles/story-e6freowx-1111114089466>. Accessed 17 September 2015.

Mimura, N. 1999. Vulnerability of island countries in the South Pacific to sea level rise and climate change. *Climate Research* 12: 137–143.

Mimura, N., Nurse, L., McLean, R.F., Agard, J., Briguglio, L., Lefale, P., Payet, R. and Sem, G. 2007. Small islands. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on*

Climate Change (Eds M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson), pp 687–716. Cambridge Press, Cambridge, UK.

Minchin, L. 2006. Going under. *Sydney Morning Herald*, National, Sydney, NSW. 12 August 2006. <www.smh.com.au/news/national/going-under/2006/08/11/1154803102254.html?page=fullpage>. Accessed 16 September 2015.

Parnell, K.E. & Smithers, S.G. 2010. Cay island dynamics in Torres Strait: The science informing community decisions. In *2010 Annual Conference of the Marine and Tropical Sciences Research Facility (MTSRF).* School of Earth and Environmental Sciences, James Cook University, Cairns, Qld.

Reis, T., Greenhalgh, A., Fell, D.G. & TSRA Near Western Ranger Group 2015. *A Terrestrial Fauna Survey of Badu Island, Torres Strait, Queensland*. Unpublished technical report to the Torres Strait Regional Authority, Land and Sea Management Unit. David Fell Environmental Pty Ltd, Alstonville, NSW.

SEWPaC. 2011. *Survey Guidelines for Australia's Threatened Mammals: Guidelines for Detecting Mammals Listed as Threatened under the Environment Protection and Biodiversity Conservation Act 1999*. Department of Sustainability, Environment, Water, Population and Communities, Canberra, ACT.

Smith, J.M.B. 1994. Patterns of disseminule dispersal by drift in the north-west Coral Sea. *New Zealand Journal of Botany* 32: 453–461.

Steffen, W. & Hughes, L. 2013. *The Critical Decade 2013: Climate Change Science, Risks and Response*. Climate Commission Secretariat (Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education), Canberra, ACT.

Suppiah, R., Bathols, J., Collier, M., Kent, D. & O'Grady, J. 2010. *Observed and Future Climates of the Torres Strait Region*. Report to the Torres Strait Regional Authority. CSIRO, Marine and Atmospheric Research. Aspendale, Vic. <www.tsra.gov.au>.

Sweatman, J. (unpublished). *Journal of a Surveying Voyage to the N.E. Coast of Australia and Torres' Strait in Her Maj. Schooner "Bramble", Lieut. C.B. Yule, Commander 1842–1847*. 2: 15–16.

Thomas, O. 1924. Some new Australasian Muridae. *Annals and Magazine of Natural History* 13: 296–299.

Torres Strait Regional Authority. 2014. *Torres Strait Climate Change Strategy 2014–2018*. Report prepared by the Land and Sea Management Unit, Torres Strait Regional Authority. July 2014. <www.tsra.gov.au>.

Turner, M. & Batianoff, G.N. 2007. Chapter 20 Vulnerability of island flora and fauna in the Great Barrier Reef to climate change. In *Climate Change and the Great Barrier Reef: A Vulnerability Assessment* (Eds J.E. Johnson & P.A. Marshall.), pp 621-666. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Canberra, ACT.

Turvey, S. & Helgen, K. 2008. *Geocapromys thoracatus*. The IUCN Red List of Threatened Species 2008: e.T9003A12949306. <http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T9003A12949306.en>. Accessed 2 June 2016.

Walker, T.A. 1988. The flora and fauna of Bramble Cay, January 1987. *Queensland Naturalist* 28: 32–36.

Waller, N., Gynther, I., Freeman, A., Lavery, T. & Leung, L.K.-P. 2014. Has Australia lost another mammal species? The story of the Bramble Cay melomys (*Melomys rubicola*). *Programme and Abstracts, 2014 AGM, Australian Mammal Society*.

Watson, J.J. 2009. *Terrestrial Vertebrate Fauna of the Pulu Indigenous Protected Area, Torres Strait*. Unpublished report to Arafura Consulting. Gondwana Ecology Group, Kenmore, Qld.

Watson, J.J. 2012. *Terrestrial Vertebrate Fauna of the Proposed Central Islands Indigenous Protected Area, Torres Strait*. Unpublished report to Arafura Consulting. Gondwana Ecology Group, Kenmore, Qld.

Webb, A.P. & Kench, P.S. 2010. The dynamic response of reef islands to sea-level rise: Evidence from multi-decadal analysis of island change in the Central Pacific. *Global and Planetary Change*, doi:10.1016/j.gloplacha.2010.05.003.

Willmott, W.F., Palfreyman, W.D., Trail, D.S. & Whitaker, W.G. 1969. *The Igneous Rocks of Torres Strait, Queensland and Papua.* Record No. 1969/119. Report to the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, Commonwealth Government.

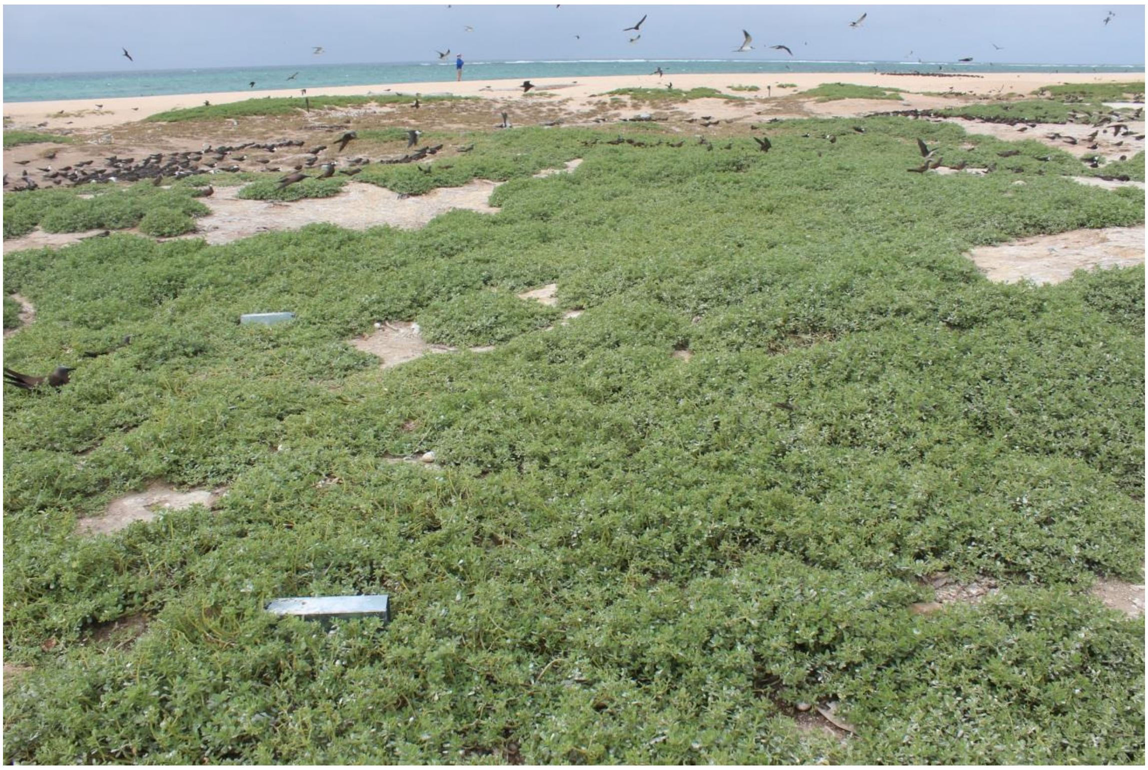
Woinarski, J.C.Z., Burbidge, A.A. & Harrison, P.L. 2014. *The Action Plan for Australian Mammals 2012*. CSIRO Publishing, Collingwood, Vic.

Woodroffe, C., Kennedy, D., Rasmussen, C., and Smithers, S. 2000. Holocene reef growth in Torres Strait. *Marine Geology* 170: 331–346, doi:10.1016/S0025-3227(00)00094-3.

Yazici, I., Turkan, I., Sekmen, A.H. & Demiral, T. 2007. Salinity tolerance of purslane (*Portulaca oleracea* L.) is achieved by enhanced antioxidative system, lower level of lipid peroxidation and proline accumulation. *Environmental and Experimental Botany* 61: 49–57.

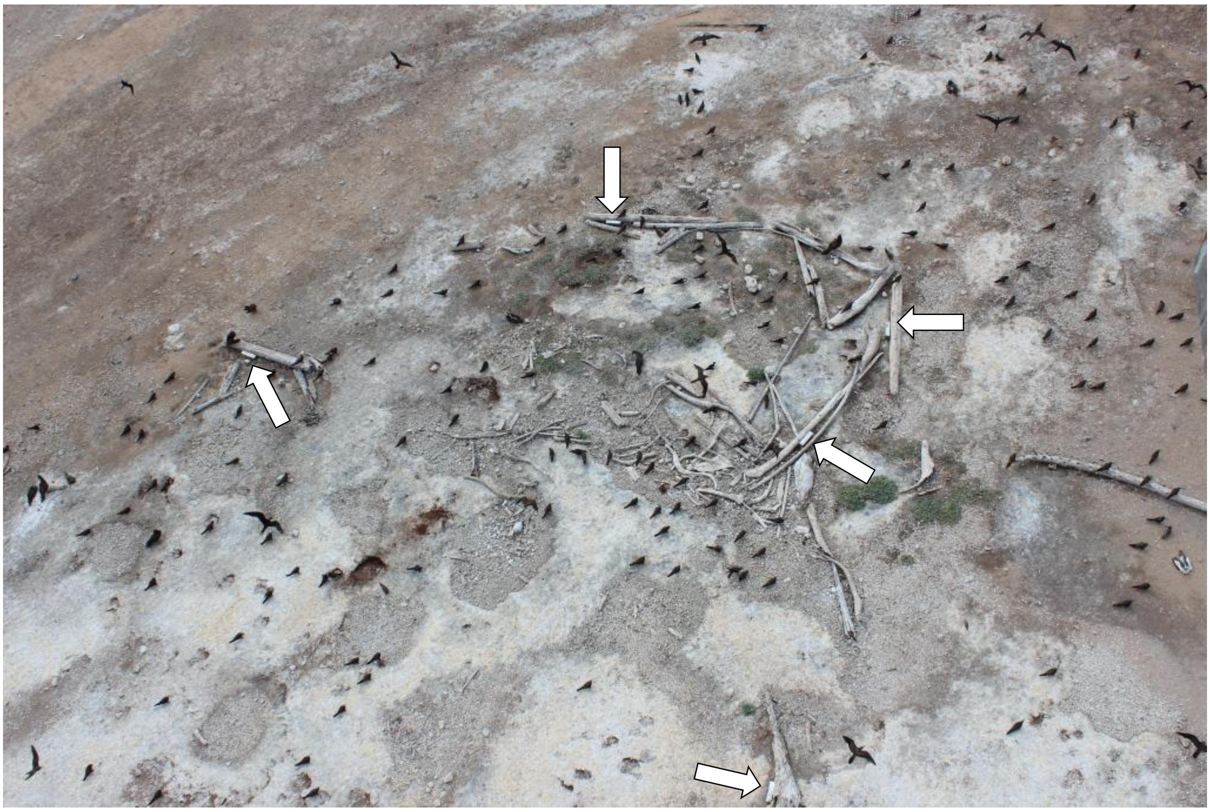
APPENDICES

Appendix 1. Survey program for the Bramble Cay melomys, August–September 2014.



1a. Sherman traps set in an area with the densest cover of *Portulaca oleracea*, north-west of the lighthouse tower. (Photo: Ian Gynther).

1b. Elliott traps set amid scattered *Portulaca oleracea* at the periphery of the cay's vegetated area, north of the lighthouse tower. (Photo: Ian Gynther).



1c. Mammal traps (arrowed) set alongside logs to the east of the lighthouse tower. (Photo: Ian Gynther).

1d. Mammal traps (arrowed) set beneath a phosphatic rock ledge, north-east of the lighthouse tower. (Photo: Ian Gynther).

1e. A camera trap and bait lure positioned within scattered *Portulaca oleracea* near the periphery of the cay's vegetated area, north of the lighthouse tower. (Photo: Ian Gynther).

1f. Conducting an active search for signs of the Bramble Cay melomys. (Photo: Natalie Waller).

1g. Camera trap image of adult sooty terns at night. The lure containing small mammal bait is visible between the two individuals closest to the camera. (Photo: Natalie Waller).

1h. Another camera trap image, showing adolescent (right foreground; centre background) and adult sooty terns roosting at night near a bait lure. (Photo: Natalie Waller).

Appendix 2. Bramble Cay during the August–September 2014 survey expedition.

2a. Vegetation coverage of the north-western end of the island. The area of cracked substrate in the middle foreground was a shallow lagoon in March 2014. (Photo: Ian Gynther).

2b. Vegetation coverage of the south-eastern end of the island. (Photo: Ian Gynther).

2c. Area of dead, flattened sedge *Cyperus* sp. east of the lighthouse tower, looking towards the adjacent southern shoreline of the cay. (Photo: Ian Gynther).

2d. A side view of the dead sedge *Cyperus* sp. near the cay's southern shoreline, east of the lighthouse tower. The uniform direction of the flattened sedge blades is clearly visible. (Photo: Ian Gynther).

2e. Dead clump of sedge *Cyperus* sp. on a phosphatic rock outcrop at the south-eastern end of the island. The inset photo shows the same site five months earlier in March 2014. (Photos: Ian Gynther).

2f. Another view of the dead sedge *Cyperus* sp. clump on the phosphatic rock outcrop at the south-eastern end of the island. The flattened sedge blades can be seen facing away from the cay's adjacent shoreline, where the concrete blocks of the former temporary light tower lie partially submerged at mid-tide. (Photo: Ian Gynther).

2g. Dead *Portulaca oleracea* in a swale parallel to the cay's northern shoreline, north-west of the lighthouse tower. (Photo: Ian Gynther).

2h. View along the swale adjacent to the cay's northern shoreline, north-west of the lighthouse tower, showing living *Portulaca oleracea* growing only in areas of higher elevation. (Photo: Ian Gynther).

2i. View from the lighthouse tower of the swale adjacent to the cay's northern shoreline, showing the distribution of dead *Portulaca oleracea*. Asterisks indicate a few sites with piles of dead bird eggs. (Photo: Ian Gynther).

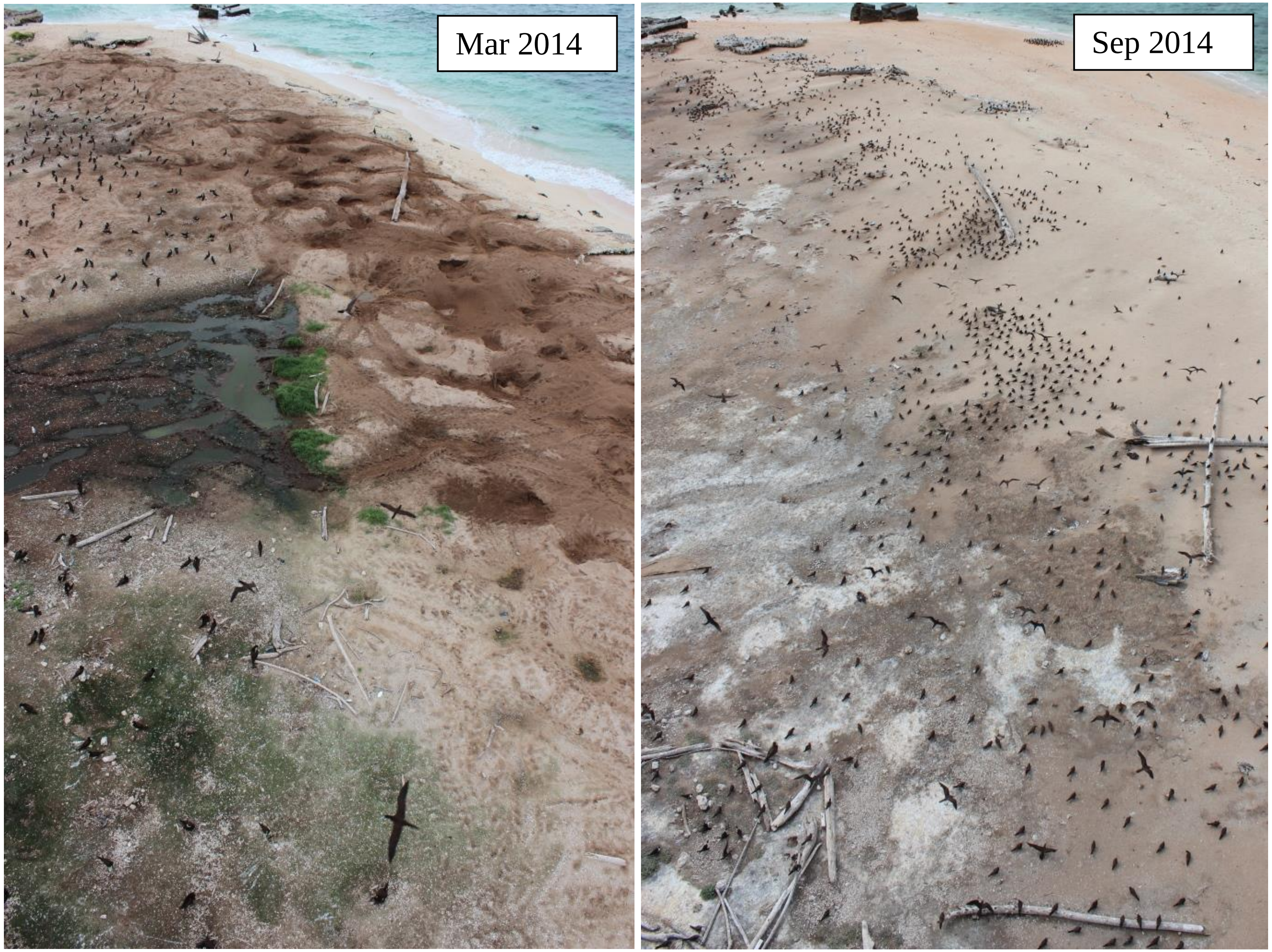
2j. Wide view of the swale with dead *Portulaca oleracea* adjacent to the cay's northern shoreline, taken from the lighthouse tower. The arrows indicate the apparent direction of seawater flow. Locations of piles of dead bird eggs (asterisks) and bird eggs combined with timber flotsam (dots) are shown. (Photo: Ian Gynther).

2k. Deposits of dead bird eggs and beach wrack at the north-western end of the swale running parallel to the cay's northern shoreline. (Photo: Ian Gynther).

2l. Close view of a deposit of dead bird eggs and beach wrack at the north-western end of the swale running parallel to the cay's northern shoreline. (Photo: Ian Gynther).

2m. Piles of dead bird eggs and beach-washed timber at the north-western end of the swale running parallel to the cay's northern shoreline. (Photo: Ian Gynther).

2n. Close view of a pile of dead bird eggs, beach-washed timber and pumice at the north-western end of the swale running parallel to the cay's northern shoreline. (Photo: Ian Gynther).



2o. View south-east from the lighthouse tower in March (left) and September (right) 2014. The concrete blocks of the former lighthouse tower and the exposed phosphatic rock outcrops, visible at the very top of each photo, provide reference points. Changes in the presence and distribution of beach-washed logs and other timber are evident, as is the absence of living sedge *Cyperus* sp. and turtle nest excavations in September. Note that tide heights were different when these two photos were taken. (Photo: Ian Gynther).

Appendix 3. Bird census of Bramble Cay during the August–September 2014 survey expedition.

Ian Gynther (EHP) & Tristan Simpson (Torres Strait Regional Authority)

A list of all bird species seen on or adjacent to Bramble Cay was compiled between 30 August and 5 September 2014. Over the course of the visit, the numbers of birds present on the island were also counted where this was possible. For some species, however, conducting counts was problematic due to the large populations present and the constant movement of individuals, i.e., birds flying within the colony, to and from the island, and circling in the air above the cay and its immediately surrounding waters (**Photo A**). For these species, only rough estimates of abundance were made. When attempting to assess reproductive success, counting numbers of active nests was not possible due to difficulties in distinguishing between nesting and roosting birds (**Photo B**). Also, for the most abundant species in the rookery, no counts or estimates of young and adolescents were made, although the presence of immature individuals was noted.

The ten bird species recorded are shown in the table below, along with an indication of actual or estimated abundance. All had been documented for the island previously. Of the five species for which there was evidence of current or recent reproductive activity, only three could be confirmed to have bred on Bramble Cay due to the presence of eggs or flightless offspring. These species, in order of decreasing abundance, were sooty tern *Onychoprion fuscata* (**Photos C** & **D**), common noddy *Anous stolidus* (**Photos E** & **F**) and brown booby *Sula leucogaster* (**Photos G** & **H**). The discovery of large drifts of dead eggs near the north-western end of the island (see **Appendix 2k–n**) indicated that considerable disruption to bird breeding activity had occurred at some point during the five months preceding this census.

Species	**Population count or estimated range**	**Signs of current breeding activity**[1]
Lesser frigatebird *Fregata ariel*	4–6	–
Great frigatebird *Fregata minor*	7–8	–
Brown booby *Sula leucogaster*	500–800	Young, adolescents
Wandering tattler *Tringa incana*	2	–
Ruddy turnstone *Arenaria interpres*	11–12	–
Common noddy *Anous stolidus*	5000–7000	Eggs, chicks, young, adolescents
Bridled tern *Onychoprion anaethetus*	10–14	Single adolescent
Sooty tern *Onychoprion fuscata*	8000–10000	Eggs, young, adolescents
Crested tern *Thalasseus bergii*	24–36	Adolescents
Silver gull *Chroicocephalus novaehollandiae*	3	Single adolescent

[1]Chicks possess down, young are individuals with pin feathers present, and adolescents are fully feathered but still possess immature plumage.

A. Bird activity on Bramble Cay in the late afternoon. (Photo: Ian Gynther).

B. Nesting and loafing sooty terns and common noddies west of the lighthouse tower. An adolescent brown booby (arrowed) is also visible (Photo: Ian Gynther).


C. Adult sooty tern incubating an egg. (Photo: Ian Gynther).


D. Daytime crèche of adolescent sooty terns (foreground) north-west of the lighthouse tower. Adults are visible in the background, along with common noddies. (Photo: Ian Gynther).

E. Adult common noddy on its nest. (Photo: Ian Gynther).

F. Adult common noddy with young on the upper platform of the lighthouse tower. (Photo: Ian Gynther).

G. Young brown booby awaiting parents to return with food. (Photo: Ian Gynther).

H. Adolescent brown booby perching on an Elliott trap. (Photo: Ian Gynther).