Island translocation of the northern quoll *Dasyurus hallucatus* as a conservation response to the spread of the cane toad *Chaunus [Bufo] marinus* in the Northern Territory, Australia.

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Report submitted to the Natural Heritage Trust Strategic Reserve Program, as a component of project ***2005/162: Monitoring & Management of Cane Toad Impact in the Northern Territory***.

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Photos: front cover – Martin Armstrong releasing a founder quoll (photo: Ian Morris); above – Kym Brennan and Lirrwa Ganambarr monitoring quoll condition (photo: Ian Morris)

Summary

The northern quoll *Dasyurus hallucatus* has declined rapidly with the spread of the cane toad *Chaunus [Bufo] marinus* across northern Australia, and is now listed as endangered. In response to the collapse of northern quoll populations on the mainland Top End of the Northern Territory, we established two translocated island populations, of 19 founder individuals (Pobassoo Island) and 45 individuals (Astell Island), in February-March 2003. Prior to translocation, these islands, off north-eastern Arnhem Land, were not inhabited by quolls. The selection of these islands for this translocation was based on criteria including habitat suitability (areas of rugged sandstone), lack of other significant conservation values, lack of human settlement, small likelihood of colonisation by toads, and approval from Aboriginal landowners.

In collaboration with landowners and Indigenous ranger groups, the population of translocated quolls has been monitored at least annually since founding. Based on analysis of capture-mark-recapture data from the most recent monitoring episode (December 2007), the population of adult female (the demographic cohort showing least variable intra-annual variation) quolls on these islands is now 818 (Pobassoo Island) and 4820 (Astell Island), increases of 74-fold and 142-fold respectively over a 5-year period, a remarkable population growth rate.

On most monitoring trips, and for the founder population, tissue samples were taken for genetic analysis, a range of morphological variables was measured to assess condition, and the sex and age characteristics recorded. The translocated population has shown a slight loss of genetic diversity (as expected in a closed island population). Body condition does not differ significantly from known mainland populations, nor between islands. Compared with known mainland populations, the translocated island population has a high survival rate, with the most recent sampling showing 3% of known age females being in their 4th year, and 29% in their 3rd year.

The success of these two translocated island populations is despite two major disturbance events – a fire that burnt about 70% of Astell Island in August 2003 and a Category 5 cyclone in March 2005 that passed directly over the islands, and stripped and felled most trees on both islands. There is no appreciable trace in the demographic pattern of either of these major disturbances.

CONTENTS

Introduction

Australian mammals have had an extraordinary extinction rate over the last 200 years. That rate would be even higher if it was not for the persistence on islands of nine species that disappeared from their far more extensive mainland ranges (Burbidge 1989, 1999; Burbidge and Manly 2002; McKenzie *et al*. 2007). For these and other species, islands may provide some quarantine from the otherwise often largely pervasive threats of feral predators and disease; and may be exposed to land use characteristics that are distinct from those of the continent as a whole.

Recognising this quarantine and conservation value, there has been a series of conservation-oriented translocations of Australian fauna, particularly threatened mammals, to offshore islands, with some notable successes (e.g. Abbott 2000) and a typically higher success rate than many alternative conservation management options (Burbidge 1989).

But translocation may be a risky strategy, and many translocations have failed or been characterised by poor conception (Griffith 1989, Copley 1994, Wolf 1998). Translocations of carnivores may be especially problematical, given their typically relatively low densities and because of the possibility of unwanted impacts on native prey species (Miller 1999). Recognising the potential risks but conservation benefit of translocations, but also the need to consider a broad range of consequences to the environments to which translocated populations are moved, translocation guidelines have been established internationally (notably IUCN's *Position statement on translocation of living organisms*), and in some Australian jurisdictions, and a set of guidelines for Australia has been drafted but not ratified (Anon 1994).

Here, we describe the rationale and implementation of a translocation project for the northern quoll *Dasyurus hallucatus*. This carnivorous marsupial is known to be extremely susceptible to toxins ingested during predation attempts on the exotic cane toad *Chaunus [Bufo] marinus*. Northern quolls have declined rapidly, often to regional extinction, following the invasion of areas by cane toads (Burnett 1997); and the northern quoll has been recognised as the native species most threatened by cane toads (van Dam *et al*. 2002). Cane toads are spreading rapidly across northern Australia and their eventual range is likely to encompass almost entirely that of the northern quoll (Sutherst *et al.* 1996). In at least the medium term it is highly unlikely that there will be any mechanism available to effectively slow the spread or reduce the population of cane toads in northern Australia. As a consequence of these factors, the northern quoll has recently been listed as endangered under Australia's *Environment Protection and Biodiversity Conservation Act*.

From 2001 to 2003, populations of northern quoll were monitored before and after the invasion front of cane toads in the World Heritage listed Kakadu National Park - at 20,000 km^2, the largest conservation reserve in northern Australia. These monitoring results indicated catastrophic loss of quolls within 1-2 years of the arrival of toads (Watson and Woinarski 2003, 2004; Oakwood 2006). If quolls could not be retained in such a large and well-resourced conservation reserve, their fate across the rest of mainland northern Australia must be considered highly insecure. In response to this demonstrated loss, we developed a program to capture a founder population of quolls from parts of the Northern Territory mainland not yet colonised by toads, and to translocate these individuals to offshore islands, likely to be far less prone to toad invasion. This program was recognised by the National Cane Toad Taskforce as a high priority response for reducing the impact of cane toads on Australian biodiversity (Taylor and Edwards 2005).

This report describes the translocation program, including the selection of translocation sites, the process of collecting and translocating founders and, particularly, monitoring of the fate of the translocated populations. This monitoring includes an assessment of changes in population density and total size, assessment of population structure, and assessment of condition and reproductive status. Where possible, these parameters are compared with information available from studies of northern quolls in wild mainland populations, particularly including those of Oakwood (2000, 2002) and Braithwaite and Griffiths (1994) in lowland Kakadu, that of Begg (1981) in a rugged sandstone habitat in Kakadu, that of Schmitt *et al*. (1989) in a range of habitats in the north Kimberley, and a brief radio-tracking study by King (1989) in the Pilbara.

Methods

The northern quoll: relevant biological details

Northern quolls are small to medium-sized (average weight of adult male = 760 g, adult female = 460 g: Oakwood 2002) carnivorous marsupials, with a broad and flexible diet comprising mostly invertebrates (Oakwood 2002). They are nocturnal and shelter during the day in tree hollows, hollow logs or rock piles, typically moving frequently amongst a set of den sites (Oakwood 2002).

Reproduction is annual and highly synchronised within a population, but may vary by a few weeks between even nearby populations (Schmitt *et al*. 1989). In lowland Kakadu, mating occurs in late May to mid June (the mid Dry season in this highly seasonal monsoonal climate), and young are born in mid to late June, with an average litter size of 7.3 (Oakwood 2000). Begg (1981) reported average litter size as 6.4 in a Kakadu sandstone site, and, Schmitt *et al*. (1989) reported average litter size as 7.2 in a rugged Kimberley site, although with some variation between years. Braithwaite and Griffiths (1994) reported average litter size of 7.0 in lowland Kakadu, with this being appreciably greater earlier in the breeding season than later. Young are carried in a rudimentary pouch for about 60-70 days, then left in a den while the female forages, until independence when about 4-5 months old (Begg 1981; Oakwood 2000). Immediately after the mating period, typically all males die (Dickman and Braithwaite 1992; Oakwood 2000; Oakwood *et al*. 2001), although a few second year males were reported in the studies of Begg (1981) (12.5%) and Schmitt *et al*. (1989) (4.3%), both from rugged sandstone sites. A small proportion of females survive to breed in their second year: 27% in Oakwood's (2000) study [with these all being of females that included some rocky areas within their home range]; 5.2-13% in Braithwaite and Griffiths' (1994) study; and 21% in Begg's (1981) study (with 6% surviving to a third year).

In lowland forest, Oakwood (2002) found that female home range size averaged 35 ha, with some overlap amongst females at high densities, and that male home range was probably similar to that of females in the non-breeding season, but may exceed 100 ha (with substantial overlap with other individuals) in the breeding season. In a site with more rugged (and hence probably higher quality) habitat, Schmitt *et al*. (1989) reported far smaller home ranges, of 2.3 ha for (7) females, and 1.8 ha for (2) males; but also reported a 1-day movement of 2.5 km for a male. King (1989) reported "activity areas" (minimum convex polygons) for three radio-tracked female quolls to vary from 75 to 443 ha, and for five males to vary from 5 to 1109 ha, with one male moving 3.5 km. Begg (1981) reported maximum distance moved for a female of 1.1 km and for a male of 0.9 km, but noted that most juvenile males (6-7 months) dispersed from his study area altogether.

Population size of northern quolls at any site is highly variable throughout the year, given the pronounced die-off of males after breeding, and the appearance in the trappable population of the cohort of juveniles when weaned (typically after January: Schmitt *et al*. 1989). The only available estimates of population density are those of Schmitt *et al*. (1989), which varied from 1.8 to 13.2 individuals per 2.25 ha grid (being highest in the most rugged grid) and Oakwood (2002) which varied from 1-4 females/km^2 in lowland Kakadu.

Body size and condition also varies considerably across the year, between sexes and reproductive and age classes (with second year adults typically heavier than first year: Begg 1981). Given the complex web of allometric relationships, body condition may be most effectively measured by tail diameter (with animals in good nutritional status storing fat in the tail: Schmitt *et al*. 1979), expressed relative to body size (e.g. against head or pes length: Oakwood 1997).

Although there is considerable information on demography and survivorship, there is little on the causes of mortality. During and immediately after the mating period, males are known to exhibit weight loss, proliferation of parasites and decline in haematocrit and plasma albumin (Schmitt *et al*. 1989; Oakwood *et al*. 2000), with these probably a response to the intense physical effort involved with roving large areas to seek mates (Oakwood 2002). For males this physiological debilitation is probably the ultimate cause of mortality (Oakwood 2000). For radio-tracked individuals followed to their death, Oakwood (2000) reported the proximate cause of mortality for eight males to be vehicles (three), predation (two by wild dogs and one by olive python *Liasis olivaceus*) and uncertain (two individuals); and for seven females to be predation (two by wild dogs, two by feral cats, one by owl and one by king brown snake *Pseudechis australis*) and unknown toxin (one individual). The rate of predation appeared to be greatest in areas subject to more recent and intensive fire.

Translocation: island selection

The Northern Territory includes 233 islands > 20 ha (Woinarski *et al*. 2007). Northern quolls are known to occur naturally on 10 of these islands: Groote Eylandt (2277 km^2), Vanderlin (262 km^2), Marchinbar (210 km^2), Inglis (82 km^2), North-east Isle (4.2 km^2), Angarmbulumardja (1.7 km^2), North Point (1.5 km^2), "Island 158" (1.2 km^2), "Island 149" (1.1 km^2) and Finch (0.8 km^2)

(Parker 1973; Dixon and Huxley 1985; Johnson and Kerle 1991; Abbott and Burbidge 1995; Woinarski *et al*. 1999a, 2007). Notably, they do not occur on the two large Tiwi islands, Melville (5809 km^2) and Bathurst (1699 km^2), presumably because these contain none of the rugged sandstone that is their optimum and core habitat in northern Australia (Braithwaite and Griffiths 1994; Woinarski *et al*. 2003; Firth *et al*. 2006a).

We developed a candidate set of islands potentially suitable for translocation sites, based on the criteria of:

- adequate size for likely persistence over an at least 30 yr time-frame (> 1 km^2, but preferably > 10 km^2);
- occurrence of suitable habitat (areas of rugged sandstone);
- absence of human habitation;
- relatively low risk of toad colonisation (i.e. little visited by humans, distant from mainland, not in the outflow area of mainland rivers);
- moderate accessibility;
- absence of other conservation values susceptible to predation or competition from translocated quolls (noting that many Northern Territory islands provide very significant nesting sites for seabirds and marine turtles: Chatto 2001; Chatto and Baker in press).

These criteria restricted the candidate set to about 10 islands. Almost all Northern Territory islands, including uninhabited ones, are owned by Aboriginal Land Trusts. Hence, final selection of islands from the reduced candidate pool was undertaken only after a period of detailed consultation with Aboriginal landowners. This consultation involved Aboriginal people from the lands from which the quoll founder populations were drawn, the Northern Land Council, and landowners from the candidate islands. Consultations particularly involved an intricate dialogue relating to the handover of responsibility for wildlife from one Aboriginal group to another.

Ultimately, two islands were selected for translocation sites: Astell and Pobassoo, both in the English Company group off north-eastern Arnhem Land (Fig. 1; Table 1). Previous detailed surveys had indicated that these islands supported no plant (Woinarski *et al*. 2000), ant (Woinarski *et al*. 1998), herpetofauna (Woinarski *et al*. 1999b), bird (Woinarski *et al*. 2001a) or mammal (Woinarski *et al*. 1999a) species of conservation significance likely to be affected by the quoll translocation, and – unlike many islands in this group – had no significant nesting sites for marine turtles or seabirds (Chatto 2001, Chatto and Baker in press). Indeed, there were no marsupials or rodents present on these two islands (Woinarski *et al*. 1999a).

Both islands are rugged, and are dominated by eucalypt (particularly *Eucalyptus tetrodonta*) woodlands, with more restricted areas of coastal vine thicket, mangroves and strand (Plate 1: Woinarski *et al*. 2000). Note that quolls were probably present on these islands at the time when rapid sea level rise (about 8-12,000 years ago) last isolated them, and became locally extinct sometime afterwards (Woinarski *et al*. 1999a).

Plate 1: Habitat photographs of Pobassoo (top) and Astell (bottom) Islands [photos: Ian Morris, Terry Mahney]

Founder population and translocation procedure

Founder stock were drawn from a range of sites across the mainland Northern Territory, particularly from lowland areas on the Darwin rural fringe and from some sites in Kakadu National Park (Table 1). Collection of these animals was timed to immediately precede the cane toad invasion front, and to coincide with the main occurrence in the population of independent juveniles (February-March 2003), as these were considered most likely to be adaptable to translocation and because adults have such a short life expectancy.

Animals were collected using Elliott and cage traps and initially transported to the Territory Wildlife Park for comprehensive health inspection, genetic sampling and temporary (1 to 9 days) housing (in purpose-built enclosures). In the course of this collection and temporary housing, two animals died.

Nineteen captured animals (eight males; 11 females) were moved to Pobassoo Island on 28 February 2003, by light plane from Darwin to Gove (3 hr) and from there by boat (2 hr). During this travel, animals were housed individually in calico bags or in small darkened holding cages (65 cm x 15 cm x 15 cm). Twenty-three and 22 captured animals (11 males; 34 females) were moved similarly to Astell Island, on 14 March and 27 March 2003 respectively. All animals survived the transport.

Plate 2. Radio-tracking was used to monitor the immediate fate of the founder population following release (Photo: Ian Morris).

Animals were released together at three sites on Pobassoo Island and one site on Astell Island. Of the released animals, all were micro-chipped (with Destron PIT tags) and 10 animals from each island were fitted with a radio-collar (Sirtrack) and their post-release movements subsequently monitored for a 10-14 day period (Plate 2). During this period, we checked for mortality of all tracked animals and for as many as possible we recorded denning locations daily.

Disturbance

Approximately 70% of Astell Island was burnt in a single fire in August 2003. At the time of the fire the island had been long-unburnt and hence had large fuel loads, and the fire was of relatively high intensity.

Cyclone Ingrid passed directly over both islands on 12 March 2005 as a category 5 cyclone, with wind gusts to 325 km hr^{-1} and >300 mm of rainfall (Bureau of Meteorology). All trees on both islands were stripped and many were felled (Plate 3).

Plate 3. Impact on vegetation of Cyclone Ingrid on Pobassoo Island– photograph taken 1 month after cyclone (Photo: K. Brennan).

Monitoring

The translocated quolls were monitored on seven occasions subsequent to the initial translocation trip (Table 2). Most of the early monitoring trips were timed for the early to mid Dry season, when adult males were present. To provide more information on reproductive success, most of the later trips took place in December, when adult males were largely absent and the weaned young of the year were entering the trappable population.

For a range of logistical and other reasons, the sampling procedure and monitoring protocol varied amongst these trips, before the imposition of a consistent protocol on the sixth trip. In most trips, sampling was done using either (or both) trapping grids (initially an array of 7 x 10 traps, spaced 20 m apart, in later trips an array of 5 x 5 traps, spaced 20 m apart) or trapping transects (a line of 10 traps spaced 20 m apart), over a 3 or 5 night period. Wherever possible these grids or transects were sited consistently between trapping trips, with this sitting aiming to sample the (limited) range of environmental variation present on both islands and as broadly across the geographic extent of the islands as was logistically feasible (Fig. 2). All traps used were cage traps (65 cm x 15 cm x 15 cm), baited with a mixture of peanut butter, honey and oats. Traps were set and baited in the late afternoon and checked (and then closed) in the early morning.

For every individual caught, we recorded sex (all trips), and reproductive condition (all trips), age (as either 1st year or ≥ 2 years, and informed in part on known history of marked animals) (trips 2, 4, 5, 6 and 7), weight (all trips), head length (trips 3, 4, 5 and 7), pes (hindfoot) length (trips 3, 4, 5 and 7), and tail circumference (trips 3, 4, 5 and 7). On all but trip 7 we marked every individual by microchip (with Destron PIT tags), and on trip 7 with eartags (Model 1005-1 self-piercing ear tag (National Band and Tag Co.)). Small sections of ear tissue were taken from all individuals on all trips (except trips 2a, b and 3) for subsequent genetic analysis.

Given methodological inconsistencies, it is difficult to compare condition and abundance estimates between trips, a problem compounded by the intra-annual substantial variation in demographic composition and population size due to periods of annual die-off of adult males and reappearance in the trappable population of juveniles. The most complete information on condition was collected on trips 4 (December 2005) and 7 (December 2007). For these trips, we calculated three indices of condition: ratio of weight to pes length, the ratio of tail circumference to pes length, and the ratio of tail circumference to head length, and compared these indices amongst trips and islands, using two-way ANOVA. Where appropriate, these were also compared with comparable measurements from two much smaller samples from the Darwin area (from quolls surveyed in November-December 2001 by B.Rankmore; and from the initial capture of the colonists, collected in February-March). These two sets of comparative data have some constraints: of the condition indices considered only one (weight:pes) was available for the November-December mainland sample, and the colonist data derive from a time of year when the age structure of the population is notably different to that of the December islands data set.

The age composition (sex and reproductive status) of all quolls captured was tabulated for all trips.

Calculation of population size

Assessment of total quoll population size is complex, given (i) the marked intra-annual variability in quoll demographic characteristics, and (ii) variably-sized and overlapping home ranges (with relatively long-distance movements of at least some individuals), rendering it difficult to assess the effective trapping area of any network of traps.

One consistent and simple measure of abundance is trap success rate (captures per 100 trap-nights). This was calculated for every trip. However, it is a crude measure as by itself it cannot provide any estimate of total population size, it will not necessarily directly correlate with total population size, and it may be substantially influenced by variation between trips in the siting of trap areas.

To estimate the size of the northern quoll population, we require a measure of population size on trapping grids and the effective sampling area of the grid, and hence density. To calculate population size on the grids, we analysed capture-mark-recapture data for each of the December 2006 and December 2007 trips. We used Huggins Closed Captures model in program MARK (White and Burnham, 1999) to estimate the probability of initial capture (p) of quoll individuals on a grid and the probability of recapture (c) (Williams *et al*. 2001). Given the temporal variability in that part of the population other than adult females, we restricted our analyses to only adult females.

The effective trapping area of a trapping grid comprises the grid area itself (in this case 80 m x 80 m, that is 0.64 ha), plus an additional boundary area around its perimeter. There are two commonly used approaches available to estimate the width of the boundary strip, and hence of the effective trapping area: 1) use half of the average home range size; and 2) use half of the mean (across recaptured individuals) of maximum recapture distance moved within and between trapping grids (Williams *et al*. 2001). The following equation was used to calculate effective trapping area:

$$A(W) = L^2 + 4LW + \pi W^2$$

Where A(W) is the effective trapping area, L is the length of the trapping grid, W is the width of the boundary strip.

For an estimate of the effective trapping area calculated from home range information, we used the 2.3 ha mean home range size (hence, radius 85 m) given in Schmitt *et al*. (1989), because this study was based in comparable rugged and rocky habitat. From the formula above, this gives an effective trapping area for each grid as 5.63 ha.

The alternative method for calculating the effective trapping area of a grid is based on the mean maximum recapture distance. We calculated all such distances for all recaptured animals within and between trapping grids (Appendices 1 and 2) for the 2006 and 2007 monitoring trips, and calculated the mean distance as 157 m. Therefore, the formula above gives effective trapping area of a grid based on mean distance moved is 5.09 ha, an estimate encouragingly similar to that calculated above from a different set of assumptions.

From the estimates of the population size on the trapping grid and the effective area sampled by the grid, we can derive population density and, hence, by extrapolation, the total population size of each island.

Monitoring of changes in the genetic structure of the populations

The genetic structure of the translocated quolls was monitored regularly from the initial founding population. Levels of genetic diversity have been determined for the founder population and each of the first three years subsequent to translocation, on both Astell and Pobassoo Islands; and these compared with samples taken from two (far longer isolated) endemic island populations (Groote Eylandt and Marchinbar Island) and from several mainland sites. These results are reported in detail elsewhere (Cardoso *et al*. submitted).

Food resources, diet and environmental impact

On these translocated islands, quolls would be a top-order predator. Accordingly, it is feasible that they may have some significant impacts on animal species already present, especially if the quolls achieve high population density. We addressed this issue through collection of scats from a large sample of trapped quolls, on all trips. If quolls are having a substantial impact on any prey items, then one would expect a trend for change in dietary composition over the course of this study. At this stage, we have not yet completed analysis of these (>200) scat samples.

Results

Radio-tracking of initial release animals

Radio-tracking fixes were obtained for 19 animals (1 animal dropped the collar), ten on Astell Island and nine on Pobassoo Island, consisting of nine males and ten females (Table 3). The number of fixes where the exact location of the animal was obtained ranged from one to ten per animal (Table 3). Following release, some animals dispersed widely and rapidly, extending more than 1 km from the release site within 3-4 days. Rock crevices were most commonly used for denning with 13 individuals using this den type exclusively (Table 3). Four individuals used fallen logs and two used tree hollows (Table 3). Over the course of this radio-tracking (up to 14 days after initial release), all animals survived, and collars were removed from all individuals at the end of this period.

Condition

For each of the three condition indices, there were no significant differences neither between islands nor between trips 4 and 7 (Table 4). There was no significant difference in the condition (weight:pes) of female quolls from the islands and those of the November-December mainland sample (Mann-Whitney U test: z=0.48, p=0.63; islands mean = 9.00, s.e.=0.21, range=2.94 - 27.65, n=209; mainland mean = 9.48, s.e.=0.58, range = 7.06 - 13.46, n=10: Fig. 3).

Trap success

Trap success increased slowly in the 15 months following initial release, but then escalated very substantially by trip 3 (25 months post-release) on Pobassoo Island and by trip 4 (33 months post-release) on Astell Island (Fig. 4; Table 2). Trap success rates were affected by the month of trapping, with early-mid Dry season trips occurring in periods when males were present, but December trips occurring when there were very few males in the population. In the more recent trips, trap success rates have generally been higher on Astell Island than Pobassoo Island.

The 20-60% trap success rate recorded for the most recent 4-5 trips is extraordinarily high compared with previous studies of this species from mainland Australia: in comparison, Oakwood (2000) recorded a mean trap success of 7.6% (varying seasonally from 2 to 17) at her Kapalga site, and Schmitt *et al*. (1989) reported 400 captures from 20,000 trap-nights (i.e. 2% trap success) in their Kimberley sites (calculated with additional information presented in Bradley *et al*. 1987).

Population size

We estimated the population size of adult female quolls on Astell and Pobassoo Islands based on December 2006 and 2007 survey data. The probability of initial capture (± s.e.) was similar between each survey (*2006* $p = 0.26 \pm 0.03$; *2007* $p = 0.22 \pm 0.03$). Likewise, the probability of recapture (± s.e.) following initial capture was similar between each survey and was reasonably high, suggesting adequate trapping effort (*2006* $c = 0.46 \pm 0.02$; *2007* $c = 0.42 \pm 0.02$).

Based on an effective trapping area of 5.6 ha, we estimated the density of adult females to be 2.55 (with 95% confidence interval 2.26 - 3.12) ha^{-1} in 2006 and 3.80 (95% CI 3.23 - 4.97) ha^{-1} in 2007 on Astell Island. On Pobassoo Island, we estimated the density of adult females to be 1.95 (95% CI 1.60 - 2.44) ha^{-1} in 2006 and 2.09 (95% CI 1.82 - 2.91) ha^{-1} in 2007.

Extrapolating these density estimates to the total islands' area produced estimates of the total population *of adult females* on Astell Island in December 2006 of 3228 (95% CI 2872-3960) individuals, and in December 2007 of 4820 (95% CI 4099-6306) individuals. On Pobassoo Island, the comparable estimates are for December 2006 of 766 (95% CI 627-957) adult females, and in December 2007 of 818 (95% CI 714-1140) .

Compared to the number of adult females in the founding stock less than 5 years earlier, these population estimates represent a 142-fold (Astell) and 74-fold (Pobassoo) increase, a remarkable population growth rate.

Using the alternative effective trapping area of 5.09 ha (based on recorded individual movements), these estimates become:

Astell	2006:	density 2.81 ha^{-1};	total population 3551
	2007:	density 4.18 ha^{-1};	total population 5303
Pobassoo	2006:	density 2.15 ha^{-1};	total population 843
	2007:	density 2.30 ha^{-1};	total population 900.

Population structure and reproduction

Consistent with previous studies, the sex and age composition of the population was highly variable between seasons (Table 5). Of all captures where sex was recorded, 78% of individuals were females. Third year females were first detected in the population in December 2005 (Trip 4) and 4th year females in December 2007 (Trip 7). Second year males were detected in December on Trips 4, 6 and 7 (Table 5) however no 2nd year males have been detected making it through to a second breeding season.

There was some variation in age structure even for surveys undertaken at the same time of year, most notably with relatively few 1st year individuals recorded in December 2006 (18.4% of known-age individuals) compared with December 2005 (45.7%) and December 2007 (35.4%). This may reflect reduced reproductive output, or a later breeding season, in 2006.

Both the age and sex structure of the population varied significantly between islands. Over Trips 4 to 7, females comprised 86% of the (known-sex) captured individuals on Astell Island but only 65% of those on Pobassoo Island (χ^2 = 46.9, p<0.0001). Over the three December trapping periods (Trips 4, 6 and 7), the female age structure on Astell Island comprised 11.8% 1st years, 67.2% 2nd years, 19.0% 3rd years and 2.0% 4th years: the age composition on Pobassoo Island was more biased towards younger age-groups (27.2%, 61.0%, 11.8% and 0%, respectively: p=0.025, Kolmogorov-Smirnov 2-sample test).

High levels of breeding were recorded throughout the surveys. The percentage of 2nd year females recording signs of breeding in that year varied between 58 and 100% during Trips 6 and 7 (Fig. 5). During Trip 7 (December 2007), 33% of the 3rd year females were recorded as breeding (Fig. 5).

The proportions of older (>2 years) females in these island populations, and the proportions of females known to have bred at older ages, surpasses that previously recorded for mainland populations. The most recent sample reported that 29% of known-age females were in their third year and 3% in their fourth year: comparable figures from the savanna woodlands in Kakadu National Park are 27% and 0% (Oakwood 2000) and 5.2-13% (Braithwaite and Griffiths 1994), with 21% and 6% reported from the sandstone uplands of Kakadu (Begg 1981).

Genetics

Genetic variation was found to decrease slowly over time since the foundation of the translocated island populations in 2003. Recent genetic bottlenecks were not detected in the island populations. Three generations post-translocation, the island populations have maintained a moderate, although reduced, level of genetic diversity (*A* = 4.1–4.2; Heterozygosity *He* = 0.56–0.59) compared to the mainland source populations (*A* = 5.0–8.4; *He* = 0.56–0.71), but higher than two endemic island populations [Groote Eylandt and Marchinbar Island] (*A* = 1.5–2.9; *He* = 0.11–0.34). Losses of genetic variation and divergence from ancestral allele frequencies in the translocated populations through genetic drift are suggestive of effects exacerbated by founder events. Full results are described in (Cardoso *et al.* submitted).

Discussion

The translocated populations on these two islands have done remarkably well, increasing from a founder population of 64 individuals in February-April 2003 to more than 5600 individuals (estimate for mature females only) in December 2007. By any measure, this is an extraordinarily successful achievement of the primary objective.

We recognise that our assessment is short-term. Our aim is to ensure that these island quoll populations (and a small set of natural populations on other islands: Woinarski *et al*. 2007) remain viable over a period of decades, long enough to reasonably assume that some progress will have been made with control methods for cane toads, and/or for genetic and/or behavioural selection to reduce the susceptibility of quolls to toads. Over a longer period - of centuries to millennia - the quolls may not persist on these islands, as evident in the pre-translocation absence of quolls from these two islands and many other apparently suitable islands off the Northern Territory coast: it is a reasonable assumption that quolls were on these islands prior to their isolation and have become extinct over the roughly 10,000 years since rapid sea level rise (Woinarski *et al*. 1999a).

In assessing the relative merits of a range of possible mitigation measures for the impact of toads upon northern quolls, Brook and Whitehead (2005) suggested that a minimum viable population (<10% risk of extinction over a 100 year period) for northern quolls was 19,100 individuals, and calculated that this would require a protected (island or exclosure) area of 22,000 ha. The results of the Astell and Pobassoo Islands translocations suggest that this areal figure may be a substantial over-estimate. The two islands used here as translocation sites are appreciably smaller (1.8% and 5.8% of the suggested minimum area), but currently support a population of quolls that, while still below the calculated minimum viable population, suggests a reasonably low risk of extinction over a medium time (100 year) frame.

Cane toads may reach Astell and/or Pobassoo Islands. We recognise that these islands are occasionally visited by people, and that they are not far from the mainland (Table 1). But two factors may limit their ability to then establish: (i) the islands lack permanent water; and (ii) the very abundance of quolls on these islands may mean that any castaway toads would be quickly killed (with resultant loss of the predating individual quoll, inconsequential for the total quoll population).

Possibly more serious to the security of these translocated populations is their very success. The populations now seem to be at densities far surpassing any previously recorded natural populations. It is possible that this may lead to resource depletion and/or to the development of abnormal social characteristics, however there is as yet no sign of such characteristics. The condition of individuals on these islands is similar to comparable wild populations, and breeding success continues to be very good.

Further, the genetic structure of the populations is healthy, with only very small (and expected) loss of genetic diversity, due to genetic drift. This effect was more pronounced on Astell Island than on Pobassoo Island, probably because of differences in substructure in the founding population. Despite this effect, the mixing of founding individuals from subdivided mainland populations led to increase in the overall effective population size of the original founders. This is a desirable conservation outcome, because it may benefit the long-term persistence of this population. By comparison, northern quolls naturally endemic to islands have suffered severe genetic erosion, a result that is consistent with other Australian studies of island and mainland fauna (Eldridge *et al.* 1999, 2004).

The very high density of quolls (and their apparently greater longevity) on these islands compared to wild mainland populations is notable, particularly in view of the recent widespread decline of quolls (and other native mammals) across northern Australia, even preceding the advent of cane toads (Braithwaite and Griffiths 1994; Woinarski *et al*. 2001b). Clearly, the factors contributing to such mainland decline are not operating (comparably) in these islands. Inappropriate fire regime has been one of the factors implicated or suggested in the decline of mammals on the mainland of northern Australia (e.g. Woinarski *et al*. 2001b; Parson *et al*. 2003; Firth *et al*. 2006b). The two translocated quoll populations provide an interesting contrast in the impact of fire, given that one island (Pobassoo) has remained unburnt for the 5 years since quoll release, whereas the other (Astell) was mostly burnt soon after release. Notwithstanding this contrast in fire regimes, the proliferation of quolls on these islands has largely tracked in parallel. A possible exception is in the results from Trip 3 (where trap success on Astell was notably lower than Pobassoo), however the trap regime on this Trip was relatively unsystematic such that we attach little confidence to this apparent disparity. One striking feature of the population growth is the lack of any response to the extreme habitat destruction caused by Cyclone Ingrid two years after the translocation.

We suspect that the unusual success of the translocated quolls is largely related to the lack of predators. With the exception of small populations of some diurnal raptors, quolls are the top order predators on these islands. The corollary of this exceptional success in the absence of predators on these two islands is that predators may be the factor most limiting quoll numbers in mainland areas, and some recent increase in predator pressure (e.g. through increased densities or spread of feral cats) may be a main factor contributing to the pre-toad decline of quolls on mainland Australia, consistent with arguments presented by Johnson (2006).

These two translocated populations afford an interesting experimental contrast. Towards 5 years after founding, there now appears to be some demographical divergence between the two populations, with a notably more unbalanced sex ratio on Astell Island and a tendency for females to live longer there. Monitoring of these populations should be continued, not only simply to check for their safety from invasion by toads, but also because they represent an exceptional opportunity to track genetic and demographic change in a closed population, and the factors that influence that change.

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Table 1. Characteristics of the two translocation islands, and the founder populations of northern quolls.

	Pobassoo	Astell
Island size (ha)	392	1268
maximum elevation (m)	78	74
distance to mainland (km)	2.3	5.4
Founder population		
total	19	45
females	11	34
males	8	11
from Darwin rural area	19	26
from Kakadu National Park	0	14
from Hayes Creek	0	5

Table 2. Chronicle of all field trips, showing sampling procedures and basic results. Only captures are provided for trips 2a, b and 3, as animals were not marked on these trips. P – Pobassoo Island, A – Astell Island, T – Total.

Trip no.	Dates	Sampling	Trapping effort (trap-nights)	Total quolls caught (no. different individuals)	Trap success rate
0	March 2003	Two grids (10 x 7) in 2 habitat types. Open 3 nights	P 420 A 420 T 840	P 1 (1) A 17 (7) T 18 (8)	P 0.24 A 4.05 T 2.14
1	July-Aug 2003	Same grids as trip 0 plus 4 transects (10 traps each). Open 3 nights	P 540 A 540 T 1080	P 5 (4) A 15 (11) T 20 (15)	P 0.93 A 2.78 T 2.38
2a	April 2004	All traps in different locations. Astell: 2 grids (28 traps) 4 transects (20 traps each). Open for 3 nights. Pobassoo: 2 grids (28 traps) 2 transects (20 traps each). Open 2 nights	P 272 A 464 T 600	P 1 A 31 T 32	P 0.37 A 6.68 T 5.33
2b	June-July 2004	Pobassoo only: Two grids and 4 transects from trip 1 plus an additional 4 transects. Open 3 nights	P 642 A 0 T 642	P 11 A 0 T 11	P 1.71 A 0 T 1.71
3	April 2005	Trapping grids and transects not defined, as objective was only to ensure persistence following cyclone	P 117 A 42 T 159	P 28 A 4 T 32	P 23.93 A 9.52 T 20.13
4	8-16 Dec 2005	Trapped transects in same location as trip 1 but increased number of transects to 6 on Pobassoo and 8 on Astell. Open 3 nights	P 180 A 240 T 420	P 32 (24) A 96 (71) T 128 (95)	P 17.78 A 40.00 T 30.48
5	28 July – 5 Aug 2006	Trapped the same transects as trip 4. Open 3 nights	P 180 A 240 T 420	P 56 (37) A 139 (83) T 195 (120)	P 31.11 A 57.92 T 46.43
6	Dec 2006	Grids of 25 traps covering 80m x 80m area. Astell: 12 grids; Pobassoo: 8 grids.	P 1000 A 1300 T 2300	P 178 (88) A 333 (145) T 511 (233)	P 17.80 A 25.62 T 22.22
7	Dec 2007	Re-sampled the grids from trip 6 for Pobassoo and a subsample of grids (10) on Astell.	P 1000 A 1250 T 2250	P 223 (149) A 455 (214) T 678 (363)	P 22.3 A 36.4 T 30.13

Table 3. Summary of northern quoll radio-tracking data for the period 10-14 days after initial release. Den types: Rock = rock crevice; log = fallen log and Tree = tree hollow.

Animal	**PIT tag**	**Sex**	**Island**	**No. of fixes**	**No. of different dens**	**Den types used**
Ast2	413F7B6AOE	Female	Astell	7	3	Rock
Ast22	503363043C	Male	Astell	4	6	Rock
Ast26	413A7EO43C	Male	Astell	2	1	Log
Ast28	413F6D253B	Female	Astell	6	2	Rock
Ast3	5032664023	Male	Astell	6	3	Rock; Log
Ast36	502D3E185B	Male	Astell	3	3	Rock
Ast5	5032526679	Female	Astell	7	7	Rock
Ast56	5033016574	Female	Astell	7	5	Rock
Ast58	414B6C1C67	Female	Astell	3	3	Rock; Tree
Ast6	5006572F4	Female	Astell	5	5	Rock
Pob22	413F203D2D	Male	Pobassoo	7	3	Rock
Pob24	422E5D4606	Male	Pobassoo	9	7	Rock
Pob26	422D4F6875	Female	Pobassoo	4	4	Rock; Log
Pob28	422D707527	Male	Pobassoo	4	3	Rock
Pob3	500B795947	Male	Pobassoo	3	3	Log
Pob32	500D43210F	Female	Pobassoo	6	5	Rock; Tree
Pob34	500B6A532A	Female	Pobassoo	1	1	Rock
Pob38	500BD06F5A	Male	Pobassoo	10	8	Rock
Pob4	500D324325	Female	Pobassoo	7	4	Rock
Mean				**5.3**	**4**	

Table 4. Comparisons of northern quoll condition indices (for females only) between trips 4 and 7 (December 2005 and 2007) and islands. (a) The index used is tail circumference (mm) divided by head length (mm); (b) The index used is tail circumference (mm) divided by pes length (mm); (c) The index used is weight (g) divided by pes length (mm).

index	mean (s.e)				F (p) [from 2-way ANOVA]		
	Astell 2005	Astell 2007	Pobassoo 2005	Pobassoo 2007	island	year	island – year interaction
tail : head (a)	0.608 (0.14)	0.629 (0.10)	0.630 (0.30)	0.580 (0.14)	0.55 (0.46)	0.66 (0.42)	3.67 (0.06)
tail : pes (b)	1.035 (0.26)	1.077 (0.19)	1.140 (0.59)	1.046 (0.26)	1.02 (0.31)	0.52 (0.47)	3.52 (0.06)
weight: pes (c)	8.99 (0.43)	8.85 (0.30)	10.35 (0.97)	9.08 (0.47)	1.76 (0.19)	1.39 (0.24)	0.93 (0.34)

Table 5. The number of individuals of each sex and age class captured on each island for surveys 1, 4, 5, 6, and 7. "Age class" is defined as the year of life in which the animal is in at the time of survey, in relation to each breeding event, i.e. a female recorded in December that has had three breeding seasons is considered a 4th year female.

			Age class					
Survey	**Island**	**Sex**	**1st yr**	**2nd yr**	**3rd yr**	**4th yr**	**Unknown or unrecorded**	**total**
1. July-Aug 03	Astell	Female	5	2	0	0	0	**7**
		Male	4	0	0	0	0	**4**
		Total	**9**	**2**	**0**	**0**	**0**	**11**
	Pobassoo	Female	2	0	0	0	0	**2**
		Male	1	1	0	0	0	**2**
		Total	**3**	**1**	**0**	**0**	**0**	**4**
4. Dec 05	Astell	Female	15	38	0	0	1	**54**
		Male	16	1	0	0	0	**17**
		Total	**31**	**39**	**0**	**0**	**1**	**71**
	Pobassoo	Female	2	8	1	0	0	**11**
		Male	10	3	0	0	0	**13**
		Total	**12**	**11**	**1**	**0**	**0**	**24**
5. Jul-Aug 06	Astell	Female	19	27	0	0	19	**65**
		Male	18	0	0	0	0	**18**
		Total	**37**	**27**	**0**	**0**	**19**	**83**
	Pobassoo	Female	5	7	12	0	0	**24**
		Male	13	0	0	0	0	**13**
		Total	**18**	**7**	**12**	**0**	**0**	**37**
6. Dec 06	Astell	Female	1	106	15	0	12	**134**
		Male	8	0	0	0	0	**8**
		Unknown/unrecorded	2	1	0	0	0	**3**
		Total	**11**	**107**	**15**	**0**	**12**	**145**
	Pobassoo	Female	16	42	1	0	5	**64**
		Male	8	10	0	0	0	**18**
		Unknown/unrecorded	3	0	0	0	3	**6**
		Total	**27**	**52**	**1**	**0**	**8**	**88**
7. Dec 07	Astell	Female	20	61	43	6	37	**167**
		Male	13	4	0	0	7	**24**
		Unknown/unrecorded	12	3	0	0	8	**23**
		Total	**45**	**68**	**43**	**6**	**52**	**214**
	Pobassoo	Female	19	33	14	0	21	**87**
		Male	29	5	0	0	21	**55**
		Unknown/unrecorded	0	1	0	0	6	**7**
		Total	**48**	**39**	**14**	**0**	**48**	**149**

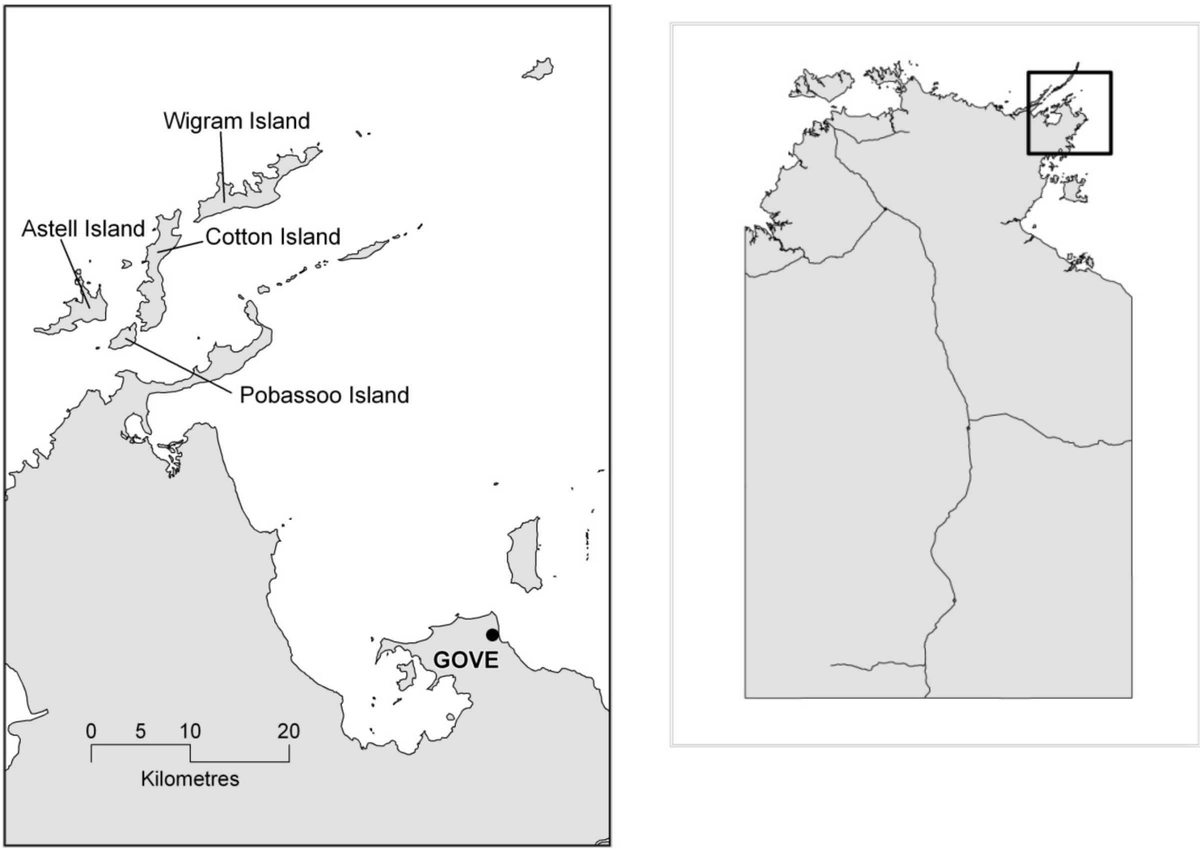

Figure 1. Location of the two islands used in the northern quoll translocation.

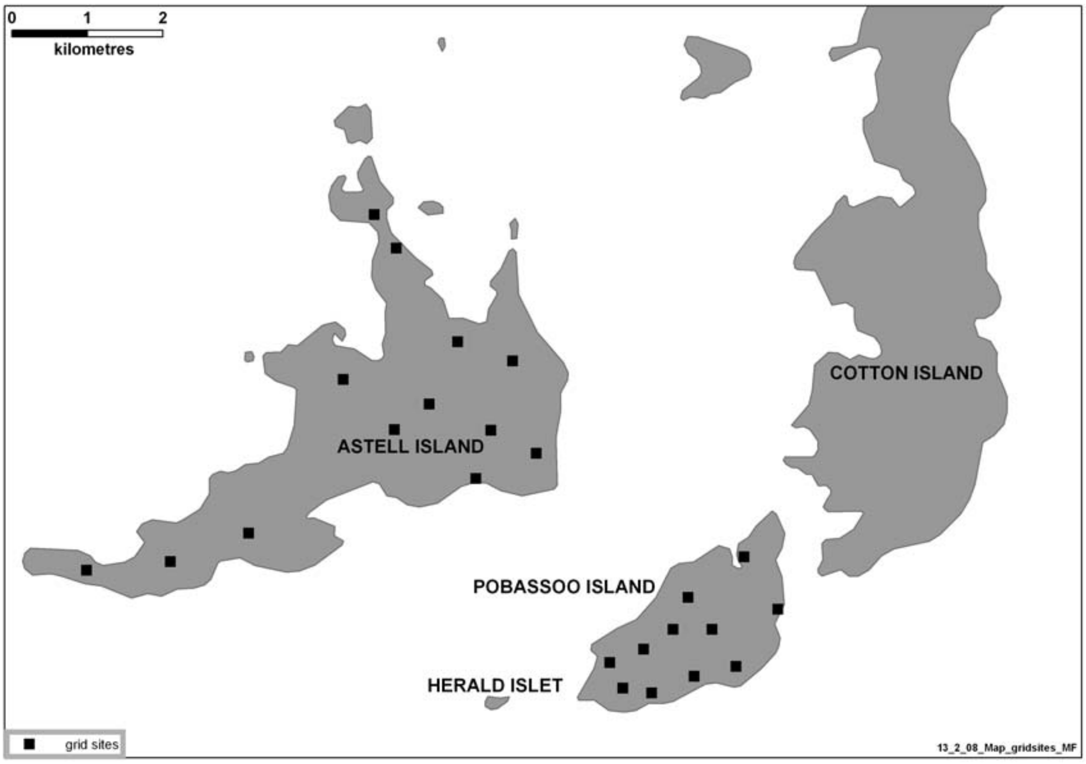

Figure 2. Location of trapping grids used on the two islands, for Trips 6 and 7.

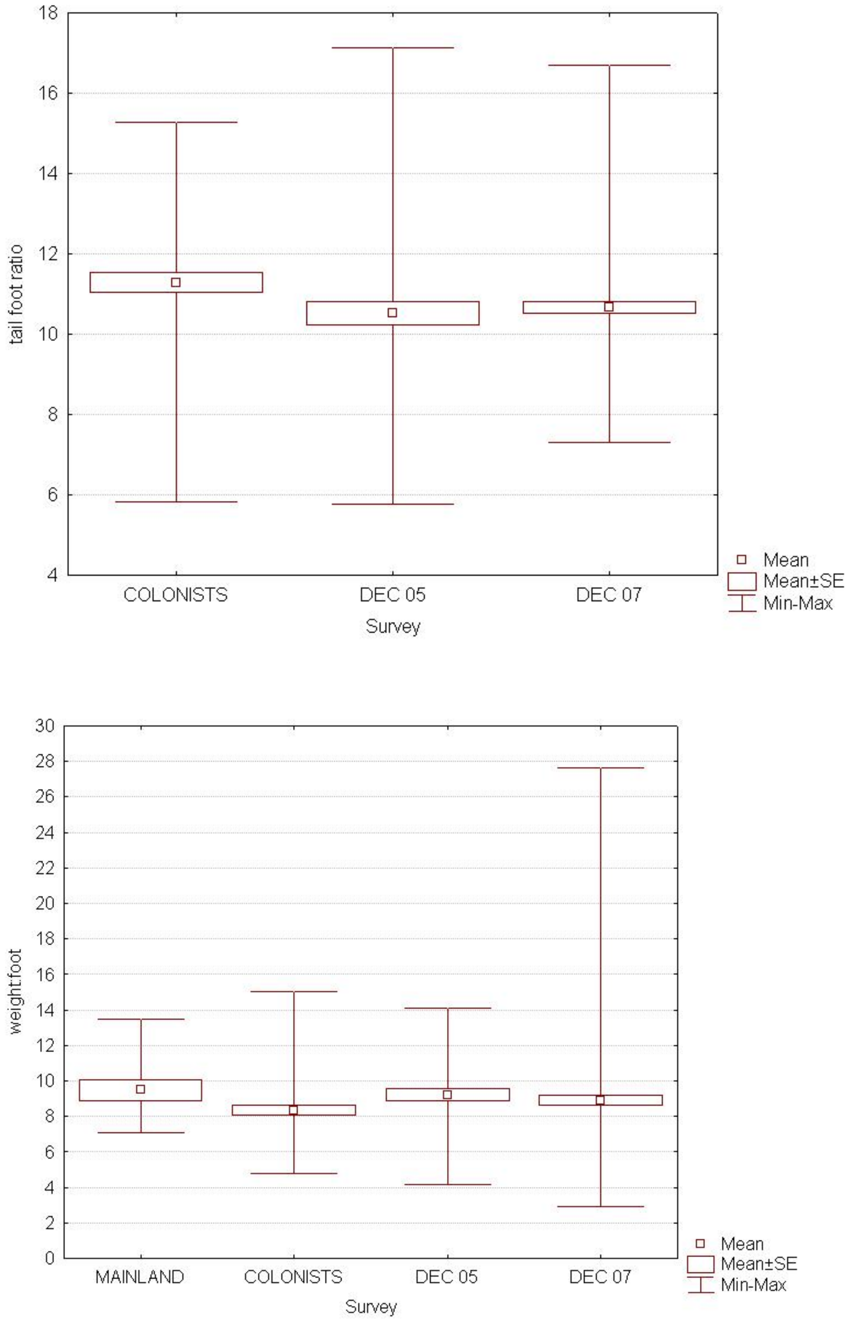

Figure 3. Comparison of condition scores for the translocated quoll populations in December 2005 and December 2007, and with a small sample of quolls captured on the mainland at comparable time of year, and with the founder population ("colonists") prior to release.

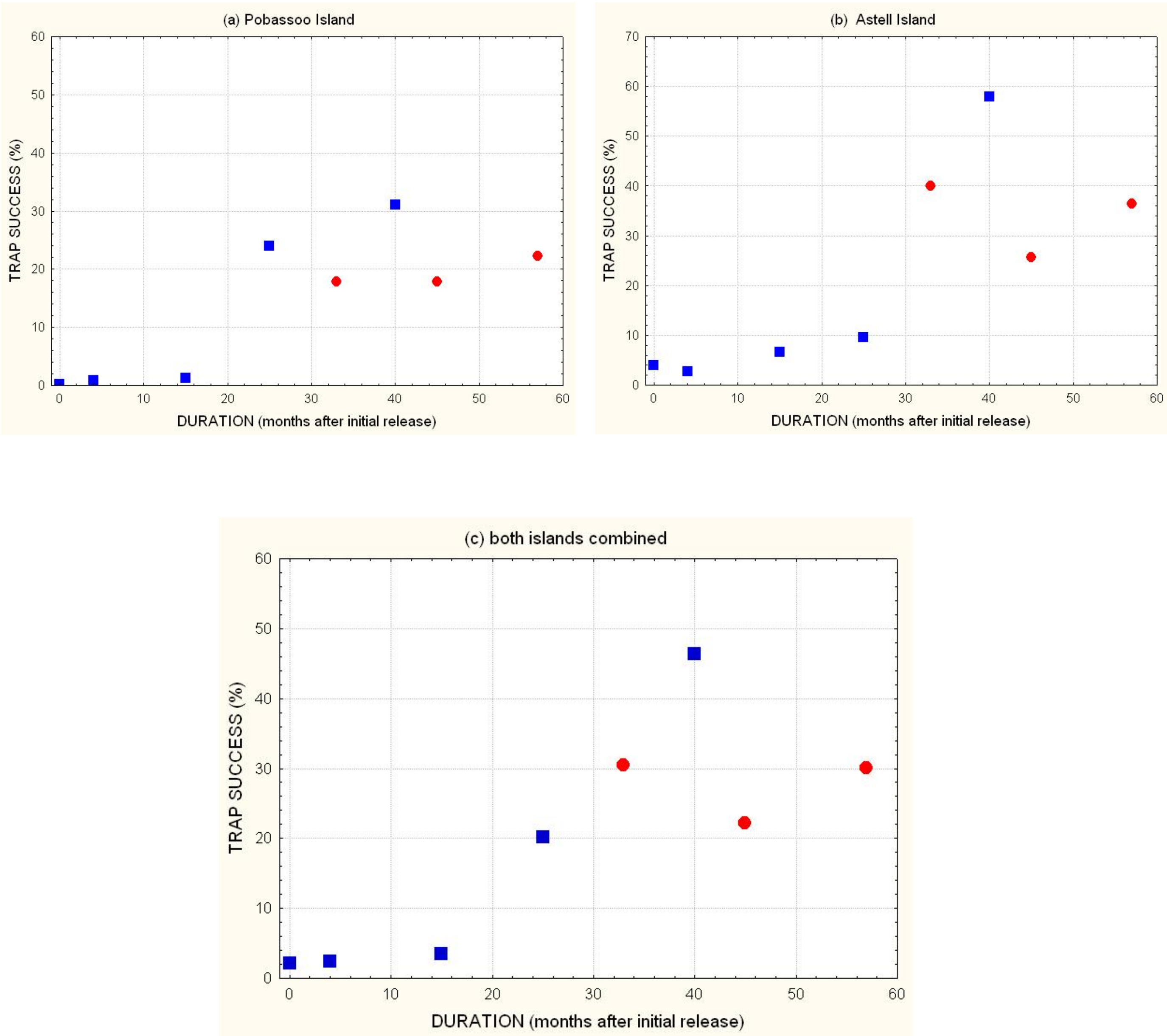

Figure 4. Change in overall trap success rate (the number of individuals caught per 100 trap-nights) after release of the founder individuals. Note that red circles designate trips undertaken in December (when the population comprises mostly adult females) and blue squares denote trips undertaken in the period March-August, when males are present.

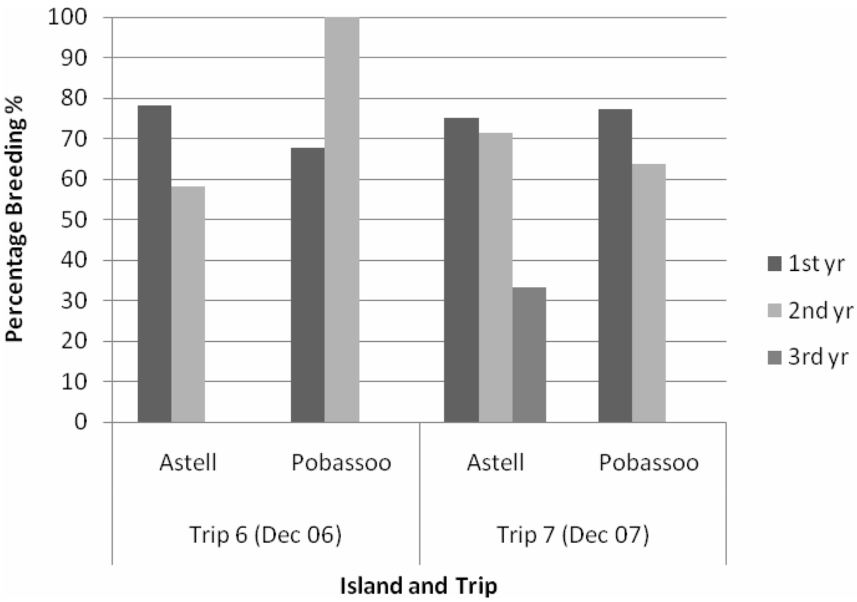

Figure 5: The percentage of females in each age class showing signs of breeding for Trips 6 and 7 for each island. See Table 5 for conventions for age classification.

Appendix 1: Summary of distance moved between recaptures within each 2007 trapping grid by northern quolls.

Island	**Grid**	**Mean distance moved (m)**	**Standard error**	**Mean maximum distance moved (m)**	**Standard error**
Astell	A13	35.59	6.65	43.12	6.98
Astell	A14	46.65	6.44	53.69	7.12
Astell	A15	38.57	4.30	52.43	7.13
Astell	A16	38.49	6.39	53.52	5.15
Astell	A4	35.11	3.10	52.66	4.43
Astell	A5	37.93	4.79	50.84	8.17
Astell	A6	45.78	5.27	52.82	7.38
Astell	A7	47.45	4.29	62.22	6.71
Astell	A8	35.93	4.28	50.05	6.48
Astell	A9	44.12	4.07	56.9	5.01
	mean	**40.56**	**4.963**	**52.82**	**6.45**
Pobassoo	P1	43.21	4.85	50.64	6.05
Pobassoo	P10	31.31	11.61	58.28	1.72
Pobassoo	P11	35.36	5.63	40.88	5.13
Pobassoo	P2	29.04	4.41	35.32	8.88
Pobassoo	P3	41.08	7.19	43.55	10.68
Pobassoo	P5	43.64	6.72	56.75	7.41
Pobassoo	P8	38.95	3.73	50.19	4.32
Pobassoo	P9	38.79	6.42	56.23	10.08
	mean	**37.67**	**6.32**	**48.98**	**6.78**

Appendix 2. a) Summary of individual movement of northern quolls between trapping grids from December 2006 survey.

		Grid												
Island	**Animal ID**	**1**	**10**	**11**	**13**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Distance moved (m)**
Astell														
	414A542E66								1	1				611.02
	44571F2822									1	1			1243.43
	985100010476096								1	1				611.02
	985100010731019							1	1					927.18
													mean	**848.16**
Pobassoo														
	00066FF1FF			1					1					475.29
	464E2D2039					1	1							316.35
	464E2D2039		1				1							494.19
	4653790869			1					1					475.29
	46541D5633			1					1					475.29
	465738262B			1					1					475.29
	4664240912			1					1					475.29
	466867316D			1					1					475.29
	46757F1E0A			1					1					475.29
	46775D155C			1					1					475.29
	5032613D27			1									1	481.88
	50330D6973			1			1							487.02
	blue left ear											1	1	265.61
													mean	**449.80**

Appendix 2.b) Summary of individual movement of northern quolls between trapping grids from December 2007 survey.

		Grid															
Island	**Animal ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**13**	**14**	**15**	**16**	**Distance moved (m)**
Astell	413F0A1361								1					1			974.58
	413F0A1361						1							1			766.52
	413F0A1361						1		1								1720.73
	985120019157610						1							1			766.52
	5033063A47						1			1							944.11
	5032582A6C							1		1							663.72
	5032351B0B							1		1							663.72
	282									1			1				985.55
	985100010476096					1	1										611.02
	465E7E5372						1							1			766.52
	44571F2822							1						1			526.39
	985120019629507					1	1										611.02
	173														1	1	519.31
	161														1	1	519.31
	193														1	1	519.31
																mean	**770.56**
Pobassoo	465331030E									1	1						448.22
	583		1	1													316.35
	587			1								1					487.02
	596	1		1													1034.77
	599			1								1					487.02
	985100010211318								1	1							265.61
	985100010393445		1									1					586.06
	985120013436222									1	1						448.22
	985120018995058			1								1					487.02
	985120029390204			1							1						494.19
	985100010465067									1	1						448.22
	557		1	1													316.35
	left paw marked blue	1	1														856.97
																mean	**513.54**