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The latest chapter in a conservation story: completing 10 years of post-translocation monitoring for a population of great crested newt (*Triturus cristatus*) in Scotland

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ABSTRACT
During the late 1990s, industrial development threatened a large population of great crested newt (*Triturus cristatus*) at Gartcosh, North Lanarkshire, Scotland. In 2004 – 2006, the population was relocated during the first *ex situ* conservation-based translocation in Scotland, from Gartcosh Industrial Site to the specially created Gartcosh Nature Reserve (GNR). By 2006, 1,012 great crested newts had been translocated to GNR. Peak adult counts obtained by torchlight survey in 2006 were low but continued to increase steadily, exceeding 400 adults in 2010. Later monitoring recorded a decline with 221 adults in 2011. Thereafter, surveys consistently recorded over 400 adults but no monitoring occurred in 2014. In 2015, the highest counts (515 adults) throughout the entire monitoring period were recorded, and a significant increase in overall population growth over time (1998 – 2003, 2006 – 2013, 2015) identified. Until 2011, amphibian fencing prevented great crested newt migration between each of the four zones within GNR and each zone effectively contained a great crested newt subpopulation. When adult counts within zones over time (2006 – 2013, 2015) were examined, two zones had increased whilst two zones had declined. Significant differences in mean counts were found for all zones, with overall growth highest in Bothlin Burn. This may indicate migration between zones, or differences in habitat allowing two zones to thrive whilst the other two faltered. The population retains its status as the largest in Scotland, with the effect of the translocation being negligible or positive. However, our results indicate the need for continued monitoring of translocated amphibian populations and studies on great crested newt migration. Additionally, the zone declines indicate that some ponds may be less favourable and require modification to remain suitable for great crested newts in the longer term.

INTRODUCTION

In 2004, the International Union for Conservation of Nature (IUCN) Amphibian Specialist Group published a Global Amphibian Assessment (GAA) which estimated that 32.5% of amphibian species are threatened with extinction, in comparison with 23% of mammals and 12% of birds (Stuart *et al.*, 2004). Although the amphibian database has been updated twice since the GAA in 2004 (IUCN, 2008), the GAA was the last comprehensive amphibian assessment made and the outcomes remain pertinent in amphibian conservation today. Human exploitation of aquatic and terrestrial ecosystems (Denöel & Ficetola, 2008) continues to expose amphibians to “a cocktail of abiotic and biotic stressors” (Blaustein & Kiesecker, 2002). As a result, 42% of amphibian species are in decline (IUCN, 2008). Diagnosis for decline is complex as decline factors have close interactions and the effects of any one factor are often context dependent (Beebee & Griffiths, 2005). Additionally, threats to many species are likely to be underestimated due to data deficiency (Howard & Bickford, 2014). Therefore, recommendations to halt declines can only be made and implemented from consistent long-term monitoring programmes (Kröpfli *et al.*, 2010).

The great crested newt (*Triturus cristatus*), hereafter GCN, is widely distributed across mainland Europe and the UK, although UK populations tend to be localised in their occurrence (Edgar & Bird, 2006; Beebee, 2015; O’Brien *et al.*, 2015). GCN have declined across their range in the UK due to housing and industrial development, and agricultural intensification. Ponds have also been stocked with fish for recreational angling without consideration of potential predation on newt larvae (Langton *et al.*, 2001). Consequently, suitable GCN habitat has been lost or become degraded (Gent, 2001; Edgar *et al.*, 2005; Edgar & Bird, 2006; O’Brien, 2016). GCN are ill-equipped to cope with loss of breeding ponds due to their breeding and dispersal strategies; adults are philopatric to breeding ponds and migration to new ponds is limited to distances around 1.6km (Edgar & Bird, 2006; Beebee, 2015; Haubrock & Altrichter, 2016). Breeding success is further impaired by 50% egg abortion caused by a chromosomal defect

(Macgregor, 1995). The habitat requirements of GCN are specific, unlike other widespread amphibians and GCN infrequently occupy urban or garden ponds (Oldham *et al*., 2000; Gustafson *et al*., 2009; Beebee, 2015). The combination of these factors has reduced, fragmented and isolated populations (O'Brien *et al*., 2015).

GCN are a species of international importance, listed on Annexes II and IV of the EC Habitats Directive, Appendix II of the Bern Convention, and the IUCN Red List of Threatened Species with a decreasing population trend, although classed 'Least Concern' due to widespread distribution (IUCN, 2016). GCN populations are protected by UK and European legislation at all life stages (Rees *et al*., 2014b; Gustafson *et al*., 2016; Lewis *et al*., 2016). In the UK, GCN are protected by Schedule 2 of the Conservation *(Natural Habitats etc.)* Regulations, 1994. European legislation is enforced under the Conservation of Habitats and Species Regulations, 2010. This legislation states it is an offence to kill, injure or take GCN individuals. Disturbance is prohibited and breeding sites and hibernacula are protected (McNeill *et al*., 2012). Where land development threatens GCN, developers are required to survey for them. If surveys reveal GCN in the UK, developers must propose mitigation for GCN and their habitat (Edgar *et al*., 2005; Lewis *et al*., 2013; Lewis *et al*., 2016) in order to obtain a licence from the relevant government regulatory agency (e.g. Natural England, Scottish Natural Heritage) before proceeding with development (McNeill *et al*., 2012).

In England, the 'rare' status of GCN is frequently disputed due to widespread distribution of populations, many of which conflict with development (Lewis *et al*., 2016). Indeed, the cost of conservation measures has received negative coverage in journalistic media, with suggestions that GCN do not require such measures and that they involve misuse of government funding. Conversely, in Scotland, the species is uncommon with a restricted distribution in the south and highlands of Scotland. The majority of populations are small despite being present in around 200 locations in Scotland (O'Brien *et al*., 2015; O'Brien, 2016). The largest population of GCN in Scotland can be found at Gartcosh, North Larnarkshire. With 1,012 adults counted by trapping in 2006, this local population was estimated to represent 9-29% of the overall Scottish population (McNeill, 2010).

During the 1990s, industrial development threatened this significant population of GCN. From 2004 – 2006, the population was relocated in the first conservation-based translocation in Scotland, from the Amphibian Conservation Area (ACA) within Gartcosh Industrial Site to the specially created Gartcosh Nature Reserve (GNR) (McNeill, 2010; McNeill *et al*., 2012). Maps of GNR (Fig. 1; Appendix 1) in relation to ACA (Fig. 2) are provided. The licence granted by the Scottish Executive required 10 years of post-translocation monitoring, but this was supplemented by an intensive research project funded by Scottish Natural Heritage and carried out by DCM in consultation with North Lanarkshire Council (NLC) from 2006 – 2010 (NcNeill, 2010). Thereafter, torchlight surveys were conducted by environmental consultancies but concluded in 2013. In 2015, the most recent year of post-translocation monitoring was completed by LRH as part of a University of Glasgow Masters research project.

Amphibian monitoring in the UK commonly uses torchlight survey, which requires less training and time than other methods such as bottle-trapping and netting (Gent & Gibson, 1998; Langton *et al*., 2001; Sewell *et al*., 2013). It is thought to cause little disturbance and is applicable to large-scale, volunteer recording schemes (Langton *et al*., 2001; Kröpfli *et al*., 2010). Torchlight surveys are conducted in the breeding season, between March and June. A surveyor walks slowly around the edge of a pond with a high-powered torch scanning the marginal vegetation and pond bottom. Since newt activity varies with temperature, surveys are recommended when air temperature exceeds 5°C (Langton *et al*., 2001; Sewell *et al*., 2013). In comparison to many tropical amphibians, temperate amphibians (such as those in the UK) are seasonal and have relatively short breeding seasons, reducing the survey timeframe. Bad weather can prolong breeding but impedes survey effort (Griffiths & Inns, 1998; Sewell *et al*., 2013). Hence, surveys are best conducted on warm, calm nights without rain and wind, which cause water perturbation. Torchlight survey is a monitoring requirement for population assessment of GCN pre- and post-translocation (Natural England, 2015).

Translocation has been reviewed as a mitigation method for GCN (Oldham *et al*., 1991; Oldham & Humphries, 2000; May, 1996; Edgar & Griffiths, 2004; Edgar *et al*., 2005; Lewis *et al*., 2007; Lewis, 2012; Gustafson *et al*., 2016; Lewis *et al*., 2016) but the effectiveness of translocation remains largely unknown due to lack of pre- and post-translocation monitoring in addition to sparse publication of reports on translocation success or failure (Gustafson *et al*., 2016; Lewis *et al*., 2016). Consequently, approximated annual investment of £20 - £40 million into mitigation by translocation in the UK (Lewis *et al*., 2016) may be open to question. Furthermore, data deficiency of GCN distribution records cannot be mitigated by volunteer recording due to the protected species status of GCN, which requires surveyors to either possess a species licence or be accompanied by a licence holder (McNeill *et al*., 2012).

Fig. 1. Google Map of GNR showing all four zones: Bothlin Burn, Stepping Stone, Garnqueen Hill and Railway Junction. Bothlin Burn consists of eight ponds in two clusters (BB1-BB8), whereas Stepping Stone is a small cluster of three ponds (SS1-SS3). Garnqueen Hill consists of seven ponds in two clusters (GQ1-GQ7) and Railway Junction consists of six ponds (RJ1-RJ6). Peak adult counts obtained for GCN in each pond are indicated by size of points (grey).

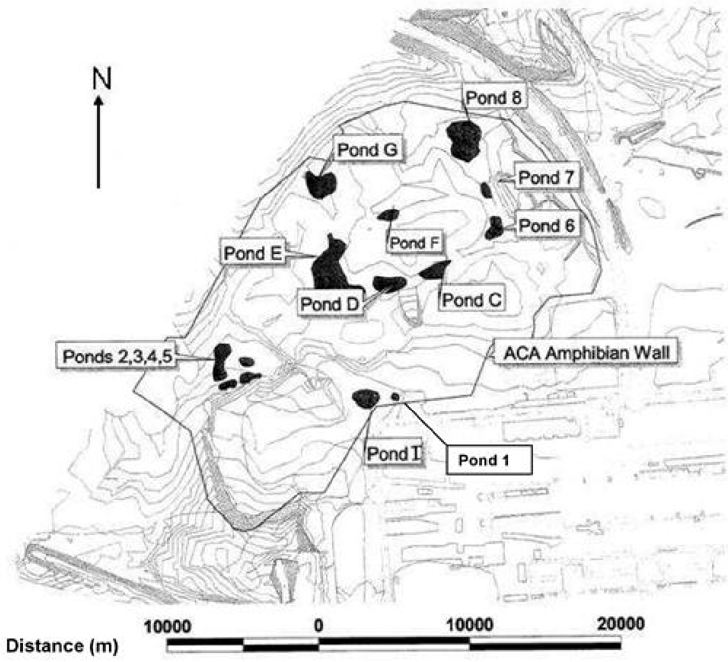

Fig. 2. Map of ponds located within the Amphibian Conservation Area (ACA), which was the donor site for the GCN translocation. Six (C,D,E,F,G,I) of the seven original ponds are shown on the map; pond L is not. Ponds 1-8 were created when the ACA was established and amphibian wall built. Map reproduced with permission from Ironside Farrer. Modified by McNeill (2010) to show the location of Pond 1.

Here, we report on the results of a translocation for GCN in Scotland. With six years of pre-translocation data and 10 years of post-translocation data, we now have a long-term study from which to infer conclusions. Our overarching aim was to assess the impact of translocation to guide future conservation of this GCN population. Our specific objectives consisted of population analysis over time, at the level of the entire site and at specific zones within the site. To address these objectives, we assessed: population size within GNR over the entire monitoring period (1998 – 2003, 2006 – 2013, 2015); adult counts within GNR over the post-translocation monitoring period (2006 – 2013, 2015); and whether adult counts in each zone of GNR over the post-translocation monitoring period (2006 – 2013, 2015) were substantially different to one another. The GCN population at Gartcosh appears to have increased post-translocation and retains its status as the largest in Scotland. Translocation may therefore be an effective conservation mitigation strategy. However, our results also indicate the need for continued monitoring, encompassing all life stages of translocated amphibian populations, and studies on GCN migration. Additionally, the zone declines we detected indicate that some ponds may be less favourable and may require modification to support more GCN.

MATERIALS AND METHODS

Study site & data collection

GNR contains 24 ponds distributed across four distinct zones: Bothlin Burn (BB), Stepping Stone (SS), Garnqueen Hill (GQ) and Railway Junction (RJ) (Fig. 1; Appendix 1). Each pond was surveyed by torchlight 4 – 6 times during March – June each year from 2006 – 2015, except 2014. Surveys started 30 minutes after dusk on calm, dry nights with temperatures exceeding 5 °C. The order of ponds surveyed during each visit was randomised. Observers walked slowly around each pond with a Cluson 1,000,000 candlepower torch, checking for all adult amphibians in the torch beam at 1 m intervals, and recording observations (species, number, and sex). Total adult counts were recorded after one full circuit, in accordance with standard methodology (Gent & Gibson, 1998). Amphibian species other than GCN are not reported in this paper. Where possible, 100% of the shoreline was searched. Survey time per pond was dependent on pond size. A complete survey of all 24 ponds took approximately 10 hours over three consecutive nights. Surveys were standardised by using the same type of torch, bulb and battery strength. The maximum counts per pond were summed to produce zone and site counts, following which population sizes were classed in accordance with guidelines established by English Nature (2001). The survey protocol is shown in Appendix 2: the habitat data recorded are not reported in this paper, nor are the numbers of amphibians other than GCN.

Data analysis

All data analysis was performed using the statistical programming environment R v 3.3.2 (R Core Team, 2016). A Generalised Linear Model (GLM) was fitted to adult count data from the entire monitoring period (1998 – 2003, 2006 – 2013, 2015) to test for the relationship between ‘adult counts’ (response variable) and the explanatory variable ‘year’. A second GLM was fitted to adult count data from subpopulations in each zone of GNR from the post-translocation monitoring period (2006 – 2013, 2015). This GLM was used to assess change in adult counts over time and variation in adult counts between zones of GNR that were established post-translocation. The GLM tested for correlation between ‘adult counts’ (response variable) and two explanatory variables, ‘year’ and ‘zone’.

A negative binomial distribution was specified for all models as the response variable was integer count data and Poisson distributed models initially specified were overdispersed when tested ($P < 0.05$) using the R package RVAideMemoire v 0.9-45-2 (Hervé, 2015). A negative binomial distribution can control for aggregation in count data and prevent biased parameter estimates (Harrison, 2014). All models considered were nested and so the best model was chosen using stepwise backward deletion of terms based on Likelihood Ratio Tests (LRT). Final negative binomial models were tested for overdispersion as above and model fit assessed using the Hosmer and Lemeshow Goodness of Fit Test (Hosmer & Lemeshow, 2000) within the R package ‘ResourceSelection’ v 0.2-4 (Lele *et al.*, 2014) and by visual examination of fit and residuals. Model predictions were obtained using inbuilt R functions (R Core Team, 2016) and model results plotted for evaluation using the R package ‘ggplot2’ v 2.1.0 (Wickham, 2009). A Tukey’s Posthoc Test was performed on the second GLM to generate pairwise comparison of means for all levels of the factor ‘zone’ using the R package ‘multcomp’ v 0.1-7 (Hothorn *et al.*, 2009).

RESULTS

Torchlight survey

Prior to translocation, the GCN counts at Gartcosh were consistently low (under 100 breeding adults), excluding a pre-translocation peak of 140 adult GCN in 2001 (Table 1, Fig. 3). Counts initially remained low post-translocation in 2006 and 2007 but increased to 299 adults in 2008. Counts then dipped slightly in 2009 before doubling in 2010 to 432 adults. Thereafter, there was a sharp decline as adult counts halved in 2011 but numbers recovered by 2012 with 454 adults recorded, remaining high with 428 GCN counted in the last year of monitoring by environmental consultants (2013). In 2015, the highest adult counts throughout the entire monitoring period were observed, with 382 males and 133 females (Appendix 3) totalling 515 adult GCN (Table 1). Despite GCN adults being released into GNR with a sex ratio of 1:1 ±10%, with males being slightly higher (Table 1), torchlight surveys repeatedly displayed a substantial male bias, ranging from 1: 2.3 to 1: 4.2 over the course of the 10-year post-translocation monitoring period (Table 1).

Pre-translocation		Post-translocation						
Year	ACA	Year	Adults	GNR	BB	SS	GQ	RJ
1998	68	Trans	M	529	285	-	217	217
		Pop 04-06	F	483	246	-	208	208
			Total	1012	531	-	425	425
1999	66	HEL 2006	M	67	36	1	20	10
			F	29	17	0	5	7
			Total	96	53	1	25	17
2000	93	HEL 2007	M	76	43	2	16	13
			F	32	11	1	12	8
			Total	108	54	3	28	21
2001	140	HEL 2008	M	241	142	0	31	68
			F	58	35	0	10	13
			Total	299	177	0	41	81
2002	77	HEL 2009	M	195	118	1	64	12
			F	54	37	0	13	4
			Total	249	170	1	77	16
2003	78	URS 2010	M	320	197	6	60	63
			F	112	74	3	25	17
			Total	432	271	9	85	80
		URS 2011	M	166	93	1	65	36
			F	55	24	0	26	7
			Total	221	117	1	91	43
		URS 2012	M	335	249	10	47	48
			F	119	96	3	11	20
			Total	454	345	13	58	68
		AAL 2013	M	348	258	26	86	36
			F	80	40	8	20	20
			Total	428	298	34	106	56
		LRH 2015	M	382	122	10	144	106
			F	133	39	4	49	60
			Total	515	161	14	193	166

Table 1. Peak adult GCN counts detected by torchlight survey at: the ACA, Gartcosh, North Lanarkshire, prior to translocation (Knowles & Bates, 2003) in 2004 – 2006; GNR following translocation between 2006 – 2015 as surveyed by Heritage Environmental Ltd (HEL, 2006-2009), URS Corporation Ltd (URS, 2010-2012), Acorna Associates Ltd (AAL, 2013), and LRH (2015). GCN male and female counts in the ACA from 1998 – 2003 are unknown thus only total adult counts are given. GCN male and female counts in GNR are given per zone in addition to total adult count. Summed counts from Kellett & Bates (2006) following translocation completion are also given, where SS counts were included in BB counts. These summed counts represent actual translocated adults, not torchlight counts. SS ponds were not recorded separately from BB ponds until 2006. Total adult counts per zone are given in addition to total counts for GNR.

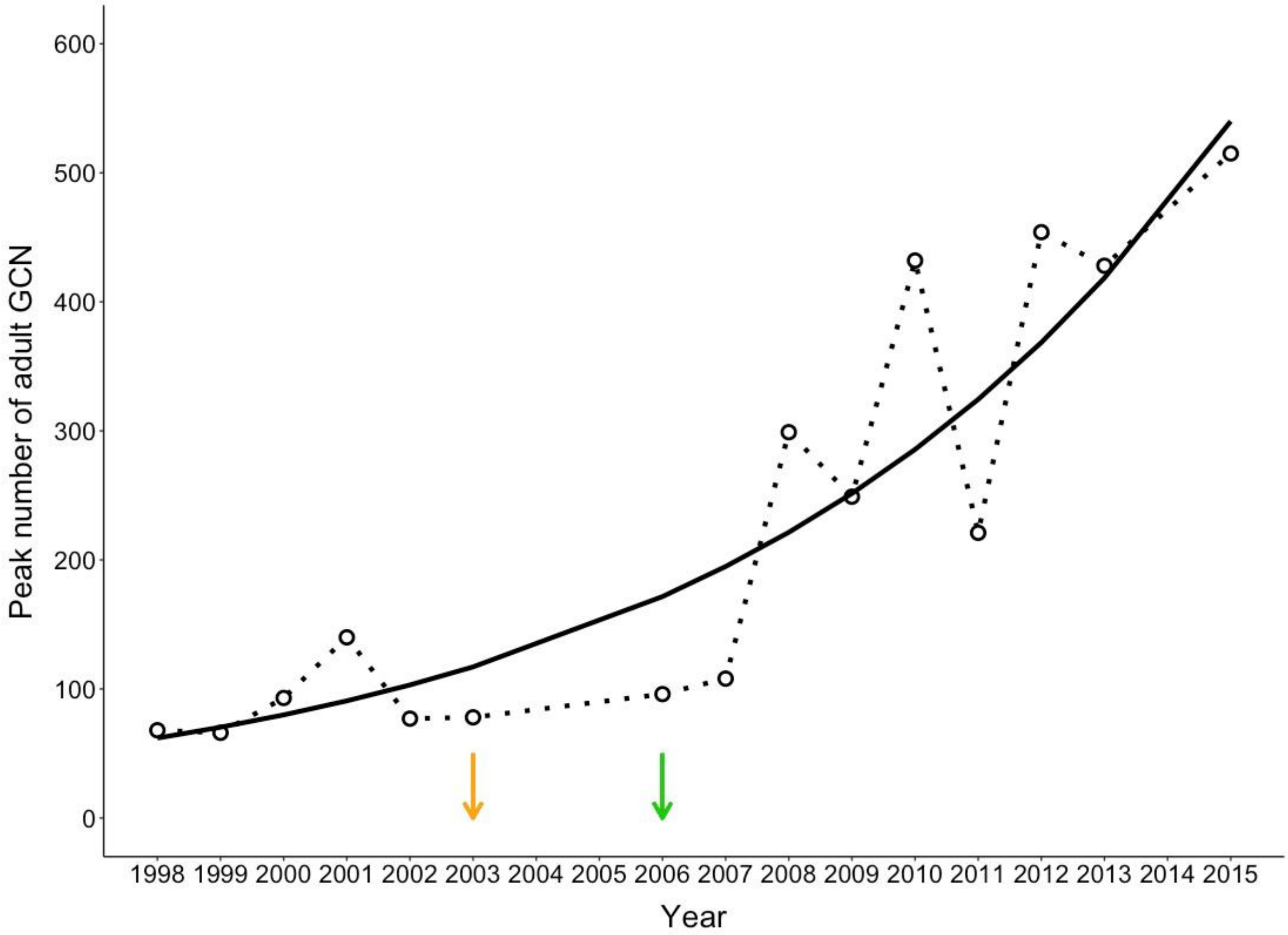

Fig. 3. GCN adult counts between 1998 – 2015 before and following translocation from the ACA to GNR. The orange arrow indicates the end of pre-translocation data whilst the green arrow indicates the start of post-translocation data. No torchlight monitoring occurred during 2004, 2005, or 2014. Adult counts from 2006 – 2015 are from ponds within GNR that contain the translocated population of GCN. The observed (dotted line) and predicted (solid line) adult counts were highest in the last year of post-translocation monitoring in 2015.

Population size throughout entire monitoring period

Year positively influenced adult counts (GLM: F_{13} = 66.681, P < 0.001, R^2 = 81.50%) over the entire monitoring period for GCN (1998 – 2003, 2006 – 2013, 2015), thus this relationship is supportive of growth in adult numbers over time pre- and post-translocation (Fig. 3). Population size in each zone of GNR (Appendix 3) was classed using criteria based on adult counts (small ≤ 10 adults, medium 11-100 adults, large >100 adults) from English Nature (2001). Each zone possessed medium or large subpopulations in 2015 compared to small or medium subpopulations post-translocation in 2006 (McNeill, 2010). Notably, RJ was medium prior to 2015 but is now large. Although RJ is isolated from other zones within GNR, counts have gradually increased from 2006 – 2013, after which the number of adult GCN tripled in 2015. Alongside RJ, GQ has also increased steadily. Indeed, both GQ (193 adults) and RJ (166 adults) exceeded BB in 2015. Prior to 2015, BB possessed the highest adult counts but numbers have been decreasing since 2012. Adult counts in SS remain low and have decreased since 2013.

Adult counts within GNR zones over post-translocation monitoring period

Year positively influenced adult counts within all four zones (GLM: F_{34} = 31.064, P < 0.001, R^2 = 12.78%), thus this relationship confirms growth in adult numbers over time in GNR zones (Fig. 4a).

Difference in adult counts between zones of GNR (post-translocation)

Zone had a significant effect on adult counts (GLM: F_{31} = 47.301, P < 0.001, R^2 = 57.30%). The following values reported for each zone in addition to p-value are the linear estimate ± standard error. Significant negative correlations were observed between adult counts and BB (-430.178 ± 63.152, P < 0.001), GQ (-0.944 ± 0.232, P < 0.001), RJ (-1.173 ± 0.233, P < 0.001) and SS (-3.306 ± 0.265, P < 0.001). A Tukey's post-hoc test was conducted; differences between the means of all zones were significant (P < 0.01), excluding the mean difference between RJ and GQ (P > 0.05) (Fig. 4b). The greatest difference was observed between SS and BB.

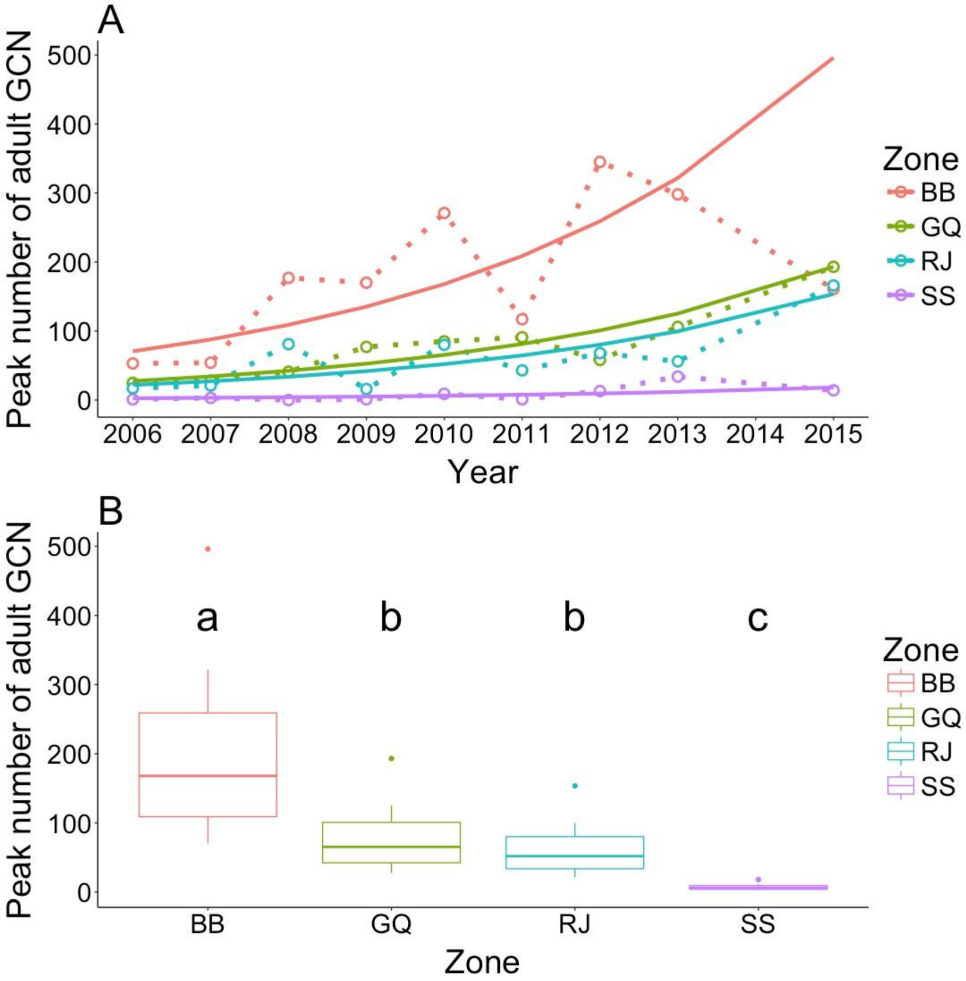

Fig. 4. Variation in GCN adult counts over (a) post-translocation monitoring period (2006 – 2013, 2015) in GNR zones and (b) between GNR zones. In Fig. 4a, dotted lines show observed GCN counts; solid lines show trends generated by the GLM. BB counts were highest every year except 2015, when GQ counts exceeded all other zones. RJ has increased steadily but SS counts remain consistently low. In Fig. 4b, the results of the Tukey's post-hoc test are shown. The boxplots represent the distribution of adult counts recorded each year in each GNR zone. The median (line), lower and upper quartiles (lower and upper box), and minimum and maximum (whiskers) adult counts are displayed for each box. Differences between the mean peak adult count of all zones were significant ($P < 0.01$), excluding the mean difference between RJ and GQ ($P > 0.05$). Significance is denoted by letters, where different letters indicate a statistically significant difference between the mean adult counts of zones.

DISCUSSION

Post-translocation monitoring has shown that peak counts of GCN adults within the GNR have increased five-fold in the 10 years since translocation from the original ACA; thus the translocated population appears to be flourishing on the basis of adult counts. This contrasts with a recent study by Lewis *et al.* (2016) who found populations at mitigation sites in England had declined, resulting in extinction at 4/18 sites. However, our study corroborates results of Gustafson *et al.* (2016) who captured a number of GCN individuals seven years post-translocation comparable to the number originally translocated. Low counts recorded in 2006 and 2007 may have been post-translocation fluctuations as GCN adults are philopatric to breeding sites and individuals may have migrated back to the pre-translocation site (McNeill, 2010; Gustafson *et al.*, 2016). A decline was observed in 2011 but GCN populations are subject to natural fluctuation (Gustafson *et al.*, 2016) and have been speculated to cycle every four years (Arntzen & Teunis, 1993; Cook, 1994; Skei *et al.*, 2006; McNeill, 2010). Data from GNR zones in 2015 may support this natural cycling as BB counts declined four years on from 2011. Nevertheless, the population remains the largest in Scotland (O'Brien, 2016) with 515 adults recorded by LRH in 2015. English Nature (2001) recommended peak adult counts instead of density as a method of population assessment for GCN as small populations can exist at high density and vice versa (Sewell *et al.*, 2013). Lewis *et al.* (2007) demonstrated that there is high concordance between both methods of population assessment. However, peak adult counts are best supported where counts have been taken early and late in the GCN breeding season to reveal 'true' peaks rather than 'false' peaks as a result of poor timing of torchlight survey (Sewell *et al.*, 2013). Torchlight survey reportedly produces a minimum estimate (6-23%) of population size (Griffiths & Inns, 1998): on this basis, the 2015 GNR population (2,239 – 8,583 adults) has vastly exceeded the number originally translocated (1,012 adults). Conversely, following translocation of a known number of 1,012 GCN adults to the new GNR, adult counts stood at around 100 adults in 2006 and 2007, representing roughly 10% of the population, in the lower half of Griffiths and Inns' (1998) range.

A male bias has been observed consistently in peak adult counts since post-translocation monitoring began in 2006; prior to this the population had a 1:1 ±10% sex ratio (McNeill, 2010). This may result from detection bias, with male activities making them easier to observe. Males defend lekking areas in ponds to perform breeding displays to attract females (McNeill, 2010; Beebee, 2015) and are more morphologically distinct than females due to characteristic dorsal crests and white-striped tails that reflect torchlight (Langton *et al*., 2001; Edgar & Bird, 2006). Detection bias can be investigated through Capture-Mark-Recapture (CMR) but this takes several years (Kröpfli *et al*., 2010). Alternatively, bottle trapping is unbiased towards sex and can obviate detection bias (Griffiths & Inns, 1998). However, welfare issues and time required for trap deployment and checks must be taken into consideration (Gent & Gibson, 1998; Sewell *et al*., 2013).

Substantial changes in adult counts across all four GNR zones occurred during 2006 – 2015. While BB and SS experienced declines, GQ and RJ counts have increased. There are two plausible hypotheses as to why these changes have occurred and we will discuss support for each. One hypothesis is dispersal within GNR; the other is source-sink dynamics. Amphibian fencing and walls, designed to prevent migration between zones of GNR, were in place from the start of post-translocation monitoring (McNeill, 2010). However, these had been removed in May 2011 prior to torchlight monitoring by LRH in 2015. Consequently, there were no longer any physical barriers to exchange between GCN in different zones of GNR. Indeed, GCN were observed by LRH outside of RJ zone in 2015 and they had traversed the only wall that might contain GCN in this particular zone. Given the capability of adult GCN to disperse up to 1.6 km (Edgar & Bird, 2006; Beebee, 2015; Haubrock & Altrichter, 2016), exchange between zones is highly plausible. A study on dispersal of GCN within and outside GNR would be beneficial in understanding the dynamics of this population and its long-term viability. Connectivity between zones within GNR, and populations external to GNR, is crucial for enhanced genetic exchange and recruitment to this population. SS counts remained consistently low over nine years; thus, these small ponds may be unfavourable for GCN. Water levels of SS1 and SS3 dropped considerably in 2015 (observation by LRH). Created ponds that fail to hold water due to inadequate design or maintenance can result in extinction of GCN populations (Lewis *et al*., 2016). Therefore, the entire SS zone may require modification to encourage and support GCN (advised pond management for GCN is given by Langton *et al*., 2001) as these ponds may aid dispersal of GCN between zones BB and GQ now that fences have been removed (McNeill, 2010).

The alternate hypothesis to that of dispersal between zones of GNR is simultaneous extinction and colonization of ponds i.e. source-sink dynamics (Griffiths *et al*., 2010). Fundamentally, "sinks" are poor quality habitat that cannot support GCN without connectivity to other ponds and where a population therefore goes extinct. However, if individuals continually migrate from "source" or good quality ponds to sinks, sinks can persist indefinitely. Ponds in GNR may have developed into sinks in the years following translocation (e.g. SS ponds). Although an even sex ratio of GCN adults was broadly established across all zones of GNR by translocation completion, torchlight counts in 2006 and 2007 indicated the number of adult GCN in all zones was below the recommended minimum viable breeding population size, in terms of both females and adults (Halley *et al*., 1996; Griffiths & Williams, 2001). In 2008, BB surpassed this threshold but adult counts in other zones remained low and unpromising for long-term breeding viability. Additionally, RJ is isolated from other zones and consequently, ponds may have low genetic and population viability (Edgar & Bird, 2006; Lewis *et al*., 2013). It is important for GNR population survival to identify additional sources of recruitment. The nearest source population is Drumcavel Quarry (McNeill, 2010; McNeill *et al*., 2012), approximately 1 mile north of GNR across a major motorway. Connecting these two populations, and improving connectivity between GNR ponds using corridors to enable juvenile and adult dispersal, is necessary to increase recruitment and genetic diversity. Given recent road and housing developments, and the pre-existing railway line, this may be challenging to implement. In England, Lewis *et al*. (2013) found GCN were lost from mitigation sites where roads interfered with possible migration paths. Nonetheless, improved connectivity may be the only way to ensure North Lanarkshire GCN populations function as a successful metapopulation. However, Halley *et al*. (1996) found even large populations (ponds with over 100 females located more than 3km from a source) have little chance of surviving 20 generations.

Crucially, we have only adult count data to infer translocation success of the Gartcosh GCN population. Monitoring of all life stages was performed by DCM during her research from 2006 – 2008 and the relationship between breeding success and adult presence tested (McNeill, 2010). Breeding adult counts were high in most ponds but egg, larvae and metamorph counts suggested breeding failure. Furthermore, peak larval counts did not correspond to peak adult counts thus high adult counts do not indicate many breeding adults and subsequently breeding success. This detailed assessment of population viability was not continued in monitoring from 2007 – 2015, where only adult counts were recorded. It is essential that future monitoring incorporate all life stages as presence of one life stage does not reliably indicate presence of others or provide information on long-term recruitment (McNeill, 2010). Furthermore, whilst adult counts appear to indicate the population is thriving, GCN adults can live as long as 14-16 years (Hagstrom, 1979; Francillon-Veillot *et al*., 1990; Gustafson *et al*., 2016; O'Brien, 2016). Adults observed during torchlight survey in 2015 could be the same adults originally translocated, which leaves room for doubt as to whether developmental stages are surviving to adulthood. McNeill (2010) found some evidence of recruitment using CMR, as all adults originally translocated to GNR were photographed and adults recruited within GNR were not amongst these records. However, the situation in years following completion of McNeill's study in 2010 is unknown. Given our population estimate based on peak adult counts in 2015, we believe recruitment has continued to occur within GNR. Nonetheless, CMR is essential to confirm the population consists primarily of new adults in all zones and absence of adults originally translocated to GNR. CMR requires long-term study (Kröpfli *et al*., 2010) and consequently incurs financial cost and substantial investigator effort. Thus it is clear why torchlight survey retains its appeal as a cost-effective and time-efficient monitoring tool. Nonetheless, annual torchlight monitoring of GCN at Gartcosh can only continue with licensed volunteers from local amphibian groups or environmental consultants contracted by NLC.

All literature reviews of translocation emphasise problems encountered by lack of long-term monitoring and failure to produce final reports. Importance of long-term monitoring to determine translocation success was also emphasised by Gustafson *et al*. (2016) in their study of GCN translocation in Sweden. The Gartcosh GCN translocation was an excellent opportunity to understand the potential and flaws of translocation. This Scottish case study appears to provide evidence for success of translocation as a mitigation method in the UK. However, we would suggest cautious interpretation of the torchlight count data. Although 10 years of post-translocation monitoring data exist, they only show the adult life stage. Adult counts indicate population increase but Gartcosh GCN are at risk of becoming a relic population if breeding and subsequent recruitment are not facilitated through continued habitat management and conservation effort. Since the study by McNeill (2010), recruitment has not been confirmed within GNR. Furthermore, although changes within zones are suggestive of dispersal within GNR, routes of dispersal between zones of GNR and sites external to GNR for population exchange remain unidentified. Consequently, we recommend future studies on breeding and dispersal in this population and connectivity between sites. Future management should improve existing ponds (e.g. SS) within the nature reserve to prevent drying out and to maintain ponds at different states of succession to provide varied habitat for GCN (Gustafson *et al*., 2016). Addition of new ponds between zones is necessary to maintain and improve connectivity between zones, such as GQ and RJ. This is vital with the forthcoming addition of an access road through the nature reserve to a new housing development (*pers. comm*. Pardeep Chand, NLC), which could seriously impact this population. This development alone should imply investment in further monitoring.

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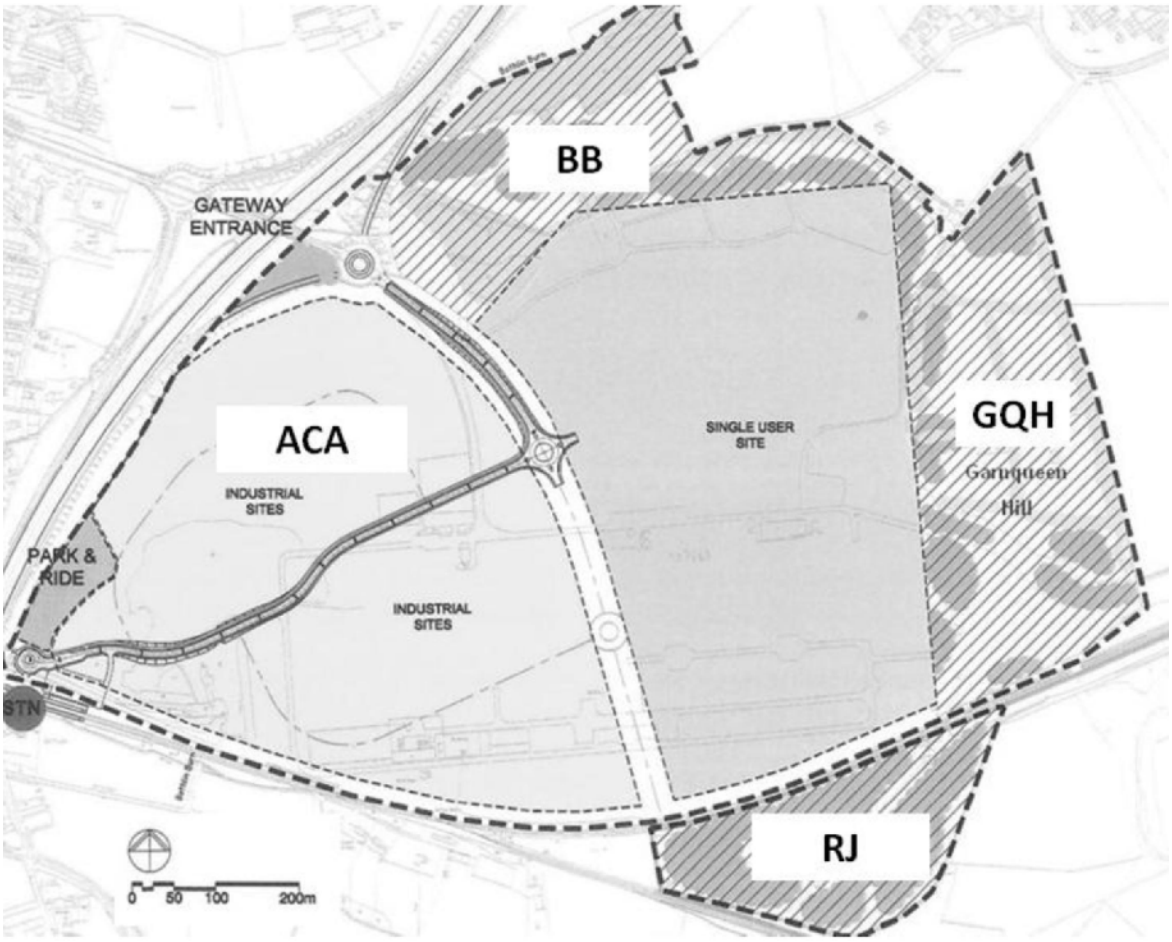
Appendix 1 Map of Gartcosh Industrial Site, North Lanarkshire. The donor site, Amphibian Conservation Area (ACA), is shown in relation to the receptor site, Gartcosh Nature Reserve. The reserve is indicated by hatched lines. Three zones within the nature reserve, Bothlin Burn (BB), Garnqueen Hill (GQH) and Railway Junction (RJ), are shown but the fourth (Stepping Stone) is not shown (see Fig. 1 in main text). This figure was produced by McNeill (2010) after being modified from a map produced by Scottish Enterprise.



Appendix 2.

GCN Survey Form

Surveyor details

Name of surveyor(s)	1.	2.
3.	4.	5.
6.	7.	8.

Pond location details

Site name	
Location name (taken from nearby hamlet/ farm/house/ woodland etc)	
Pond full grid reference	

Habitat suitability factors (refer to HSI guidance and summary notes below)

HSI Visit Date	24/05/13	Score	SI value
1. Map Location. Score: A (optimal), B (marginal) or C (unsuitable).			
2. Pond area in m^2. Estimate.			
3. Number of years in ten pond dries up. Estimate or ask landowner.			
4. Water quality. Score: 1 = bad, 2 = poor, 3 = moderate, 4 = good.			
5. Percentage perimeter shaded (to at least 1 m from shore). Estimate.			
6. Waterfowl impact. Score: 1 = major, 2 = minor, 3 = none.			
7. Fish presence. Score: 1 = major, 2 = minor, 3 = possible, 4 = absent.			
8. Number of ponds within 1 km (1: 25 0000 maps) not separated by barriers to dispersal.			
9. Terrestrial habitat. Score: 1 = none, 2 = poor, 3 = moderate, 4 = good.			
10.Percentage of pond surface occupied by aquatic vegetation (March-May). Estimate.			
HSI Score			
Pond pH			

Water quality Bad = clearly polluted, only pollution-tolerant invertebrates, no submerged plants; Poor = low invertebrate, diversity, few submerged plants; Moderate = moderate invertebrate diversity; Good = abundant and diverse invertebrate community.
Waterfowl impact Major = severe impact of waterfowl i.e. little or no evidence of submerged plants, water turbid, pond banks showing patches where vegetation removed, evidence of provisioning waterfowl; Minor = waterfowl present, but little indication of impact on pond vegetation, pond still supports submerged plants and banks are not denuded of vegetation; None = no evidence of waterfowl impact (moorhens may be present).
Fish presence Major = dense populations of fish known to be present; Minor = small numbers of crucian carp, goldfish or stickleback known to be present; Possible = no evidence of fish, but local conditions suggest that they may be present; Absent = no records of fish stocking and no fish revealed during survey(s).
Terrestrial habitat None = clearly no suitable habitat within immediate pond locale; Poor = habitat with poor structure that offers limited opportunities for foraging and shelter (e.g. amenity grassland); Moderate = offers opportunities for foraging and shelter, but may not be extensive; Good = extensive habitat that offers good opportunities for foraging and shelter completely surrounds pond e.g. rough grassland, scrub or woodland.

- Life stage: Adult = adult, Imm = frog/toadlet or young newt, Larva = newt tadpole or frog/toad tadpole, Egg = newt egg/ frogspawn clump/ toadspawn strings
- Provide counts of adults, immatures and spawn clumps/ strings but indicate detection of eggs and larvae with a tick
- Water clarity 1 = good, pond bottom visible, 2 = intermediate, bottom visible in shallows, 3 = turbid, bottom not visible
- Rainfall 0 = none, 1 = yesterday, 2 = immediately prior, 3 = during daytime survey, 4 = during night survey (i.e. torch survey).

Visit 1	Number / life stage						Date (dd/mm/yy)	
Species (GCN, smooth, palmate, toad, frog)	Adult			Length (mm)	Larva	Egg	Survey Time (24h)	to
	M	F	Unk				Air temp (ºC)	
							Water clarity (1-3)	
							Water temp (ºC)	
							Water pH	
							Conductivity	
							Rainfall (0, 1, 2, 3,4)	
							Wind disturbing water (tick)	
							Bright moonlight (tick)	
							% shoreline searched	
							Notes:	

Visit 2	Number / life stage						Date (dd/mm/yy)	
Species (GCN, smooth, palmate, toad, frog)	Adult			Lmm	Larva	Egg	Survey Time (24h)	to
	M	F	Unk				Air temp (ºC)	
							Water clarity (1-3)	
							Water temp (ºC)	
							Water pH	
							Conductivity	
							Rainfall (0, 1, 2, 3,4)	
							Wind disturbing water (tick)	
							Bright moonlight (tick)	
							% shoreline searched	
							Notes:	

Visit 3	Number / life stage						Date (dd/mm/yy)	
Species (GCN, smooth, palmate, toad, frog)	Adult			Lmm	Larva	Egg	Survey Time (24h)	to
	M	F	Unk				Air temp (ºC)	
							Water clarity (1-3)	
							Water temp (ºC)	
							Water pH	
							Conductivity	
							Rainfall (0, 1, 2, 3,4)	
							Wind disturbing water (tick)	
							Bright moonlight (tick)	
							% shoreline searched	
							Notes:	

Visit 4	Number / life stage						Date (dd/mm/yy)	
Species (GCN, smooth, palmate, toad, frog)	Adult			Lmm	Larva	Egg	Survey Time (24h)	to
	M	F	Unk				Air temp (^{o}C)	
							Water clarity (1-3)	
							Water temp (^{o}C)	
							Water pH	
							Conductivity	
							Rainfall (0, 1, 2, 3,4)	
							Wind disturbing water (tick)	
							Bright moonlight (tick)	
							% shoreline searched	
							Notes:	

The survey form was designed by Erik Paterson (Jacobs UK Ltd), a licenced ecological consultant, and developed by LRH for purposes of this study.

APPENDIX 3

Nature Reserve Zone / Pond		Torchlight Survey														
		1			2			3			4			5		
		GCN			GCN			GCN			GCN			GCN		
		M	F	Un	M	F	Un	M	F	Un	M	F	Un	M	F	Un
Bothlin Burn (BB)	BB1	18	2	0	9	0	0	17	5	0	4	2	0	0	1	0
	BB2	28	1	0	11	2	0	21	4	0	1	0	0	0	0	0
	BB3	14	2	0	5	0	0	12	5	0	4	1	0	2	1	0
	BB4	26	2	0	9	2	0	19	4	0	5	3	0	0	0	0
	BB5	20	1	1	11	1	0	0	0	0	5	0	0	0	0	0
	BB6	0	0	0	0	1	0	3	3	0	1	1	0	3	4	0
	BB7	16	3	0	19	12	1	11	10	0	10	6	0	12	6	0
	BB8	0	0	0	7	2	1	11	8	0	9	3	0	9	5	0
Stepping Stone (SS)	SS1	5	0	0	1	0	0	1	0	0	0	1	0	0	1	0
	SS2	3	0	0	2	3	0	0	1	0	0	0	1	0	2	0
	SS3	2	1	0	1	1	0	0	0	0	0	2	0	0	1	0
Garnqueen Hill (GQ)	GQ1	3	0	0	2	0	1	0	0	0	1	1	0	0	0	0
	GQ2	13	2	0	7	2	0	0	1	0	1	1	0	1	3	0
	GQ3	27	5	0	24	12	0	42	12	0	10	2	0	27	8	0
	GQ4	34	6	0	26	11	1	35	15	0	6	1	0	6	2	0
	GQ5	29	12	0	24	11	0	21	9	0	18	8	0	15	5	0
	GQ6	29	2	0	30	9	0	11	5	0	6	5	0	2	2	0
	GQ7	9	0	0	7	4	0	8	2	0	10	1	0	7	3	0
Railway Junction (RJ)	RJ1	25	1	0	16	8	1	5	5	0	15	5	0	3	1	0
	RJ2	21	6	0	8	4	0	6	4	0	5	4	0	1	1	0
	RJ3	5	2	0	6	1	0	14	7	0	9	10	0	3	0	0
	RJ4	19	8	0	29	11	0	13	6	0	18	12	0	11	6	0
	RJ5	14	10	0	23	11	2	32	15	0	11	15	0	1	2	0
	RJ6	22	9	0	15	13	0	22	12	0	17	14	0	4	3	0
Total		382	75	1	292	121	7	304	133	0	166	98	1	107	57	0
		458			420			437			265			164		

Summary of GCN adults recorded on all five torchlight surveys at each pond in GNR during 2015. Sex of individuals are given. Peak male and female adult counts are highlighted in bold. Peak counts were recorded as the highest adult count obtained for each sex in across all ponds in GNR during torchlight surveys in 2015.

Zone	2006	2007	2008	2009	2010	2011	2012	2013	2015
BB	Med 53	Med 54	Large 177	Large 170	Large 271	Large 117	Large 345	Large 298	Large 161
SS	- -	Small 3	NA 0	Small 1	Small 9	Small 1	Med 13	Med 34	Med 14
GQ	Med 25	Med 28	Med 41	Med 77	Med 85	Med 91	Large 131	Large 106	Large 193
RJ	Med 17	Med 21	Med 81	Med 16	Med 80	Med 43	Med 68	Med 56	Large 166

GCN adult counts and population size classes for each zone in GNR. Using peak adult counts, populations are classified as small (≤ 10), medium (11-100), or large (>100), using criteria from English Nature (2001). In 2006, counts were not recorded separately for SS and were included in counts for BB.