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Establishment of conservation refuge populations for Scotland's rare freshwater fish, the powan *Coregonus lavaretus*

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ABSTRACT
The powan (*Coregonus lavaretus*) is arguably the rarest freshwater fish in Scotland. Between 2008 and 2010 conservation refuge sites for this species were created at four reservoirs in Argyll, two each to receive translocations of fish (mostly eggs and unfed fry) from the only two sites where this species naturally occurs in Scotland, Lochs Lomond and Eck. This paper describes a study to determine if attempts to create conservation refuges have been successful. Powan from Loch Lomond were translocated to Allt na Lairige and Lochan Shira in 2009 and 2010 and then sampled in both 2014 and 2015. Powan from Loch Eck were translocated to Lochs Glashan and Tarsan, in 2010 and 2011 and sampled in 2015. Sampling at all sites showed that the individuals which were moved as eggs and unfed fry (and for two sites also as adults), had survived and that their growth was in line with that expected from their native population. Age analysis of powan collected also showed the presence of juveniles at all sites, which could only have resulted from spawning by the originally introduced fish in the conservation site. Taken together, survivorship, good growth and successful spawning by the translocated fish indicate that successful refuge populations of powan are being established at all four conservation sites.

INTRODUCTION
The European whitefish *Coregonus lavaretus* (L. 1758), known in Scotland as "powan" is arguably the rarest freshwater fish in Scotland. Found naturally only in Loch Lomond and Loch Eck, the species is a priority species for a UK Biodiversity Action Plan (UKBAP) and protected under Schedule 5 of the Wildlife and Countryside Act 1981. The Loch Eck population has additional protection as a feature of interest in the Site of Special Scientific Interest (SSSI) that applies there. Because there are only two native populations and because natural dispersal of obligate freshwater species to new habitats is highly restricted, these populations (and thus the species in Scotland), are highly vulnerable (Etheridge et al., 2014). There is significant evidence to show that powan from these two natural populations differ very significantly in morphology, parasite fauna, feeding ecology and life-history (Pomeroy, 1991; Brown & Scott, 1994; Etheridge et al., 2012). Thus to a considerable extent the conservation requirements of each population need to be considered separately (Etheridge et al., 2012).

The use of conservation translocations to create new populations of vulnerable species in new habitats as insurance against loss of a natural population has been widely employed across a range of taxa (Linklater et al., 2011; Coleman et al., 2013; Müller & Eriksson, 2013). Creation of "conservation refuge" or "Arc" sites has been a conservation tool used for several rare freshwater fishes. In Scotland this has included creating conservation refuge populations for Arctic charr (*Salvelinus alpinus* (L.)), vendace (*Coregonus albula* (L.)) and sparling (smelt) (*Osmerus eperlanus* (L.)) (see Maitland et al., 2009; Maitland & Lyle, 2013; Adams et al., 2014). Two conservation translocations for powan from the Loch Lomond population were made around 1990 to Loch Sloy and Carron Valley reservoir; both of these sites now successfully support self-sustaining populations of Loch Lomond powan (Maitland & Lyle 2013). At that time however there was no conservation refuge established for the Loch Eck powan population.

In 2008 Scottish and Southern Energy supported a conservation proposal from Scottish Natural Heritage to establish additional refuge sites for the only two native populations of powan in Scotland. The objective was to establish two new refuge sites for each of these populations in selected hydro-electric reservoirs in Argyll.

The process of selecting appropriate introduction reservoirs for powan was carried out following IUCN Guidance criteria in 2008 (IUCN 1998, 2012). These criteria require that site characteristics meet the ecological needs of a self-sustaining population for the species being translocated and the need for long-term ecosystem and population security (details of the site selection process for powan are

given in Adams et al., 2014). This process resulted in Allt na Lairige and Lochan Shira reservoirs being selected as the conservation refuge sites to receive powan from the Loch Lomond population, and Loch Tarsan and Loch Glashan reservoirs as recipients of powan from the Loch Eck population.

Collections of eggs taken from ripe female powan were made each January at Loch Lomond (2009 & 2010) and Loch Eck (2010 & 2011). Each separate batch of eggs was fertilised by milt taken from a separate single male thus creating a 'family' (Table 1). Fertilised eggs were incubated for approximately 550 degree-days in the SCENE hatchery at Loch Lomond using incubation techniques described by Rottmann & Shireman (1988).

Introductions of powan to Allt na Lairige and Lochan Shira were made under licence, by translocating well developed eggs in 2009, and then fed and unfed fry in 2010 from the Loch Lomond population to each of these sites. In addition a small number of eggs obtained from the Loch Lomond population translocated to Loch Sloy were also used (see Table 1). Introductions of powan to Loch Tarsan and Loch Glashan were made by translocating fed and unfed fry in 2010, then fed, unfed fry and ripe adult fish in 2011 from the Loch Eck stock (Table 1). Full details are given in Adams et al., 2009.

Although the translocations were successfully completed, that is fish were moved, it was not known if these resulted in the establishment of new self-sustaining populations of powan. Here we present a study to determine the success of the conservation translocations. Two levels of success in the establishment of a new conservation population can be defined. First that the fish introduced to the new conservation refuge site have survived, and second, that they have reproduced. The occurrence of juveniles from successful *in situ* reproduction provides strong evidence of progress towards a self-sustaining population. The objectives of this study were therefore, a) to determine if translocated powan had survived in each of the four conservation reservoirs, and b) to establish if there was evidence of *in situ* reproduction having occurred by the collection of juvenile powan.

METHODS

To avoid potential impact on the process of establishment of the new population, surveying of the conservation reservoirs was delayed until the fish introduced as eggs and fry were likely to have reached maturity and spawned at least once. For powan in Scotland a delay between introduction of eggs and sampling of 4+ years was regarded as appropriate.

Destination	Year of translocation	Source	Life stage introduced (& Number)	Number of Families
Lochan Shira	2009	Sloy	Eggs (10,200)	9
Lochan Shira	2009	Lomond	Eggs (39,200)	41
Lochan Shira	2010	Lomond	Unfed fry (51,100)	46
Allt na Lairige	2009	Sloy	Eggs (6840)	9
Allt na Lairige	2009	Lomond	Eggs (23,040)	41
Allt na Lairige	2010	Lomond	Unfed fry (41,800)	46
Loch Tarsan	2010	Eck	Unfed fry (115,300)	99
Loch Tarsan	2011	Eck	Unfed fry (9,000)	69
Loch Tarsan	2011	Eck	Adults (150)	unknown
Loch Glashan	2010	Eck	Unfed fry (90,600)	99
Loch Glashan	2011	Eck	Unfed fry (9,000)	69
Loch Glashan	2011	Eck	Adults (136)	Unknown

Table 1. Conservation translocations of powan, destination (the new translocation site), year of translocation, their source (donor site) and the life stage and the number of full or half sibling groups translocated. Note: Loch Sloy sourced powan comprise a previous translocation of the Loch Lomond powan population.

The reservoirs were surveyed for powan by gill netting in 2014 (Allt na Lairige and Lochan Shira) and in 2015 (Lochan Shira; Loch Tarsan and Loch Glashan). The principal nets used at all sites were Norden monofilament survey nets comprising 12 panels with mesh sizes varying between 5mm and 55mm. Two types of Norden nets were used - Norden benthic nets which measure 30m long x 1.5m deep and were set on to the bottom of the reservoirs in littoral, sublittoral and profundal habitats and Norden pelagic nets which are 30m long x 6m deep and were set at the water surface over deep water areas. On occasion, single mesh nets (30m x 1.5m) were also used (see below). All nets were set from a boat and left out overnight. For each net location, the water depths were measured and recorded using a Plastimo Echotest II hand-held sonar and net geographic positions were determined and recorded using a Garmin 60CSx GPS.

At this relatively early stage in the process of establishing new fish populations, netting effort was initially minimised to balance between satisfactorily assessing the developing fish population and the potential for unnecessary damage to the population. Fish caught were counted and identified to species. For powan, fork length was measured, each fish was photographed and scale samples taken for age determination. Tissue samples were taken and preserved in ethanol as part of a separate study on whitefish genetics. The powan were retained and stored (frozen) for further analysis if necessary. Other fish species caught were noted. Powan age was determined by scale annuli analysis; scales where the annuli were indistinct or damaged or which were replacement scales were not included in further analysis.

At Allt na Lairige (Lat/ Long: 56° 19.1¢N 004° 49.3¢ W; 37 ha surface area) three Norden benthic survey nets were set individually on 26th March 2014 and retrieved the next morning. The approximate locations of these nets are shown in Fig. 1.

At Lochan Shira (Lat/ Long: 56° 20.6¢N, 004° 57.3¢ W; 144 ha surface area) four Norden benthic surveys nets were set out individually on 27th March 2014, and retrieved the next day. However, strong easterly winds severely restricted sampling and the survey was unsatisfactory. Consequently, a second visit was made on 2nd June 2014 when four Norden nets, one 16.5mm and two 36mm single mesh nets were set and retrieved the next day. The nets were arranged in three pairs (i.e. 1 Norden + 1 single mesh) and one individual Norden. Because sampling data from 2014 was limited, three Norden benthic nets were set (one each) in littoral, sublittoral and profundal habitats and one Norden pelagic net set over deep, open water again on 1st July 2015. The approximate locations of these nets are shown in Fig. 2.

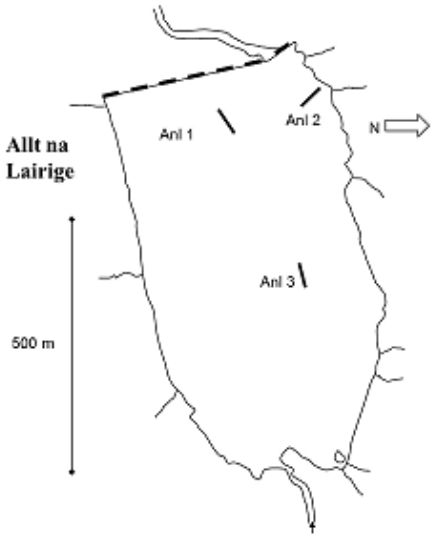

Fig. 1. An outline map of Allt na Lairige Reservoir showing the approximate locations of the gill nets (see text and Supplementary Table 1).

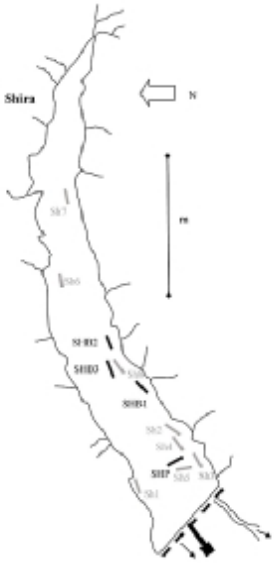

Fig. 2. An outline map of Lochan Shira Reservoir showing the approximate locations of the gill nets in 2014 (grey bars) and 2015 (black bars) (see text and Supplementary Table 2).

At Loch Glashan (Lat/ Long: 56° 05.2¢N, 005° 21.0¢ W; 194 ha surface area) three Norden benthic nets were set, one each in littoral, sublittoral and profundal habitats and one Norden pelagic net set over deep, open water on 2nd July 2015 and retrieved the next day. Further sampling was undertaken on the 3rd July 2015 when two Norden benthic nets were set onto littoral habitats plus the Norden pelagic net in open water. Detailed locations are shown in Fig. 3.

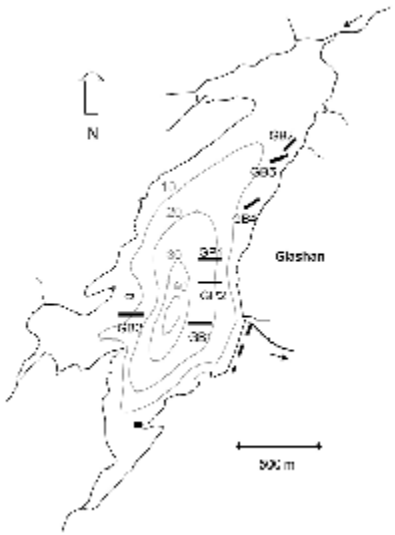

Fig. 3. A bathymetric map of Loch Glashan Reservoir showing the approximate locations of the gill nets (see text and Supplementary Table 2).

At Loch Tarsan (Lat/ Long: 56° 00.7¢N, 005° 05.2¢ W; 106 ha surface area) three Norden benthic nets were set (one each) onto littoral, sublittoral and profundal habitats and one Norden pelagic net set over deep, open water on 5th July 2015. Detailed locations are shown in Fig. 4.

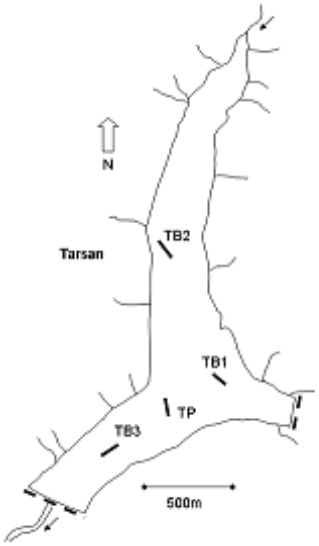

Fig. 4. An outline map of Loch Tarsan Reservoir showing the approximate locations of the gill nets (see text and Supplementary Table 3).

RESULTS

Allt na Lairige

Three species of fish were collected from Allt na Lairige including brown trout *Salmo trutta*, minnow *Phoxinus phoxinus* and nine powan (Table 2 & Supplementary data Table S1). The age and length (fork length) of eight of these powan are shown in Figure 5. Seven collected fish were ages either 4+ or 5+ years old (i.e. between 4 and 5 and between 5 and 6 years) and of around 281- 327mm fork length) but one was an underyearling (0+ i.e. <1 year old) of 130mm fork-length. There were no fish between the ages of 1+ and 4+. Fish from 4+ and 5+ years old can only be fish that were released as a part of the translocation process in 2009 and 2010. For comparison of growth, mean size at age of powan from the donor population (Loch Lomond) collected from between 1979 and 1988 derived from the literature (Brown & Scott, 1994) is shown (Fig. 5A).

Lochan Shira Reservoir

Four species of fish were collected in Lochan Shira, brown trout, minnow, three-spined sticklebacks *Gasterosteus aculeatus* and including 29 powan (Table 2 & Supplementary data Table S2). The age structure of these powan shows 12 fish ranging in age from 0+ (underyearling) to 2+ years old and ranging in length from 155mm to 172mm and 5 fish in the age range 5+ to 6+ years old and ranging in fork-length from 226-310mm (Figure 5B). There were no fish aged 3 or 4. Mean size at age of powan from the donor population (Loch Lomond) collected from between 1979 and 1988 derived from the literature (Brown & Scott, 1994) is shown (Fig. 5B).

Loch Glashan

Four species of fish were collected in Loch Glashan: powan, brown trout, minnow and three-spined sticklebacks (Table 2 & Supplementary data Table S3). In total 45 powan were collected. The fork lengths and ages of 44 powan are shown in Figure 5C. Powan covered the range of ages from 0+ to 5+ (although no 4+ age class was recorded). Fish of age 5+ could comprise juvenile fish that were translocated as unfed fry in 2010; fish of younger than 4 years must have originated from *in situ* spawning either by individuals translocated as adults or by individuals translocated to Glashan as juveniles (Table 1). Powan of less than 3 years old ranged in size from 145 to 219mm. For comparison of growth, mean size at age of powan from the donor population (Loch Eck) collected from between 1984 and 1987 and from 1991 and 1992, derived from the literature (Brown & Scott, 1994) is shown (Fig. 5C).

Loch Tarsan Reservoir

Three species of fish were caught: powan, brown trout and minnow. In total 85 powan were collected (Table 2 & Supplementary data Table S4). The fork lengths and ages of 67 powan are shown in Figure 5D. Powan ranged in age from 1+ to 7+ years old (although there was no 6+ age class). The single fish of age 7+ was identified as a fish translocated as an adult (identified by an adipose fin clip mark). Fish from the age 5 year class (N=21) were most likely fish that had been translocated to Loch Tarsan as unfed fry. Powan from age 4+ and younger were certainly the product of *in situ* spawning by translocated individuals. Mean size at age of powan from the donor population (Loch Eck) collected from between 1984 and 1987 and from 1991 and 1992, derived from the literature (Brown & Scott, 1994) is shown (Fig. 5D).

Site	Sampling Date	Catch
Allt na Lairige	March 2014	9 powan 15 brown trout 1 minnow
Lochan Shira	March 2014	0 powan 8 brown trout 1 3-spined stickleback
Lochan Shira	June 2014	9 powan 1 brown trout 4 3-spined stickleback 1 minnow
Lochan Shira	July 2015	20 powan 3 brown trout 3 3-spined stickleback 5 minnow
Loch Glashan	July 2015	45 powan 21 brown trout 38 3-spined stickleback 7 minnow
Loch Tarsan	July 2015	85 powan 14 brown trout 3 minnow

Table 2. Netting and catch details at the 4 conservation refuge sites.

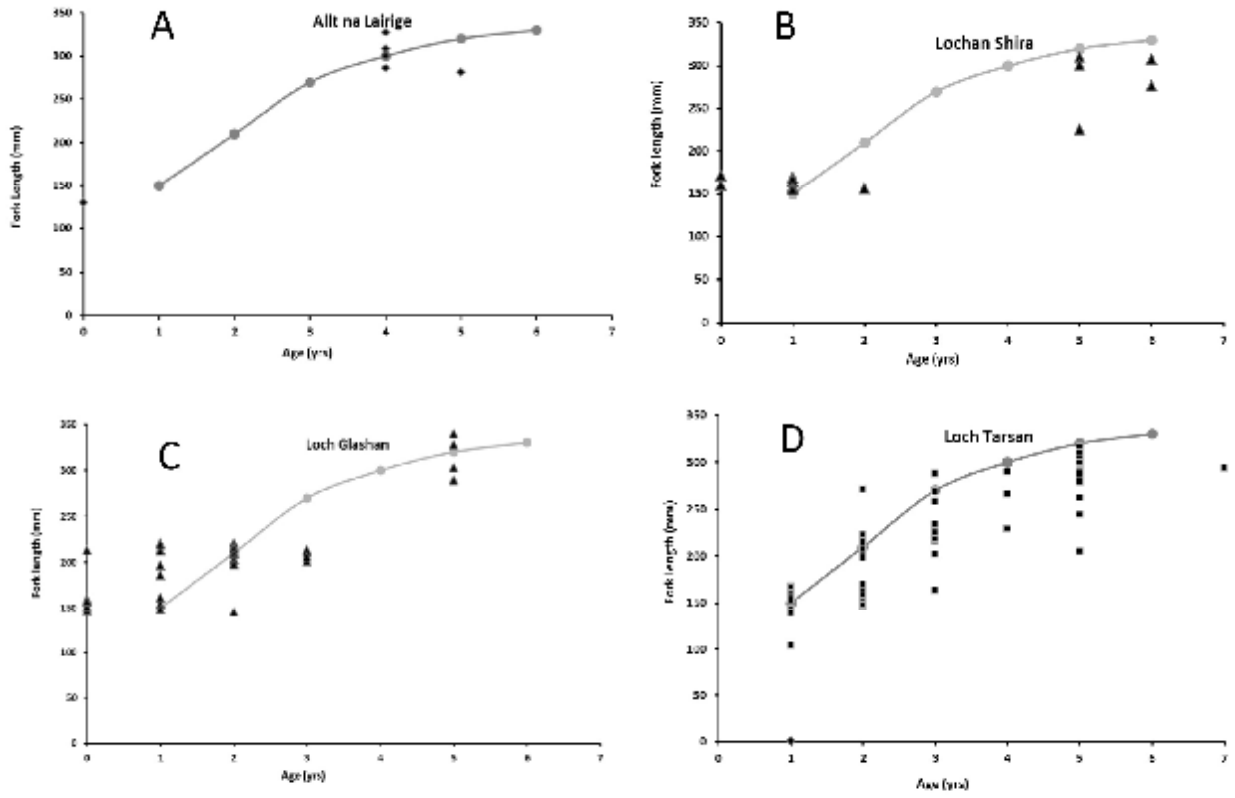

Fig. 5. The fork lengths and ages of powan caught at A) Allt na Lairige in 2014 and B) Lochan Shira in 2015 (both black triangles) and the mean fork-length at age of powan from Loch Lomond (grey circles, grey line) collected between 1979 & 1988 (Brown and Scott, 1994) and powan caught in C) Loch Glashan and D) Loch Tarsan in 2015 (both black triangles) and the mean fork-length at age of powan from Loch Eck (grey circles, grey line) collected between 1984 &1987 and 1991 &1992 (Brown and Scott, 1994).

DISCUSSION

It is clear from the survey data presented here that powan translocated to each of the four conservation refuge sites have survived in all of the new sites to which they were introduced. Fish that were translocated as recently hatched and unfed fry or as eggs have grown largely in line with the expected growth for powan in their natural location (Brown & Scott 1994). Although there are only limited data for Allt na Lairige, fish at age 4+ years old that were translocated as eggs and unfed fry were around the mean of powan from their native Loch Lomond at the same age from between 1979 and 1988 (Fig. 5A) (Brown & Scott 1994). This is also true for powan of 5+ years old in Loch Glashan where size at age is in line with that of the donor population, Loch Eck (Brown & Scott, 1994) (Fig. 5C). Powan of 5+ and 6 + years old in Loch Shira (Fig. 5B) and 5+ years old from Loch Tarsan (Fig. 5D) were marginally smaller in size than the average for each of the donor populations but the difference is relatively small.

Successful spawning by translocated individuals has occurred at all sites. First generation offspring of translocated powan are evidenced by juveniles of less than 3 years old (Supplementary data Plates 1, 2 & 3). In Lochs Tarsan, Glashan and Shira the abundance of these age classes relative to the total powan catch is high indicating strong recruitment to the population over multiple year classes of at least three years. At Allt na Lairige a single underyearling individual indicates *in situ* spawning of fish translocated as an egg or unfed fry. The strength of recruitment to the population at this site is less certain and the relatively small size of this site (and thus the probable size of the population) precluded a higher sampling effort on the juvenile population at the time of survey.

The growth of juveniles that resulted from *in situ* spawning, that is fish of ages 0+ to 3+ are also in line with the sizes expected in the donor populations Loch Lomond and Loch Eck (Figures 5A to D) (Brown & Scott 1994).

Thus the conclusion of this study is that at all four conservation refuge sites, significant numbers of translocated powan survived and their growth was in line with expectations derived from their donor populations. In addition, in all populations, there was evidence of longer term population establishment by successful breeding by translocated powan in their new habitat. Although not fully quantified in this study, for the reservoirs of Lochs Glashan, Tarsan and Shira, first generation juveniles from *in situ* breeding were clearly relatively abundant. In Allt na Lairige the lighter sampling effort did show *in situ* spawning had occurred but was not quantitatively indicative.

We conclude that this conservation translocation effort was successful to the extent that these four refuge sites now support successfully spawning powan populations. Thus there is now a strong likelihood that these powan will establish long-term self-sustaining populations.

Supplementary data supporting this study can be found at:
www.gnhs.org.uk/gn26_3/Adams_supplement.pdf

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