Pine Hoverfly

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Summary

- The pine hoverfly, *Blera fallax* (Diptera, Syrphidae), is restricted to just two sites in Scotland: Curr Wood and Anagach Wood (Fig. 1). It was identified as a priority species under the UK Biodiversity Action Plan (UKBAP) and is listed in the UK Red Data Book as category 1 (Endangered). The main aim of the Species Action Framework (SAF) project was to restore the pine hoverfly from two to five historical localities by 2012.
- Under the UK Species Action Plan, the Royal Society for the Protection of Birds (RSPB) and the Malloch Society had formed a pine hoverfly steering group, which was expanded for the SAF project to include Forestry Commission Scotland (FCS). In 2007, this steering group appointed a Project Officer, to complete the actions identified for the SAF project.
- Comprehensive surveys were carried out to confirm the status of the pine hoverfly, and habitat creation and captive-rearing techniques were developed. Three suitable sites were located within the species' historic range and, through correspondence and consultation with landowners and managers, breeding habitat was created in preparation for translocation.
- In 2009, 179 captive-bred pine hoverflies were released in Rothiemurchus Estate, a site within their historical distribution. Forty-three pine hoverfly larvae were subsequently found in artificial breeding habitat created at the release site, and up to 1 km from there. With promising initial results, the process was repeated in 2010 at Abernethy Forest and 2011 at Inshriach Forest, the success of which is yet to be determined.
- During the preparation of sites for translocation, pine hoverflies from captive breeding in the first year were used to develop microsatellite markers to assess the genetic health of the Scottish population (by comparison with a population in Sweden). The findings suggested that the two Scottish populations were genetically distinct, and both had gone through a recent population bottleneck, which may have a deleterious effect on fitness. Methods were also developed for non-invasive extraction of DNA from pupae to monitor the Scottish population, and to further test populations for potential translocations from the Continent in the future.
- Experiments monitoring pine hoverfly larval growth in competitive conditions and different rot-hole environments suggest that competition for resources may limit adult size. However, different species of hoverfly inhabiting Scots pine rot-holes seem to differ in their utilisation of the habitat, and are therefore not likely to affect recovery of the pine hoverfly.
- These findings on the biology, life strategies and techniques for monitoring the genetic health of the pine hoverfly have been combined to develop protocols for on-going conservation management.
- The pine hoverfly is a relic of our ancient, boreal, Caledonian pine forest, which is now restricted in Britain and Ireland to Scotland, as relatively small fragments. Our appreciation of its importance is exemplified by the enthusiastic participation of numerous organisations, private landowners and managers throughout the course of the SAF project.

Introduction

The pine hoverfly (*Blera fallax*) is a hairy, mainly black species with a bright, red-tipped abdomen and a yellow face. It has a wingspan of 8.0–9.5 mm and resembles a small bumblebee.

Why was this species on the Species Action List?

The pine hoverfly met criterion 1a of the Species Action Framework, as a species for conservation action (SNH, 2007). It was restricted in the UK to only two sites in the central Scottish Highlands; there had been a documented decline in numbers and distribution since the early 20th century; population levels at the two remaining sites were low; and it remained under threat of extinction. There was sufficient knowledge of the species' habitat requirements for targeted action to be taken to help the species recover. It was a UKBAP Priority Species and is included on the Scottish Biodiversity List. It is also considered to be declining and under threat in Europe.

Habitat, distribution and abundance

In Scotland the pine hoverfly is associated with mature Scots pine (*Pinus sylvestris*) although in Europe it also occurs in association with other conifer species. Most historical records refer to native pinewood sites but the modern records are more closely linked to mature plantations where forestry operations are taking place. Despite at least 10 years of survey work only two remaining populations are known, both of which occur in Strathspey in the north-western Cairngorms, centred on the area between Aviemore and Grantown-on-Spey (Fig. 1). In historical times this species was recorded from Deeside (eastern Cairngorms), along the River Findhorn and in several other parts of Strathspey.

Fig 1. Extant pine hoverfly sites, Curr and Anagach woods, and translocation sites, Rothiemurchus Estate, Abernethy Forest (including Dell Wood, not currently a site suitable for translocation), and Inshriach Forest.

General ecology

Pine hoverfly larvae develop in wet situations in pine stumps, usually where there has been some softening or decay of the heartwood by the pine butt-rot fungus (*Phaeolus schweinitzi*). The pine stump needs to have a diameter greater than 40 cm in order to support a large enough wet decay area. The larvae can emerge as adults after only one year if conditions are suitable, but if conditions are not so because of a small area of decay or overcrowding they may remain as larvae for at least two years. The larvae leave the decay to pupate around the margin of the stump or in surrounding undergrowth. Each fresh stump can probably support the appropriate decay for a period of 8-10 years before the stump dries out completely; therefore a continuity of stumps is required. In a natural situation it is considered that pine hoverfly larvae would develop in the stumps of large pines which, weakened by an attack of the butt-rot fungus, would snap off during storms. However, given the lack of extensive areas of large, old pines in Scotland where this process could take place naturally, the species relies, perhaps almost entirely, on stumps cut as part of forestry operations. Evidence from Norway and Finland supports this position. Adults have been seen feeding on flowers of raspberry, but little else is known about their behaviour or dispersive abilities.

History of decline, contributory factors and current threats

The pine hoverfly was first known in Britain in the late 19th century when a Victorian collector found the first specimen buzzing at his hotel window in Braemar. There were occasional records up until the 1940s, but then a marked gap in the latter part of the 20th century apart from the discovery of a number of individuals, presumed to be from one breeding stump, in the 1980s. After some ten years of searching, larvae of the hoverfly were eventually found in Scotland in the late 1990s, and the understanding of the conditions which they required for development prompted a widespread survey for further sites. Despite this, only two sites are currently known.

There is no current threat to the populations in the conventional sense; the main issue is that at present our pinewoods do not have the extent of mature or over-mature pines which this species requires. Ironically, felling within native pinewoods during the early 20th century probably meant that pine hoverfly populations remained high; conservation efforts in recent decades have stopped this felling, but with a consequential negative impact on the species. The other important factor is that present population levels are considered so low

and localised that any large scale colonisation events into surrounding appropriate habitat may be unlikely.

Aims

Aims for 2007-2012

The SAF project for pine hoverfly worked towards the following three objectives:

- Maintain viable populations at the two currently occupied sites.
- Increase the amount of suitable breeding habitat and populations at currently occupied sites to increase the potential for further colonisation.
- Achieve an increase in the range to five sites by 2012.

Several actions were identified:

- Develop partnership with the site owners and other forestry interests in Strathspey, to promote appropriate management of existing and potential new sites.
- Prepare a guidance note on habitat management for the pine hoverfly.
- Boost populations on current sites using suitable management techniques to a level where colonisation of new sites might occur.
- Continue to develop techniques for artificial breeding sites, and use to monitor for the presence of the species elsewhere.
- Monitor the effectiveness of the actions in order to refine future management.

Management Action

Summary of the main actions carried out

The SAF project included work in four main areas:

- Creating more breeding habitat and expanding the two currently occupied sites (Curr and Anagach woods, Fig. 1).
- Surveying the occupied sites and regularly monitoring these over the SAF project period.
- Removing a small number of larvae to develop techniques for captive rearing and breeding.
- Locating sites within the species' historic range (see Fig. 1) for translocation of captive-bred individuals, and developing partnerships with landowners and managers at these sites and in areas where habitat could be created or expanded in the future.

Under the UK Species Action Plan, the RSPB and the Malloch Society had formed a pine hoverfly steering group, which was expanded for the SAF project to include FCS. In 2007, this steering group appointed a Project Officer, primarily managed by the Malloch Society, to complete the actions identified for the SAF project. The Project Officer also worked in collaboration with expertise at the University of Stirling, which jointly funded the research.

Habitat creation

Following successful techniques of habitat creation for the hoverfly *Callicera rufa*, which also inhabits pine rot-holes (MacGowan, 1994), we created rot-holes by boring holes into the centre of stumps left after felling, using either a chainsaw or a drill (see text box below), thereby mimicking the rotting process (Fig. 2).

Fig 2. Bored rot-holes created using a chainsaw (left) and by drilling into the heartwood (right).

Table 1. Artificial habitat created at six sites over eight years.

Number of artificial rot-holes created							
Site	**2003**	**2007**	**2008**	**2009**	**2010**	**2011**	**Total**
Curr Wood	42	17	15	60		50	184
Anagach Wood	10		25				35
Rothiemurchus Estate	18		76			30	124
Abernethy (RSPB)					100	10	110
Dell Wood (SNH)		16					16
Inshriach (FCS)						160	160

Artificial breeding habitat was previously created within a 10 ha area in one of the extant sites for the pine hoverfly, Curr Wood (Fig. 1) in 2003, where 42 rot-holes were bored using a chainsaw. From 2007 to 2009, an additional 92 chainsaw-bored holes were created within the same area, and in June 2011 these were supplemented with 50 drill-bored holes (Table 1).

Methods for creating habitat

Using a chainsaw, holes were created by making two parallel 15 cm-deep cuts straight down into the surface of the stump. These were positioned either side of the heartwood centre roughly 15–20 cm apart. Two further cuts were made perpendicular to and connecting the initial cuts to complete a square on the surface. These were made at 45° angles into the centre of the stump to join at a point about 15 cm deep thus cutting out a triangular wedge. The hole was filled with either sawdust (untreated from a local sawmill) or wood-chips, or sawdust and chips, and the triangular wedge was used to partially cover the hole to protect the content from evaporation while allowing rainwater to fill the cavity.

Using a petrol-powered drill and 25 mm auger bit, roughly 10 cm diameter circular holes were created by boring repeatedly into the centre of the stump, resulting in a 15 cm-deep cavity occupying the heartwood. Sawdust created by the drilling process was used to fill the hole, and thick bark was used to partially cover the cavity.

In 2008, 25 holes were cut in stumps in the second extant site, Anagach Wood (Fig. 1), using a chainsaw and filled with pine wood-chips (Table 1). These were within a 10 ha area and were created near locations where the pine hoverfly had been recorded previously.

Habitat surveys

At Curr Wood, emergence traps were positioned over 104 seemingly suitable rotting stumps, and a 3 km transect was surveyed at least daily between May and July 2008. A total of six adults were caught in traps and marked on the thorax with non-toxic enamel paint, and two ovipositing females were caught and marked at stumps, but no adults were re-sighted.

Fourteen rot-hole surveys were carried out at Curr and Anagach woods between November 2007 and February 2011. The detritus content of chainsaw-bored rot-holes, plastic pots, and stumps with natural heart-rot was searched for pine hoverfly presence.

Curr Wood

Each year from 2007 to 2011 the chainsaw-bored rot-holes, and two stumps with natural heart-rot, were searched for pine hoverfly presence. All other naturally rotted holes (28) were too difficult to access because of their depth and small openings, and the remaining bored stumps (47%) did not retain water.

Anagach Wood

Of c. 200 Scots pine stumps searched in Anagach Wood, 10 had naturally rotted holes that retained water. No pine hoverfly larvae or puparia were found in any breeding habitat, artificially created or natural, in Anagach Wood.

Table 2. Survey results reporting total larval abundance per year at each site (N), and number of adults released (between May and July) or larvae (L) released (between September and October) at each site (R).

Site	Owner/ manager	2007	2008	2009		2010		2011	
		N	N	N	R	N	R	N	R
Curr Wood	Private	35	109	142	0	111	10(5/5)*	37	24 (8/16)*
Anagach Wood	Community owned	0	0	0	0	0	0	0	0
Rothiemurchus Estate	Private	0	0	0	84(L)	43	95 (50/45)*	3	48 (24/33)*
Abernethy Forest	RSPB	–	0	0	0	–	51(L)	3	78 (30/48)*
Inshriach Forest	FCS	–	–	–	–	0	0	–	40(L)

– not surveyed * males/females

Captive breeding for translocation

In October 2008, a survey identified 100 pine hoverfly larvae in the artificially created rot-holes at Curr Wood. Because this was probably a small fraction of the actual population size based on the amount of available naturally rotted habitat, we removed 50 larvae for captive breeding in the laboratory. From this initial sample, more than 1,200 larvae were bred in captivity, of which 430 have been released at translocation sites and the source site (Table 2).

Competition in Scots pine rot-holes

Experiments were conducted to study how larvae respond to substrate conditions and intra-specific competition effects (Rotheray, 2012). Behavioural observations were also made to inform rearing and habitat creation techniques, as well as to investigate microhabitat use and life history (Rotheray, 2013). The composition of fill material within the rot-hole and the number of other larvae present can both affect pine hoverfly larval growth, which has consequences for adult size. The experiments suggest that optimal growth requires a minimum of 40 ml of pine sawdust (or chips and sawdust) and 70 ml of spring water per larva (Rotheray, 2012).

Rearing larvae

Larvae were transferred individually to 1 l glass-bottle microcosms, which were designed to simulate rot-holes. A mix of pine sawdust, chips and spring water was allotted to each bottle based on observation of rot-holes in the field. Larvae were kept in climate-controlled facilities with thermal conditions that mimicked those experienced in the field in Strathspey, estimated using on-site data-loggers and Met Office reports. However, to avoid mortality due to freezing of the water in the microcosms, temperatures were kept above 1°C. Bark pieces were provided to allow larvae to crawl out of the water, or approach the surface to breathe, as well as moss plugs at the top of the microcosm, which fully developed larvae require for overwintering or pupation (Rotheray, 2012).

Upon emergence, all adults were kept in captivity in 2009 (19 males and 19 females), and in subsequent years a random selection of individuals were kept for captive rearing (15 males and 24 females in 2010, 30 males and 30 females in 2011) while the rest were released at the translocation site. Those kept for captive breeding were moved into breeding cages.

Adult flight cages

Two types of cage were tested: one large outdoor cage positioned on-site at the release location, where an observer could enter to record adult behaviour and time budgets in a close-to-natural situation; and four small indoor cages that provided better control over light and temperature and were used primarily to observe mating and

oviposition behaviour (Fig. 3). A range of food-plants were presented to adults in both types of cages based on what was available in and around Curr Wood. They were collected from the field and positioned in bottles filled with water, plugged with netting to prevent individuals from falling in. Cotton wool soaked in dilute honey solution provided an additional nectar source.

Fig 3. Outdoor cage for captive breeding and observing behaviour of pine hoverfly (left), and indoor cages for observing mating and oviposition behaviour (right).

Adults were on the wing, in captivity, from 11 May until 24 August, and males and females had a mean lifespan of 38 and 34 days, respectively (Table 3). In total, 44% and 43% of the day (between 08.00 and 20.00 hrs BST in good weather conditions) were spent feeding and resting, respectively. Individuals were most often observed resting on the walls and roof of the netting. Adult pine hoverflies fed on rowan (66%), greater stitchwort (27%), umbellifers (23%), bedstraws (2%), dog rose (<1%), and buttercups (<1%). In indoor cages, adults spent most of their time on the roof of the cage at the closest point to the light source. Flowers had to be positioned near this area in order for adults to land on them and feed. Water was imbibed only when the netting near the top of the cage was sprayed.

Mating requirements

Males aged 11 days and females aged 15 days were observed mating in the indoor cages (Table 3). Moving individuals between cages led to a cessation of mating attempts for several days. Therefore, to encourage as much mating as possible, the remaining individuals were divided

Table 3. Details of pine hoverfly life history, fecundity and oviposition, and larval and adult rearing requirements.

Life History	Dates	Days	Range
Time from oviposition to 1st visible instar	24th June to 15th July	21	194
Time from visible instar to final instar	24th June to 16th June	326	28 – 326*
Pupation period	15th April to 16th June	62	13 – 36
Time from first instar to adult	16th July to 11th May	415	270 – 357*
Emergence	11th May to 30th June	41	16
Flight period	11th May to 24th August	105	7 – 105
Time from emergence to mating	11th May until 27th June	47	11 – 30
Time from emergence to oviposition	11th May to 10th July	60	14 – 30
Oviposition	24th June to 24th August	61	5 – 61
Maximum recorded adult age	31st May to 24th August	86	7 – 86
Biology			
Fecundity	188 maximum eggs per female		5 – 188
Oviposition stimuli	Water soaked Scots pine sawdust (0.5 l)		
Early instar mortality	24 %**		
Late instar mortality	4 %**		
Rearing/dietary requirements			
Larval	Minimum 40 ml pine sawdust + 70 ml water per larva		
Adult	Pollen + nectar (particularly Rosaceae) + dilute honey solution and water		

* Estimated (due to unknown individual first instars), and based on univoltine life cycle
** Based on mortality in 2009 larval growth conditions

between two cages and no further manipulations were made. In total, 11 males and 13 females were recorded mating in the first year (out of a total of 19 males and 19 females).

Oviposition requirements

A number of different techniques were attempted in the small cages to induce oviposition and determine preferences; however, females were not observed ovipositing in artificial rot-holes in either the outdoor or indoor cage environment. Oviposition was triggered only upon sealing gravid females into freezer bags, with wet pine sawdust. Females would begin ovipositing eggs instantly or within 20 minutes of being sealed into the bag.

Females were gravid no sooner than 14 days after first mating. The oviposition period in captivity was between 24 June and 24 August. Each female produced 10-50 eggs per clutch, with up to 188 eggs laid per female (Table 3). In 2009, five females survived to oviposit resulting in more than 463 larvae, and in each of 2010 and 2011, 14 females produced more than 800 larvae.

Rearing captive-bred larvae

Freezer bags of water-soaked pine sawdust and pine hoverfly eggs were sprayed with spring water daily, but otherwise remained un-manipulated for several weeks to avoid harming the eggs and first instars. If larvae had grown sufficiently, i.e. were clearly visible (body length >0.5 mm), the content of the bags was carefully searched, and larvae were counted and transferred into glass microcosms prepared with substrate as described above. Between September and November, a random selection of captive-bred second and third instars (body length >1 cm) were transferred to breeding habitat created at each translocation site (84 in 2009, 51 in 2010, 40 in 2011).

Translocation sites and habitat preparation

Three translocation sites were selected based on four main criteria:

1. Within the species' historic range, and surveys over a number of years had confirmed its absence at the time of translocation.
2. Of sufficient distance (>5 km) from existing populations that natural colonisation was unlikely.
3. Had sufficient suitable habitat and potential for long-term habitat supplementation.
4. Would receive a long-term (at least 50 years) commitment to protecting, monitoring and supplementing habitat.

A standard approach at each site was used to determine the presence of the hoverfly and the condition of the habitat. Thorough surveys of the area were carried out by means of exhaustive searches, emergence traps over rotting pine stumps, and artificial rot-holes created at least a year in advance, to confirm as far as possible the species' absence within the area for translocation. Thereafter, habitat creation techniques varied across sites depending on what habitat was available, as detailed below.

Rothiemurchus Estate

This site is 20 km south of Curr Wood on the privately owned, 3,000 ha Rothiemurchus Estate (Fig. 1). The pine hoverfly was first recorded in nearby Aviemore in the late 19th century, and was last recorded in 1942 (Rotheray and MacGowan, 2000). This site was considered suitable for the first translocation attempt due to the large number of Scots pine stumps available for easy habitat creation, and the keen interest of foresters to develop the site for this species as part of their biodiversity action remit.

In 2003, holes were cut in 18 stumps within a 500 m^2 area using a chainsaw as described above. In 2007, the hoverflies *C. rufa* and *Myathropa florea* were found in 12 of 18 rot-holes on Rothiemurchus Estate. Based on empty and live puparia found on site, at least seven *C. rufa* and 19 *M. florea* survived to the adult stage in August and September of the same year.

In July 2008, two additional groups of holes in stumps were created, spaced 1 km from each other and the original site, so forming three points of an equilateral triangle. While the design was based on groups of available stumps within the area, this enabled a first estimate of dispersal ability. The two groups consisted of 46 and 30 stumps, giving a total of 94 chainsaw-cut rot-holes. Fifteen Norway spruce stumps (eight and seven at each site) were used in addition to Scots pine to investigate the option of utilising another species of tree, the stumps of which are large and abundant at the site, to create habitat for the pine hoverfly. Rot-holes were created in the same way using a chainsaw.

In September 2009, 84 captive-reared second and third instar larvae were transferred in groups of

three into 28 bored Scots pine stumps at the most northern of the three sites created at Rothiemurchus. This site was chosen because it was the greatest distance from the road, and had the greatest number of bored stumps (46). In May and June 2010, 95 captive-reared adults (50 males and 45 females) were released at the same site (Table 2). In September, 43 first instar larvae were found in 12 stumps, four of which were found in the south-west group 1 km away from the release site, demonstrating that mating and oviposition had successfully occurred.

In June 2011, 30 additional drill-bored holes were created in Scots pine stumps at the most northerly site (Table 1). Between May and June, 48 adults (24 males and 24 females) were released at the same site in Rothiemurchus Estate, and in September three large larvae were found that were considered to be semivoltine i.e. larvae from the previous year developing for two years (Table 2; Rotheray, 2012). Surveys indicated that a total of 37 larvae found at Curr Wood were also semivoltine (Table 2).

Abernethy Forest and Dell Woods

The second translocation site was Abernethy Forest National Nature Reserve, 8 km south of Curr Wood, owned and managed by the RSPB. It extends over 2,800 ha, two thirds of which is native Caledonian forest (Summers *et al*., 1997) (Fig. 1). The pine hoverfly was first recorded at Loch Garten in Abernethy Forest in 1934, and was last seen in the same area in 1982 (Rotheray and MacGowan, 2000). Since then habitat creation in the form of plastic pots and bored holes has been tried but no pine hoverfly larvae have been found. Stump habitat in Abernethy Forest is limited, so trees were felled to create enough stumps.

The site selected for translocation was a 10 ha plantation where Scots pines range from c. 20 to 50 cm diameter. The site was planted in 1958, and is close to the last observation site for the pine hoverfly at Loch Garten. In August 2010, 100 trees of 28-40 cm diameter were felled. These were distributed evenly across a 10 ha area. They were cut at a minimum height of 28 cm from the ground in order to ensure enough depth for bored holes. The holes were drilled, partially covered using large chain-sawed slabs from the felled tree, and monitored for water retention over several months. Due to a lack of rain, each hole was filled or topped up, using bottled spring water or water from Loch Garten, one month after boring. No relationship was evident between several stump variables (including diameter, circumference, height, and hole diameter) and water retention, which was measured as height of water in the bored hole. In addition to holes in stumps, 10 holes were bored in the side of felled trees to attempt an alternative form of habitat creation, but none of these appeared to retain water.

In 2008, only hoverfly larvae of the genus *Sphegina* were found inhabiting the artificial breeding sites created at Abernethy Forest. In October and November 2010, 87% of bored holes were retaining water two months after felling and hole boring. In September 2010, 51 pine hoverfly larvae were transferred in groups of three into 17 holes. In April 2011, 10 empty puparia and 11 live pupated pine hoverflies were found around the holes. In May and June 2011, 78 adults (30 males and 48 females) were released at Abernethy Forest (Table 2). In September 2011, *Sphegina* spp. larvae (about 30) and three pine hoverfly larvae, considered to be semivoltine, were found in bored holes (Table 2).

Dell Woods, owned by Scottish Natural Heritage (SNH), is 375 ha of native pinewood and is part of Abernethy Forest, 5 km from Curr Wood (Fig. 1). Due to a lack of suitably sized stumps or available Scots pine trees for felling, breeding habitat was created by sinking 16 plastic pots into the earth and filling them with Scots pine chips. They were situated every 2 m along a transect extending from inside the woodland to an exposed area. Surveying here began in 2007 and continued annually until 2010. Four species have been identified inhabiting these plastic pots, but no pine hoverfly larvae or pupae have been found.

Inshriach Forest

The third translocation site was Inshriach Forest, 8 km south of Rothiemurchus Estate, which comprises 3,000 ha of forest and is owned and managed by FCS (Fig. 1). Like Abernethy Forest, Inshriach lacked a sufficient number of large stumps and thus felling was required. A 5 ha Scots pine plantation site was identified where enough suitable trees were available for felling and supplement in the long-term. When investigating habitat creation techniques, it is important to know if suitable habitat can be created as part of normal harvesting rotations. In order to test this, 160 trees were felled comprising two size ranges (20 cm and 30 cm diameter), and two height ranges (60 cm and 'normal felling height', roughly 20 cm or as close to the ground as machines allow), duplicated 40 times. Both a petrol-powered drill and chainsaw

(due to logistical and mechanical issues) were used to create holes. Each stump was filled with sawdust created from the boring process, and partially covered with the bored wedge or large pieces left from creating the cavity. Felling and hole-boring were complete by November 2011, and 40 second and third instar larvae in groups of four were transferred into holes retaining water (Table 2). This investigation is continuing.

Conservation genetics and population supplementation

Supplementation of breeding habitat (minimum of 10 newly bored rot-holes per year), and of captive-reared larvae and adults, will continue at each site as necessary until monitoring shows signs that a self-sustaining population exists. To further inform management of these small populations, DNA extracted from pine hoverfly individuals that died in captivity was used to develop microsatellite markers (Rotheray *et al.*, 2011). Genetic variation was measured by comparing the Scottish population with Swedish specimens considered to represent a more outbred population (Rotheray *et al.*, 2012). While the genetic variation was lower in the Scottish population the fitness consequences of this difference are unknown. Therefore further monitoring is necessary in order to detect detrimental effects such as those from inbreeding. To assist these plans, a preliminary investigation into non-invasive techniques for extracting DNA was carried out (Rotheray, 2012). Sufficient DNA for microsatellite amplification was extracted not only from small pieces of adult tissue such as single, terminal tarsal segments and wing tips, but also from sections of year-old empty puparia (Rotheray, 2012).

Unfortunately, 2011 appeared to have been a very poor year for the pine hoverfly at all sites, including the main natural wild population at Curr Wood. No new larvae were found at any site in 2011, the surviving populations consisting of larvae that were developing over two years. This suggests a failure of adult breeding at all sites, perhaps due to cold and wet weather during the adult breeding season. Large population fluctuations due to stochastic events are not uncommon in insects. The pine hoverfly may have a 'bet-hedging' strategy in order to cope during these adverse periods, involving a number of larvae developing over two years regardless of growth conditions. However, with the current precariously low population size, periods when larval habitat is very restricted could drive the species to extinction. Efforts are currently underway to apply the techniques developed under the SAF project to continue captive breeding of the pine hoverfly at Edinburgh Zoo (see below).

Publicity

- During the SAF project, seven oral presentations were given to academics and interested parties or enthusiasts on the conservation management of the pine hoverfly.
- In 2009, the translocation of the pine hoverfly to Rothiemurchus Estate was publicised in several local and national newspapers, and on several websites including the BBC.
- BBC Radio Scotland's Out of Doors programme featured the project during the translocation at RSPB Abernethy in 2010.
- BBC Autumnwatch Live filmed a short piece recording the third translocation of pine hoverfly larvae into Inshriach Forest in 2011. This was made available through a link on the presenter Liz Bonnin's blog website.

Lessons Learnt, Further Work and Future Recommendations

1. The main difficulty in captive breeding and translocation projects for invertebrates is often that there are few analogous studies and very little background information, unlike the case for most vertebrates. Well-managed breeding programmes as properly integrated

Key Management Messages

- To create habitat suitable for the pine hoverfly's larval stage, rot-holes should be bored into Scots pine stumps of at least 30 cm diameter. Where possible, these should be filled with wood chips or sawdust, and protected from desiccation by partially covering with wood or bark.
- Adult pine hoverflies feed on a wide range of plants associated with Scots pine woodland. In addition to retaining or planting flowering trees such as rowan and bird cherry, opening the canopy and creating or keeping woodland-edge habitat should naturally encourage such flora.
- Conservation management on the landscape scale should consider that the pine hoverfly can disperse 1 km.
- To establish presence and monitor populations over time, survey work should focus on the larval stage of the pine hoverfly. The optimal detection time is late summer (August to September).

components of wider efforts have good conservation potential, and should continue in order to supplement translocation efforts and preserve the species.

2. Having an effective means to measure abundance of any endangered species is essential to monitor population trajectories and the effectiveness of management actions. The most cost-effective approach for the pine hoverfly is to focus survey work on the larval stage, as it occupies a discrete, easily monitored habitat, sampling is not invasive, and we now know enough about the life cycle to design suitable protocols. Optimal detection time is late summer (August to September).
3. We can also monitor the genetic health of populations by extracting DNA from empty puparia. Acquiring DNA in this way will also facilitate monitoring of captive-bred populations, where non-invasive sampling methods are required to prevent the inadvertent mortality of rare captive specimens.
4. Intraspecific larval growth experiments demonstrated that competition for resources can occur in artificial rot holes, therefore future translocations should ensure that the smallest possible number of pine hoverfly larvae is introduced into each rot hole. While interspecific competition in a rot-hole is not likely to affect the recovery of the pine hoverfly, further experimentation may identify whether there are competition effects between species for resources that may inhibit growth and larval survival.
5. The success of re-establishment depends on on-going management at translocation sites and at Curr Wood, where expansion and supplementation of the breeding habitat is imperative. This requires long-term cooperation of landowners and managers to implement informed, conservation-based practices. Management for the pine hoverfly is inexpensive, and can probably fall in line with normal harvesting rotations. Investigations should continue at Inshriach Forest.
6. Forestry in the UK now includes retaining deadwood, including stumps, as part of management guidance and good practice, however widespread understanding and appreciation of the biodiversity importance of deadwood is needed (Forest Enterprise, 2002).
7. Fundamental knowledge of the ecology and natural history of the pine hoverfly, and clarification of some of the practical approaches that will be required in its conservation, have only been achieved through the full-time employment of a project manager under SAF. This study is an example of what can be achieved in four years of focused research, in cooperation with foresters, landowners and managers, to re-establish an endangered insect.

New and ongoing work since SAF ended

Population levels of the hoverfly continue to give concern, and increased effort is being put into habitat creation to supplement the older artificial holes at the key sites. The captive breeding population at Stirling University was unfortunately lost and now efforts are underway to establish a new population. The Royal Zoological Society of Scotland (RZSS) now has a bespoke rearing facility in place at Edinburgh Zoo. Twenty-three pine hoverfly larvae have been obtained from Finland and these are being used by Zoo staff to gain experience in breeding this species with the potential for these being used to supplement the Scottish populations. This can only happen if the strict criteria set out by the National Species Reintroduction Forum are met. Hopefully Scottish material will be available for this project in 2016.

Other continuing and new areas of work include:

- Management action, mainly focused on the Curr Wood and Abernethy sites, with new artificial rot holes being created – 43 to date at Curr Wood and a continuing programme of c. 10 per year at Abernethy.
- Replenishment of existing holes at Curr Wood with new wood chips, and general maintenance.
- Annual monitoring at existing sites.
- Artificial holes have been cut at a new site, Loch Vaa, by Seafield Estate. These will continue to be monitored and 'seeded' with larvae when these become available.

Further Information

www.mallochsociety.org.uk/blera-2006-status – the Malloch Society website includes descriptions of management actions and images at different stages of the project.

http://www.bbc.co.uk/blogs/natureuk/2011/11/liz-bonnin-the-science-behind.shtml. – correspondence with Kathryn Jeffs from BBC Autumnwatch Live resulted in a short piece of footage recording the third translocation of larvae into Inshriach Forest in 2011. While this did not make the final editorial on the programme, it was made available on presenter Liz Bonnin's blog website.

http://www.snh.gov.uk/protecting-scotlands-nature/reintroducing-native-species/scct/ – information on the new Scottish Code for Conservation Translocations, published in 2014.

Two additional publications written about the project include:

Rotheray GE, Rotheray EL. 2012. Translocating the Pine Hoverfly, *Blera fallax*. *Antenna* 36: 36-41.

Rotheray EL. 2010. Restoring the endangered pine hoverfly in the UK. In: *Global Re-introduction Perspective: 2010*. PS Soorae (ed). IUCN/SSC Re-introduction Specialist Group & Environmental Agency: Abu Dhabi; 21-24.

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Rotheray EL, Greminger MP, Nater A, Krützen M, Goulson D, Bussière LF. 2011. Polymorphic microsatellite loci for the endangered pine hoverfly *Blera fallax* (Diptera: Syrphidae). *Conservation Genetic Resources* 4: 117–120.

Rotheray EL, Lepais O, Greminger MP, Nater A, Krützen M, Goulson D, Bussière LF. 2012. Genetic variation and population decline of an endangered hoverfly *Blera fallax* (Diptera: Syrphidae). *Conservation Genetics* 13: 1283-1291.

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Rotheray EL. 2013. Differences in ecomorphology and microhabitat use of four saproxylic larvae (Diptera, Syrphidae) in Scots pine stump rot holes. *Ecological Entomology* 38: 219-229.

Rotheray GE, MacGowan I. 2000. Status and breeding sites of three presumed endangered Scottish saproxylic syrphids (Diptera, Syrphidae). *Journal of Insect Conservation* 4: 215–223.

Summers RW, Proctor R, Raistrick P, Taylor S. 1997. The structure of Abernethy Forest, Strathspey, Scotland. *Botanical Journal of Scotland* 49: 39–55.

The SAF Partners

- The Malloch Society
- The Royal Society for the Protection of Birds
- Forestry Commission Scotland

The Species Action Framework Handbook

This account comes from the Species Action Framework Handbook published by Scottish Natural Heritage. For more information on the handbook please go to www.snh.gov.uk/speciesactionframework.

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