Distribution and population dynamics of the Kerry Slug, *Geomalacus maculosus* (Arionidae)

Irish Wildlife Manual No. 54

An Roinn
Ealaíon, Oidhreachta agus Gaeltachta
Department of
Arts, Heritage and the Gaeltacht

Distribution and population dynamics of the Kerry Slug, *Geomalacus maculosus* (Arionidae)

Rory Mc Donnell & Mike Gormally

Applied Ecology Unit, Centre for Environmental Science, School of Natural Sciences, NUI Galway, Ireland.

Citation:

Mc Donnell, R.J. and Gormally, M.J. (2011). Distribution and population dynamics of the Kerry Slug, *Geomalacus maculosus* (Arionidae). *Irish Wildlife Manuals*, No. 54. National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

Cover photo: *Geomalacus maculosus* © Rory Mc Donnell

The NPWS Project Officer for this report was: Dr Brian Nelson; brian.nelson@environ.ie

Irish Wildlife Manuals Series Editor: F. Marnell & N. Kingston

ISSN 1393 – 6670

CONTENTS

EXECUTIVE SUMMARY

The Kerry Slug, *Geomalacus maculosus* is listed on Annex II and IV of the EU Habitats Directive 92/43/EC. In Ireland, seven Special Areas of Conservation (SACs) have been designated for its conservation. The slug is also protected under the Wildlife Act 1976 (as amended) having been added under Statutory Instrument No. 112 of 1990.

During surveys in Cos Cork and Kerry from March 2009 to March 2011, *G. maculosus* was collected in 44 ten kilometre grid squares (hectads) and from a range of habitats including deciduous forest, blanket bog, heath, wet grassland, conifer plantations and clearfell areas (Chapter 2). These data include three hectads (V55, V64 and V72) where the last records are pre-1965 and six hectads (V48, V82, V93, V94, V97 and Q91) where there are no previous records for the species. The presence of the species in conifer plantations has only recently been recognised and is one that has implications for its conservation. The slug was only ever found on trees and rock outcrops.

To identify a suitable trap for *G. maculosus* (Chapter 3), the efficacy of a range of refuge traps (wood trap, Styrofoam trap and various baited and unbaited 0.25m^2 metric traps) were tested on tree trunks and the woodland floor in native oak woodland at Glengarriff Nature Reserve (Co. Cork) and on rock outcrops and blanket bog at Cashelkeelty (Co. Kerry). Moistened metric traps placed on sandstone outcrops and wrapped in a continuous band around tree trunks proved to be the most successful for capturing the species.

Band and outcrop traps were also used to accrue monthly baseline monitoring data for *G. maculosus* at Glengarriff Nature Reserve and Cashelkeelty from January to December 2010 (Chapter 4). Power analysis of these data showed that if 70 trees were checked once monthly for 120 months at Glengarriff and 73 outcrops checked once monthly for 118 months at Cashelkeelty, this would be sufficient to identify 30% (vulnerable), 50% (endangered) and 80% (critically endangered) declines at both sites with a 90% probability.

In a mobility and spatial distribution study in Uragh Wood (Co. Kerry), *G. maculosus* was sub-dominant (Chapter 5), appeared to move infrequently between trees (mean mobility ($\pm$SD): 10.90m $\pm$ 2.86m) and was randomly distributed in the study area from July 12-September 14 2010. At a blanket bog site at Leahill (Co. Cork), *G. maculosus* was the dominant slug species on outcrops and the mean ($\pm$SD) distance moved by the species was 1.0m $\pm$ 0.0m (November 15-December 8 2010).

Uncontrolled burning, at least in the short-term, appeared to have an adverse effect on *G. maculosus* (Chapter 6). In this study, the species was trapped on an unburnt site on every sampling occasion but on an adjacent burnt site the species was first trapped on outcrops approximately three months after burning. In terms of invasion by *Rhododendron ponticum,* the abundance of *G. maculosus* in an infested area of Glengarriff Nature Reserve was less than in an uninfested area of the same woodland. We also examined the impact of commercial afforestation (Glanteenassig Forest, Co. Kerry) and found that *G. maculosus* density was significantly greater on outcrops on a blanket bog compared to an adjacent high density conifer site, low density conifer site and clearfell area..

The first population density estimates for *G. maculosus* are presented in Chapter 7. In a deciduous woodland at Glengarriff Nature Reserve (September 5 – October 9 2010) the mean density ($\pm$SD) (0.08m^{-2} $\pm$ 0.04m^{-2}) was eight times larger than that in a *R. ponticum* infested area (0.01m^{-2} $\pm$ 0.005 m^{-}

^{2}) of the reserve. These results add further weight to the hypothesis that *R. ponticum* is a major threat to *G. maculosus* in Ireland. However, in an amenity conifer woodland (Derreen Forest, Co. Kerry) studied later in the year, the mean density (± SD) of *G. maculosus* was $0.15m^{-2}$ ± $0.04m^{-2}$ (November 7 – December 9 2010) which suggests that certain conifer forests can support populations of the species. On a lowland blanket bog adjacent to Derreen Forest, the mean density (±SD) was surprisingly low ($0.03m^{-2}$ ± $0.01m^{-2}$) but this may have been a consequence of the very cold weather experienced in Ireland during late November and December 2010.

ACKNOWLEDGEMENTS

Sincerest thanks to Dr Steve Langton, Dr Deirdre Lynn and Dr Chris Williams for statistical advice and to Dr David Bourke for assistance with producing distribution maps. Thanks to Paul Whelan for running the project website and to Rory Hodd for assistance with bryophyte identification. We are grateful to Dr Brian Nelson, Dr Roy Anderson and Dr Ferdia Marnell for useful discussions on the ecology of *Geomalacus maculosus*. Thanks to Clare Heardman, Paddy Graham, Michael Sullivan, Declan O'Donnell, Izabela Witkowska, Sarah O'Loughlin, Ciaran Nugent, David Barrett, Connor Dolan, John Hynes and Frank McMahon for assistance with site selection and fieldwork. We thank Denise Hall, Frank Sullivan, Patrick Sullivan and Patrick Somers for permission to sample on their land and to Izabela Witkowska for information on the management history of Glanteenassig Forest. We are grateful to everybody who submitted date-locality records to the project website, e-mail address and by post.

1. INTRODUCTION

Background information on *Geomalacus maculosus*

The Kerry Slug, *Geomalacus maculosus*, was first discovered in Co. Kerry, Ireland in 1842 and described as a new species in 1843 (Allman 1843, 1844, 1846). In 1868 the species was also discovered in northern Spain and five years later it was collected in northern Portugal. Although it has been reported from Brittany in France (Demars 1873), there is no voucher material in museum collections nor any subsequent records and consequently the French record is now widely regarded as being erroneous (Platts & Speight 1988; Falkner *et al.* 2002). There are three other species known within the genus, *G. anguiformis*, *G. malagensis* and *G. oliveirae* (Castillejo *et al.* 1994). These are not known, nor is there any evidence to suggest, that they exist in Ireland (Platts & Speight 1988).

Although, in recent times, *G. maculosus* has been repeatedly collected in south-west Ireland and northern Spain, there is evidence of a decline in its core Iberian range (Platts & Speight 1988) and it is listed as 'vulnerable' in Spain by Verdu & Galante (2005). In Portugal, records of the species over the past 100 years have been rare (Platts & Speight 1988) and in Ireland there is a dearth of quantitative data on favourable management practices, the habitat size required to sustain populations and genetic variation across its home range (NPWS 2008). For these reasons and because of its narrow global distribution, *G. maculosus* was listed on Appendix II of the Bern Convention and subsequently on Annex II and Annex IV of the EU Habitats Directive 92/43/EC. Annex II lists fauna and flora species that require the designation of Special Areas of Conservation for habitats that contribute to conserving these species. In Ireland, seven Special Areas of Conservation (SACs) have been designated (Table 1) for *Geomalacus maculosus* (NPWS 2010). Annex IV lists fauna and flora species of community interest that require strict protection and under Irish legislation the slug is protected by the Wildlife Act 1976 under Statutory Instrument No. 112 of 1990. The main threats to *G. maculosus* in Ireland are considered to be afforestation and forestry management, invasion of woodland by *Rhododendron ponticum*, agricultural reclamation and infrastructure development (NPWS 2010).

Table 1: Special Areas of Conservation which list *Geomalacus maculosus* as a selection feature (NPWS 2010).

Site number	Site name	County
000090	Glengarriff Harbour and Woodland	Cork
000093	Caha Mountains	Cork/Kerry
000102	Sheep's Head	Cork
000365	Killarney National Park, Macgillycuddy's Reeks and Caragh River catchment	Cork/Kerry
000370	Lough Yganavan and Lough Nambrackdarrig	Kerry
001342	Cloonee and Inchiquin Loughs, Uragh Wood	Kerry
002173	Blackwater River (Kerry)	Kerry

A recent conservation assessment of the species in Ireland (NPWS 2008) concluded that it was in Favourable Conservation Status and that there was no evidence of any recent range reduction. However, this assessment was based on limited data on populations, distribution and habitat condition, particularly outside SACs (NPWS 2008). In addition, Byrne *et al*. (2009) concluded that Irish populations of *G. maculosus* were strong, globally important, could expand with global warming and the species was assessed as of least concern under IUCN red list criteria.

Historically, within Ireland *G. maculosus* was thought to be restricted to the Devonian Old Red Sandstone strata of West Cork and Kerry. However, during July 2010, the species was collected on granite outcrops and on the trunks of trees in a conifer plantation near Oughterard, Co. Galway (Kearney 2010). Research on these populations is now urgently needed to determine if they are distinct from those in other parts of Ireland. Nevertheless, throughout the rest of its Irish range (West Cork and Kerry), *G. maculosus* occurs in three general habitat types. These are deciduous woodland (usually *Quercus* dominated), blanket bog or unimproved oligotrophic open moor and lake shores (NPWS 2010; Platts & Speight 1988). Within these habitats, the species tends only be present if there is outcropping of Devonian Old Red Sandstone (NPWS 2010), humid conditions and lichen, liverwort and/or mosses for the species to shelter in and feed on (Platts & Speight 1988). Individuals that occur in woodlands tend to be brown with yellow spots (Plate 1) whereas in more open situations specimens are grey/black with white spots (Plate 2). Juveniles, on the other hand, usually have two dark lateral stripes which become less obvious with age. *Geomalacus maculosus* is also capable of rolling into a ball (Plate 3) when it is disturbed (Platts & Speight 1988) and this is a useful identification character for the species.

Plate 1: Specimen of *Geomalacus maculosus* collected in a woodland (© Rory Mc Donnell).

Plate 2: Specimen of *Geomalacus maculosus* collected on a lowland blanket bog (© Rory Mc Donnell).

Plate 3: *Geomalacus maculosus* in its characteristic ball shape (© Rory Mc Donnell).

Like many slugs, *G. maculosus* is a crepuscular animal and it takes refuge in crevices in rocks or under the bark of trees during the day. However, Platts & Speight (1988) and Taylor (1906) recorded diurnal activity during or after rain. In terms of life history, the species is hermaphroditic and can self-fertilise. Eggs are deposited between July and October in batches of 18-30 with hatching taking place after 6-8 weeks (Rogers 1900). Juveniles usually reach maturity after two years and specimens can live for greater than 6 years (Oldham 1942). Although Godan (1983) cites *G. maculosus* as a pest of *Beta vulgaris* (sugar beet) in Ireland, there is no evidence to support this claim.

Research Objectives

1. Resurvey suitable habitats in West Cork and Kerry with the overall aim of providing an up-to-date database for *G. maculosus*. Sites where the last records of the species are pre-1980 and pre-1950 will also be surveyed.

2. Assess a range of trapping techniques in order to recommend the most appropriate trap for surveying and population assessments.

3. Provide recommendations on the most appropriate monitoring methodology

4. Investigate the impacts of various threats.

5. Investigate the population dynamics over a range of sites of varying quality.

A separate chapter will be devoted to each of these objectives.

2. SURVEY FOR *GEOMALACUS MACULOSUS*

Rationale

A key issue affecting the conservation of *G. maculosus*, is the paucity of information on its distribution and full range in Ireland (NPWS 2010). Since 1970, the species has been recorded from forty-three hectads and older records in south-west Ireland. There are a further seven hectads shown in Kerney (1999) where the presence of the species needs to be confirmed. Apparent gaps in the range of the species also need to be investigated e.g. hectads V97, V94, V93 and V82 where there is suitable geology and habitats. Eastern limits of the current range should also be searched e.g. in hectads W37, W36 and W35 and a record in V36 from Kerney (1999) needs to be verified (NPWS 2010). In an effort to resolve these needs a survey of the species in south-west Ireland was undertaken from March 2009 to March 2011.

Materials and methods

A number of strategies were employed to encourage public participation in the survey.

(1) Firstly a project website (www.kerryslug.com) hosted by biology.ie was established in June 2009. The website includes background information on the ecology of *G. maculosus*, how to correctly identify the species, information on its current distribution and how to contact the project team. In addition, a dedicated e-mail address (kerryslug@gmail.com) was provided for enquiries and submission of records.

(2) An information leaflet on *G. maculosus* (Appendix 1) was distributed to appropriate stakeholders (including NPWS Rangers, journalists, members of the public who have submitted records to the project, Killarney National Park Education Centre, Bonane Heritage Park and Irish malacologists). The leaflet includes information on the ecology of *G. maculosus* outlined on the project website and can be downloaded at http://www.kerryslug.com. It is also available from the website of the Conchological Society of Great Britain and Ireland (http://www.conchsoc.org/resources/pdf-news-story.php?id=49).

(3) Finally, popular press articles which provided information on the survey were published in the Irish Examiner on July 20 2009, The Corkman on July 30 2009, the Irish Examiner on August 5 2010, the Irish Daily Mail on August 6 2010 and British Wildlife in February 2011.

As requested on the project website, all submitted records of *G. maculosus* included a photograph of the specimen and this enabled the project team to confirm the identification of the species. However, if the record was from a hectad where the species had not been previously collected (e.g. Q91), we visited the new locality in an attempt to confirm its presence.

Fieldwork by project personnel for the national survey was only carried out during damp weather so as to maximize the likelihood of finding specimens. At each site, outcrops or tree trunks were scanned or searched for approximately 45 minutes. As soon as a specimen was located in a hectad, its presence there was confirmed and the square was not revisited. If the species was not found, then a minimum of two sites were checked for each hectad.

Results and discussion

During the survey, *G. maculosus* was recorded from a total of 44 hectads (Figure 1) and from a range of habitats including deciduous forest, blanket bog and heath (Appendix 2). Specimens were also observed in rather atypical habitats such as conifer plantations, clearfell sites and wet grassland (Plate 4) but all of these sites contained sandstone outcrops. These data comprise a range of 4400km^2 in Co. Cork and Co. Kerry and include three hectads (V55, V64 and V72) where, according to NPWS data, the last records are pre-1965.

During the survey, *G. maculosus* was also collected in six hectads where there are no previous records of the species (Figure 1). These include reported gaps in the range (V82, V93, V94 and V97) highlighted in the recent Kerry Slug Threat Response Plan (NPWS 2010) and hectad V48 (Figure 1). Of particular interest is the record of the species in hectad Q91 (most northerly red square in Figure 1) as this area is outside of the previously known range of the species. This record was submitted to the project e-mail address by Dr. Eugene Ross (Tralee Institute of Technology) and the identification was confirmed by photograph. A visit to the site by Rory Mc Donnell on March 8 2011 confirmed the presence of the species in this hectad (Appendix 2). Interestingly, this record is from a conifer plantation which is the habitat where *G. maculosus* has recently been found in Co. Galway (Kearney 2010). The occurrence of *G. maculosus* in conifer woods in Kerry and Connemara is contrary to expectation as conifer woodland, especially closed canopy modern plantations, has not been considered a suitable habitat. Afforestation with conifers has been identified as a threat to the species (NPWS 2010). It is possible that, instead, commercial afforestation is acting as a vector for distributing the species to new areas in Ireland. We have also collected the species from the trunks of conifers in a quantitative study (see Chapter 6 below) and from conifer plantations in hectads V46, V47, V69, V77 and V94 (Appendix 2) which would seem to add further weight to this theory.

During wet conditions, juvenile slugs were regularly encountered during the day foraging on the north side of trunks, but on outcrops on blanket bogs and heaths, adults were more regularly observed and juveniles were seldom encountered. Platts & Speight (1988) stated that *G. maculosus* is rarely observed more than a few metres from standing or flowing water but we collected the species from areas where there were no obvious waterbodies, particularly in woodlands. Occasionally, we found the woodland form (brown and yellow) in more open situations (e.g. blanket bog) and the open form (black and white) in wooded areas.

The only Irish species that the general public confused with *G. maculosus* was *Limacus flavus* (Plate 5). The latter tends to be mottled yellow and brown or yellow and green and has petrol blue tentacles. Although the Kerry Slug can be brown with yellow spots, it does not have the distinct tentacle coloration of *L. flavus*. In addition, the latter is unable to curl itself into a defensive ball.

A range of sites in other hectads (Appendix 3) were also visited during wet, overcast conditions but no specimens of *G. maculosus* were located. These include W35, W36 and W37 which are adjacent to the current eastern range limit of the species in Ireland and V36 where the species has been reportedly collected (Kerney 1999) but has not been verified (NPWS 2010). However, there was suitable geology and habitats within these hectads and. consequently, they should be a priority for future survey efforts. Also, given that the species can survive in commercial conifer

plantations, we also suggest that future national surveys for *G. maculosus* target this habitat throughout the country.

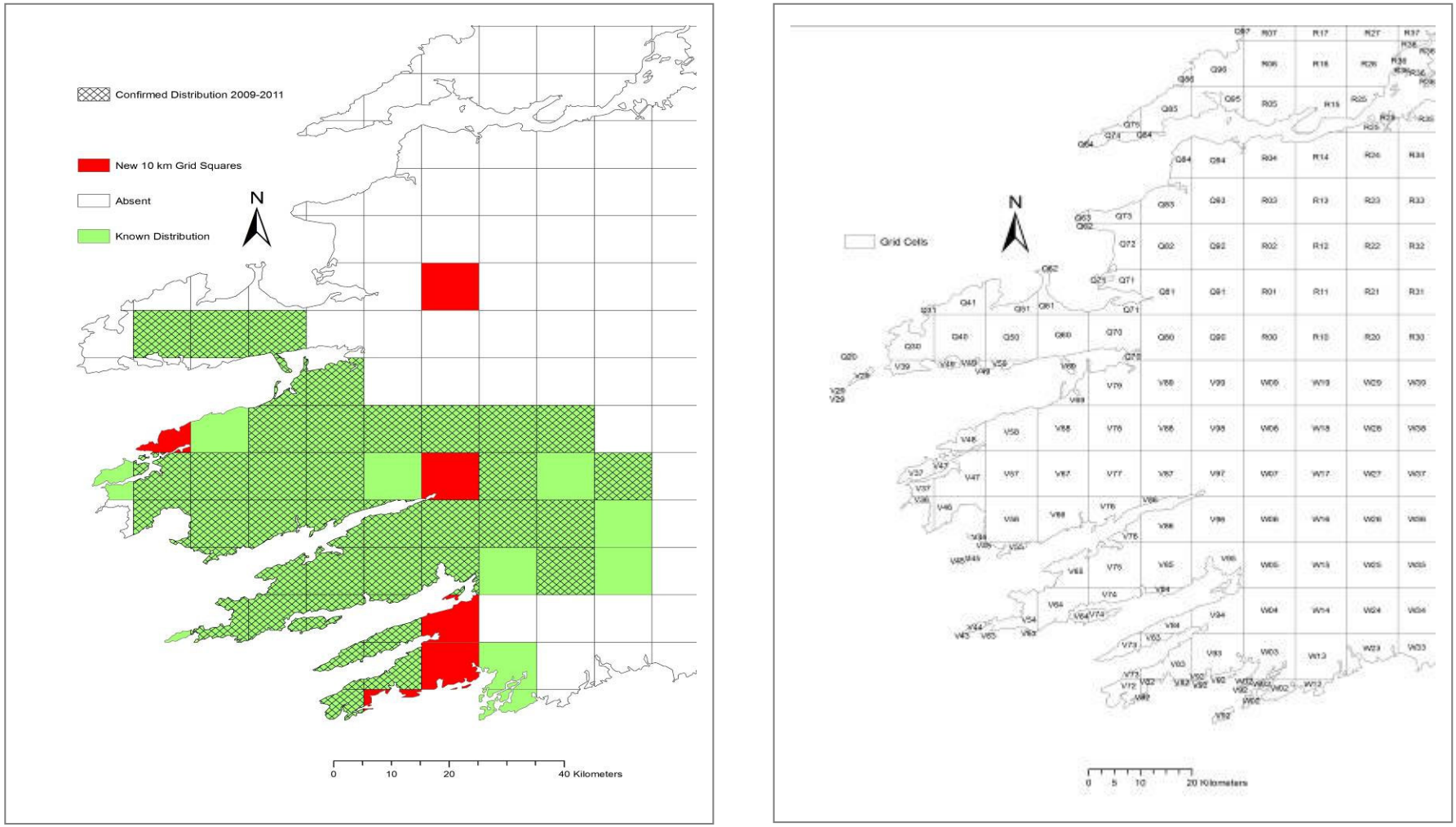

Figure 1. Maps showing the known range of *Geomalacus maculosus,* new hectads, current range confirmed during this project and numbered hectads. See Appendix 3 for a list of hectads where the species was not collected during the survey (March 2009 – March 2011).

Plate 4. A wet grassland site at Derrymacklavlode, Co. Kerry (W120831) where five specimens of *Geomalacus maculosus* were collected during the survey (© Rory Mc Donnell).

Plate 5. *Limacus flavus.* The general public occasionally confused this species with the woodland form of *Geomalacus maculosus* (© Rory Mc Donnell).

Finally, for future national surveys, the presence of *G. maculosus* at a site could be determined by using a combination of hand-searching and the band and outcrop metric traps highlighted in Chapter 3 below. If initial hand-searching during wet weather does not yield specimens, then damp band and outcrop metric traps could be placed randomly on trees and outcrops and checked weekly. Trapping should take place during wet weather on blanket bogs and heaths, and during spells of dry weather in woodlands (see Chapter 3 for details). Based on our experience, if no specimens are observed behind the traps after 4-6 weeks, it is likely that the species is not present at the site. Also, given that *G. maculosus* lives from three (Wisniewski 2000) to seven years (Oldham 1942), it would be prudent to conduct national surveys at least every three years.

3. IDENTIFICATION OF A LIVE TRAPPING METHOD FOR *GEOMALACUS MACULOSUS*

Rationale

The lack of an effective and repeatable trapping method has greatly hampered research on *G. maculosus* and the development of strategies for its conservation (NPWS 2010). This is surprising given that a wide range of traps are available for slugs (South 1992). Refuge traps are amongst the most common and they have been used in a wide range of habitats (*e.g.* Archard *et al.* 2004; Clements & Murray 1991; Young 1990). Therefore, to address this need, the efficacy of a range of refuge traps was tested with the aim of identifying a suitable trap for *G. maculosus*.

Study sites

Two sites were selected for the trapping assessment study. The first, Glengarriff Nature Reserve (V920568) located in West Cork (Figure 2) was established in 1991 covers some 300ha and forms one of the best examples of oceanic sessile oak woodland in Ireland (NPWS 2003a). According to Fossitt (2000) it is an oak-birch-holly woodland (WN1). The Reserve is part of the Glengarriff Harbour and Woodlands Special Area of Conservation (site number: 000090) and the dominant vegetation is *Quercus petraea*, *Betula pubescens*, *Ilex aquifolium*, *Calluna vulgaris*, *Vaccinium myrtillus*, *Blechnum spicant* and *Melampyrum pratense*.

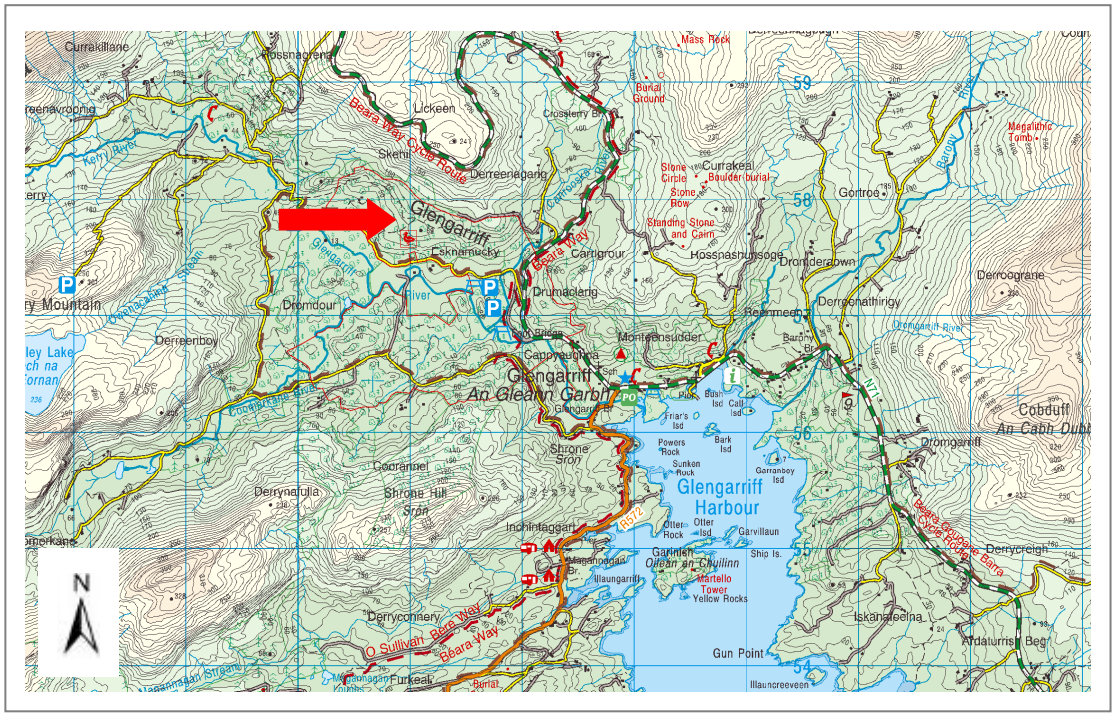

Figure 2: Ordnance Survey Map (1:50,000) with arrow showing the location of Glengarriff Nature Reserve, Co. Cork (© OSI).

The second site (V755576) is a lowland blanket bog (PB3) according to Fossitt (2000) and is located at Cashelkeelty, Co. Kerry (Figure 3). The dominant vegetation was *Molinia caerulea*, *Schoenus nigricans*, *Myrica gale*, *Calluna vulgaris*, *Erica tetralix* and *Erica cinerea*.

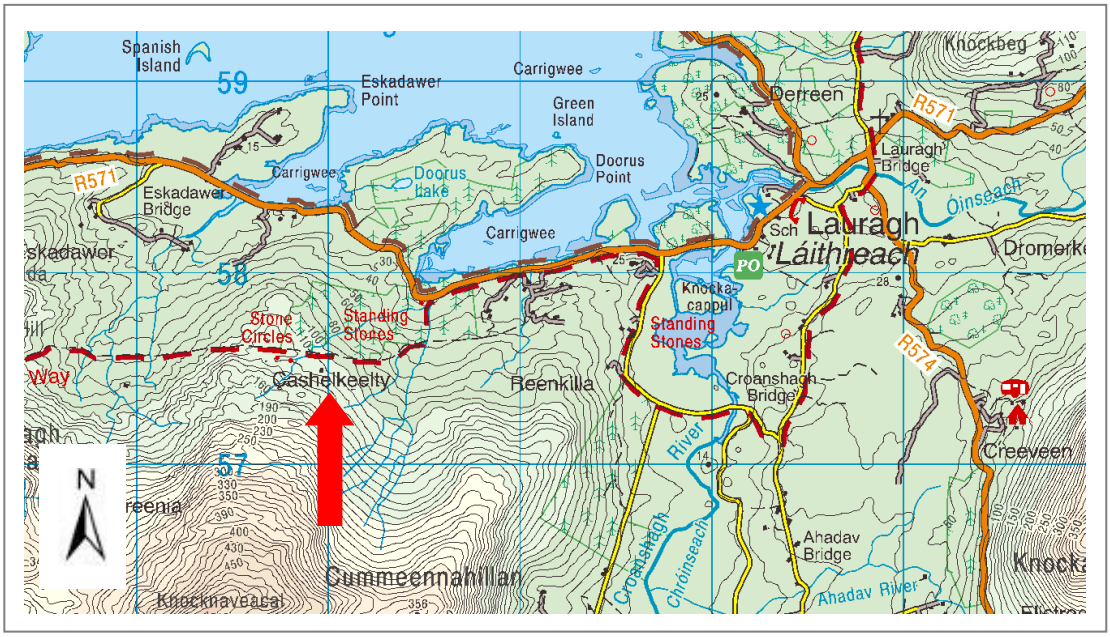

Figure 3: Ordnance Survey Map (1:50,000) with arrow showing location of lowland blanket bog at Cashelkeelty, Co. Kerry (© OSI).

These sites were selected because the woodland in Glengarriff had extensive mature, bryophyte-covered trees while the bog at Cashelkeelty had numerous exposed, sandstone outcrops and preliminary hand-searching at both sites yielded *G. maculosus.*

Methods and materials

Glengarriff Nature Reserve

At Glengarriff, eight mature *Q. petraea* with bryophyte-covered trunks and a circumference of >1.5m (measured 1.5m from the ground surface) were selected, and the following refuge traps assessed:

1. *Wood trap*: This consisted of a 50cm x 50cm square of plywood (Plate 6) with a six inch nail at each corner. The nails were calibrated so that when they were inserted into the ground there was a distance of approximately 5mm between the wood and the ground surface.

2. *Styrofoam trap*: Since Archard *et al.* (2004) successfully used traps consisting of a 24 cm square and 3 cm thick foam pad placed 5 mm above the soil surface, a similar trap was tested during our investigation. It consisted of a 50cm x 50cm square of Styrofoam boarding (Plate 7) with calibrated six inch nails in each corner. The distance between the trap and the ground surface was approximately 5 mm.

Plate 6: Wood trap used during trapping assessment (© Rory Mc Donnell).

Plate 7: Styrofoam trap used during trapping assessment (© Rory Mc Donnell).

3. *Metric trap:* These traps are manufactured by De Sangosse (Pont du Casse, France). Each trap is 50cm x 50cm and is comprised of absorbent material covered with a reflective upper surface (Plate 8) and a dark perforated plastic on the lower surface. During this project, metric traps were used in the design of three trap types:

a) *Carrot-baited metric trap:* Mc Donnell *et al.* (2009) successfully used simple baited traps to collect large numbers of the native *Deroceras laeve* in Kentucky, U.S.A. Since *G. maculosus* is also known to feed on carrots in captivity (Platts & Speight 1988), a standard metric trap baited with a 2.5cm piece of organic carrot was assessed during this study.

b) *Ethylene glycol-baited metric trap*: Brady & Pearce (2007) successfully collected various *Pallifera* species in Ohio using pitfall traps baited with venison and ethylene glycol as a preservative. The authors postulated that the slugs were attracted by the ethylene glycol as opposed to the venison since the species is a strict herbivore. Because all slugs within the genus *Pallifera* are known to feed on mosses and lichens in forests in the eastern U.S. (Burch 1962), a similar but modified trapping technique may also be suitable for *G. maculosus* in Ireland. Since the ethylene glycol in the traps of Brady & Pearce (2007) resulted in the death of specimens, the liquid (70% ethylene glycol and 30% deionised water) during the current study was placed in a Petri-dish with a netted top to prevent the specimens from drowning. This dish was then placed underneath a standard metric trap.

c) *Band metric trap*: This consisted of four individual metric traps arranged in a continuous band around the trunk of each tree (Plate 9). Prior to securing this band metric trap with 2.5cm nails, it was saturated with water and a 2.5cm piece of organic carrot was nailed to the trunk underneath each individual metric trap.

Plate 8: Metric trap (De Sangosse) used during trapping assessment (© Rory Mc Donnell).

Plate 9: Band metric trap used during trapping assessment (© Rory Mc Donnell).

The wood trap, Styrofoam trap, carrot-baited metric trap and ethylene glycol-baited metric trap were placed at the base of each trunk on either the north, south, east or west side so that for the eight trees each of these traps was represented at each aspect twice. A single band metric trap was then placed on each tree trunk, 1.5m from the ground surface (Figure 4).

Cashelkeelty Lowland Blanket Bog

At the lowland blanket bog site at Cashelkeelty, eight sandstone outcrops (>10m^2) were investigated using the wood trap, Styrofoam trap, carrot-baited metric trap and ethylene glycol-baited metric trap described above. These traps were each placed at the north, south, east or west edge of each outcrop (Figure 5) so that for the eight outcrops each trap was represented at each aspect twice. In addition, at this site four individual metric traps were placed on the north, south, east and west side of each sandstone outcrop (Plate 10). These traps will be referred to as *outcrop metric traps* herein. Styrofoam and wood traps were not used for this purpose because it proved difficult to secure them on slopes. The outcrop metric traps were saturated with water prior to use, they were kept in place using masonry nails and baited with a 2.5cm piece of organic carrot.

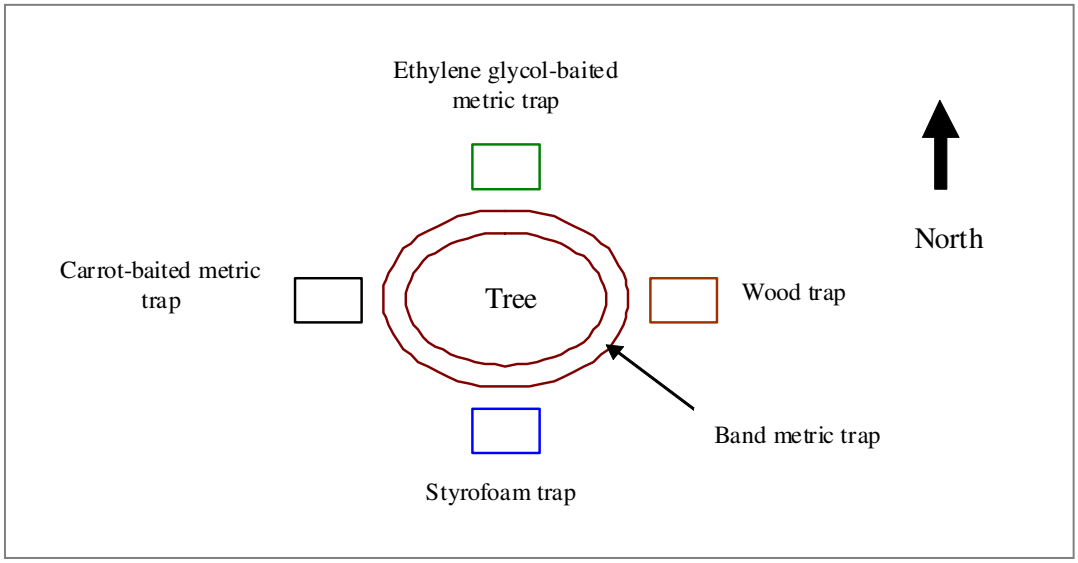

Figure 4: Arrangement of traps at a typical tree in Glengarriff Nature Reserve, Co. Cork

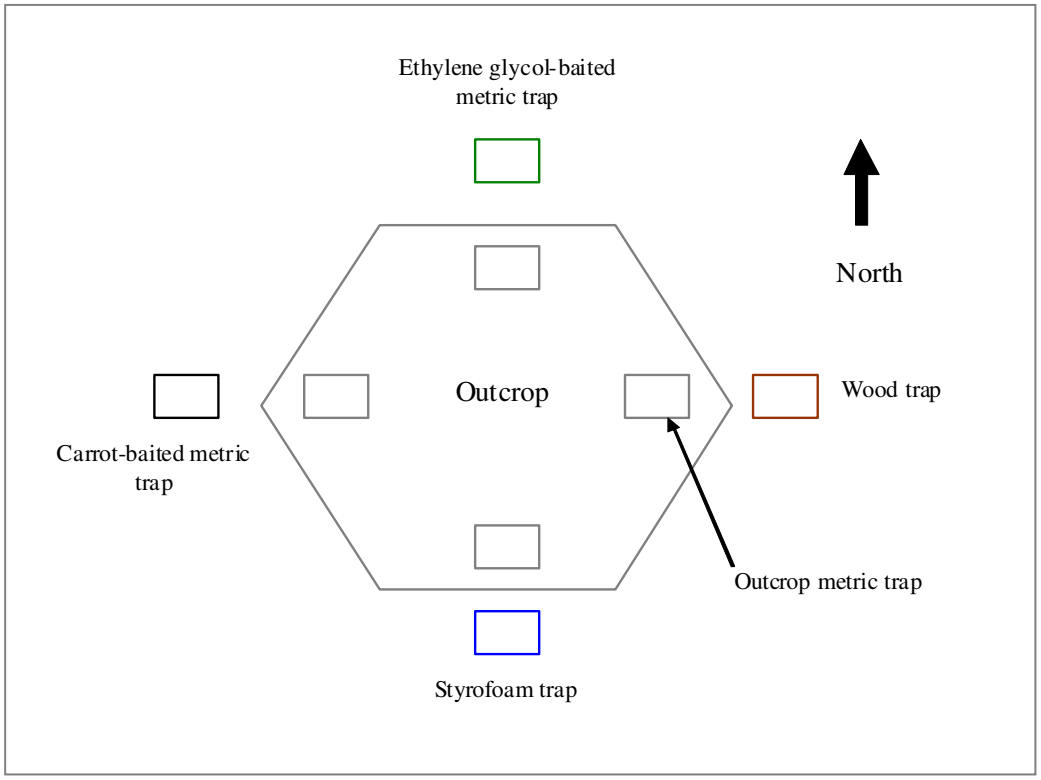

Figure 5: Arrangement of traps at a typical sandstone outcrop on the blanket bog site at Cashelkeelty, Co. Kerry

Plate 10: Outcrop metric traps used during trapping assessment. In this picture the trap on the north side of the rock is out of view. Arrow shows its location (© Rory Mc Donnell).

The various traps were set on August 19 and 20 2009 at Cashelkeelty and Glengarriff Nature Reserve respectively. The number of specimens under each trap were counted on a weekly basis and left in place. After examination, the underlying bryophytes/lichens and the underside of the traps were moistened with a mist gun for 15 seconds and the organic carrot baits were replaced. Sampling was carried out for nine weeks in the deciduous woodland and for six weeks on the blanket bog. In the woodland the total number of specimens collected under the traps increased weekly for the first six weeks and therefore sampling was continued for an additional three weeks so that a maximum catch could be identified. On the blanket bog site the number of individuals collected on a weekly basis was more stable and the largest catch was collected during week 2. Finally, to determine the impact of weather on trap efficacy, temperature (recorded at 0900hrs) and pluviometric data were obtained from Killarney National Park, Co. Kerry for the duration of the sampling period. This is the closest weather station to both study sites and is located approximately 35km and 38km from Glengarriff Nature Reserve and Cashelkeelty respectively.

Results and discussion

During the entire sampling period a total of only five *G. maculosus* specimens were collected under the wood, Styrofoam, ethylene glycol-baited and carrot-baited metric traps at both sites. In the woodland, one individual was found on the upper surface of a wood trap and another on the upper surface of a Styrofoam trap on the September 3 2009. Both specimens were actively crawling on the traps and appeared not to be using them for shelter. It is surprising that such low numbers of *G. maculosus* were collected on the woodland floor as this is thought to be a microhabitat for the species in Ireland (Platts & Speight 1988). On the blanket bog, single specimens were collected under a carrot-baited metric trap on the August 26, September 2 and September 23. The vast

majority of specimens were collected under the band metric traps (Plate 11) and the outcrop metric traps (Plate 12) at the woodland and blanket bog sites respectively.

Plate 11: Five specimens of *Geomalacus maculosus* taking refuge under a band metric trap in Glengarriff Nature Reserve, Co. Cork (© Rory Mc Donnell).

In fact, in the woodland, 24 specimens were collected under one band metric trap (Appendix 4) on a single tree and the maximum number of slugs collected during a single week was 59 (Figure 6). On the blanket bog, the maximum number of *G. maculosus* collected on a single outcrop and during a single sampling week was six (Appendix 5) and twenty-one individuals respectively (Figure 7).

There was noticeable variation in the number of specimens collected under the traps between the different sampling weeks in the woodland e.g. during week six, 59 specimens were collected compared to only 2 individuals during week nine. Numbers trapped at the blanket bog site ranged from 9 (week 4) to 21 (week 2). Since slugs do not have an external shell to retreat into during dry, sunny weather, the amount of rainfall during sampling (Appendix 6 and 7) is likely to play an important role in trap efficiency. In fact a significant negative Pearson correlation ($r= -0.683$, $p<0.05$) was observed between total *G. maculosus* abundance under the band traps at Glengarriff Nature Reserve (data were log transformed) and the mean rainfall per day during the week prior to sampling (as measured at Killarney National Park, Co. Kerry) which suggests that less slugs use the traps for refuge during wet weather. Such a relationship makes sense from a foraging point of view. During periods of rainfall, specimens will likely be foraging for food on tree trunks and as a

result they will not be collected under the traps. This hypothesis is supported by the fact that both Platts & Speight (1988) and

Plate 12: A specimen of *Geomalacus maculosus* taking refuge under an outcrop metric trap on the blanket bog site at Cashelkeelty, Co. Kerry (© Rory Mc Donnell).

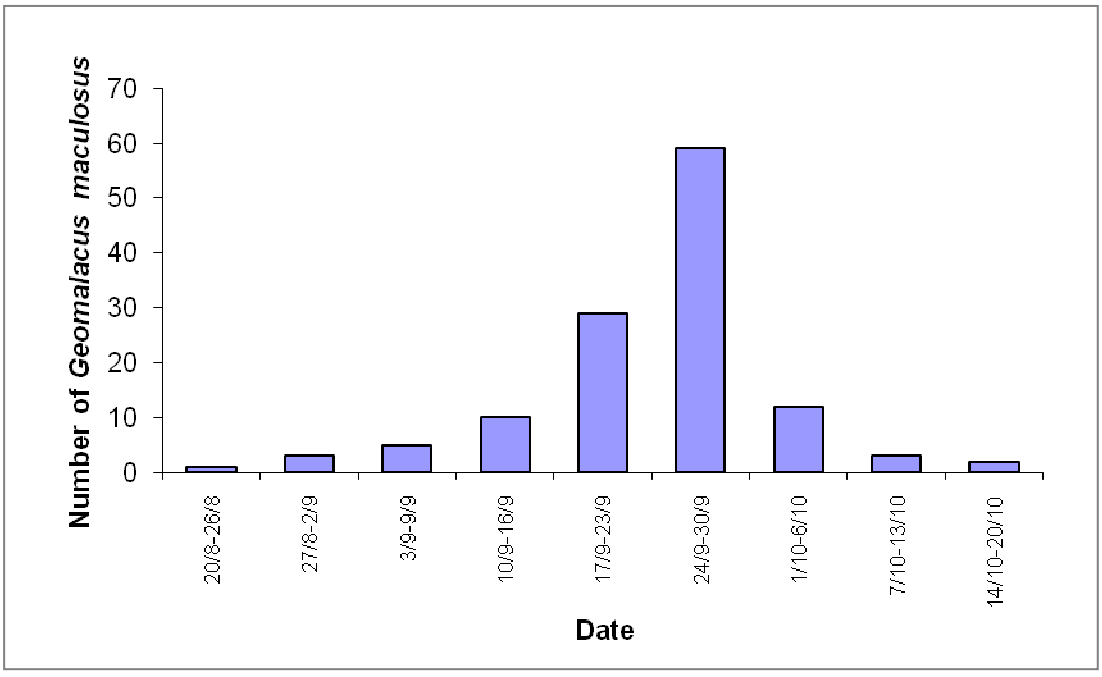

Figure 6: Total number of *Geomalacus maculosus* collected per week under the band metric traps at Glengarriff Nature Reserve, Co. Cork.

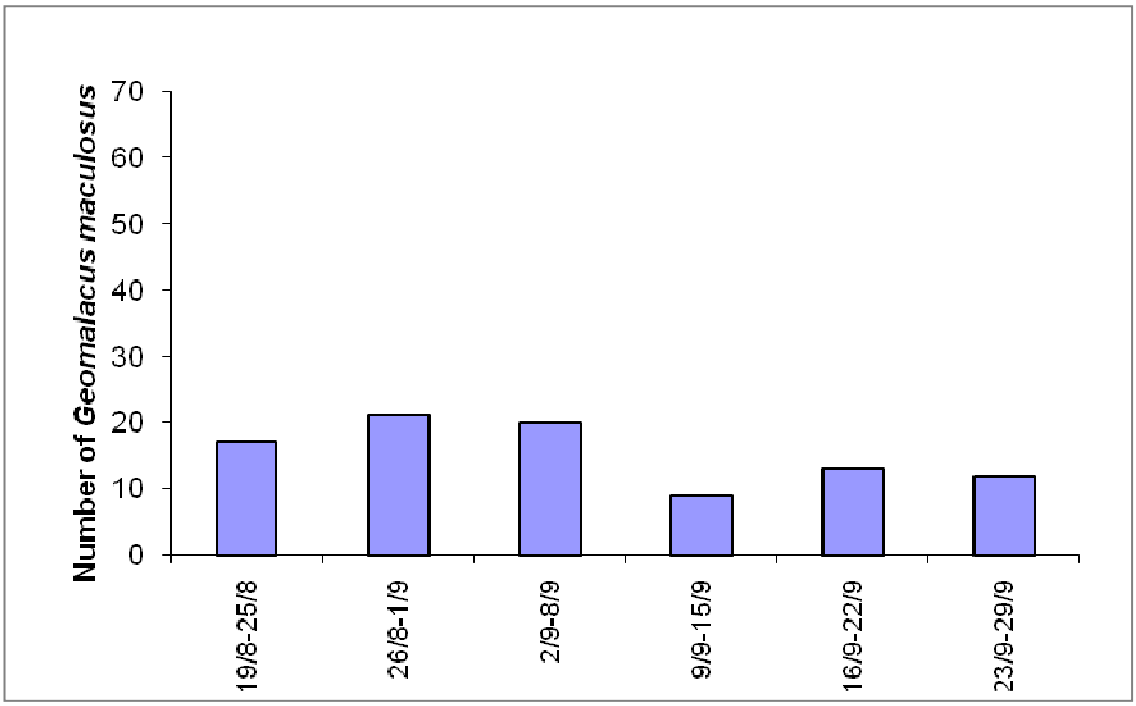

Figure 7: Total number of *Geomalacus maculosus* collected per week under the outcrop metric traps on the blanket bog site at Cashelkeelty, Co. Kerry.

Taylor (1906) have reported that the species can forage during daylight hours during or after rain. However, during dry conditions, the species is less likely to forage and more likely to seek refuge under the damp traps thereby increasing the catch size. In the woodland, the shade afforded by the canopy would also help prevent the traps from drying out during prolonged periods of dry weather. No significant correlations (Spearman) were detected between total *G. maculosus* abundance under the band traps at Glengarriff and the air temperature (Appendix 8) recorded on the day prior to ($r= +0.126$, $p>0.05$) and on the day of ($r= -0.250$, $p>0.05$) sampling (as measured at Killarney National Park, Co. Kerry).

On the blanket bog, on the other hand, a significant positive Pearson correlation ($r= +0.820$ $P<0.05$) was observed between total *G. maculosus* abundance and the mean rainfall per day during the week prior to sampling and this indicates that more slugs use the traps during wet weather. During dry sunny conditions, the outcrop traps likely dry out relatively quickly because they are directly exposed to the sun and wind thereby reducing the number of trapped specimens. Although *G. maculosus* likely forages on outcrop surfaces (Platts & Speight 1988) during damp weather, these conditions would also ensure wet outcrop traps and consequently suitable refuges for the species. Finally, no significant correlations (Pearson) were detected between total *G. maculosus* abundance under the outcrop traps and the air temperature (Appendix 9) recorded on the day prior to ($r= +0.741$, $p>0.05$) and on the day of ($r= 0.286$, $p>0.05$) sampling (as measured at Killarney National Park, Co. Kerry).

Currently no standard trapping procedure is available for *G. maculosus* and this has hampered surveying, monitoring and research on population dynamics throughout its range in Ireland, Spain and Portugal. The results of our research, however, appear to have resolved this problem as the band and outcrop metric traps acted as suitable refugia for the species in the woodland and blanket bog sites. The identification of such a repeatable trapping method will enable quantitative sampling of *G. maculosus* which in turn will enable national conservation agencies to make more informed decisions on conservation strategies for the species. The results also suggest that in woodlands, damp band metric traps should be utilised during dry weather when the slug is more likely to use them for refuge. However, on sandstone outcrops in blanket bogs, the traps are likely to be most effective during wet weather as this maintains them in a suitably damp condition for the species. In fact regression equations generated using total *G. maculosus* abundance (log transformed in the case of the data from Glengarriff) and the mean rainfall per day during the week prior to sampling at both the woodland (Appendix 6; $y = 1.264 – 0.0996.x$) and blanket bog sites (Appendix 7: $y = 11.768 + 0.7075.x$) could potentially be used during monitoring studies as a correction factor for rainfall.

The results of this chapter have been published by Mc Donnell & Gormally (2011).

4. DEVELOPMENT OF A MONITORING STRATEGY FOR *GEOMALACUS MACULOSUS*

Rationale

Species monitoring can be defined as a process in which the distribution and status of a particular species is evaluated systematically over time (NPWS 2010). Under this definition no monitoring of *G. maculosus* has been undertaken to date in Ireland and consequently in its judgment C-183/05, the European Court of Justice found against Ireland that the monitoring in place for the Kerry slug was inadequate. Although there have been studies completed on the species e.g. Barron (1998), these do not constitute repeatable undertakings and consequently cannot be interpreted as monitoring (NPWS 2010). The primary aim of this part of the research was to use the trapping methodology highlighted above to establish permanent trapping stations where baseline data would be accrued for the species in a woodland and blanket bog site over 12 months. These data could then be used as the basis for power analysis to design a monitoring program for *G. maculosus* so that a 30%, 50% and 80% decline in the species at both sites over 10 years could be detected with 90% probability. These population declines correspond to the International Union for Conservation of Nature (IUCN) categories of Vulnerable, Endangered and Critically Endangered (http://www.iucn.org/).

Study sites

The sites used for the trapping assessment study above (i.e. Glengarriff Nature Reserve and Cashelkeelty) were also used for this part of the research.

Materials and methods

Experimental design

At Glengarriff Nature Reserve, a single band traps (Plate 9) was placed 1.5m from the ground surface on eight mature *Q. petraea*. GPS co-ordinates for these trees are given in Appendix 10. At Cashelkeelty, eight sandstone outcrops were selected (Appendix 10) and four outcrop traps (Plate 10) were placed on each. The positions of the traps were determined by finding the midpoint of the outcrop and then placing an individual trap 1m from this point to the north, south, east and west. To ensure consistency, the permanent traps were checked during the second week of every month from January 2010 to December 2010 and between the hours of 8am to 11am. During each visit, the numbers of *G. maculosus* were counted without removing specimens from the sites. In addition, the organic carrot bait was replaced and the underside of each trap and the underlying trunk or sandstone outcrop was moistened for 15 seconds using a mist gun filled with deionised water.

Bryophyte species richness on the monitoring trees in Glengarriff Nature Reserve was determined by removing samples of the various species of mosses and liverworts from the area of trunk below the band traps on September 10 2009. These were identified in the laboratory using Watson (1981). In addition, tree circumference was measured 1.5m from the ground surface using a standard measuring tape and outcrop area was approximated by dividing the outcrops into squares, rectangles and triangles and then adding the individual areas to get the total surface area.

Power analysis

Although statistical power is central to every monitoring effort, it is rarely assessed. It can be defined as the probability that a monitoring strategy will detect a trend (e.g. a halving of the population) in sample measurements when the trend is occurring, despite the "noise" in the data (Gibbs & Ene 2010). In general, the basic level of power that should be utilised in any analysis is 0.80 (Cohen 1988) but since *G. maculosus* is a protected species it is important that the probability of detecting a population decline is high and for that reason, power was set to 0.90 during this study i.e. 90% probability that our specified trends will be detected. The programme MONITOR Ver. 11.0.2 (http://www.esf.edu/efb/gibbs/monitor/) was used for all power analysis. This program estimates the statistical power of ecological monitoring by using simulation procedures to evaluate how each component of a monitoring program (e.g. number of traps; frequency of sampling) influences its power to detect change. It also has an optimization function that can be used to find the least-effort sampling design once desired power levels and maximum sampling effort have been declared (Gibbs & Ene 2010). The trends tested for during this study were 30% (vulnerable), 50% (endangered) and 80% (critically endangered) declines in the population of *G. maculosus* over ten years at each of the study sites. For the optimisation models, the maximum sampling effort was 104 trees or outcrops checked four times per month.

Results and discussion

Baseline monitoring data

The total monthly counts of *G. maculosus* for the eight permanent monitoring stations in the woodland and blanket bog are presented in Figure 8. In the woodland, the maximum number of individuals observed during a given month was 47 in April while in July and September there were no specimens behind the traps. Over the twelve month monitoring period, a mean (± S.E.) of 19.33 (± 4.52) *G. maculosus* were counted per month for the eight traps in the woodland. At the blanket bog site, on the other hand, the highest count (59 individuals) was recorded during October and the lowest during May (1 individual). The mean (± S.E.) number of *G. maculosus* observed over the monitoring period at Cashelkeelty was 21.25 (± 5.68) per month. For a breakdown of the monthly counts of individuals on each individual tree and outcrop, see Appendices 9 and 10 respectively.

Interestingly, the peak in *G. maculosus* counts in the woodland occurred during April, May and June while at the blanket bog the greatest number of individuals were recorded in September, October, November and December. This difference in peak counts between the habitats could be related to environmental conditions at that time of the year e.g. September, October, November and December, when abundances were greatest on the blanket bog, are traditionally among the wettest months of the year in Ireland (www.met.ie/climate) and these conditions would obviously promote slug activity in such an open habitat. Similarly, the relatively high number of *G. maculosus* recorded on the blanket bog in July could be reflective of the unusually wet weather observed during this month in 2010. Rainfall was 220% higher (www.met.ie/climate) than the typical mean for July collected at Valentia Observatory (data from Valentia as opposed to Killarney National

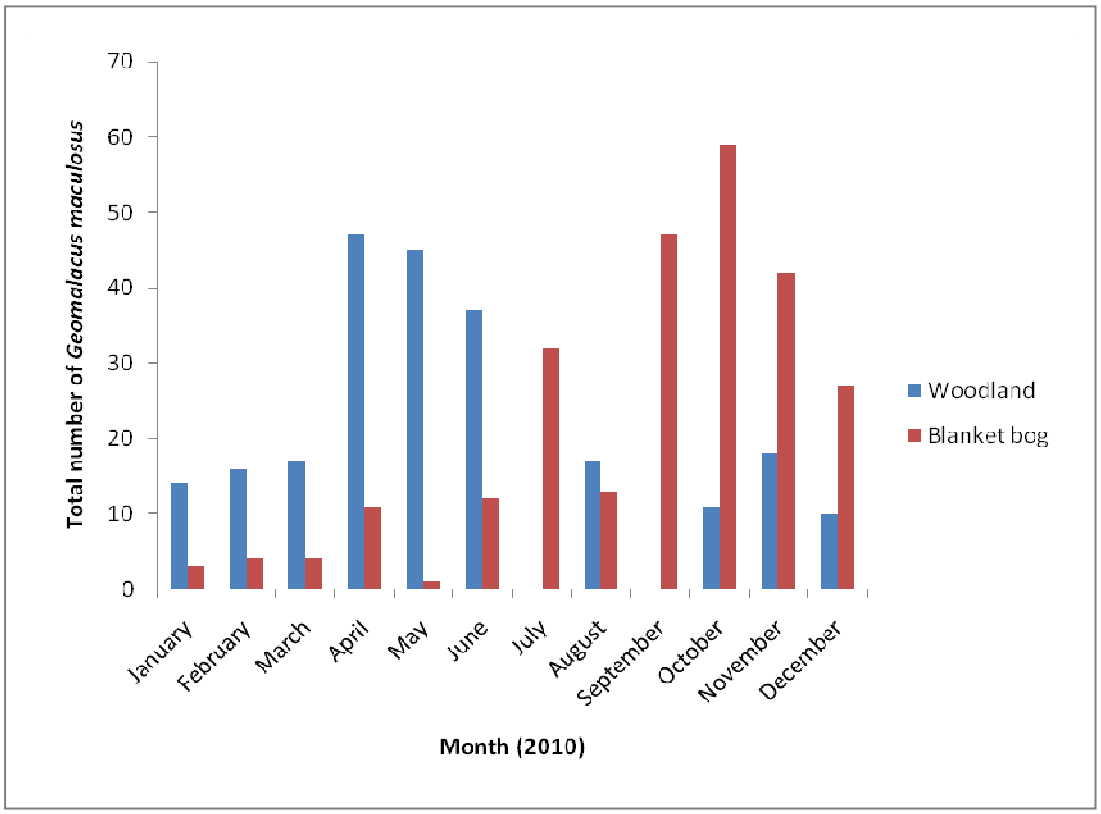

Figure 8: Monthly count data for *Geomalacus maculosus* from eight permanent monitoring stations at Glengarriff Nature Reserve, Co. Cork and Cashelkeelty, Co. Kerry.

Park were used here as mean monthly values are based on collections over a longer time period). Nevertheless it is difficult to discern patterns in seasonality from a single year of data. As monitoring of the species continues, it will be useful to determine if such patterns hold for *G. maculosus* as the identification of peak activity levels could help direct the timing of sampling for future national surveys.

During the July and September counts, no *G. maculosus* were observed behind the permanent traps in Glengarriff Nature Reserve. Therefore, to provide data on how slug numbers vary over a shorter time frame and how slug numbers increase after a period of zero counts, the traps were checked five times during July and August 2010 (Figure 9). Over that period the mean count (± S.D.) was 6.40 (± 6.80) individuals with a maximum of 17 individuals. Therefore, slugs were present in July but they were simply not found under the permanent traps on the monthly sampling date.

No statistically significant correlations (Spearman Rank) were observed between tree circumference (m) and the median monthly counts of *G. maculosus* ($r = +0.54$, $p>0.05$) in Glengarriff over the course of the monitoring period. Likewise on the blanket bog at Cashelkeelty where outcrop size (m^2) was not significantly correlated with the median monthly count data ($r = -0.22$, $p>0.05$). A correlation between total bryophyte species richness per tree and the median monthly counts of *G. maculosus* in Glengarriff also was not significant ($r = +0.04$, $p>0.05$). These results suggest that trunk size (Appendix 11), bryophyte species richness (Appendix 13) and outcrop size

(Appendix 12) are not important factors governing *G. maculosus* abundance in this woodland and blanket bog. Nevertheless, in this study only eight trees and outcrops were used and future studies should aim to have larger sample sizes and utilise multiple woodland and peatland sites.

Power analysis

In an attempt to design a long-term monitoring strategy for *G. maculosus* at both Glengarriff Nature Reserve and Cashelkeelty, the baseline data accrued during 2010 was used for power trend modelling. Since the majority of counts of *G. maculosus* per trap per month (Appendix 11 and 12) at both study sites were less than five (Glengarriff: 91.67%; Cashelkeelty: 81.25%), Gibbs & Ene (2010) recommend the use of the Cochran test. This test is used for presence/absence data in which changes in frequencies of detections on plots are the focus of trend tests. MONITOR achieves this by generating presence/absence data from initial median measures on trees or outcrops (Gibbs &

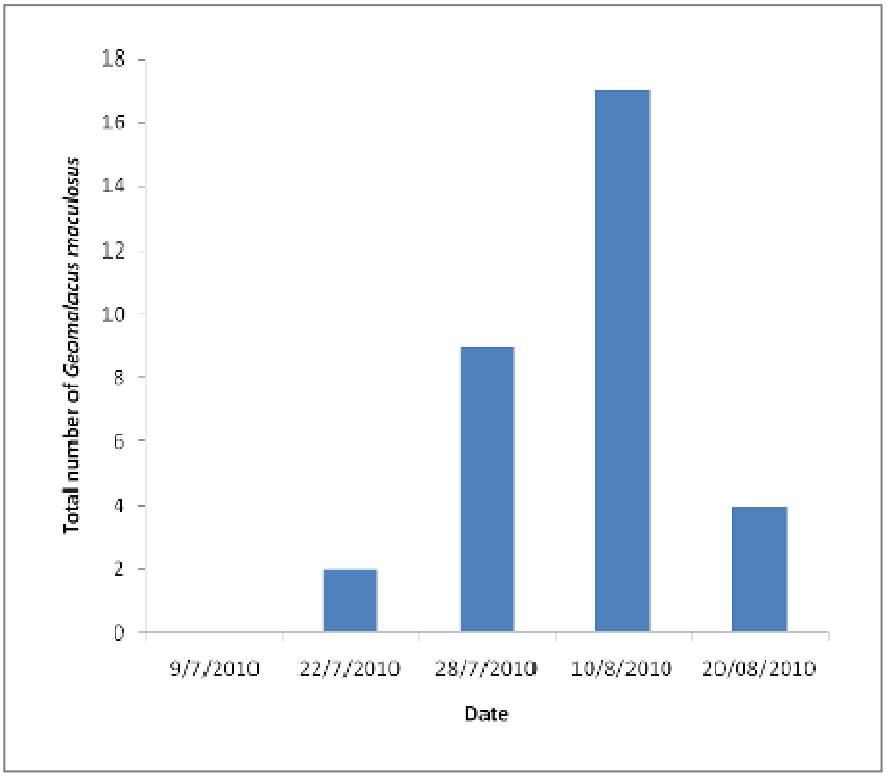

Figure 9: Count data for *Geomalacus maculosus* from eight permanent monitoring stations at Glengarriff Nature Reserve, Co. Cork (July 9 – August 20 2010).

Ene 2010). Interestingly, presence/absence data can be more effective than actual abundances when designing monitoring methodologies (Joseph *et al*. 2006).

In this study, power analysis was first used to determine if the existing sampling protocol (eight trees with a single band trap or eight outcrops with four outcrop traps each, sampled once monthly) would be sufficient to detect a 30%, 50% and 80% decrease in the size of the population at both of the study sites over a ten year period (Table 2). As mentioned above, since *G. maculosus* is a species of high conservation value, it is important that any monitoring program has a high

probability (≥90%) of identifying a population crash. For both sites, current sampling would be insufficient to detect declines of 30% and 50% over ten years as the minimum power estimate (90% or 0.90) was not met (Table 2). In fact at Glenagarriff and Cashelkeelty, the probability of identifying a 30% decrease is only 4.41% and 4.37% respectively. However, the results of the power analysis show that current sampling would be adequate to detect an 80% crash in the populations of *G. maculosus* at both sites with greater than 90% probability (power) in each case (Table 2).

Table 2. Power estimates (based on 10,000 iterations and $P<0.05$) for existing sampling (eight trees or outcrops checked once monthly) to detect a 30% (vulnerable), 50% (endangered) and 80% (critically endangered) decrease in the population of *Geomalacus maculosus* over ten years at Glengarriff Nature Reserve and Cashelkeelty.

	30% decline* (Vulnerable)	50% decline* (Endangered)	80% decline* (Critically Endangered)
Glengarriff	0.0441	0.1680	0.9758
Cashelkeelty	0.0437	0.1658	0.9732

* Declines of 30%, 50% and 80% over ten years correspond to decreases of 0.297%, 0.576% and 1.332% per month respectively.

However, given that *G. maculosus* is a protected species it would be more desirable to identify a less severe population crash so that mitigation measures can be put in place to prevent further declines. Consequently, the minimum monitoring effort (using a single band trap on each tree or four outcrop traps on each outcrop) that would be required to detect both a 30% and 50% decline in the population of the species over ten years at both sites was determined, based on a maximum sampling effort of 104 trees or outcrops checked four times per month. Since >12,000 and >800 different monitoring options were generated using the model for each site for a 50% and 30% decline respectively, only the top ten results (i.e. the ten monitoring programs that require the least sampling effort) are presented in Tables 3 and 4 for Glengarriff and Cashelkeelty respectively. Also, it is important to state that these simulations are approximations, they are subject to random error and consequently may show some oddities, but despite this, the overall trends are clear, with power increasing as the number of trees sampled and/or as the duration of sampling increases.

The minimum sampling effort required to detect a 30% decline in the population of *G. maculosus* at Glengarriff Nature Reserve over ten years (a decrease of 0.297% per month), is 70 trees, checked once monthly for 120 months. This sampling method would have a 92% probability of detecting such a trend (Table 3). For a 50% decline over ten years (0.576% per month), the minimum sampling effort required to detect this trend would be 20 trees for 118 months. This design also has a statistical power of 92%. A similar pattern exists at Cashelkeelty (Table 4) with more outcrops required to detect the lower trend. Seventy-three outcrops checked once monthly for 118 months would be adequate to identify a 30% decrease in the population of *G. maculosus* and for a 50% decline, the minimum sampling effort would be 23 outcrops for 119 months.

Table 3. The minimum sampling effort required to detect a 30% (vulnerable) and 50% (endangered) decrease in the population of *Geomalacus maculosus* over ten years at Glengarriff Nature Reserve based on a maximum sampling effort of 104 trees checked four times per month. For convenience purposes only the first ten simulation results are presented.

Trend	No. of months	No. of trees	No. of surveys per tree per month	Power estimate
30% decline	120	70	1	0.92
	118	76	1	0.91
	117	78	1	0.92
	119	77	1	0.94
	112	82	1	0.91
	117	80	1	0.93
	113	83	1	0.91
	118	80	1	0.95
	117	81	1	0.95
	115	83	1	0.95
50% decline	118	20	1	0.92
	119	23	1	0.93
	120	23	1	0.94
	116	24	1	0.91
	114	25	1	0.96
	120	24	1	0.95
	116	25	1	0.92
	112	26	1	0.92
	117	25	1	0.92
	109	27	1	0.93

Table 4. The minimum sampling effort required to detect a 30% (vulnerable) and 50% (endangered) decrease in the population of *Geomalacus maculosus* over ten years at Cashelkeelty based on a maximum sampling effort of 104 outcrops checked four times per month. For convenience purposes only the first ten simulation results are presented.

Trend	No. of months	No. of outcrops	No. of surveys per outcrop per month	Power estimate
30% decline	118	73	1	0.92
	118	74	1	0.92
	113	80	1	0.91
	116	78	1	0.93
	118	77	1	0.93
	120	76	1	0.94
	109	85	1	0.92
	119	78	1	0.94
	118	79	1	0.94
	117	80	1	0.93
50% decline	119	23	1	0.93
	120	23	1	0.93
	116	24	1	0.94
	108	26	1	0.92
	117	24	1	0.92
	109	26	1	0.94
	119	24	1	0.92
	115	25	1	0.94
	120	24	1	0.96
	116	25	1	0.97

Therefore, if a monitoring program for *G. maculosus* at both Glengarriff and Cashelkeelty is concerned with detecting 30%, 50% and 80% population declines over ten years, then the strategy outlined above for the 30% trend (Glengarriff: 70 trees checked once monthly for 120 months; Cashelkeelty: 73 outcrops checked once monthly for 118 months) should be utilised because according to our data and models such sampling will be sufficient to detect all three scenarios.

Although the above results provide a detailed methodology for monitoring *G. maculosus* at two sites, it will also be important to monitor the species throughout its Irish range and a suitable method could be identified by running a pilot study. Such a study could incorporate ten deciduous woodland and ten peatland sites randomly assigned to twenty hectads within the known range of the species. Within each site, five trees with a single band trap or five outcrops with four outcrop traps each (see Chapter 2 above for trap details) should be selected and the traps checked three times over 12 months. The data generated from this pilot study could then be used in power analysis to determine the number of hectads, number of sites and frequency of sampling that will be required for a detailed monitoring program to detect specified population declines or increases for the species over its entire Irish range.

In addition, it would be prudent to re-run the power analysis after each year of monitoring to ensure that the programme is on target to detect the desired population trends within the designated timeframe. If resources prevent the annual accrual of monitoring data on *G. maculosus*, then the programme should be completed at least once every three years as the lifespan of the species is thought to be between 3-7years (Oldham 1942; Wisniewski 2000). Given that the species is easy to identify, the band and metric traps are easily set up and the time required to check for slugs and maintain an individual trap during each visit is short (i.e. approximately 5mins), this will likely facilitate the establishment of a robust monitoring strategy.

5. MOBILITY, SPATIAL DISTRIBUTION AND COMMUNITY STRUCTURE

Rationale

The extent to which a species moves through its habitat is an important component of population dynamics as it plays a key role in distribution, dispersal and genetic diversity. No previous studies on *G. maculosus* have dealt with this topic even though baseline data on mobility is crucial for the successful conservation of a species. In this chapter, the efficacy of using elastomers (Wallin & Latty 2008) as a suitable approach for tagging *G. maculosus* was assessed. This method was then used to determine the extent and distance that *G. maculosus* moves between trees and between outcrops in an oak woodland and blanket bog respectively. Information on community structure and sympatric species are also provided and since catch sizes were sufficiently high in the woodland, nearest neighbour analysis using the Donnelly (1978) modification of the Clark & Evans Test (1954) was used to yield data on the spatial distribution of the species.

Study sites

Two sites were selected for this part of the study. The first, Uragh Wood (V830633) near Tuosist, Co. Kerry (Figure 10 and Plate 13) is located on the south-west shore of Lough Inchiquin. It is part of a Special Area of Conservation (Cloonee and Inchiquin Lough and Uragh Wood) and is a semi-natural, oceanic, sessile oak woodland with an open structure (NPWS 2003b). According to Fossitt (2000) the wood is classified as an oak-birch-holly woodland (WN1). The dominant vegetation is *Q. petraea, B. pubescens, I. aquifolium, C. vulgaris, Pteridium aquilinum, V. myrtillus* and *M. caerulea.* The second site (V881498) is a lowland blanket bog (PB3) according to Fossitt (2000) and is located in Leahill, Co. Cork (Figure 11). The dominant vegetation is *M. caerulea, S. nigricans, M. gale, C. vulgaris, E. tetralix* and *E. cinerea*. These sites were selected because *G. maculosus* was recorded there during preliminary site visits.

Materials and methods

Slug tagging

To investigate mobility in a species it is crucial to recognize and track specimens. Wallin & Latty (2008) successfully marked slugs (*Ariolimax columbianus)* by injecting a small coloured elastomer (Northwest Marine Technology, Shaw Island, Washington) just below the surface of the foot. This resulted in a highly visible coloured tag on the underside of the body. The authors concluded that this method did not increase mortality or affect slug behaviour. To determine whether elastomers would be a suitable approach for marking *G. maculosus*, ten adult slugs (five from a woodland and five from a blanket bog) were injected with the tagging material (Plate 14). For the most part, we followed the procedure outlined by Wallin & Latty (2008) but some modifications were made. Firstly, the test slugs were not anaesthetised as it was deemed too time consuming and secondly, to increase the longevity of the elastomer, the latter was not mixed with the curing agent. Although the slugs did eject some of the material immediately after tagging, a sufficient amount remained inside the foot to enable identification (Plate 14). However, there was some migration of the

Figure 10: Ordnance Survey Map (1:50,000) with arrow showing the location of Uragh Wood in Co. Kerry (© OSI).

Plate 13: Uragh Stone Circle and Uragh Wood in the background (© Rory Mc Donnell).

Figure 11: Ordnance Survey Map (1:50,000) with arrow showing the location of the lowland blanket bog at Leahill, Co. Kerry (© OSI).

Plate 14: A specimen of *Geomalacus maculosus* successfully marked on the foot in two places with red elastomer (© Rory Mc Donnell).

elastomer inside the tissue and consequently slugs could not be given an individual identification mark.

After tagging, the slugs were placed individually in plastic Tupperware containers with a perforated lid, damp moss, dead leaves and a 2.5cm piece of organic carrot. The slugs and marks were checked daily for a fortnight and weekly thereafter. After 160 days, there was 100% slug survival and all of the marks were visible. In addition, after 97 days, five of the specimens had laid several egg masses. We can, therefore, conclude that the tags themselves are robust and that the tagging procedure does not increase mortality in *G. maculosus*.

Experimental design

From herein the two study sites will be dealt with separately.

Uragh Wood

To investigate mobility in *G. maculosus*, three band traps were placed (1.5m from the ground surface) on the three trunks (A, B and C) of a large oak tree (*Q. petraea*) in Uragh Wood (Plate 15). This tree was termed the central tagging tree and it was selected because specimens were observed foraging on the trunks in a preliminary study (June 2010). Band traps were also placed on an additional 34 trees (outer observatory trees) within an area of 1177.53 m^2 with the central tagging tree at its centre. The outer observatory trees comprised sixteen *Q. petraea*, sixteen *Betula pubescens*, two *Sorbus aucuparia* and one *Ilex aquifolium*. In addition, 15 individual metric traps were placed randomly on the woodland floor and were termed woodland floor traps. All traps were saturated with deionised water prior to use and baited with a 2.5cm piece of organic carrot.

The experiment was run from the July 12 to September 14 2010 (64 days) and a total of 14 visits were made. During each visit only the *G. maculosus* obtained behind the three trunks on the central tagging tree were tagged. To ensure that the starting point of any observed movement between trees could be identified, all tagged slugs were released under the trap on the east side of Trunk C. Different colours and combinations of elastomers were used to tag *G. maculosus* so that slugs from six different sampling occasions could be readily identified. Evidence of movement from the central tagging tree was then determined by checking for tagged slugs behind the band traps on the outer observatory trees and under the woodland floor traps. In addition, a Gemini data logger which records temperature and relative humidity was placed on the trunk immediately above the band trap on the north side of an outer observatory tree that was shaded and on another that was in a more open part of the site (both trees were *B. pubescens*). In addition, light measurements using a Hanna Portable Luxmeter were taken on six different occasions (July 20, July 27, August 26, September 3, September 8 and September 14 2010) above the band trap on the north, south, east and west side of both of these outer observatory trees.

Leahill blanket bog

To investigate mobility in *G. maculosus* on the blanket bog site, 15 outcrop metric traps were placed on a large sandstone outcrop. The traps were positioned by finding the midpoint of the outcrop and then continually placing individual traps 1m from this point to the north, south, east and west (Plate 16) until the edge of the outcrop was reached. This outcrop was termed the central tagging

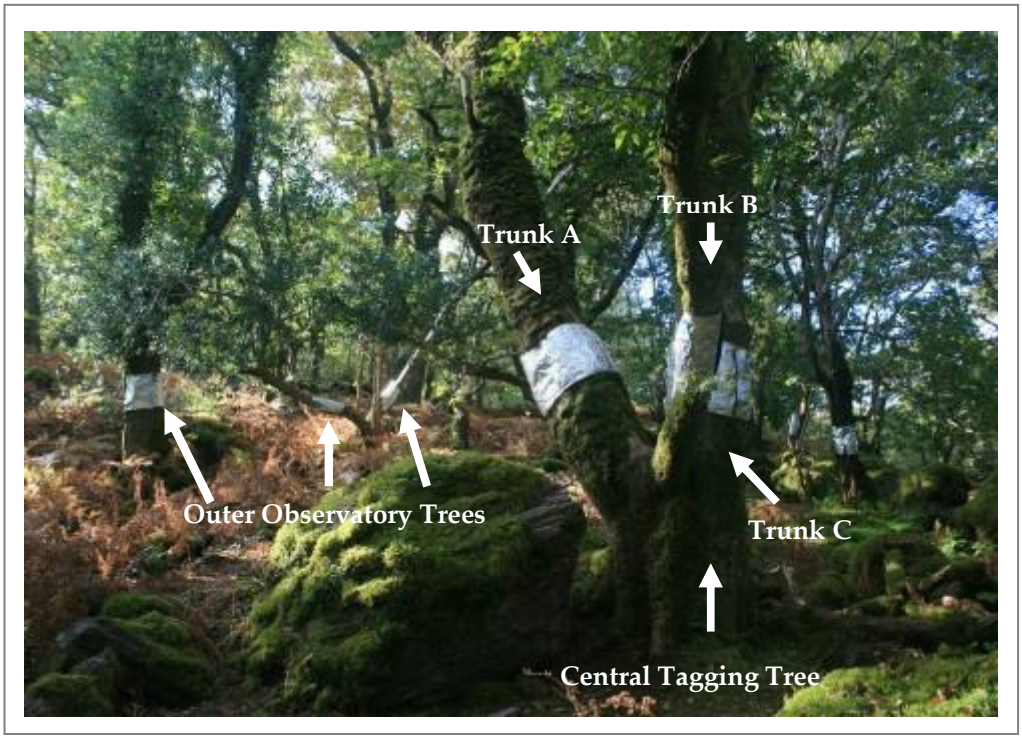

Plate 15: The central tagging tree (showing trunks A, B and C) and outer observatory trees at Uragh Wood, Co. Kerry. All tagged *Geomalacus maculosus* were released behind the band trap on trunk C (© Rory Mc Donnell).

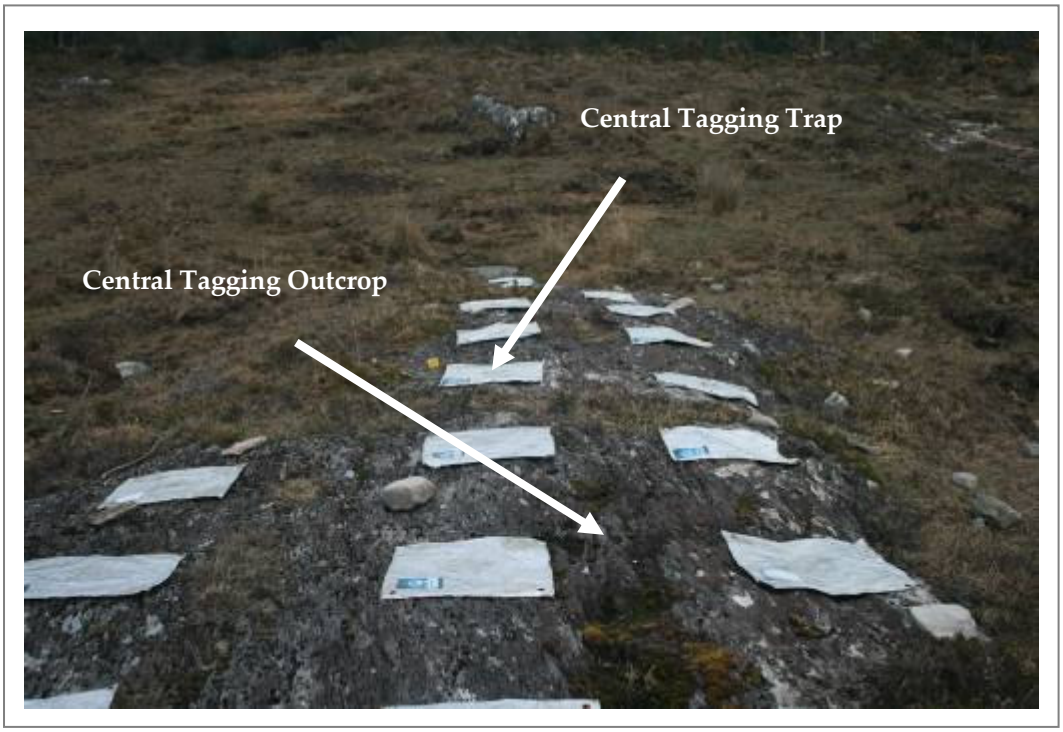

Plate 16: The central tagging outcrop at Leahill blanket bog, Co. Cork. All tagged *Geomalacus maculosus* were released behind the central tagging trap (© Rory Mc Donnell).

outcrop and it was selected because specimens were observed foraging on it in a preliminary site visit (October 2010). Traps were also placed on all the outcrops (outer observatory outcrops) surrounding the central tagging outcrop within an area of 1139.85 m^2 with the central tagging outcrop approximately at the centre. The number of traps on the outer observatory outcrops depended on outcrop size and varied from one to nine traps. The latter were positioned using the same method as for the central tagging outcrop. In addition, 15 individual metric traps were placed randomly on the blanket bog and were termed blanket bog traps. All traps were saturated with deionised water prior to use and baited with a 2.5cm piece of organic carrot.

The study was run from November 15 to December 8 2010 (23 days) and a total of 13 visits were made. During each visit only *G. maculosus* specimens obtained behind the traps on the central tagging outcrop were tagged. To ensure that the starting point of any observed movement between outcrops could be identified, all tagged slugs were released under the central trap on the central tagging outcrop. Different colours of elastomer were used to tag specimens so that slugs from three different sampling occasions could be identified. Evidence of movement from the central tagging outcrop was then determined by checking for tagged slugs behind the metric traps on the outer observatory outcrops and under the blanket bog traps.

Results and discussion

Uragh Wood

Mobility

A total of 52 *G. maculosus* were tagged and released on the central tagging tree during the course of this investigation. The number of recaptures on the central tagging tree, outer observatory trees, and distance moved are presented in Table 5. No tagged or untagged slugs were found under the woodland floor traps.

Only three tagged *G. maculosus* were recaptured on the outer observatory trees (Table 5). Two separate individuals moved 9.25m to an adjacent tree which was located southeast of the central tagging tree (Plate 17). These specimens were found 15 and 17 days after they were tagged which correspond to mobilities of 0.617m and 0.544m per day. Even though these specimens had the same colour tag, it was possible to distinguish them because one was a fully mature adult and the other was immature. A third individual was also recaptured (30 days after release) on an adjacent tree, 14.20m west-south-west (Plate 17) of the central tagging tree which corresponds to a mobility of 0.473m per day. Therefore, the mean ($\pm$ S.D.) mobility distance (n=3) covered by *G. maculosus* from the central tagging tree to the outer observatory trees in Uragh Wood was 10.90 ($\pm$ 2.86) m or 0.545 ($\pm$0.072) m per day.

The fact that only 5.8% of the marked population was recaptured on the outer observatory trees during this investigation suggests that the species does not move frequently between trees. This hypothesis of a strong fidelity for individual trees is strengthened by the fact that tagged slugs from the first day of tagging were recaptured on the central tagging tree during all subsequent site visits even after 64 days (Table 5).

Table 5: The number of *Geomalacus maculosus* released and recaptured on the central tagging tree (CTT) and outer observatory trees (OOT) during the mobility study in Uragh Wood, Co. Kerry.

Release			**Recaptures on CTT**		**Recapture on OOT**		
Date	**No. tagged & released (cumulative no.)**	**Colour of release tag**	**No. recaptures (trunk A,B or C)**	**Colour of recapture tag**	**No. recaptures**	**Colour of recapture tag**	**Distance to CTT***
July 12 2010	16 (16)	Red	-	-	-	-	-
July 13 2010	0 (16)	No tagging	2 (C)	Red	-	-	-
July 14 2010	0 (16)	No tagging	3 (C), 1 (A)	Red	-	-	-
July 15 2010	0 (16)	No tagging	2 (C), 1 (A)	Red	-	-	-
July 16 2010	0 (16)	No tagging	5 (C)	Red	-	-	-
July 20 2010	0 (16)	No tagging	2 (C)	Red	-	-	-
July 27 2010	14 (30)	Green	2 (B)	Red	1	Red	9.25m
July 29 2010	0 (30)	No tagging	1 (C)	Red	1	Red	9.25m
Aug 9 2010	8 (38)	Blue	1 (C)	Red	-	-	-
			1 (B)	Green	-	-	-
Aug 20 2010	0 (38)	No tagging	1 (C)	Red	-	-	-
			2 (C)	Green	-	-	-
Aug 26 2010	9 (47)	Orange	3 (C)	Red	1	Green	14.20
			2 (C)	Green	-	-	-
			1 (A)	Green	-	-	-

			1 (B)	Green	-	-	-
			1 (B)	Red	-	-	-
Sept 2 2010	4 (51)	Red and blue	1 (C)	Blue	-	-	-
			1 (C)	Red	-	-	-
			1 (C)	Green	-	-	-
			1 (A)	Red	-	-	-
Sept 8 2010	1 (52)	Red and green	1 (C)	Red	-	-	-
			1 (C)	Green	-	-	-
			1 (A)	Orange	-	-	-
			1 (B)	Red	-	-	-
Sept 14 2010	0 (52)	No tagging	1 (C)	Red	-	-	-
			1 (C)	Green	-	-	-

* This comprises the distance from the band trap on each tree to the woodland floor plus the distance between the trees

Plate 17: Observed movement of three marked *Geomalacus maculosus* individuals from the central tagging tree to two outer observatory trees. The red arrow (two individuals) is in a southeast direction and the yellow (1 individual) is in west-south-west direction (© Rory Mc Donnell).

Slug community composition

To provide data on the structure of the slug community at Uragh Wood, the total abundance of each slug species was recorded behind the band traps on each tree during six site visits from July 20 to September 8. The results show that the community constants and associates are relatively stable over the sampling period where a total of seven species were found (Figure 12). The most abundant species was *Lehmannia marginata* (Plate 18) which suggests that it is the dominant slug on trees in Uragh Wood. This is a species of both old and relatively new deciduous woodland but it is also known from open habitats, with exposed rocks. In Ireland, it is widespread where there is suitable habitat (Moorkens & Killeen 2009). *Geomalacus maculosus* on the other hand appeared to be always sub-dominant (i.e. prevalent in the community but not dominant) as was *Arion ater* agg. (Figure 12), which is a complex of very similar slug species. The remaining slugs, *Limax maximus, Arion intermedius* and *Limax cinereoniger* were only collected occasionally during the study and all are known from woodland (Moorkens & Killeen 2009). However, *L. cinereoniger* (Plate 19) is classed as 'vulnerable' according to Byrne *et al.* (2009) and is a species of high conservation interest because it has a restricted distribution and is a biological indicator of high quality woodlands. In Ireland, it is considered to be widespread but rare (Moorkens & Killeen 2009). To the best of our knowledge this is the first record of the species in Uragh Wood.

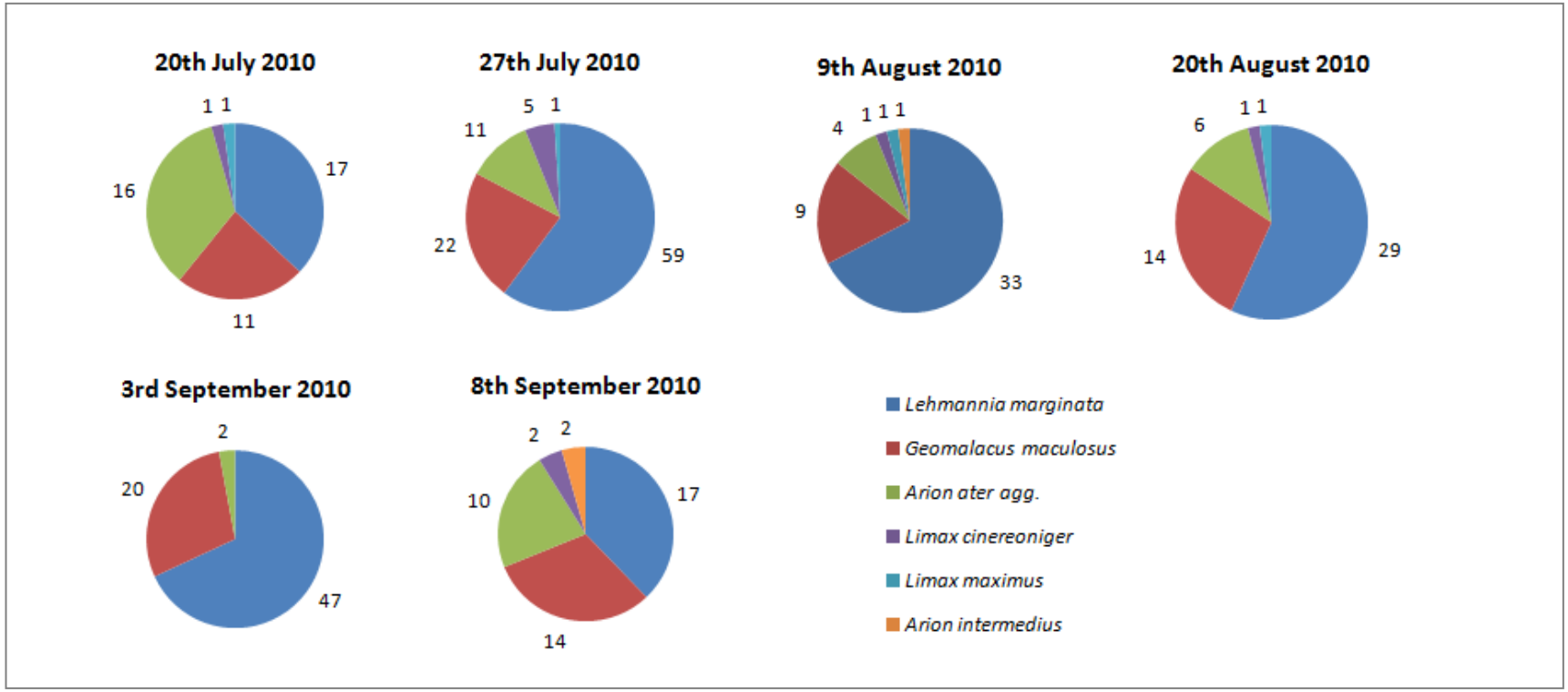

Figure 12: Slug community composition at Uragh Wood, Co. Kerry from 20th July to 8th September 2010.

Plate 18: *Lehmannia marginata* which was the dominant slug species recorded on trees in Uragh Wood, Co. Kerry from July 20 to September 8 2010 (© Rory Mc Donnell).

Plate 19: *Limax cinereoniger* which was recorded in Uragh Wood, Co. Kerry. It is a species of high conservation interest in Ireland (© Rory Mc Donnell).

Spatial distribution

Nearest neighbour analysis is a mathematical method for determining how a species is spatially distributed in a given area. It attempts to measure distributions according to whether they are clustered (typical of species living in environments where resources have a patchy distribution), random (suggests that environmental conditions and resources are consistent) or uniform (indicative of strong competition between con-specifics for a resource) (Krebs 1999). Nearest neighbour analysis for gastropods has highlighted both clustered (*Arion lusitanicus*: Grimm & Paill 2001; *Arianta arbustorum styriaca*: Kleewein 1999; *Nerita atramentosa* and *Bembicium nanum*: Underwood 1976) and random distributions (*Cellana tramoserica:* Underwood 1976) but there is currently no such information available for *G. maculosus*.

According to our data, however, this species was for the most part randomly distributed (67% of sampling occasions) in Uragh Wood from July 20 to September 8 2010 (Table 6). Interestingly, a random distribution is the least common form of distribution in nature and as mentioned above, it usually occurs in habitats where environmental conditions and resources are consistent. However, it should be noted that the pattern of distribution is not permanent for a species and it can change with season and in response to resource availability (Avila 1995). For that reason, it would be of interest in future studies to examine the spatial distribution of *G. maculosus* over 12 months.

Table 6: Analysis of the spatial distribution of *Geomalacus maculosus* in Uragh Wood, Co. Kerry by the nearest-neighbour distance method. If R=1: random spatial pattern; if R=0: clumped spatial pattern and if R approaches an upper limit of 2.15: uniform spatial pattern.

Date	Sample size	Index of aggregation (R)	Standard normal deviate (z)	Spatial distribution
July 20 2010	11	1.383	2.164*	Deviation towards uniform
July 27 2010	22	1.196	1.590	Random
Aug. 20 2010	14	1.291	1.862	Random
Aug. 26 2010	29	0.705	2.759*	Deviation towards clumped
Sept. 3 2010	20	0.975	0.281	Random
Sept. 8 2010	14	0.889	0.711	Random

* indicates a significant deviation from a random distribution.

Influence of environmental factors

During the mobility study at Uragh Wood, the impact of certain abiotic factors (Table 7) on the abundance of *G. maculosus* on specific trees was also examined. Median light intensity was significantly greater ($p<0.01$) at the outer observatory tree in the more open area compared to the

Table 7: Mean (±SD) and median light intensity, temperature and relative humidity recorded at an outer observatory tree in a shaded and open area of Uragh Wood, Co. Kerry.

		Open	**Shaded**
Temperature (°C)	n	5377	5377
	Mean ± SD	14.80 ± 2.15	14.78 ± 1.85
	Median	14.81	14.83
Relative humidity (%)	n	5377	5377
	Mean ± SD	81.33 ± 27.49[a]	91.38 ± 17.16[a]
	Median	90.90	96.60
Light intensity (klux)	n	24	24
	Mean ± SD	3.27 ± 3.41	1.07 ± 0.90
	Median	2.48[b]	0.99[b]

Values with the same superscript letter indicate a significant difference between the mean (unpaired t-test) or median (Mann Whitney U test) – a: $t = 22.74$, $p<0.001$; b: $U=143.50$, $p<0.01$)

shaded tree and median relative humidity was significantly less ($p<0.001$) at the former (Table 7). Interestingly, no *G. maculosus* were observed under the band traps at the shaded tree during the sampling period while the species was found on all but one of the sampling dates on the tree in the more open area (Figure 13). However, no statistically significant Spearman Rank correlations were observed between *G. maculosus* abundance and light intensity ($r= +0.57$, $p>0.05$), relative humidity ($r= -0.33$, $p>0.05$) and temperature ($r= 0.25$, $p>0.05$). Future research on the impact of these abiotic factors should examine a larger number of trees over a longer time period.

In an effort to determine if *G. maculosus* had a preference for any of the tree species in the study area (*Q. petraea, B. pubescens, I. aquifolium* and *S. aucuparia*), the number of specimens recorded behind the band traps on each tree was recorded on July 20, July 27, August 9, August 20, September 3 and September 8 2010. The results are presented in Table 8 below. *Geomalacus maculosus* was recorded on all tree species during the investigation but the median number per tree for each tree species was significantly greater ($p<0.05$) for *Q. petraea* (0.72) compared to *I. aquifolium* (0). There was no significant difference between the other tree species.

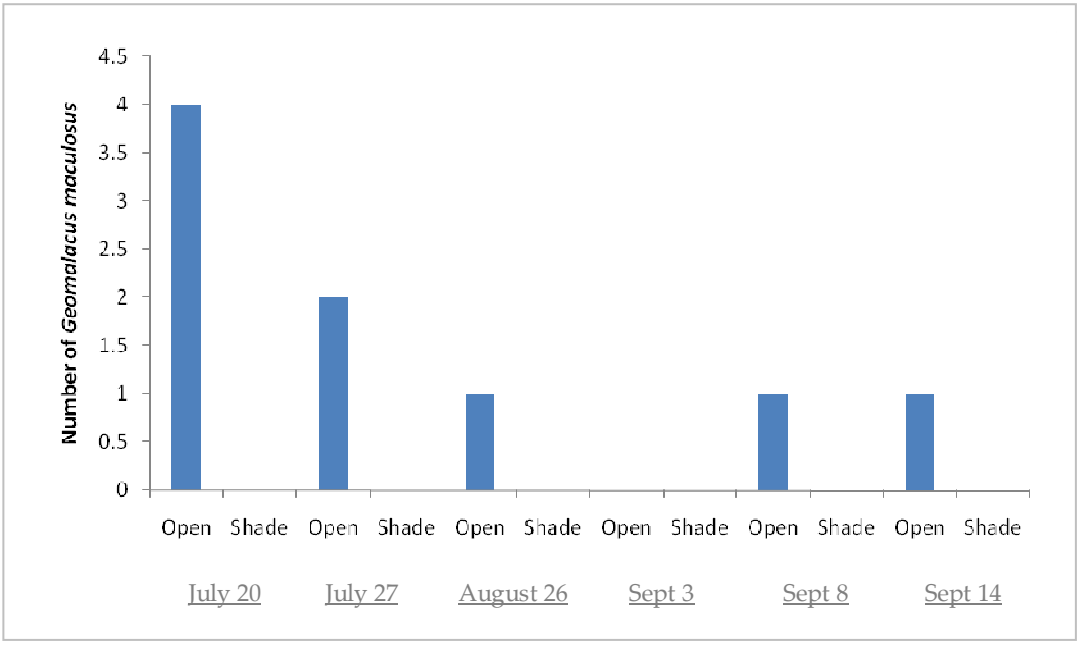

Figure 13: Number of *Geomalacus maculosus* found behind the band traps on an outer observatory tree in an open and shaded area of Uragh Wood, Co. Kerry on July 20, July 27, August 26, September 3, September 8 and September 14 2010.

Table 8. Mean (±SE) and median number of *Geomalacus maculosus* collected per tree for each species at Uragh Wood, Co. Kerry from July 20 to September 8 2010.

	Quercus petraea	*Betula pubescens*	*Sorbus aucuparia*	*Ilex aquifolium*
Sample size	6	6	6	6
Mean (±SE)	0.80 ± 0.12	0.07 ± 0.03	0.42 0.24	0.17 ± 0.17
Median	0.72	0.06	0.25	0
Quercus petraea	-	-	-	-
Betula pubescens	*3.23*	-	-	-
Sorbus aucuparia	*2.51*	*0.72*	-	-
Ilex aquifolium	*3.96**	*0.72*	*1.44*	-

K= 9.58; *P*<0.05, Kruskal – Wallis test (corrected for tied ranks). *q* values (given in italics) indicate significant differences between tree species at *p*<0.05 (*) - Nemenyi's non-parametric multiple comparisons test

Leahill blanket bog

Mobility

A total of 19 *G. maculosus* were tagged and released under the central tagging trap during the course of this investigation. The number of recaptures on the central tagging outcrop and distance moved from the central tagging trap are presented in Table 9. No slugs were recaptured on any of the outer observatory outcrops or under the blanket bog traps.

The fact that no marked specimens were recaptured on the outer observatory outcrops during this investigation suggests that the species does not move frequently between outcrops at this time of year. In fact, during the course of this research the mean air temperature recorded on the data logger was 2.88°C with a minimum of -5.57°C. Under such conditions, slugs are known to enter a phase of hibernation (South 1992) and this may account for the low level of observed movement. Therefore, future research on *G. maculosus* should incorporate mobility studies on blanket bog during other times of the year (e.g. spring) when activity is likely to be higher.

This theory of a strong affinity for individual outcrops during this study is also strengthened by the fact that tagged slugs from the first day of tagging were recaptured on the central tagging outcrop during all subsequent site visits (Table 9). In terms of movement on the central tagging outcrop, one individual was recaptured nine days after tagging under trap 10 which was located 1m to the west of the central tagging outcrop (mobility of 0.111m per day). A second individual was captured eight days after tagging under trap eight which was located 1m to the east of the central tagging trap (mobility of 0.125m per day). These data therefore correspond to a mean (± S.D.) mobility of 1.000 (± 0.000) m or 0.118 (± 0.010) m per day at the study site.

Community composition

To determine the slug species that co-occur with *G. maculosus* on the blanket bog at Leahill, the total abundance of each slug species was recorded behind the traps on each outcrop during six site visits from November 15 to December 8. The results show that as with the woodland habitat, the community constants and associates are relatively stable over the sampling period where a total of four species were found (Figure 14). The most abundant was *G. maculosus* which suggests that it is the dominant slug on outcrops at Leahill. *Arion intermedius* when present was always subdominant. The remaining slugs, *L. marginata* and *Arion ater* agg. were only collected occasionally during the study. According to Moorkens & Killeen (2009), *L. marginata* is primarily a woodland species but it has also been collected from open habitats, with exposed rocks. Interestingly, all of the sympatric species recorded at the blanket bog site were also present as co-occurring species in Uragh Wood (see above).

Since only two specimens of *G. maculosus* were observed to have moved from the central tagging trap, there was insufficient data to calculate spatial distribution for the species at Leahill.

Table 9: The number of *Geomalacus maculosus* released and recaptured on the central tagging outcrop during the mobility study at Leahill blanket bog, Co. Cork. No recaptures were made on the outer observatory outcrops.

Release			**Recaptures under central tagging trap**		**Recaptures under other traps**		
Date	**No. tagged & released (cumulative no.)**	**Colour of release tag**	**No. recaptures**	**Colour of recapture tag**	**No. recaptures (trap no.)**	**Colour of recapture tag**	**Distance to central tagging trap**
Nov 15 2010	8 (8)	Green	-	-	-	-	-
Nov 16 2010	0 (8)	No tagging	8	Green	-	-	-
Nov 17 2010	0 (8)	No tagging	8	Green	-	-	-
Nov 18 2010	0 (8)	No tagging	7	Green	-	-	-
Nov 19 2010	0 (8)	No tagging	7	Green	-	-	-
Nov 23 2010	10 (18)	Pink	6	Green	-	-	-
Nov 24 2010	0 (18)	No tagging	6	Green	1 (trap 10)	Green	1m
			9	Pink	-	-	-
Nov 25 2010	0 (18)	No tagging	7	Green	-	-	-
			9	Pink	-	-	-
Nov 26 2010	0 (18)	No tagging	5	Green	-	-	-
			10	Pink	-	-	-
Nov 30 2010	0 (18)	No tagging	5	Green	-	-	-
			10	Pink	-	-	-

Dec 1 2010	0 (18)	No tagging	4	Green	1 (trap 8)	Pink	1m
			10	Pink	-	-	-
Dec 7 2010	1 (19)	Yellow	4	Green	-	-	-
			10	Pink	-	-	-
Dec 8 2010	0 (19)	No tagging	3	Green	-	-	-
			10	Pink	-	-	-

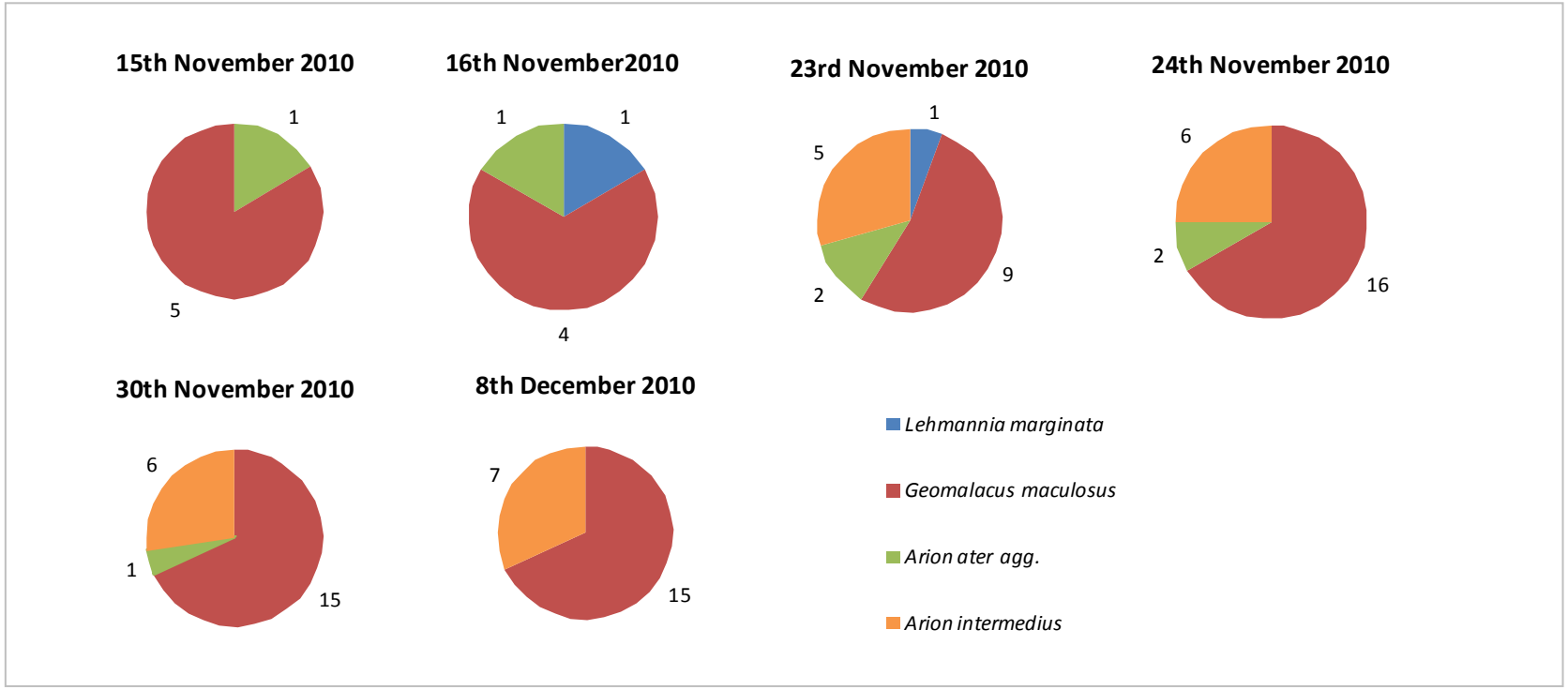

Figure 14: Slug community composition on blanket bog at Leahill, Co. Cork from November 15 to December 8 2010

6. THREATS TO *GEOMALACUS MACULOSUS*

Rationale

According to the Kerry Slug Threat Response Plan (NPWS 2010), invasion of woodland by *Rhododendron ponticum* and forestry management (including afforestation) are among the main threats to the species. However, very little information is available on the relative significance of these pressures on *G. maculosus* in Ireland (NPWS 2010). This provided the incentive for this part of the study where preliminary qualitative investigations on the impacts of *Rhododendron* invasion and uncontrolled burning on *G. maculosus* abundance were carried out. Although unmanaged fires are not listed as a primary threat to the species in the recent Threat Response Plan, they are considered a major threat to heath and blanket bog (Patrick Graham pers. comm.) and for that reason we include burning here. We also provide quantitative data on the effects of commercial forestry.

A. Impact of uncontrolled burning

Study sites

The site chosen for this investigation was an area of blanket bog approximately 4km southwest of Glengarriff Village, Co. Cork (Figure 15). The area on one side of the R572 was subjected to a severe uncontrolled burn during April 2010 while no burning occurred on the blanket bog on the other side of the road (Clare Heardman pers. comm.). The burnt site was also burnt approximately 15 years ago and there is no history of burning (controlled or uncontrolled) on the unburnt site (Con O'Sullivan pers. comm.).

Methods and materials

Four outcrops traps were placed on each of five sandstone outcrops at both the burnt and unburnt sites on May 12 2010 giving a total of twenty traps per site. The positions of the traps were determined by finding the midpoint of each outcrop and then placing an individual trap 1m from this point to the north, south, east and west. All of the traps were saturated with water prior to use and baited with organic carrot. During each visit (May 24, June 3, June 20, July 13 2010), the numbers of *G. maculosus* were counted but not removed from the sites, the organic carrot was replaced and the underside of each trap and the underlying sandstone was moistened for 15 seconds using a mist gun filled with deionised water. On July 13 2010, the landowner requested that the study be terminated and consequently sampling ceased on this date. The median number of slugs counted under the traps on each outcrop for each sampling date was compared between the sites using a Mann Whitney U test.

Results and discussion

The total number of *G. maculosus* found per week on both the burnt and the unburnt sites from May 24 to July 13 2010 is presented in Figure 16. Specimens were collected on the unburnt site on each of the four site visits but at the burnt site, the first individuals were found approximately

Figure 15: Ordnance Survey Map (1:50,000) showing the location of the burnt (blue arrow) and unburnt (red arrow) sites near Glengarriff, Co. Cork (© OSI).

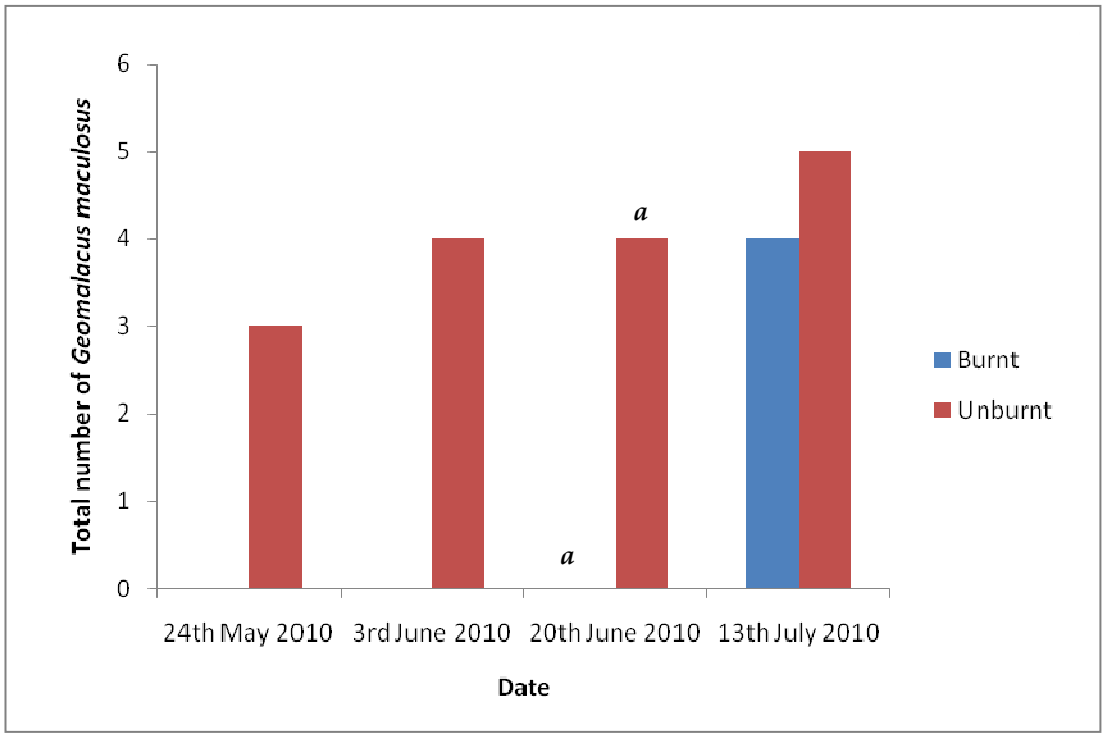

Figure 16: A comparison of the total number of *Geomalacus maculosus* found on five outcrops from May 24 to July 13 2010 at a burnt and unburnt blanket bog site near Glengarriff, Co. Cork. Bars with the same letter indicate a significant difference between the medians (Mann Whitney U test), a: median for unburnt site= 1, median for burnt site= 0, $U=2.50$, $p<0.05$.

three months after the uncontrolled burn. In fact the median number of *G. maculosus* collected on the unburnt site was significantly greater ($p<0.05$) than on the burnt site during week three of the study (Figure 16). These results suggest that burning, at least in the short term, has an adverse effect on *G. maculosus* populations but the species is eventually trapped on outcrops at the burnt site. These specimens could have survived in suitable refuges in the burnt areas or are from parts of the site that were unburnt.

B. Impact of *Rhododendron ponticum*

Study sites

Two areas of oak-birch-holly woodland, one heavily infested with *R. ponticum* and the other uninfested with this invasive species, were selected within the contiguous woodlands at Glengarriff ex (Figure 17) for investigation. According to the landowner, the infested site has had a dense growth of *R. ponticum* for at least the last 80 years (Denise Hall pers. comm.).

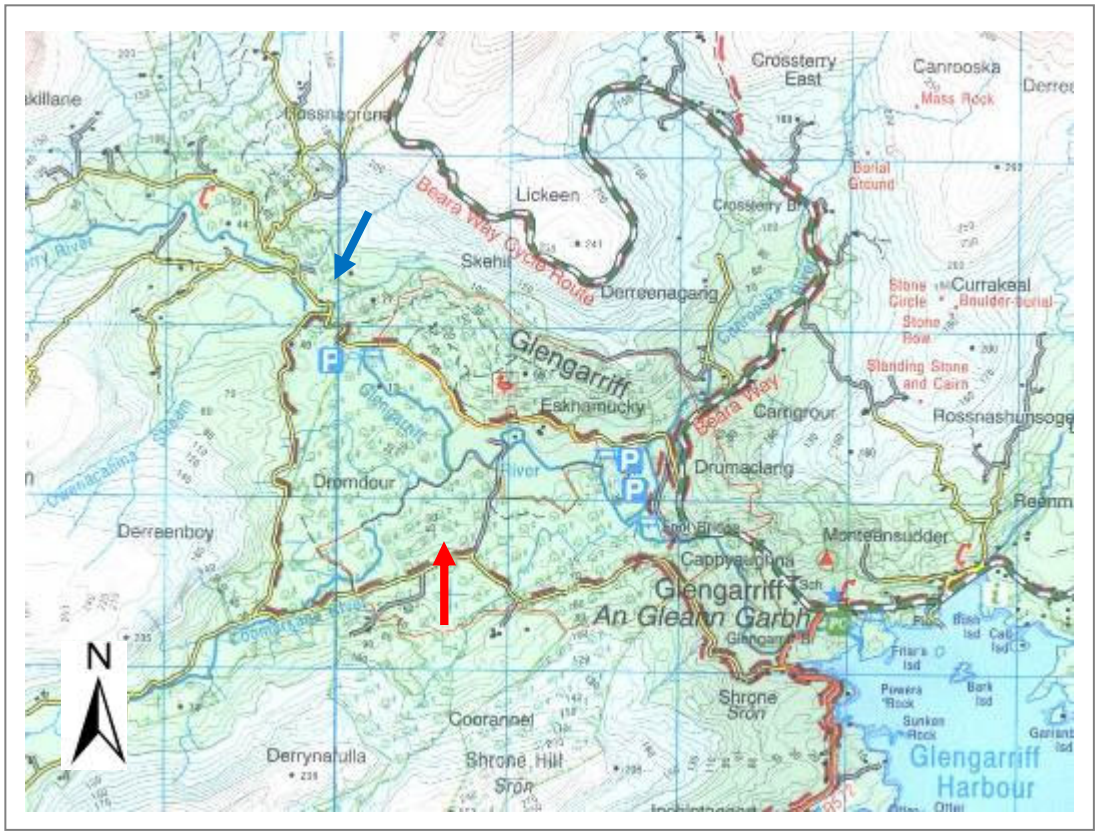

Figure 17: Ordnance Survey Map (1:50,000) showing the location of the *Rhododendron*-infested (blue arrow) and uninfested (red arrow) sites in the Glengarriff woodlands, Co. Cork (© OSI).

Materials and methods

A single band trap was placed 1.5m from the ground surface on the trunk of five mature *Q. petraea* at each site on May 13 2010. All of the traps were saturated with water and baited with organic

carrot prior to use. During each visit (May 25, June 4, June 21, July 16, July 28, August 11 2010) the number of *G. maculosus* were counted but left in place, the carrot was replaced and the underside of each trap and the underlying bryophytes were moistened for 15 seconds using a mist gun filled with deionised water. The median number of slugs counted under the band traps on each tree for each sampling date was compared between the two sites using a Mann Whitney U test.

Results and discussion

The total number of *G. maculosus* found at both the infested and uninfested sites from May 25 to August 11 2010 are presented in Figure 18. According to the Kerry Slug Threat Response Plan (NPWS 2010), *G. maculosus* can be found in areas invaded by *R. ponticum* but it appears to be less frequent than in areas which have not been invaded. This is confirmed in our study where during each site visit more individuals were consistently found under the band traps in the uninfested than the infested site and during week one the median number of individuals found at the uninfested site was significantly greater ($p<0.05$) than at the infested site (Figure 18). This also confirms the findings of Barron (1998) who concluded that *R. ponticum* has a negative effect on *G. maculosus* abundance. The impact of this invasive species on actual population sizes and densities of the Kerry slug is dealt with in Chapter 7 below.

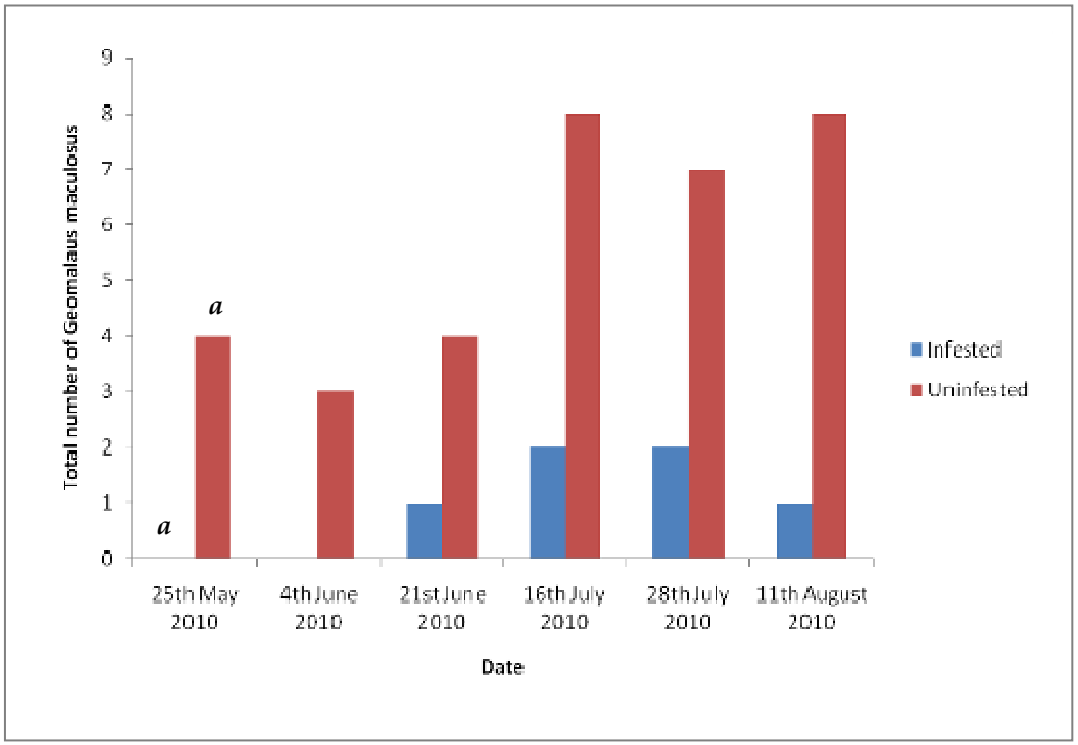

Figure 18: A comparison of the total number of *Geomalacus maculosus* found on five *Quercus petraea* in a *Rhododendron* infested and uninfested site from May 25 to August 11 2010 at Glengarriff, Co. Cork. Bars with the same letter indicate a significant difference between the medians (Mann Whitney U test), a: median for uninfested site= 1, median for infested site= 0, $U=2.50$, $p<0.05$.

C. Impact of commercial afforestation

Study sites

Glanteenassig Forest Park (Q610082) near Aughacasla in Co. Kerry was selected for this investigation (Figure 19) as *G. maculosus* has been recorded from the site (see Appendix 2). The

Figure 19: Ordnance Survey Map (1:50,000) with red arrow showing the location of Glanteenassig Forest, Co. Kerry (© OSI).

Park comprises an area of blanket bog, low density conifers, high density conifers and clearfell (Plate 20). The low density conifer site was planted in 1965 with 95% *Pinus contorta* and 5% *Picea sitchensis* while the high density conifer area was planted in 1967 with 87% *P. sitchensis* and 13% *P. contorta.* The trees in the clearfell were cut and removed in 2005 and the blanket bog is part of the Mt. Brandon SAC (Izabela Witkowska pers. comm.).

Materials and methods

At the blanket bog, low density conifer, high density conifer and clearfell sites, 15 sandstone outcrops were selected. Since the outcrops were smaller than those used in other studies that we have conducted, a single trap was placed at the centre of ten small outcrops and two traps

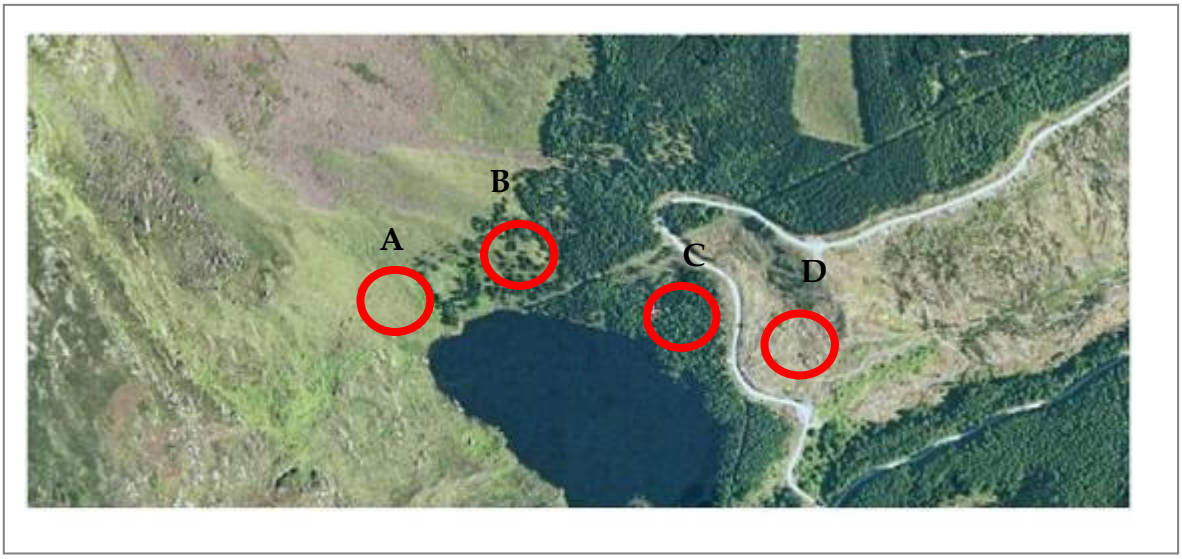

Plate 20. Glanteenassig Forest showing the locations of the blanket bog (A), low density conifer (B), high density conifer (C) and clearfell (D) study sites (© OSI).

(separated by 1m) were placed on five larger outcrops on August 20 2010. This gave a total of 20 traps per site, all of which were baited with organic carrot and saturated with water prior to use. The traps were checked weekly from August 27 to the October 16 2010 and then on a monthly basis until January 23 2011. During each visit, all of the *G. maculosus* crawling over the surface of the fifteen outcrops were collected, in addition to all of the specimens that were found under the traps at each site. These specimens were placed into labelled plastic Tuppaware containers lined with damp *Sphagnum* and at the end of the investigation they were returned to the outcrops from which they were removed. During each collection, the organic bait was replaced and the underside of each trap and the underlying sandstone was moistened for 15 seconds using a mist gun filled with deionised water. Finally, the surface area of each outcrop was calculated by dividing the outcrops into a series of squares, rectangles and triangles and then adding the individual areas to get the total surface area.

Results and discussion

According to the Kerry Slug Threat Response Plan (NPWS 2010), the widespread planting of commercial conifer forestry is likely to have had a detrimental effect on *G. maculosus* but no quantitative data is currently available on the impacts of afforestation on the species. A total of 111, 10, 0 and 9 individuals were collected on the outcrops at the blanket bog, low density conifer, high density conifer and clearfell sites respectively throughout the course of this study. However, given that specimens were collected from under traps and from the remainder of the outcrop on each sampling occasion it would be more accurate to examine the number of *G. maculosus* per metre squared of outcrop (Table 10). The results show that slug density is significantly ($p<0.001$, $K= 107.20$) greater on the outcrops at the blanket bog compared to the other sites which suggests that commercial afforestation has a negative impact on populations of the species on outcrops at Glanteenassig.

Table 10: Mean (± SE) and median number of *Geomalacus maculosus* collected per metre squared of outcrop at the blanket bog, low density conifer, high density conifer and clearfell sites in Glanteenassig Forest, Co. Kerry.

	Blanket bog	Low density conifer	High density conifer	Clearfell
Sample size	165	165	165	165
Mean (±SE)	0.247±0.038	0.038±0.017	0	0.019±0.008
Median	0	0	0	0
Blanket bog	-	-	-	-
Low density conifer	*5.70****	-	-	-
High density conifer	*6.77****	*1.07*	-	-
Clearfell	*5.86****	*0.16*	*0.92*	-

K= 107.20; *P*<0.001, Kruskal – Wallis test (corrected for tied ranks). *q* values (given in italics) indicate significant differences between sites at *p*<0.001 (***) - Nemenyi's non-parametric multiple comparisons test.

At the high density conifer site the outcrops were covered in a thin layer of soil and pine needles. Removing this layer from similar outcrops in the same area showed that lichens were absent from the sandstone. The disappearance of a primary food source for *G. maculosus* likely contributed to its absence from the outcrops at this site. To determine if the species occurs on conifer trunks in the high density area, we placed three band traps 1.5m from the ground on three conifers on September 11 and over the course of the investigation five specimens were collected behind the traps (two individuals on September 19 and one individual on September 25, October 9 and December 22 2010). Therefore, although *G. maculosus* does not appear to occur on outcrops in conifer plantations, it is present on conifer trunks and future studies on the impact of commercial forestry on the species should target this microhabitat. For information on population sizes and densities of *G. maculosus* in an amenity conifer woodland see Chapter 7.

7. POPULATION SIZE AND DENSITY ESTIMATES FOR *GEOMALACUS MACULOSUS* USING MARK-CAPTURE-RECAPTURE

Rationale

The provision of data on population sizes and densities for a protected species is a fundamental step in its conservation. For *G. maculosus* such data are not currently available because of a lack of an effective trapping method and a suitable marking system (NPWS 2010). Given that these are no longer limitations (see Chapters 2 and 4 above), the aim of this part of the research was to provide the first population size and density estimates for the species over a range of sites of varying quality.

Woodland

Study sites

After the completion of the exploratory study (see section 6B above) in the Glengarriff woodlands, the same sites (Figure 17), but different trees, were used for a mark-capture-recapture investigation. Photographs of the *Rhododendron*-infested and uninfested sites are given in Plates 21 and 22 respectively.

Plate 21: The *Rhododendron*-infested site in the Glengarriff woodlands (Co. Cork) that was used for the mark-capture-recapture study (© Rory Mc Donnell).

Plate 22: The uninfested site in the Glengarriff woodlands (Co. Cork) that was used for the mark-capture-recapture study (© Rory Mc Donnell).

Materials and methods

At both the infested and uninfested site, a single band trap was placed 1.5m from the ground on the trunk of 18 adjacent deciduous trees. In addition, 10 individual metric traps were placed randomly on the woodland floor between these trees. At the uninfested site this comprised an area of 208.29 m^2 and 196.9 m^2 at the infested site. All of the traps were saturated with water prior to use and baited with organic carrot. To determine the population sizes of *G. maculosus* at each of these sites a mark-capture-recapture study was undertaken. A robust design was chosen because this approach tends to be the most reliable as it helps to minimise the violation of mark-recapture assumptions such as equal catchability (Krebs 1999). It involves the use of primary and secondary sampling periods. Our study comprised three primary sampling periods, each of which consisted of five consecutive days (secondary periods) of sampling (September 5-9, September 19-23 and October 5-9). Specimens were marked using the elastomer tags discussed in Section 5 above and a separate colour was used for each primary sampling period (red, blue and green). Specimens were always tagged in two places (either side of the mid-dorsal line) on the foot (Plate 14) and they were returned behind the band trap where they were found. The Schnabel and Schumacher-Eschmeyer Methods were used to calculate population sizes.

Results and discussion

There are no data on the sizes of *G. maculosus* populations in its various habitats throughout Ireland. In fact, current information is restricted to anecdotal observations and limited field work

(NPWS 2010). This is surprising given the high conservation value of the species, as such data should be a key criterion in designating sites for its protection throughout its global range.

Nevertheless, we present here the first population estimates for *G. maculosus* (Table 11). Importantly, there is good agreement between the Schnabel and the Schumacher-Eschmeyer approaches, which is good evidence for robust estimates of population size (Williams *et al*. 2010). Consequently for convenience we will only refer to the Schnabel values from herein. Firstly, in an uninfested area (208.29 m^2) of oak-birch-holly woodland the population estimates were 29.00 (September 5-9), 49.56 (September 19-23) and 20.30 (October 5-9) individuals. Although the standard errors are quite large for our estimates (Table 11), this is not unusual in mark-recapture studies involving invertebrates (Williams *et al.* 2010; Matlock *et al*. 1996).

In calculating population density it is important to consider the home range of individuals that are not completely included within the sampling area as this can lead to inflated density estimates. However, when information on the mobility of the target species is known (see Mobility Study in Chapter 5 above), this can be utilised to provide more accurate estimates of density by adding half the movement radius of the species (*G. maculosus*: 5.45m) to the sampling area (Krebs 1999). In the uninfested woodland site (adjusted area: 396.04 m^2) the density estimates for *G. maculosus* (Table 11) therefore, were 0.07 m^{-2} (September 5-9), 0.13 m^{-2} (September 19-23) and 0.05 m^{-2} (October 5-9). These results are comparable with population density estimates for other slug species e.g. *Arion lusitanicus* (Grimm & Paill 2001: 0.15 m^{-2}).

The introduction of *Rhododendron* into west Cork and Kerry has had a significant effect on woodland ecology, particularly in parts of the Killarney National Park and Glengarriff Nature Reserve (NPWS 2010) but as mentioned above very little information is available on the relative significance of this invasive species on *G. maculosus*. In the infested site (196.9 m^2) used in our study, the population estimates (Table 11) were 4.00, 7.00 and 2.00 individuals for the three primary sampling periods. These estimates are seven times less than those in the uninfested site, confirming that *R. ponticum* is likely to have an adverse effect on populations of *G. maculosus.* A similar pattern was also observed in the population density (0.01, 0.02, 0.01) estimates (adjusted area of infested site: 384.11m^2).

Table 11: Population density, population size, standard error and 95% confidence intervals for *Geomalacus maculosus* in both a *Rhododendron ponticum* – infested and uninfested site in the Glengarriff woodlands (Co. Cork), as calculated by the Schnabel and Schumacher-Eschmeyer methods.

			September 5 – 9	September 19 – 23	October 5 – 9	Mean (±SD)
Uninfested site	*Schnabel*	Population density (m^{-2})*	0.07	0.13	0.05	0.08 ± 0.04
		Population size	29.00	49.56	20.30	32.95 ± 15.03
		Standard error	136.02	297.33	97.38	-
		Confidence interval (95%)	19.77 – 46.35	36.60 – 70.24	13.72 – 31.30	-
	Schumacher-Eschmeyer	Population density (m^{-2})*	0.08	0.13	0.05	0.09 ± 0.04
		Population size	31.68	50.12	21.58	34.46 ± 14.47
		Standard error	126.08	496.60	94.93	-
		Confidence interval (95%)	17.60 – 158.01	37.94 – 78.83	12.52 – 78.01	-
Infested site	*Schnabel*	Population density (m^{-2})*	0.01	0.02	0.01	0.01 ± 0.005
		Population size	4.00	7.00	2.00	4.33 ± 2.52
		Standard error	6.93	9.90	2.83	-
		Confidence interval (95%)	1.48 – 14.67	2.09 – 39.44	0.60 – 11.27	-
	Schumacher-Eschmeyer	Population density (m^{-2})*	0.01	0.02	0.01	0.01 ± 0.005
		Population size	4.67	7.33	2.00	4.67 ± 2.67

Standard error	19.80	16.06	0	-
Confidence interval (95%)	2.67 – 18.72	2.99 – 16.20	0	-

* Population density estimates are calculated by incorporating a boundary layer of half the movement radius (See Section 5) of *G. maculosus* (5.45m) into the sampling area (adjusted area of uninfested site: 396.04 m^2; adjusted area of infested site: 384.11 $m^{2)}$

Blanket bog

Study sites

This mark-capture-recapture investigation was carried out in Cashelkeelty, Co. Kerry (Figure 20). The first site was an area of lowland blanket bog (Plate 23) located approximately 500m to the west of the Cashelkeelty permanent monitoring stations (see Chapter 4 above). The two areas are also separated by a fast-flowing stream. Derreen Forest Estate is adjacent to the blanket bog and was planted in 1967 for aesthetic, as opposed to commercial, purposes (Ted O'Shea pers. comm.) Consequently it is a relatively open conifer forest with abundant lichen and bryophyte growth on the forest floor and tree trunks (Plate 24). The primary tree species present include *Picea sitchensis*, *Pinus contorta*, *Larix kaempferi* and *Pseudotsuga menziesii*. The second and third study sites were located on the edge (Plate 23) and in the centre (Plate 24) of the forest respectively.

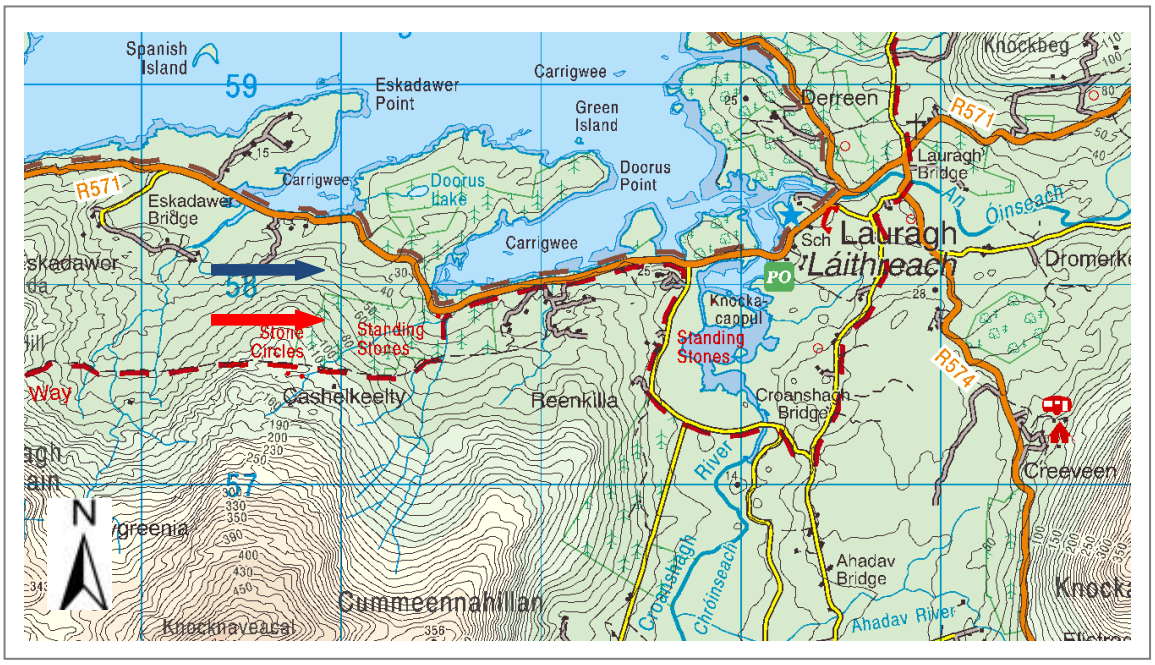

Figure 20. Ordnance Survey Map (1:50,000) showing the location of study sites at Cashelkeelty (blue arrow) and Derreen Forest Estate (red arrow), Lauragh, Co. Kerry.

Materials and methods

On the blanket bog site, twelve adjacent sandstone outcrops were selected. Metric traps were positioned at the midpoint of each of these outcrops and then every 1m from this point to the north, south, east and west until the edge of the outcrop was reached. In addition, 10 individual metric traps were placed randomly on the blanket bog between the outcrops. At both the conifer forest edge and centre, a single band trap was placed 1.5m from the ground on the trunk of 12 adjacent conifers and 10 individual metric traps were placed randomly on the woodland floor

Plate 23: Part of the blanket bog site at Cashelkeelty (foreground) and the forest edge site (Derreen Forest Estate, Co. Kerry) that were used for the mark-capture-recapture study (© Rory Mc Donnell).

between the trees. The total sizes of these study areas were 273.42 m^2, 66.94 m^2 and 73.63 m^2 for the blanket bog, forest edge and forest centre respectively. The study area is larger on the blanket bog because the distance between the outcrops was greater than that between the trees in the forest sites. As with all of our field investigations, the traps were saturated with water prior to use and baited with organic carrot. The mark-capture-recapture design was the same as that for the woodland study above but the three primary sampling periods were November 7-11, November 21-25 and December 5-9 2010.

Results and discussion

The widespread planting of commercial conifer forestry is thought to have had a detrimental effect on populations of *G. maculosus* (NPWS 2010) but our results in Chapter 6 above suggest that although the species does not appear to occur on outcrops in such forests it can survive on conifer trunks. In addition, the impact of more open conifer forestry such as that at Derreen Forest Estate

Plate 24: The conifer forest centre site at Derreen Forest Estate (Co. Kerry) that was used for the mark-capture-recapture study (© Rory Mc Donnell).

has not been considered. Surprisingly our studies show that such areas support relatively large populations of *G. maculosus* (Table 12). Over the three sampling periods (November 7-11, November 21-25 and December 5-9 2010) the population size (and density) estimates at the centre of the conifer forest were 35.34 (0.18), 31.15 (0.16) and 19.48 (0.10). These results suggest that relatively open conifer forests with abundant epiphytic, bryophytes (as at Derreen Forest Estate) can be suitable habitats for *G. maculosus*.

The population estimates for *G. maculosus* on the blanket bog site were lower than both of the conifer study sites for each primary sampling period (Table 12) which is surprising considering that 59 specimens were collected on the eight permanent monitoring outcrops (located approximately 500 metres to the east) on October 11 2010 (Figure 8). In fact, during the first sampling period the population density estimate in the conifer forest centre (0.18) was six times greater that on the blanket bog (0.03). Perhaps, the area of blanket bog used for the investigation had a small population or there was limited foraging (and consequently specimens were less likely to take refuge under the traps) in the blanket bog during the experimental period. Given the very cold weather experienced in Ireland during late November and early December 2010 (www.meteireann.ie) this would seem to be a logical explanation. This arctic snap may also explain the large decrease in population size (forest edge: 65.81%; forest centre: 44.88%) estimates observed in the final sampling period compared to the first (Table 12).

Table 12. Population density, population size, standard error and 95% confidence intervals for *Geomalacus maculosus* on a lowland blanket bog, conifer forest edge and conifer forest centre sites in Derreen Forest Estate, Co. Kerry, as calculated by the Schnabel and Schumacher-Eschmeyer methods.

			November 7-11	November 21-25	December 5-9	Mean (±SD)
Blanket bog	*Schnabel*	Population density (m^{-2})*	0.03	0.03	0.04	0.03 ± 0.01
		Population size	7.80	9.22	11.47	9.50 ± 1.85
		Standard error	17.44	44.21	68.83	-
		Confidence interval (95%)	3.49 – 19.80	6.23 – 14.21	8.47 – 16.26	-
	Schumacher-Eschmeyer	Population density (m^{-2})*	0.03	0.03	0.04	0.03 ± 0.01
		Population size	8.05	9.41	11.54	9.67 ± 1.76
		Standard error	56.94	80.38	331.01	-
		Confidence interval (95%)	5.55 – 14.63	6.86 – 14.99	10.39 – 12.98	-
Conifer forest edge	*Schnabel*	Population density (m^{-2})*	0.09	0.06	0.03	0.06 ± 0.03
		Population size	16.29	10.42	5.57	10.76 ± 5.37
		Standard error	67.18	36.08	20.85	-
		Confidence interval (95%)	10.53 – 28.86	6.15 – 18.70	3.40 – 9.63	-
	Schumacher-Eschmeyer	Population density (m^{-2})*	0.09	0.06	0.03	0.06 ± 0.03
		Population size	16.88	10.82	5.62	11.11 ± 5.64
		Standard error	124.17	59.04	80.42	-

		Confidence interval (95%)	11.78 – 29.74	6.83 – 25.94	4.60 – 7.23	-
Conifer forest centre	*Schnabel*	Population density (m^{-2})*	0.18	0.16	0.10	0.15 ± 0.04
		Population size	35.34	31.15	19.48	28.66 ± 8.22
		Standard error	264.46	256.84	158.30	-
		Confidence Interval (95%)	25.78 – 56.18	23.30 – 46.95	14.52 – 29.60	-
	Schumacher-Eschmeyer	Population density (m^{-2})*	0.18	0.16	0.10	0.15 ± 0.04
		Population size	35.96	31.43	19.72	29.04 ± 8.38
		Standard error	392.93	505.49	324.68	-
		Confidence interval (95%)	27.85 – 50.72	26.24 – 39.17	16.53 – 24.44	-

* Population density estimates are calculated by incorporating a boundary layer of half the movement radius of *G. maculosus* into the sampling area. For the blanket bog half the movement radius is 0.5m (Chapter 5) but for the conifer centre and edge sites half the movement radius for a woodland (5.45m) was used (Chapter 5). Adjusted area of blanket bog site: 290.32 m^2; adjusted area of conifer edge site: 186.02 m^2; adjusted area of conifer centre site: 197.89 m^2).

MANAGEMENT RECOMMENDATIONS

1. A major *Rhododendron* eradication programme has been in place for several decades throughout the range of *G. maculosus* in Ireland (NPWS 2010) and given the results of our studies, it would be prudent for this programme to be maintained and perhaps intensified as it is likely to facilitate the conservation of the species. Interestingly, Barron (1998) has recorded the slug in cleared areas but concluded that abundances were less than in uninfested sites. The next logical step would be to investigate actual population sizes of the Kerry slug in cleared areas of woodland (see Future Research below).

2. To effectively protect *G. maculosus* in conifer forests, it will be important to elucidate those biotic and abiotic factors which govern the abundance of *G. maculosus* in such habitats. This information could then be incorporated into the planning stages for developing Areas for Biodiversity Enhancement (ABEs) which are the main vehicle of the Forest Service for promoting the development of diverse habitats and native flora and fauna within plantations. One advantage of such an approach is that it will help the Forest Service to reach its goal of having biodiversity as a primary management objective for 15% of its forested areas (NPWS 2010).

3. The Forestry and Kerry Slug Guidelines (Forest Service 2009) describe the methods and measures by which the Forest Service will protect the species during forest operations and when issuing licenses and approvals for forestry operations. Interestingly, these guidelines state that the majority of Irish conifer plantations are managed as a commercial crop and consequently are unlikely to have trees with sufficient lichens to support the species. Our data conflict with this statement as we have collected *G. maculosus* from the trunks of conifers in Glanteenassig and from plantations in a number of hectads in Cork and Kerry (Appendix 2). If the species is present in a plantation, any activity (e.g. scarification, drainage, thinning, harvesting and road construction) is likely to adversely impact on it (Forest Service 2009) and therefore, the production of a revised set of forestry guidelines for *G. maculosus* should now be a priority as it will facilitate the conservation of the species throughout its range.

4. Environmental Impact Assessments are now mandatory for new forestry proposals greater than 50 hectares and consequently it will be important that these surveys utilize an appropriate method for sampling *G. maculosus*. The band and outcrop traps highlighted in Chapter 2 above would be a suitable approach.

5. If *G. maculosus* is discovered in a commercial plantation it may be possible to conserve the species by designating the site as a High Conservation Value Forest (HCVF). In fact a large portion of Coillte's estate has been designated as HCVF (on grounds other then the presence of *G. maculosus*). When a site achieves HCVF status, management must aim to maintain and enhance the conservation value of the site.

6. Our research showed that unmanaged burning appeared to have a negative impact on populations of *G. maculosus* in the short-term but the species was trapped on outcrops on a burnt site approximately three months after burning. Since the latter can sometimes be

used as a management tool, a rotational approach to burning on peatlands would therefore seem to be a prudent prescription if burning is to be used as a management option throughout the range of *G. maculosus*. This is because rotational burning may enable specimens from unburnt areas to colonise outcrops on burnt parts of the site if populations in the latter are negatively impacted by the fire.

7. Given that other species of conservation importance e.g. *L. cinereoniger* (listed as vulnerable in Ireland by Byrne *et al.* 2009) and *Vandenboschia speciosa* (an Annex II species in the Habitats Directive) often occur in the same sites as *G. maculosus* (e.g. Uragh Wood, Co. Kerry), it will be important that management recommendations for the Kerry slug do not impact negatively on such species. Incorporating the different requirements of a list of such specialised species into management plans i.e. a multi-species approach to conservation would be a sensible tactic.

FUTURE RESEARCH

1. An important area for future research will be to investigate the extent of colonisation of *Rhododendron*-cleared areas by *G. maculosus.* This could be achieved by using a range of sites which have been cleared for varying time periods e.g. one year, five years, ten years and fifteen years as such an approach will generate data on colonisation rates and possibly habitat features that are required to promote colonisation.
2. Similarly, the extent and rate of colonisation of clearfell areas would be beneficial. Our results show that *G. maculosus* occurs on outcrops in clearfelled sites but there is no information on the source of these populations e.g. are they a remnant of the population occurring in the plantation before it was felled or do they colonise from suitable surrounding habitats? Since we have highlighted a suitable tagging procedure for *G. maculosus* such questions could now be addressed.
3. Given the apparent low mobility of the species in woodlands and blanket bogs it is important that future research provides data on the dispersal ability of juveniles and the extent of separation of populations.
4. The recent discovery of *G. maculosus* in Lettercraffroe, Co. Galway (Kearney 2010) is an area in need of much research e.g. what is the current range of the population? Is it breeding? It will also be important to determine whether the population was accidentally introduced to the area or whether it represents a distinct population (see 5 below). If the species was accidentally introduced then the vector of introduction needs to be identified as it may provide information on where other potentially undiscovered populations exist throughout the country.
5. Research on the extent of genetic diversity in Irish populations of *G. maculosus* is now required. Population genetics could also be utilised to investigate the degree of affinity of Irish populations with those in Iberia. In addition, molecular biology could be used to determine the source of the population of *G. maculosus* in Co. Galway or to elucidate if the latter represents a distinct population. Similar questions have been successfully addressed for other slug species in other parts of the world (Mc Donnell *et al.* 2011).
6. Future research should also aim to generate data on basic ecological and biological features of the species e.g. adult longevity in the wild; the extent of outcrossing and self-fertilisation; natural enemies; diseases; and the degree of mixing between woodland and peatland populations.
7. Finally, given that *G. maculosus* is now known to occur outside of its historical range in Cos Cork and Kerry, future surveys for the species should be on a national scale.

BIBLIOGRAPHY & RELEVANT LITERATURE

Allman, G.J. (1843) On a new genus of terrestrial gastropod *Athenaeum* **829:** 851.

Allman, G.J. (1844) On a new genus of terrestrial gastropod *Report to the British Association for the Advancement of Science* **1843**: 77.

Allman, G.J. (1846) Description of a new genus of pulmonary gastropods. *Annals & Magazine of Natural History* **17:** 297-99.

Archard, G.A., Bohan, D.A., Hughes, L. & Wiltshire, C.W. (2004) Spatial sampling to detect slug abundance in an arable field. *Annals of Applied Biology* **145:** 165-73.

Avila, V. L. (1995) *Biology: Investigating Life on Earth.* Jones and Bartlett.

Barron, C. (1998) *The distribution of the Kerry Slug,* Geomalacus maculosus, *within the oakwoods of Killarney National Park, southwest Ireland: The influence of* Rhododendron ponticum. A project prepared in partial fulfilment of a B.Sc. in Countryside Management. Welsh Institute of Rural Studies, Aberystwyth.

Brady, J.K. & Pearce, T.A. (2007) Terrestrial slugs in strip mined and unmined forested land, Tuscarawas County, Ohio, U.S.A. *Proceedings of the Academy of Natural Sciences* **156:** 117-22.

Burch, J.B. (1962) *How to Know the Eastern Land Snails.* William. C. Brown Company Publishers, Dubuque, Iowa.

Byrne, A., Moorkens, E.A., Anderson, R., Killeen, I.J. & Regan, E.C. (2009) *Ireland Red List No. 2 – Non-Marine Molluscs.* National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland.

Castillejo, J., Garrido, C. & Iglesias, J. (1994) The slugs of the genus *Geomalacus* Allan, 1843, from the Iberian peninsula (Gastropoda: Pulmonata: Arionidae). *Basteria* **58**: 15-26.

Clark, P.J. & Evans, F.C. (1954) Distance to nearest-neighbour as a measure of spatial relationships in populations. *Ecology* **35:** 445-53.

Clements R.O. & Murray, P.J. (1991) Comparison between defined-area slug traps and other methods of trapping slugs in cereal fields. *Crop Protection* **10:** 152-54.

Cohen, J. (1988) *Statistical Power Analysis for the Behavioural Sciences.* Lawrence Erlbaum, Hillsdale, New Jersey.

Desmars, J. (1873) *Essai d'un Catalogue méthodique et descriptif des Mollusques terrestres, fluviatiles et marine observés dans l'Ille de Vilaine, les departments limitrophes de l'Ouest de la France, et sur les côtes de la Manchede Brest à Cherbourg.* Chauvin, Redun.

Donnelly, K. (1978) Simulations to determine the variance and edge-effect of total nearest neighbour distance. In: I. Hodder. *Simulation Methods in Archaeology,* Pp. 91-95. Cambridge University Press, London.

Falkner, G., Ripken, T.E.J. & Falkner, M. (2002) *Mollusques continentaux de France Liste de Référence annotéeet Bibliographie.* Patrimoines Naturels, 52, Museum d'Histoire Naturelle, Paris.

Forest Service (2007) *National Forest Inventory Republic of Ireland –Results.* Forest Service, Department of Agriculture, Fisheries and Food, Dublin

Forest Service (2009) *Forestry and Kerry Slug Guidelines.* Department of Agriculture, Fisheries and Food, Dublin

Fossitt, J.A. (2000) *A Guide to Habitats in Ireland.* The Heritage Council, Kilkenny.

Gibbs, J.P. & Ene, E. (2010) Program Monitor: Estimating the statistical power of ecological monitoring programs. Version 11. http://www.esf.edu/efb/gibbs/monitor/

Godan, D. (1983) *Pest slugs and snails. Biology and control.* Springer-Verlag, Berlin.

Grimm, B. & Paill, W. (2001) Spatial distribution and home range of the pest slug *Arion lusitanicus* (Mollusca: Pulmonata). *Acta Oecologica* **22:** 219-27.

Joseph, L.N., Field, S.A., Wilcox, C. & Possingham, H.P. (2006) Presence-absence versus abundance data for monitoring threatened species. *Conservation Biology* **20:** 1679-87.

Kearney, J. (2010) Kerry slug (*Geomalacus maculosus* Allman 1843) recorded at Lettercraffroe, Co. Galway. *Irish Naturalists' Journal* **31:** 68-69.

Kerney, M.P. (1999) *Atlas of the land and freshwater molluscs of Britain and Ireland.* Harley Books, Colchester

Kleewein, D. (1999) Population size, density, spatial distribution and dispersal in an Austrian population of the land snail *Arianta arbustorum styriaca* (Gastropoda: Helicidae). *Journal of Molluscan Studies* **65:** 303-15.

Krebs, C.J. (1999) *Ecological Methodology. 2nd Edition.* Benjamin Cummings, Menlo Park, California.

Mc Donnell, R.J. & Gormally, M.J. (2011) Identification of a live trapping method for the protected European slug, *Geomalacus maculosus* Allman 1843 (Arionidae). *Journal of Conchology* **40:** 483-485.

Mc Donnell, R.J., Rugman-Jones, P., Backeljau, T., Breugelmans, K., Jordaens, K., Stouthamer, R., Paine, T.D. & Gormally, M.J. (2011) Molecular identification of the exotic slug *Arion subfuscus* sensu lato (Gastropoda: Pulmonata) in California, with comments on the source location of introduced populations. *Biological Invasions* **13:** 61-66.

Mc Donnell, R.J., Paine, T.D., Stouthammer, R., Gormally, M.J. & Harwood, J.D. (2008) Molecular and morphological evidence for the occurrence of two new species of invasive slugs in Kentucky, *Arion intermedius* Normand, 1852, and *Arion hortensis* d'Audebard de Férussac, 1819 (Arionidae: Stylommatophora). *Journal of the Kentucky Academy of Science* **69:** 117–23

Matlock, R.B., Welch, J.B. & Parker, F.D. (1996) Estimating population density per unit area from mark, release, recapture data. *Ecological Applications* **6**: 1241–45.

Moorkens, E. A. & Killeen, I. J. (2009) Database of association with habitat and environmental variables for non-shelled slugs and bivalves of Britain and Ireland. *Irish Wildlife Manuals*, No. 41. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland.

NPWS (2003a) *Site synopsis for Glengarriff Harbour and Woodland Special Area of Conservation.* National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland.

NPWS (2003b) *Site synopsis for Cloonee, Inchiquin Lough and Uragh Wood Special Area of Conservation.* National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland.

NPWS (2008) *Conservation Status Assessment Report for Geomalacus maculosus.* National Parks and Wildlife Service, Dublin.

NPWS (2010) *Threat Response Plan - Kerry Slug* Geomalacus maculosus. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin

Oldham, L. (1942) Notes on *Geomalacus maculosus. Journal of Molluscan Studies* **3**: 94-104.

Platts, E.A. & Speight, M.C.D. (1988) The taxonomy and distribution of the Kerry slug, *Geomalacus maculosus* Allman, 1843 (Mollusca: Arionidae) with a discussion of its status as a threatened species. *Irish Naturalists' Journal* **22:** 417-30.

Rogers, T. (1900) The eggs of the Kerry Slug, *Geomalacus maculosus*. Allman. *Irish Naturalist* **9:** 168-70.

South, A. (1992) *Terrestrial Slugs: Biology, ecology and control*. Chapman and Hall, London.

Taylor, J.W. (1906) *Monograph of the Land and Freshwater Mollusca of the British Isles. 2.* Taylor Brothers, Leeds.

Underwood, A.J. (1976) Nearest neighbour analysis of spatial dispersion of intertidal prosobranch gastropods within two substrata. *Oecologia* **26:** 257-66.

Verdú, J.R. & Galante, E. (2005) *Libro Rojo de los Invertebrados de España*. Dirección General de Conservación de la Naturaleza, Madrid.

Wallin, K.F. & Latty, T.M. (2008) Novel intermediate-term individual marking technique for slugs. *Journal of Molluscan Studies* **74:** 299-300.

Watson, E.V. (1981) *British Mosses and Liverworts*. Cambridge University Press, Cambridge.

Williams, C.D., Gormally, M.J. & Knutson, L.V. (2010) Very high population estimates and limited movement of snail-killing flies (Diptera: Sciomyzidae) on an Irish turlough (temporary lake). *Biology and Environment: Proceedings of the Royal Irish Academy* **110:** 81–94.

Wisniewski, P.J. (2000) Husbandry and breeding of Kerry spotted slug *Geomalacus maculosus* at the endangered species breeding unit, Martin Mere. *International Zoo Yearbook* **37:** 319-321.

Young, A.G. (1990) Assessment of slug activity using bran-baited traps *Crop Protection* **9:** 355-58.

Personal Communications

(1) Mr. Paddy Graham, Conservation Ranger, Glengarriff Woods Nature Reserve, Glengarriff, Co. Cork.

(2) Ms. Denise Hall, Glengarriff, Co. Cork.

(3) Ms. Clare Heardman, Conservation Ranger, Glengarriff Woods Nature Reserve, Glengarriff, Co. Cork.

(4) Dr. Katherine Kelleher, Senior Project Ecologist, Fehily Timoney & Company, Core House, Pouladuff Road, Cork City, Co. Cork.

(5) Mr. Ted O'Shea, Derreen Gardens and Forest Estate, Lauragh, Co. Kerry.

(6) Mr. Con O'Sullivan, Loughavoul, Glengarriff, Co. Cork

(7) Ms. Izabela Witkowska, Forest Manager-RS2I, Coillte Teo, Lower Main Street Castleisland, Co. Kerry.

APPENDIX 1. KERRY SLUG INFORMATION LEAFLET

Background information on the Kerry Slug

The Kerry Slug (scientific name: *Geomalacus maculosus*) was first discovered beside Caragh Lake in Co. Kerry in 1842. It is an easily recognizable, medium sized slug (up to 9cm in length) and individuals can be brown with yellow spots (see Photo 1) or black with white spots (see Photo 2).

Photo 1. Brown and yellow spotted Kerry Slug *(photo by Rory Mc Donnell).*

Photo 2. Black and white spotted Kerry Slug *(photo by Eddie Dunne).*

Unlike many other slug species, the Kerry Slug is not regarded as a pest and is associated with wild habitats away from humans. In Ireland this invertebrate is protected under the Wildlife Act 1976 and under the EU Habitats Directive (as an Annex II and Annex IV species). In addition, seven Special Areas of Conservation (SACs) have been designated for the protection of the species.

Where is the Kerry Slug found?

The global distribution of the Kerry Slug is Ireland, Spain and Portugal and although the species has been reported from France, its presence there has never been confirmed. In Ireland, the slug is restricted to west Cork and Co. Kerry. In these areas it is found in two habitat types, oak dominated woodland (see Photo 3) and unimproved open moor or blanket bog (see Photo 4).

Photo 3. Typical woodland habitat of the Kerry Slug in West Cork and Kerry *(photo by Rory Mc Donnell).*

Photo 4. Typical peatland habitat of the Kerry Slug in West Cork and Kerry *(photo by Ciarán Sullivan).*

Within these woodlands it is only present if there are deciduous trees that are covered in bryophytes (such as mosses and liverworts) and its presence on moors and blankets bogs is dependent on sandstone outcrops and boulders largely bare of vegetation except for lichens and bryophytes on which the species is thought to feed.

When is the best time to spot the Kerry Slug?

The best time to find the Kerry Slug is on wet, cloudy days when specimens are often seen crawling over tree trunks or sandstone outcrops in suitable habitat. During sunny, warm weather the slug takes refuge under bryophytes, in cracks on sandstone rocks and behind the vegetation at the base of sandstone boulders. Surveys at dawn, dusk and during the night in Spain have also proved successful.

How will I know if I have found a Kerry Slug?

The Kerry Slug has a number of characteristics make it relatively easy to identify. Firstly, when disturbed, it curls itself up into a defensive ball (see Photo 5).

Photo 5. The Kerry Slug curled into its characteristic defensive ball (*photo by Rory Mc Donnell).*

Its habitat specificity, restricted distribution in Ireland and unique coloration (see Photos 1 and 2) also make this slug easy to recognize. However, because the Kerry Slug is a protected species, specimens should never be removed from their habitat or harmed in any way.

Are there any other slugs which look like the Kerry Slug?

There is one Irish slug which may be confused with the Kerry Slug. It is called the Cellar Slug (scientific name: *Limacus flavus*) but it tends to be mottled yellow and green or yellow and brown and has distinct petrol blue tentacles (see Photo 6).

Photo 6. The Cellar Slug *(photo by Rory Mc Donnell)*.

Although the Kerry Slug can be brown with yellow spots (see Photo 1), it does not have the distinct tentacle coloration of the Cellar Slug. In addition, the latter is unable to curl itself into a defensive ball and it is not restricted to west Cork and Co. Kerry. In fact the Cellar Slug has been recorded from throughout the country.

What will I do if I find a Kerry Slug?

The project team welcomes records at any time of the year. If you have found a Kerry Slug you can upload your record to the project website (www.kerryslug.com). Alternatively you can send the information by e-mail to kerryslug@gmail.com or by post to *Dr. Rory Mc Donnell, Applied Ecology Unit, Centre for Environmental Science, School of Natural Sciences, NUI Galway*. Please include details of the location (preferably with grid reference) and date of the sighting. We also encourage observers to send a photograph with their submissions. The project team can be contacted at *+353 91 493863*.

What are the aims of the Kerry Slug National Survey?

The aim of the survey is to accrue modern records for this internationally important invertebrate with the overall objective of producing an up-to-date distribution map. In Ireland, there are five 10km grid squares where the species has not been recorded since pre-1950 and other areas where the last records are pre-1980. The survey will help to address these important shortcomings. This investigation also forms an integral part of a wider study to examine the population ecology of the Kerry Slug and to develop a suitable monitoring protocol for the species.

Photo 7. A Kerry Slug on a sandstone outcrop in Co. Kerry *(photo by Rory Mc Donnell)*.

The Kerry Slug National Survey

A collaboration between the ***National Parks and Wildlife Service*** *and the* ***Applied Ecology Unit at the National University of Ireland, Galway***

NUI Galway
OÉ Gaillimh

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

Applied Ecology Unit

APPENDIX 2. DATE-LOCALITY RECORDS FOR *GEOMALACUS MACULOSUS* GENERATED DURING THIS PROJECT. RECORDS IN BLUE FONT ARE THE FIRST RECORDS OF THE SPECIES WITHIN THAT HECTAD.

Hectad	Date	Number of individuals	GPS Co-ordinates(Irish GridReference)	Location	Habitat	Recorder
Q40	Mar 11 2011	1	Q4684504217	Ballybowler, Co. Kerry	Heath	Rory McDonnell
Q50	Aug 19 2010	1	Q5947308135	Glanteenassig, Co. Kerry	Blanket bog	Rory Mc Donnell
Q60	Aug 19 2010	1	Q6001808077	Glanteenassig Forest, Co. Kerry	Clearfell	Rory Mc Donnell
	Oct 9 2008	1	Q699094	Camp, Co. Kerry	Mixed deciduous woodland	Martin Cawley
Q91	**Mar 25 2010**	**1**	**Q9356618866**	**Maghanknockane, Co. Kerry**	**Conifers on blanket bog**	**Eugene Ross and Tom Sheehan**
	Mar 6 2011	**1**	**Q9707718121**	**Between Muingnaminnane and Reanagowan, Co. Kerry**	**Conifers on blanket bog**	**Rory Mc Donnell**
V46	Mar 10 2011	1	V4293167455	Kinard, Co. Kerry	Young conifer stand	Rory Mc Donnell
V47	Oct 2 2010	1	V4848472152	Between Aghatubrid and Tullig, Co. Kerry	Conifer plantation	Rory Mc Donnell
V48	**Mar 11 2011**	**1**	**V4454180426**	**Ballycarbery, Co. Kerrry**	**Improved heath**	**Rory Mc Donnell**
V54	May 8 2009	1	V5502347631	Cod Head, near Allihies, Co. Cork	Blanket bog	Rory Mc Donnell
	May 8 2009	2	V5527247595	Cod Head, near Allihies, Co. Cork	Blanket bog	Rory Mc Donnell
	June 1 2006	-	V578458	Gariflan Point, East of Allihies, Co. Cork	Not provided	Geraldine Holyoak
V55	Oct 2 2010	1	V565582	Glanbeg, Co. Kerry	Blanket bog	Rory Mc Donnell
	May 18 2006	-	V532589	East of Derrynane House, Darrynane Mor, Co. Kerry	Not provided	Geraldine Holyoak

	May 19 2006	-	V530570	Lambs Head, southwest of Caherdaniel, Co. Kerry	Not provided	Geraldine Holyoak
V56	May 20 2006	-	V540640	South shore of Lough Currane, Waterville, Co. Kerry	Lake shore	Geraldine Holyoak
V57	Oct 2 2010	1	V5547372014	Mastergeehy, Co. Kerry	Planted oaks beside conifer plantation	Rory Mc Donnell
V64	Oct 12 2009	1	V648471	At base of Miskish Mt (Slieve Miskish Mts) on the Beara Peninsula, Co. Cork	Blanket bog	Sara Curtis
	July 10 2010	1	V648471	At base of Miskish Mt (Slieve Miskish Mts) on the Beara Peninsula, Co. Cork	Blanket bog	Sara Curtis
V65	May 5 2009	1	V688558	Cappul Bridge, Ardgroom, Co. Cork	Blanket bog	Rory Mc Donnell
	May 8 2009	1	V6772454567	Barrees, Beara Peninsula, Co. Cork	Blanket bog	Rory Mc Donnell
	June 5 2009	3	V6771954570	Barrees, Beara Peninsula, Co. Cork	Blanket bog	Rory Mc Donnell
	August 2009	-	V694576	Between Coosemore and Dog's Point, Ardgroom, Co. Cork	Coastal rocky heath	Rory Hodd
V66	Sept 25 2009	1	V6986967693	Sneem, Co. Kerry	Blanket bog	Rory Mc Donnell
	Sept 25 2009	1	V6242961288	Sneem, Co. Kerry	Blanket bog	Rory Mc Donnell
	Sept 25 2009	1	V6243461305	Sneem, Co. Kerry	Blanket bog	Rory Mc Donnell
	May 20 2006	-	V600620	North of Liss, Co. Kerry	Not provided	Geraldine Holyoak
V67	May 15 2006	-	V600722	West end of Derriana Lough, Cappanagroun, Co. Kerry	Not provided	Geraldine Holyoak
	May 15 2006	-	V600700	Near south shore of Cloonaghlin Lough, Garreiny, Co. Kerry	Not provided	Geraldine Holyoak
V68	Sept 15 2006	-	V630840	Tooreenealagh, Co. Kerry	Not provided	Geraldine Holyoak
V69	Mar 11 2011	1	V6617591029	Faha, Co. Kerry	Open conifer forest	Rory Mc Donnell

V72	May 1 2009	1	V7792924030	Mallavoge, near Crookhaven, Co. Cork	Blanket bog	Rory Mc Donnell
	May 4 2008	-	V770234	Mallavoge, near Crookhaven, Co. Cork	Not provided	Geraldine Holyoak
	May 8 1996	1	V770248	Barley Cove, Co. Cork	Heath	Martin Cawley
V73	May 1 2009	1	V7368634368	Sheep's Head, Co. Cork	Blanket bog	Rory Mc Donnell
V74	May 8 2009	2	V7761647724	West of Adrigole, Co. Cork	Blanket bog	Rory Mc Donnell
V75	June 5 2009	3	V7552657635	Cashelkeelty, near Lauragh, Co. Kerry	Blanket bog	Rory Mc Donnell
	June 5 2009	1	V7553357535	Cashelkeelty, near Lauragh, Co. Kerry	Blanket bog	Rory Mc Donnell
	July 23 2009	2	V7553957560	Cashelkeelty, near Lauragh, Co. Kerry	Blanket bog	Rory Mc Donnell
	Aug 19 2009	52	-	Cashelkeelty, near Lauragh, Co. Kerry	Blanket bog	Rory Mc Donnell
	May 6 2006	-	V760580	Derreen House and Gardens, near Lauragh, Co. Kerry	Not provided	Geraldine Holyoak
	Oct 10 2010	Many	V745545	Lauragh, Co. Kerry	Blanket bog	Caroline Sullivan
	Oct 10 2010	Many	V752550	Lauragh, Co. Kerry	Blanket bog	Caroline Sullivan
V76	Sept 25 2009	1	V7831667791	Derreenafoyle, Co. Kerry	Blanket bog	Rory Mc Donnell
	Sept 25 2009	1	V7840667773	Derreenafoyle, Co. Kerry	Blanket bog	Rory Mc Donnell
V77	Oct 2 2010	1	V7730373818	Gearha North, Co. Kerry	Conifer plantation	Rory Mc Donnell
	Sept 10 2010	4	V7620177602	Ballaghbeama Gap, Co. Kerry	Not provided	David Tuloup
V78	Oct 20 2009	-	V78638536	Lough Coomloughra, Macgillycuddy's Reeks, Co. Kerry	Lake edge	Rory Hodd
	May 27 2006	-	V720850	Glencar Hotel and grounds, Glencar, Co. Kerry	Not provided	Geraldine Holyoak
V79	July 2006	-	V70399574	L. Yganavan, Cromane, Co. Kerry.	Lake edge	Rory Hodd
V82	**Sept 17 2010**	**1**	**V8004525921**	**Heath near Crookhaven, Co. Cork**	**Heath**	**Rory Mc Donnell**

V83	May 1 2009	1	V8091839371	Sheep's Head, Co. Cork	Blanket bog	Rory Mc Donnell
V84	Nov – Dec 2010	Many	V8813349829	Leahill, near Adrigole, Co. Cork	Blanket bog	Rory Mc Donnell
V85	May 8 2009	3	V8709950373	Curragh, Co. Cork	Blanket bog	Rory Mc Donnell
V86	Aug 20 2009	1	V860622	Gleninchiquin, Beara Penninsula	Blanket bog	Rory Mc Donnell
	June-Sept 2010	Many	V830633	Uragh Woods, Beara Penninsula	Oak woodland	Rory Mc Donnell
	May-June 2010	Many	V894683	Killaha, southwest of Kenmare, Co. Kerry	Blanket bog	Helen Riney
V88	Oct 12 2009	-	V81168496	Hag's Glen, Macgillycuddy's Reeks, Co. Kerry	Not provided	Rory Hodd
	Oct 28 2009	1	V844814	Foot of Carrauntoohil at Idir dha Loch, Co Kerry	Blanket bog	Esther Asprey
	Oct 29 2009	1	V864827	Derrycarna, Co. Kerry	Blanket bog	Esther Asprey
	May 23 2006	-	V880820	Lord Brandon's Cottage, 4km from Derrylea, Co. Kerry	Not provided	Geraldine Holyoak
	Sept 24 2006	-	V830870	Cronin's Yard, south of Knocknafaeghun, Co. Kerry	Not provided	Geraldine Holyoak
	Sept 25 2006	-	V811840	Hags Glen, Macgillycuddy's Reeks, Co. Kerry	Not provided	Geraldine Holyoak
V93	**Oct 1 2010**	**1**	**V9554339923**	**Dromreagh, near Carrigboy, Co. Cork**	**Blanket bog**	**Rory Mc Donnell**
V94	**Mar 9 2011**	**1**	**V9880542023**	**Glanlough, Co. Cork**	**Conifer plantation**	**Rory McDonnell**
V95	May 8 2009	7	V9206556804	Glengarriff Nature Reserve, Co. Cork	Oak woodland	Rory Mc Donnell
	May 8 2009	1	V9212656301	Glengarriff Nature Reserve, Co. Cork	Oak woodland	Rory Mc Donnell
	May 15 2009	1	V9215256289	Glengarriff Nature Reserve, Co. Cork	Oak woodland	Rory Mc Donnell
	May 25 2009	2	V9206556804	Glengarriff Nature Reserve, Co. Cork	Oak woodland	Rory Mc Donnell
	July 20 2009	8	V9206556804	Glengarriff Nature Reserve, Co. Cork	Oak woodland	Rory Mc Donnell

	July 21 2009	4	V9206556804	Glengarriff Nature Reserve, Co. Cork	Oak woodland	Rory Mc Donnell
	July 22 2009	3	V9206556804	Glengarriff Nature Reserve, Co. Cork	Oak woodland	Rory Mc Donnell
	July 20 2009	1	V9206556804	Glengarriff Nature Reserve, Co. Cork	Oak woodland	Rory Mc Donnell
	April 27 2010	4	V9206556804	Glengarriff Nature Reserve, Co. Cork	Oak woodland	Clare Heardman
	June 14 2006	-	V900570	Dromdour, near Glengarriff, Co. Cork	Not provided	Geraldine Holyoak
	Nov 24 1996	2	V920570	Glengarriff, Co. Cork	Oak woodland	Martin Cawley
V96	May-June 2010	Many	V906670	Barraduff, south of Kenmare, Co. Cork	Blanket bog	Helen Riney
V97	**Aug 27 2009**	**1**	**V9161979802**	**Near Derrycunihy Church, Killarney National Park, Co. Kerry**	**Blanket bog**	**Rory Mc Donnell**
V98	April 28 2009	2	V9126581014	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	April 28 2009	1	V9124880986	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	April 28 2009	1	V9125580995	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	April 28 2009	1	V9122581002	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	April 29 2009	1	V9105281004	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	April 29 2009	2	V9104781003	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	April 29 2009	1	V9105381020	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	April 29 2009	2	V9103081059	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell

April 29 2009	2	V9099881097	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 29 2009	1	V9091780936	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 29 2009	1	V9112080973	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 29 2009	2	V9112580977	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 29 2009	1	V9113880958	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 29 2009	2	V9113980962	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 29 2009	1	V9118280937	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 29 2009	1	V9121480964	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 29 2009	1	V9121180990	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 29 2009	1	V9122781005	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 30 2009	2	V9325882833	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 30 2009	1	V9348582838	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 30 2009	1	V9345882828	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
April 30 2009	1	V9347082825	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell

	April 30 2009	1	V9304782829	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	June 4 2009	5	V9126581014	Derrycunihy Woods, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	Aug 27 2009	1	V9160180081	Near Derrycunihy Church, Killarney National Park, Co. Kerry	Oak woodland	Rory Mc Donnell
	May 17 2005	-	V938839	Five Mile Bridge, Killarney National Park, Co. Kerry	Not provided	Geraldine Holyoak
	June 2 2005	-	V909811	Derrycunihy Woods, Killarney National Park, Co. Kerry	Not provided	Geraldine Holyoak
	June 4 2005	-	V900800	Ladies View, Derrycunihy, Killarney National Park, Co. Kerry	Not provided	Geraldine Holyoak
W06	June 13 2006	-	W070650	N ear Coomroe, Co. Cork	Not provided	Geraldine Holyoak
W07	Oct 10 2010	1	W052757	Morley's Bridge, near Kilgarvin, Co. Kerry	Heath	Rory Mc Donnell
W08	Oct 10 2010	1	W095816	Clonkeen (close to junction of N22 and R569), Co. Kerry	Blanket bog	Rory Mc Donnell
W15	Oct 9 2010	1	W134568	Cousane, Co. Cork	Heath with wet grassland	Rory Mc Donnell
W16	Oct 31 2010	1	W168674	Derryvaleen, Co. Cork.	Heath and rocky grassland	Jenny Seawright
W18	Oct 10 2010	5	W120831	Derrymacklavlode, Co. Kerry	Wet grassland	Rory Mc Donnell
W27	Oct 10 2010	3	W264746	Lissacresig, Co. Cork	Heath	Rory Mc Donnell

APPENDIX 3. DATE-LOCALITY AND HABITAT DATA FOR THOSE HECTADS WHERE *GEOMALACUS MACULOSUS* WAS NOT RECORDED DURING THE PROJECT.

Hectad	Previous record (from NPWS data)	Resurvey Date	GPS Co-ordinates (Irish Grid Reference)	Habitat and location*
Q92	No records	Mar 6 2011	Q9803121519	Conifer plantation, Glantaunyalkeen, Co. Kerry
		Mar 6 2011	Q9830821713	Birch stand on the edge of a conifer plantation, Glantaunyalkeen, Co. Kerry
V36	Kearney (1999)	Mar 10 2011	V3934465492	Blanket bog interspersed with wet grassland, Tooreen, Co. Kerry
		Mar 10 2011	V3936168486	Heath interspersed with grassland, Rathkieran, Co. Kerry
V37	Post-1965	Oct 2 2010	V3465973718	Grazed heath with wet grassland on Valencia Island, Co. Kerry
		Oct 2 2010	V3438873689	Grazed heath with interspersed wet grassland on Valencia Island, Co. Kerry
		Oct 2 2010	V3730375940	Grazed heath on Valencia Island, Co. Kerry
V44	Post-1965	Mar 9 2011	V4930241273	Grazed heath on Dursey Island, Co. Cork
		Mar 9 2011	V4899641271	Grazed heath on Dursey Island, Co. Cork
V45	Pre-1965	Mar 10 2011	V4960959899	Grazed heath, Coomatloukane, Co. Kerry
		Mar 10 2011	V4970059400	Heath, Coomatloukane, Co. Kerry
V49	No records	Mar 11 2011	V4242998943	Small stand of oak, holly and birch, Ballymacdoyle, Co. Kerry
		Mar 11 2011	V4144999786	Small stand of oak and birch, Ballyameenboght, Co. Kerry
V58	1988	Oct 2 2010	V5277983704	Bryophyte-covered conifers near Lisbane, Co. Kerry
		Oct 2 2010	V5561386210	Small stand of oak, holly and birch near Kells, Co. Kerry
V87	1987	Oct 2 2010	V8621877442	Grazed blanket bog, close to junction of N71 and R568, Carrig East, Co. Kerry
		Oct 2 2010	V8506375886	Grazed (sheep) blanket bog, near Slievaduff, Co. Kerry
V92	Post-1965	Mar 9 2011	V9273629737	Heath, south of Skull, Co. Cork

		Mar 9 2011	V9008829861	Heath, Croch, Co. Cork
W02	Post-1965	Mar 9 2011	W0932428964	Knockomagh Wood Nature Reserve, Ballyoughtera, Co. Cork
		Mar 9 2011	W087286	Heath near Baltimore, Co. Cork
W03	1990	Mar 9 2011	W0364434849	Heath, just outside Hollyhill, Co. Cork
		Mar 9 2011	W0611035178	Blanket bog, Toormore, Co. Cork
W05	1988	Mar 9 2011	W0280351255	Oak-birch woodland, Inchiclogh, Co. Cork
		Mar 9 2011	W0053056589	Birch on the edge of a conifer plantation, Coorloum, Co. Cork
W17	1988	July 22 2009	W197778	Cascade Wood, Ballyvourney, Co. Cork
		July 22 2009	W194774	Gobnait's Wood, Ballyvourney, Co. Cork
W25	1988	Oct 9 2010	W2008454499	Oak-holly woodland, Inchanadreen, Co. Cork
		Oct 9 2010	W228548	Blanket bog, close to Dunmanway, Co. Cork
		Mar 9 2011	W2268455125	Heath, Coom, Co. Cork
W26	1987	Oct 10 2010	W244674	Dry heath, Inchigeelagh, Co. Cork
			W244674	Clearfell, Inchigeelagh, Co. Cork
W35	No records	Mar 8 2011	W305532	Mixed deciduous and conifer forest, Manch, Co. Cork
			W3804359553	Conifer plantation, Killaneer, Co. Cork
W36	No records	Mar 8 2011	W389672	Warrenscourt Forest, Carrigdarrery, Co, Cork
			W315606	Heath, Coppeen, Co. Cork
W37	No records	Oct 10 2010	W376723	Ummera Wood, Macroom, Co. Cork
		Mar 8 2011	W354778	Conifer plantation, Clonavrick, Co. Cork
		Mar 8 2011	W3779172326	Ummera Wood, Macroom, Co. Cork

* All sites had sandstone outcropping.

APPENDIX 4. THE NUMBER OF *GEOMALACUS MACULOSUS* COUNTED PER WEEK UNDER THE BAND METRIC TRAPS IN THE WOODLAND SITE AT GLENGARRIFF NATURE RESERVE FROM AUGUST 20 2009 TO OCTOBER 20 2009.

	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Tree 6	Tree 7	Tree 8	**Total**
Week 1	1	0	0	0	0	0	0	0	**1**
Week 2	0	0	2	1	0	0	0	0	**3**
Week 3	2	0	3	0	0	0	0	0	**5**
Week 4	2	0	0	0	8	0	0	0	**10**
Week 5	2	3	7	1	8	5	2	1	**29**
Week 6	8	3	24	0	10	7	3	4	**59**
Week 7	2	3	3	0	0	3	1	0	**12**
Week 8	0	0	2	0	0	0	1	0	**3**
Week 9	0	0	2	0	0	0	0	0	**2**

The dates for the sampling weeks are Week 1: Aug 20 - 26; Week 2: Aug 27 – Sept 2; Week 3: Sept 3-9; Week 4: Sept 10 - 16; Week 5: Sept 17 - 23; Week 6: Sept 24 - 30; Week 7: Oct 1 - 6; Week 8: Oct 7 - 13; Week 9: Oct 14 - 20.

APPENDIX 5. THE NUMBER OF *GEOMALACUS MACULOSUS* COUNTED PER WEEK UNDER THE OUTCROP METRIC TRAPS ON THE LOWLAND BLANKET BOG SITE AT CASHELKEELTY FROM AUGUST 19 2009 TO SEPTEMBER 29 2009.

	Outcrop 1	Outcrop 2	Outcrop 3	Outcrop 4	Outcrop 5	Outcrop 6	Outcrop 7	Outcrop 8	**Total**
Week 1	2	0	3	2	6	2	1	1	**17**
Week 2	3	1	2	6	4	2	0	3	**21**
Week 3	2	2	3	1	5	2	2	3	**20**
Week 4	2	2	0	1	2	0	1	1	**9**
Week 5	5	2	0	1	1	1	2	1	**13**
Week 6	2	3	0	4	1	0	1	1	**12**

The dates for the sampling weeks are Week 1: Aug 19 - 25; Week 2: Aug 26 - Sept 1; Week 3: Sept 2 - 8; Week 4: Sept 9 - 15; Week 5: Sept 16 - 22; Week 6: Sept 23 -29.

APPENDIX 6. RAINFALL DATA (MM) MEASURED AT KILLARNEY NATIONAL PARK DURING THE WEEK PRIOR TO SAMPLING FOR THE TRAPPING ASSESSMENT STUDY AT GLENGARRIFF NATURE RESERVE, CO. CORK (AUGUST 20 – OCTOBER 20 2009).

Date	Aug 20 - 26	Aug 27- Sept 2	Sept 3 - 9	Sept 10 - 16	Sept 17 - 23	Sept 24 - 30	Oct 1 - 6	Oct 7 - 13	Oct 14 - 20
Day 1	9.3	14.2	5	0	0	0	0	0.2	0
Day 2	0	0	0	0	0	0	0	4.6	0
Day 3	0	0	0	0	0	0	0	0	0
Day 4	22.7	24.2	14.4	0	3.3	0	2.6	0	0
Day 5	1.7	6	31.2	0	1	0	18.7	11.4	2
Day 6	27.6	6.2	2	0	0	0.1	25.9	0	27.4
Day 7	0.2	19.3	0	0	0	0.8	0.2	0.1	6.4
Total	61.5	69.9	52.6	0	4.3	0.9	47.4	16.3	35.8
Mean (± SE) per day	8.79 ± 4.44	9.99 ± 3.57	7.51 ± 4.40	0.00 ± 0.00	0.61 ± 0.47	0.13 ± 0.11	6.77 ± 4.10	2.33 ± 1.64	5.11 ± 3.82

Linear regression of mean rainfall per day during the week prior to sampling with total *G. maculosus* abundance (Appendix 4) generated the following equation: $y = 1.264 – 0.0996.x$ ($F = 6.124$, $p<0.05$). The total *G. maculosus* abundance data were normalised using log transformations.

APPENDIX 7. RAINFALL DATA (MM) MEASURED AT KILLARNEY NATIONAL PARK DURING THE WEEK PRIOR TO SAMPLING FOR THE TRAPPING ASSESSMENT STUDY AT CASHELKEELTY, CO. KERRY (AUGUST 19 – SEPTEMBER 29 2009).

Date	Aug 19 - 25	Aug 26 – Sept 1	Sept 2 - 8	Sept 9 - 15	Sept 16 - 22	Sept 23 - 29
Day 1	23.3	0.2	19.3	0	0	0
Day 2	9.3	14.2	5	0	0	0
Day 3	0	0	0	0	0	0
Day 4	0	0	0	0	0	0
Day 5	22.7	24.2	14.4	0	3.3	0
Day 6	1.7	6	31.2	0	1	0
Day 7	27.6	6.2	2	0	0	0.1
Total rainfall	84.60	50.80	71.90	0.00	4.30	0.10
Mean (± SE) rainfall per day	12.09 ± 4.60	7.26 ± 3.43	10.27 ± 4.48	0.00 ± 0.00	0.61 ± 0.47	0.01 ± 0.01

Linear regression of mean rainfall per day during the week prior to sampling with total *G. maculosus* abundance (Appendix 5) generated the following equation: $y = 11.768 + 0.7075.x$ ($F = 8.221$, $p<0.05$).

APPENDIX 8. TEMPERATURE (°C) RECORDED AT 0900HRS ON THE DAY OF SAMPLING AND ON DAY PRIOR TO SAMPLING AS MEASURED AT KILLARNEY NATIONAL PARK DURING THE TRAPPING ASSESSMENT STUDY AT GLENGARRIFF NATURE RESERVE, CO. CORK (AUGUST 20 – OCTOBER 20 2009).

Date	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9
Day of sampling	16.5	12.4	11	12.2	14.6	12.1	14.4	14	9.5
Day before sampling	14	12.9	15.4	12.2	15.7	13.5	10.6	8.5	13.1

The dates for the sampling weeks are Week 1: Aug 20 - 26; Week 2: Aug 27 – Sept 2; Week 3: Sept 3-9; Week 4: Sept 10 - 16; Week 5: Sept 17 - 23; Week 6: Sept 24 - 30; Week 7: Oct 1 - 6; Week 8: Oct 7 - 13; Week 9: Oct 14 - 20

APPENDIX 9. TEMPERATURE (°C) RECORDED AT 0900HRS ON THE DAY OF SAMPLING AND ON THE DAY PRIOR TO SAMPLING AS MEASURED AT KILLARNEY NATIONAL PARK DURING THE TRAPPING ASSESSMENT STUDY AT CASHELKEELTY, CO. KERRY (AUGUST 19 – SEPTEMBER 29 2009).

Date	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Day of sampling	14	12.9	15.4	12.2	15.7	13.5
Day before sampling	14	15	15.5	11.3	15.1	14.1

The dates for the sampling weeks are Week 1: Aug 19 - 25; Week 2: Aug 26 - Sept 1; Week 3: Sept 2 - 8; Week 4: Sept 9 - 15; Week 5: Sept 16 - 22; Week 6: Sept 23 -29.

APPENDIX 10. GPS CO-ORDINATES (IRISH GRID REFERENCE) FOR THE EIGHT PERMANENT MONITORING STATIONS AT GLENGARRIFF NATURE RESERVE, CO. CORK AND CASHELKEELTY, CO. KERRY.

Station Number	Glengarriff Nature Reserve	Cashelkeelty
1	V9197056769	V7555157615
2	V9198256749	V7557157604
3	V9194556746	V7562157591
4	V9194956674	V7565757566
5	V9199056661	V7569757563
6	V9194256658	V7557757559
7	V9183156713	V7553757560
8	V9185856699	V7554157582

APPENDIX 11. MONTHLY COUNT AND TREE CIRCUMFERENCE DATA FOR THE EIGHT PERMANENT MONITORING STATIONS IN GLENGARRIFF NATURE RESERVE, CO. CORK.

	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Tree 6	Tree 7	Tree 8
Jan 11 2010	1	1	1	3	1	4	0	2
Feb 11 2010	1	2	1	4	0	6	0	2
Mar 09 2010	1	1	3	4	1	5	1	1
April 13 2010	2	3	20	1	7	8	2	4
May 11 2010	3	3	27	1	4	2	2	3
June 10 2010	2	2	19	1	3	4	2	4
July 9 2010	0	0	0	0	0	0	0	0
Aug10 2010	3	0	5	0	2	0	4	3
Sept 14 2010	0	0	0	0	0	0	0	0
Oct 13 2010	1	0	0	0	8	0	2	0
Nov 14 2010	3	0	7	2	4	1	1	0
Dec 9 2010	1	0	1	1	5	1	1	0
Mean monthly count (±SD)	1.50 ± 1.09	1.00 ± 1.21	7.00 ± 9.48	1.42 ± 1.51	2.92 ± 2.75	2.58 ± 2.75	1.25 ± 1.22	1.58 ± 1.62
Median monthly count	1.00	0.50	2.00	1.00	2.50	1.50	1.00	1.50
Tree circumference (m)	137	163	162	145	178	172	138	180

APPENDIX 12. MONTHLY COUNT AND OUTCROP SIZE DATA FOR THE EIGHT PERMANENT MONITORING STATIONS AT CASHELKEELTY, CO. KERRY.

	Outcrop 1	Outcrop 2	Outcrop 3	Outcrop 4	Outcrop 5	Outcrop 6	Outcrop 7	Outcrop 8
Jan 12 2010	1	0	1	0	0	0	0	1
Feb 12 2010	1	0	1	1	0	0	0	1
Mar 10 2010	1	0	1	1	0	0	0	1
April 11 2010	2	3	0	1	3	0	1	1
May 11 2010	0	0	0	1	0	0	0	0
June 9 2010	2	4	1	1	2	0	1	1
July 15 2010	2	3	5	6	3	2	4	7
Aug 10 2010	2	2	1	4	0	2	1	1
Sept 10 2010	5	4	10	7	3	3	8	7
Oct 11 2010	7	7	7	12	4	9	5	8
Nov 9 2010	6	8	9	4	3	2	7	3
Dec 6 2010	9	6	4	2	1	1	3	1
Mean monthly count (±SD)	3.17 ± 2.86	3.08 ± 2.84	3.33 ± 3.60	3.33 ± 3.53	1.58 ± 1.56	1.58 ± 2.76	2.50 ± 2.88	2.67 ± 2.90
Median monthly count	2.00	3.00	1.00	1.50	1.50	0.50	1.00	1.00
Outcrop area (m^2)	47.70	24.70	21.76	18.62	11.61	52.08	96.33	15.18

APPENDIX 13. BRYOPHYTE SPECIES RECORDED ON THE EIGHT PERMANENT MONITORING TREES IN GLENGARRIFF NATURE RESERVE, CO. CORK (SEPTEMBER 10 2009).

Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Tree 6	Tree 7	Tree 8
Isothecium myosuroides	*Eurhynchium praelongum*	*Eurhynchium praelongum*	*Hypnum resupinatum*	*Eurhynchium praelongum*	*Eurhynchium praelongum*	*Eurhynchium praelongum*	*Eurhynchium praelongum*
	Hypnum resupinatum	*Hypnum resupinatum*	*Isothecium myosuroides*	*Lophocolea fragrans*	*Isothecium myosuroides*	*Isothecium myosuroides*	*Isothecium myosuroides*
	Isothecium myosuroides	*Isothecium myosuroides*	*Thuidium tamariscinum*	*Plagiochila* sp.	*Plagiochila* sp.		
	Thuidium tamariscinum	*Thuidium tamariscinum*					
	Frullania fragilifolia						
	Plagiochila sp.						