Monitoring *Powelliphanta* land snails: an assessment of the current technique and the development of a new mark-recapture technique

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Monitoring *Powelliphanta* land snails: an assessment of the current technique and the development of a new mark-recapture technique

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There are currently no proven techniques for monitoring populations of land snails in the genus *Powelliphanta*. The Department of Conservation has developed a method for establishing an index of abundance. Although this method is routinely used, its reliability remains unclear. Many *Powelliphanta* species and sub-species are currently listed as threatened. Improving estimates of population trends and assessing the effectiveness of conservation management is therefore critical. The main aim of this research is to improve the techniques used for assessing and monitoring populations of these animals. The study is split in to three main parts: an assessment of the current monitoring technique, a description of a newly developed mark-recapture technique and an analysis of the ancillary data that can be collected when utilising a mark-recapture method. The second two chapters focus on *Powelliphanta augusta*, a species that was translocated from its natural habitat to make way for coal mining.

It was found that a large proportion of snails are overlooked when using the current monitoring technique. On average, approximately 30% of snails were observed during a standard monitoring event. However, the proportion of snails overlooked at each monitoring plot was highly variable, ranging from 10% to over 50%. It is recommended that this method is used with extreme caution.

An alternative mark-recapture technique is described, which was developed to monitor the critically endangered snail *P. augusta*. To have confidence in the results obtained from the monitoring, it was important to establish if the method was reliable and, in particular, if the mark-recapture assumptions underpinning the statistical analysis were being met. It was concluded that the method is reliable and is a practical alternative to the standard method for monitoring *Powelliphanta* snails. Recommendations are made for further improvement and refinement of this mark-recapture technique. Abundance estimates were produced for *P. augusta* at all sites in which they currently occur. The abundance estimates showed that most of the populations are stable and may even be growing.

As a species that is relatively new to science, there were many important aspects of the ecology of *P. augusta* that were completely unknown. An advantage of using a mark-recapture technique for monitoring is the possibility of developing a richer understanding of the ecology and behaviour of the animal being studied by estimating other parameters. It was found that annual survival is in excess of 80% in most locations, which is higher than previously estimated. It was previously unknown how fast *P. augusta* grows in the wild. Average shell growth was found to be approximately 2.6mm over a year. It is estimated that the average age of reproductive maturity is eight years old, younger than previously thought. Other parameters are explored, such as population structure and recruitment. A model of population persistence suggests that most of the *P. augusta* populations appear to be able to persist at present. Further recommendations are made regarding the management of the species and the management of *Powelliphanta* in general.

Keywords: *Powelliphanta augusta*, monitoring, mark-recapture, translocation, land snails.

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Introduction

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I. Introduction

Powelliphanta is a genus of large land snail in the Rhytididae family (Climo, 1977). The genus is endemic to New Zealand and its species are known for their bright and colourful shells (Walker, 2003). There are at least ten species, in addition to many recognised sub-species (Trewick, 2008). They are carnivorous, mostly consuming earthworms, supplemented by slugs, millipedes and other snails (Powell, 1979). They are found in a variety of habitat types, from lowland forest to alpine tussock and, in order to conserve water, they are generally nocturnal, often found buried in litter, under logs or concealed under favoured plant species during the day (Walker, 2003). Generally speaking, the ecology of many *Powelliphanta* species is not well understood, with many important aspects of life history, such as fecundity, growth rates, and longevity largely unknown (Walker, 2003).

The extant populations of *Powelliphanta* snails which occur in New Zealand today are often remnant populations and the genus is likely to have been more widespread previously (Walker, 2003). The snails are still found on both the North Island and South Island but are now limited to the west of both islands, with a particular stronghold in the mountains of North-west Nelson (Walker, 2003).

Powelliphanta species, along with a small group of other invertebrates, are classified as 'animals' under the Wildlife Act (1953) and are 'absolutely protected'. Unlike many other invertebrates, they have also received some attention relating to their conservation needs (Meads, Walker, & Elliott, 1984). The key threats to the genus have been identified as habitat loss and predation, with predation by exotic predators, such as rats and possums, the most pressing current issue (Walker, 2003). The development of species recovery plans (Walker, 2003) has identified key strategies in an attempt to halt the decline of *Powelliphanta* species. These strategies include the protection of remaining habitat and the control of exotic predators, as well as increased public engagement. The final key strategy, which is particularly relevant to this thesis, calls for accurate data on current population trends to be obtained.

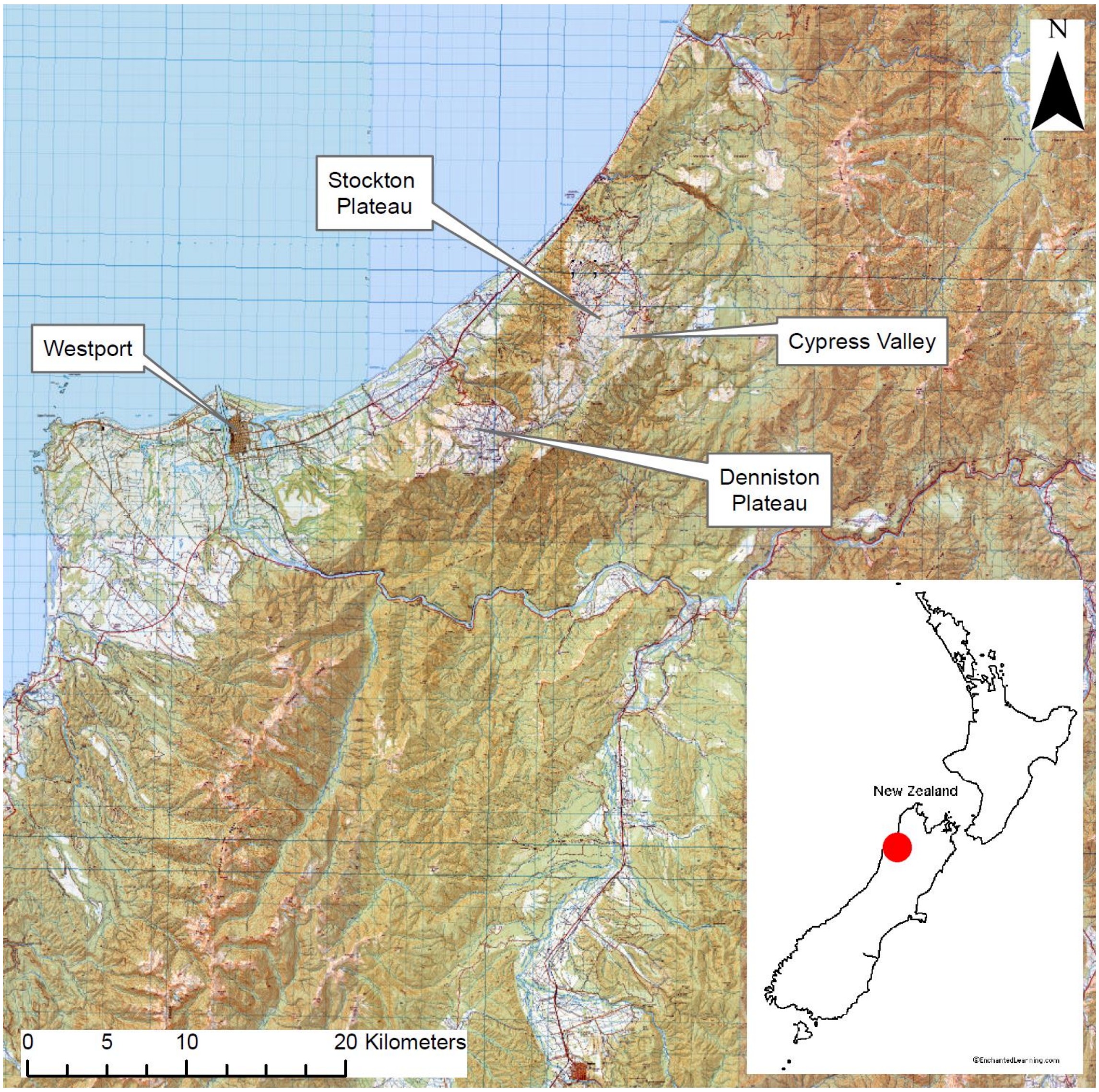
Many of the species and sub-species in this genus are currently listed as threatened on the New Zealand Threat Classification System Lists (Hitchmough, Bull, & Cromarty, 2007) and it is unclear how successful current management is proving to be. Improving estimates of population trends and, in turn, the effectiveness of any conservation management, is therefore crucial to the conservation of the genus. The main aim of this study is to improve the techniques used for monitoring populations of these animals and to provide more clarity and certainty to conservation managers. The study is split in to three main parts: an assessment of the current monitoring technique (Chapter 2), a description of a newly developed mark-recapture technique (Chapter 3), and an analysis of the ancillary data that can be collected when utilising a mark-recapture method, which may provide vital information to conservation managers (Chapter 4). There is a particular focus on *Powelliphanta augusta*, a critically endangered (Hitchmough, et al., 2007) and only recently discovered (Walker, Trewick, & Barker, 2008) member of the genus.

The background to the research presented in this thesis was the widely debated decision to award Solid Energy New Zealand Limited a Wildlife Permit to translocate *Powelliphanta augusta* from its natural habitat on Mount Augustus, located at Stockton Mine, north of Westport on the West Coast of the South Island (see Figure 1). Shells of *P. augusta* were first collected in 1996 by the Nelson Botanical Society but were not examined in detail until 2003 (Walker, et al., 2008). It was initially assumed that the shells were of *P. patrickensis*, another snail that occurs in the wider region. However, a detailed examination of the shells indicated they were but most likely a new species, previously unrecognised (Trewick, Walker, & Jordan, 2008). By 2003, a large proportion of the former range of this new species, including the area where the original six shells were collected, had already been stripped for the mining of high quality coking coal for export. A population of the snails was found on the slopes of Mount Augustus, some of which was scheduled for further coal mining. In order to proceed with mining, Solid Energy was required to translocate the snails that occurred in the mining footprint to another location.

Initial estimates of the number of snails in the mining footprint, and therefore requiring translocation, ranged from less than 500 snails, by the Department of Conservation (DOC, 2006b) to just over 1,100 snails, by Solid Energy's contracted ecologists (DOC, 2006a). A snail search and recovery programme was undertaken during 2006 and 2007, resulting in the capture of over 6,000 animals, with an unknown number remaining undetected (Gruner, 2010). The initial estimates of the number of the snails present were based on a standard technique for monitoring *Powelliphanta* (Walker, 1997) and were shown to be grossly inaccurate. Chapter 2 of this thesis is an assessment of that standard technique for monitoring *Powelliphanta* snails. The standard technique involves carefully searching for snails in a 10x10m plot. In order to assess the accuracy of this technique, plots were searched using this method and then destructively searched in an attempt to find all snails that were actually present. It was then possible to compare the number of snails found during the monitoring of a plot and the actual number present. This relationship was completely unknown until now.

Figure 1 - Map of study area

The location of the study site, both nationally and locally, along with key landmarks.



No large scale translocations had been attempted previously for any species of *Powelliphanta*. The recovery plans for *Powelliphanta* (Walker, 2003) identifies seven small-scale historical translocations, which appear to have been successful, in the sense that the animals are still extant in their new homes. However, these translocations were not well documented and were of relatively few snails (likely to be in the tens or hundreds, rather than thousands). Generally speaking, these translocated populations are found at a low density and are subject to intense predation pressure (Walker, 2003). In New Zealand, *Placostylus* snails have been translocated on a number of occasions in the past (Stringer & Parrish, 2008). However, like the historical *Powelliphanta* translocations, the details are sketchy and record keeping has been poor or non-existent (Stringer & Parrish, 2008). More recently, small-scale translocations of captive bred *Placostylus* have been unsuccessful, most likely due to dry weather and desiccation (Stringer & Parrish, 2008). Internationally, there are few examples of the translocation of land snails for conservation purposes (Allan, 2010). One example, a reintroduction of *Partula taeniata* to the Pacific island of Moorea, was unsuccessful due to predation (Coote, Clarke, Hickman, Murray, & Pearce-Kelly, 2004).

The uncertainty regarding *Powelliphanta* translocations in general, and the lack of any knowledge regarding *P. augusta* translocations in particular, was a key criticism of the plan to translocate the species, with many commentators holding the view that it was inappropriate and too great a risk. Furthermore, to translocate the snails to an area in which they did not previously occur, was also seen as a risk and an unnecessary disruption to the natural patterns (and therefore biodiversity) in those areas (Barker & Overton, 2007). There was bitter division between the supporters and detractors of the programme to translocate, both within the scientific community and the local community. The issue became a headline news item, regularly appearing in the mass media with depictions of the 'multi-national fossil fuel company' versus an 'endangered snail' or 'greenies' versus 'West Coast miners'. A lack of data during the first few years of the translocation programme meant that there was much speculation and little evidence-based discussion. Each item of good news or bad news was seized upon to show that the project was succeeding or failing, depending on perspective. With the whole issue becoming clouded by politics, and the survival of a species in doubt, there was a clear need for robust population data, based on sound methods.

Mark-recapture methods are commonly used to monitor vertebrate species, with ever more complex and technologically advanced methods becoming available. In contrast, the techniques available for monitoring invertebrate species are often crude and non-specific, with the exception of economically valuable invertebrates, such as species of rock lobster (Turner, 2011). The initial monitoring programme, immediately implemented post-translocation to track the short-term survival of *P. augusta*, utilised an harmonic radar method, based on published methods (Lövei, Stringer, Devine, & Cartellieri, 1997) and involved monitoring the fate of a small selection of marked animals at each site. This data were analysed and published in 2009 (Efford, Lloyd, & Gruner). This technique, whilst useful, proved to be labour intensive and therefore costly. There were also concerns that the frequency of weekly monitoring may be damaging the habitat and that continual disturbance, particularly during winter months, when the animals are largely immobile, may be harmful for the snails. Furthermore, it was unclear whether the small number of snails directly being monitored was representative of the whole population at each site (Hamilton & Rodgers, 2008). There was therefore still a need to develop a new method for monitoring *P. augusta* that could be utilised for the long-term monitoring of the species.

By the end of 2007, of the more than 6,000 snails that had been collected from the slopes of Mount Augustus, over 4,000 had been released to two new translocation sites. The remaining snails remained in captivity, for the purposes of captive breeding, research and as a back-up, in case the translocations failed (Gruner, 2007). Of the two new translocation sites, one was close to the source habitat, just to the north of Mount Augustus, known as 'Extended Site B'. The second was at Mount Rochfort, on the Denniston Plateau, approximately 16 kilometres to the south-west of Mount Augustus. In addition to these two populations that were translocated by hand, an additional population was transferred mechanically, to an area at Extended Site B, through a process of 'vegetation direct transfer', which is the mechanical transfer of habitat using machinery adapted from the coal mining operation (Rodgers, Simcock, Bartlett, Wratten, & Boyer, 2011). There was also the remaining population in an area of natural habitat at Mount Augustus, known as 'Site A', which was not part of the mining footprint. In order to better understand how these various populations were faring, there was a need for robust monitoring. However, the standard monitoring technique for *Powelliphanta* (Walker, 1997), which had been used to initially assess the population size at Mount Augustus, was thought to be unreliable due to the grossly inaccurate abundance estimates produced. It was proposed by the Department of Conservation's Technical Advisory Group for the species that a new mark-recapture method be developed for the long term monitoring of the snails (Gruner, 2007).

There were many questions to answer during the development of the new mark-recapture monitoring technique. How to monitor without harming the snail or its habitat? When best to monitor to maximise captures? How to attach tags to shells and ensure these marks persisted? How to ensure that the assumptions that underpin mark-recapture statistical analysis are being met? Over time, the mark-recapture field protocol has been adapted and refined, with important contributions by a number of people. The field protocol has been through several iterations (Gruner, 2008; Weston & Gruner, 2009; Weston, Gruner, & Hamilton, 2011) and was still in development when last published. The latest version of the field protocol is published here in Chapter 3 of this thesis. That chapter provides abundance estimates for *P. augusta*, at all of the sites in which they now occur, after five years of annual monitoring (2009 to 2013). Chapter 3 also assesses the method in terms of the mark-recapture assumptions that underpin it, including an assessment of tag loss over five years.

During the five year period of mark-recapture monitoring, conservation managers were forced to make decisions without a good understanding of the species. As *P. augusta* had only recently been discovered, very little was known about its life history or ecology. An advantage of using a mark-recapture technique for monitoring is the possibility of developing a richer understanding of the ecology and behaviour of the animal being studied by assessing other parameters (Lettink & Armstrong, 2003). By marking individuals, which are then found over time, it may be possible to gain a greater understanding of parameters such as survival, recruitment, growth, dispersal and range. Such data may then inform the development of population models that can be used to assess population viability over time (Lettink & Armstrong, 2003). Chapter 4 explores what other information can be gained from the *P. augusta* mark-recapture monitoring programme. Survival estimates are presented, along with insights in to the rate of snail growth, population structure and recruitment. These new data are then used to update an existing model of population persistence, in an attempt to better understand the current status of the species. The specific aims and objectives of each chapter are described below.

The key aim of Chapter 2 is to assess the accuracy of the standard plot method for monitoring *Powelliphanta* and examine whether it can be consistently used to estimate an index of abundance and population trends over time. The specific objectives are as follows:

- confirm that snails are often overlooked using the plot method
- calculate what proportion of snails are overlooked
- establish whether this proportion is consistent
- explore whether a standard 'multiplier' can be used to estimate actual abundance
- explore whether variables, such as shell size and habitat type, impact on search efficiency (snail detectability)

The key aim of Chapter 3 is to describe the newly developed mark-recapture method and assess its suitability for the monitoring of *Powelliphanta* snails.

Specific objectives are as follows:

- formally describe this newly developed technique for monitoring *Powelliphanta* snails
- examine whether the mark-recapture assumptions are being met, with specific reference to the following:
    - Tag loss
    - Population closure (births, deaths, immigration and emigration)
- assess the suitability of the technique, with particular reference to practicality and animal welfare
- produce abundance estimates, with confidence intervals, for *P. augusta* at the different sites in which they now occur

The key aim of Chapter 4 is to glean as much information as possible from the data collected to date, to gain a better understanding of the ecology and conservation status of *P. augusta*, to assist conservation managers with their decision making.

Specific objectives are as follows:

- produce survival estimates, with confidence intervals, for *P. augusta* at the different sites in which they now occur
- estimate growth rates for *P. augusta* at different life stages
- assess the population structure at each of the sites in which they now occur
- look for evidence of recruitment in the translocated populations
- update the existing model of population persistence, incorporating the above information
- assess the current status of the populations in both their natural and new habitat

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Chapter 2

Assessing the accuracy of the standard plot method for monitoring *Powelliphanta* snail populations

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Abstract

There are currently no proven techniques for monitoring populations of land snails in the genus *Powelliphanta*. The Department of Conservation (DOC) has developed a method for establishing an index of abundance. Although this method is routinely used by DOC, its reliability remains unclear.

Many *Powelliphanta* species and sub-species are currently listed as threatened. Improving estimates of population trends and assessing the effectiveness of conservation management is therefore critical. The main aim of this research is to improve the techniques used for assessing and monitoring populations of these animals.

The study is split in to three main parts: an assessment of the current monitoring technique, a description of a newly developed mark-recapture technique and an analysis of the ancillary data that can be collected when utilising a mark-recapture method, which may provide vital information to conservation managers.

This chapter is concerned with the first part of the study: an assessment of the current monitoring technique. Fourteen plots, using that method, were established in the proposed Cypress Mine site in Buller. Each plot was searched once, representing a standard monitoring event. Each plot was then searched intensively seven further times during the same day, in an attempt to find all snails present.

Results indicate that a mean of approximately 28% of snails present are observed during a standard monitoring event. However, there was a large amount of variability from plot to plot, with a standard deviation of 19.3% and the proportion of snails being observed at each plot ranging from approximately 8% to just over 55%.

An attempt is made to create a model to estimate what proportion of snails were left unobserved after all eight searches. It is estimated that approximately 97% of all snails present were found after eight searches. The data are further analysed to explore the impact of the two variables that may be important: habitat type and shell size. Whilst there may be some variability due to these factors, none were shown to be statistically significant.

It is concluded that the plot method may have some use but should be used with caution and that the inherent uncertainly involved should be understood by conservation managers.

It is vital that accurate data on population dynamics and trends over time is obtained, if we

are to successfully halt the decline, and eventual extinction, of populations and species in this iconic genus.

I. Introduction

Permanent plots (quadrats) are commonly used in ecological research, including with land snails, both within New Zealand (e.g. Sherley, Stringer, Parrish, & Flux, 1998) and internationally (e.g. Mand, Talvi, Ehlvest, & Kiristaja, 2002). However, it is unclear how suitable this technique is for studying land snails. There are currently no proven techniques for establishing absolute abundance or survival rates of *Powelliphanta* snails, which means obtaining data on current population trends is difficult and subject to dispute. The Department of Conservation (DOC) has developed a method for establishing an index of abundance, which, in theory, can be used to monitor trends over time (Walker, 1997). This technique involves searchers crawling on their hands and knees carefully searching for snails, on or near the ground surface, in a quadrat, usually a 10 m x 10 m plot (known as the 'plot method' and described in full in Appendix A). However, it is unknown how reliable this method is. Furthermore, it has been suggested that the method has the potential to degrade snail habitat and may inadvertently kill snails and/or damage eggs (Walker, 1997). There are also concerns that the act of monitoring may cause the animals to vacate the area being monitored, thereby confounding any results derived (Turner, 2011).

The reliability of the standard plot method was questioned following a population assessment for the critically endangered snail *Powelliphanta augusta*. It was not until 2005 that this animal was first confirmed as a distinct species (Trewick, 2005) and not until 2008 that it was formally described (Walker, Trewick, & Barker, 2008). By 2006, the species had already lost much of its habitat due to development at Stockton coal mine (Walker, et al., 2008). Furthermore, much of the remaining habitat was scheduled to be mined in the following few years. This resulted in plans being developed to translocate the majority of the remaining snails. The translocation plan involved holding animals in captivity in the short term, whilst suitable release sites were found, and in the longer term for the purposes of captive breeding, risk management and research. In order to make good management decisions, it was important to know the approximate number of animals present. Population surveys had already been undertaken (Buckingham, Newburry, & Rudolph, 2005; Charteris, Buckingham, & Bartlett, 2005), conducted on behalf of the coal company Solid Energy New Zealand Ltd. These surveys utilised the plot method, in addition to an untested nocturnal transect method (later abandoned), and the results were used to make a number of population estimates. These estimates ranged from less than 500 snails, by the Department of Conservation (DOC, 2006b) to just over 1,100 snails, by Solid Energy's contracted ecologists (DOC, 2006a).

A snail search and recovery programme was undertaken during 2006 and 2007. This programme utilised an intensive search technique, which aimed to maximise the number of snails found, rather than preserve habitat integrity, which was scheduled to be mined anyway. Unlike the plot method, this type of search involves the repeated act of systematically sifting through litter and soil and uprooting vegetation and can be described as a 'destructive search'. In addition, at some locations, searches were undertaken at night, in an attempt to capture live animals whilst they were out foraging. The search programme resulted in the capture of over 6,000 animals, with an unknown number undetected (Gruner, 2010).

The cost of relocation, and the costs resulting from delays in development at Stockton Mine, ran in to millions of dollars for Solid Energy. Furthermore, the ability to make effective management decisions relating to the captured animals was somewhat compromised, as focus was shifted to what to do with the high number of animals being recovered, rather than the best places to which to translocate them. The gross underestimate of the population clearly resulted in unnecessary costs and hindered the conservation effort.

It would appear that the plot method almost certainly fails to detect some animals and that a destructive search would result in finding a greater number. This is probably to be expected and would most likely be the case when monitoring a variety of taxa. However, in order to obtain reliable population estimates when using the plot method, it is necessary to know the percentage of the population that is detected with this method. Even if the aim is to obtain only an index of abundance, rather than absolute abundance, it is important to know if this percentage is consistent or not.

Unfortunately, it was not possible simply to extrapolate from the data collected during the search and recovery of *P. augusta*. This was because the search effort was not uniform (a different amount of effort was expended at each search area), different methods were used at different locations (nocturnal searches, diurnal searches or both) and searches were undertaken over multiple days, introducing an environmental condition bias and allowing snails to move in and out of the search areas. In short, the searches were not conducted under experimental conditions, making any subsequent analysis unsound. In light of this, a collaborative proposal was developed to explore the issue of accuracy in snail population assessments (Gruner, 2010). Due to a lack of funding, the original proposal was not followed up. However, after further development of the proposal by the author, suitable funding was gained from Solid Energy to undertake the study using *Powelliphanta patrickensis*, another sub-alpine snail, also found on the Stockton Plateau. The key aim of this first part of the study, therefore, was to assess the accuracy of the plot method and examine whether it can be consistently used to obtain reliable population estimates of *Powelliphanta* snails.

Strictly speaking, the results may only be applicable to *P. patrickensis* and snails with a similar morphology, as some morphological factors may influence search efficiency (e.g. shell colouration and size). Because search efficiency is almost certainly influenced by habitat type, our results may also only apply to the habitat types in which the surveys were undertaken. To explore this issue, surveys were undertaken in two different habitat types: one that is easy to search and one that is considered difficult to search. It should be noted that as this is a field experiment, the number of replicate surveys may be too small to detect a reliable trend. It should therefore be considered a pilot study.

II. Aims and objectives

A research proposal authored by Gruner (2010) was adapted for this study. The key aim is to assess the accuracy of the plot method and examine whether it can be consistently used to estimate an index of abundance and population trends of *Powelliphanta* snails over time. The specific objectives are as follows:

- confirm that snails are often overlooked using the plot method
- calculate what proportion of snails are overlooked
- establish whether this proportion is consistent
- explore whether a standard 'multiplier' can be used to estimate actual abundance
- explore whether variables, such as shell size and habitat type, impact on search efficiency (snail detectability)

III. Methods

i. Study site

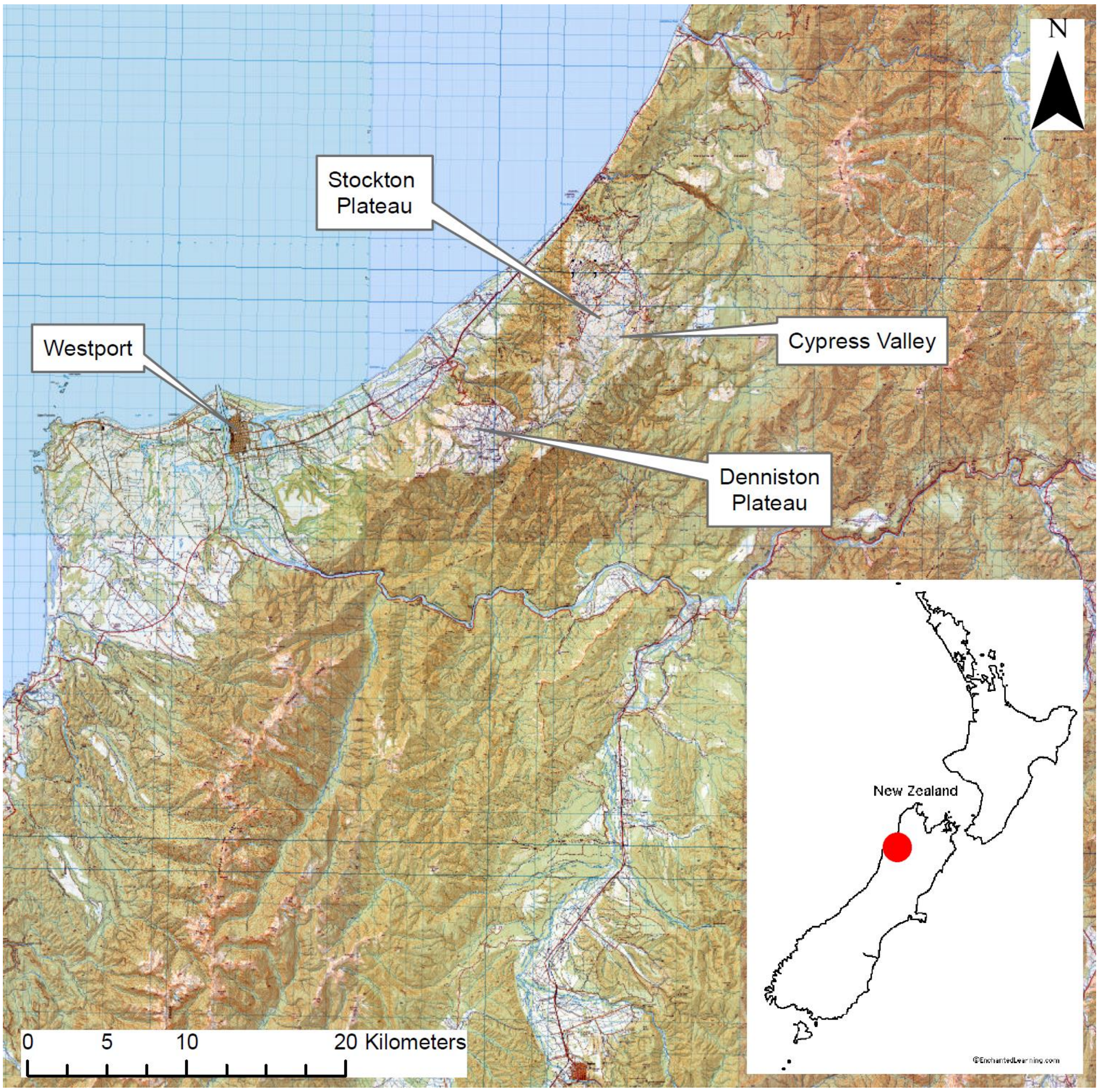
Solid Energy's proposed Cypress Mine, Buller, was the chosen study site and the target species was *P. patrickensis*. The Cypress Valley is situated on the Stockton Plateau, in the Buller region, on the West Coast of the South Island of New Zealand (see Figure 1). The site is approximately 700m above sea level and falls within the Ngakawau Ecological District. The area receives between 5 to 6 metres of precipitation per year and is characterised by coal measure soils, with manuka scrub and tussock grasslands being common vegetation types in the Valley itself (Mitchell Partnerships, 1998). The wider area is considered to be of conservation significance and a range of iconic species are known to occur there, including the great spotted kiwi (*Apteryx haastii*) and the giant land snail *Powelliphanta patrickensis* (Thomas, Toft, & Mason, 1997). The discovery of the Nelson green gecko (*Naultinus stellatus*) in the vicinity, along with the West Coast green gecko (*Naultinus tuberculatus*), which was already known to occur there, makes this the only site in New Zealand where two species of green gecko are known to co-occur (King, 2013).

Fourteen 10x10m plots were established, using the standard Department of Conservation method (see Appendix A), following Walker (1997). It was important that the snail plots were established only in areas where development was going to occur and the habitat was going to be compromised as a consequence. All work was carried out under a wildlife permit, issued by the Department of Conservation. All snails found were translocated to a Department of Conservation approved release area, adjacent to the proposed development.

Plots were only established in areas where *Powelliphanta* snails are known to occur in relatively high densities. This is because too many zero counts at plots would make any analysis difficult, if not impossible.

Figure 1 - Map of study area

The location of the study site, both nationally and locally, along with key landmarks.



ii. Sampling

A baseline survey of snail habitat in the proposed Cypress Mine area and surrounds was previously undertaken during 2012. That survey involved establishing 12 standard 10x10m snail plots in each of the different habitat types that had been previously mapped in the region (Mitchell Partnerships, 1998) (see Figure 2). The results of this baseline survey (unpublished data) established that, based on the snail plot data, the two habitat types 'manuka scrub' and 'tussock/flax' contained the highest densities of snails. Interestingly, discussions with the field team who had undertaken the survey, revealed that manuka scrub was considered to be an 'easy' habitat type in which to search for snails and that tussock/flax was considered to be 'difficult. The main reason given was the ease of finding snails in manuka litter and the difficulty of finding those concealed in cavities within and at the base of flax and, to a lesser extent, tussock.

Prior to this current study, it was unknown how many plots would be needed to obtain results with any degree of statistical certainty. As such, this current study should be considered a pilot study. The funds available allowed for the establishment of up to 14 plots to test the accuracy of the plot method as a monitoring tool. It was decided that seven plots would be established in manuka scrub habitat and seven in tussock/flax habitat. This would allow for a limited comparison of searches in different habitat types. The plots were not randomly located but were chosen by the field Team Leader at the start of each day to ensure that they were located in the correct habitat type and that they were also in areas likely to contain snails (as mentioned above, searching many plots with zero counts of snails would be pointless). As the purpose of this study was not to establish the overall abundance of snails in the area (which would require randomised plots) but to test the accuracy of searching within the actual plot, the lack of randomisation was not considered to be an issue.

Figure 2 - Map of plot locations

Aerial photograph (2013) showing the precise location of each plot within the Cypress consent boundary.

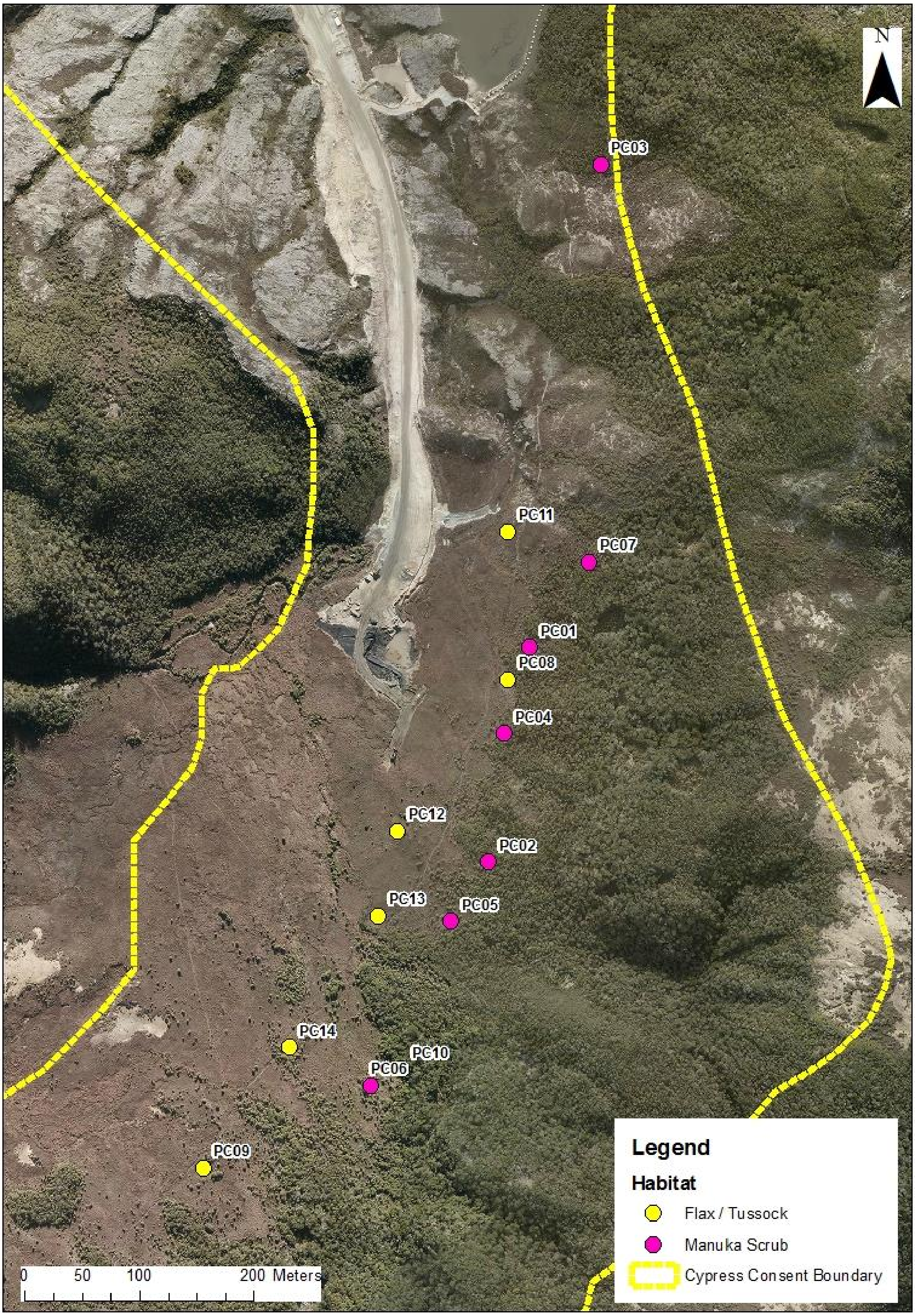


Table 1 - Plot details

Shows key information about each of the fourteen plots that were searched.

Plot ID	Habitat Type	Date Searched	Easting (NZMG)	Northing (NZMG)	Catchment	Sub-Catchment	Altitude asl (m)
PC01	Manuka Scrub	18/09/2012	2417968	5944511	Ngakawau	St Patricks	705
PC02	Manuka Scrub	19/09/2012	2417932	5944324	Ngakawau	St Patricks	712
PC03	Manuka Scrub	20/09/2012	2418030	5944933	Ngakawau	St Patricks	704
PC04	Manuka Scrub	25/09/2012	2417946	5944436	Ngakawau	St Patricks	713
PC05	Manuka Scrub	26/09/2012	2417899	5944272	Ngakawau	St Patricks	714
PC06	Manuka Scrub	27/09/2012	2417829	5944129	Ngakawau	St Patricks	714
PC07	Manuka Scrub	2/10/2012	2418020	5944586	Ngakawau	St Patricks	706
PC08	Flax / Tussock	3/10/2012	2417949	5944483	Ngakawau	St Patricks	701
PC09	Flax / Tussock	4/10/2012	2417683	5944057	Waimangaroa	Cypress	708
PC10	Flax / Tussock	10/10/2012	2417856	5944143	Waimangaroa	Cypress	712
PC11	Flax / Tussock	11/10/2012	2417949	5944612	Ngakawau	St Patricks	703
PC12	Flax / Tussock	16/10/2012	2417853	5944351	Ngakawau	St Patricks	705
PC13	Flax / Tussock	17/10/2012	2417836	5944277	Waimangaroa	Cypress	711
PC14	Flax / Tussock	24/10/2012	2417758	5944162	Waimangaroa	Cypress	705

iii. Search methods

Each plot was initially searched using the standard plot method, looking for snails on or near the surface, to replicate the results that would be obtained from a standard monitoring event. Following the careful search, the plot was then searched an additional seven times, using a 'destructive' technique, which aims to find every snail present. The technique is considered to be destructive as, unlike the standard plot method, it allows searchers to damage the habitat in an attempt to find all snails present. This destructive method has been used successfully to find and translocate snails out of harm's way, where development is to occur, and has been adapted from the Mt Augustus search protocol (DOC, 2006c). Analysis of translocation data, using a travelling mean approach, has estimated that eight destructive searches will find approximately 95% of the total number of snails found after up to 13 repeated searches (Gruner, 2010).

Each individual search event lasted approximately 4 person hours, which equates to a total search time of 32 person hours at each 10x10m plot. Whilst it would be preferable to find all snails present, the level of effort required would make this unfeasible and would allow only for the search of a small number of plots. Therefore, the total number found will be considered to constitute all 'findable' snails after eight consecutive searches (1 standard and 7 destructive).

To mitigate observer bias, at the start of each search survey staff were rotated to avoid the individual observers re-searching the same area. All eight searches in each plot were undertaken during the same day. This was to prevent snails migrating in or out of the plot during the night, when they are usually active. Furthermore, the study took place in autumn, when the snails are generally active and closer to the surface (during cold or dry weather they can become inactive and burrow further down in to the litter and soil) (Walker, 2003).

Data recorded included the number of snails found in each search and a measurement of the maximum diameter of shells (following Walker, 1997). A tally was also kept of the number of empty shells found. A standard vegetation reconnaissance plot was assessed at each 10x10m plot (following Allen, 1993), collecting variables such as species composition, canopy height, litter depth and soil depth. A meteorological station is located at the study site, which could provide data relating to temperature, humidity and rainfall, if needed.

iv. Statistical analysis

The total number of snails found in the standard plot monitoring search was compared with the total number of 'findable' snails in the plot after all eight searches. The mean percentage of snails found in the standard plot monitoring search was calculated for all plots, along with the 95% confidence interval. The distribution of mean percentages was tested for normality and a *t-test*, using Mini-tab was undertaken to establish the level of statistical significance.

Using GenStat, exponential curves were fitted to the cumulative results from each plot, in an attempt to estimate the asymptote (the point at which the curve flattens out, indicating that 100% of all snails present had been observed). The fitted curve type was $y = A+BR^x$, with 'A' representing the asymptote. This exercise was not possible for plots with low (≤2) snails counts, so was only undertaken for 10 of the plots. This also allows for a second estimate of mean percentage of snails found during a monitoring event, based on estimated total abundance, not just the number of 'findable' snails.

The relationship between habitat type and detectability of snails was explored. The analyses described above were also undertaken for the sub-groups of plot data from the two habitat types, to examine whether habitat type may impact on results obtained. The statistical significance of any difference observed was also tested.

A similar analysis was also undertaken for snail shell size (maximum diameter). *A t-test*, using Minitab, was undertaken to establish statistical significance. There may be some issues with using a *t-test* in this instance, as the number of snails varied between plots and searches, meaning the averages are based on a different number of snails. A second test of significance was therefore also undertaken (REML or restricted maximum likelihood).

An analysis of the destructive searches was also undertaken to gain a better understanding of the effectiveness of successive destructive searching (following Gruner, 2010), which may be useful for any future snail translocations.

IV. Results

i. Proportion of 'findable' snails observed

Searches revealed a total number of snails ranging from 0 to 36 in the studied plots with most snails found in the first and second searches (Table 2). Figure 3 compares the number of snails found during the first search, representing a monitoring event, with the number found in all subsequent searches of each plot. Figure 4 shows the same information expressed as percentages.

The proportion of snails observed during a first search, representing a monitoring event, varied from 8.3% to 55.6%. The mean percentage of snails observed during search 1 in all plots was found to be 28.85%, with a standard deviation of 19.3%. A t-test found the mean percentages to be normally distributed, with a p-value of 0.389. The 95% confidence interval was calculated to be between 17.18% and 40.51%.

Table 2 - Results of plot searches

Shows the number of snails observed during each search, at each plot, with totals.

	Search 1	Search 2	Search 3	Search 4	Search 5	Search 6	Search 7	Search 8	Total
PC01	3	11	4	4	2	2	2	2	30
PC02	5	1	2	0	0	0	1	0	9
PC03	8	5	4	1	3	1	0	1	23
PC04	6	4	4	0	3	0	3	1	21
PC05	6	3	0	2	1	0	0	0	12
PC06	13	7	5	2	6	2	1	0	36
PC07	1	0	1	0	0	0	0	0	2
PC08	7	4	2	1	0	1	0	0	15
PC09	0	0	0	1	0	0	0	0	1
PC10	1	4	2	2	1	2	0	0	12
PC11	3	3	0	0	1	0	2	1	10
PC12	0	1	0	0	0	0	0	0	1
PC13	1	2	0	0	1	0	0	0	4
PC14	0	0	0	0	0	0	0	0	0
Total	**54**	**45**	**24**	**13**	**18**	**8**	**9**	**5**	**176**

Figure 3 - Snails observed in each plot (number)

Compares the number of snails found during the first search of each plot, representing a monitoring event, with the number found in all subsequent searches of each plot.

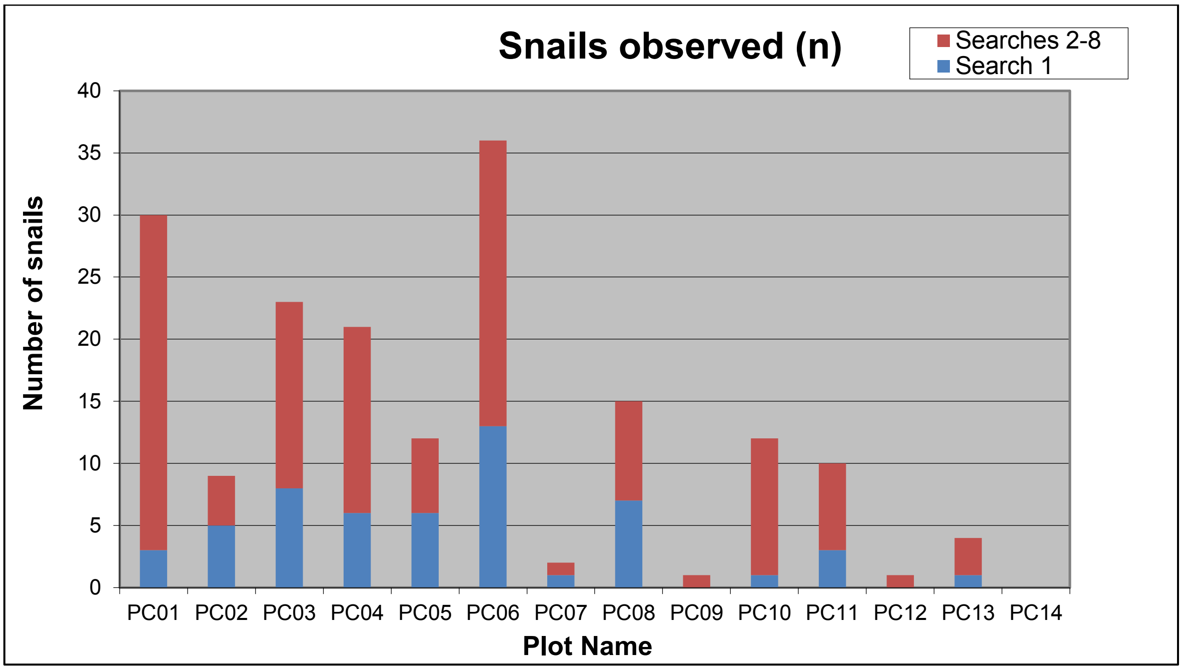
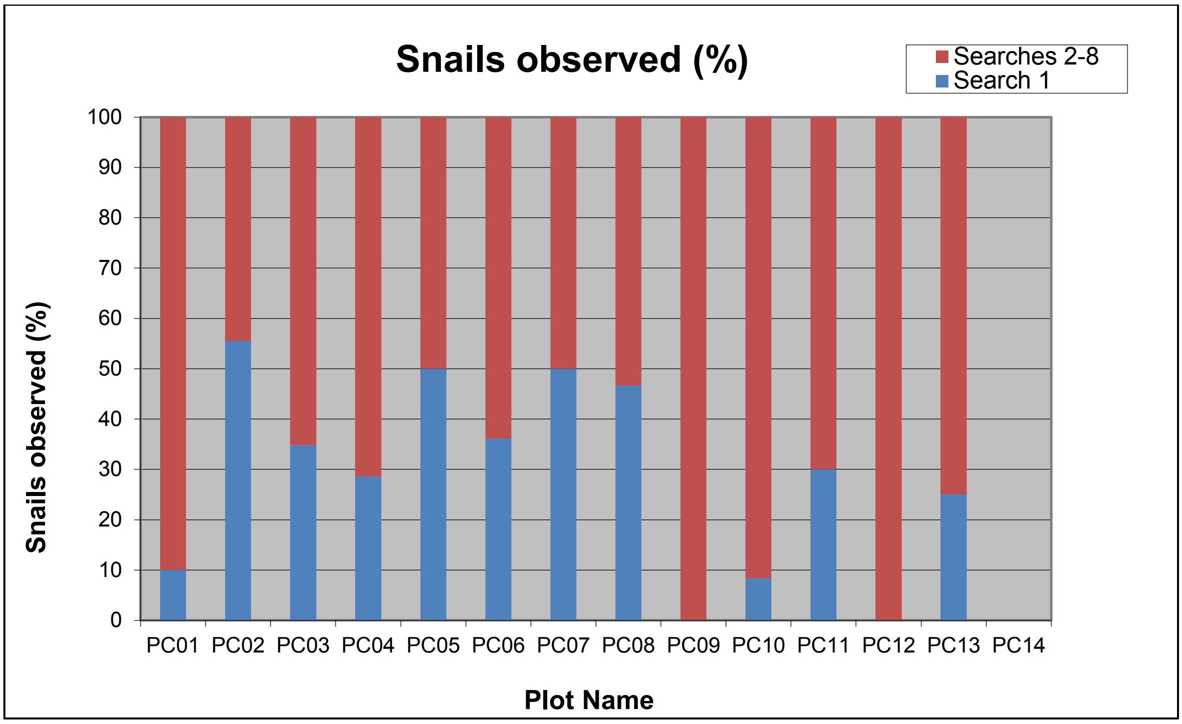


Figure 4 - Snails observed in each plot (percentage)

Shows the percentage found during the first search of each, representing a monitoring event, of the total found in all subsequent searches of each plot.



ii. Estimating the proportion of snails not observed

The results detailed above are for all 'findable' snails that were observed during eight searches. It is assumed that, at least in some plots, there would have been some snails that were not found during any of the searches. The number of 'non-findable' snails is obviously unknown.

Exponential curves were fitted to the cumulative results from each plot, in an attempt to estimate the asymptote (the point at which the curve flattens out, indicating that 100% of all snails present have been observed). This exercise was not possible for plots with low (≤2) snails counts, so was only undertaken for 10 of the plots. Nine of the ten plots had a good fit, with one plot having no fit. For the plots with low snail counts and the one with no fit, it is assumed that 100% of all snails were found during the eight searches. All calculated estimates were rounded to the nearest whole number (representing a single snail). The results are detailed in Appendix B: Estimating the proportion of snails not observed.

It is estimated that snails were missed (not observed) at five of the 13 plots with snails present (Figure 5). The percentage of snails not observed at these five plots ranged from approximately 3% to 16% (Figure 6). Over the 13 plots where snails were observed, it is estimated that approximately 97% of all snails present were observed.

The mean number of snails found during the first search, as a proportion of the estimated total number of snails, was calculated as approximately 28%, with a standard deviation of 19.3%. These figures are in a similar range to those calculated for total 'findable' snails, where the mean was 29.85% and the standard deviation 19.3%. A comparison of search efficiency, based on the two totals (estimated and actual found), is shown in Figure 7.

Figure 5 - Snails observed - with estimates (n)

Compares the number of snails observed during the first search with the number of snails observed during the subsequent seven searches (as Figure 3, above), with the estimated number of snails not observed.

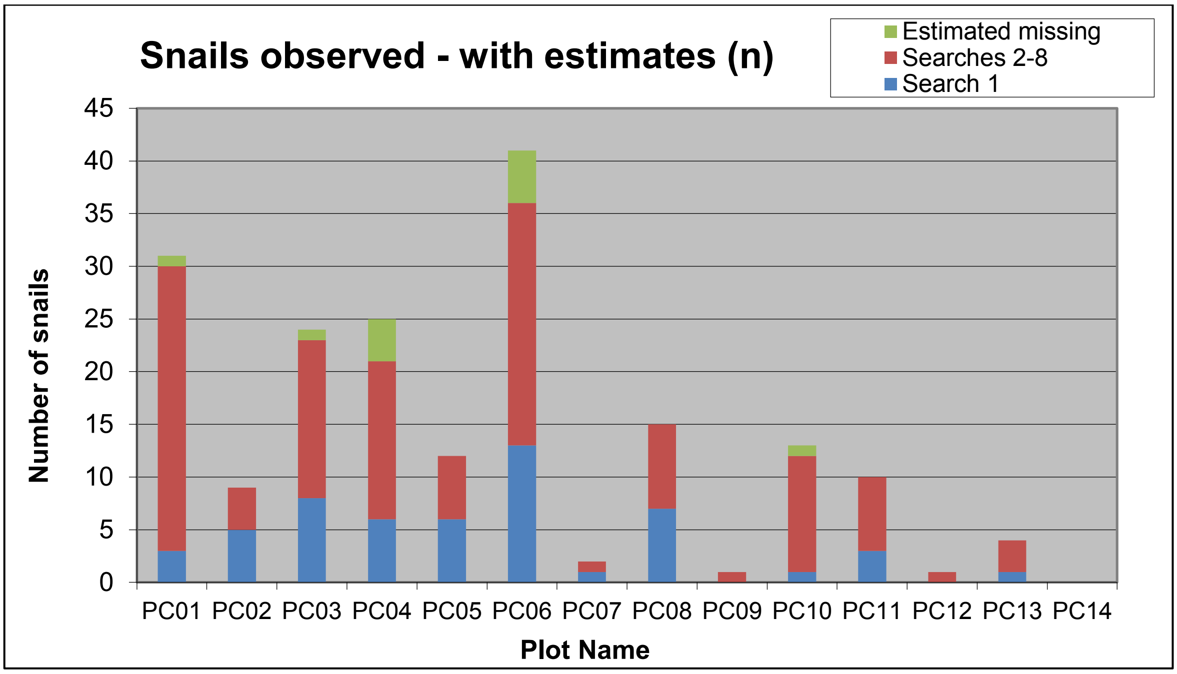


Figure 6 - Snails observed - with estimates (%)

Shows the percentage of snails observed during the first search, the percentage of snails observed during the subsequent seven searches (as Figure 4, above), with the estimated percentage of snails not observed.

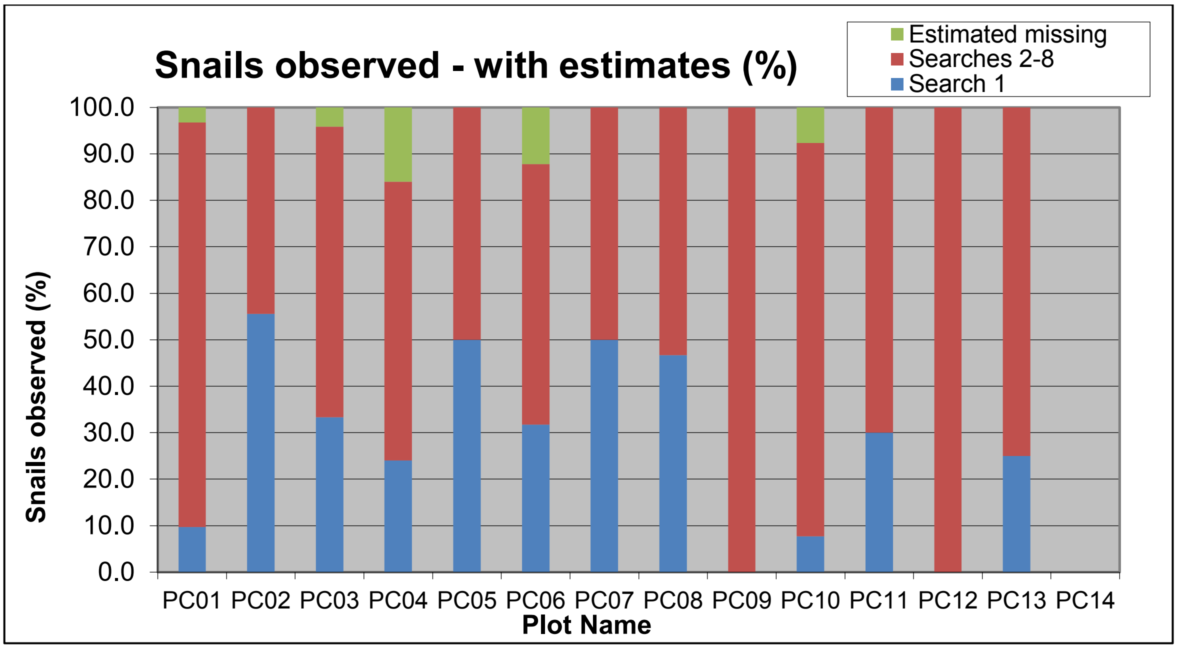
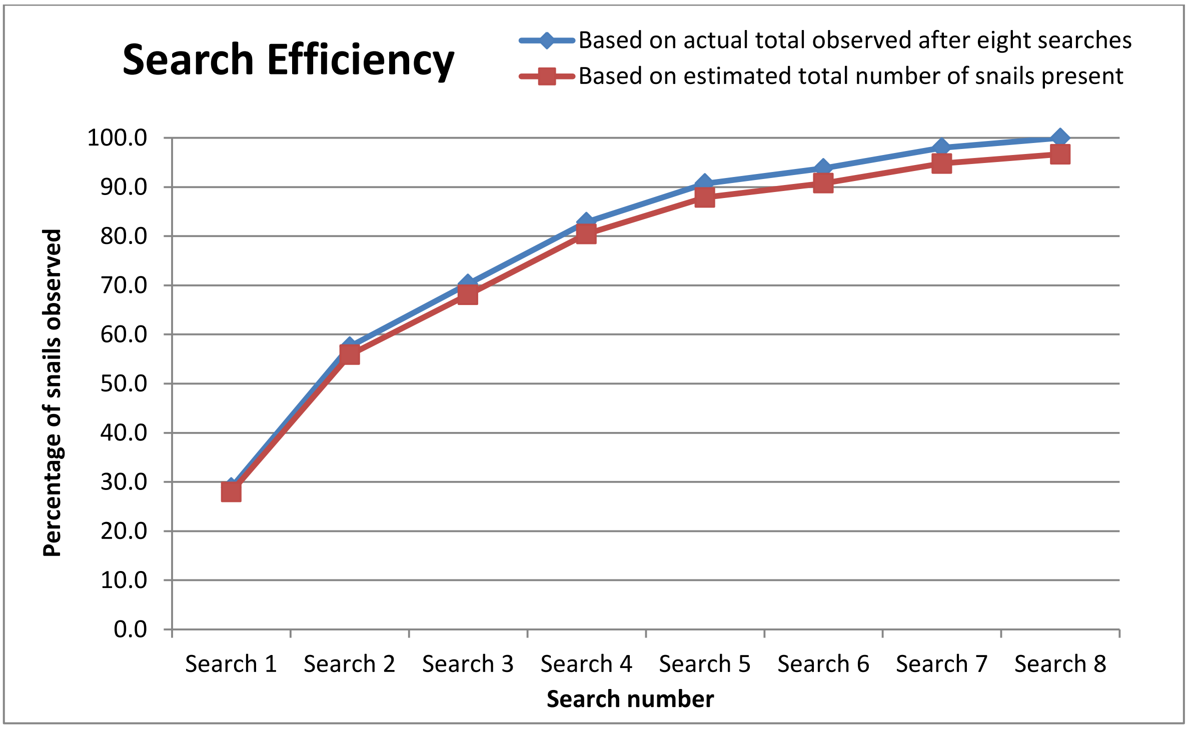


Figure 7 - Comparing search efficiency

Compares the search efficiency based on the total number of snails observed with the search efficiency based on the estimated total number of snails present.



iii. Influence of habitat type on detectability

Snail detection for each habitat type were analysed independently and are shown in Table 3. The travelling mean for each habitat type is shown in Figure 8. The average proportion of snails observed during the first search in manuka scrub habitat appears to stabilise at approximately 38% (Figure 8). In contrast, the average proportion of snails observed during the first search in tussock/flax habitat appears to stabilise at approximately 18%. Despite this apparent difference, no statistical significance was observed between the proportion of snails detected during the first search in the two habitat types (t-test, $p<0.065$). A test of normality, analysing the data from each habitat separately, found the plots in both habitat types to be normally distributed. The density of snails per plot was much lower in tussock/flax habitat, with an average of 7.2 snails per plot, compared with 19.0 snails per plot in manuka scrub.

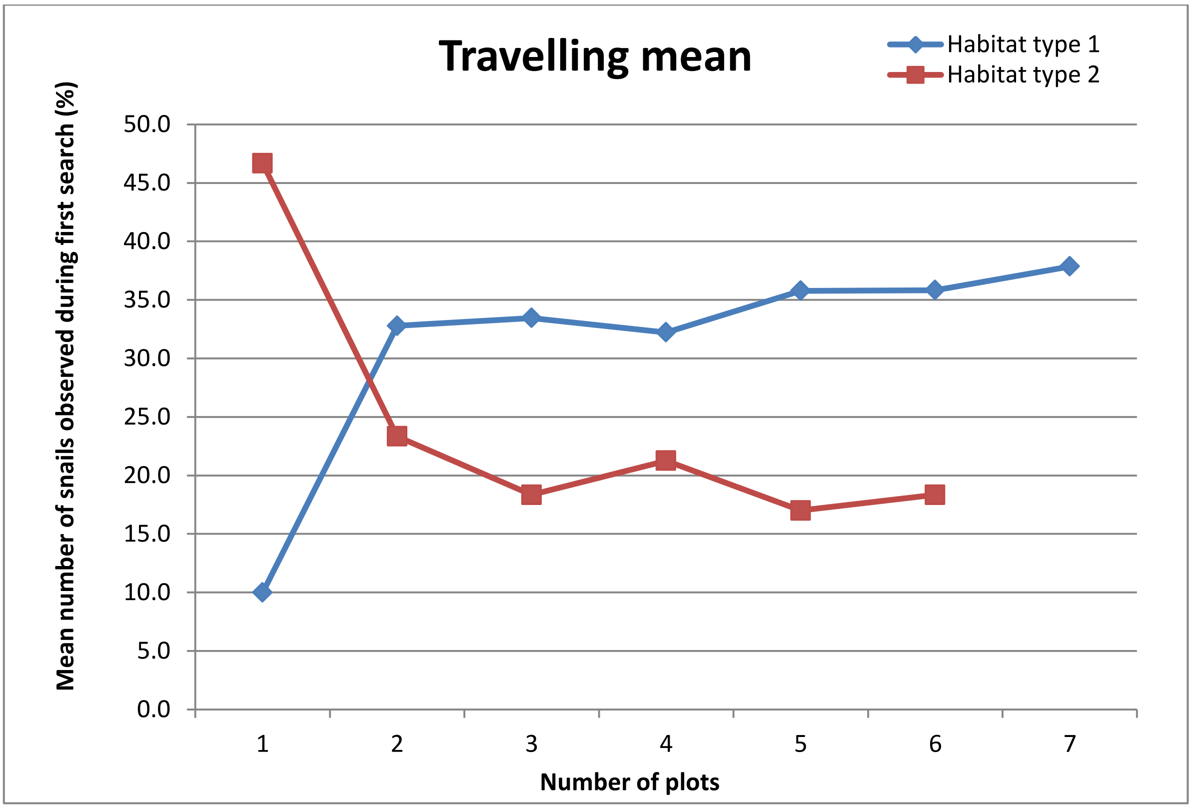
Table 3 - Snail observations by habitat type

Shows the results relating to the number of snails observed, broken down by habitat type.

Habitat type	Description	Number of plots	Percentage of individual snails observed during first search (%)	Mean total number of snails observed per plot	Standard deviation
1	Manuka scrub	7	37.9	19.0	15.7
2	Tussock/flax	6	18.3	7.2	18.7

Figure 8 - Travelling mean number of snails observed during first search

Shows the number of snails observed during a first search with the results from each plot pooled to obtain a travelling mean, broken down by habitat type.



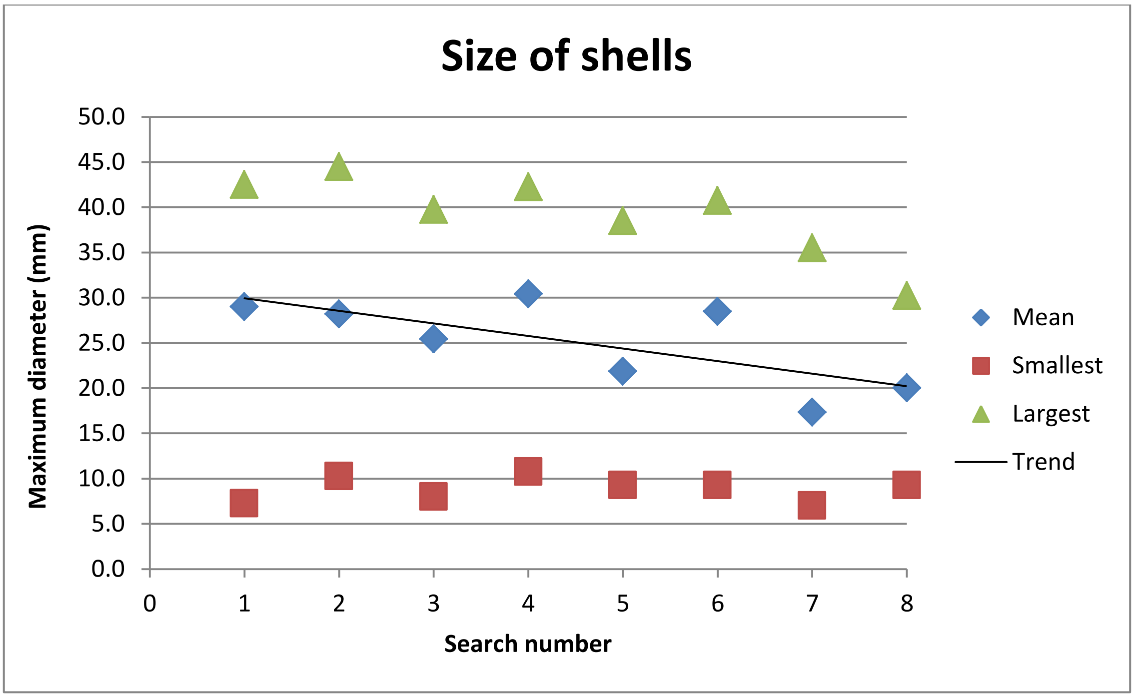
iv. Influence of shell size on detectability

An analysis of snail size (maximum diameter of shells) found that a range of different sized snails were found during each of the eight searches (see Table 4 and Figure 9). The mean snail size for all searches was 26.8mm. Across all plots, the mean size of snail found during the first search was 29.0mm and 25.8mm for the subsequent seven searches.

Table 4 - Shell size results

		Shell size - maximum diameter (mm)				
Search Number	**Number of snails**	**Mean**	**Standard deviation**	**Minimum**	**Median**	**Maximum**
1	54	29.0	9.5	7.3	31.9	42.5
2	45	28.2	10.6	10.3	30.3	44.5
3	24	25.4	10.8	8.0	24.9	39.8
4	13	30.4	11.4	10.8	35.8	42.3
5	18	21.9	11.5	9.3	17.0	38.5
6	8	28.5	10.7	9.3	31.6	40.8
7	9	17.3	10.8	7.0	13.3	35.5
8	5	20.0	8.3	9.3	20.3	30.3

Figure 9 - Size of shells



As illustrated in Figure 9, the mean size (maximum diameter) of snails observed during each search slowly declines. Figure 9 also shows the largest value and smallest value from each search, illustrating the range of snail sizes that were observed.

A t-test showed that there was no significant difference between the mean maximum diameter of snails found during search one and the mean maximum diameter of the remaining snails found in subsequent searches ($p = 0.083$). An REML (restricted maximum likelihood) analysis also showed that there was no significant difference between the mean maximum diameter ($p = 0.157$).

V. Discussion

As expected, the results confirm that a large proportion of snails are overlooked during a standard monitoring event, when using the plot method. It is more difficult to draw firm conclusions on the proportion of snails that are overlooked, with this number ranging from less than 10% to over 50% at individual plots. Attempting to compare results of separate monitoring events over time, at any individual plot, is likely to be impossible to do with any certainty and the results may be highly misleading.

The fact that the percentages of snails found at all plots were normally distributed does provide some reassurance about the usefulness of the method as a monitoring technique. It indicates that the percentages may not be completely random, but simply highly variable. It may be that with enough plots (and a large number is probably needed in any given location) it may be possible to get a very rough indication of population trends over a long period of time. However, this information is unlikely to be useful for highly threatened species, where accurate information is essential for timely conservation management.

Whilst habitat was not considered to be a statistically significant factor in determining detectability and the percentage of snails found, it may be that this is mainly due to the relatively small sample size in this study. Approximately 38% of total snails present were observed in manuka scrub habitat, compared with just 18% in tussock/flax, indicating that habitat type may still be an important consideration when designing monitoring programmes. Whilst the results of periodic monitoring at any particular set of monitoring plots, in any one geographical location, may be (cautiously) compared over time, it is unlikely that comparing monitoring results from one geographical location with another will be meaningful, particularly where there are significant differences in habitat composition.

Shell size (maximum diameter) was also not a statistically significant factor. However, once again, this may be due to the relatively small sample size in this study. Analysis of the data shows there appears to be a very gradual decline in the number of larger snails that are found in each successive search, whilst the number of small snails (near hatchling size) remains relatively constant. This may indicate that a disproportionate number of small snails are missed during a monitoring event, which would present a skewed picture of population demographics. Finding an appropriate monitoring technique for smaller snails (hatchlings and juveniles) is likely to remain an issue with any monitoring technique currently available. This presents an issue for conservation managers, where threats to adults and younger life stages may often differ in extent and by type. Resolving this issue would be a major step forward in improving the monitoring techniques (and conservation) of this genus.

The results for actual snails observed after all searches were similar to the modelled results for all snails present. It seems reasonable to assume that the eight searches were sufficient to find almost all snails present. Just under 30% of those were observed during the monitoring events across all plots. However, the use of a common multiplier, to predict the actual population size, based on the number of snails observed during monitoring, should be attempted with caution, due to the large variability observed.

The limits of this study should be acknowledged as, strictly speaking, the results only apply to this particular study site and this species. A larger and more comprehensive study, across multiple habitat types, and with multiple species, would be needed (including with larger snails in lowland habitats, where detectability may be significantly different) to form conclusions for the genus as a whole. As this is unlikely to happen, for a variety of reasons, including the cost and the destructive nature of the research (this was an almost unique opportunity), the figure of 30% may be a useful ‘rule of thumb’, when dealing with the smaller upland species of snail at least.

The search and relocation of snails to alternative locations can be a useful mitigation tool when habitat disturbance is unavoidable. With just 30% of snails found during a first search, it is suggested that at least two searches should be undertaken, which may result in the finding of over 60% of snails present (see Figure 7). Further searches, beyond the initial two, appear to yield fewer and fewer snails, making the effort less and less rewarding. However, any decision should be based on the individual species and an accurate assessment of threat status (unavailable for *Powelliphanta* species at the time of writing). It may be that five searches, allowing for approximately 90% of snails present to be found, would be suitable for very small populations and/or those species that are highly threatened.

It is concluded that the plot method has some use but should be used with caution and that the inherent uncertainly involved should be fully understood by conservation managers. The benefits of using this technique should also be recognised. In addition to potentially allowing for a rough population trend to be established over time, the plot method does also allow for limited monitoring of younger life stages (which other monitoring techniques do not). It also provides valuable information on causes of mortality, through the examination of the shells for predation signs (although the interpretation of such signs is by no means easy and is often the subject of disagreement by experts). However, for critically threatened species, it is concluded that alternative methods for the monitoring of population trends are urgently needed to replace or compliment the plot method. To address this challenge, a newly developed mark-recapture monitoring method is described in Chapter Three of this thesis. However, this method also has issues. It may be that the best solution would utilise both methods to extract the greatest amount of use from both. Regardless of the methods decided upon, it is vital that accurate data on population dynamics and trends over time is obtained to successfully halt the decline, and eventual extinction, in populations and species of this iconic genus.

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Chapter 3

The development of a mark-recapture technique for monitoring *Powelliphanta* snail populations

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Abstract

The driver for the development of a new *Powelliphanta* snail monitoring technique was the translocation programme of the critically threatened snail *Powelliphanta augusta*, as there were concerns about the accuracy of the standard monitoring technique known as the 'plot method'. The circumstances surrounding the translocation programme and the concerns relating to the plot method are described in detail in Chapter 2 of this thesis. A mark-recapture method was first trialled in 2008 and shown to have promise. This technique has since been refined and used annually for five years to assess the abundance of *P. augusta* populations at up to 10 different monitoring sites per year, both in their new translocation sites and in the remaining natural habitat. The key aim of this chapter is to describe the newly developed mark-recapture method, assess its suitability for the monitoring of *Powelliphanta* snails and produce reliable abundance estimates.

In addition to the mark-recapture monitoring, a number of ancillary activities were also undertaken to assist with testing the mark-recapture assumptions. These assumptions mainly relate to tag loss and a closed population (births, deaths, immigration and emigration). Rates of tag loss are shown to be extremely low, meaning the polyethylene tags used are likely to be suitable for the monitoring of *Powelliphanta* snails. The assumption of population closure is shown to have been violated but this is not considered significant. A recommendation is made to further examine the occurrence of migration and explore the extent of any edge effect that might be occurring.

It is concluded that the mark-recapture technique described in this chapter does appear to be suitable for the monitoring of *Powelliphanta* snails, in terms of logistics, animal welfare, and statistical analysis. Some of the refinements made to the field protocol are discussed, in addition to some of the key learnings from the five year study. Recommendations are made for improvements for any future studies.

In contrast to popular opinion, and some of the misleading information published in the literature (e.g. (Morris, 2010) and (Germano et al., 2015)), it would appear that the *P. augusta* populations are stable and may even be increasing in some cases. In the short to

medium term it is concluded that the snail populations are likely to be secure at all sites. However, it will take many years, possibly decades, to confirm long-term sustainability.

I. Introduction

The driver for the development of a new *Powelliphanta* snail monitoring technique was the translocation programme of the critically threatened snail *Powelliphanta augusta*, as there were concerns about the accuracy of the standard monitoring technique known as the 'plot method'. The circumstances surrounding the translocation programme and the concerns relating to the plot method are described in detail in Chapter 2 of this thesis. Upon translocation of the snails to several locations, there was a legal requirement for Solid Energy to monitor the *P. augusta* snail populations for ten years, in both the small area of remaining natural habitat and the two newly established release areas. The initial, short-term programme utilised an harmonic radar method, based on published methods (Lövei, Stringer, Devine, & Cartellieri, 1997) and involved monitoring the fate of a small selection of marked animals at each site. This data was analysed and published in 2009 (Efford, Lloyd, & Gruner). This technique, whilst useful, proved to be labour intensive and therefore costly. There were also concerns that the frequency of weekly monitoring may be damaging the habitat and that continual disturbance, particularly during winter months, when the species is largely immobile, may be harmful for the snails. Furthermore, it was unclear whether the small number of snails directly being monitored were representative of the whole population at each site (Hamilton & Rodgers, 2008). The Technical Advisory Group for the species had already advocated for the development of a mark-recapture technique for the long term monitoring of the species (Gruner, 2007), so the decision was made to investigate this option further.

A trial protocol was developed (MacKenzie, 2007) and a short pilot study was carried out to ascertain whether a mark–recapture technique might be a feasible option for monitoring *Powelliphanta* snails (Sharpe, 2008). Both this pilot study and the subsequent analysis (MacKenzie, 2008) showed that mark-recapture techniques might be suitable both from a practical and statistical perspective. In early 2009, the technique was further trialled by using it to assess abundance at two different sites in which *P. augusta* occurs, the work being supervised by the author. The analysis (MacKenzie, 2009) confirmed that the technique appeared to work. Under supervision of the author, this technique has since been used annually for five years to assess the abundance of *P. augusta* populations at up to ten different monitoring sites per year.

Over time, the mark-recapture field protocol has been adapted and refined, with important contributions by a number of people. The field protocol has been through several iterations (Gruner, 2008; Weston & Gruner, 2009; Weston, Gruner, & Hamilton, 2011) and was still in development when last written up. The latest version of the field protocol is published here in part iii of the Methods section below.

The translocation of *P. augusta* (and snail management in general) has been an emotive subject and a great deal of misinformation has been published in the media. A contributing factor has been that almost all of the related research to date, if written up at all, has been in the form of unpublished 'grey' literature, held by a company or government department. From a conservation management perspective, there is value in publishing the results of the five-year mark-recapture monitoring programme, along with a description of the method used, including the key learnings from the programme. It is also important to establish if the method is reliable and, in particular, if the mark-recapture assumptions (Lettink & Armstrong, 2003) are being met. In addition to publishing the field protocol and the associated results from the five years of monitoring, the suitability of this method for monitoring *Powelliphanta* snails is assessed here.

II. Aims and objectives

The key aim of this chapter is to describe the newly developed mark-recapture method and assess its suitability for the monitoring of *Powelliphanta* snails.

Specific objectives are as follows:

- formally describe this newly developed technique for monitoring *Powelliphanta* snails
- examine whether the mark-recapture assumptions are being met, with specific reference to the following:
  - Tag loss
  - Population closure (births, deaths, immigration and emigration)
- assess the suitability of the technique, with particular reference to practicality and animal welfare
- produce abundance estimates, with confidence intervals, for *P. augusta* at the different sites in which they now occur

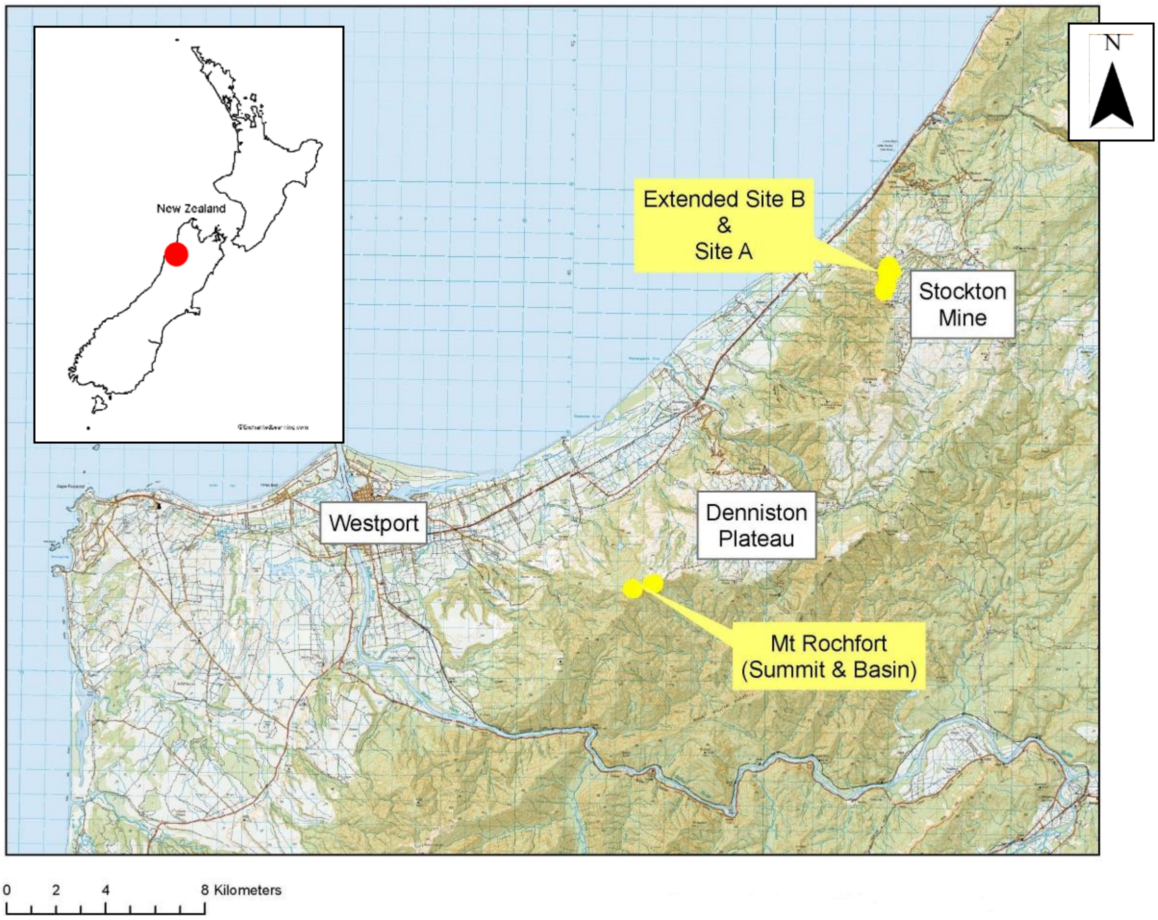
III. Methods

i. Study site

The study sites are located on the Stockton and Denniston plateaux, Buller, on the West Coast of the South Island (see Figure 1). Prior to the translocation programme, *P. augusta* was restricted to the slopes of Mount Augustus. It can still be found there in a small area of remaining natural habitat, known as 'Site A', just outside the Stockton Mine area. The species now also occurs in two new translocation areas. One is close to the source habitat, just to the north, known as 'Extended Site B'. The second is at Mount Rochfort, on the Denniston Plateau, approximately 16 kilometres to the south-west, where snails were released to the Mt Rochfort 'Summit' and 'Basin'.

Figure 1 – Map of Study Area

The location of the study sites, both nationally and locally, along with key landmarks.



The Mount Augustus habitat types have been described in detail elsewhere (Walker, Trewick, & Barker, 2008). However, the two translocation sites, Extended Site B and Mt Rochfort (Summit and Basin) had only been mapped by habitat very roughly, for release purposes, in terms of quality. Due to this, it was important to collect data on the habitat types in these areas. During 2012, one hundred and forty 5 x 5 metre vegetation reconnaissance plots were surveyed to provide habitat descriptions and allow for the production of detailed habitat maps. The results are summarised in Appendix C, along with the maps produced.

ii. Sampling

To obtain a reliable and comprehensive monitoring programme, it was important to sample in all the different types of habitat in which the species now occurs. As a bare minimum, this required the establishment of monitoring blocks in each of the three locations that the species now occurs. To capture variability in the habitat quality at each of these three locations, multiple monitoring blocks in representative habitat were set up in each location. In total, ten monitoring blocks were established and are listed below in Table 1.

Table 1 – Monitoring block details

Information relating to each of the long term monitoring (LTM) blocks. 'VDT' refers to 'Vegetation Direct Transfer', a means of transferring habitat mechanically using heavy machinery. It is not possible to compare the habitat quality of the VDT with the other sites at present due to uncertainties about the process.

Location	Monitoring Block Name	Location Type	Habitat Quality	Size (hectares)
Mt Augustus	Site A Upper	Natural Habitat	High	0.38
Mt Augustus	Site A Lower	Natural Habitat	Low-Moderate	0.32
Extended Site B	West 1	Translocation (manual)	High	0.25
Extended Site B	North East	Translocation (manual)	Moderate	0.23
Extended Site B	West 3	Translocation (manual)	Low	0.19
Extended Site B	R6 VDT	Translocation (VDT)	n/a (VDT)*	0.38
Mt Rochfort	Basin A	Translocation (manual)	Low/Moderate	0.29
Mt Rochfort	Basin B	Translocation (manual)	Low	0.25
Mt Rochfort	Summit A	Translocation (manual)	High/Moderate	0.33
Mt Rochfort	Summit B	Translocation (manual)	Low	0.41

To effectively plan releases of the snails, the habitat quality at the translocation sites had already been mapped by the Department for Conservation. The habitat was classified as high, moderate or low quality or unsuitable, in terms of the suitability for *P. augusta* releases. These maps were utilised to identify potential monitoring blocks and field visits were undertaken to confirm and mark out the monitoring blocks. Consideration was also given to access and health and safety risks to field staff undertaking the surveys. Ideally, each of the monitoring blocks would have had the same size and shape. However, the mountainous terrain made this impossible and it was a case of finding blocks that were in representative habitat that was safe and accessible for a field team to monitor at night, when the snails are active.

At Extended Site B, three blocks were set up to represent high, moderate and low quality habitat respectively. An additional monitoring block was set up in habitat that had been moved mechanically from the source site. This process is known as vegetation direct transfer (VDT) and utilises heavy machinery from the mining operation to lift habitat on to trucks and transfer it to another location (Rodgers, Simcock, Bartlett, Wratten, & Boyer, 2011). The technique allows for the transfer of not only any snails present but also the entire habitat, including soil, vegetation and earthworms. This monitoring block was of particular interest, as it was unclear how many snails had been transferred in this way and whether any would have survived the process. A map and photos of the Extended Site B monitoring blocks are shown below in Figures 2 to 6.

Figure 2 – Map of Extended Site B

Detailed map showing the four monitoring blocks in the translocation site at Extended Site B. 'LTM Block', identified by yellow boundary line, refers to the 'Long Term Monitoring Block', as listed in Table 1, above.

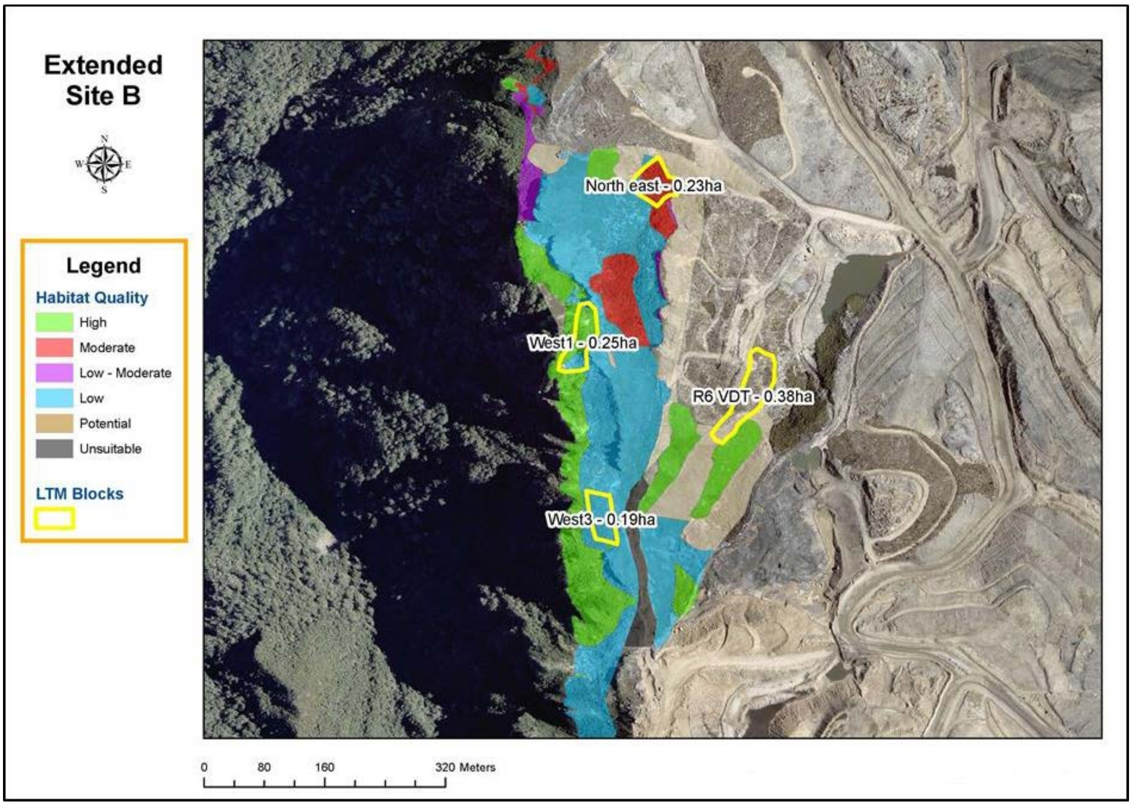


Figure 3 – Photo of West 1 Monitoring Block (high quality habitat)

Figure 4 – Photo of North East Monitoring Block (moderate quality habitat)

Figure 5 – Photo of West 3 Monitoring Block (low quality habitat)

Figure 6 – Photo of R6 VDT Monitoring Block (vegetation direct transfer habitat)

At Mt Rochfort, two blocks were established at the Summit release area and an additional two in the Basin release area. These were representative of the habitat quality in the vicinity. A map and photos of these blocks are shown below in Figures 7 to 11.

Figure 7 – Map of Mount Rochfort

Detailed map showing the four Mount Rochfort Monitoring Blocks.

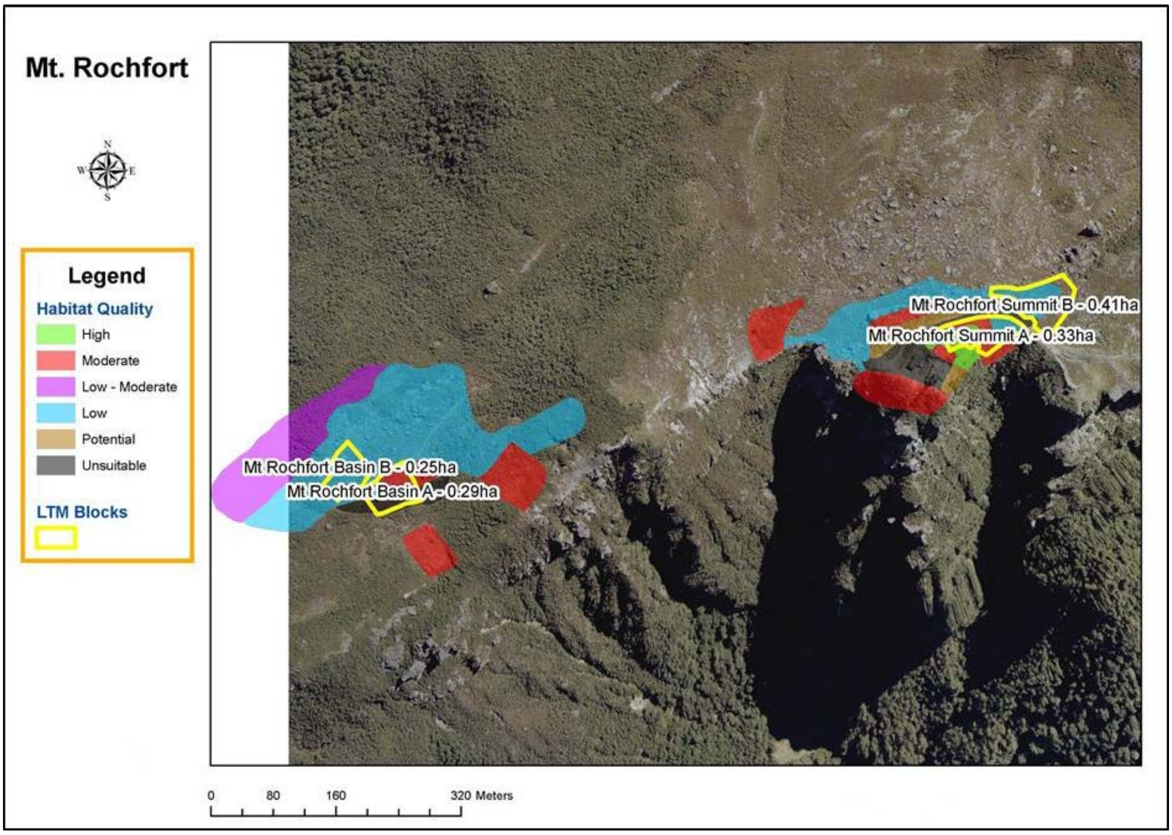


Figure 8 – Photo of Summit A Monitoring Block (moderate/high quality habitat)

Figure 9 – Photo of Summit B Monitoring Block (low quality habitat)

Figure 10 – Photo of Basin A Monitoring Block (low/moderate quality habitat)

Figure 11 – Photo of Basin B Monitoring Block (low quality habitat)

In the remaining natural habitat at Mt Augustus (Site A), there was a small area of high quality habitat and a larger area of lower quality habitat, necessitating the establishment of two additional monitoring blocks. Establishing monitoring blocks in the remaining area of natural habitat not only allowed for the monitoring of the natural population but also provided a useful comparison for results from the new translocation sites. A map and photos of these blocks is shown below in Figures 12 to 14. As shown in the aerial photo, these two blocks are adjacent to the Stockton coal mine, which is to the east.

Figure 12 – Map of Site A

Detailed map showing the two monitoring blocks in the remaining natural habitat at Mount Augustus. Note that the Mount Augustus area was not mapped in the same way as the translocation sites. However, the monitoring blocks have been assigned a habitat quality status based on a visual inspection and on knowledge of preferred habitat types.

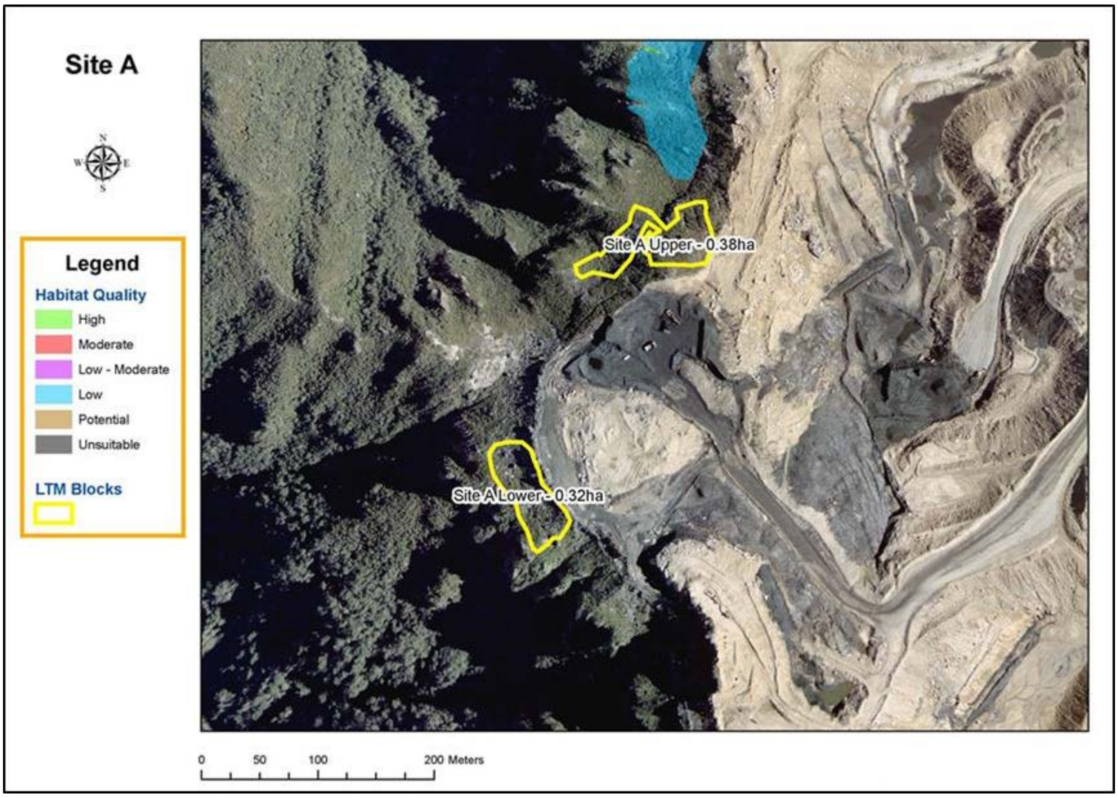


Figure 13 - Photo of Site A Upper monitoring block (high quality habitat)

Figure 14 – Photo of Site A Lower Monitoring Block (low-moderate quality habitat)

Monitoring was undertaken annually, with different sites monitored in each season. The choice of sites was somewhat dictated by available resources and also by management priorities. Table 2 shows the years in which monitoring occurred at each site. Appendix D contains details of the specific dates that monitoring occurred, along with specific locations.

Table 2 - Primary monitoring periods in *P. augusta* monitoring programme

Highlighted green tick indicates survey undertaken and highlighted red with a cross indicates survey not undertaken.

	Site A Upper	Site A Lower	West 1	North East	West 3	R6 VDT	Basin A	Basin B	Summit A	Summit B
2008/09	√	X	√	X	X	X	X	X	X	X
2009/10	X	X	√	√	√	X	√	√	√	√
2010/11	√	√	√	√	√	√	√	√	√	√
2011/12	√	√	√	√	√	√	√	√	√	√
2012/13	√	√	√	√	√	√	X	X	X	X

Only two sites were monitored during 2008/2009, as these were the two pilot study sites. Site A Upper, the small remaining area of high quality natural habitat, was 'rested' in 2009/10, until the impacts of mark-recapture monitoring (if any) were better understood. Site A Lower and R6 VDT blocks were added in the 2010/2011 season to increase representativeness. Due to funding limitations during the 2012/2013 season, only six out of ten blocks were monitored. West 1, the site with the tag loss experiment running, was the only site to be monitored in all five years of this study. The surveys started on 3 February 2009 and were completed on 20 May 2013. In total, this constituted 35 separate monitoring periods at all sites. On average, each monitoring period consisted of five individual surveys, meaning the total survey effort was approximately 175 nights of survey work over five years. The monitoring team size averaged six personnel during this period, which is the equivalent of 1,050 person days or 8,400 person hours. These figures relate to the number of successful survey nights and do not include the many nights where monitoring was abandoned, due to extreme weather or snail inactivity due to unsuitable weather conditions. The effort taken to gather these data has, therefore, been substantial. In addition to involvement in the various field surveys, I managed the entire monitoring programme throughout this period, including training/managing field staff, development of the field protocol, data and site management, as well as liaising with key stakeholders, such as Solid Energy, the Department of Conservation, Ngāti Waewae, and other researchers.

iii. Mark-recapture field protocol

The latest version of the field monitoring protocol (Weston, et al., 2011), which includes background information and details specific to *P. augusta*, is attached in full as Appendix E. Described below is a simplified summary of the field protocol that was followed.

Snail surveys

Each year that a site was monitored, five to seven surveys were undertaken in late spring/summer (i.e. November to March) to mark and recapture snails. Where possible, surveys occurred at least two days apart, to ensure independence between them, and were no more than two weeks apart to minimise the chances of immigration, emigration and mortality during the monitoring period. Surveys were undertaken at night, when conditions are favourable for snail movement. Ideally that consisted of comparatively mild and wet weather, with temperatures of at least 8°C and fog or drizzle/rain. However, it was found that snails were active in slightly cooler temperatures and also on fine nights, where ground conditions were still damp from recent precipitation. Each survey consisted of one search per night. Each search covered a clearly delineated monitoring area at the site, where the boundaries were physically marked with chain, posts and reflective tags. This permanent marking ensures that the same area is monitored in successive years.

Searches covered the entire monitoring area in a 'strip search'. This was achieved by a team of at least four people working side by side, each team member covering no more than a 2m wide strip. The outermost searcher marked the edge of the search strip with a measuring tape, to ensure the next search strip was laid out adjoining the previous one. On a slope, searching was best done walking uphill. When the top was reached, the field team walked single file back down to spread out along the start of the next search strip. Wherever possible, the route back down was located outside of the monitoring plot and utilised bare ground and/or rocks to walk along. This was to keep any habitat damage to a minimum. It was important to keep search effort consistent between searches. Each team member was equipped with two torches: one headlight and one handheld torch.

When snails were found

When a snail (marked or unmarked) was found, it was transferred to a plastic container, partly filled with damp moss or litter, with a perforated lid. The Task Leader provided a GPS location to the finder (if required), who then completed a snail record card to put in the container with the snail. This card recorded finder name, GPS location, habitat and micro-habitat information. All types of forms used during the surveys can be found in Appendix E. The snail was then taken to the snail-marking station (a covered area, such as a tent, vehicle or hut, near the survey area) to be processed. The site where the snail was found was marked with a red flashing LED light. The light and container were both labelled with the same number to ensure that the snail was later released where it was found. In areas of tall canopy, or dense vegetation, pig tailed standards were also used, with the LED lights attached to the top. A separate person in the team was responsible for marking capture locations, labelling of containers and transporting to and from the snail-marking-station (this person is known as the 'runner'). Care had to be taken that the search team stayed in line while snails were captured.

Marking of snails

An extra person in the search team was tasked with the marking of snails and completing the relevant paperwork. This occurred at the snail-marking-station. All snails were marked with polyethylene tags, imprinted with sequential numbers (Hallprint Pty Ltd, www.hallprint.com). For *P. augusta*, 8mm x 4mm, terracotta brown and/or transparent tags (based on shell size and colouration), were mainly used. Snails were wiped dry with a paper towel, a small area of the shell was roughened with fine sandpaper, and the tag was glued with superglue to this spot. Snails with a maximum diameter between 20mm and <25mm were tagged with transparent tags on the dorsal surface of the shell near the apex. Snails with a maximum diameter of 25mm or larger were tagged with a coloured tag on the ventral side. Tags on the ventral side were attached immediately behind the aperture to prevent the shell from overgrowing the tag. Snails with a maximum diameter smaller than 20mm were not tagged. Snails were kept on a damp paper towel for a few minutes until the superglue was touch dry. Snails were then measured (maximum diameter) and weighed. A photograph was also taken of each snail encountered. Snails were then transferred to their original container and taken back to the exact location where they were found.

Data collection

The following information was recorded during each search:

- the time period and the total person-time spent searching the monitoring area
- temperature, relative humidity and wind speed at beginning and end of search
- for each snail, tag number, shell size and weight
- for each snail, GPS location (once per season)
- for each snail, description of any damage to shell, habitat & micro-habitat details

Standard snail search forms are used to collect this information (see appendix 2).

Equipment list

As a guide, the following was used at each site:

- pig tailed standards, plastic chain, ear tags and reflective tape (to permanently mark the monitoring area)
- torches (x2 per team member)
- watch
- 50m measuring tape to mark edge of each search strip, temporary (x2)
- sturdy plastic containers for snail transport (x20)
- pegs (x20)
- flashing LED lights (x20)
- marker pen
- shelter/tent for snail-marking station
- set of callipers
- set of scales
- waterproof camera
- paper towels
- sandpaper (waterproof, P 400)
- superglue (non-drip gel) – 'Selleys Quick Fix' used here
- polyethylene tags
- forceps
- spray bottle (filtered or rain water)
- datasheets
- thermometer
- hygrometer
- anemometer
- GPS unit

iv. Ancillary activities

Several ancillary activities were undertaken over the course of the study to provide data to support the main mark-recapture monitoring study. There was a need to test some of the mark-recapture assumptions, such as there being a closed population. There was also a need to establish whether there was an issue with tag loss and, if so, at what rate. These ancillary activities included walkthrough surveys adjacent to the monitoring blocks, movement tracking of tagged snails within the monitoring blocks and a tag loss experiment. The details of each of these ancillary activities are described below.

Walkthrough surveys adjacent to long-term monitoring blocks

Night surveys outside long-term monitoring sites were undertaken towards the end of the 2012 season. Four nights of nocturnal walkthrough surveys were undertaken in the Extended Site B release area, covering the areas outside of the four monitoring blocks. This involved walking along unmarked routes, searching for snails out foraging on the surface. The main purpose of this activity was to determine if migration was occurring with marked snails outside long-term monitoring sites. It also provided an opportunity to discover the fate of snails that had gone 'missing'. The data was not used to derive abundance estimates.

Movement tracking

During the 2012 season, a GPS location for every snail observed was recorded on every occasion, to allow for the tracking of movement of all snails that were encountered. The purpose of this was to try to understand the pattern and extent of snail movement and therefore determine the likelihood of snails leaving the monitoring block during the monitoring period (migration). This was important as any migration would potentially violate one of the mark-recapture assumptions of a closed population (i.e. no birth, deaths or migration during the survey period).

Tag loss

An estimate of tag loss rate is essential to attain reliable estimates for population parameters from the monitoring. To achieve this, a study was set up in the 'West 1' monitoring block at Extended Site B during the first season in 2009. Double tagging is a standard means of estimating tag loss, which can then be used to adjust abundance estimates (Seber & Felton, 1981). All snails found at this site were also double tagged in subsequent seasons. Any tag loss was then recorded each year. In total, 121 snails were double tagged.

v. Statistical analysis

The monitoring programme uses the principles of the robust design for mark-recapture studies (Lettink & Armstrong 2003). This design consists of a primary interval for monitoring (annual surveys) and a secondary interval within this (several surveys within each year). The primary interval allows for an open population with births, deaths, immigration and emigration, while the secondary interval assumes closure. Results from the secondary interval give estimates of abundance for every year surveys are completed, while the primary interval allows estimation of survival rates, recruitment and population growth rate over time (see Chapter 4). Ultimately, estimates of population growth rates are needed to establish whether the monitored populations are self-sustaining. However, these estimates could be expected only after 3-5 primary monitoring intervals (i.e. after 3-5 years if monitoring occurred annually). Estimates of abundance were obtained annually at different sites to gauge persistence and the probable success of the programme.

Each year, the data collected from the field was added to an Excel spreadsheet for subsequent analysis. The snail encounter data, used to produce abundance estimates, was extracted from this dataset and analysed annually by Darryl Mackenzie (Proteus Consulting), an independent expert in mark-recapture analysis (MacKenzie, 2009, 2010, 2011, 2012, 2013). The analysis of mark-recapture data is complex and can be easily misinterpreted. It is recommended that analysis is therefore undertaken by a suitably qualified expert to avoid mistakes (Lettink & Armstrong, 2003). Furthermore, this species was considered to be 'Nationally Critical' on the New Zealand Threat Classification Lists (Hitchmough, Bull, & Cromarty, 2007). For these reasons, expert help was sought with the analysis. The snail survival data was analysed simultaneously (see Chapter 4 of this thesis).

The following is a summary of the approach used for analysis (MacKenzie, 2013). Survival and capture probabilities were estimated directly in the model. Abundance was estimated using secondary calculations with the Huggins estimator (Huggins, 1991). A number of models were fit to the data and compared using Akaike's Information Criterion, corrected for small samples (Burnham & Anderson, 2002). Estimates from all models were combined using model averaging (Burnham & Anderson, 2002). All analyses were conducted with

Program MARK, via the R package, RMark. See Appendix H for more details on model selection.

The mark-recapture assumptions were tested with any available data (e.g. such as the wider area surveys). Tag loss was assessed through analysis of the results from the tag loss experiment at West 1. Evidence of death and migration was gained by examining the dataset to see if snails had been found either deceased, or outside the monitoring block, after a capture event in the same season. The practicality of the technique was assessed through personal experience and feedback from other members of the monitoring team over the five year period (2009-2013).

There are several limitations to this study. The methodology for mark-recapture monitoring of *P. augusta* described above targets mainly the adult to sub-adult cohorts in the population. Snails with a diameter below approximately 20 mm are rarely detected, as detection probability decreases with size (pers. obs.). This means that the results only apply to the larger snails, and recruitment to the population can be detected only by smaller snails reaching sub-adult size. Strictly speaking, the results also apply only to the monitoring areas searched.

IV. Results

Over the five year period, the combined surveys resulted in the capture and marking of 965 individual *P. augusta* snails, with a total of 1,809 individual encounters. Many snails were observed just once, whilst many others were observed multiple times in a season, with some even observed every season that a site was monitored. This number of encounters was sufficient to obtain abundance estimates for each primary monitoring period and for trends over time to be observed. The number of snails marked and the number of observations was variable at each site. Table 3 summarises the number of snail observations at each site.

Table 3 – Snails observed at each site

Number of individual snails marked and the number of individual encounters, along with site details.

Monitoring Block Name	Location Type	Habitat Quality	Size (hectares)	Snails marked	Individual encounters
Site A Upper	Natural Habitat	High/Moderate	0.38	334	569
Site A Lower	Natural Habitat	Low/Moderate	0.32	61	89
West 1	Translocation (manual)	High	0.25	171	432
North East	Translocation (manual)	Moderate	0.23	58	104
West3	Translocation (manual)	Low	0.19	79	153
R6 VDT	Translocation (VDT)	VDT	0.38	82	155
Basin A	Translocation (manual)	Low/Moderate	0.29	112	197
Basin B	Translocation (manual)	Low	0.25	13	16
Summit A	Translocation (manual)	High/Moderate	0.33	41	69
Summit B	Translocation (manual)	Low	0.41	14	25
			Totals	**965**	**1809**

i. Abundance estimates (absolute)

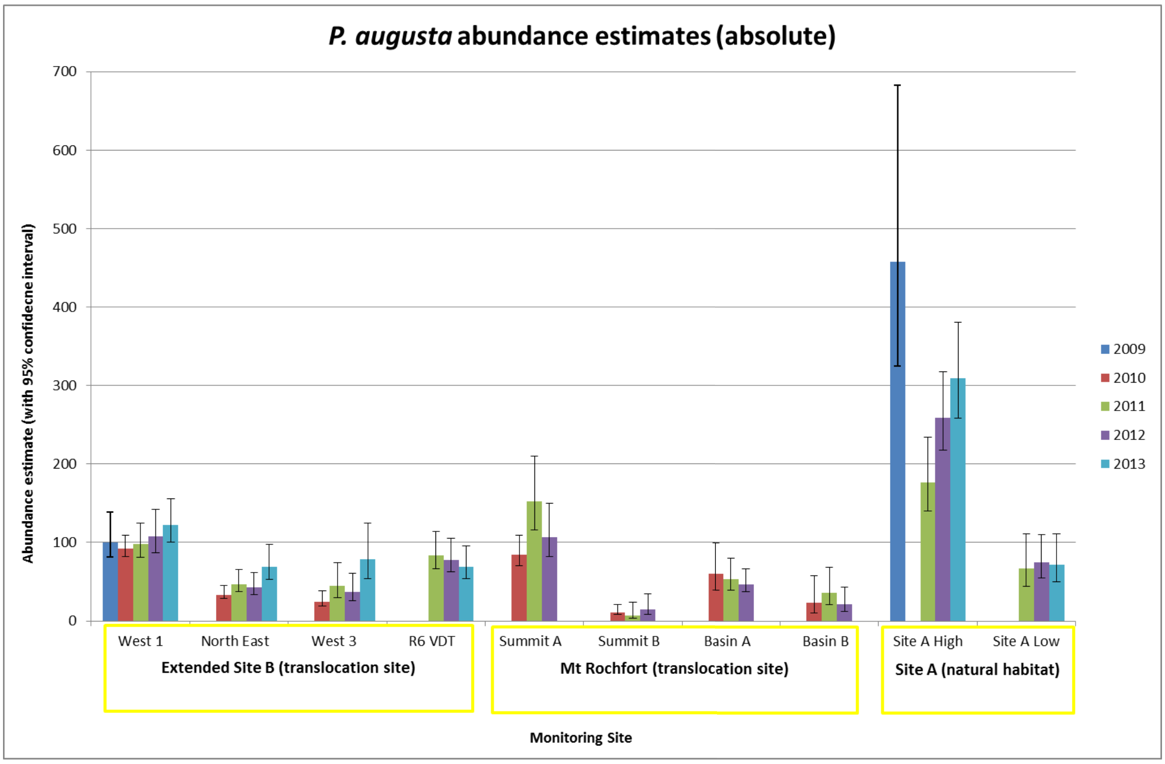
The modelled averaged *P. augusta* abundance estimates for the five year survey period are shown in Table 4. The total number of snails estimated in each monitoring block ranges from just 7 at Summit B in 2011 to 458 at Site A High in 2009. Despite fairly wide confidence intervals in some instances, the abundance estimates are reasonably consistent across years and, in most cases, appear to correspond with what might have been expected, based on the quality and size of each site. As well as the abundance estimate (n), the standard error (SE) and the 95% confidence interval are also shown in the table. Figure 15, shows the abundance estimates, with the 95% confidence intervals. The abundance estimates relate to adult and sub-adult snails and do not include those with a maximum diameter <20mm. Note that the numbers shown in Table 4 are estimates of absolute abundance in each monitoring block and have not been adjusted according to the size of the block, which is variable.

Table 4 - Abundance estimates (absolute)

n = abundance estimate, SE = standard error, 95% CI = the lower and upper limits of the 95% confidence interval. Cells with a 'x' and red fill indicate that the site was not surveyed in that year.

Year	Site	West 1	North East	West 3	R6 VDT	Summit A	Summit B	Basin A	Basin B	Site A (High)	Site A (Low)
2009	n	100	x	x	x	x	x	x	x	458	x
	SE	14	x	x	x	x	x	x	x	89	x
	95% CI	81	x	x	x	x	x	x	x	325	x
		139	x	x	x	x	x	x	x	683	x
2010	n	92	33	24	x	84	11	60	23	x	x
	SE	7	4	4	x	10	3	15	11	x	x
	95% CI	82	29	19	x	70	8	39	10	x	x
		109	45	38	x	109	21	99	58	x	x
2011	n	98	47	45	83	152	7	53	36	177	67
	SE	11	7	11	12	23	4	10	11	24	16
	95% CI	81	37	30	66	116	3	39	21	140	44
		125	65	74	114	210	24	80	68	234	111
2012	n	108	43	37	78	107	15	47	21	259	75
	SE	14	7	8	10	17	6	7	7	25	13
	95% CI	87	33	26	63	82	8	37	12	218	55
		142	62	61	105	150	34	66	43	318	110
2013	n	122	69	79	69	x	x	x	x	309	72
	SE	14	11	18	10	x	x	x	x	31	15
	95% CI	100	53	54	54	x	x	x	x	258	50
		156	97	125	96	x	x	x	x	381	111

Figure 15 - Abundance estimates (absolute)



ii. Abundance estimates (per hectare)

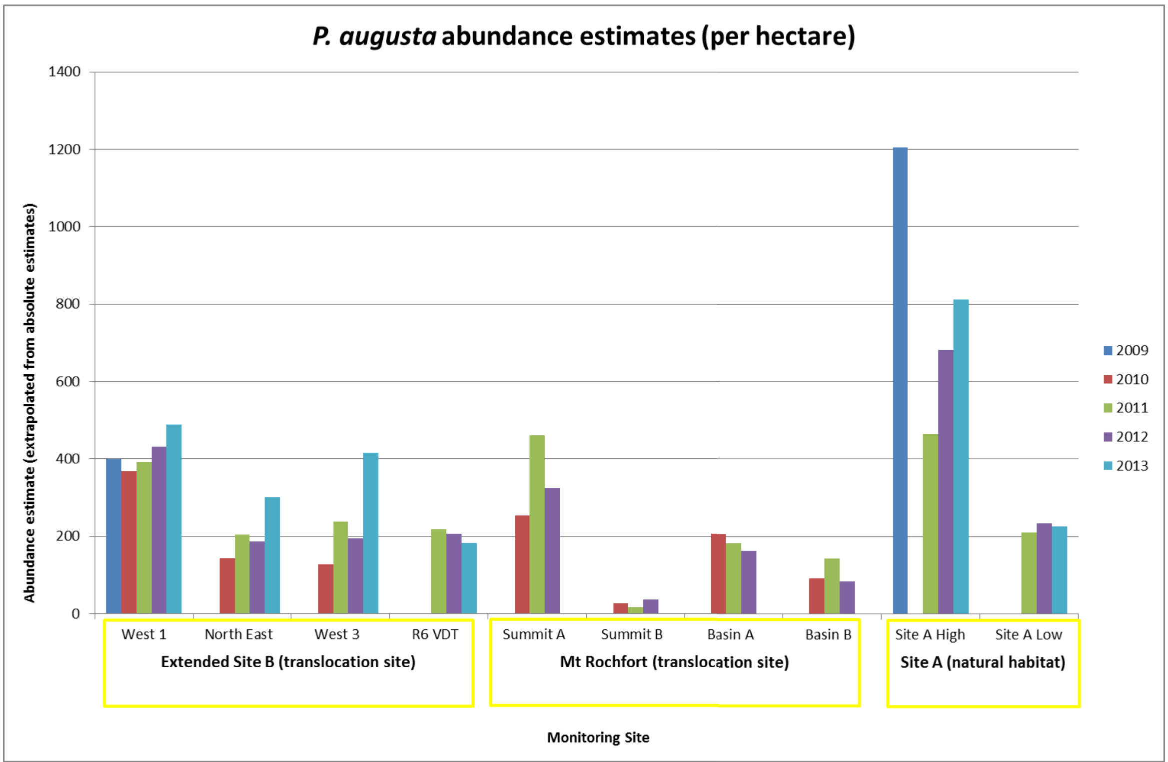
As the monitoring blocks are different sizes, the estimates of absolute abundance have been converted to abundance per hectare, allowing for comparison of different sites. These abundance estimates are shown in Table 5 and Figure 16. Note the scale on the y axis is different to that on Figure 15. These figures show that the estimated abundance of *P. augusta*, during this monitoring period, ranges from 17 snails per hectare, at Summit B in 2011, to 1,205 snails per hectare, at Site A High in 2009.

Table 5 - Abundance estimates (snails per hectare)

n = abundance estimate, SE = standard error, 95% CI = lower and upper limits of the 95% confidence interval.

	Site									
Year	West 1	North East	West 3	R6 VDT	Summit A	Summit B	Basin A	Basin B	Site A High	Site A Low
2009	400	x	x	x	x	x	x	x	1205	x
2010	368	143	126	x	255	27	207	92	x	x
2011	392	204	237	218	461	17	183	144	466	209
2012	432	187	195	205	324	37	162	84	682	234
2013	488	300	416	182	x	x	x	x	813	225

Figure 16 - Abundance estimates (per hectare)



iii. Ancillary activities

Walkthrough surveys adjacent to long-term monitoring sites

Towards the end of the 2012 season, four nocturnal walkthrough surveys were undertaken in the Extended Site B release area, covering the areas outside of the monitoring plots. The main purpose of this activity was to determine if migration was occurring with marked snails outside long-term monitoring sites. A total of 46 snails were observed. Three of these had been previously tagged as a part of the monitoring programme. One of the them (snail 'A358') had been observed previously that season within a monitoring plot. The full mark-recapture encounter history for this snail is shown in Table 6.

Table 6 - Encounter history for snail A358

Mark-recapture encounter history (0 = not observed, 1 = first capture that season, 2 = recapture that season)

Tag #1	Tag #2	Location	Monitoring block	Night 1: 03/02/2009	Night 2: 04/02/2009	Night 3: 05/02/2009	Night 4: 20/02/2009	Night 5: 21/02/2009	Night 6: 23/02/2009	Night 7: 18/03/2009	Night 1: 01/12/2009	Night 2: 07/01/2010	Night 3: 18/02/2010	Night 4: 14/03/2010	Night 5: 21/03/2010	Night 1: 03/02/2011	Night 2: 22/02/2011	Night 3: 16/03/2011	Night 4: 25/03/2011	Night 5: 26/03/2011	Night 6: 16/04/2011	Night 1: 31/01/2012	Night 2: 02/02/2012	Night 3: 14/02/2012	Night 4: 21/02/2012	Night 5: 23/02/2012	Night 1: 16/01/2013	Night 2: 04/02/2013	Night 3: 18/03/2013	Night 4: 03/04/2013	Night 5: 11/04/2013	Night 6: 18/04/2013	Night 7: 05/05/2013	Night 8: 17/05/2013
A358	A359	Extended Site B	West 1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	0	**1**	0	**2**	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0

Snail 'A358' had been first captured and tagged in the West 1 monitoring plot during the 2010 season. This snail was not observed during the 2011 season but was recaptured 14/02/2012. Approximately two weeks later it was observed outside the monitoring plot during the walkthrough surveys. This snail was not observed again during the 2012 or 2013 season.

Movement tracking

All sites were monitored five times during the 2012 season, which resulted in a total of 365 individual snails being captured and 483 individual observations (some snails were observed more than once). The majority of snails, 266 or approximately 73%, were observed just once, no snail was observed on all five surveys in a monitoring block and just one snail was observed on four survey nights. Table 7 summarises the total number observed during the 2012 season at each site, with a breakdown of the number of snails observed on 1, 2 3, 4 or 5 nights, along with the percentage.

Table 7 - Number of survey nights individual snails were observed

The total number of snails observed during the 2012 season at each site is given, with a breakdown of the number observed on 1, 2 3, 4 or 5 nights, followed by percentage of total in brackets.

			Number of surveys individual snails observed				
Location	**Monitoring Block**	**Snails observed**	**1**	**2**	**3**	**4**	**5**
Extended Site B	West 1	54	38 (70)	13 (24)	3 (6)	0 (0)	0 (0)
Extended Site B	North East	23	15 (65)	6 (26)	1 (4)	1 (4)	0 (0)
Extended Site B	West3	16	13 (81)	2 (13)	1 (6)	0 (0)	0 (0)
Extended Site B	R6 VDT	43	30 (70)	12 (28)	1 (2)	0 (0)	0 (0)
Mt Rochfort	Basin A	21	16 (76)	4 (19)	1 (5)	0 (0)	0 (0)
Mt Rochfort	Basin B	5	2 (40)	3 (60)	0 (0)	0 (0)	0 (0)
Mt Rochfort	Summit A	41	29 (71)	10 (24)	2 (5)	0 (0)	0 (0)
Mt Rochfort	Summit B	4	2 (50)	2 (50)	0 (0)	0 (0)	0 (0)
Mt Augustus	Site A Upper	126	96 (76)	23 (18)	7 (6)	0 (0)	0 (0)
Mt Augustus	Site A Lower	32	25 (78)	6 (19)	1 (3)	0 (0)	0 (0)
	Total	**365**	**266 (72.9)**	**81 (22.2)**	**17 (4.7)**	**1 (0.3)**	**0 (0.0)**

At most sites, the pattern of snails observed on one or more nights seemed to be consistent with the abundance at the site. The percentage observed seemed to be fairly uniform across all sites, with the exception of Summit B and Basin B. These two sites appear to have very low density populations and the number of snails available for capture was therefore low. However, a surprisingly high percentage were observed on more than one night, in comparison to the other sites, perhaps indicating that the few snails at these sites are more active than at other sites. One explanation could be that, due to the low quality of habitat at these sites, snails are comparatively more active to meet their needs (e.g. forage for food or find a mate).

The results from the tracking of movement are shown in Figures 17 to 26. Different coloured dots show snail observations on different survey nights and the black arrows show the general direction of movement of an individual snail over time. Snails were occasionally found together in the same location and in such instances appear on the maps as a single dot. Only snails observed within the monitoring blocks (shown on maps by a yellow boundary line) were included. On some of the maps the snails may appear to be just outside of this area. However, this can be attributed to GPS error, where readings can be inaccurate by three to five metres, depending on satellite reception and configuration.

Figure 17 - Snail movement at West 1, Extended Site B

Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time.

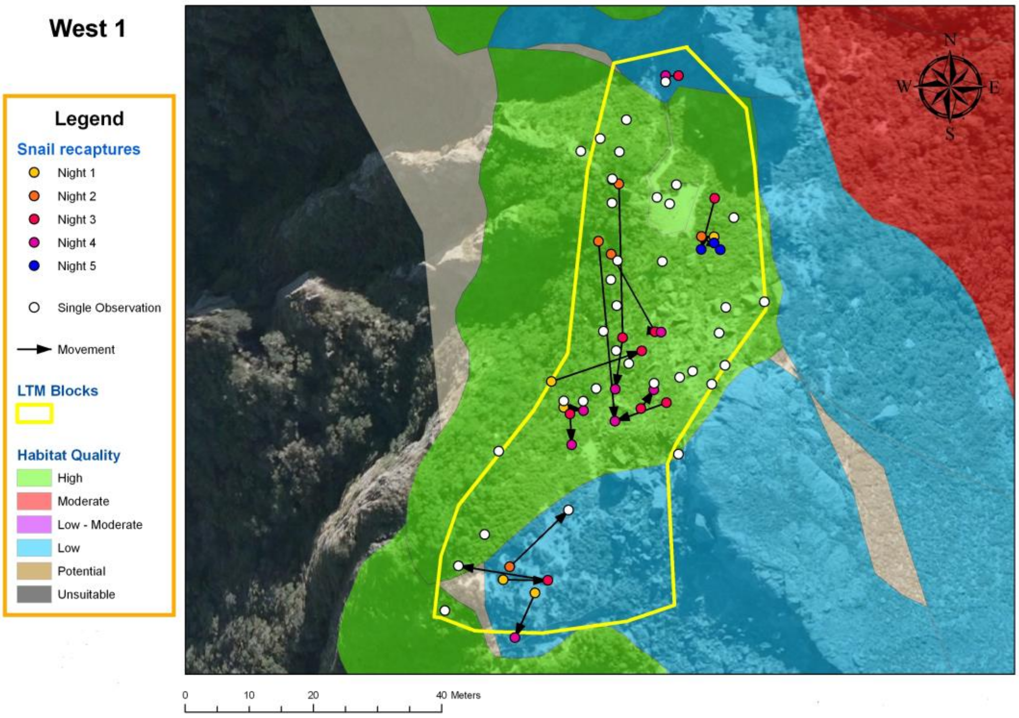


Figure 18 - Snail movement at North East, Extended Site B.

Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time.

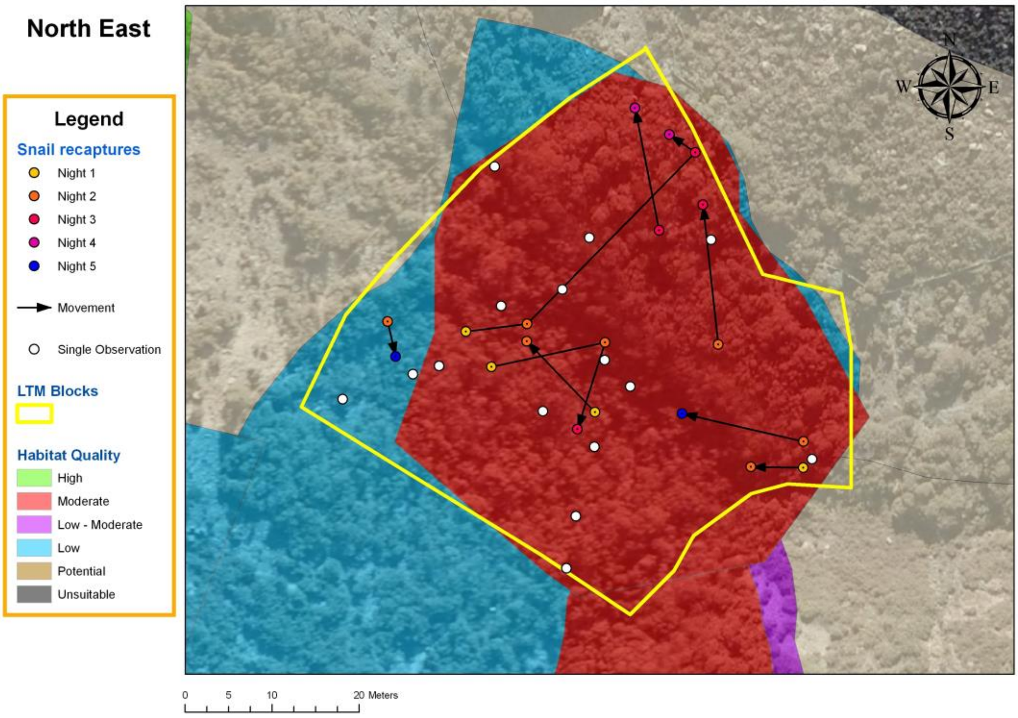


Figure 19 - Snail movement at R6 VDT, Extended Site B

Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time. As this is a VDT site, there was no way of replicating the habitat quality survey undertaken elsewhere. The closest category, in comparison to the other sites, would be 'Low-Moderate' (pers. obs.).

Figure 20 - Snail movement at West 3, Extended Site B

Snail movement at West 3, Extended Site B. Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time.

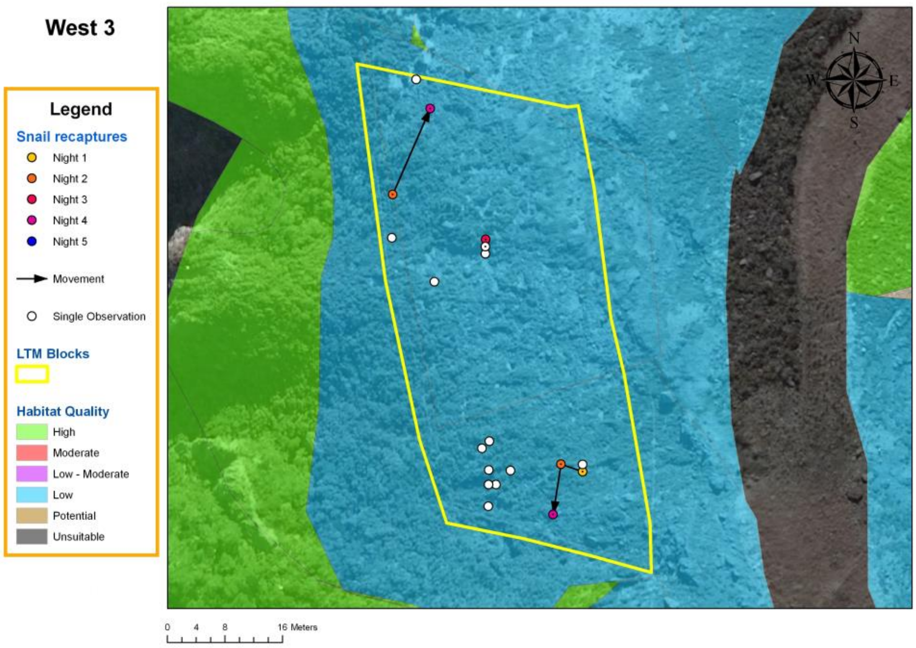


Figure 21 - Snail movement at Summit A, Mt Rochfort

Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time.

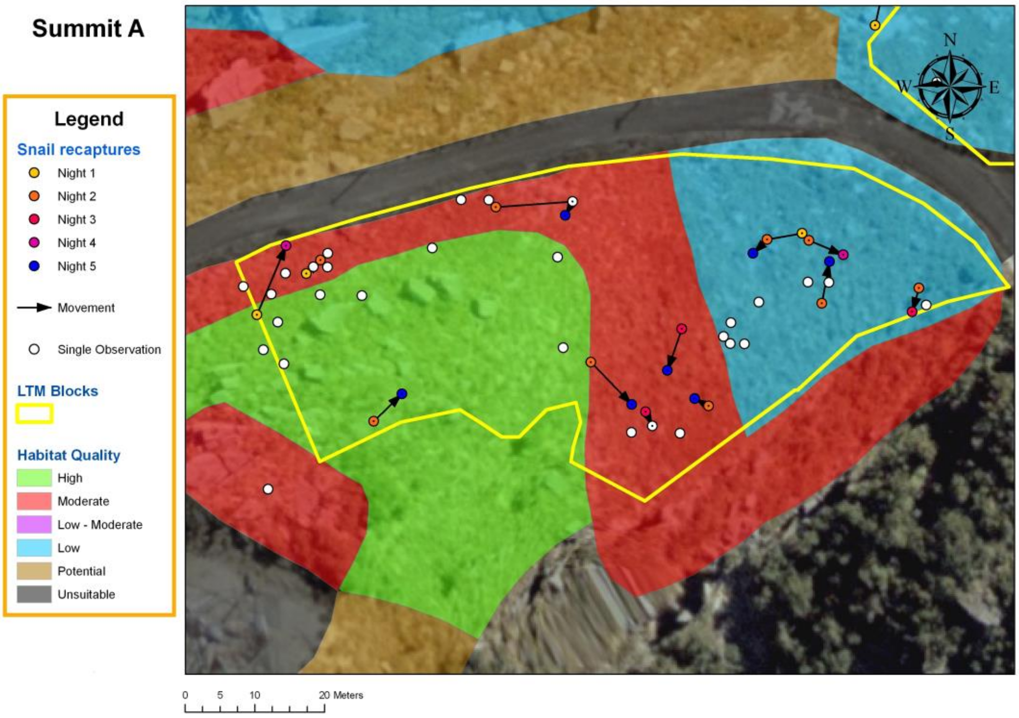


Figure 22 - Snail movement at Summit B, Mt Rochfort

Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time.

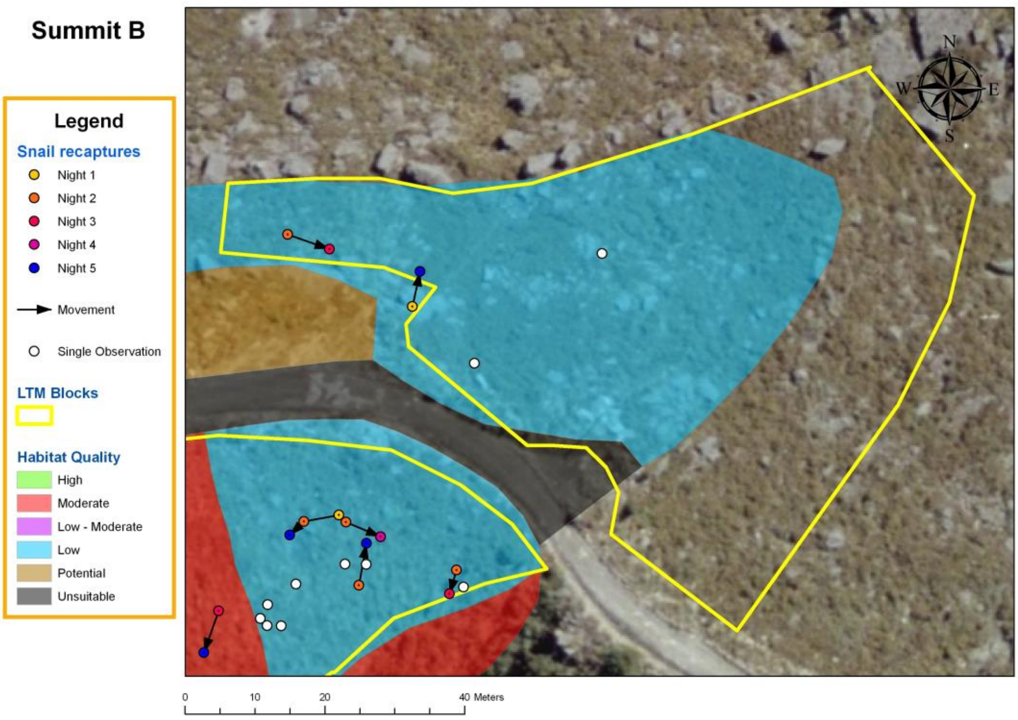


Figure 23 - Snail movement at Basin A, Mt Rochfort

Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time.

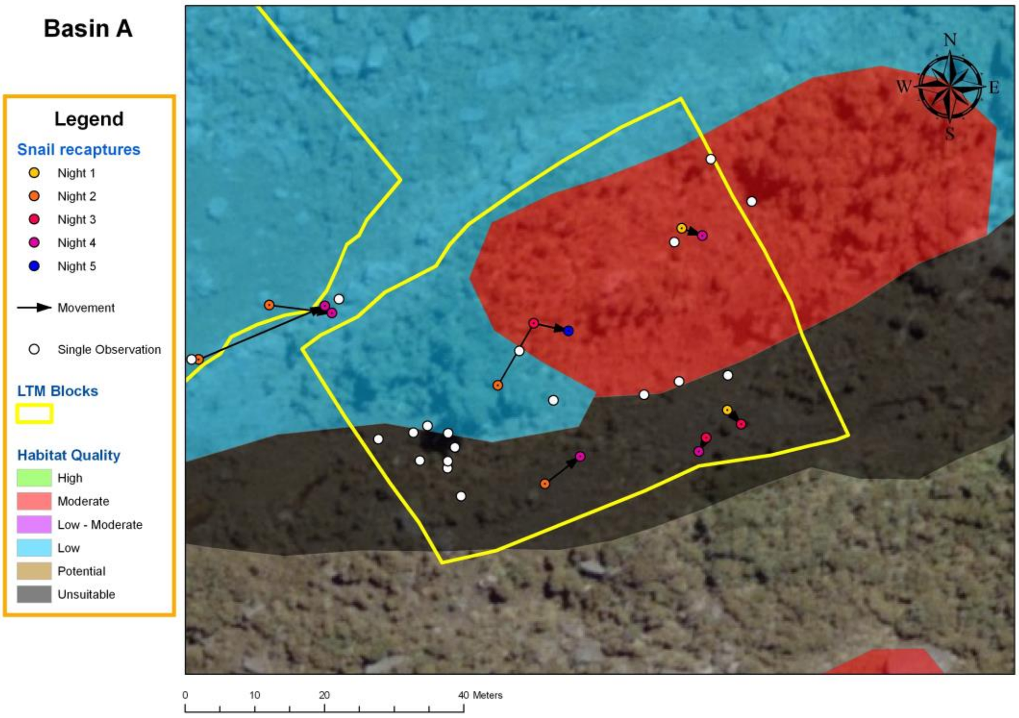


Figure 24 - Snail movement at Basin B, Mt Rochfort

Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time.

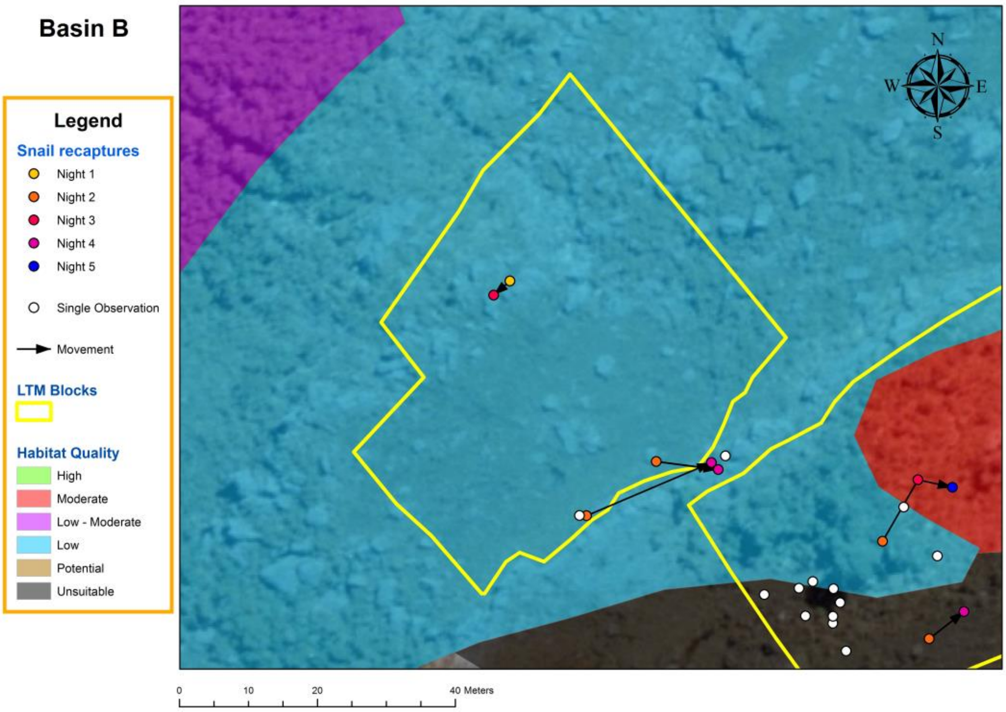


Figure 25 - Snail movement at Site A Upper, Mt Augustus

Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time. As this was natural habitat, this site was not assessed in terms of habitat quality and suitability for snails. The closest category, in comparison to the other sites, would be 'High' (pers. obs.).

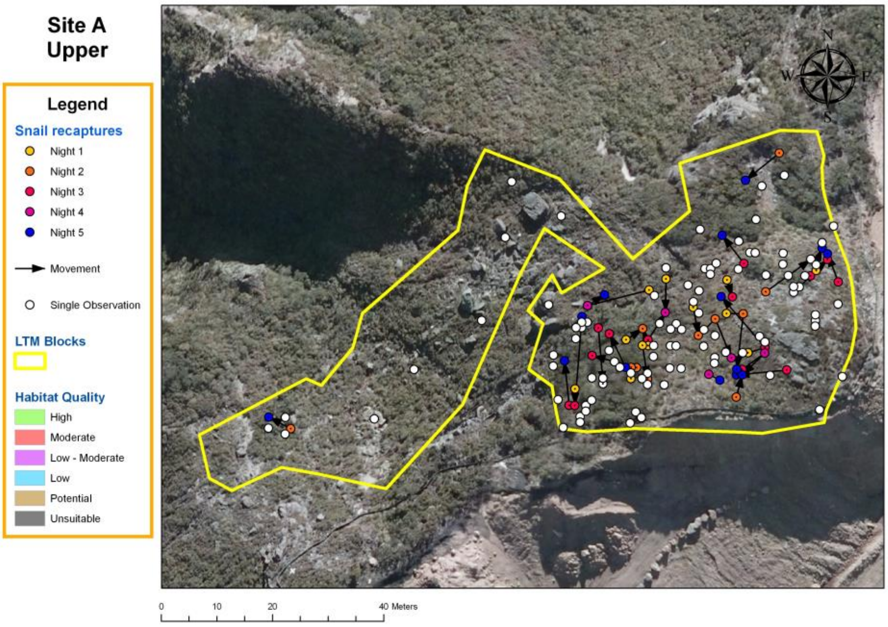
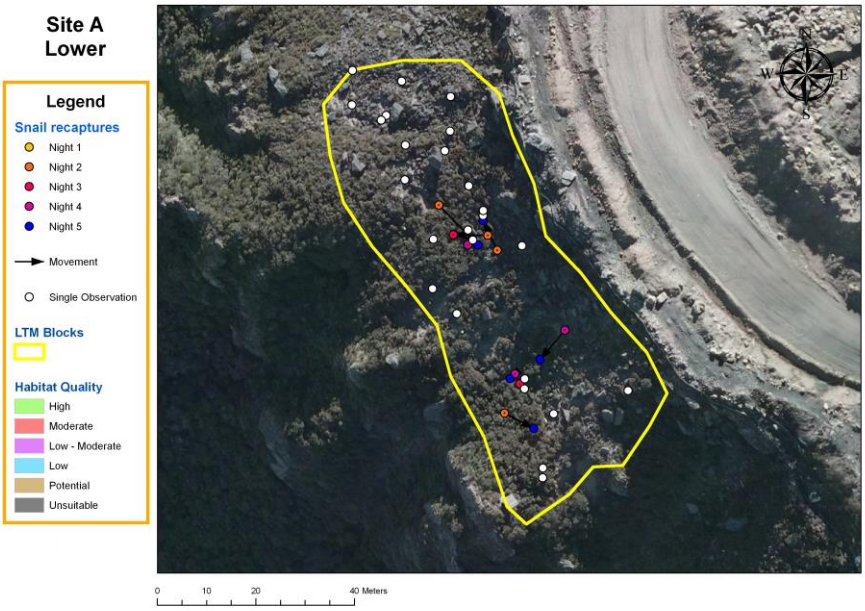


Figure 26 - Snail movement at Site A Lower, Mt Augustus

Coloured dots show snail observations on different survey nights and black arrows show the general direction of movement of an individual snail over time. As this was natural habitat, this site was not assessed in terms of habitat quality and suitability for snails. The closest category, in comparison to the other sites, would be 'Low-Moderate' (pers. obs.).



Because of GPS error, it is impossible to calculate average displacement. For those snails that were recaptured a week apart, displacement was often less than 10 metres. Taking in to account GPS error from both the first and second reading, any derived calculations would be highly dubious. Instead, tracking over the course of several weeks presents a general picture of snail movement and provides as indication of the likelihood of snails dispersing from the monitoring block.

The distribution of snails at each monitoring block may provide some indication of habitat preference. At some sites, particularly where there is moderate to high quality habitat, or a mixture of habitats, the distribution was fairly even (e.g. West 1 and North East). In contrast, clustering was observed at other sites, possibly highlighting habitat preference. This was particularly noted at R6 VDT, where a follow-up field inspection identified ideal conditions for snails, such as suitable shelter and moisture. There was also a marked contrast within Site A Upper, where the eastern side of the block contained almost all of the snails. The habitat in this area is the closest to the natural habitat where *P. augusta* was found in high densities. The habitat in the western side of the block is not as high quality and this appeared to be demonstrated by the results. The amount of movement exhibited by each snail was highly variable (and as expected). These snails appear to be highly individual, with some being active and others sedentary. Movement appeared to be somewhat sporadic and random. In some cases snails were moving from high quality to low quality habitat but in others it was the reverse. The single snail observed on four occasions during the 2012 season was of interest. It was observed at North East and travelled approximately 40 metres in four weeks. Note that this was a minimum, as the snail may well have moved in other directions on other nights. Finally, it is worth noting that 75% of the snails observed in Basin A were located in habitat that had been defined as unsuitable for snails by the Department of Conservation.

Tag loss

In total, one hundred and twenty one snails were selected to be double tagged as a part of the tag loss experiment. Some smaller snails (20mm to <25mm) were not selected after the first season as there were concerns that these were too small for the placement of two tags, which may lead to the shell growing over one of the tags (see Figure 27). Note that West 1 monitoring block at Extended Site B, where this experiment was undertaken, was the only monitoring block that was surveyed in all five seasons of this study.

Figure 27 - Snail growing over tag

Example of a smaller snail growing over a tag. Smaller snails may not be suitable for double tagging.

The encounter history for these 121 snails is shown in Table 9. The table shows the seasons in which snails were first captured and then if they were captured again in subsequent seasons. Note that this includes a small number of snails that were found deceased, as any empty shell of a snail that had been part of the experiment was checked to see if both tags were intact or not, before being collected from the field.

This data is also summarised in Table 8, which shows a breakdown of results for those snails observed after 1, 2, 3 and 4 seasons, as well as results for all observations. Of the 156 recaptures of double tagged snails over the five seasons, 155 were observed with two tags intact and one snail was observed with 1 tag lost. This equates to a tag loss rate of 0.6% over the term of the study. Given that just one snail was observed with one tag lost, it is assumed that zero snails lost both tags, although this remains a possibility, if unlikely. Taking into account the fact that some snails were observed over 2, 3 and 4 seasons, the annual tag loss rate is even lower, at approximately 0.3%.

Table 8 - Summary of tag loss data

A breakdown of results for those snails observed after 1, 2, 3 and 4 seasons, as well as results for all observations. Note that 121 snails were double tagged in total.

	Years after snail first tagged				
	1	2	3	4	All
Observations with 2 tags (#)	71	43	31	10	155
Observations with 1 tag (#)	1	0	0	0	1
Tag loss estimate (%)	1.4	0.0	0.0	0.0	0.6

The single snail with the lost tag was ‘A003/A004’. This was initially captured on the first night of the first season and was just the second snail to be tagged in the entire monitoring programme. It was found a year later with just one tag. It is likely that human error was the cause (when applying the tag), rather than any issue with the tag or the adhesive. Tag loss is not thought to be a significant factor and has not been incorporated into the abundance estimates.

Table 9 - Encounter history of double tagged snails

Cells marked '1' and highlighted green indicate a positive observation and cells marked '0' and highlighted red indicate that the snail was not observed.

First captured 2008/2009						
Tag #1	Tag #2	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013
A000	A001	1	1	0	0	0
A002	A003	1	1	0	0	0
A004	A005	1	0	0	0	0
A006	A007	1	1	1	1	1
A008	A009	1	1	1	1	0
A010	A011	1	1	1	0	0
A012	A013	1	1	1	1	1
A014	A015	1	0	0	0	0
A016	A017	1	1	1	0	0
A018	A019	1	1	0	0	0
A020	A021	1	0	0	0	0
A022	A023	1	0	1	0	0
A024	A025	1	1	1	0	0
A026	A027	1	1	0	0	0
A028	A029	1	0	0	0	0
A030	A031	1	1	1	1	0
A032	A033	1	1	0	0	0
A034	A035	1	1	0	1	0
A036	A037	1	1	0	1	1
A038	A039	1	1	1	1	1
A040	A041	1	1	1	1	1
A042	A043	1	1	0	0	0
A044	A045	1	1	1	1	0
A046	A047	1	0	0	0	0
A048	A049	1	1	1	0	0
A050	A051	1	0	0	0	1
A052	A053	1	1	1	1	0
A054	A055	1	1	1	1	1
A056	A057	1	0	0	0	0
A058	A059	1	0	1	0	0
A060	A061	1	0	0	0	0
A062	A063	1	0	0	0	0
A064	A065	1	0	0	0	0
A066	A067	1	0	0	0	0
A068	A069	1	1	0	0	0
A070	A071	1	1	1	0	0
A072	A073	1	1	0	0	0
A074	A075	1	1	0	0	0
A076	A077	1	1	1	0	0
A079	A080	1	0	1	1	1
A081	A082	1	0	0	0	0
A083	A084	1	0	0	0	0
A085	A086	1	0	1	0	0
A087	A090	1	0	1	1	0
A091	A092	1	1	1	0	0
A093	A094	1	0	0	0	0
A095	A096	1	1	0	0	0
A097	A098	1	1	0	1	0
A099	A100	1	1	0	0	0
A101	A102	1	1	1	1	0
A103	A104	1	1	0	0	0
A105	A106	1	1	0	0	0
A107	A108	1	0	0	1	0
A109	A110	1	1	1	0	0
A111	A112	1	1	0	0	0
A113	A114	1	0	1	0	0
A115	A116	1	1	0	1	1
A117	A118	1	1	0	1	0
A119	A120	1	1	0	0	0
A121	A122	1	0	1	1	1
A123	A124	1	0	0	0	0
A125	A126	1	1	0	0	0
A127	A128	1	0	0	1	0

First captured 2009/20010						
Tag #1	Tag #2	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013
A290	A350	n/a	1	0	0	0
A292	A355	n/a	1	0	1	1
A293	A317	n/a	1	1	0	1
A295	A613	n/a	1	1	0	0
A296	A612	n/a	1	1	0	0
A298	B587	n/a	1	0	1	0
A299	A650	n/a	1	1	1	1
A309	A310	n/a	1	0	0	0
A311	A312	n/a	1	1	1	0
A313	A314	n/a	1	1	0	0
A315	A316	n/a	1	0	0	0
A344	A345	n/a	1	1	1	0
A346	A347	n/a	1	1	0	0
A348	A349	n/a	1	1	0	0
A351	A352	n/a	1	0	0	0
A353	A354	n/a	1	1	1	1
A356	A357	n/a	1	0	0	1
A358	A359	n/a	1	0	1	0
A360	A361	n/a	1	1	0	1
A362	A363	n/a	1	1	1	1
A364	A365	n/a	1	0	0	0
A366	A367	n/a	1	0	0	0
A406	A407	n/a	1	0	0	0
A408	A409	n/a	1	0	0	0
A410	A411	n/a	1	1	0	1
A412	A414	n/a	1	1	1	1
A415	A416	n/a	1	0	1	1
A467	A468	n/a	1	1	1	0
A469	A470	n/a	1	1	1	1

First captured 2010/2011						
Tag #1	Tag #2	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013
A592	A593	n/a	n/a	1	0	0
A594	B574	n/a	n/a	1	1	1
A596	A597	n/a	n/a	1	0	0
A598	A599	n/a	n/a	1	0	1
A600	A601	n/a	n/a	1	0	0
A640	A641	n/a	n/a	1	0	0
A642	A643	n/a	n/a	1	1	0
A644	A645	n/a	n/a	1	0	1
A646	A647	n/a	n/a	1	1	1
A648	A649	n/a	n/a	1	1	0
A651	A652	n/a	n/a	1	1	0
A678	A679	n/a	n/a	1	0	0
A680	A681	n/a	n/a	1	1	0
A682	A683	n/a	n/a	1	0	1
A684	A685	n/a	n/a	1	0	0
D523	D524	n/a	n/a	1	0	0
D525	D526	n/a	n/a	1	1	1

First captured 2011/2012						
Tag #1	Tag #2	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013
B572	B573	n/a	n/a	n/a	1	1
B579	B580	n/a	n/a	n/a	1	1
B581	B582	n/a	n/a	n/a	1	1
B585	B586	n/a	n/a	n/a	1	0
B592	A837	n/a	n/a	n/a	1	1
F101	B641	n/a	n/a	n/a	1	0
F102	B786	n/a	n/a	n/a	1	1
F103	B593	n/a	n/a	n/a	1	0
F106	B788	n/a	n/a	n/a	1	1
F113	B686	n/a	n/a	n/a	1	1
F114	B640	n/a	n/a	n/a	1	1
F118	B738	n/a	n/a	n/a	1	1

V. Discussion

The primary driver for developing a mark-recapture method for the monitoring of *Powelliphanta* snails was to evaluate and monitor the status of the remaining populations of the critically endangered snail *Powelliphanta augusta*. Five years on, it is now possible to report on the status of the species at each of the sites in which they now occur, both in the remaining natural habitat and in the translocation areas. In contrast to popular opinion, and some of the misleading information published in the literature (e.g. (Morris, 2010), and (Germano, et al., 2015)), it appears that the populations are stable and may even be increasing in some cases.

When assessing abundance at each site, it is most useful to look at the results that have been adjusted to estimate the number of snails per hectare, as this allows for a comparative assessment. At the translocation sites, current abundance is most likely determined somewhat by the number of snails that were actually moved to these sites and, to a lesser degree, how the snails have fared since translocation. Different numbers of snails were transferred to each site depending on habitat quality and assumptions about carrying capacity. In all cases where snails were hand translocated, fewer snails were released than the sites were thought able to sustain. It is likely to be some years before the sites reach carrying capacity and it is possible to determine how the translocations sites compare with the natural habitat. Furthermore, it is likely to take even longer, perhaps decades, before it is possible to determine whether the snails will persist in the long term. However, with the data collected to date, it is possible to comment on the direction the populations are taking at present.

Abundance at Mount Augustus

Abundance is clearly greatest in the highest quality area of natural habitat, represented by the monitoring block ‘Site A Upper’. This area most likely hosts a subpopulation at the natural carrying capacity for this species in the most suitable habitat available. A high degree of clustering was observed at this site, demonstrating that only half of the block contains habitat of the highest quality, with the other half being closer in nature to Site A Lower. The second monitoring block in the natural habitat, Site A Lower, represents the marginal habitat in which the species naturally occurs. Abundance here is much lower than at Site A Upper and may reflect the carrying capacity in this type of habitat.

It is unclear whether the dramatic population decline observed in 2011 at Site A Upper was to some extent an artefact of the statistical analysis (note the wide confidence interval) or due to something impacting on the population. Coal mining was still occurring in the vicinity after the first survey in 2009 and field staff noted coal dust deposition in the monitoring area. It is possible that this may have had an impact on snail survival. The results to date suggest that the population is increasing again since mining ceased. Based on the data available, it seems that abundance in the natural habitat is stable and, at least in the short to medium term, this population is secure.

Comments on the security of the various populations *of P. augusta* are made in the paragraphs below. It should be noted that when assessing the status of the populations at the various sites, an abundance estimate provides just one variable for consideration. Estimates relating to recruitment, growth and survival are also important variables, which in combination with abundance, allow for a more thorough assessment of the viability of a population (Lettink & Armstrong, 2003). Fortunately, the mark-recapture methodology used in this study provides ancillary data that can help to estimate some of these variables. This will be explored in detail in Chapter 4 of this thesis.

Abundance at Extended Site B

At Extended Site B, for the sites where snails were hand translocated (West 1, North East, West 3), all sites appear to be performing well. Whilst abundance at these sites is lower than at Site A Upper, it is higher than that observed at Site A Lower, indicating that habitat quality may fall somewhere between the two examples of natural habitat. Snails were released in the greatest number at West 1, with fewer released to North East and the lowest number released to West 3. In all cases the estimated abundance is now higher than at the initial release. As might be expected, there have been the greatest increases at the sites in which snails were released in lower numbers, as the gap between carrying capacity and released snails is probably greatest at these sites. The populations appear to be adjusting to the available habitat and, in the short term at least, appear to be secure.

The remaining site at Extended Site B, R6 VDT, differs from all other sites as the snails here were mechanically translocated, along with the natural habitat. An important question to answer at this site was whether any snails would survive the process at all. The data collected to date confirms that snails (or strictly speaking, *P. augusta*) are able to survive the process of mechanical translocation by VDT and persist, at least in the short to medium term. This finding is of great interest, as the vegetation direct transfer process has the potential to contribute to conservation in the future, particularly where manual translocations are practically difficult and/or cost prohibitive. However, in contrast to the other monitoring blocks at Extended Site B, R6 VDT has exhibited a slow and steady decline in snail abundance. The movement analysis showed a strong sign of clustering at this site, perhaps indicating that the habitat is relatively heterogeneous and possibly quite unsuitable in some locations. One concern at this site is the lack of younger snails coming through to the cohort being monitored, in comparison with other sites. This is discussed in Chapter 4 of this thesis. In term of the wider use of VDT, it is worth noting that the R6 VDT is not a good example of the possibilities of VDT, as it is an early example of the process. Much has been learned from the trials and recent examples of VDT have been much more impressive (S. Roxburgh, pers. comm.).

Abundance at Mount Rochfort

The Mount Rochfort sites appear to have been the least successful over the five year monitoring period. Snail translocation to Mount Rochfort Basin was always thought to be somewhat risky by the Department of Conservation, due to doubts about the suitability of the habitat available (I. Gruner, pers. comm.), and the data appears to confirm that this site is likely to support only a low-density population in the short to medium term. The large area of marginal habitat surrounding Mount Rochfort Summit, represented by 'Summit B', appears to be able to only support a very low-density population, which is unlikely to be sustainable in the long term. Interestingly, Summit B and Basin B had by far the highest percentage of snails observed more than once in a season, despite the low densities observed. This may be an indication of the snails at these sites being more active, searching for their needs (e.g. food or a mate) in a scarce environment, where the habitat is unsuitable.

In contrast, the Mount Rochfort Summit itself, represented by 'Summit A' is of a much higher quality and appears to contain habitat more suitable for *P. augusta*. This site appears able to sustain a greater abundance of snails than any other site at Mt Rochfort. However, there are issues with this site that may make in unviable in the long term. Public access, and the naturally small area, both pose issues. Perhaps more importantly, another snail species, *P. patrickensis*, is known to occur in the vicinity. The two species, although very similar in many respects, do not naturally occur in the same location. It is unknown how the two species will interact in the long term, both from a competition perspective, as both are considered generalists in their choice of earthworm prey (Waterhouse, Boyer, & Wratten, 2014), but also in terms of any possible hybridisation, which would alter the natural genetic course of both species. In hindsight, for the above reasons, Mount Rochfort may have been a poor choice as a release site for *P. augusta*.

Assessing the mark-recapture methodology

To have confidence in the results, it is important to establish if the method used is reliable and, in particular, if the mark-recapture assumptions underpinning the statistical analysis of a closed population are being met. The main assumptions relate to tag loss, births, deaths and migration (Lettink & Armstrong, 2003). Tag loss was investigated through the tag loss experiment, which involved the double tagging of snails at one monitoring site, which is a standard method for estimating tag loss (Seber & Felton, 1981). The closed population assumption, requiring no additions or deletions to the population, is more difficult to assess. It is recognised that these assumptions relating to a closed population are unlikely to be completely met in real world, wild populations (Pollock, Nichols, Brownie, & Hines, 1990). However, an assessment of to what extent they are being met is needed to understand the possible level of uncertainty and whether the abundance estimates are likely to be reliable or not. This can sometimes be assessed by having a good understanding of the ecology of the animal. For example, knowing whether it is a sedentary or highly mobile animal or having an understanding of the breeding season. The design of the monitoring site can also help, where natural features or artificial barriers can be used to contain the population. Unfortunately, in this instance, our understanding of the ecology of *P. augusta* was not sophisticated enough to rely on. The choice of monitoring sites was limited to where the snails occurred and where a monitoring team could safely access, meaning it was not possible to choose a contained area. Furthermore, as one of the aims of the study was to assess how the populations were coping in a new environment, it was not desirable to artificially contain them in certain areas, as that would not provide useful information on how they were actually dispersing, if at all. It was therefore necessary to gather additional information to determine whether any violations of the assumptions were significant.

Tag loss

The ability to effectively identify snails upon recapture is obviously a key factor with this type of study. Ideally, recognition would be achieved through some identifying feature on the animal, for example the individual markings on fins of cetaceans (Lettink & Armstrong, 2003). It is possible that over time shell pattern and colour could be used for snails. Indeed, the possibility of photo recognition has been explored elsewhere (Turner, 2011), where it was found that snails could be identified in the short term but that this became less reliable over a longer period, as the snail shells changed over time (e.g. after 6 months), as they grew, were damaged, or naturally degraded. Without a reliable natural feature, it was necessary to trial the attachment of an artificial numbered tag. Based on the results to date, it appears that the polyethylene tags used in this study are highly suitable for monitoring snails. Tag loss rates were found to be extremely low and not likely to be an issue. Furthermore, from a practical perspective, it was possible to quickly attach the tags in the field, with minimum interference and manipulation of the snails, using a temporary shelter, such as a tent, vehicle or hut. A high level of tag loss would have had serious implications for the reliability of the estimates (Pollock, et al., 1990). Strictly speaking, the tag loss experiment results apply only to *P. augusta* and the environment within which the study was carried out. For any future study, in another location and/or with another species, it would be advisable to replicate the tag loss study to estimate the rate of tag loss, if any. If necessary, the estimate of tag loss can be built in to the modelling and the abundance estimates adjusted accordingly.

Births and deaths

There was some evidence of mortality occurring during the season, with a handful of animals found deceased after having been captured earlier in the monitoring season. This included the observation of a half-eaten snail, dropped by a possum that had been disturbed by the monitoring team. It is also likely that some births may have occurred during the monitoring period, although it was not possible to confirm this. As the monitoring technique does not include snails with a maximum diameter of <20mm, 'births', in this instance, refer to those snails who become part of the study through a small amount of shell growth during the monitoring period. In both cases, due to the short time interval of the annual monitoring period (four to eight weeks) compared to the estimated lifespan, and the very low number of snails likely to be involved, nether births or deaths are thought to be a significant issue.

Immigration and emigration

Migration is likely to have been the assumption that may have been violated to the greatest degree. The walkthrough surveys, adjacent to the monitoring plots, were successful in confirming that migration was occurring. A snail that had been previously captured during a monitoring event that season, had moved out of the block and was therefore unavailable for recapture during a subsequent survey. The analysis of individual snail movement during the 2012 season also showed that migration was likely to be occurring. Although the snails were not observed moving long distances during the survey period, it was shown that they could move far enough to leave the monitoring area. Indeed, a number of snails were found near the boundary of the monitoring blocks, indicating that some snails were likely to be moving in and/or out during the survey period. It is therefore clear that there was some violation of the closure assumption. However, it is unclear whether this is significant. Without a more detailed study, such as tracking individual snail movement with a transponder for example, it is impossible to fully assess this issue. It is worth noting that of the forty-six snails observed during the walkthrough surveys adjacent to the monitoring blocks, just three tagged snails were observed. Furthermore, of the three tagged snails, only one had been observed previously that season within the monitoring block. The movement tracking results also showed that a large proportion of snails did not move great distances over many weeks and remained within the monitoring plots during the survey period. This is supported by the very early monitoring of *P. augusta* that was undertaken with a small number of animals fitted with transponders. After 18 months, most animals had stayed close to their release point, with median net displacement of just 19 m (Efford, et al., 2009). It is therefore assumed that migration, whilst occurring to a limited degree, is probably relatively minor and likely to be equal across years. Furthermore, there is unlikely to be any difference in migration patterns between marked and unmarked snails. Finally, snails are generally more sedentary and slow moving than many other animals that are studied in the wild using mark-recapture methods. It is therefore concluded that migration is probably not a significant issue in this study or for *Powelliphanta* snails in general. Estimating the percentage of snails that are migrating to/from the monitoring block during the survey period would be of value. It is recommended that this issue is explored to identify if there is some kind of edge effect occurring on the boundary and, if so, incorporate this in to the statistical analysis.

Movement

Movement varied between individual snails and this was expected, with some being active and others sedentary. There was no evidence of homing or any other discernible pattern to the movement observed. In some cases snails were moving from high quality to low quality habitat but in others it was the reverse. This was consistent with the findings of a previous study of a small sample of *P. augusta* snails fitted with transponders (Efford, et al., 2009). The snail observed at North East that travelled approximately 40 metres in four weeks was of interest. This distance was far greater than expected and such movement has not been documented previously. The fact that 75% of the snails observed in Basin A were located in habitat that had been defined as unsuitable for snails by the Department of Conservation was of interest. This could explain the gradual decline of the population at this site or could indicate that knowledge of habitat preference is still very limited. It is recommended that locations of marked snails are recorded at every capture, rather than just once per season, to better understand dispersal and habitat preference. It may be useful to employ high precision equipment, allowing for the reading of a location to a few centimetres, rather than standard GPS units, which have an error of 3-5 metres. This would allow for a much better understanding to emerge and would also allow for accurate estimates of distances travelled to be calculated.

Methodological changes and further recommendations

Without the development of the mark-recapture methodology used here, it would be impossible to assess the current status of the current populations in such detail or with such confidence. There is value in formally publishing the methodology, as there may be other situations in which it could be utilised. Indeed, two new studies relating to the long-term monitoring of *P. patrickensis* have been established recently, on both the Stockton and Denniston Plateaux, in relation to two different coal mining developments. The field protocol has been a 'living' document over the five-year period, with a number of important changes being made as more knowledge was gained. There is value in discussing some of these changes and sharing some of the key learnings that have been obtained over the period of the study.

The tag loss experiment was thought to be particularly useful, as it demonstrated that polyethylene tags appear to work well with *Powelliphanta* snails. Several different coloured tags were trialled during the study. It is recommended that the coloured tags which most closely match the colour of the snail shell are used, and that transparent tags are not used. The latter were trialled, as it was thought that coloured tags could potentially attract predators. However, the transparent tags were very difficult to read in the field at night. Furthermore, the process through which colour is added to the polyethylene tag during the manufacturing process appears to soften the tag somewhat, making it easier to attach to a snail shell. In contrast, the transparent tags are less flexible and more difficult to attach.

The adhesive used to attach a tag is also of importance and, with the low rate of tag loss, there appears to be no issue with the effectiveness of the cyanoacrylate based glue used here. The snails appeared to not be affected by either the glue or the tag, although it was noted that the placement of the tag was important, to avoid the snail growing over the tag. For this reason, such tags are not suitable for smaller snails (e.g. <20mm). Concerns have been raised about the use of adhesives such as the one used here, as it has been shown that they can affect the behaviour of rats in a laboratory based setting (Turner, 2011), making them more attracted to snail shells, in comparison to other glues. There was no evidence of this occurring in the field and no freshly tagged snails were found to have been predated by rat. However, this may simply be due to the low rat numbers in this alpine environment and the intensive predator control programme in place. The choice of adhesive should be re-evaluated for future studies, should rats be considered a potential issue. Any change to the adhesive would certainly require the replication of the tag loss study, using the new adhesive.

Whilst suitable for most habitat types, this monitoring technique is reliant on searchers being able to observe snails whilst slowly walking through a monitoring plot, without having to actively search or disturb the habitat. It was almost impossible to achieve this in flax-dominant habitat, as the bushy undergrowth obscured snails that were active. An attempt was made to establish a plot in such habitat but was abandoned due to this issue. Furthermore, in areas that are very sensitive, it may not be desirable to have people walking over the habitat five or more times over a similar number of weeks. Careful consideration should be given to the location of monitoring plots and it should be recognised that this technique may not be suitable for all habitat types.

The variable size and shape of the monitoring blocks would ideally be consistent, allowing for a direct comparison of the absolute estimates derived from the mark-recapture analysis. Furthermore, a uniform shape and size makes the field work easier to undertake. It is recommended that, if conditions allow, all monitoring plots are established as the same shape and size. For *Powelliphanta* snails, a 70m x 70m quadrat (0.49 hectares) is recommended.

Animal welfare is also an important consideration. Whilst there was no evidence in this study that welfare was an issue, it is assumed that there would have been some negative impacts on the snails within the monitoring plots. The presence of people walking, no matter how carefully, undoubtedly increases the chance of crushing, particularly as the monitoring is designed to occur when snails are most active. Also, there is likely to be some minor habitat damage associated with the monitoring events. The risks above mainly relate to the monitoring plots, rather than the wider area, of which the monitoring plots are representative, meaning the overall impact is likely to be relatively minor. Steps can also be taken to minimise the impact, such as walking on bare ground and/or rocks wherever possible. There is a broader risk with undertaking monitoring such as this, as *Powelliphanta* populations are often found in relatively undisturbed and remote locations (Walker, 2003). Because such monitoring requires the presence of field workers, it bears the risk of introducing unwanted weeds, pests or even disease. It is recommended that factors such as this are considered and risk assessed when any monitoring programme is being designed.

One important factor that requires more consideration is the interval between survey nights. It is desirable for the surveys to be considered independent, meaning that enough time must elapse between the surveys nights. However, this must be balanced with the need to complete all surveys in a season within the shortest time possible, which minimises the chances of violating the assumptions relating to population closure. At present, not enough is known about *P. augusta* ecology to understand why snails are active when they are, how frequently they are active, or how long they might rest between bouts of activity. We can hypothesise that the key drivers behind snail movement as those that are typical to many animals, such as searching for a mate, looking for food or finding a better resting place. As such, it is likely that snail movement is highly variable and difficult to predict. This is further complicated by the fact that *P. augusta* are generally only active under certain environmental conditions, requiring a warm, moist environment. The monitoring of *P. augusta* since translocation in 2007 has shown that they are highly inactive during dry or cold spells. Feedback from the field teams has indicated that snails are most active following a long dry period, which is intuitive if the drivers for movement are indeed those listed above. However, after many days of very suitable conditions, this activity declines considerably, to the point that after a week or more of ideal conditions, snails are fairly inactive. The assumption here is that they are likely to have met all of their short term needs and have no reason to be active. During the first year of the study, survey nights were undertaken on consecutive nights, wherever possible. It is likely that such an approach would make the surveys unreliable, as many snails would be active at the start but far fewer in the following days. The approach to monitoring was changed in the following seasons, to allow a week interval between surveys. However, as surveys could only occur in certain weather conditions, the interval could easily be drawn out to two or more weeks, meaning the total survey period, to achieve a minimum of five surveys at each plot, would take several months. Such a long survey period would undoubtedly carry a greater risk of violating the closed population assumption. A compromise was found by leaving a two to three day interval between each survey. Ideally, this would be composed of suitable conditions, interspersed by unsuitable conditions, making snail activity relatively high during all surveys. Increasing the number of snail recaptures leads to more precise estimates, so it was important to try and time the surveys to coincide with times of high snail activity. In some cases, it may be necessary to increase the number of survey nights from five, to 6 or 7, to obtain a suitable number of recaptures. This can be assessed as the surveys progress during the season, depending on results. One option that was trialled during the first season was to undertake two consecutive surveys of a monitoring block on any one night. However, this was abandoned after one season as it was unknown how handling a snail would affect its immediate, short term behaviour. Some snails that were captured during the first sweep were re-observed in exactly the same place, indicating that there may be some short term effect. Furthermore, the impact on the habitat was likely to be negative, as there was no time for it to ‘bounce back’ and walking through it again may have caused damage. The best solution to solve this problem would be to get a better understanding of snail activity and design the monitoring programme accordingly. The most recent project set up to monitor *Poweliphanta* snails has incorporated aspects of this research to assist with our understanding.

It should be noted that some of the learnings from this study may relate only to *P. augusta*, a species that is naturally found in a relatively small area and which has quite specific environmental requirements. For other species, natural activity and/or habitat, for example, may be quite different. Another project, currently underway, which utilises this method with the snail *P. patrickensis*, has found that this species is active even during dry weather conditions, as long as the ground cover is still relatively moist from previous precipitation (per obs.). Furthermore, the forest habitat, in which some of the plots are located, is often easy to search and the snails are readily observable. Although only used in a sub-alpine setting to date, it is expected that this monitoring technique would be suitable for use with lowland snails, particularly in forest habitats, where they often occur (Walker, 2003).

Whilst some challenges remain to refine this monitoring technique, the results to date indicate that, with sufficient planning, it may indeed be a suitable method for monitoring *Powelliphanta* snails. The abundance estimates, whilst having broad confidence intervals, are likely to be far more accurate than any estimates obtained with the standard plot monitoring method commonly in use today. The effort, and therefore cost, is somewhat higher than that associated with the plot method (described in Chapter 2). However, a direct comparison is impossible, as the unreliability of the standard plot method means it is unknown how many standard plots would be required for a similar level of certainty (this is likely to be much higher that the number of standard plots monitored at present). The mark-recapture technique described here may be particularly suitable for highly endangered *Powelliphanta* species, where accurate population information is of vital importance and/or where the impact of management treatments needs to be measured. It is a technique that is most suited to long-term monitoring, as the value of the data obtained increases over time, as more is collected. It is recommended that for most *Powelliphanta* species, a 5 to 10 year interval between primary monitoring events is sufficient, although this may need to be decreased to 1 to 3 years for highly endangered species, or where there is concern for a population due to sudden changes to the local environment. Once again, it is important to design the programme for the species in question.

The two monitoring techniques now available, the standard plot method and this mark-recapture technique, may, in fact, be complimentary. It is recommended that the two be considered for use in a 'hybrid' monitoring programme, where the use of both can provide a much richer picture than the use of one technique alone. Indeed, this is the approach now being taken with the two new *P. patrickensis* monitoring projects mentioned above. The standard plot technique is useful for observing smaller snails and eggs (pers. obs.). It also allows for the observation of snails in difficult to search habitats. Finally, the collection of shells from beneath the surface can provide useful information on mortality, particularly where predators may be an issue, as they often leave tell-tale signs on the shells (Meads, Walker, & Elliott, 1984). In combination with the data from a mark-recapture study, this information may be hugely beneficial for the management and conservation of the many threatened species of *Powelliphanta*.

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Chapter 4

The ecology and conservation of *Powelliphanta augusta* – what can we learn from mark-recapture population monitoring?

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List of Tables and Figures

Abstract

Since the widely debated decision to award Solid Energy New Zealand Limited a Wildlife Permit to translocate *Powelliphanta augusta* from a large proportion of its remaining natural habitat, almost everything published on the subject, both in the mainstream media and academic literature, has been pessimistic about the prospects for the species. The first attempts to monitor the translocated population, using a very small sample of snails fitted with transponders, produced results that were equally pessimistic about the viability of the species, with the authors stating that the results and assumptions suggest that "the translocated populations of *Powelliphanta augusta* will not persist in the long term" (Efford, Lloyd, & Gruner, 2009). All of these papers acknowledge that there is a lack of information available on *P. augusta* to fully understand the status of any of the populations, whether captive, translocated or those in their remaining natural habitat.

After five years of long term monitoring (2009 to 2013), using mark-recapture techniques, the abundance results appear to suggest that most of the translocated populations are stable and may even be increasing (see Chapter 3). With new information available, it is timely to reassess the status of the species. What is the outlook for the species, in the short to medium term, based on the information available? Abundance estimates are just one piece of information that can be used to understand the population dynamics of a species. An advantage of using a mark-recapture technique for monitoring is the possibility of developing a richer understanding of the ecology and behaviour of the animal being studied by estimating other parameters (Lettink & Armstrong, 2003). By marking individuals, which are then found over time, it may be possible to gain a greater understanding of parameters such as survival, recruitment, growth, dispersal and range. Such data may then inform the development of population models that can be used to assess population viability over time (Lettink & Armstrong, 2003).

The key aim of the work in this chapter is to glean as much information as possible from the data collected to date, to gain a better understanding of the ecology and conservation status of *P.* augusta, to assist conservation managers with their decision making.

This chapter examines survival, growth, population structure and recruitment. The updated information is then used to update a previous model of population persistence (Efford, et al., 2009) and assess the current status of the *P. augusta* populations in both their natural and new habitat. Annual survival is estimated to be in excess of 80% at most sites, higher than the previous estimates of between 55% to 79% (Efford, et al., 2009). Estimated snail growth rates are shown to be much faster than previously suggested. It is also shown that growth rates are different for different cohorts, with growth being faster among smaller snails. For the first time, the age of reproductive maturity is estimated, based on actual data from snails in the wild. It is estimated that *P. augusta* takes approximately eight years to reach adulthood. A detailed analysis of the structure of each population shows that abundance estimates alone do not demonstrate the current health of a population. The structure at most sites is shown to be relatively healthy, although there are some locations that show signs of concern. It was previously unknown whether *P. augusta* could reproduce in the new habitats it has been translocated to. Evidence is provided to suggest that reproduction is occurring. The initial model of population persistence predicted that the future for *P. augusta* was bleak, showing that none of the populations were likely to persist. At the time, this was widely seen as evidence of failure of the translocation programme. Five years on, this model is updated here with more accurate information. Based on the data available now, most of the *P. augusta* populations appear to be able to persist under current conditions. In fact, many of the populations appear to be increasing. After five years of mark-recapture monitoring, it seems that the future for *P. augusta* may be more secure than originally thought.

It is far too soon to claim that the species is secure and that the translocations have been successful. It is likely to take decades to prove the latter and that the populations are self-sustaining in the long-term. It is strongly recommended that monitoring continues in the future, perhaps at five to ten year intervals, to accurately monitor the status of the species, in both the natural habitat and the new habitats it has been translocated to.

I. Introduction

Since the widely debated decision to award Solid Energy a Wildlife Permit to translocate *Powelliphanta augusta* from a large proportion of its remaining natural habitat, almost everything published on the subject, both in the mainstream media and academic literature, has been pessimistic about the prospects for the species. In a paper describing the taxonomy and conservation status of the species, the authors comment that "despite a growing international awareness of the importance of biodiversity conservation, the demand for foreign earnings continues to take priority over the protection of our biota" and "less than a decade after this species was first discovered, it is on the brink of extinction in the wild'' (Trewick, Walker, & Jordan, 2008). The paper describing the species (Walker, Trewick, & Barker, 2008) states that the best chance of its survival is in the "sliver" of natural habitat that remains, but then goes on to describe this habitat as low quality, fragmented and possibly unsuitable. The first attempts to monitor the translocated population, using a very small sample of snails fitted with transponders, produced results that were equally pessimistic about the viability of the species, with the authors stating that the results and assumptions suggest that "the translocated populations of *Powelliphanta augusta* will not persist in the long term" (Efford, et al., 2009). The viability of the captive population, held by the Department of Conservation, has also been questioned. An attempt to model the population dynamics of the captive snails found that the size distribution was not typical of a wild population, growth rates were retarded and the rate of hatchling mortality was extremely high (James, Brown, Weston, & Walker, 2012). The authors go on to state that "the captive snails are now at an even greater risk of extinction in the event of further catastrophes such as disease outbreaks or freak incidents". To their credit, without exception, all of these papers acknowledge that there is a lack of information available on *P. augusta* to fully understand the status any of the populations, whether captive, translocated or those in their remaining natural habitat. However, it seems that this lack of information does not prevent many from determining that the species is unlikely to persist. Perhaps unsurprisingly, given this negative picture, attention from mainstream media has also often been negative. Whilst the occasional newspaper article citing the positives from the project appears to receive little attention, any bad news seems to be widely disseminated, such as the now infamous incident where 800 captive snails, at the Department of Conservation storage facility, were frozen due to a malfunction in their storage unit. A major component of the *P. augusta* project is the ongoing rehabilitation of Mount Augustus, using innovative methods, including vegetation direct transfer, to create suitable habitat for the release of snails hatched in captivity. However, in an article on the snail, the respected wildlife photographer and filmmaker, Rod Morris, declared that “efforts at habitat rehabilitation for *Powelliphanta augusta* at Stockton Mine are unlikely ever to succeed” and goes on to conclude that the project has the “whiff on an unfortunate experiment” (Morris, 2010).

Depending on an individual’s philosophical outlook, the decision to allow the translocations to proceed may or may not be judged as having been appropriate. However, much of the literature published to date appears to be loaded with judgement and opinion. Instead of clearly stating what is known and certain, judgments have been made about the viability of the species, based on very little and, in some instances, flawed information. This becomes unhelpful when conservation managers are attempting to make important decisions about the species. After five years of long term monitoring, using mark-recapture techniques, the abundance results appear to suggest that most of the populations are stable and may even be increasing (see Chapter 3). With new information available, it is timely to reassess the status of the species. What is the outlook for the species, in the short to medium term, based on the information available? Abundance estimates are just one piece of information that can be used to understand the population dynamics of a species. An advantage of using a mark-recapture technique for monitoring is the possibility of developing a richer understanding of the ecology and behaviour of the animal being studied. By marking individuals, which are then recaptured over time, it may be possible to gain a greater understanding of parameters such as survival, recruitment, growth, dispersal and range. Such data may then inform the development of population models that can be used to assess viability over time (Lettink & Armstrong, 2003). This additional information may be particularly useful for the conservation management of species that are not well studied, such as *Powelliphanta* snails (Walker, 2003).

Simple parameters, such as growth rates and longevity in the wild, are currently unknown for *P. augusta*. (Walker, et al., 2008). Furthermore, even with marked animals, survival estimates are difficult to produce if there is immigration and emigration occurring at the study site. An estimate of ‘survival’ is often only ‘apparent survival’ and may well be a gross underestimate or overestimate, depending on the rate of movement in and out of the study area (Gilroy, Virzi, Boulton, & Lockwood, 2012). Recruitment is another key population variable that is not well understood, both in terms of whether it is happening and, if so, how fast. This is partly because wild populations have not been well studied but also because small snails are difficult to detect. For example, when searching for foraging animals at night, it is difficult to find animals with a shell diameter of less than 20mm. This means that the important life stages of hatchlings and juveniles are generally not surveyed, meaning results apply only to adults and sub-adults. However, using mark-recapture methods over time, it is possible to observe new, unmarked animals appearing in the study population when they become detectable. All of this information is vital for conservation managers to assess whether current management treatments are working and if this species has a viable future. The current level of uncertainty surrounding the population dynamics of *P. augusta* clearly needs to be addressed. This chapter explores the mark-recapture data available after five years of monitoring in an attempt to better assess survival, growth, population structure and recruitment. The updated information is then used to update a model of population persistence and assess the current status of the *P. augusta* populations in their natural and new habitat.

II. Aims and objectives

The key aim of the third part of this study is to glean as much information as possible from the data collected to date, to gain a better understanding of the ecology and conservation status of *P.* augusta, to assist conservation managers with their decision making.

Specific objectives are as follows:

- produce survival estimates, with confidence intervals, for *P. augusta* at the different sites in which they now occur
- estimate growth rates for *P. augusta* at different life stages
- assess the population structure at each of the sites in which they now occur
- look for evidence of recruitment in the translocated populations
- update the existing model of population persistence, incorporating the above information
- assess the current status of the populations in both their natural and new habitat

III. Methods

i. Study site & sampling

A full description of the study sites can be found in Chapter 3 of this thesis. That chapter also clearly outlines the sampling strategy and the mark-recapture method used for monitoring.

ii. Survival estimates

Survival estimates were produced from the mark-recapture data collected over the five year period, 2009 to 2013. The *P. augusta* monitoring programme uses the principles of the robust design for mark-recapture studies (Lettink & Armstrong 2003). The design used here consists of a primary interval for monitoring (annual surveys) and a secondary interval within this (several surveys within each year). The primary interval allows for an open population with births, deaths, immigration and emigration, while the secondary interval assumes a closed population. Results from the secondary interval give estimates of abundance for every year surveys are completed, while the primary interval allows estimation of survival rates. See Chapter 3 for a more detailed discussion regarding the mark-recapture method and the assumptions involved.

The analysis of mark-recapture data is complex and can be easily misinterpreted. It is recommended that analysis is therefore undertaken by a suitably qualified expert to avoid mistakes (Lettink & Armstrong, 2003). Furthermore, this species is considered to be 'Nationally Critical' on the New Zealand Threat Classification Lists (Hitchmough, Bull, & Cromarty, 2007). For these reasons, expert help was sought with the analysis. Each year, the data collected from the field were added to an Excel spreadsheet for subsequent analysis. The snail encounter data, used to produce abundance and survival estimates, were extracted from this dataset and analysed annually by Darryl Mackenzie (Proteus Consulting), an independent expert in mark-recapture analysis (MacKenzie, 2009, 2010, 2011, 2012, 2013).

The following is a summary of the approach used for analysis (MacKenzie, 2013). Survival and capture probabilities were estimated directly in the model. Abundance was estimated using secondary calculations with the Huggins estimator (Huggins, 1991). A number of models were fit to the data and compared using Akaike's Information Criterion, corrected for small samples (Burnham & Anderson, 2002). Estimates from all models were combined using model averaging (Burnham & Anderson, 2002). All analyses were conducted with Program MARK, via the R package, RMark.

There are several limitations to this analysis. Any mark-recapture study relies on certain assumptions. These assumptions are addressed in Chapter 3 of this thesis. The methodology for the mark-recapture monitoring of *P. augusta* targets the adult to sub-adult cohorts in the population. Snails with a maximum diameter below 20 mm are rarely detected, as detection probability decreases with size (pers. obs.). This means that the results apply only to these snails with a maximum diameter greater the 20mm. Strictly speaking, the results also apply only to the actual monitoring blocks searched. Furthermore, survival estimates are difficult to produce if there is immigration and emigration occurring at the study site (Gilroy, et al., 2012). An estimate of 'survival' is often only 'apparent survival' and may well be a gross underestimate or overestimate, depending on the level of movement in and out of the study area. The results presented here can be considered minimum estimates, as snails leaving the monitoring block are not accounted for.

iii. Growth

Estimating the rate of *P. augusta* growth in the wild is an important element of assessing the status of the current populations. An estimate of the rate of growth will help with estimating the age of reproductive maturity, an important element of the population model of population persistence. Attempts to measure shell growth during the first two years of monitoring had shown that getting accurate measurements can be difficult. The method for measuring snails followed standard practice for *Powelliphanta* (Walker, 1997), where the maximum diameter of snail shell is measured to one decimal place. Precisely measuring the maximum diameter of a snail shell takes practice. Furthermore, undertaking this task at night, with poor lighting, often in wet conditions, can lead to mistakes being made. In addition, having different people undertaking the task at different locations and on different nights can also lead to inaccuracies. Given that *P. augusta* shell growth is likely to be relatively slow, any inaccuracy can seriously impact on the results. It became obvious that there was an issue with the early data when analysis of the data indicated that some snails appeared to have shrunk over the course of a season, which seemed unlikely. Discussions with the Department of Conservation revealed that they had witnessed similar anomalies over the years with their various snail monitoring programmes. It was agreed that any observed shrinkage was most likely the result of errors in the measuring process. It was decided that there would be a focus on obtaining more accurate measurements of growth over a single season by obtaining highly accurate measurements during the 2012 and 2013 seasons. The task of measuring the snails was assigned to one individual in the team, who measured all snails over both seasons. This individual was provided with additional training and the set up for measuring (lighting, shelter etc) was improved in an attempt to resolve some of the identified issues. Obtaining two accurate measurements of maximum diameter of shell size, approximately a year apart, allowed for an accurate assessment of growth of all snails captured.

Previous research on *Powelliphanta* snails had shown that the rate of growth is probably not linear, with faster growth during the first few years and slower growth over time (Walker, 2003). This may be attributed to the fact that snail shells grow in a circular manner and the standard measurement of shell size is maximum diameter. To better understand the growth of *P. augusta* at different life stages, the results were also broken down by cohort. As the mark-recapture programme only deals with snails with a maximum diameter ≥20mm, 20mm was used as the lower limit. The largest snails observed were approximately 40mm in size. Maximum diameter was used to divide the population into the following four cohorts:

1. 20.0-25mm (sub-adult 1)
2. 25.1-30.0mm (sub-adult 2)
3. 30.1-35.0mm (adult 1)
4. ≥35.1mm (adult 2)

Rates of growth were also categorised by site, habitat quality and by site type (e.g. translocation, natural habitat and vegetation direct transfer). As monitoring did not occur at the Mount Rochfort release sites in 2013, the growth results presented here, from the measurements taken in 2012 and 2013, only relate to snails at the Extended Site B translocation sites and the Mount Augustus natural habitat, where monitoring did occur in both seasons.

iv. Population structure

Population structure is another parameter that may be important in assessing the viability of a population and/or a species. The maximum diameter of shells is the typical method for assessing the relative age of *Powelliphanta* snails (Walker, 1997). *Powelliphanta* snails have a variety of recognised life stages, which include egg, hatchling, juvenile, sub-adult and adult. *Powelliphanta* snails are considered to have reached adulthood upon achieving the capacity to produce offspring. These stages have been informally defined for *P. augusta* by the Department of Conservation, based on the captive *P. augusta* population. As the snails are kept in conditions that do not simulate their natural environment, it is unclear if these snails are representative on the species. The size of the various life stages have not been defined for the species in the wild and it is currently unknown at what size the species reaches adulthood.

In order to better understand the populations at each of the sites in which *P. augusta* now occurs, an attempt was made to identify the population structure at each of the sites and identify any changes which may have occurred during the course of the five-year monitoring period. As with the analysis of growth, maximum diameter of shell size was used to divide the population into the following four cohorts:

5. 20.0-25mm (sub-adult 1)
6. 25.1-30.0mm (sub-adult 2)
7. 30.1-35.0mm (adult 1)
8. ≥35.1mm (adult 2)

All snails observed at each monitoring block, in each year, were allocated to their appropriate cohort, providing a comparative breakdown of the population structure at each monitoring block. These figures were then converted to percentages of the total number of snails observed at each monitoring block. It was assumed that the snails observed were representative of the population structure of all snails in the monitoring block, including those that hadn't been observed (excluding snails with a maximum diameter of <20mm). The mark-recapture abundance estimates, presented in Chapter 3 of this thesis, were then used to calculate the likely number of snails in each cohort, at each monitoring block. This provides a comparative assessment of the population structure, over time, at each monitoring block, including those snails with a maximum diameter ≥20mm that were not observed.

A limitation of this approach is the assumption that the distribution of snails observed may be representative of the actual population. In fact, this is unlikely to be the case, as smaller animals are harder to observe and are therefore most likely under represented. The results are therefore likely to be somewhat skewed, with larger snails being over-estimated and smaller snails being under-estimated. However, this issue is most likely consistent across years and across sites (i.e. smaller snails are always harder to see), so is not thought to be a major issue.

v. Recruitment

For a population to be sustainable in the long term, recruitment obviously needs to occur and, furthermore, needs to be at a sufficient rate to replenish losses (emigration and mortality) to the population. Unfortunately, for *P. augusta*, and for most *Powelliphanta* snails, our knowledge of recruitment in the wild is extremely limited. The possibility of setting up an experiment to monitor recruitment, under controlled conditions in the wild, was explored in 2011. This included the option of setting up a small predator proof enclosure in a snail free area. After a small release, this fence would also prevent dispersal of the snails, which could then be observed over time to establish if recruitment was occurring. However, the practicalities and cost of the exercise proved to be prohibitive and was abandoned. Instead, other information and datasets were reviewed in an attempt to infer if recruitment was occurring and, if so, at what rate. This included a previous study on another species of *Powelliphanta*, the captive breeding programme data, the translocation recovery data, and current knowledge of the reproduction of *P. augusta*. However, despite having some useful information from which to infer, it was recognised that some direct information from the species at the sites in which they now occur was needed.

One significant area of contention between the various parties involved in management decisions was the uncertainty regarding whether *P. augusta* is a highly specialised species, only able to persist in the unique conditions in which it naturally occurred, or whether the species, whilst only occurring on top of one mountain when discovered, was more than capable of persisting in other environments. Some held the view that *P. augusta* would simply not be able to reproduce in their new environments, as the basic requirements would be absent. In an attempt to detect whether recruitment was occurring, two permanent 10x10m snail monitoring plots were established at each mark-recapture monitoring block, a total of twenty plots. Details regarding the plots are found below in Table 1. These plots were searched after the mark-recapture monitoring season had ended to avoid disturbing the plots.

Table 1 - Diurnal snail monitoring plot details

Details of the 10x10m monitoring plots, including search date and location.

Date	Site	Monitoring Block	Plot Name	Easting (NZMG)	Northing (NZMG)
19/04/2012	Extended Site B	West 1	Plot A	2414564	5948565
19/04/2012	Extended Site B	West 1	Plot B	2414583	5948618
17/04/2012	Extended Site B	North East	Plot A	2414684	5948778
17/04/2012	Extended Site B	North East	Plot B	2414691	5948795
18/04/2012	Extended Site B	West 3	Plot A	2414610	5948343
18/04/2012	Extended Site B	West 3	Plot B	2414603	5948374
13/04/2012	Extended Site B	R6-VDT	Plot A	2414843	5948545
13/04/2012	Extended Site B	R6-VDT	Plot B	2414809	5948499
24/04/2012	Mt Rochfort	Summit A	Plot A	2405375	5935375
24/04/2012	Mt Rochfort	Summit A	Plot B	2405347	5935752
24/04/2012	Mt Rochfort	Summit B	Plot A	2405433	5935787
24/04/2012	Mt Rochfort	Summit B	Plot B	2405364	5935802
1/05/2012	Mt Rochfort	Basin A	Plot A	2404608	5935523
1/05/2012	Mt Rochfort	Basin A	Plot B	2404566	5935522
1/05/2012	Mt Rochfort	Basin B	Plot A	2404554	5935557
1/05/2012	Mt Rochfort	Basin B	Plot B	2404536	5935542
23/04/2012	Mt Augustus	Site A Upper	Plot A	2414625	5947983
23/04/2012	Mt Augustus	Site A Upper	Plot B	2414603	5947977
20/04/2012	Mt Augustus	Site A Lower	Plot A	2414501	5947717
20/04/2012	Mt Augustus	Site A Lower	Plot B	2414481	5947761

The plots were established and searched using the standard Department of Conservation methodology (Walker, 1997), as described in Chapter 2 of this thesis. This method was chosen, as the nature of the searching, sifting through surface vegetation, on hands and knees, presents a good chance of observing those life stages that are not monitored with the mark-recapture method. This was therefore an attempt to detect smaller snails (i.e. maximum diameter <20mm) and to provide evidence of egg production, both of which would help to determine whether recruitment was occurring. Another reason for establishing these plots was to obtain a baseline population estimate using the diurnal plot method (as described in Chapter 2), where snail data is recorded and the snails are then placed back where they were found. Note that these plots were established prior to the investigation conducted in Chapter 2, which found the methodology to be somewhat unreliable for the purpose of producing abundance estimates. Despite this, any observation of hatchling snails or eggs would be useful in indicating whether recruitment was occurring.

vi. Model of population persistence

A well designed mark-recapture study will allow for estimates of abundance, along with other parameters, such as survival, population growth rate and recruitment. This information can then be used to develop population models that can be used to assess the viability of a population over time. Such a model was developed for *P. augusta* upon completion of the initial monitoring of the released snails (Efford, et al., 2009). This initial, short-term, monitoring programme utilised an harmonic radar method, based on published methods (Lövei, Stringer, Devine, & Cartellieri, 1997) and involved monitoring the fate of a small selection of marked animals at each site. However, it was unclear whether the small number of snails directly being monitored was representative of the whole population at each site (Hamilton & Rodgers, 2008). A major issue with the model of population persistence that was developed, as identified during the analysis (Efford, et al., 2009), was uncertainty surrounding some of the key parameters, such as age of maturity and rates of survival. After five years of mark-recapture monitoring, some of these key parameters can now be estimated with more certainty. In this chapter, the model is utilised but it is updated with the new information that has been collected during the course of this study. No changes have been made to the model itself, it is simply updated with more accurate data. A brief description of the model, which is adapted from the original publication (Efford, et al., 2009), can be found below. Full details of the model, reproduced from the original publication without modification, can be found in Appendix F.

Figure 1 illustrates a demographic model for *P. augusta*. It makes several simplifying assumptions, particularly that snails in a cohort mature synchronously at age M (measured from the year eggs were laid), and that mortality and fecundity are constant with age among adults. This model shown in Figure 1 enables the production of estimates of thresholds of annual survival required for long-term population persistence as a function of age at maturity and fecundity (eggs laid per year), as shown in table 2.

Figure 1 - Annual model of snail life history

Adults survive at rate S_A and produce f eggs per year. These survive at rate sE and in the following year hatch and survive at rate sH. The resulting annual cohorts of immature snails Y2, Y3, ..., YM–1 survive at rate sY and grow until they reach maturity at M years after laying (Efford, et al., 2009).

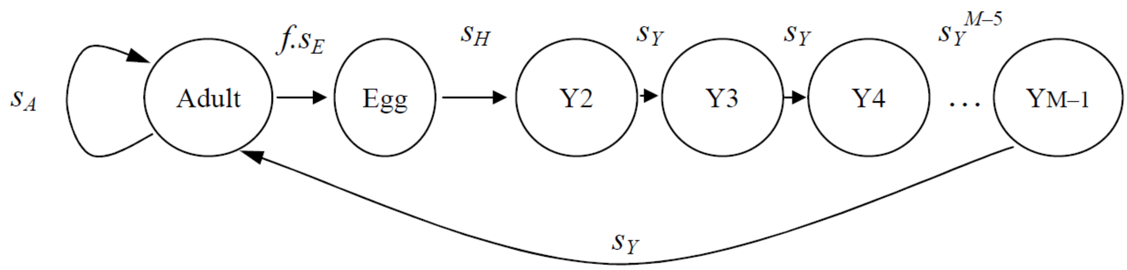


Table 2 - Thresholds of annual survival required

Threshold of annual survival (%) needed for long-term population persistence as a function of age at maturity and fecundity (Efford, et al., 2009).

		Fecundity (Eggs per Year)						
		0.5	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**
Age at maturity (years)	2	73.2	61.8	54.9	50.0	46.3	43.4	41.0
	4	79.8	72.4	68.0	64.8	62.3	60.3	58.6
	6	83.3	77.8	74.5	72.0	70.2	68.6	67.3
	8	85.6	81.2	78.5	76.5	75.0	73.7	72.7
	10	87.2	83.5	81.2	79.6	78.3	77.3	76.4
	12	88.5	85.3	83.3	81.9	80.8	79.8	79.1
	14	89.5	86.6	84.9	83.6	82.6	81.8	81.2
	16	90.3	87.7	86.2	85.0	84.2	83.4	82.8
	18	90.9	88.6	87.2	86.2	85.4	84.7	84.2
	20	91.5	89.4	88.1	87.2	86.4	85.8	85.3
	22	92.0	90.0	88.9	88.0	87.3	86.8	86.3
	24	92.4	90.6	89.5	88.7	88.1	87.6	87.1
	26	92.8	91.1	90.1	89.3	88.8	88.3	87.9
	28	93.1	91.6	90.6	89.9	89.3	88.9	88.5
	30	93.5	91.9	91.0	90.4	89.9	89.4	89.1

IV. Results

i. Survival estimates

Annual survival estimates for *P. augusta* at each monitoring block are shown in Table 3. In addition to an estimate of survival, the upper and lower confidence limits and standard error are also shown. Survival rates appear to have been relatively stable across all sites, with some sites showing an increase over time. The most recent data available for each monitoring block shows that all blocks have an annual survival rate in excess of 80%, with the exception of the Summit B and Basin B at Mt Rochfort. These two blocks have very wide confidence intervals, as the number of recaptured snails was very low. Both of these blocks also have relatively low abundance of *P. augusta* and are likely to be poor habitat for *P. augusta* (see Chapter 3 of this thesis for more information).

Table 3 – Annual survival estimates for *Powelliphanta augusta*

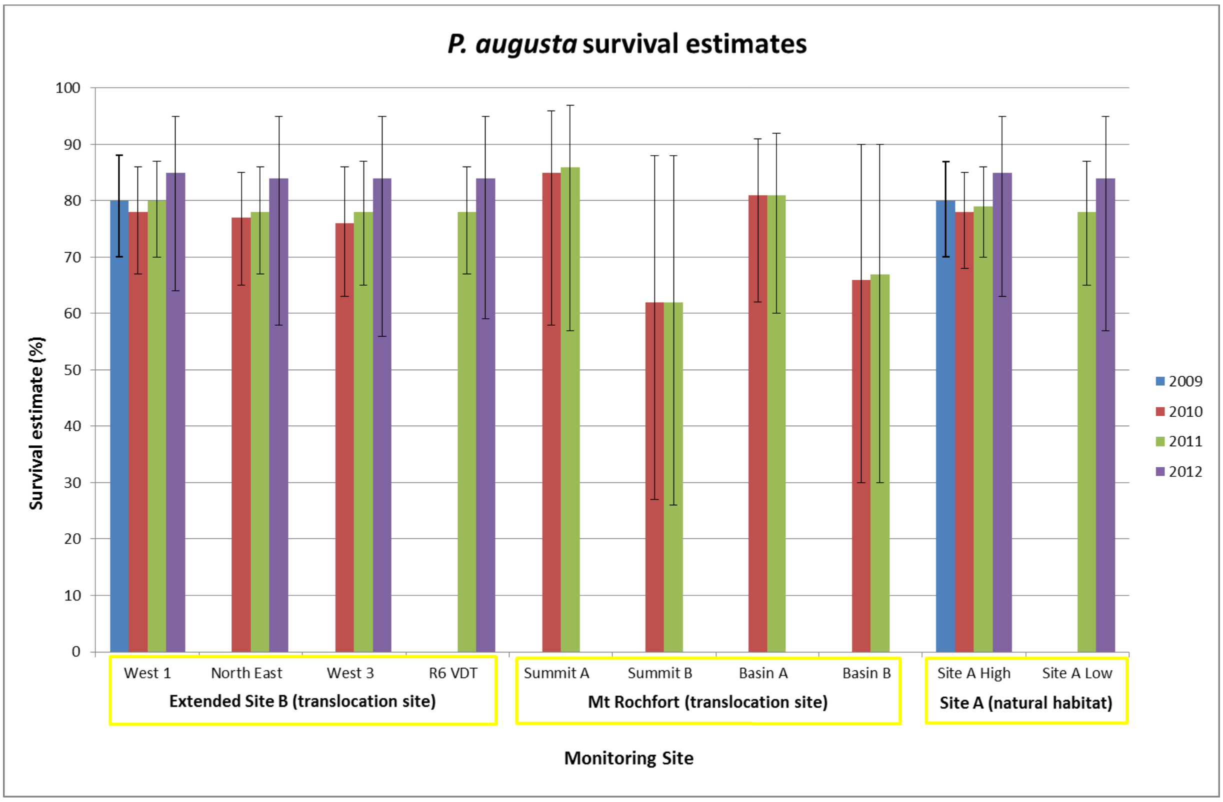
Survival estimates (%) for *P. augusta* at each monitoring block, along with the upper and lower confidence intervals (C.I.) and standard error (S.E.).

		Extended Site B				Mount Rochfort				Mount Augustus	
Type	Year	West 1	North East	West 3	R6 VDT	Summit A	Summit B	Basin A	Basin B	Site A High	Site A Low
Survival (%)	2009	80	n/a	n/a	n/a	n/a	n/a	n/a	n/a	80	n/a
C.I. (upper)	2009	88	n/a	n/a	n/a	n/a	n/a	n/a	n/a	87	n/a
C.I. (lower)	2009	70	n/a	n/a	n/a	n/a	n/a	n/a	n/a	70	n/a
S.E.	2009	5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	4	n/a
Survival (%)	2010	78	77	76	n/a	85	62	81	66	78	n/a
C.I. (upper)	2010	86	85	86	n/a	96	88	91	90	85	n/a
C.I. (lower)	2010	67	65	63	n/a	58	27	62	30	68	n/a
S.E.	2010	5	5	6	n/a	9	18	8	17	5	n/a
Survival (%)	2011	80	78	78	78	86	62	81	67	79	78
C.I. (upper)	2011	87	86	87	86	97	88	92	90	86	87
C.I. (lower)	2011	70	67	65	67	57	26	60	30	70	65
S.E.	2011	4	5	6	5	9	18	8	18	4	6
Survival (%)	2012	85	84	84	84	n/a	n/a	n/a	n/a	85	84
C.I. (upper)	2012	95	95	95	95	n/a	n/a	n/a	n/a	95	95
C.I. (lower)	2012	64	58	56	59	n/a	n/a	n/a	n/a	63	57
S.E.	2012	8	9	10	9	n/a	n/a	n/a	n/a	8	9

Figure 2 is a graphical representation of the results, allowing for a comparison over time and across sites.

Figure 2 - Annual survival estimates for *Powelliphanta augusta*

Survival estimates (%) for *P. augusta* at each monitoring block, along with the upper and lower confidence intervals (C.I.).



ii. Growth

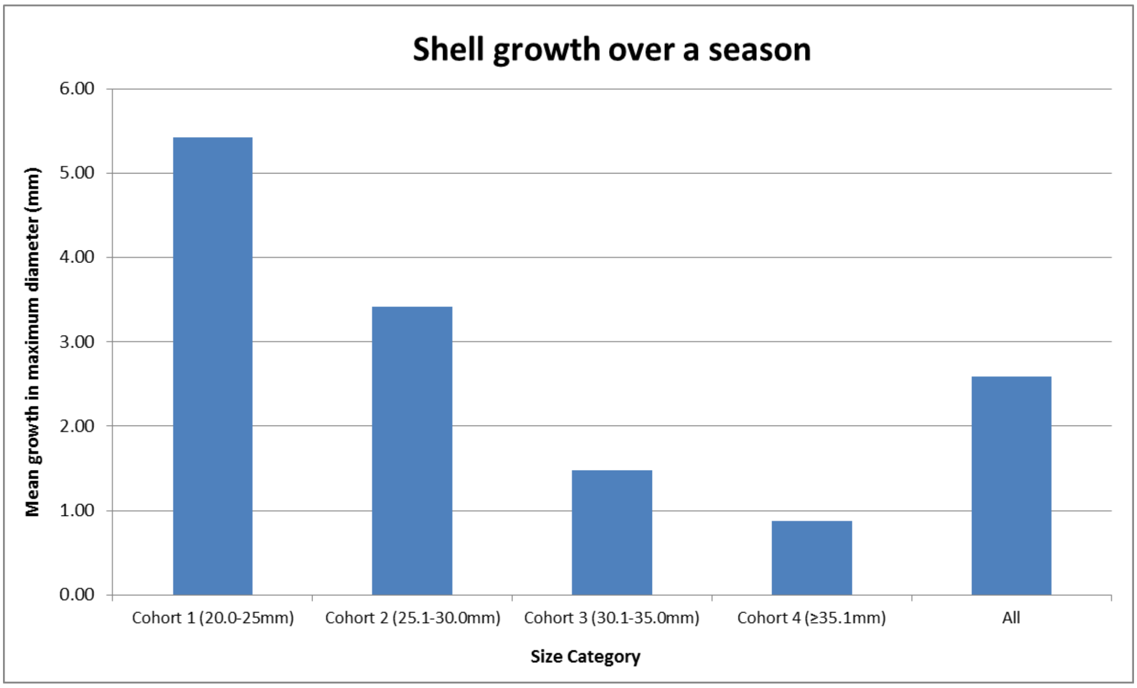
In total, 106 individual snails were observed during the 2012 season and recaptured in the 2013 season, allowing for a direct measurement of growth in the maximum diameter of shells. These snails were observed in all six monitoring blocks where monitored occurred in both the 2012 and 2013 seasons. During the 2012 season, which was baseline measuring point, the smallest snail observed had a maximum diameter of 21.2mm and the largest snail had a maximum diameter of 40.2mm, with a range of snails sizes in between. The average growth observed for all snails was approximately 2.6mm. The average growth of sub-adult snails in the first two cohorts (snails with a maximum diameter <30mm) was approximately 4mm over the course of the season. The smallest amount of observed growth was 0mm, with two very large snails not exhibiting any discernible growth. The largest amount of shell growth observed was 8.4mm over a season. This was initially considered an anomaly, as such growth was surprising. However, five other snails exhibited growth in excess of 7mm over the season. A summary of the results is shown below in Table 4 and Figure 3. Full results for all 106 snails are shown in Appendix G.

Table 4 – Shell growth over a single season
Mean growth in shell maximum diameter observed over a single season for 106 snails, broken down by category, with the number of snails the calculation is based on shown in brackets.

Location	Monitoring Block	Mean growth (mm) Cohort 1	Mean growth (mm) Cohort 2	Mean growth (mm) Cohort 3	Mean growth (mm) Cohort 4	Mean growth (mm) All snails
Extended Site B	West 1	5.33 (6)	3.03 (4)	1.49 (5)	0.90 (13)	2.26 (28)
Extended Site B	North East	6.83 (2)	2.38 (3)	0.85 (1)	1.18 (2)	3.00 (8)
Extended Site B	West 3	5.45 (1)	4.50 (4)	n/a (0)	0.27 (3)	3.03 (8)
Extended Site B	R6 VDT	7.80 (2)	5.77 (3)	2.28 (5)	1.52 (5)	3.46 (15)
Mt Augustus	Site A Lower	5.65 (2)	1.88 (4)	n/a (0)	n/a (0)	3.13 (6)
Mt Augustus	Site A Upper	1.75 (2)	3.39 (21)	1.21 (13)	0.44 (5)	2.26 (41)
Extended Site B	Translocation	5.67 (9)	3.39 (11)	1.38 (6)	0.83 (18)	2.53 (44)
Extended Site B	VDT	7.80 (2)	5.77 (3)	2.28 (5)	1.52 (5)	3.46 (15)
Mt Augustus	Natural habitat	3.70 (4)	3.14 (25)	1.21 (13)	0.44 (5)	2.37 (47)
All	All	5.43 (15)	3.41 (39)	1.48 (24)	0.88 (28)	2.59 (106)

Figure 3 – Shell growth over a single season

Mean growth in shell maximum diameter observed over a single season for 106 snails, collected across six sites, broken down by category (N= 15 for cohort 1, 39 for cohort 2, 24 for cohort 3 and 28 for cohort 4).



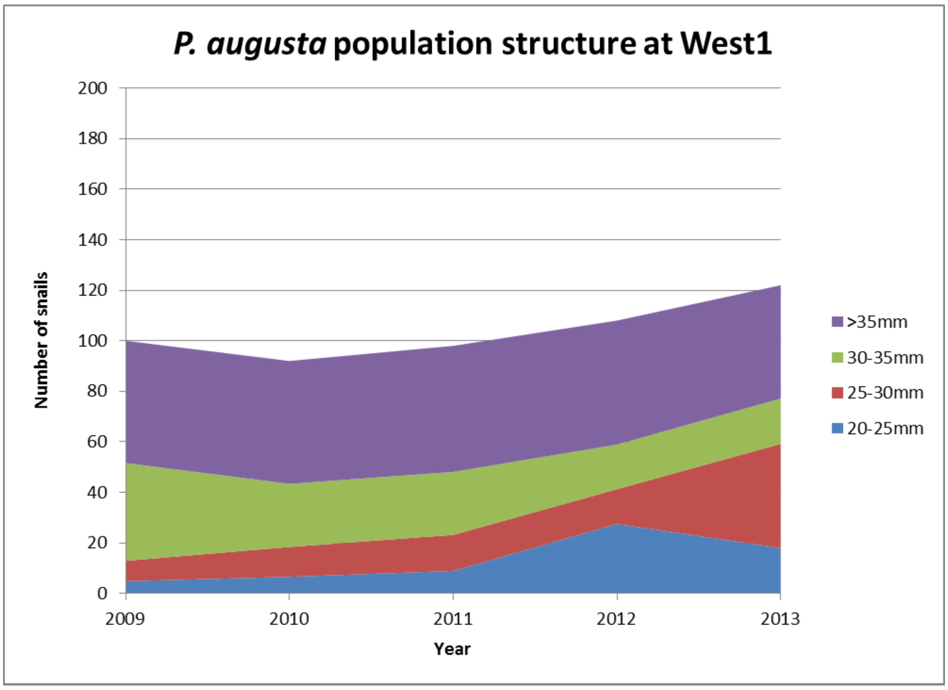
As expected, growth appears to be faster amongst younger snails, than their older counterparts. The fastest growth in all sub-categories was observed at the Vegetation Direct Transfer monitoring block, R6 VDT, where average growth of 7.80mm was observed in Cohort 1, albeit with a sample size of just two snails. With a sample size of just 106 snails in total, all of the sub-categories should be treated with caution, as the sample size for these sub-categories was in some cases quite small. For example, at the Mt Augustus monitoring block, Site A Upper, just two snails were observed in the Cohort 1 category, where the average growth was just 1.75mm.

iii. Population structure

The attempts to model the population structure of *P. augusta* snails at each monitoring block are shown below in Figures 4 to 13.

Figure 4 - Population structure at West 1 (Extended Site B)

Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size.



The results from the West 1 monitoring block (Figure 4) indicate that there has been an increase in the number of snails in the two smaller cohorts over the study period. Based on the estimate of how long it takes for a snail to reach a maximum diameter of 20mm, it is possible that some of the smaller snails that had joined the population being monitored by 2013 were born in the translocation area. It was previously unknown whether snails could hatch and survive in the translocation sites. The other two monitoring blocks at Extended Site B, where snails were translocated by hand, also indicate increases in the number of snails in the two smaller cohorts (Figures 5 and 6).

Figure 5 - Population structure at North East (Extended Site B)

Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size.

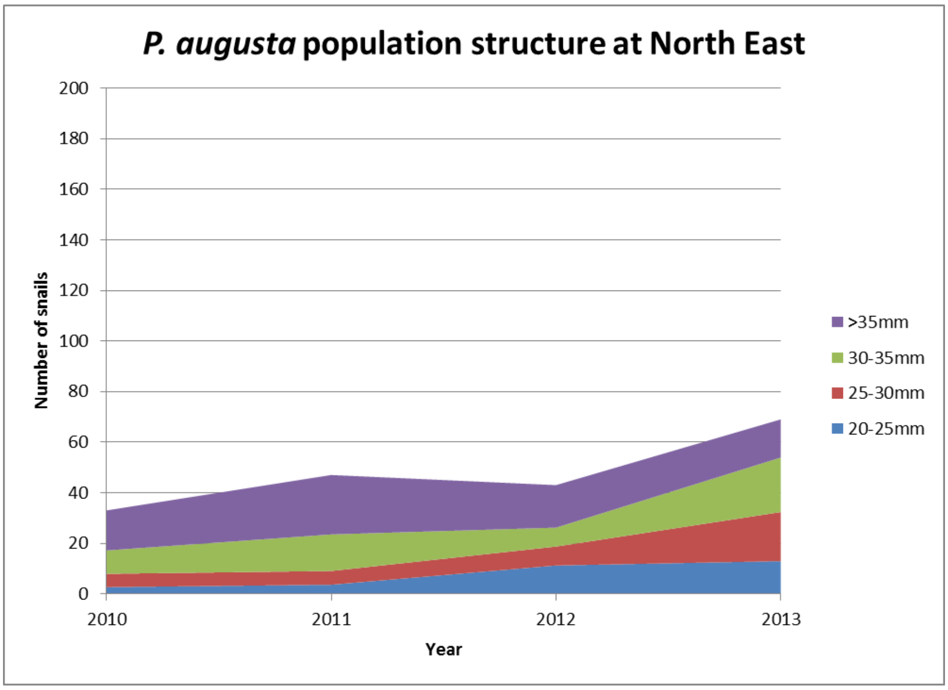
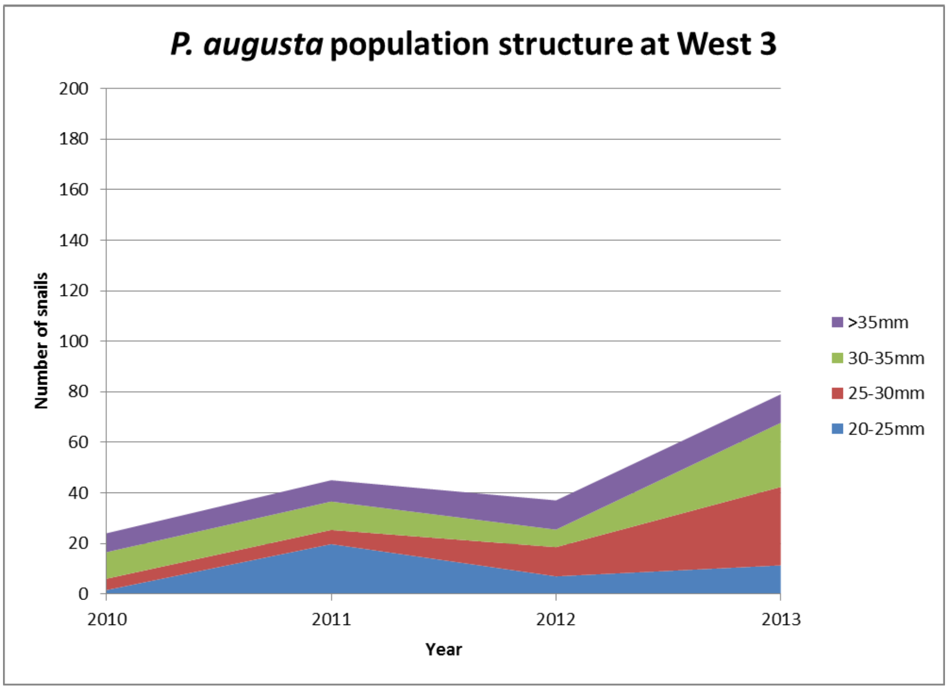


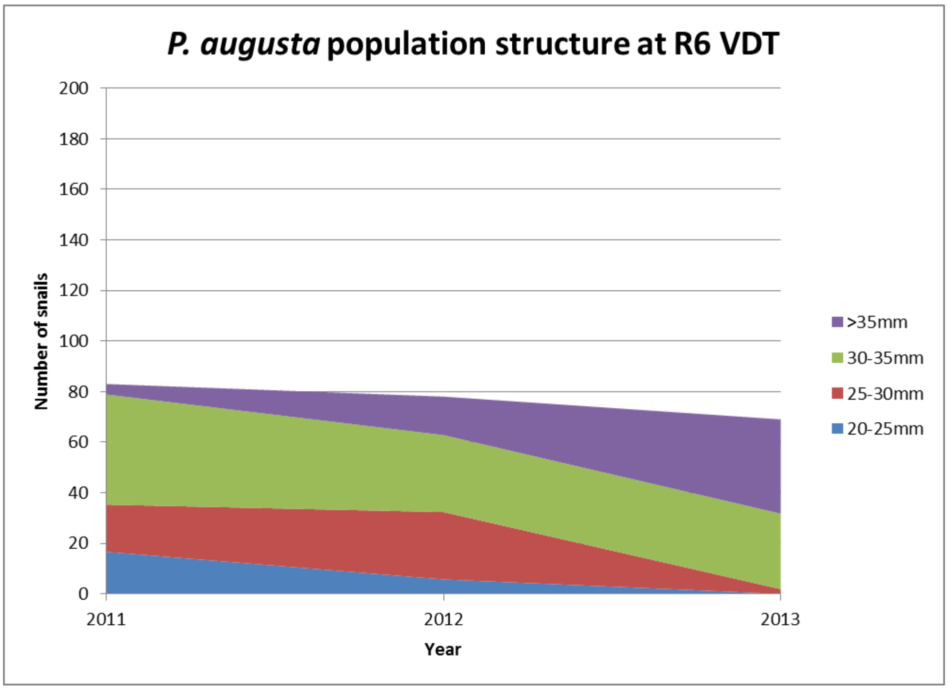
Figure 6 - Population structure at West 3 (Extended Site B)

Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size.



The remaining monitoring block at Extended Site B is R6 VDT (Figure 7), where snails were transferred mechanically, along with their habitat. Looking at the abundance estimates in isolation, this site appeared to have remained relatively stable over the study period. However, examining the results in more detail, by modelling the population structure, reveals a different picture. In contrast to the other three monitoring blocks at Extended Site B, at this site there has been a steady decline in the number of snails in the smaller two cohorts. By 2013, these two cohorts were barely represented, with the bulk of the population composed of older, larger snails.

Figure 7 - Population structure at R6 VDT (Extended Site B)
Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size.



At the Mount Rochfort monitoring blocks, it's difficult to read much in to the results from Summit B (Figure 9) or Basin B (Figure 11), due to the very small population present. At Summit A (Figure 8), there appears to have been a decline in the number of snails in the two smaller cohorts, resulting in a decline overall.

At Basin A (Figure 10), although the smallest cohort appears to have grown in size over the study period, the next size up (25mm-30mm) has not been detected at all, resulting in a population that is dominated by older, larger snails. It should be noted that as the Mount Rochfort monitoring blocks were not surveyed in 2013, there are only three data points from which to detect a trend, which is the absolute minimum required. Further data will help to confirm the likely trajectory of the populations at these monitoring blocks.

Figure 8 - Population structure at Summit A (Mount Rochfort)

Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size.

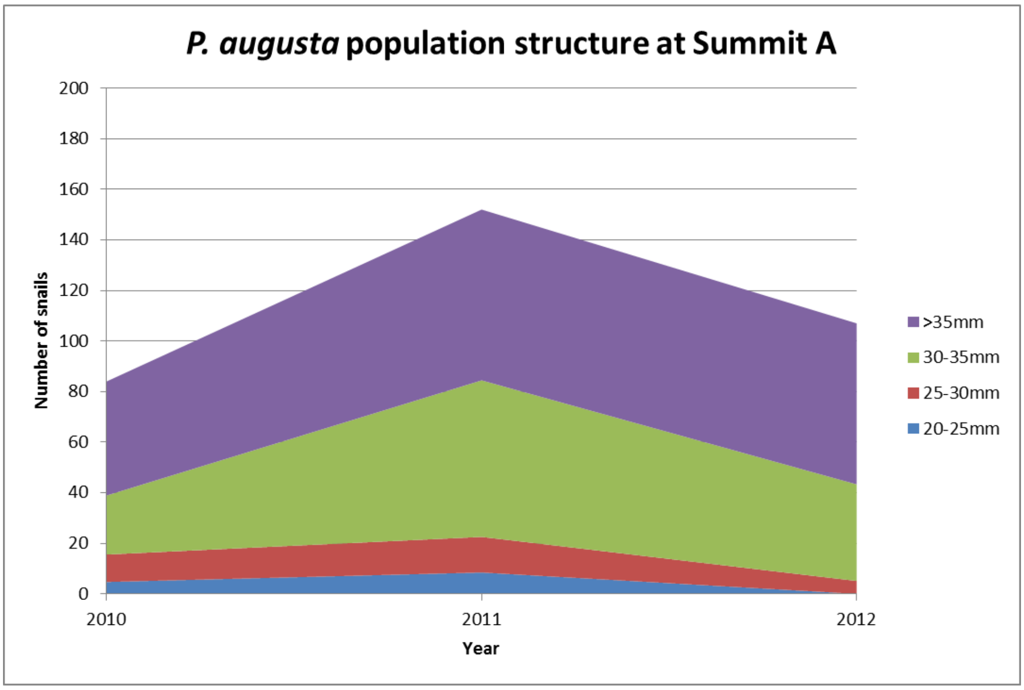


Figure 9 - Population structure at Summit B (Mount Rochfort)

Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size.

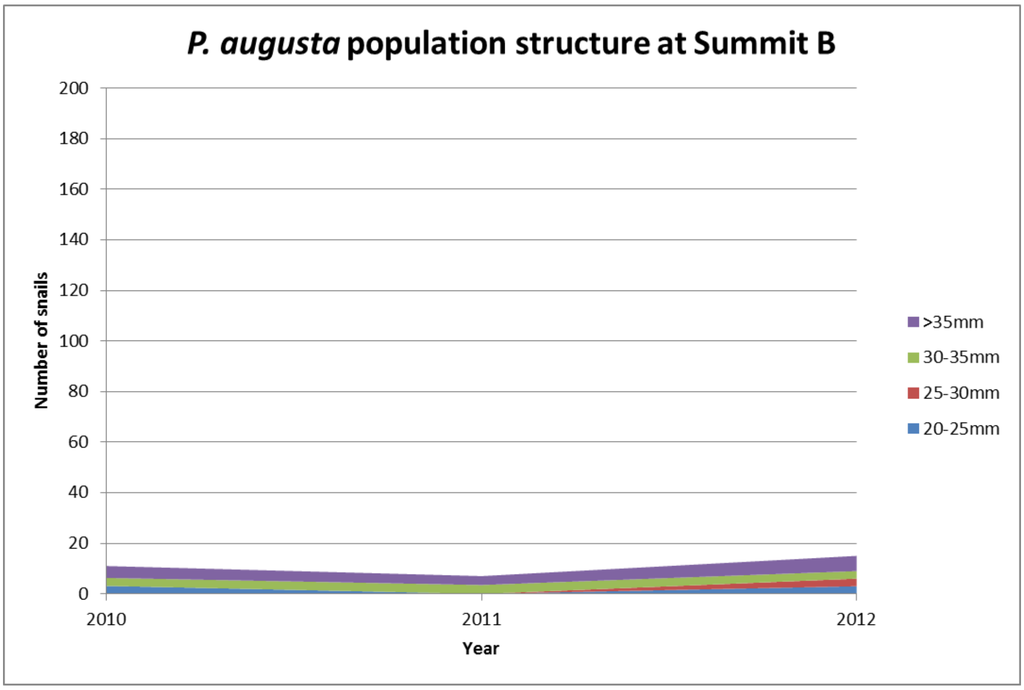


Figure 10 - Population structure at Basin A (Mount Rochfort)

Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size.

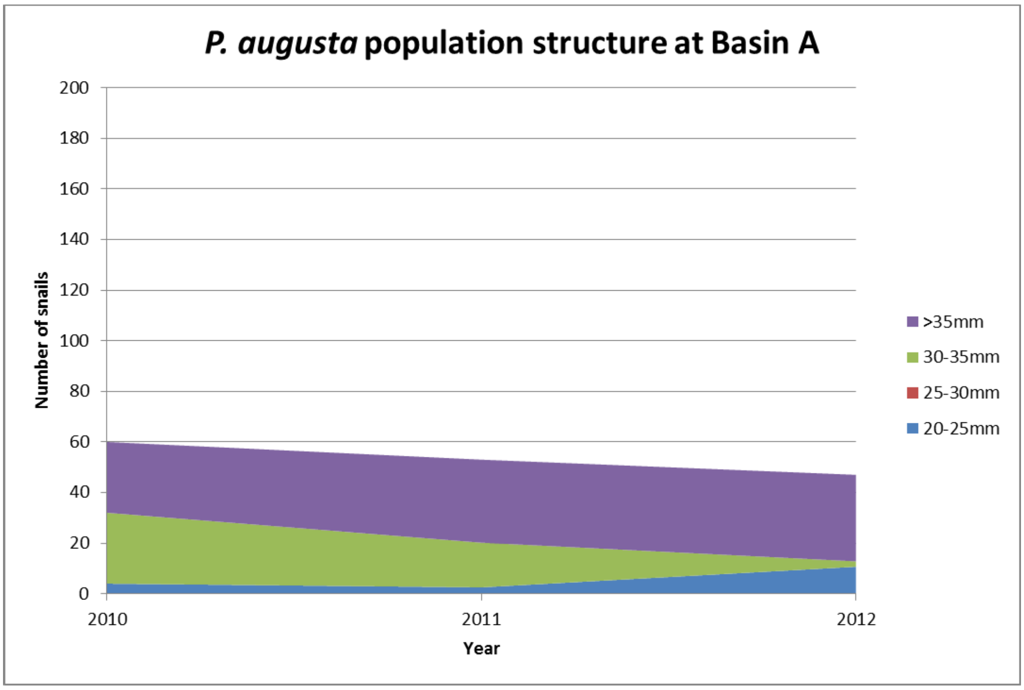
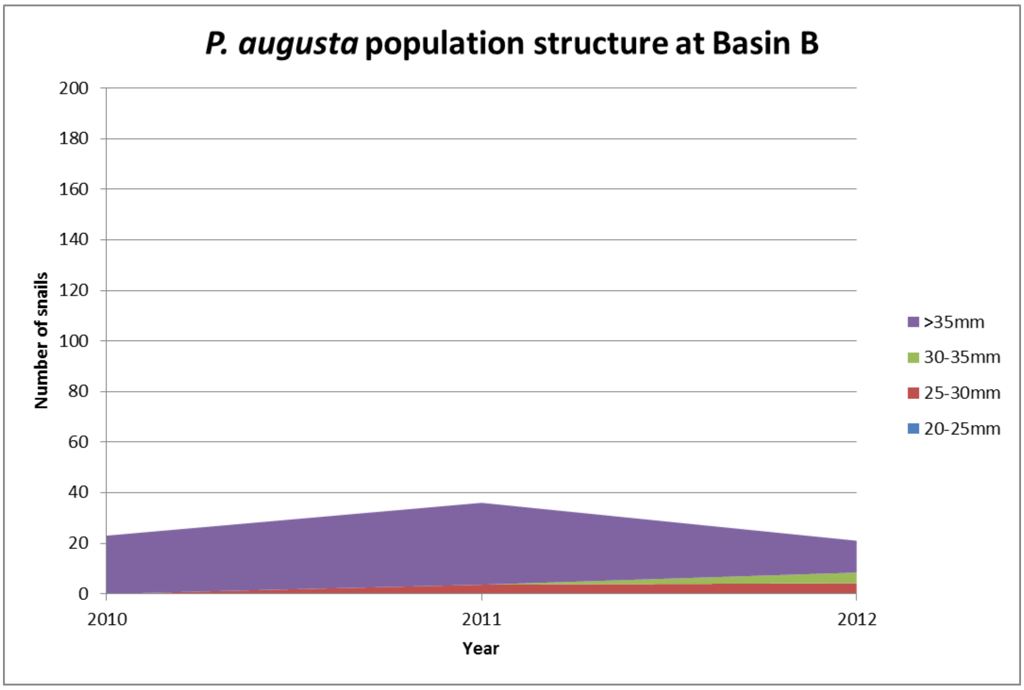


Figure 11 - Population structure at Basin B (Mount Rochfort)

Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size.



The Mount Augustus monitoring blocks are of interest, as they are the best indication we have of what a healthy monitored population may look like in its natural environment. At Site A Upper (Figure 12), all four cohorts are well represented, with the middle two cohorts dominating the population. Similarly, Site A Lower (Figure 13), also displays this trend, with the smallest and largest snails being in a minority.

Figure 12 - Population structure at Site A Upper (Mount Augustus)

Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size (note y axis differs with other figures).

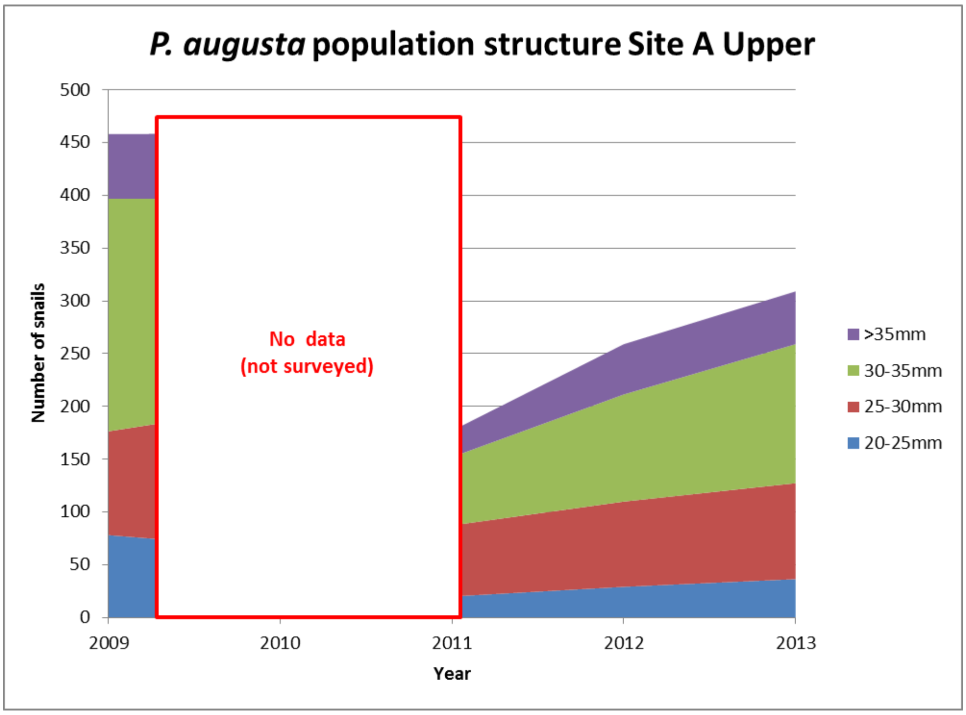
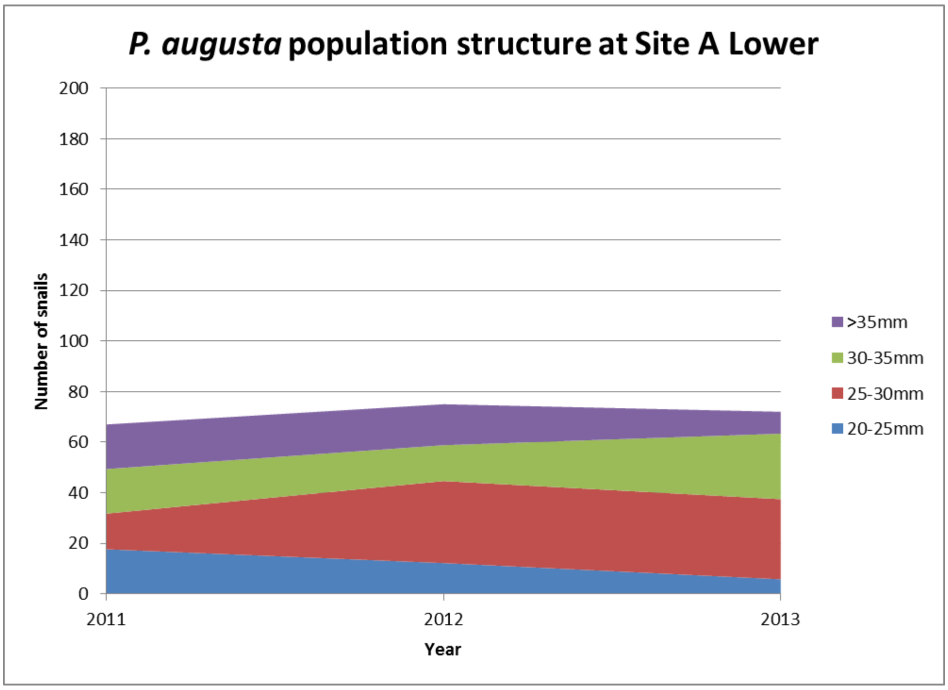


Figure 13 - Population structure at Site A Lower (Mount Augustus)

Shows the estimated composition of the population at this monitoring block over the study period, broken down into four cohorts, based on maximum diameter of shell size.



iv. Recruitment

The results from the 10x10m snail monitoring plot surveys are shown below in Table 5 and Figure 14. Of note in Table 5 was the observation of an egg at the West 1 monitoring block, possibly indicating that *P. augusta* are able to produce eggs at this translocation site.

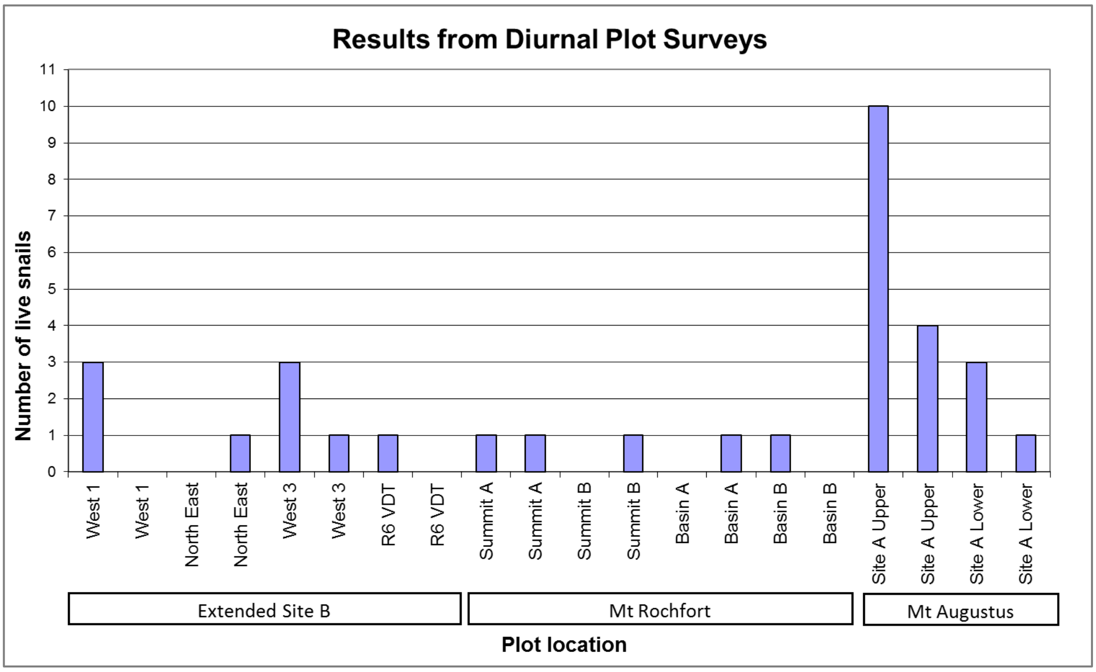
Table 5 - Results from the diurnal monitoring plots

A breakdown of results from the diurnal monitoring plots.

Date	Site	Monitoring Block	Plot Name	Easting (NZMG)	Northing (NZMG)	Snails (#)	Eggs (#)	Shells (#)
19/04/2012	Extended Site B	West 1	Plot A	2414564	5948565	3	1	0
19/04/2012	Extended Site B	West 1	Plot B	2414583	5948618	0	0	3
17/04/2012	Extended Site B	North East	Plot A	2414684	5948778	0	0	1
17/04/2012	Extended Site B	North East	Plot B	2414691	5948795	1	0	1
18/04/2012	Extended Site B	West 3	Plot A	2414610	5948343	3	0	1
18/04/2012	Extended Site B	West 3	Plot B	2414603	5948374	1	0	0
13/04/2012	Extended Site B	R6-VDT	Plot A	2414843	5948545	0	0	0
13/04/2012	Extended Site B	R6-VDT	Plot B	2414809	5948499	1	0	2
24/04/2012	Mt Rochfort	Summit A	Plot A	2405375	5935375	1	0	0
24/04/2012	Mt Rochfort	Summit A	Plot B	2405347	5935752	1	0	0
24/04/2012	Mt Rochfort	Summit B	Plot A	2405433	5935787	0	0	0
24/04/2012	Mt Rochfort	Summit B	Plot B	2405364	5935802	1	0	0
1/05/2012	Mt Rochfort	Basin A	Plot A	2404608	5935523	0	0	0
1/05/2012	Mt Rochfort	Basin A	Plot B	2404566	5935522	1	0	0
1/05/2012	Mt Rochfort	Basin B	Plot A	2404554	5935557	2	0	0
1/05/2012	Mt Rochfort	Basin B	Plot B	2404536	5935542	0	0	1
23/04/2012	Mt Augustus	Site A Upper	Plot A	2414625	5947983	10	0	9
23/04/2012	Mt Augustus	Site A Upper	Plot B	2414603	5947977	4	0	12
20/04/2012	Mt Augustus	Site A Lower	Plot A	2414501	5947717	1	0	2
20/04/2012	Mt Augustus	Site A Lower	Plot B	2414481	5947761	3	0	0

Figure 14 - Results from diurnal plot surveys

A graphical display of results from the diurnal monitoring plots (as shown in Table 5).

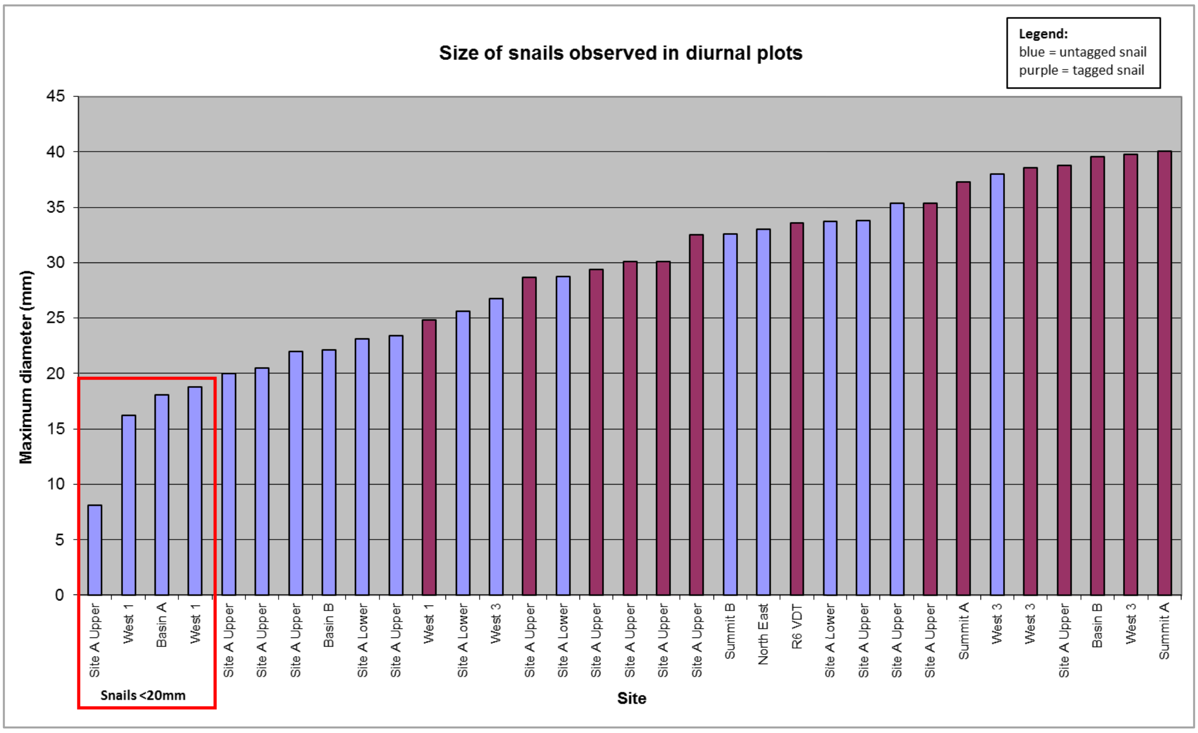


The main purpose of the diurnal surveys within the context of this chapter was to find evidence of recruitment. Figure 15 shows a breakdown of the snail observations by size (maximum diameter). In total, four snails were observed that were under <20mm and therefore not included in the mark-recapture study. Of these four snails, three were observed in translocation sites, possibly providing evidence that *P. augusta* are able to reproduce at these sites.

The sample size in this survey was small, with a large proportion of snails being observed at the Mt Augustus monitoring blocks, where abundance is estimated to be high. The results are probably a reflection of the limitation of this methodology (see Chapter 2), which may be unreliable with low to moderate density populations. However, the survey achieved its purpose in attempting to find evidence of recruitment in the wild, albeit limited evidence.

Figure 15 - Size of snails observed in diurnal plots

A breakdown of the snails observed by size. Also shows at what site (monitoring block) the snails were observed and whether they had been previously tagged in the mark-recapture study, with purple indicating tagged and blue indicating untagged. Untagged snails of less than 20 mm (red square) are considered to have hatched after relocation and may be proof of recruitment.



Another benefit of undertaking these diurnal surveys was the ability to provide a snapshot of the number of snails that had been observed and tagged as a part of the mark-recapture monitoring programme. Excluding the snails with a maximum diameter <20mm, which are not part of the mark-recapture study, approximately half of the snails observed were found to have been previously tagged. It should be noted that these results should be treated with caution, as the study site is open, allowing tagged and untagged snails to move in and out of the monitoring blocks. However, it is still of interest to see a rough estimate of the proportion of snails that had been tagged. Looking at the comparison of tagged vs untagged snails is of even more interest when broken down by cohort (see Table 6). Approximately 86% of snails in the smallest cohort had not been previously tagged. In contrast, of the snails in the largest cohort, approximately 22% had not been tagged. This would appear to support the (intuitive) assumption that smaller snails may be more difficult to detect than larger snails and therefore underestimated in the mark-recapture study. As stated above, any conclusion must be treated with extreme caution, due to the small sample size. However, if detection rates were investigated further, this could be incorporated in to the mark-recapture analyses, allowing for more robust abundance estimates. This would also provide a better assessment of the population structure at any given site. The results here appear to further support the view that no single methodology is ideal for monitoring *Powelliphanta* snails and that a composite methodology, incorporating aspects of both nocturnal and diurnal methodologies may provide the most robust data.

Table 6 - Tagged v untagged snails by cohort

Cohort	Maximum Diameter (mm)	Snails observed	Tagged (n)	Tagged (%)	Untagged (n)	Untagged (%)
0	<20	4	0	0%	4	100%
1	20.0-25.0	7	1	14%	6	86%
2	25.1-30.0	5	2	40%	3	60%
3	30.1-35.0	8	4	50%	4	50%
4	≥35.1	9	7	78%	2	22%
	Totals	33	14	42%	19	58%

v. Model of population persistence

The model of population persistence that was previously created following the *P. augusta* translocations and initial monitoring attempts (Efford, et al., 2009) is shown below in Figure 16 and described in full in Appendix F. The model shows the required annual survival for a population to persist. The key estimated variables are annual survival, age of maturity and fecundity (number of eggs produced per year by an adult snail). A major issue with the population model at the time was uncertainty surrounding these key parameters. The authors assumed an age of maturity somewhere between ten and twenty years of age, based on the limited data available. Survival rates were based on the limited study that had been undertaken at the time, which included monitoring at translocation sites at Extended Site B and Mount Rochfort, but not in the natural habitat at Mount Augustus. The estimated survival rates from that limited study were between approximately 55% at the worst performing site and 80% at the best performing site (Efford, et al., 2009).

Figure 16 - Orginal model of population persistence (Efford, et al., 2009)

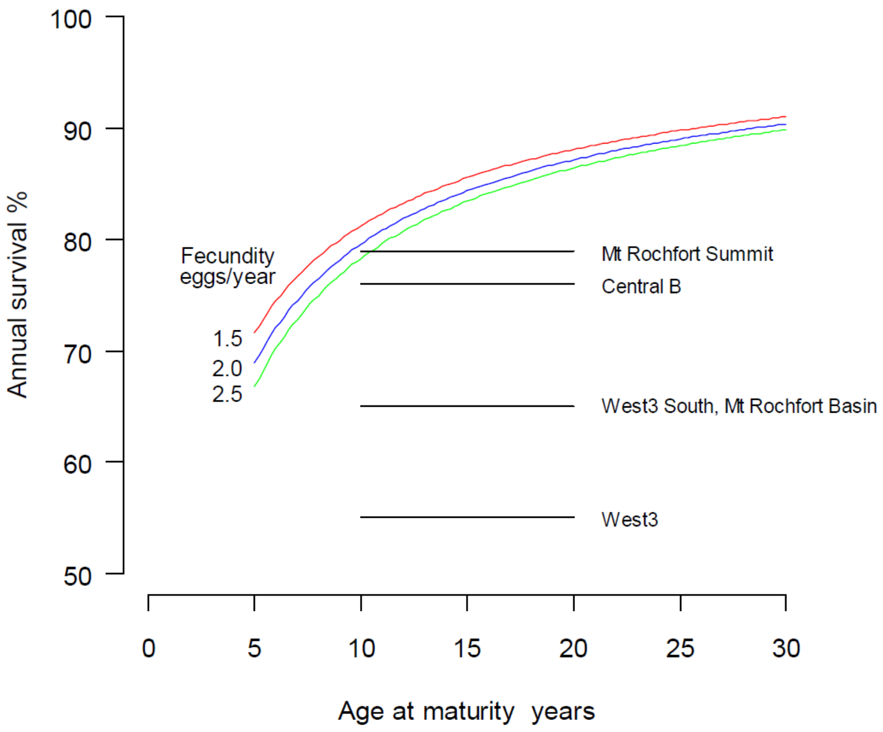


Figure 15: Threshold of annual survival needed for long-term population persistence as a function of age at maturity for three levels of fecundity (eggs laid per year). Estimated annual survival of translocated snails is shown for the five study sites as horizontal lines spanning a plausible range of ages at maturity.

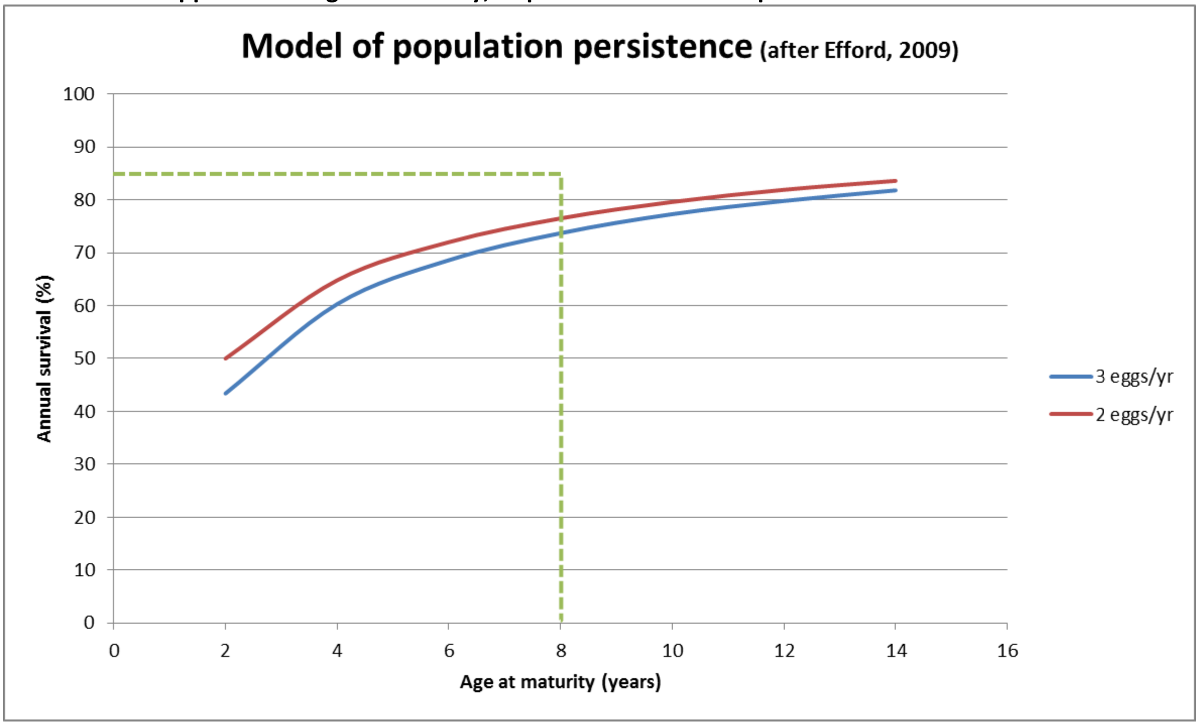
The number of eggs produced per year by *P. augusta* in the wild is unknown. The authors modelled a range of scenarios, from 0.5 to 3.5 eggs per year. As shown in Figure 16, with an age of maturity estimated to be 10-20 years, the model predicted that the future for *P. augusta* was bleak, showing that none of the populations were likely to persist in the long term. At the time, this was widely seen as evidence of failure of the translocation programme.

This model can now be updated by adding the data that are available after five years of mark-recapture monitoring. The data available now suggests that eight years is the probable age of reproductive maturity for *P. augusta*. Discounting Summit B and Basin B at Mount Rochfort, which can probably be considered unsuitable habitat for *P. augusta* (see Chapter 3), the most recent survival estimates for all other sites, both translocation and natural habitat, are approximately 85%.

The number of eggs produced per year in the wild is still unknown. In captivity, soon after collection, snails were observed laying two to three eggs in Spring (Walker, et al., 2008). Further research on the captive population demonstrated a strong link between environmental conditions and the numbers of eggs laid, with a large increase in eggs being laid with warmer temperatures and a greater supply of food (Phillips, R. unpublished data). Using the captive population to predict fecundity, both in terms of the size of clutches and the frequency of laying, is somewhat flawed. There are a number of factors that may impact on the likelihood of snails mating and producing offspring in captivity, that are not representative of snails in the wild. Whilst searching for snails on Mount Augustus, eggs were regularly found in clutches of two and three (pers. obs.). The number of eggs in a clutch may be related to snail size, with larger snails producing more eggs (Jordaens, Dillen, & Backeljau, 2007). It is unknown at what frequency eggs are laid in the wild for *P. augusta*. For the genus in general, annual egg production has been estimated as being as high as 5–10 eggs per year and no more than 20 (Walker, 2003). As an alpine species of *Powelliphanta*, annual egg production of *P. augusta* is likely to be much lower than their lowland relatives, due to inactivity during the colder winter months and the fact that they are comparatively much smaller in size. Based on the limited information available, it seems reasonable to assume that adult *P. augusta* snails may be able to produce on average a minimum of two to three eggs per year in the wild. This is the main area of uncertainty in updating the model of population persistence. Fortunately, it is also the least sensitive variable, with age of reproductive maturity and estimated survival playing a more important role in determining the likelihood of population persistence. Minor changes in the rate of annual egg production have little effect for snails with an age of maturity of 8 years. Figure 17 shows the updated model of population persistence.

Figure 17 - Updated model of population persistence .

The red and green lines indicate the required annual survival, for a range of ages of maturity, based on snails producing 2 or 3 eggs per year respectively. The green, hatched line represents the current survival estimates and approximate age of maturity, as presented in this chapter.



Based on the latest data, with the exception of Summit B and Basin B, all populations appear to be able to persist in the short to medium term. In fact, the populations appear to be growing. It is worth noting that the survival estimates are minimum estimates, as they do not account for snails that may have simply left the monitoring area. Furthermore, the estimate of egg production is also likely to be a minimum estimate and could be much higher. As discussed previously, the age of maturity is also likely to be a minimum estimate, as younger snails have been observed reproducing. After five years of mark-recapture monitoring, it would seem that the future for *P. augusta* may be less bleak than originally thought.

V. Discussion

The decision to allow a large proportion of *P. augusta* to be translocated from its natural habitat, to allow the mining of coal, was undoubtedly contentious and was widely debated at the time. The paper describing the taxonomy and conservation status of the species stated that "despite a growing international awareness of the importance of biodiversity conservation, the demand for foreign earnings continues to take priority over the protection of our biota" and "less than a decade after this species was first discovered, it is on the brink of extinction in the wild'' (Trewick, et al., 2008). The first attempts to monitor the translocated populations produced results that were equally pessimistic, with the authors stating that the results and assumptions suggest that "the translocated populations of *Powelliphanta augusta* will not persist in the long term" (Efford, et al., 2009). Both of these papers acknowledged that there was a lack of information available on *P. augusta* to fully understand the status of any of the populations, whether captive, translocated or those in their remaining natural habitat. To address this, the technical advisory group for the species advocated developing a mark-recapture based monitoring programme to monitor the species. This programme is discussed in detail in Chapter 3 of this thesis, along with the abundance estimates gained, the production of which was a main aim of the monitoring programme.

After five years of long term monitoring, using mark-recapture techniques, the abundance results appear to suggest that most of the populations are stable and may even be increasing. However, abundance estimates are just one piece of information that can be used to understand the population dynamics of a species. An advantage of using a mark-recapture technique for monitoring is the possibility of developing a richer understanding of the ecology and behaviour of the animal being studied by estimating other parameters (Lettink & Armstrong, 2003). By marking individuals, which are then recaptured over time, it has been possible to gain a greater understanding of parameters such as survival, growth, population structure and recruitment. In turn, this improved understanding of the ecology of *P. augusta* allows for the remodelling of population persistence and a better assessment of the status of the species.

Survival

Prior to this mark-recapture study, the only estimates of annual survival rates were from a small-scale study undertaken between 2007 and 2009, where survival estimates ranged from 55% at a monitoring block in Extended Site B to 79% at Mount Rochfort Summit (Efford, et al., 2009). The updated estimates presented in this chapter are higher than the original estimates. The most recent data available for each monitoring block shows that all blocks have an annual survival rate in excess of 80%, with the exception of the Summit B and Basin B at Mt Rochfort. Both of these blocks also have relatively low abundance of *P. augusta* and are likely to be poor habitat for *P. augusta* (see Chapter 3 of this thesis for more information). The results presented in this chapter indicate that survival rates appear to have been relatively stable across all sites, with some sites showing an increase over time. The relatively wide confidence intervals should be noted. It is of interest that the survival estimates from the previous study (Efford, et al., 2009) also had relatively wide confidence intervals, which may indicate that improvements to the method may be required to increase certainty. This could be achieved by increasing the number of snail recaptures, perhaps by surveying over more nights.

Growth

Prior to the results presented here, existing data on rates of *P. augusta* shell growth was very limited and fraught with issues. Data from the captive population indicated that the rate of growth was likely to be very slow (James, et al., 2012). However, there are clear limitations in extrapolating data from a captive population and applying to a wild population. Measurements were taken for the snails in the early transponder monitoring study, which found that growth was slow (pers. obs.). However, only snails with a maximum diameter of over 32mm were chosen for the study, due to the size of the transponder attachments. If, as expected, growth is faster during early life stages, the results obtained from that study are not representative of all life stages. In the paper describing the species, the authors state that rates of growth in the wild are unknown but that they are likely to be slower than lowland relatives (Walker, et al., 2008).

An attempt was made to accurately measure shell growth over a year by taking two accurate measurements approximately one year apart. The average growth observed for all 106 snails captured in both seasons was approximately 2.6mm. As expected, growth in maximum diameter appears to be faster amongst younger snails, than their older counterparts. However, the speed of growth was much faster than expected. It was also unexpected that snail growth would be faster in the translocation sites, in comparison with the natural habitat. With a sample size of just 106 snails in total, the results should be treated with caution. However, whilst the limitations of the data must be recognised, this presents the first opportunity to estimate growth rates of *P. augusta* in the wild and therefore the age of reproductive maturity. In the paper describing the species, the authors suggest sexual maturity is reached at approximately 36mm in size (Walker, et al., 2008). However, the smallest snail to have produced eggs in the captive *P. augusta* population was just 25mm in size (Efford, et al., 2009), suggesting that 36mm may be an overestimate. Analysis of data from the captive population of *P. augusta* found that over 98% of eggs were laid by parents with a maximum shell diameter greater than 32 mm, with the authors proposing that 32mm was the age of maturity (James, et al., 2012). It is unclear whether these results from the captive population are an artefact of the captive husbandry techniques (e.g. the way in which the snails have been housed, individually and in groups, at different sizes). Furthermore, the captive population may not represent a wild population. However, 32mm has been adopted by the Department of Conservation as the probable age of maturity and is therefore the best estimate we have. Based on the results, it would seem fair to estimate that it would take between three and four years for a snail to grow from 20mm to 32mm and therefore reach reproductive maturity.

One of the limitations of the mark-recapture study is that it does not provide data on snails with a maximum diameter less than 20mm. With no other data available from populations in the wild, the best estimates we have come from the captive populations. The only published data to date showed that hatchling and juvenile *P. augusta* snails in captivity were very slow growing (James, et al., 2012). More recent modelling of the captive populations suggested that snails would take approximately eight years to reach 32mm in captivity (Phillips, R. unpublished data). In a concurrent experiment, the captive population of sixty hatchling snails held at Lincoln University found that shell growth was faster than expected and that snails would take four to five years to reach 20mm in size. Limited modelling of this data suggests that, on average, it would take 7 to 8 years for a snail to reach 32mm (S.

Boyer, 2014. pers. comm.). Based on all of the above information, it would seem reasonable to assume that the average age of reproductive maturity is, at most, eight years old.

Population structure

Population structure is another parameter that may be important in assessing the viability of a population and/or a species. The abundance estimates presented in Chapter 3 are an estimate of how many snails are likely to be present in each monitoring block. However, they are not sensitive to different life stages. The benefit of this analysis, which attempted to estimate the number of snails in different cohorts is the ability to assess the comparative health of the population structure over time.

The Mount Augustus monitoring blocks are of particular interest, as they are the best indication we have of what a healthy monitored population may look like in its natural environment. At both monitoring sites in the natural habitat, all four cohorts are well represented, with the middle two cohorts dominating the population.

The results from the Extended Site B monitoring blocks indicate that there has been an increase in the number of snails in the two smaller cohorts over the study period. Based on the estimate of how long it takes for a snail to reach a maximum diameter of 20mm, it is possible that some of the smaller snails that have joined the population being monitored were born in the translocation area. It was previously unknown whether snails could hatch and survive in the translocation sites.

The remaining monitoring block at Extended Site B is R6 VDT, where snails were transferred mechanically, along with their habitat. Looking at the abundance estimates in isolation, this site appeared to have remained relatively stable over the study period. However, examining the results in more detail reveals a different picture. There has been a steady decline in the number of snails in the smaller two cohorts. It is unclear whether this can be attributed to a lack of recruitment, high mortality or difficulty to detect the snails in the VDT. With so few snails in the smaller cohorts, it is difficult to see how this population can persist in the longer term, unless this trend is reversed. The R6 VDT site is an early example of the process of VDT, which has subsequently been refined and much improved. The results presented here should not be treated as being representative of more recent VDT, which is likely to provide much better snail habitat.

At the Mount Rochfort monitoring blocks, it's difficult to read much in to the results from Summit B or Basin B, due to the very small populations present. At Summit A there appears to have been a decline in the number of snails in the two smaller cohorts, resulting in a decline overall. At Basin A although the smallest cohort appears to have grown in size over the study period, the next size up (25mm-30mm) has not been detected at all, resulting in a population that is dominated by older, larger snails. It should be noted that as the Mount Rochfort monitoring blocks were not surveyed in 2013, as a consequence there are only three data points from which to detect a trend, which is the absolute minimum required. Further data will help to confirm the likely trajectory of the populations at these monitoring blocks. Examining the structure of the different populations, rather than viewing the abundance estimates in isolation, has proved to be a useful exercise and provides a more detailed understanding of the current status of each population and the likely trajectory it is on.

Recruitment

For a population to be sustainable in the long term, recruitment obviously needs to occur and, furthermore, needs to be at a sufficient rate to replenish losses to the population. Unfortunately, for *P. augusta*, and for most *Powelliphanta* snails, our knowledge of recruitment in the wild is extremely limited. As the mark-recapture methodology used in this study only monitors snails with a maximum diameter greater than 20mm, the only way to infer recruitment is occurring is to wait until new snails appear in the population being monitored. At the start of this study, the time it would take for snails to reach 20mm in size was unknown (and is still unknown for snails in the wild). The main purpose of the diurnal surveys of 10x10m plots was to directly search for smaller snails and eggs as evidence of recruitment. In total, four snails were observed that were under <20mm, including one hatchling (measured at approximately 8mm). Of these four snails, three were observed in translocation sites, possibly providing evidence that *P. augusta* are able to reproduce at these sites. A single egg was also observed at the West 1 monitoring block, possibly indicating that *P. augusta* are able to produce eggs at this translocation site.

The sample size in this particular survey was small, with a large proportion of snails being observed at the Mt Augustus monitoring blocks, where abundance is estimated to be high. The limited results are probably a reflection of the limitation of this methodology (see

Chapter 2), which may be unreliable with low to moderate density populations. However, the survey achieved its purpose in attempting to find evidence of recruitment in the wild, albeit limited evidence.

Another benefit of undertaking these diurnal surveys was the ability to provide a snapshot of the number of snails that had been observed and tagged as a part of the mark-recapture monitoring programme. Approximately half of the snails observed were found to have been previously tagged. It is of interest to obtain an estimate of the proportion of snails that had been tagged, as it may provide an indication of the effectiveness of the searching techniques being utilised. Looking at the comparison of tagged versus untagged snails is of even more interest when broken down by cohort. Approximately 86% of snails in the smallest cohort had not been previously tagged. In contrast, of the snails in the largest cohort, approximately 22% had not been tagged. This would appear to support the (intuitive) assumption that smaller snails may be more difficult to detect than larger snails and therefore underestimated in the mark-recapture study. If detection rates were investigated further, this could be incorporated in to the mark-recapture analyses, allowing for more robust abundance estimates. The results here appear to further support the view that no single methodology is ideal for monitoring *Powelliphanta* snails and that a composite methodology, incorporating aspects of both nocturnal and diurnal methodologies may provide the most robust data.

Model of population persistence

The initial model of population persistence (Efford, et al., 2009) predicted that the future for *P. augusta* was bleak, showing that none of the populations would persist in the long term. At the time, this was widely seen as evidence of failure of the translocation programme. Five years on, this model can now be updated with more accurate information. Based on the data available now, all *P. augusta* populations appear to be able to persist in the short to medium term, with the exception of Summit B and Basin B, which are unlikely to be suitable habitat. In fact, both the abundance estimates and the population persistence model suggest that the populations are growing. After five years of mark-recapture monitoring, it would seem that the future for *P. augusta* may be less bleak than originally thought. Based on the results presented in Chapter 3 and 4 of this thesis, there does not appear to be any justification in claiming that the species is on the brink of extinction in the wild, as suggested in an earlier study (Walker, et al., 2008).

The limitations of the mark-recapture methodology employed needs to be recognised. Furthermore, with only five years of data available, it is far too soon to claim that the species is secure and that the translocations have been successful. It is likely to take decades to prove that the translocations were successful and that the populations are self-sustaining in the long-term. However, another season of mark-recapture monitoring is scheduled for the summer of 2015/2016, almost ten years after the first snails were collected from the slopes of Mount Augustus. This additional data point will build upon the data presented here. It is strongly recommended that such monitoring continues in the future, perhaps at five to ten year intervals, to accurately monitor the status of this remarkable species, in both the natural habitat and the new habitat it appears to be adapting to.

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Chapter 5

Summary and Recommendations

Table of Contents

I. Summary and recommendations

The main chapters in this thesis have a specific discussion that covers the respective chapter. The purpose of this chapter is to summarise the key findings and to provide recommendations for further research or improvements. Furthermore, during the course of this study, there have been developments in land snail conservation and, in particular, the use of mark-recapture as a study tool. This chapter will highlight some of this recent research to better understand the context of the thesis in the broader global context.

The key aim of Chapter 2 was to assess the accuracy of the standard plot method for monitoring *Powelliphanta* (Walker, 1997) and examine whether it can be consistently used to estimate an index of abundance and population trends over time. As expected, the results confirmed that a large proportion of snails are overlooked during a standard monitoring event, when using this method. This is unsurprising, as very few monitoring techniques are designed to monitor all individuals present. However, what was important was that the proportion of snails overlooked at each plot was highly variable, ranging from 10% to over 50%. Any attempt to compare the results of separate monitoring events over time at any individual plot should therefore be undertaken with extreme caution. The fact that the percentages of snails found at all plots were normally distributed does provide some reassurance about the usefulness of the method as a monitoring technique. With enough plots, it may be possible to get a very rough indication of population trends over a long period of time. However, this information is unlikely to be useful for highly threatened species, where accurate information is essential for timely conservation management. On average, approximately 30% of snails were observed during a standard monitoring event. This figure of 30% may be a useful 'rule of thumb' when attempting to interpret results derived from any monitoring using this method. Despite the clear limitations, the standard plot method is still being utilised by the Department of Conservation in New Zealand to monitor many threatened species of *Powelliphanta*.

The key aim of Chapter 3 was to describe a newly developed mark-recapture method for monitoring *Powelliphanta* snails and assess its suitability for such monitoring. This technique was developed to monitor the critically endangered snail *Powelliphanta augusta*, as an alternative to the standard method for *Powelliphanta* monitoring. To have confidence in the results obtained from the monitoring, it was important to establish if the method was reliable and, in particular, if the mark-recapture assumptions underpinning the statistical analysis were being met. The main assumptions relate to tag loss, births, deaths and migration (Lettink & Armstrong, 2003). Tag loss was investigated through a tag loss experiment, which involved the double tagging of snails at one monitoring site, which is a standard method for estimating tag loss (Seber & Felton, 1981). Tag loss rates were found to be extremely low and unlikely to be an issue. Furthermore, from a practical perspective, it was possible to quickly attach the tags in the field, with minimum interference and manipulation of the snails, using a temporary shelter, such as a tent, vehicle or hut. A concurrent study, in the United States of America, found that plastic tags, normally used as queen bee marks, also worked on *Cipangopaludina chinensis* (Viviparidae), a species of freshwater snail being monitored, with zero tag loss observed during the two year study period (McCann, 2014). Another concurrent study on a land snail, this time in Canada, found that marking snail shells with a permanent marker was ineffective (Morgan, 2014). It would seem that plastic markers are an excellent way of marking snail shells and may be the best method currently available. An improvement to this method would be to find a way of identifying an individual snail without having to handle the animal. One possibility would be to use photographs of snail shells to identify individual snails. This has been trialled previously in New Zealand, on another species of *Powelliphanta*, using human judgement to visually assess photographs over time (Turner, 2011). It was found that whilst possible, this became difficult over time, as snail shells changed. It is recommended that photographic recognition is explored further but through the use of computer software for shell recognition, which may be more reliable.

The closed population assumption, requiring no additions or deletions to the population, through births, deaths or migration, was more difficult to assess. It is recognised that the assumptions relating to a closed population are unlikely to be completely met in real world, wild populations (Pollock, Nichols, Brownie, & Hines, 1990). However, estimating the extent and therefore significance of any violation was necessary. There was some evidence of mortality occurring during the monitoring period. As the monitoring technique does not include snails with a maximum diameter of <20mm, 'births', in this instance, refer to those snails who become part of the study through a small amount of shell growth during the monitoring period. In both cases, due to the short time interval of the annual monitoring period (four to eight weeks) compared to the long lifespan of the species, and the very low number of snails likely to be involved, neither births or deaths are thought to be a significant issue.

Migration is likely to have been the assumption that may have been violated to the greatest degree. Indeed, it was shown that there was some violation of the closure assumption due to migration. However, it is unclear whether this is significant. Without a more detailed study, such as tracking individual snail movement with a transponder for example, it is impossible to fully assess this issue. Based on the results obtained, it is assumed that migration, whilst occurring to a limited degree, is probably relatively minor and likely to be equal across years. Furthermore, there is unlikely to be any difference in migration patterns between marked and unmarked snails. Finally, snails are generally more sedentary and slow moving than many other animals that are studied in the wild using mark-recapture methods. It is therefore concluded that migration is probably not a significant issue in this study. Estimating the percentage of snails that are migrating to/from the monitoring block during the survey period would be of great value. It is recommended that this issue is explored to identify if there is some kind of edge effect occurring on the boundary of a monitoring block. If the extent of migration could be established, it would be possible to incorporate this data in to the statistical analysis. A recent study of *Thersites mitchellae* (Camaenidae), a species of endangered land snail in Australia, recommends using radio-telemetry to compliment mark-recapture studies, stating that such an approach can assist with testing the closure assumption and can help with estimating the extent of migration in and out of the study area (Parkyn, Brooks, & Newell, 2014). Interestingly, the study also found that the current guidelines for the approach to surveying the target species, provided by the National Parks and Wildlife Service in Australia, did not fully correspond with the findings of the study, perhaps indicating that the inadequacy of the traditional methods used for surveying land snails is not an issue confined to New Zealand.

Abundance estimates were produced for *P. augusta* at all sites in which they currently occur, including both its natural habitat and the new habitats in to which it has been translocated. The production of the annual abundance estimates has been an essential element of the conservation effort for the species, as until the estimates were made available, there was no reliable data on the status of the various populations. The only data available led to commentators predicting that the translocated populations were unlikely to persist in the long term (Efford, Lloyd, & Gruner, 2009) and that the species was on the brink of extinction in the wild (Walker, Trewick, & Barker, 2008). In contrast to these assertions, the abundance estimates showed that, at most of the sites in which the species occurs, the populations are both stable and may even be growing.

One concern with the abundance estimates obtained was the wide confidence intervals. This issue was also identified in a concurrent study of a species of freshwater snail, where a mark-recapture method was being trialled (McCann, 2014). It is recommended in that study, and here, that in future studies some effort is undertaken to increase recaptures, either through increased sampling or by employing a more efficient sampling technique, in an effort to reduce the width of confidence intervals. However, the abundance estimates obtained using the new mark-recapture method, whilst having wide confidence intervals, are likely to be far more accurate than any estimates obtained with the standard plot monitoring method, commonly in use today.

Recommendations are made in Chapter 3 to further refine the mark-recapture method. Whilst some challenges remain, the results to date indicate that it is a suitable method for monitoring *Powelliphanta* snails. In light of the results presented in this thesis, highlighting the limitations of the standard plot method, and the advances in mark-recapture approaches to monitoring, it is strongly recommended that the Department of Conservation undertakes a review of the techniques used to monitor *Powelliphanta* snails. For critically threatened species of *Powelliphanta*, in particular, it is recommended that alternative methods are urgently found to replace or compliment the standard plot method. A recent study of freshwater snails also concluded that mark-recapture methods were superior to traditional survey methods, such as density estimates derived from plots or transects (McCann, 2014).

To fully understand the dynamics of a species, it is desirable to understand all life stages. It was found that a disproportionate number of small snails (hatchlings and juveniles) may be missed during a monitoring event using the standard plot method, which would present a skewed picture of population demographics. Finding an appropriate monitoring technique for smaller snails is likely to remain an issue with any monitoring technique currently available. The mark-recapture approach described here does not deal with these life stages at all. This presents an issue for conservation managers, where threats to adults and younger life stages may often differ in extent and by type. Resolving this issue would be a major step forward in improving the monitoring techniques (and conservation) of this genus. It is recommended that further trails are undertaken to improve the techniques used for monitoring these younger life stages.

The newly developed mark-recapture monitoring method described in Chapter 3 has the potential to become an important component of any *Powelliphanta* monitoring method developed in the future. However, as discussed, this method also has issues. It may be that the best solution would be a hybrid method, utilising aspects of both the new and old methods, to extract the greatest amount of use from both. Furthermore, supplementing these approaches to monitoring with other techniques, such as radio-telemetry, may result in an integrated approach that provides robust data and is superior to any single approach used in isolation.

Abundance estimates are just one piece of information that can be used to understand the population dynamics of a species. An advantage of using a mark-recapture technique for monitoring is the possibility of developing a richer understanding of the ecology and behaviour of the animal being studied by estimating other parameters (Lettink & Armstrong, 2003). By marking individuals, which are then found over time, it may be possible to gain a greater understanding of parameters such as survival, recruitment, growth, dispersal and range. Such data may then inform the development of population models that can be used to assess population viability over time (Lettink & Armstrong, 2003). The key aim of Chapter 4 was to glean as much information as possible from the data collected, to gain a better understanding of the ecology and conservation status of *P. augusta*, to assist conservation managers with their decision making. As a species that was relatively new to science, and only formally described recently (Walker, et al., 2008), there were many important aspects of the ecology of *P. augusta* that were completely unknown.

Previous estimates of *P. augusta* annual survival ranged from 55% to 79% (Efford, et al., 2009). The most recent data available for each monitoring block from the mark-recapture monitoring shows that the annual survival rate is in excess of 80% in most locations. The results indicate that survival rates appear to have been relatively stable across all sites, with some sites showing an increase over time. One issue identified during the study was snails leaving the study block during the monitoring period, which can lead to an underestimate of survival. The results obtained can therefore be considered minimum survival estimates or 'apparent survival'. This issue was also identified in a recent study of land snails in Sweden (Schmera, Baur, & Baur, 2015). It is recommended that this issue is explored in further detail, as there are now statistical techniques to deal with 'apparent survival' in mark-recapture studies, allowing emigration to be factored in to produce estimates of 'true survival' (Gilroy, Virzi, Boulton, & Lockwood, 2012).

It was previously unknown how fast *P. augusta* grows in the wild but it was assumed to be a slow process (Walker, et al., 2008). The average growth observed for 106 snails captured approximately one year apart was approximately 2.6mm. As expected, growth in shell maximum diameter appears to be faster amongst younger snails, than their older counterparts. Overall, the speed of growth was much faster than expected. A concurrent study conducted in Sweden found that shell growth of *Chondrina clienta* (Chondrinidae), an alpine land snail, was variable both in terms of individual growth and between different size classes (Schmera, et al., 2015), which corresponds with the findings here. Interestingly, the study in Sweden also found that snail shell growth occurs throughout the year, even in winter, when the snails are largely immobile, which was unexpected. Upland species of *Powelliphanta*, such as *P. augusta*, are also generally immobile during winter months. It has previously been assumed that shell growth of upland species of *Powelliphanta* snails would be slower than of their lowland relatives (Walker, et al., 2008), partly due to the restricted period of activity. It would be of interest to explore whether shell growth continues over winter, which could be achieved by tracking individual snails in different size classes. If growth does occur throughout the year, this may partly explain the results obtained in this study, with shell growth faster than expected.

With a sample size of just 106 snails in total, the results should be treated with caution. However, whilst the limitations of the data must be recognised, this presents the first opportunity to estimate growth rates of *P. augusta* in the wild and therefore the age of reproductive maturity. Based on the results, it is estimated that it would take between three and four years for a snail to grow from 20mm to 32mm and therefore reach reproductive maturity. One of the limitations of the mark-recapture study is that it does not provide data on snails with a maximum diameter less than 20mm. Data from the captive populations was therefore used to estimate growth of younger life stages. It is estimated that the average age of reproductive maturity is, at most, eight years old.

Population structure is another parameter that may be important in assessing the viability of a population and/or a species. The abundance estimates presented in Chapter 3 are an estimate of how many snails are likely to be present in each monitoring block. However, they are not sensitive to different life stages. The benefit of the analysis of population structure, which attempted to estimate the number of snails in different cohorts, is the ability to assess the comparative health of the population structure over time. It was found that population structure was different at different sites. Many sites appeared to contain a healthy structure, with all cohorts being represented. However, some sites showed some areas for concern, particularly the R6 VDT site, where the smaller cohorts had disappeared from the captured snails entirely. This site should be monitored closely in future to ascertain the status of the population. Examining the structure of the different populations, rather than viewing the abundance estimates in isolation, proved to be a useful exercise and provided a more detailed understanding of the current status of each population and the likely trajectory it is on. It is recommended that the analysis of population structure be undertaken when mark-recapture monitoring occurs, to complement the abundance and survival estimates produced.

For a population to be sustainable in the long term, recruitment obviously needs to occur and, furthermore, needs to be at a sufficient rate to replenish losses to the population. Unfortunately, for *P. augusta*, and for most *Powelliphanta* snails, our knowledge of recruitment in the wild is extremely limited. Whilst this study found some limited evidence of recruitment, further research is required to better understand recruitment. Due to the logistical difficulties of obtaining such data, it may be that recruitment will simply need to be inferred (i.e. if older snails are dying, yet the population remains stable over the long term, it may be assumed that recruitment is occurring).

Whilst investigating recruitment, it was possible to observe the number of snails in different cohorts that had been tagged. It was found that approximately 86% of snails in the smallest cohort in the study had not been tagged. In contrast, of the snails in the largest cohort, approximately just 22% had not been tagged. This would appear to support the (intuitive) assumption that smaller snails may be more difficult to detect than larger snails and are therefore underestimated in a mark-recapture study. It is recommended that detection rates are investigated further, as this could be incorporated in to the mark-recapture analyses, allowing for more robust abundance estimates.

An initial model of population persistence (Efford, et al., 2009) predicted that the future for *P. augusta* was bleak, showing that none of the populations would persist in the long term. At the time, this was widely seen as evidence of failure of the translocation programme. However, the original results were limited by the data available at the time. Five years on, this model has been updated here with more accurate information, particularly relating to survival and age of maturity. Based on the data available now, the model suggests that all *P. augusta* populations appear to be able to persist at present, with the exception of Summit B and Basin B, which are unlikely to be suitable habitat. In fact, both the abundance estimates and the population persistence model suggest that the populations may be growing at some sites.

It is likely to take decades to determine whether the translocations of *P. augusta* has been a success and there remain a number of challenges ahead. To date, the conservation effort for *P. augusta* has largely been funded by Solid Energy New Zealand Limited, as a condition of the wildlife permit that allowed them to translocate the species. This funding has included annual monitoring, intensive ground-based pest control of exotic predators, weed control and captive management. This funding agreement comes to an end in 2016, when the project becomes the sole responsibility of the Department of Conservation. It is currently unclear what capacity the Department will have to fund conservation efforts for *P. augusta*. It is strongly recommended that funds be found to continue the work that has been undertaken to date, even if in a reduced capacity. Monitoring is recognised as a crucial aspect of good management (Walker, 2003) and, in this instance, it would be disappointing to see it cease or revert back to the standard technique, which has been shown to be unreliable. It is recommended that mark-recapture monitoring be undertaken with a frequency of 5 to 10 years which, given that the populations appear to be stable, should be sufficient to detect any downward trend. It would also be wise to undertake annual checks of the site to determine presence and identify any new risks. It is also recommended that the areas in which the populations occur are included in the aerial pest control operations, which occur periodically in the Buller region. If funds allow, it would also be wise to keep a small number of snails in the captive management programme, to further research the species and as a back-up population.

A study on the impact of climate change on giant land snails in South America has found that many species will be vulnerable due to small ranges and poor dispersal (Beltramino, Vogler, Gregoric, & Rumi, 2015). Most species of *Powelliphanta* would also fall in to this category. To date, climate change has not been seriously addressed as a risk for *Powelliphanta* in New Zealand. It is recommended that this oversight is rectified as a matter of urgency, as all other conservation efforts, such as habitat preservation and predator control, may prove to be futile in the face of accelerated climate change.

Mining and quarrying have been identified as a key risk for land snails in Europe, both through habitat loss and dust deposition (Cuttelod, Seddon, Neubert, & Commission, 2011; Moreira, Calado, & Dias, 2015). It will be of great interest and, possibly of international importance, if it can be shown that Mount Augustus has been rehabilitated, post-mining, to the extent that the snails that have since been released are able to survive and thrive. It is recommended that further research, including the monitoring of released snails, is undertaken at this site in particular, given the potential wider benefits to research on post-mining rehabilitation.

The translocation of *P. augusta* is a classic case of mitigation-driven translocation. It has been recognised that mitigation-driven, rather than conservation driven, translocations are becoming more common internationally (Germano et al., 2015). Unfortunately, *P. augusta* was used as an example, with the authors incorrectly stating that several of the translocated populations have already failed, citing non-peer reviewed journals (Germano, et al., 2015). However, a valid point is raised about the need for more transparency and better documentation of the outcomes. In part, this thesis seeks to address those concerns, aiming to document some of the keys learnings and to prevent valuable research disappearing in to the void of grey literature.

The final recommendation relates to the threat status of all *Powelliphanta* land snails. The current assessments of threat status for *Powelliphanta* snails are now out of date, having been assembled in 2005 (Hitchmough, Bull, & Cromarty, 2007). The threat status of other gastropods has since been reviewed, with the authors stating that *Powelliphanta* was specifically excluded as the genus was being reviewed and a revision was nearing completion (Mahlfeld, Brook, Roscoe, Hitchmough, & Stringer, 2012). Three years have since passed. In the absence of accurate and up to date assessments, it is very difficult for conservation managers to allocate funds and plan work. It is likely that the status of some species will change, some for the better and some for the worse. It is recommended that this information be made publically available at the earliest convenience.

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Appendices

Appendix A: 10m x 10m snail plot setup and search

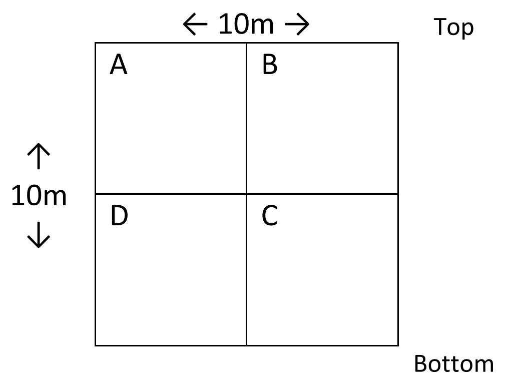
(Reproduced without edit from the Department of Conservation document 'Standard Plot Method - DOCDM-610358')

1. **Laying out the plot**

- Using a compass and tapes layout the plot. Orientate it so it runs parallel to the dominant slope. Care should be taken to make sure corners are at right angles and tape runs as straight as possible between corners. Try to get the tape as close to the ground as practical. Once the boundary of the plot is established use extra tapes or string lines to divide plot into four 5 x 5 metre quadrats.

- Permanently mark each corner of the plot using aluminium stakes. Label corners A, B, C, D clockwise from A always located at the top left corner (if looking from below).

- If woody vegetation is present nail permolat near to each corner with bearing and distance to corner to help with peg relocation.



2. **Plot recce vegetation description**

- Before a snail plot is searched for the first time a full recce vegetation description should be completed using the standard recce method.

3. **Search plot.**

- Four people are generally used to search a plot, though two people are adequate. It normally takes one and a half to two hours to search a 10 x 10 metre plot with four searchers depending on the habitat and the number of snails being found.

- Start by spreading four searchers across base of the first 5 x 5 metre quadrat (C or D). Each searcher has an area approximately 1.25 metres wide to search.

- Search systematically up the plot making sure no one gets to far behind or ahead as this could lead to areas being missed. Use sticks (or similar) to mark the edge of search areas between searchers and/or check verbally where others have been (e.g. "I've searched up to that log").

- Once at the top of the plot, return to the bottom ready for the next two quadrats by walking around the outside of the plot.

- When searching a 10 x 10 metre plot with two people only run two additional down tapes splitting each quadrat in half vertically creating four 2.5 metre strips to be searched. It is much easier for two searchers to keep track of where they have been in the narrower strips.

4. Measuring live snails, shells and fragments.

- For all snails and shells found record quadrat, species (if known), alive or dead, maximum diameter, estimated shell age, predation and any other comments on the datasheet provided. For fragments record number found in each quadrat.

- Collect all shells and fragments found and place in clearly labelled plastic zip lock bags with plot identifier and date. One bag per plot is normally sufficient though if lots of shells are being found bag shells by quadrat.

- At the edge of the plot, snails, shells or fragments are considered inside the plot as soon as part of them is under the tape. Shells that are just outside should be moved further away to avoid confusion at the next assessment.

- Minimise handling of any live snails found. Record maximum diameter and once measured return the snail to where it was found covering it with a layer of litter to reduce the chance of desiccation or predation (it is not uncommon to have weka on or around plots when searching). If necessary temporarily mark snail location while the plot is still being searched to minimise the chance of trampling.

5. Cleaning shells

- Any collected shells or fragments should be cleaned before they are sent to DOC for predation confirmation.

- Wash shells using warm water in a sink. To soften accumulated soil and litter in the shells it may be necessary to soak the shells briefly.

- Use a toothbrush or similar with water clean the outside of the shell, and use a wire hook to gently pull soil and litter from inside the shell. Be careful not to apply too much pressure to the shells during the cleaning process as some of the older shells can be very fragile.

- Wash each plot worth of shells separately and double check against data to make sure all shells are accounted for before starting with shells from another plot.

- Once clean, remove as much of the internal and external water by gently shaking the shells and wiping with a dry paper towel or cloth. The shells can then be laid out on a sheet of newspaper to dry. Take care not to dry shells in direct sunlight or near a heat source as the shells may start to disintegrate if they dry too quickly.

- Turn shells occasionally to make sure shells dry evenly and that water marks do not remain.

- Once shells are dry confirm predator ID and separate into individual bags for each plot for checking by DOC.

Appendix B: Estimating the proportion of snails not observed

Using GenStat, exponential curves were fitted to the cumulative results from each plot, in an attempt to estimate the asymptote (the point at which the curve flattens out, indicating that 100% of all snails present have been observed). The fitted curve type was y = A+BR^x, with 'A' representing the asymptote.

This exercise was not possible for plots with low (≤2) snails counts, so was undertaken for 10 of the plots. Nine of these plots had a good fit, with one having no fit. For the plots with low snail counts (and the one with no fit), it was assumed that 100% of all snails were found during the eight searches. All calculated estimates were rounded to the nearest whole number.

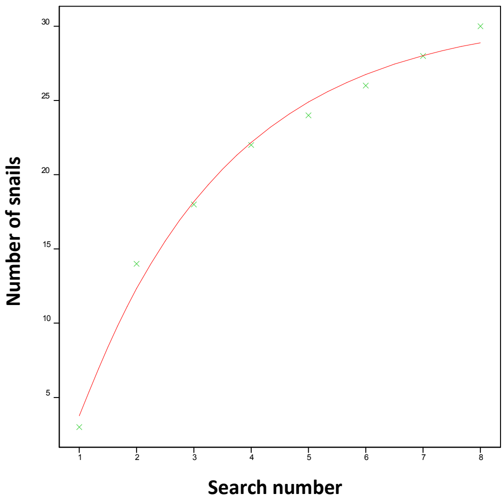
Results from fitting the exponential curves

	Plot Name													
Values	**PC01**	**PC02**	**PC03**	**PC04**	**PC05**	**PC06**	**PC07**	**PC08**	**PC09**	**PC10**	**PC11**	**PC12**	**PC13**	**PC14**
R^2	98.5	88.5	98.9	96.0	93.5	98.1	n/a	99.2	n/a	98.8	no fit	n/a	86.5	n/a
R	0.682	0.634	0.685	0.816	0.631	0.755	n/a	0.514	n/a	0.706	no fit	n/a	0.529	n/a
B	-39.53	-6.35	-23.44	-22.86	-10.15	-36.97	n/a	-15.61	n/a	-17.51	no fit	n/a	-5.39	n/a
A	30.74	8.96	24.06	25.05	12.49	40.86	n/a	15.05	n/a	13.43	no fit	n/a	4.00	n/a

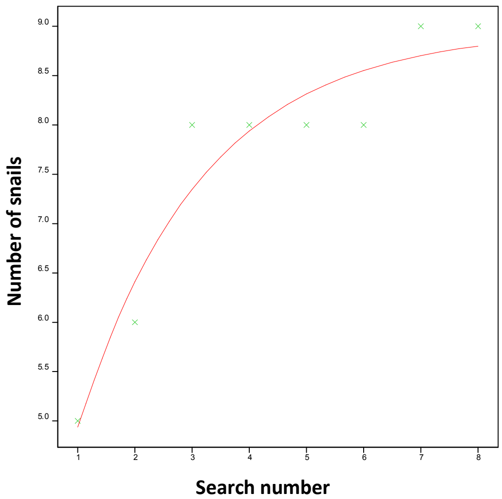
Fitted curve graphs

The following graphs were generated in GenStat and show the relationship between the observed results (green crosses) and fitted curve (red line). Search number is shown on the x axis and number of snails of the y axis.

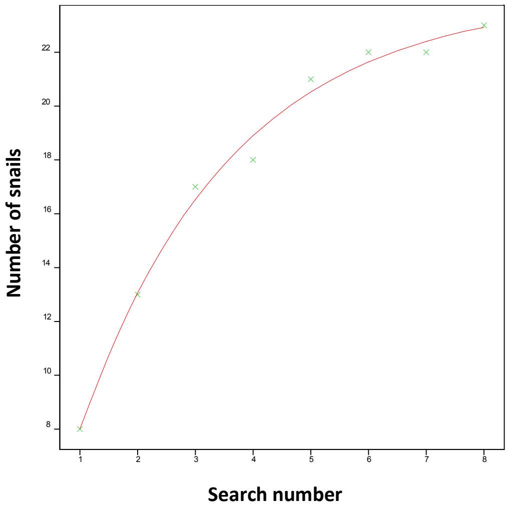
Fitted and observed relationship at plot PC01



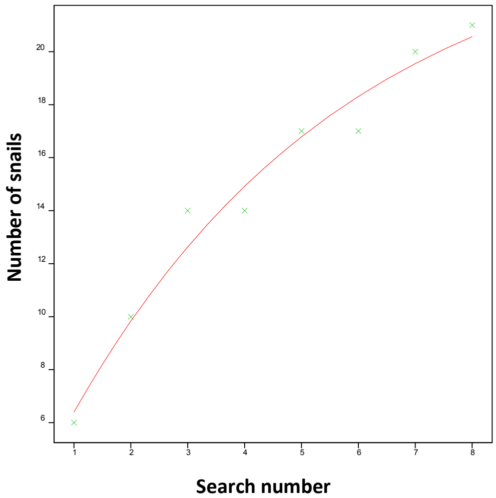
Fitted and observed relationship at plot PC02



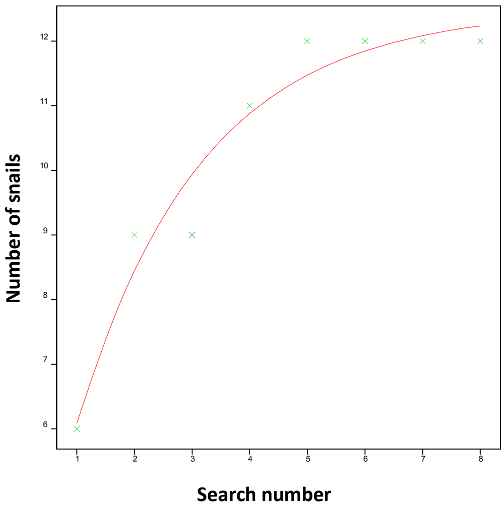
Fitted and observed relationship at plot PC03



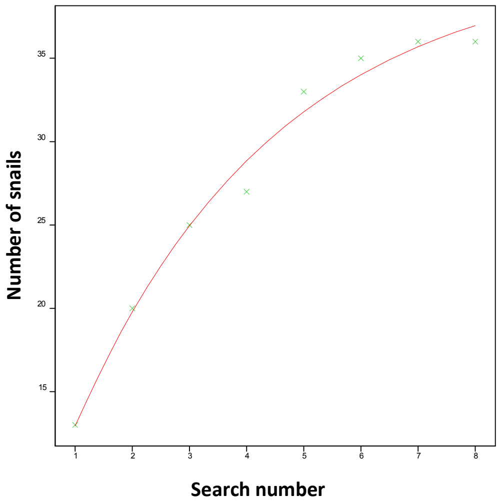
Fitted and observed relationship at plot PC04



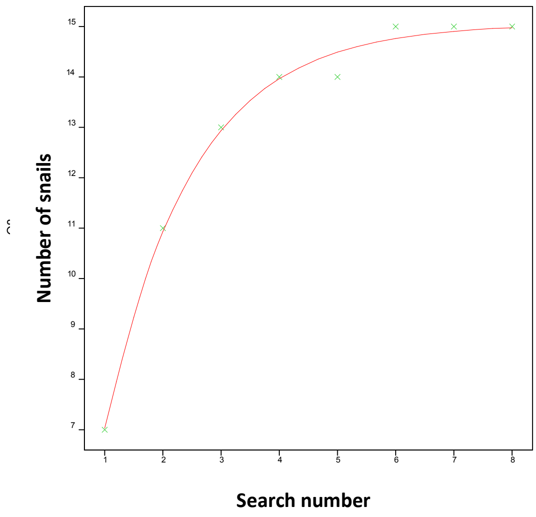
Fitted and observed relationship at plot PC05



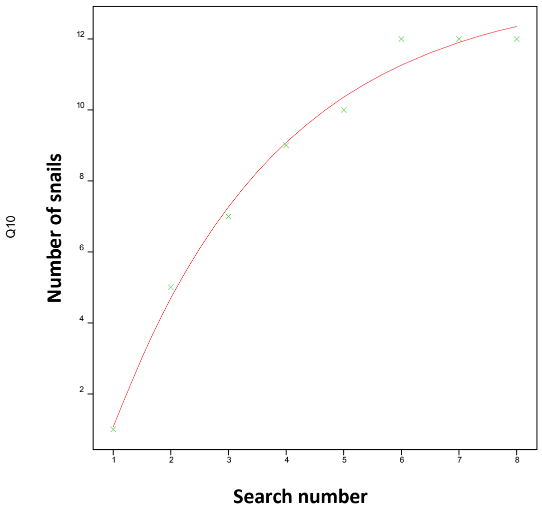
Fitted and observed relationship at plot PC06



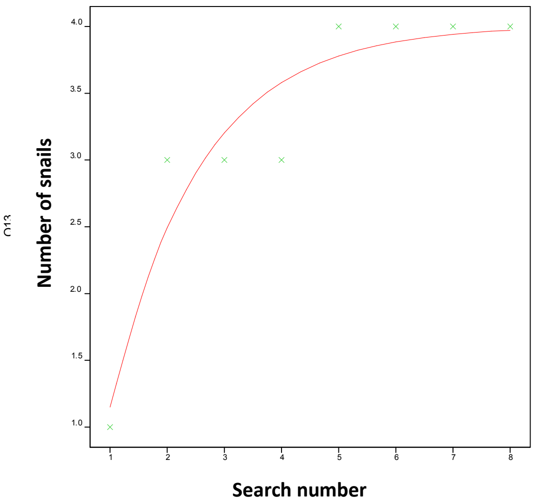
Fitted and observed relationship at plot PC08



Fitted and observed relationship at plot PC10



Fitted and observed relationship at plot PC13



Legend:
x observation
--- fitted curve

Comparison of actual snails observed with estimated snails present

	Plot Name													
Snails observed	**PC01**	**PC02**	**PC03**	**PC04**	**PC05**	**PC06**	**PC07**	**PC08**	**PC09**	**PC10**	**PC11**	**PC12**	**PC13**	**PC14**
Actual total (#)	30	9	23	21	12	36	2	15	1	12	10	1	4	n/a
Actual 1 search (#)	3	5	8	6	6	13	1	7	0	1	3	0	1	n/a
Actual 1st search (%)	10.0	55.6	34.8	28.6	50.0	36.1	50.0	46.7	0.0	8.3	30.0	0.0	25.0	n/a
Estimated total (#)	31	9	24	25	12	41	2	15	1	13	10	1	4	n/a
Estimate 1st search (%)	9.7	55.6	33.3	24.0	50.0	31.7	50.0	46.7	0.0	7.7	30.0	0.0	25.0	n/a
Estimate of total (%)	96.8	100.0	95.8	84.0	100.0	87.8	100.0	100.0	100.0	92.3	100.0	100.0	100.0	n/a

Appendix C: Habitat descriptions of the *Powelliphanta augusta* release areas

Habitat Type Categories

Mapped Habitat Type: "Forest"

General description: Mixed forest >2.5m canopy

This description was used for the forest habitat that was not beech dominant. It is a typically stunted sub-alpine forest, often being only around three to five metres high. In some areas a large proportion of the canopy was either pink pine (*Halocarpus biforme*) or southern rata (*Metrosideros umbellata*), however it is generally a very diverse species mix in both the canopy and sub-canopy. Many areas around the Mt Rochfort Basin were noticeably pink pine dominant, while at most other sites this species rarely dominated the canopy, but was a common feature in the diverse mix. Other common canopy species include mountain toatoa (*Phyllocladdus alpina*), yellow-silver pine (*Lepidothamnus intermedius*), *Pseudopanax linearis* and *Dracophyllum longifolium.* Manuka (*Leptospermum scoparium*) and mountain beech (*Nothofagus solandrii var. ciffortioides*) are also common in this forest type. *Pittosporum rigidum, Archeria traversii, Gahnia procera, and* weeping matipo *(Myrsine divaricata)* usually feature in the sub-canopy, as do haumakaroa (*Raukaua simplex), Cyathodes juniperina* and various *coprosma* species. Many small groundcover herbs, grasses and ferns were noted and most plots in this habitat type contained Lanternberry (*Luzuriaga parviflora*) and the ferns *Hymenophyllum multifidum* and *Grammitis billardierei.* Undergrowth is generally very dense, contributing to a high overall vegetation cover, and groundcover is mostly litter or moss.

Photo: Mixed forest

Mapped Habitat Type: "Forest"

General Description: Beech dominant forest >2m canopy

Like the mixed forest, this is mostly a stunted (less than seven metres high) sub-alpine forest with one exception, an area to the north of the Mt Rochfort Basin which was tall (over ten metre high canopy) forest. Mountain beech (*Nothofagus solandrii var. cliffortioides*) was usually the dominant species, however silver beech (*Nothofagus menziesii*) was often present and was dominant in small patches. Here and there other species such as pink pine and Southern rata were present in the canopy, but this beech habitat proved to be generally much less diverse than the mixed forest, not only in the canopy but also in the subcanopy/undergrowth.

Photo: Beech dominant forest

Mapped Habitat Type: “Manuka scrub”

General Description: Manuka dominant scrub 0.5-2.5m canopy

Despite the canopy height of this type description being so variable, the ground cover plant species and canopy density remained very similar throughout, and so this was all included in one habitat type. Wire rush (*Empodisma minus*) was often present beneath, and sometimes this was quite dense. Sun orchids *(Thelymitra sp.)* are often present. Other patches of lower canopy manuka were included into other habitat types; often the prostrate manuka was mixed with a lot of wire rush, *Dracophyllum* and small herbs, so was included in the ‘wire rush/bog herbfield’ habitat. Where the manuka was sparse, with little or no soil and litter beneath, it was included in the “rocky” category.

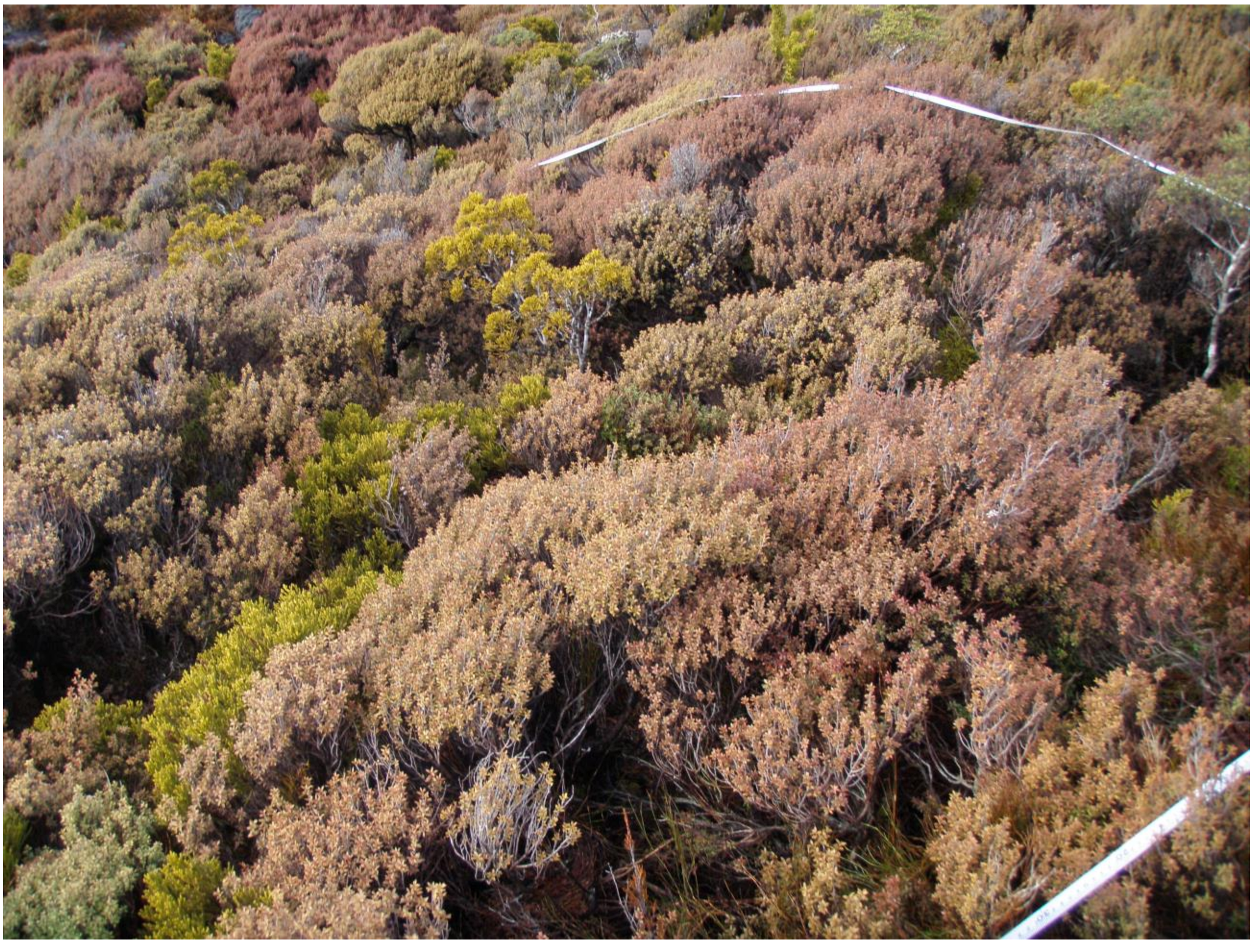


Photo: Manuka dominant scrub

Mapped Habitat Type: "Mixed Scrub"

General Description: Mixed scrub 0.5-2.5m canopy

This was a slightly variable habitat type, however it almost always contained a rich mix of almost every plant species found in the area, and the vegetation is dense. Often this habitat appeared to be a succession following on from flax dominant or flax/grass mix habitats and still contained a reasonable amount of mountain flax *(Phormium cookianum)* and snow tussock (*Chionochloa flavescens)*. Inanga (*Dracophyllum longifolium*) is a common and occasionally dominant feature in this mix, with pink pine, weeping matipo, *Pseudopanax linearis, Coprosma spp.,* and *Olearia colensoi* also common. Forest species such as southern rata, kamahi (*Weinmannia racemosa*) and mountain beech are also present in this mix as seedlings and stunted saplings.

Photo: Mixed scrub in the Mt Rochfort basin

Photo: Mixed scrub typical at Extended Site B

Mapped Habitat Type "Mixed Scrub"

General description: *Olearia colensoi* dominant scrub 0.5-2m canopy

This shrub species is often referred to as leatherwood or muttonbird scrub. Where it dominates, this species provides a dense canopy cover and litter which appears sometimes to suppress growth of other shrub species somewhat, however grasses such as *Schoenus pauciflorus* and *Chionochloa flavescens* are often present beneath, as well as *Cyathodes juniperina* and *Forstera mackayii*. Often this scrub forms small isolated patches between mixed scrub and forest habitat.

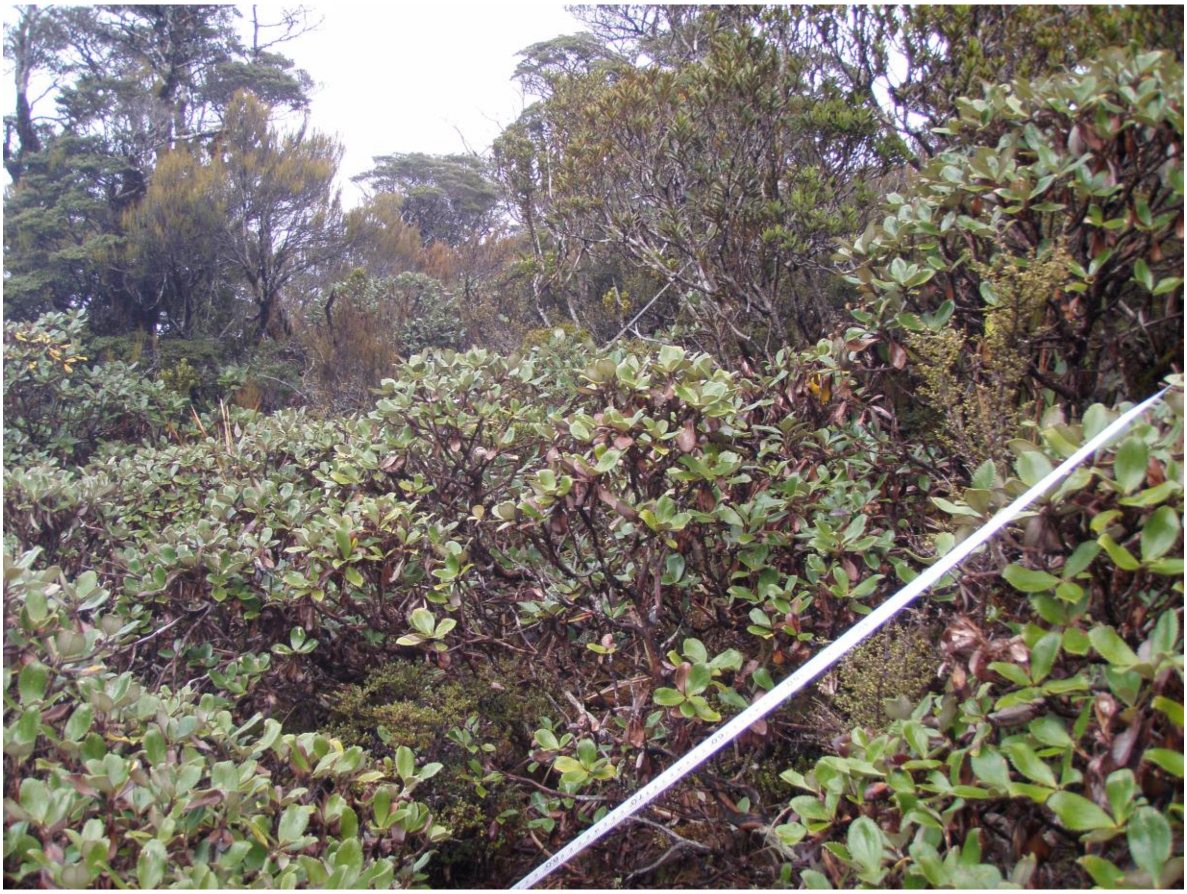


Photo: *Olearia colensoi* dominant scrub

Mapped Habitat Type: "Grass/Flax"

General Description: Flax dominant

As expected, mountain flax is the dominant species in this habitat, and in some places it appears to be an early stage in a succession of regrowth following historic fires in the area (some tree stumps remain, with occasional charcoal remnants). Some grasses, particularly *Chionochloa flavascens*, grow amongst the flax here and there, as well as some shrub species that may eventually succeed the flax. Manuka, leatherwood and inanga were the most common of these shrubs. A large variety of small herbs and ferns were often found sheltering beneath the flax canopy. Litter is typically inconsistent, with deep patches of dead matted flax leaves interspersed with bare ground.

Plots were unable to be surveyed in many areas of almost 100 percent flax, particularly at the Mt Rochfort summit site, as in most places this habitat was seen on ledges amongst vertical rock faces. Other areas that superficially appear to be "flax dominant habitat" are little more than scattered flax bushes growing from cracks in the rock pavement, and such areas were included in the "rocky" category.

Photo: Flax dominant

Mapped Habitat Type: “Grass/Flax”

General description: Flax/gahnia/Chionochloa grasses mixed

Many areas were noticed to be a near 50/50 mix of flax and grasses/sedges and could not be separated into one category or the other. Dominant species in this mix were usually mountain flax, *Chionochloa flavascens* and *Gahnia spp.*, and sometimes red tussock (*Chionochloa rubra*). Canopy height was usually 0.9m to 1.5m, the standard height of most of these tussockland species. The habitat was often a lot more diverse than just this however, with *Astelia nervosa* common. Woody species such as yellow-silver pine, manuka, pink pine, inanga and *Pseudopanax linearis* often make up around 10 to 20 percent of the canopy and sometimes emerge above the flax and grass. These will eventually succeed the grasses, sedges and flax. Wire rush often made up 2 to 5 percent of subcanopy cover, along with a variety of small herbs and ferns. Ground cover was usually found to be very dense and the litter deep.

Photo: Flax/grass mix

Mapped Habitat Type: "Grass/Flax"

General Description: Grass dominant

In some of these areas snow tussock *Chionochloa flavascens* was the noticeably dominant species, while in others (generally flatter and poorly drained zones) *Chionochloa rubra* was more dominant. Coal measure tussock *C. juncea* was dominant in other areas that were a little rockier and often included a significant amount of manuka. Other grasses such as *Schoenus pauciflorus* and *Carpha alpina* are often common in the lower tier in this type, as well as wire rush. Mountain flax and occasional shrubs, such as manuka and southern rata are also a feature. Various other small shrubs, herbs and ferns were found, however this habitat type generally contained far less plant species per 5x5 metre plot than the flax dominant and flax/grass mix habitat types.

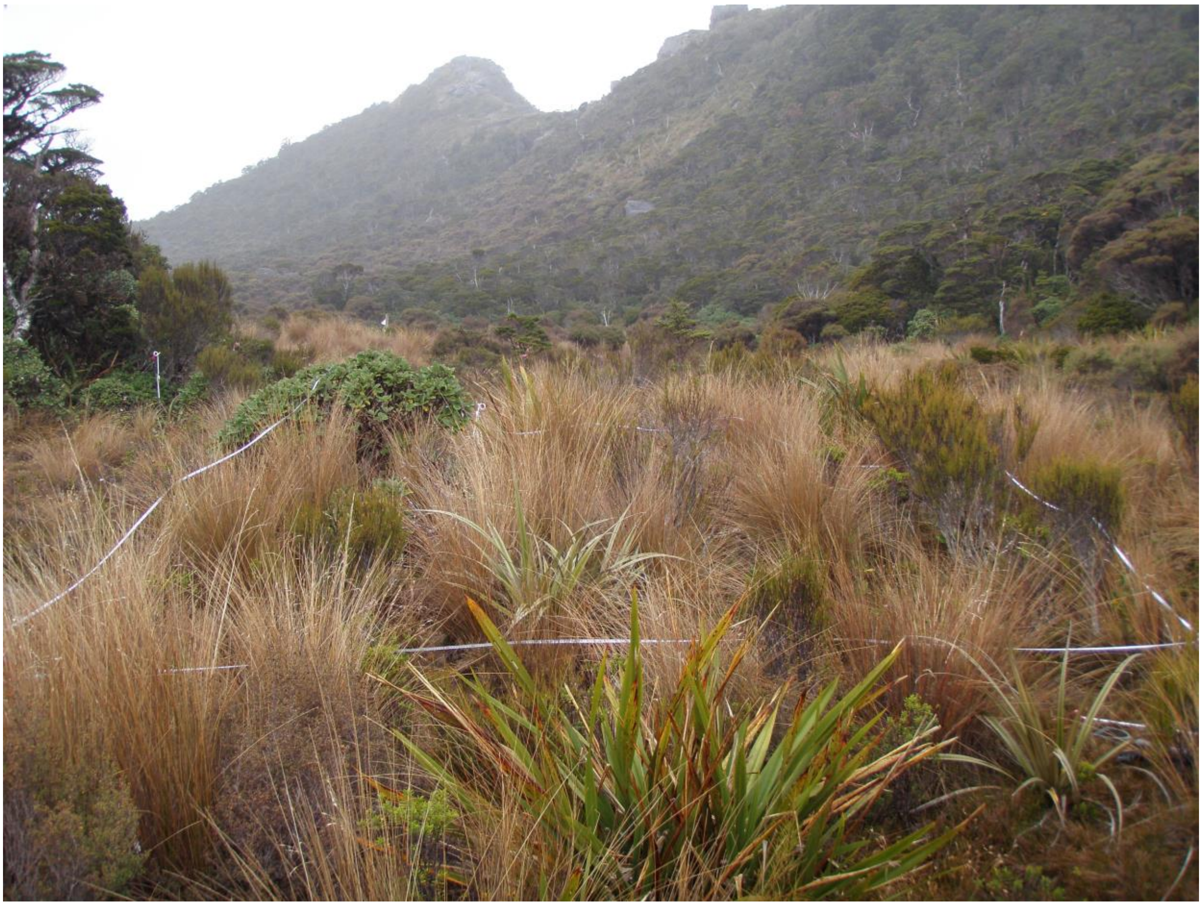


Photo: Grass dominant

Mapped Habitat Type: "Prostrate Scrub"

General Description: Prostrate or low podocarp dominant scrub

These areas were dominated by pink pine *(Halocarpus biforme)*, yellow-silver pine (*Lepidothamnus intermedius)* or pygmy pine (*L. laxifolius dominant)* or sometimes hybrids of these three species. It often contained little else other than occasional scattered tufts of *gahnia sp*. and some wire rush as groundcover. This scrub was either prostrate or erect and up to around 70cm high, too low and homogenous to include in the "mixed scrub" category.

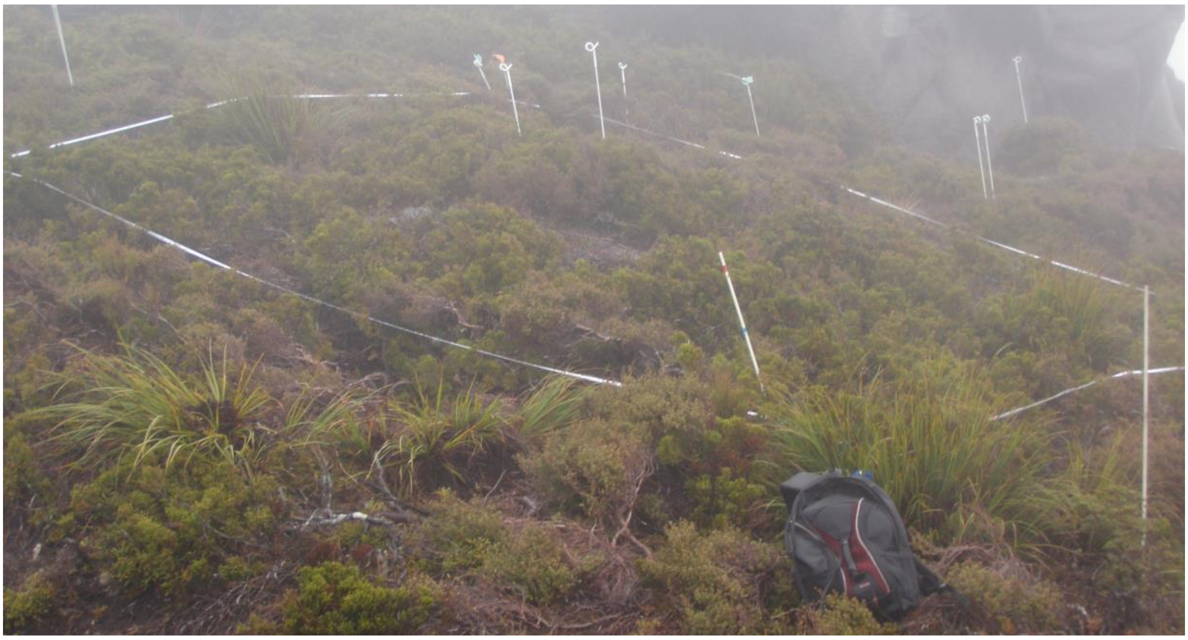


Photo: Prostrate or low podocarp dominant scrub

Mapped Habitat Type: "Bog/Herbfield"

General Description: Wire rush/bog herbfield

This habitat type was more or less poorly drained and featured wire rush as a dominant species in the lower tier. Canopy top height rarely reached above this under 30cm tier and rarely more than 60cm. Manuka is often the dominant woody species here and was usually in prostrate form. Some areas contained scattered shrubs, as well as flax and grasses reaching above 50cm. *Dracophyllum uniflorum* and *D. rosmarinifolium* grow stunted and prostrate, interwoven with wire rush. Tangle fern is present in most areas, and is occasionally dominant. The many small flowering herbs are also a feature of this habitat type. *Celmisia dubia,* sundew (*Drosera spathulata*)*,* little mountain heath and (*Pentachondra pumila*) are common here, as are bog cushion plants such as *Donatia novae-zelandiae*.

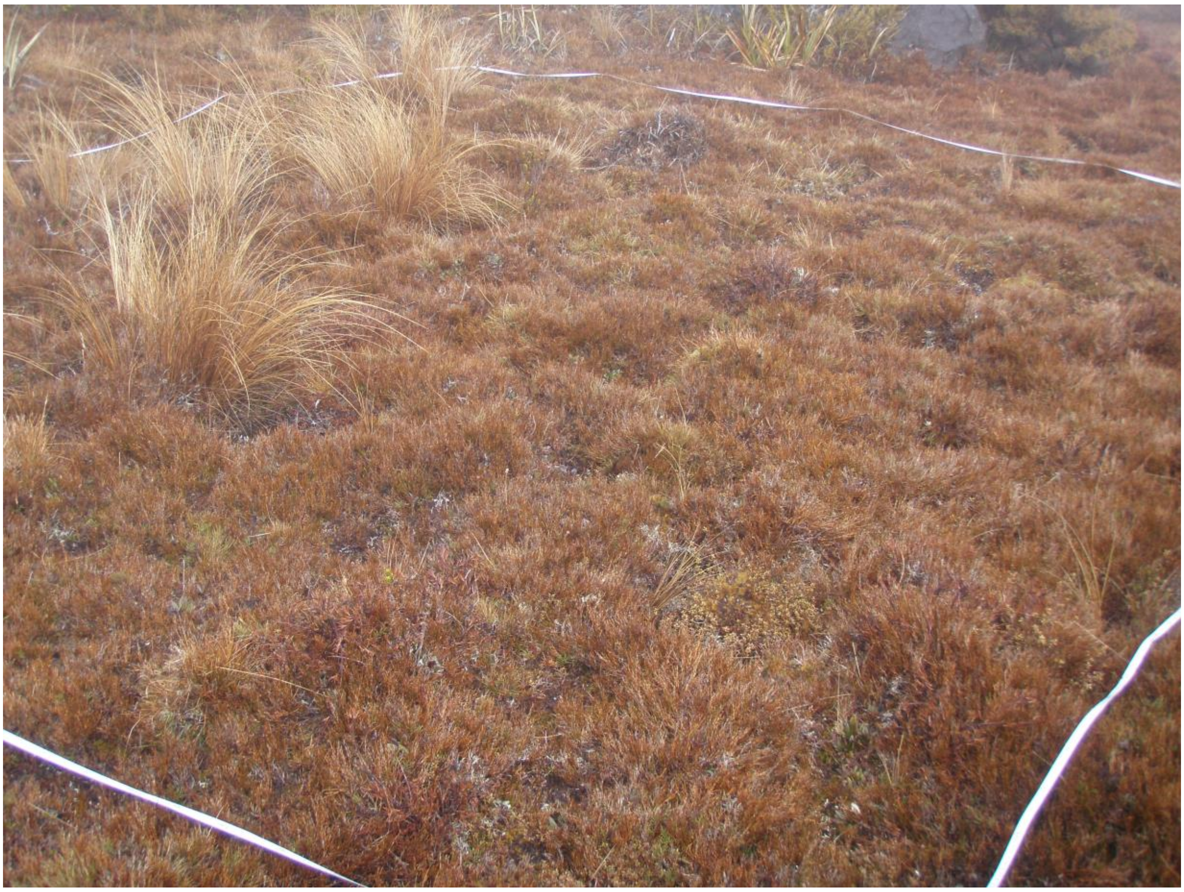


Photo: Wire rush/bog herbfield

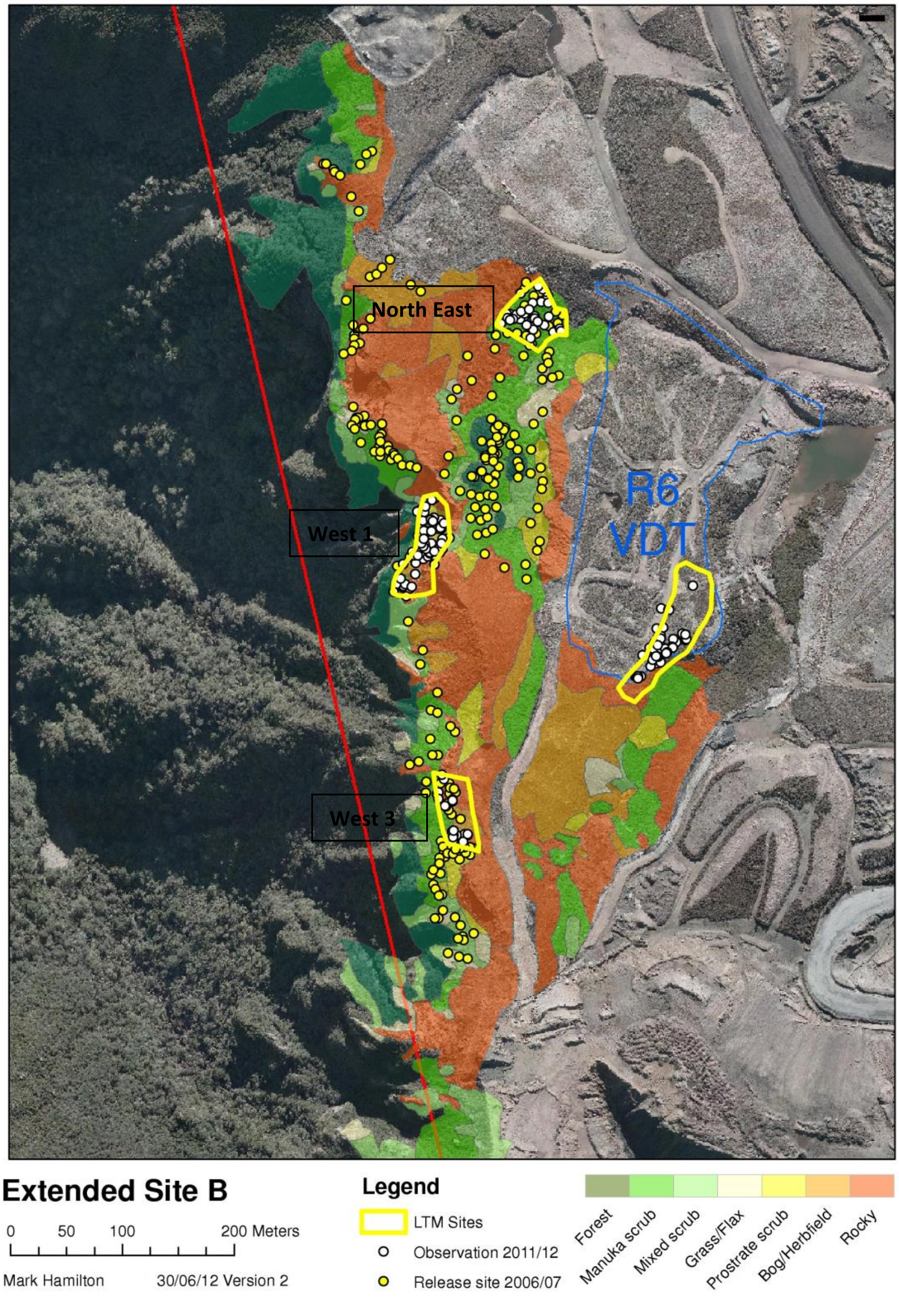
Mapped Habitat Type: "Rocky"

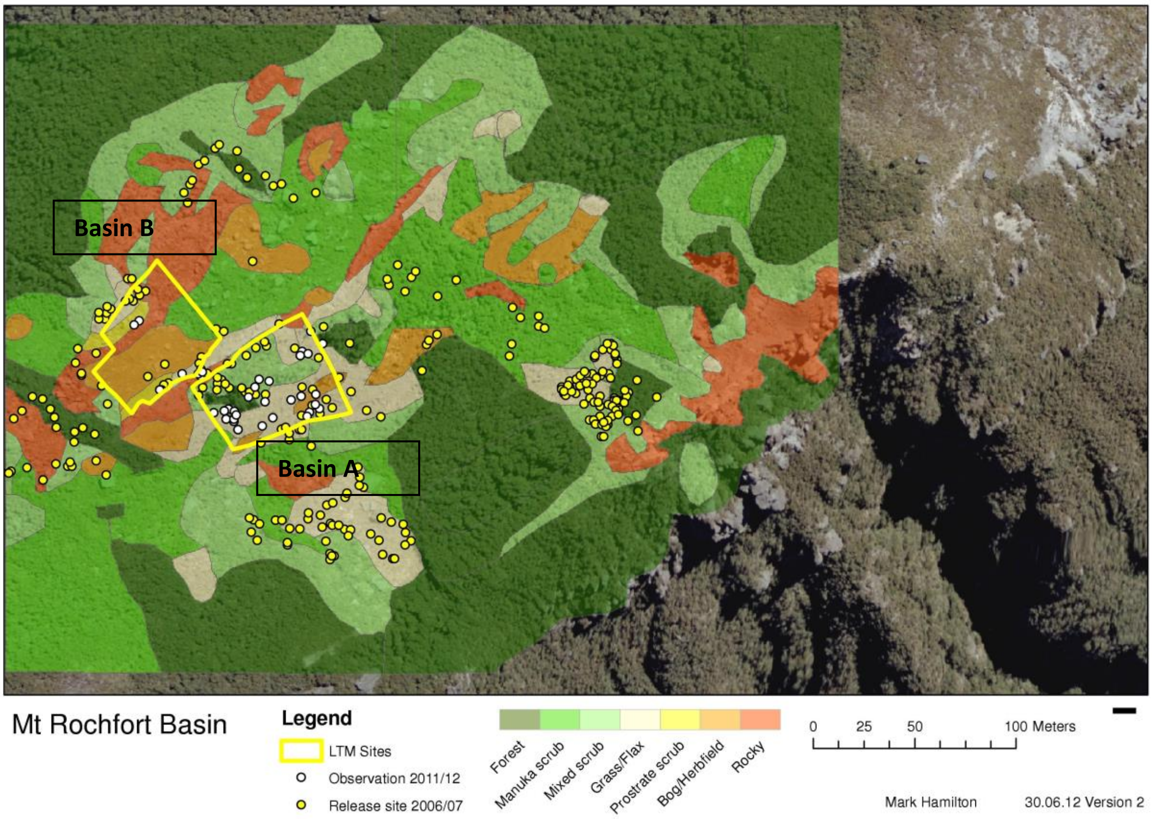
General Description: Rocky

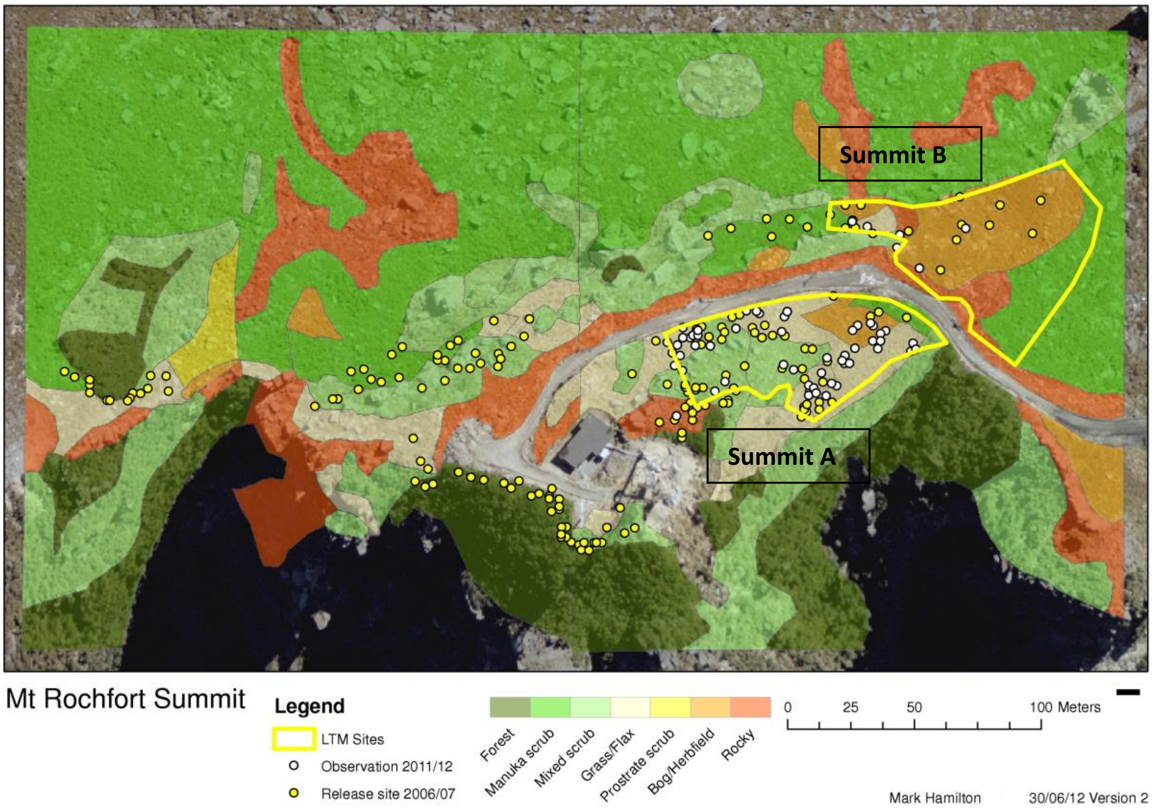
This habitat included pavement rock, silty and eroded areas and boulder fields with patchy habitat, scattered herbs or scrub, grass, prostrate herbs or wire rush. Canopy height and species mix were variable, but most areas with less than 40 percent soil and vegetation cover were included in this category.

Photo: Rocky habitat

Habitat Maps




Basin B
Basin A
Mt Rochfort Basin
Legend
LTM Sites
Observation 2011/12
Release site 2006/07
Forest
Manuka scrub
Mixed scrub
Grass/Flax
Prostrate scrub
Bog/Herbfield
Rocky
0 25 50 100 Meters
Mark Hamilton
30.06.12 Version 2


Summit B
Summit A
Mt Rochfort Summit
Legend
LTM Sites
Observation 2011/12
Release site 2006/07
Forest
Manuka scrub
Mixed scrub
Grass/Flax
Prostrate scrub
Bog/Herbfield
Rocky
0 25 50 100 Meters
Mark Hamilton
30/06/12 Version 2

Appendix D: Mark-recapture monitoring details

Table 1 lists each of the *Powelliphanta augusta* long term monitoring blocks, including an approximate GPS location. Table 2 is a detailed list of the dates that monitoring was undertaken.

Table 1: *Powelliphanta augusta* long term monitoring block details

Monitoring Block Name	Location	Type	Habitat Quality	Size (hectares)	Location Easting (NZMG)	Location Northing (NZMG)
Site A Upper	Mt. Augustus	Natural Habitat	High/Moderate	0.38	2414634	5947964
Site A Lower	Mt. Augustus	Natural Habitat	Low/Moderate	0.32	2414509	5947769
West 1	Extended Site B	Translocation (manual)	High	0.25	2414608	5948614
North East	Extended Site B	Translocation (manual)	Moderate	0.23	2414688	5948821
West3	Extended Site B	Translocation (manual)	Low	0.19	2414632	5948369
R6 VDT	Extended Site B	Translocation (VDT)	VDT	0.38	2414804	5948530
Basin A	Mt. Rochfort	Translocation (manual)	Low/Moderate	0.29	2404575	5935552
Basin B	Mt. Rochfort	Translocation (manual)	Low	0.25	2404539	5935535
Summit A	Mt. Rochfort	Translocation (manual)	High/Moderate	0.33	2405366	5935767
Summit B	Mt. Rochfort	Translocation (manual)	Low	0.41	2405451	5935785

Table 2: Detailed list of the dates that monitoring was undertaken at each block

Site A Upper	Site A Lower	West 1	North East	West 3	R6 VDT	Basin A	Basin B	Summit A	Summit B
16/04/2009	29/01/2011	03/02/2009	05/03/2010	10/12/2009	16/01/2011	20/03/2010	20/03/2010	13/01/2010	11/12/2009
17/04/2009	26/03/2011	04/02/2009	16/03/2010	19/12/2009	07/02/2011	01/03/2011	01/03/2011	14/01/2010	30/12/2009
18/04/2009	04/04/2011	05/02/2009	23/03/2010	11/01/2010	21/02/2011	17/03/2011	17/03/2011	17/01/2010	24/01/2010
05/02/2011	05/12/2011	20/02/2009	30/03/2010	20/01/2010	22/02/2011	27/03/2011	27/03/2011	24/02/2010	25/02/2010
15/03/2011	12/12/2011	21/02/2009	13/04/2010	21/01/2010	03/04/2011	31/01/2012	31/01/2012	01/03/2010	03/03/2010
16/03/2011	19/12/2011	23/02/2009	16/01/2011	17/02/2010	05/12/2011	02/02/2012	02/02/2012	10/03/2010	17/01/2011
15/04/2011	06/01/2012	18/03/2009	07/02/2011	03/02/2011	13/12/2011	10/02/2012	09/02/2012	29/03/2010	01/03/2011
03/12/2011	12/01/2012	01/12/2009	21/02/2011	22/02/2011	19/12/2011	15/02/2012	10/02/2012	17/01/2011	17/03/2011
06/12/2011	19/03/2013	07/01/2010	25/02/2011	16/03/2011	06/01/2012	21/02/2012	22/02/2012	01/03/2011	28/01/2012
15/12/2011	31/03/2013	18/02/2010	03/04/2011	25/03/2011	12/01/2012			17/03/2011	01/02/2012
29/12/2011	18/04/2013	14/03/2010	16/04/2011	26/03/2011	19/03/2013			27/03/2011	04/02/2012
10/01/2012	22/04/2013	21/03/2010	28/01/2012	28/01/2012	31/03/2013			28//02/2012	13/02/2012
17/03/2013	17/05/2013	03/02/2011	01/02/2012	31/01/2012	03/04/2013			01/02/2012	14/02/2012
25/03/2013		22/02/2011	09/02/2012	09/02/2012	05/04/2013			04/02/2012	
17/04/2013		16/03/2011	15/02/2012	15/02/2012	16/04/2013			09/02/2012	
28/04/2013		25/03/2011	22/02/2012	23/02/2012	19/04/2013			14/02/2012	
03/05/2013		26/03/2011	03/04/2013	16/01/2013	21/04/2013				
		16/04/2011	16/04/2013	04/02/2013	02/05/2013				
		31/01/2012	19/04/2013	18/03/2013					
		02/02/2012	22/04/2013	11/04/2013					
		14/02/2012	05/05/2013	21/04/2013					
		21/02/2012	20/05/2013	20/05/2013					
		23/02/2012							
		16/01/2013							
		04/02/2013							
		18/03/2013							
		03/04/2013							
		11/04/2013							
		18/04/2013							
		05/05/2013							
		17/05/2013							

Appendix E: *Powelliphanta augusta* mark-recapture monitoring protocol

Protocol for Mark-Recapture Monitoring of *Powelliphanta augusta*

Version 3 – November 2011

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Introduction

At a meeting of the *P. augusta* Technical Advisory Group (TAG) in March 2007, mark-recapture techniques and site occupancy modelling were identified as potentially useful tools to monitor *P. augusta* populations. John McLennan (Environmental Services Ltd) and Ian Stringer (Department of Conservation), as members of the TAG, took on the task of exploring these options. In collaboration with Daryl MacKenzie (Proteus Consulting) a trial protocol was developed (MacKenzie, 2007) to test the suitability of these methods for *P. augusta*. The following protocol has been developed based on this draft methodology that was trialled (and altered) in two successive pilot studies in May and December 2007 and during the first monitoring attempts undertaken in February – April 2009 (Gruner et al. 2007, Sharpe 2008, Mackenzie 2009). Methods and results of the pilot studies and initial monitoring were subsequently reviewed by Darryl and further recommendations made (MacKenzie 2008, 2009, 2010, 2011).

The methodology is intended for the long-term monitoring of *P. augusta* populations in the wild with the overall objective of assessing whether the populations are self-sustaining. Securing at least one self-sustaining population in the wild is the long-term species recovery goal for *P. augusta*.

More specifically, the objectives of the long-term monitoring are to:

1. Provide annual survival estimates within the monitored areas to be used in population modelling [1]
2. Provide estimates of population size within the monitored areas
3. Detect trends in population size over time

Solid Energy New Zealand (SENZ) are required by Wildlife Permit 11/633, 12 April 2006, to fund the costs of monitoring of snail populations for a period of no less than 10 years (Clause 50). Transponder monitoring started with the first translocation of snails in December 2006. This means that SENZ are obliged to fund the monitoring programme at

[1] In the short to medium term, mark-recapture monitoring, as outlined here, can only provide abundance and survival estimates relating to adult and sub-adult snails. Other techniques may be required for monitoring juveniles, hatchings and egg production. Over time, it is possible that recruitment can be inferred through increases in the number of sub-adults.

least until December 2016. After this, monitoring may become the responsibility of the West Coast *Tai Poutini* Conservancy/Buller *Kawatiri* Area Office.

Robust Design

The monitoring programme uses the principles of the robust design for mark-recapture studies (Lettink & Armstrong 2003). This design consists of a primary interval for monitoring, e.g. annual surveys, and a secondary interval within this, e.g. several weekly surveys within each year. The primary interval allows for an open population with births, deaths, immigration and emigration, while the secondary interval assumes closure. Results from the secondary interval give estimates of population size for every year surveys are done, while the primary interval allows estimation of survival rates, recruitment and population growth rate over time.

Ultimately, estimates of population growth rates are needed to establish whether the monitored populations are self-sustaining. However, these estimates can only be expected after 3-5 primary monitoring intervals, i.e. after 3-5 years if monitoring occurs annually. In the interim, estimates of population size will be useful to gauge persistence and the likely success of the programme.

Details of the monitoring programme for *P. augusta* using the robust design are presented below.

Study Sites

P. augusta currently occur at five more or less isolated locations in the wild:

- Site A, a remnant of original habitat at the western edge of the original range
- Extended Site B, a translocation site several hundred metres to the north of the original habitat
- Mt Rochfort Summit, a translocation site at the southern end of the Buller coal plateau
- Mt Rochfort Basin, a translocation site at the southern end of the Buller coal plateau and to the west of Mt Rochfort Summit

See appendix 1 for maps of these sites. Further sites may be added to this list in future, if additional translocation sites are used.[2] Each translocation site is in itself not homogeneous, but consists of more or less isolated pockets of habitat of varying habitat quality. Consequently, at least two different pockets representing different levels of habitat quality have been selected at each release site. Each of the monitored areas will be approximately 0.3 ha but will vary in size and shape due to the nature of the terrain.

Monitoring of all release areas will be annual, which would provide first adult survival estimates in 2011/12 and first estimates of population growth rates in 2013/14 (Table 1). Each year of monitoring provides an estimate of current population size.

[2] These include a rehabilitated Mt. Augustus, where the snails were collected from, and an area of potential snail habitat between the 'Rockies' and 'Millerton areas.

Table 1. Primary monitoring periods in *P. augusta* monitoring programme.

Spring / Summer	Roch Summit Upper	Roch Summit Lower	Roch Basin Upper	Roch Basin Lower	Site B North East	Site B West 3 Sth	Site B West 1	R6 VDT	Site A Upper	Site A Lower
Quality	High /Mod	Low	Mod	Low	Mod	Low	High	n/a	High	Low /Mod
2008/09	X	X	X	X	X	X	√	X	√	X
2009/10	√	√	√	√	√	√	√	X	X	X
2010/11	√	√	√	√	√	√	√	√	√	√
2011/12	√	√	√	√	√	√	√	√	√	√
2012/13	TBC	TBC	√	√	√	√	√	√	√	√
2013/14	TBC	TBC	√	√	√	√	√	√	√	√
2014/15	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC
2015/16	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC
2016/17	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC

Snail Surveys

Each year a site is monitored, a minimum of five surveys in late spring/summer (i.e. November to March) are undertaken to mark and recapture snails. Up to seven surveys may be required, depending on the results and the desired level of certainty. Surveys must occur at least two days apart[3] to ensure independence between them, and be no more than two weeks apart to minimise any immigration, emigration and mortality during the monitoring period. Surveys are undertaken at night, when conditions are favourable for snail movement; ideally that is comparatively mild temperatures of at least 8°C with fog or drizzle/rain. Each survey consists of one search per night[4]. Each search covers a clearly delineated monitoring area at the site. Pig tailed standards, red plastic chain and ear tags (with reflective tape on them) have been used to mark out the sites. The monitoring areas need to be carefully selected to be representative of the overall habitat (i.e. contain areas considered low, moderate and high quality at each site) and permanently marked, so that the same area will be monitored in successive years.

Searches cover the entire monitoring area in a strip search. This is best done by a team of at least four people working side by side, each team member covering no more than a 2m wide strip. The outermost searcher marks the edge of the search strip with a measuring tape, to ensure the next search strip is laid out adjoining the previous one. Habitat damage should be kept to a minimum. On a slope, searching is best done walking uphill. When the

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[3] This requirement is currently being reviewed. The previous requirement was one week between searches. From Nov. 2011, the requirement is for two days to elapse between searches. However, this may be reduced to one day, if evidence suggests the length of interval doesn't impact upon availability of snails for recapture.

[4] Amendment made January 2011: A meeting between Ingrid Gruner and Rodney Phillips (DOC) and Mark Hamilton (MBC) in December 2010 there was agreement to switch from two searches per night at each monitoring site to one search per night for the 2011 and possibly future surveys. Each search will be slightly more intensive than previously and sites may require additional search nights (to be confirmed). This will be offset by being able to search two sites per night and will minimise the chance of damage to habitat and snails through trampling, increase the number of snail encounters (majority of snails were found on first sweep in 2010 surveys) and decrease overall effort.

top is reached the team walks single file back down to spread out along the start of the next search strip. It is important to keep search effort consistent between searches. Each team member is equipped with two torches: one headlight and one handheld torch.

Walkthrough surveys adjacent to long-term monitoring sites[5]

Night surveys outside long-term monitoring sites will be undertaken during the 2011/2012 season. The main purpose of this activity will be to gauge the amount of migration occurring with marked snails outside long-term monitoring sites. It will also provide an opportunity to discover the fate of snails that have gone 'missing'. Furthermore, it will provide a better understanding of habitat use and dispersal. This is particularly important in translocation sites where habitat quality is highly variable. The data will not be used to derive abundance or survival estimates.

Diurnal Plot surveys[6]

Two permanent 10x10m snail monitoring plots will be established at each monitoring site. This will allow for the monitoring of smaller snails (i.e. maximum diameter <20mm) and may even provide evidence of egg production. There will also be the opportunity to calibrate this standard monitoring method with the mark-recapture method being trialled here. Finally, this will also provide baseline monitoring data, using standards techniques, should the West Coast *Tai Poutini* Conservancy/Buller *Kawatiri* Area Office opt to use the plot methodology in future years.

When snails are found

When a snail (marked or unmarked) is found, it is transferred to a plastic container, partly filled with damp moss or litter, with a perforated lid. The Task Leader will provide a GPS location to the finder, who will complete a snail record card to put in the container with the snail. This card records finder, GPS location, habitat and micro-habitat information. The snail is then taken to the snail-marking station processed. The site where the snail was found should be marked with red flashing LED lights. The lights and container are both labelled with the same number to ensure that the snail is later released back to where it was found. In areas of tall canopy, or dense vegetation, pig tailed standards are also used, with the LED lights attached to the top. A separate person in the team should be responsible for marking of capture locations, labelling of containers and transport to and from the snail-marking-station (this person is known as the 'runner').

Care has to be taken that the search team stays in line while snails are captured or measured.

Marking of snails

An extra person in the search team is tasked with the marking of snails and completing the relevant paperwork. This occurs at the snail-marking-station, a shelter or tent near the search area. All snails are marked with polyethylene tags imprinted with sequential numbers

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[5] Amendment June 2011.

[6] Amendment November 2011.

and used for tagging shellfish (Hallprint Pty Ltd, www.hallprint.com)[7]. Snails are wiped dry with a paper towel, a small area on the underside of the shell near the aperture is roughened with fine sandpaper, and the tag is glued with superglue to this spot. Snails are kept on a damp paper towel for a few minutes until the superglue is touch dry. Snails are then measured (maximum diameter) and weighed. A photograph will also be taken of each snail encountered.[8] Snails are then transferred back to their container and taken back to the location where they were found.

The polyethylene tags are still in the trial phase, but success with waterproof paper tags to date suggests that this is likely to be a suitable method to individually mark the snails long-term (see also Henry & Jarne 2007). Should the polyethylene tags fail, batch marks in the form of different coloured paint dots will need to be used (a different colour for each search night). Henry & Jarne (2007) recommend car-body paint in felt-tipped pens for this purpose. Alternatively, small waterproof paper tags affixed with superglue may be used.

Snail size and tag placement[9]

Snails with a maximum diameter smaller than 20mm shall not be tagged. Snails with a maximum diameter between 20mm and <25mm shall be tagged with transparent tags on the dorsal surface of the shell near the apex. Snails with a maximum diameter of 25mm or larger shall be tagged with a coloured tag on the ventral side. Tags on the ventral side shall be attached immediately behind the aperture to prevent the shell from overgrowing the tag. Once transparent tags have been found to work well and tag loss rates are known, coloured tags may no longer be used.

Data Collection

Data to be recorded during each search are:

- the time period and the total person-time spent searching the monitoring area;
- temperature, relative humidity and wind speed at beginning and end of search;
- for each snail, tag number, shell size and weight
- for each snail, description of any damage, habitat & micro-habitat details[8]

Standard snail search forms will be used to collect this information (see appendix 2).[8]

Tag Loss Rate

An estimate of tag loss rate is essential to attain reliable estimates for population parameters from the monitoring. To achieve this, a study has been set up at 'West 1' in Extended Site B. All snails found during monitoring at this site in 2008/09 were double tagged. Any subsequent tag loss will be recorded during subsequent years. If tag loss is found to be significant, other tagging techniques will be considered.

[7] 8mm x 4mm, terracotta brown tags
[8] Amendment November 2011
[9] Amendment January 2011

Limitations
The methodology for mark-recapture monitoring of *P. augusta* described above, targets mainly the adult to sub-adult cohorts in the population. Snails with a diameter below approximately 20 mm are rarely detected, as detection probability decreases with size. This means that the results apply only to the larger snails, and recruitment in the population can only be detected by smaller snails reaching sub-adult size.

Strictly speaking, the results also apply only to the monitoring area searched. To be representative of the overall site, this area needs to be carefully selected, and in the case of Extended Site B, several monitoring areas with different habitat characteristics (high, medium, low) will need to be monitored.

Gear List
As a guide, the following will be required as a minimum at each site:

- pig tailed standards, chain, eartags & relective tape to permanently mark the monitoring area (only once)
- torches, two per team member, batteries and chargers
- watch
- 2 x 50m measuring tape to mark edge of each search strip, temporary
- c. 20 plastic containers for snail transport
- c. 20 pegs, flashing LED lights, marker pen to mark snail capture locations
- shelter/tent for snail-marking station
- set of callipers and scales
- waterproof camera
- paper towels, sandpaper (waterproof, P 400), superglue (non-drip gel), tags, tweezers, spray bottle (use filtered or rain water), and datasheets
- thermometer, hygrometer, anemometer

Data Analysis
Data will be analysed annually by Darryl MacKenzie at Proteus Consulting using the software "MARK", with reporting in May/June.

Field work
All field work will be carried out by a team of snail searchers from MBC Contracting Limited, Westport.

References

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Lettink, M.; Armstrong, D.P. 2003. An introduction to using mark-recapture analysis for monitoring threatened species. – Department of Conservation Technical Series 28A, Department of Conservation, Wellington.

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MacKenzie, D.I. 2011. Report on Monitoring Trials for *Powelliphanta augusta.* Abundance and survival estimation of *Powelliphanta augusta* and *Powelliphanta patrickensis* (2010/2011). Unpublished report prepared for Solid Energy New Zealand.

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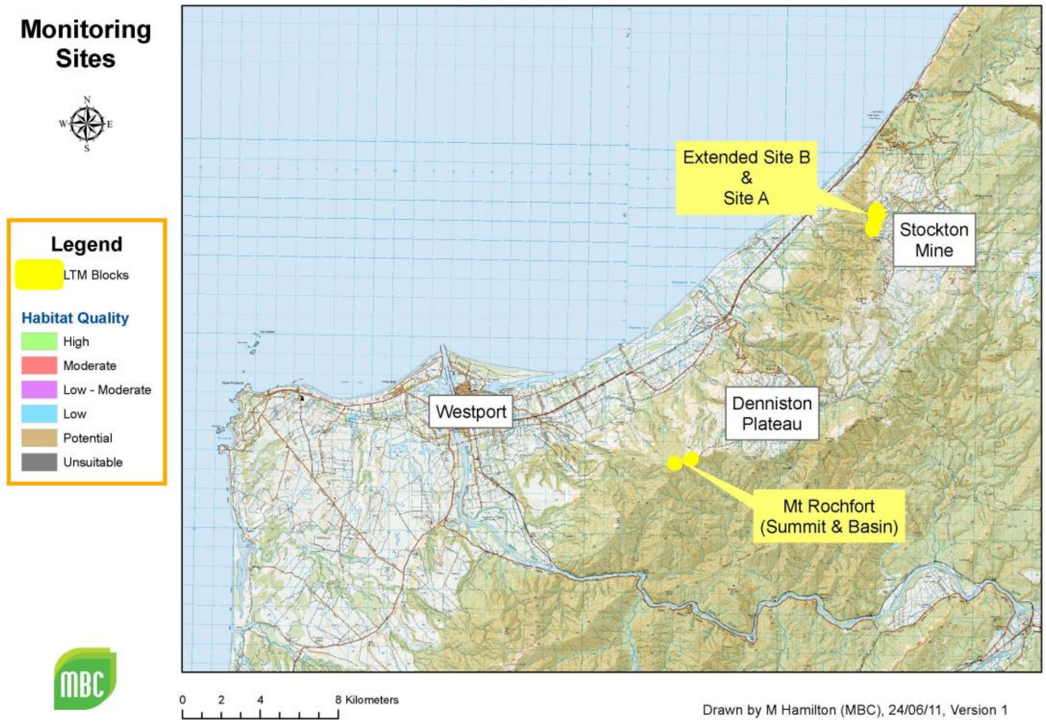
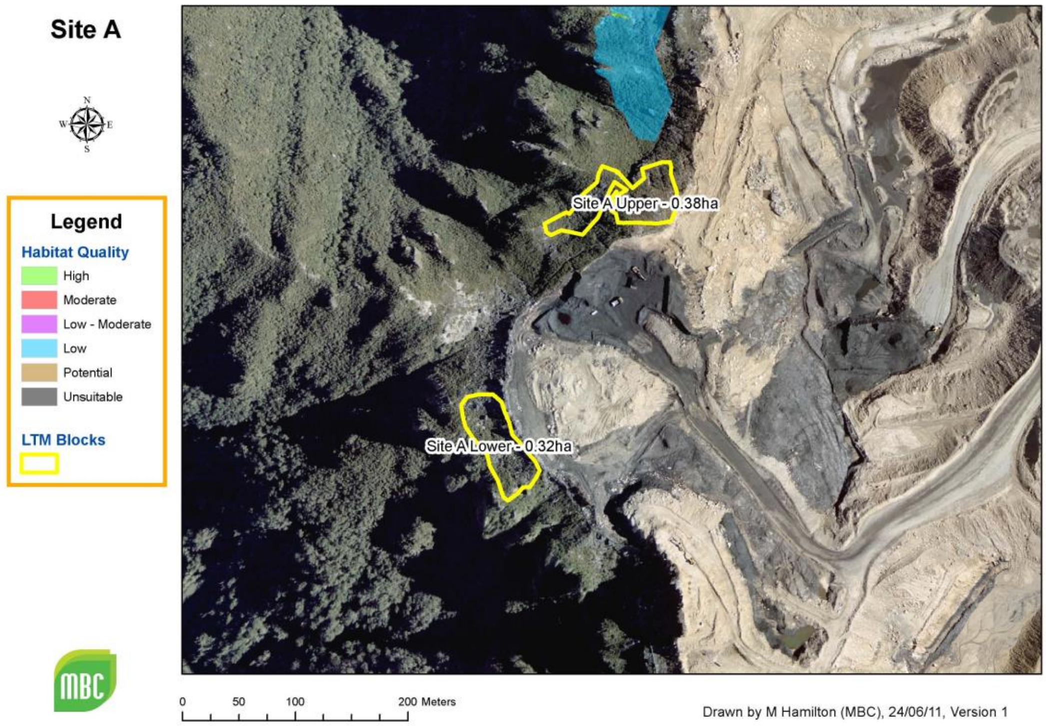
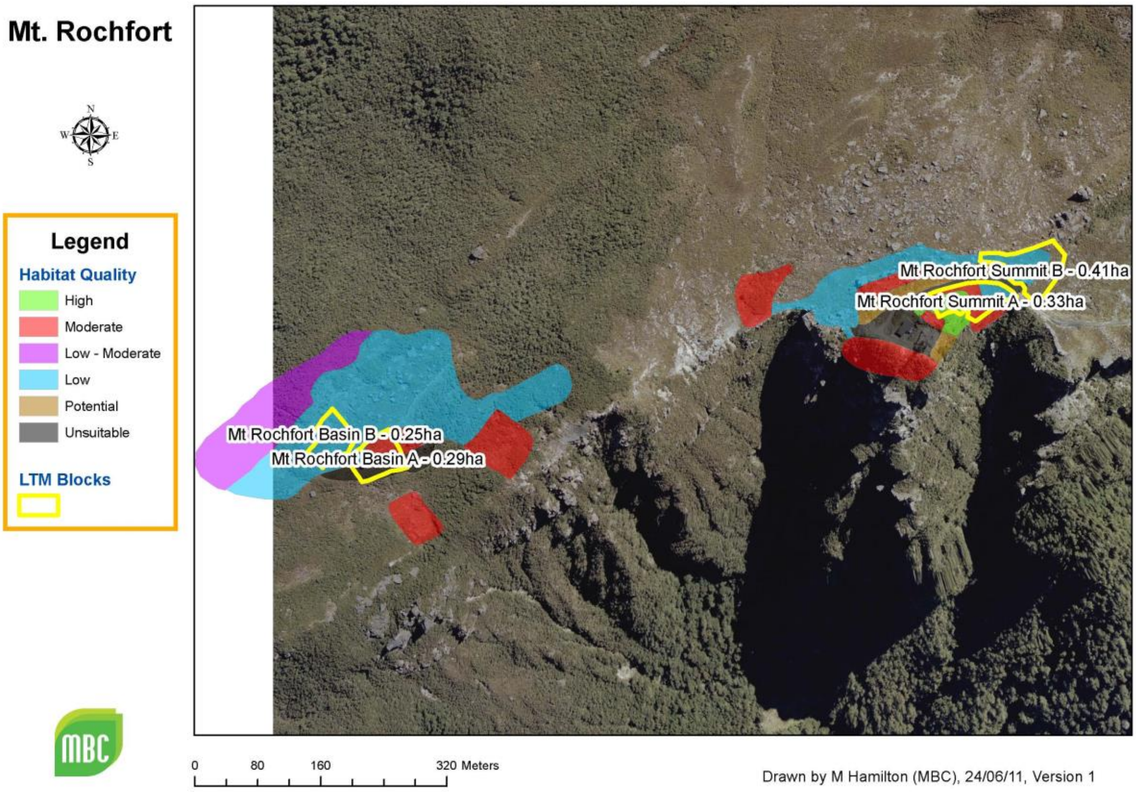
Appendices

Appendix 1 – Maps of monitoring locations

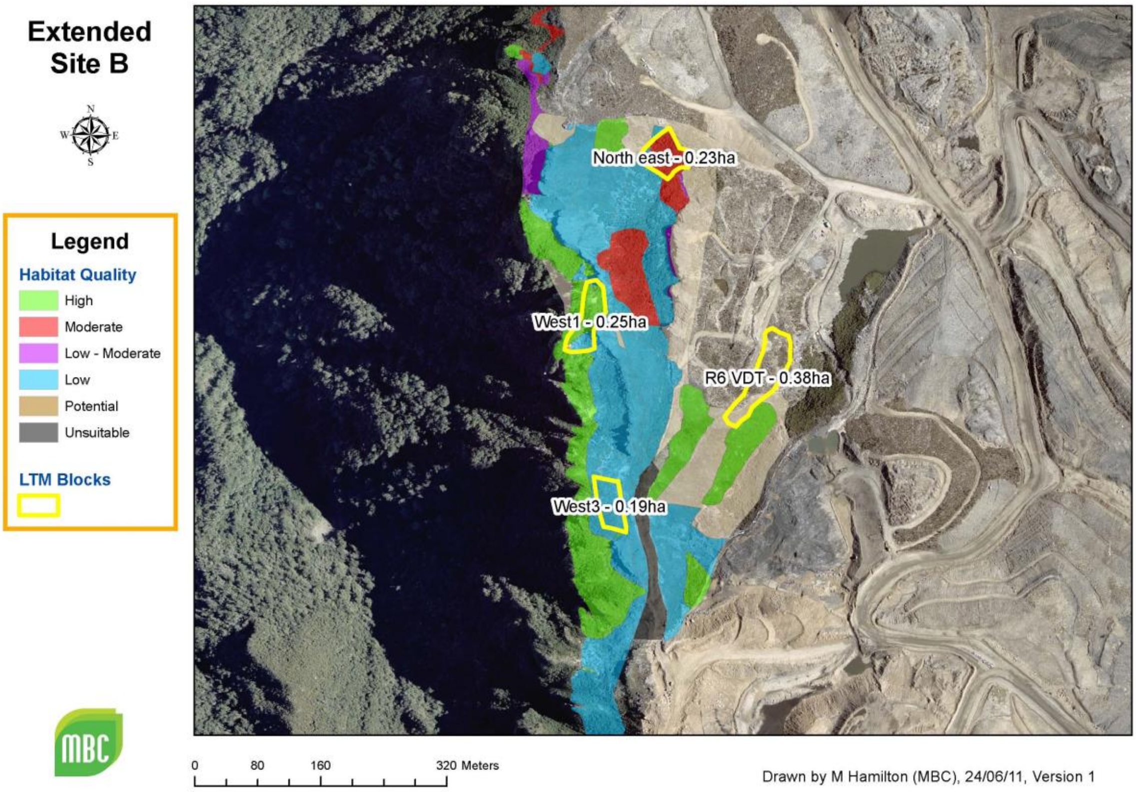




Mt. Rochfort



Extended Site B



Appendix 2 – Snail search forms

LTM - DAILY SEARCH REPORT

circle type of search **Nocturnal** **Diurnal**

This form is to be completed for all snails found whilst undertaking mark-recapture monitoring
A separate form must be completed for each search
The snail numbering will use the LTM tag #

Date (dd/mm/yy) and time

Date	**Time started**	**Time finished**

Comments (notes on any breaks and estimated time actively searching)

LTM Block searched:

Weather conditions

At start		**At Noon**		**At End**	
Humidity Wind (km/hr) Wind direction Rain DegC		Humidity Wind (km/hr) Wind direction Rain DegC		Humidity Wind (km/hr) Wind direction Rain DegC	

Searchers (names of people searching)

Task Leader:	Field staff:	Field staff:
Runner:	Field staff:	Field staff:
Paperwork:	Field staff:	Field staff:
	Field staff:	Field staff:

Snails Found (refer to snail form for details of snails)

Newly marked snail #	Comments	Recaptured snail #	Comments

LTM - Live Snail Record

This form is to be completed for all snails found whilst undertaking mark-recapture monitoring

All snails are to be placed in a plastic container.

The snail numbering will use the LTM tag #

Finder Name:			**Observer Signature:**			
Snail ID:			**Date:**		**Time:**	
LTM PLot:			**Was snail active?**		**Yes** **No**	
Newly tagged?	**Yes**	**No**	**White tag # (if any)?**			
Search of Area:	**1 2 3 4 5 6 7 8 10**					
Methodology:	**Plot**	**Nocturnal**		**Photo number:**		
Comments on snail condition / damage (circle appropriate description):	**No damage**	**Slight damage** (One or two small dents)	**Moderate damage** (Multiple dents / chips)	**Severe damage** (Multiple larger dents / chips / holes)	**Fatal damage** (Damage so extensive, snail most likely will not survive)	**Description of damage**

GPS Location: **N**

E

SNAIL MEASUREMENTS

Shell diameter:

Shell weight:

COMMENTS ON VEGETATION

Vegetation type/description

Micro habitat (e.g. Litter, moss, under fern etc)

Other notes:

LTM - Daily Shell Summary Record

Special notes:	
This form is to be completed for all snail shells found Each group of shells shall be placed in a plastic bag. One bag per search block per day. The bag shall be clearly marked with the total number of shells, search method, and the search block number. The snail shell numbering is as follows: SH## for a snail shell (eg 12Mar11-SH09) or LTM tag #.	
Date dd/mm/yy	
LTM block	Survey methodology
SNAIL SHELL NUMBERS	

LTM SNAIL CARD

Snail ID (if any): **LTM Block:**

Time Found:

GPS N **Finder:**
E

Search Type: DPI or Nocturnal

Snail Active: Yes or No

Canopy Height:

Microhabitat:

Appendix F: Model of population persistence

Reproduced from the original (Efford, Lloyd, & Gruner, 2009), without modification.

MODEL OF POPULATION PERSISTENCE

Figure 14 illustrates a demographic model for *Powelliphanta*. It makes several simplifying assumptions, particularly that snails in a cohort mature synchronously at age M (measured from the year eggs were laid), and that mortality and fecundity are constant with age among adults.

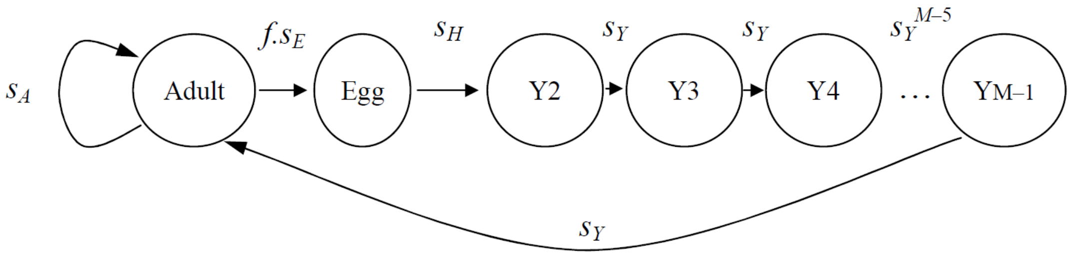


Figure 14: Annual model of snail life history. Adults survive at rate s_A and produce *f* eggs per year. These survive at rate s_E and in the following year hatch and survive at rate s_H. The resulting annual cohorts of immature snails Y_2, Y_3, ..., Y_{M-1} survive at rate s_Y and grow until they reach maturity at M years after laying.

We lack data to distinguish the survival rates of eggs, young and adults, and other parameters are known only approximately. There seems little risk here in treating all the survival rates as the same ($s_E = s_H = s_Y = s_A = s$). [If, as seems possible, the survival rate of immature stages is less than adult survival then a higher adult survival rate would be needed for population persistence].

Long-term persistence of a population requires that recruitment at least balances population losses due to mortality. We can specify the conditions under which annual recruitment to the 'Adult' class exactly balances mortality ($1 - s$):

$$1 - s = fs^M .$$

We solve this equation for given M and f to find the threshold of survival rate that leads to population persistence. The solution is the positive root of the equation:

$$fs^M + s - 1 = 0 .$$

This is achieved in R with the functions:

```
fn <- function (s, M, fec) fec * s^M + s - 1
surv <- function (M, fec) uniroot(fn, interval=c(0,1), fec=fec, M=M)$root
```

A call to 'surv' returns the threshold value of survival for the given values of M and fec. For example:

```
> surv(M = 25, fec = 2.0)
[1] 0.8903404
```

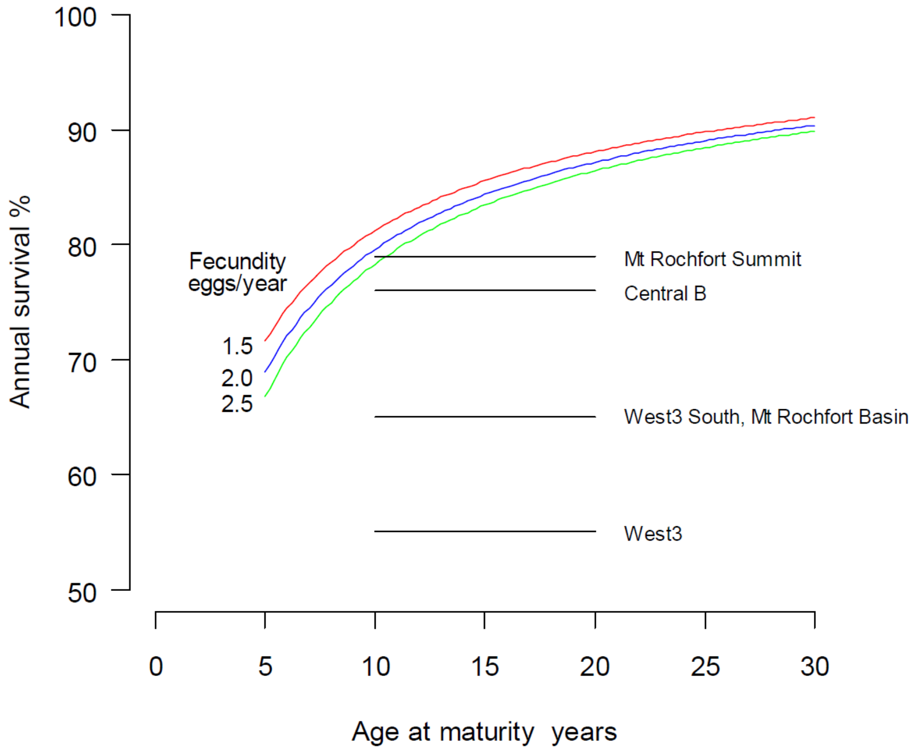


Figure 15: Threshold of annual survival needed for long-term population persistence as a function of age at maturity for three levels of fecundity (eggs laid per year). Estimated annual survival of translocated snails is shown for the five study sites as horizontal lines spanning a plausible range of ages at maturity.

Table 8: Threshold of annual survival (%) needed for long-term population persistence as a function of age at maturity and fecundity.

		Fecundity (Eggs per Year)						
		0.5	1.0	1.5	2.0	2.5	3.0	3.5
Age at maturity (years)	2	73.2	61.8	54.9	50.0	46.3	43.4	41.0
	4	79.8	72.4	68.0	64.8	62.3	60.3	58.6
	6	83.3	77.8	74.5	72.0	70.2	68.6	67.3
	8	85.6	81.2	78.5	76.5	75.0	73.7	72.7
	10	87.2	83.5	81.2	79.6	78.3	77.3	76.4
	12	88.5	85.3	83.3	81.9	80.8	79.8	79.1
	14	89.5	86.6	84.9	83.6	82.6	81.8	81.2
	16	90.3	87.7	86.2	85.0	84.2	83.4	82.8
	18	90.9	88.6	87.2	86.2	85.4	84.7	84.2
	20	91.5	89.4	88.1	87.2	86.4	85.8	85.3
	22	92.0	90.0	88.9	88.0	87.3	86.8	86.3
	24	92.4	90.6	89.5	88.7	88.1	87.6	87.1
	26	92.8	91.1	90.1	89.3	88.8	88.3	87.9
	28	93.1	91.6	90.6	89.9	89.3	88.9	88.5
	30	93.5	91.9	91.0	90.4	89.9	89.4	89.1

R code to generate table (uses 'surv' above)

```
## make table of required annual survival %
## for range of age at maturity (M) and annual fecundity (fec)

s.table <- function (M, fec) {
  temp <- expand.grid(M=M, fec=fec)
  temp2 <- t(apply(temp,1, function(x) surv(x[1], x[2])))
  temp3 <- matrix (round(100*temp2,1), nr=length(M))
  dimnames(temp3) <- list(M,fec)
  temp3
}
s.table(M=seq(2,30,2), fec=seq(0.5,3.5,0.5))
```

Appendix G: Shell growth over a season

Snail	Location	Monitoring Block	Site Type	Cohort	Season 2012 size (mm)	Season 2013 size (mm)	Growth (mm)
1	Extended Site B	West 1	Translocation	1	21.2	24.4	3.2
2	Extended Site B	North East	Translocation	1	22.0	28.6	6.6
3	Extended Site B	West 1	Translocation	1	22.0	27.2	5.2
4	Extended Site B	West 1	Translocation	1	22.1	29.4	7.3
5	Extended Site B	West 1	Translocation	1	22.3	28.9	6.6
6	Extended Site B	West 3	Translocation	1	22.3	27.8	5.5
7	Mt Augustus	Site A Lower	Natural	1	22.7	27.4	4.7
8	Extended Site B	West 1	Translocation	1	23.0	27.2	4.2
9	Mt Augustus	Site A Upper	Natural	1	23.0	24.7	1.7
10	Extended Site B	R6 VDT	VDT	1	23.2	30.4	7.2
11	Extended Site B	North East	Translocation	1	23.7	30.8	7.1
12	Extended Site B	West 1	Translocation	1	24.0	29.6	5.6
13	Mt Augustus	Site A Lower	Natural	1	24.1	30.7	6.6
14	Extended Site B	R6 VDT	VDT	1	24.5	32.9	8.4
15	Mt Augustus	Site A Upper	Natural	1	24.5	26.3	1.8
16	Mt Augustus	Site A Upper	Natural	2	25.1	28.4	3.3
17	Mt Augustus	Site A Upper	Natural	2	25.1	32.3	7.2
18	Extended Site B	R6 VDT	VDT	2	25.4	32.6	7.2
19	Extended Site B	West 1	Translocation	2	25.4	27.8	2.4
20	Extended Site B	West 3	Translocation	2	25.5	30.6	5.1
21	Extended Site B	West 3	Translocation	2	25.9	30.1	4.2
22	Extended Site B	West 3	Translocation	2	26.1	30.9	4.8
23	Mt Augustus	Site A Upper	Natural	2	26.1	29.0	2.9
24	Mt Augustus	Site A Upper	Natural	2	26.3	29.8	3.5
25	Mt Augustus	Site A Upper	Natural	2	26.3	30.0	3.7
26	Mt Augustus	Site A Lower	Natural	2	26.4	28.3	1.9
27	Mt Augustus	Site A Upper	Natural	2	26.4	29.1	2.7
28	Mt Augustus	Site A Upper	Natural	2	26.4	33.3	6.9
29	Extended Site B	R6 VDT	VDT	2	26.7	32.2	5.5
30	Mt Augustus	Site A Upper	Natural	2	27.0	31.1	4.1
31	Mt Augustus	Site A Upper	Natural	2	27.0	31.0	4.0
32	Mt Augustus	Site A Lower	Natural	2	27.1	28.9	1.8
33	Mt Augustus	Site A Upper	Natural	2	27.3	29.3	2.0
34	Extended Site B	West 1	Translocation	2	27.4	33.7	6.3
35	Mt Augustus	Site A Upper	Natural	2	27.5	31.4	3.9
36	Extended Site B	North East	Translocation	2	27.7	30.9	3.2
37	Mt Augustus	Site A Lower	Natural	2	27.7	29.7	2.0
38	Mt Augustus	Site A Upper	Natural	2	27.7	32.1	4.4
39	Mt Augustus	Site A Upper	Natural	2	27.7	30.2	2.5
40	Mt Augustus	Site A Upper	Natural	2	27.9	32.1	4.2
41	Mt Augustus	Site A Upper	Natural	2	28.0	29.4	1.4
42	Mt Augustus	Site A Upper	Natural	2	28.0	32.6	4.6
43	Mt Augustus	Site A Lower	Natural	2	28.1	29.9	1.8
44	Extended Site B	West 3	Translocation	2	28.2	32.2	4.0
45	Mt Augustus	Site A Upper	Natural	2	28.2	32.2	4.0
46	Extended Site B	R6 VDT	VDT	2	28.6	33.2	4.6
47	Extended Site B	West 1	Translocation	2	28.6	30.2	1.6
48	Extended Site B	West 1	Translocation	2	28.6	30.4	1.8
49	Mt Augustus	Site A Upper	Natural	2	29.0	30.3	1.3
50	Mt Augustus	Site A Upper	Natural	2	29.2	31.0	1.8
51	Extended Site B	North East	Translocation	2	29.4	31.9	2.5
52	Mt Augustus	Site A Upper	Natural	2	29.5	30.4	0.9
53	Extended Site B	North East	Translocation	2	29.7	31.2	1.5
54	Mt Augustus	Site A Upper	Natural	2	29.9	31.7	1.8

Snail	Location	Monitoring Block	Site Type	Cohort	2012 size (mm)	2013 size (mm)	Growth (mm)
55	Mt Augustus	Site A Upper	Natural	3	30.2	30.9	0.7
56	Mt Augustus	Site A Upper	Natural	3	30.2	31.4	1.2
57	Extended Site B	West 1	Translocation	3	30.7	32.6	1.9
58	Mt Augustus	Site A Upper	Natural	3	31.2	33.2	2.0
59	Extended Site B	R6 VDT	VDT	3	31.4	34.0	2.6
60	Extended Site B	West 1	Translocation	3	31.6	34.1	2.5
61	Extended Site B	West 1	Translocation	3	31.7	33.7	2.0
62	Mt Augustus	Site A Upper	Natural	3	31.8	33.7	1.9
63	Mt Augustus	Site A Upper	Natural	3	32.0	32.6	0.6
64	Mt Augustus	Site A Upper	Natural	3	32.3	33.3	1.0
65	Mt Augustus	Site A Upper	Natural	3	32.4	33.2	0.8
66	Extended Site B	R6 VDT	VDT	3	32.9	36.6	3.7
67	Extended Site B	North East	Translocation	3	33.0	33.9	0.9
68	Mt Augustus	Site A Upper	Natural	3	33.0	35.3	2.3
69	Extended Site B	R6 VDT	VDT	3	33.1	36.2	3.1
70	Extended Site B	R6 VDT	VDT	3	34.0	35.0	1.0
71	Mt Augustus	Site A Upper	Natural	3	34.0	35.3	1.3
72	Mt Augustus	Site A Upper	Natural	3	34.1	35.0	0.9
73	Mt Augustus	Site A Upper	Natural	3	34.2	35.2	1.0
74	Mt Augustus	Site A Upper	Natural	3	34.4	35.6	1.2
75	Extended Site B	West 1	Translocation	3	34.5	34.7	0.2
76	Extended Site B	R6 VDT	VDT	3	34.6	35.6	1.0
77	Extended Site B	West 1	Translocation	3	35.0	35.9	0.9
78	Mt Augustus	Site A Upper	Natural	3	35.0	35.8	0.8
79	Extended Site B	R6 VDT	VDT	4	35.2	36.0	0.8
80	Mt Augustus	Site A Upper	Natural	4	35.5	35.8	0.3
81	Mt Augustus	Site A Upper	Natural	4	35.6	36.0	0.4
82	Extended Site B	R6 VDT	VDT	4	35.9	37.3	1.4
83	Extended Site B	North East	Translocation	4	36.1	37.3	1.2
84	Extended Site B	West 1	Translocation	4	36.1	37.6	1.5
85	Extended Site B	West 3	Translocation	4	36.1	36.7	0.6
86	Extended Site B	R6 VDT	VDT	4	36.2	37.0	0.8
87	Extended Site B	West 1	Translocation	4	36.4	37.2	0.8
88	Extended Site B	R6 VDT	VDT	4	36.5	39.6	3.1
89	Extended Site B	West 1	Translocation	4	37.1	38.0	0.9
90	Extended Site B	R6 VDT	VDT	4	37.2	38.7	1.5
91	Extended Site B	North East	Translocation	4	37.3	38.5	1.2
92	Extended Site B	West 1	Translocation	4	37.4	38.2	0.8
93	Extended Site B	West 1	Translocation	4	37.5	38.7	1.2
94	Mt Augustus	Site A Upper	Natural	4	37.5	38.2	0.7
95	Extended Site B	West 1	Translocation	4	37.7	39.1	1.4
96	Mt Augustus	Site A Upper	Natural	4	37.7	38.0	0.3
97	Extended Site B	West 1	Translocation	4	37.9	39.7	1.8
98	Mt Augustus	Site A Upper	Natural	4	37.9	38.4	0.5
99	Extended Site B	West 1	Translocation	4	38.0	38.5	0.5
100	Extended Site B	West 1	Translocation	4	38.3	38.8	0.5
101	Extended Site B	West 1	Translocation	4	38.3	38.7	0.4
102	Extended Site B	West 1	Translocation	4	38.5	38.5	0.0
103	Extended Site B	West 1	Translocation	4	38.6	39.6	1.0
104	Extended Site B	West 3	Translocation	4	39.7	39.7	0.0
105	Extended Site B	West 3	Translocation	4	39.8	40.0	0.2
106	Extended Site B	West 1	Translocation	4	40.2	41.2	1.0

Appendix H: Model selection for mark-recapture analysis

Reproduced without edit from the following:
MacKenzie, D. I. (2013). Abundance and Survival Estimation of Powelliphanta augusta and Powelliphanta patrickensis: Unpublished document. Proteus Wildlife Research Consultants, Dunedin.

Table 1: Site groupings based upon habitat quality. Site A High and West 1 remained ungrouped and independent.

Habitat Quality	Sites Grouped
Low	Site A Low and West 3
Medium	North East and R6 VDT

Table 2: Factors considered as potentially affecting *Powelliphanta augusta* survival and capture probabilities.

Factor	Description	Abbreviation	Probability
Year	Probability varies by year	Yr	Both
Grouped sites	Sites designated as low and medium quality have the same probability; all other sites are independent (Table 1).	Gsite	Both
Site specific	Probability varies for all sites	Site	Survival
Pooled surveys	Probability is different for surveys that have been pooled together compared to single surveys.	Psurveys	Capture
Heterogeneity	Among snail variation in capture probability; either relatively low or high.	Het	Capture

Table 3: Summary of model selection procedure for mark-recapture data of *Powelliphanta augusta* using the full data set. ΔAICc is the relative difference in AICc values compared to the top ranked model, *w* is the AICc model weight, *K* is the number of parameters and Deviance is a measure of the fit of the model to the data.

Model	ΔAICc	*w*	*K*	Deviance
S(Yr),p(Yr+GSite+PSurveys),pi(.)	0.00	0.38	13	7834.22
S(.),p(Yr+GSite+PSurveys),pi(.)	0.09	0.36	10	7840.42
S(GSite),p(Yr+GSite+PSurveys),pi(.)	2.96	0.09	13	7837.18
S(Yr),p(Yr+GSite+PSurveys+Het),pi(.)	4.05	0.05	15	7834.19
S(.),p(Yr+GSite+PSurveys+Het),pi(.)	4.16	0.05	12	7840.42
S(Yr),p(Yr+GSite+PSurveys+Het),pi(GSite)	4.52	0.04	18	7828.52
S(Site),p(Yr+GSite+PSurveys),pi(.)	6.25	0.02	15	7836.38
S(GSite),p(Yr+GSite+PSurveys+Het),pi(.)	7.04	0.01	15	7837.18
S(.),p(Yr+GSite+PSurveys+Het),pi(GSite)	7.54	0.01	15	7837.68
S(Site),p(Yr+GSite+PSurveys+Het),pi(.)	10.34	0.00	17	7836.38
S(GSite),p(Yr+GSite+PSurveys+Het),pi(GSite)	11.82	0.00	18	7835.81
S(Site),p(Yr+GSite+PSurveys+Het),pi(GSite)	14.92	0.00	20	7834.79
S(Yr),p(Yr+GSite),pi(.)	38.44	0.00	12	7874.70
S(.),p(Yr+GSite),pi(.)	38.69	0.00	9	7881.04
S(GSite),p(Yr+GSite),pi(.)	42.30	0.00	12	7878.56
S(Yr),p(Yr+GSite+Het),pi(.)	42.52	0.00	14	7874.70
S(.),p(Yr+GSite+Het),pi(.)	42.75	0.00	11	7881.04
S(Yr),p(Yr+GSite+Het),pi(GSite)	42.85	0.00	17	7868.90
S(Site),p(Yr+GSite),pi(.)	45.07	0.00	14	7877.25
S(.),p(Yr+GSite+Het),pi(GSite)	45.54	0.00	14	7877.72
S(GSite),p(Yr+GSite+Het),pi(.)	46.38	0.00	14	7878.56
S(Site),p(Yr+GSite+Het),pi(.)	49.16	0.00	16	7877.25
S(GSite),p(Yr+GSite+Het),pi(GSite)	50.60	0.00	17	7876.64
S(Site),p(Yr+GSite+Het),pi(GSite)	53.14	0.00	19	7875.07

Table 4: Summary of model selection procedure for mark-recapture data of *Powelliphanta augusta* with the 'pruned' dataset; excluding the January and February 2013 surveys from West 1 and West 3. ΔAICc is the relative difference in AICc values compared to the top ranked model, *w* is the AICc model weight, *K* is the number of parameters and Deviance is a measure of the fit of the model to the data.

Model	ΔAICc	*w*	*K*	Deviance
S(.),p(Yr+GSite+PSurveys)	0.00	0.38	10	7654.57
S(Yr),p(Yr+GSite+PSurveys)	0.41	0.31	13	7648.88
S(GSite),p(Yr+GSite+PSurveys)	2.50	0.11	13	7650.96
S(Yr),p(Yr+GSite+PSurveys+Het),pi(.)	3.91	0.05	15	7648.29
S(.),p(Yr+GSite+PSurveys+Het),pi(.)	4.07	0.05	12	7654.57
S(Yr),p(Yr+GSite+PSurveys+Het),pi(GSite)	4.72	0.04	18	7642.95
S(Site),p(Yr+GSite+PSurveys)	5.51	0.02	15	7649.89
S(GSite),p(Yr+GSite+PSurveys+Het),pi(.)	6.58	0.01	15	7650.96
S(.),p(Yr+GSite+PSurveys+Het),pi(GSite)	7.45	0.01	15	7651.83
S(Site),p(Yr+GSite+PSurveys+Het),pi(.)	9.60	0.00	17	7649.89
S(GSite),p(Yr+GSite+PSurveys+Het),pi(GSite)	11.38	0.00	18	7649.62
S(Site),p(Yr+GSite+PSurveys+Het),pi(GSite)	14.21	0.00	20	7648.33
S(.),p(Yr+GSite)	37.95	0.00	9	7694.55
S(Yr),p(Yr+GSite)	38.20	0.00	12	7688.70
S(Yr),p(Yr+GSite+Het),pi(.)	41.13	0.00	14	7687.55
S(GSite),p(Yr+GSite)	41.22	0.00	12	7691.73
S(.),p(Yr+GSite+Het),pi(.)	42.01	0.00	11	7694.55
S(Yr),p(Yr+GSite+Het),pi(GSite)	42.92	0.00	17	7683.20
S(Site),p(Yr+GSite)	43.74	0.00	14	7690.17
S(.),p(Yr+GSite+Het),pi(GSite)	44.71	0.00	14	7691.14
S(GSite),p(Yr+GSite+Het)	45.30	0.00	14	7691.73
S(Site),p(Yr+GSite+Het)	47.83	0.00	16	7690.17
S(GSite),p(Yr+GSite+Het),pi(GSite)	49.46	0.00	17	7689.74
S(Site),p(Yr+GSite+Het),pi(GSite)	51.79	0.00	19	7687.96

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