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UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS

School of Civil Engineering and The Environment

Towards the ecology and conservation of sand lizard (*Lacerta agilis*) populations in Southern England

by

Helen Fearnley

Thesis for the degree of Doctor of Philosophy

December 2009

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ABSTRACT

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The sand lizard (*Lacerta agilis*) is a rare, elusive and cryptic reptile species of conservation importance in the UK. Knowledge of its ecology and behaviour has limited the development of a reliable and effective methodology for population monitoring; this threatens to compromise conservation effort. The behaviour of sand lizards varies seasonally, with sex and with environmental conditions, none of which are fully understood. This aim of this thesis is to further our ecological knowledge of the sand lizard, specifically by investigating factors which influence the detection probability of this species and through exploration of population monitoring and estimation methods.

The detection rate of both male and female lizards in a captive population was found to be heavily dependent on their sex and reproductive stage. The detection probability of males was higher (39%) before mating than after mating (33%): with pre-mated males this was strongly associated with temperature and time of day; and with post-mated males it was linked to changeable conditions with solar radiation values between 200-700Wm⁻². The detection probabilities of females were higher after mating (40%) than before (25%) with additional variations in detection rate during and after egg laying. Pre-mated females were most commonly observed basking in a preferred range of ultra-violet light and post-mated they favoured conditions where the ground surface temperature ranged between 17.5°C and 27.5°C.

An intensive capture-mark-recapture study was performed on independent sand lizard populations and pattern matching software was used to assist with the identification of individual sand lizards from their dorsal patterning. The low recapture rate of sand lizards proved problematic and population estimates were generated using Program MARK following amalgamation of the data from each field season: but this nonetheless generated the first estimates of sand lizard populations in the UK, with a maximum mean density of 222Ha⁻². The survivorship of males was consistently higher than females (0.67 vs. 0.26) and the detection rates and populations estimates differed between years. A high number of individuals were encountered only once, resulting in wide confidence limits of abundance estimates for this species.

The range of microclimates available within a structurally diverse array of heathland vegetation were quantified and found to be more extensive than previously thought. The range of microhabitats within the preferred temperature range for sand lizards increased from Spring to Summer, so the need for a lizard to be in the open, and thus available for detection decreased.

The obstacles encountered when attempting to monitor sand lizards populations arise from the unpredictable nature of the species. Future sand lizard surveys should be conducted at times when the detection probability maximised, as described in this thesis. A national monitoring scheme should steer away from absolute abundance estimates of populations and consider the use of occupancy estimation to monitor our remaining populations.

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DECLARATION OF AUTHORSHIP

I, Helen Fearnley, declare that the thesis entitled 'Towards the ecology and conservation of the sand lizard (*Lacerta agilis*) in the United Kingdom' and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- none of this work has been published before submission

Signed:

Date:.....

Acknowledgements

Numerous people and organisations have contributed to this research. It has been a unique and remarkable experience and on reflection it amazes me, how so many busy people have freely and enthusiastically made time for me ... whether for conversation about all things reptilian, field and statistical advice or just to check in, so thank you. Thanks are also due to SITA Trust (part of a recycling and waste management company which supports environmental projects through the landfill communities fund) and The People's Trust for Endangered Species (PTES) who jointly funded this project. This research would not have been possible without support and guidance from The Herpetological Conservation Trust and my university supervisors Malcolm Hudson and John Allen, so here's a massive 'thank you!' to you all for making the sand lizard PhD idea, a reality.

I would also like to thank Nick Moulton, Dave Bird, David Hurst, Chris Gleed-Owen, John Wilkinson, Helen Wraight, Tony Gent, Paul Jones, Tim Woodfine, Marwell Preservation Trust, Martin Nobel, Jo Moody, Chris Reading, Bill Whittaker, Nick Smith, Lex Hiby, John Forster, Jim Foster & Jacqui Holmes for the help, advice and time you made to help during the course of this study, it was never unnoticed and always appreciated, so thank you and thank you again.

Thanks to all my friends both past and present for enduring the abstract lizard related conversations and for the words of motivation and distraction during the never-ending writing up phase ...you're brilliant ... Finally, mum and dad, thank you both, for EVERYTHING ... especially when I broke the wrist (no more kite flying in gale force winds, I promise) ... your support, encouragement, logic and stability are priceless ... and thank you both a few more times and a few more again ... and yes, I'm pleased to say I think, finally I've finished it!

Definitions and abbreviations

AIC	Akaike's Information Criterion
ARC	Amphibian and Reptile Conservation Trust formally known as The Herpetological Conservation Trust
CMR	Capture-Mark-Recapture
Ectotherms	Organisms which control their body temperatures through external means. Organisms also known as cold blooded
FCS	Favourable Conservation Status
Heliothermic	Process of heat gain from the sun
IUCN	International Union for the Conservation of Nature
NARRS	National Amphibian and Reptile Recording Scheme
Parsimonious	Least complex explanation
PBT	Preferred Body Temperature
SAP	Species Action Plan
Spermatogenesis	The process where male spermatogonia develop into sperm
Thermoregulation	The maintenance of a constant internal temperature of an organism independent of the environmental temperature
Thigmothemic	Process of absorbing heat through contact with warm surfaces

1 General Introduction

Reptiles are an ancient, diverse and versatile group of animals; and the majority of species show a negative response to anthropogenic manipulation of worldwide habitats (Conservation International 2007; IUCN 2009b). Lizards are a very large and widespread group of squamate reptiles found on every continent except Antarctica. They exhibit nocturnal or diurnal behaviour and are present in many different and extreme habitats, including deserts, rainforest, prairies, marshes, rocky outcrops, in temperate and rain forests (Lamb & Johnson 2005). The number of lizard species known to science has increased over the past few decades and is expected to continue to do so (Beebee & Griffiths 2000), with advances in molecular genetics and an ability to access more remote habitats in isolated corners of the world. Recent research has identified that remote tropical and humid forests are home to several endemic lizard species (Collen *et al.* 2008; Conservation International 2007).

However, as our knowledge increases, one fifth of Europe's reptile species are threatened¹ and forty two percent of European reptiles are in decline, which places them in a higher risk category than European mammals and birds (IUCN 2009a). The declines in reptiles are associated with the growth of human populations, agricultural intensification, urban sprawl, climate change, pollution and competition with invasive species (Corbett & Tamarind 1979; Edgar 2002; Edgar & Bird 2006; IUCN 2009a; NCC 1983).

The sand lizard, *Lacerta agilis* is a member of the most species rich reptilian family in Europe the Lacertidae (Cox & Temple 2009). In recent decades sand lizard populations have suffered extensive declines in number and range in the UK (House & Spellerberg 1983), northern France, Belgium, the Netherlands, northern Germany, Denmark, Sweden and Estonia (Edgar & Bird 2006) and as such, the

¹ IUCN define threatened species as those identified to be vulnerable, endangered and critically endangered based on five scientific criteria that evaluate the risk of extinction of the species based on biological factors such as: rate of decline, population size, area of geographic distribution, degree of population, and distribution fragmentation (IUCN 2009b).

sand lizard is a European Protected Species (EPS), and is threatened in much of its North Western range which includes the United Kingdom.

The remaining populations and habitat of UK's sand lizards are now the focus of conservation efforts resulting from European and domestic legislation. In the UK sand lizards are protected through nature conservation legislation via a combination of Regulation 39 of the Habitats Regulations 1994 (as amended 2007, 2008 and 2009), and via section 9(4) b & c and section 9(5) of the Wildlife & Countryside Act 1981 (as amended) which make it an offence to deliberately kill, injure, capture, transport, sell, exchange a sand lizard or to disturb or destroy them, their nest site or place of shelter. More importantly in the context of this research, the national conservation of the species and its habitat has been driven through the listing of the sand lizard in Annex II of the Bern Convention and Annex IVa of the Habitats Directive.

The Bern Convention on Biological Diversity has placed a legal obligation on countries to conserve and monitor the strictly protected flora and fauna species listed in its annexes. Both UK's lowland heathland habitat and sand lizards are listed in these annexes and were identified as priority species for conservation action. National objectives for the conservation of sand lizards were set out in a Species Action Plan (SAP) which provides the framework for all conservation work (The Herpetological Conservation Trust 2009). Early SAPs identified and addressed the major threats to the sand lizard populations as those relating to the degradation and loss of their habitat and since then the plans have evolved to contain specific targets directed at increasing the range, connectivity and occupancy of the species in suitable areas of habitat. The current objectives of the most recent SAP cover the protection and management of sand lizards and their habitat, additional distribution surveys, population and conservation status monitoring, scientific research, the improved coordination of conservation efforts and raising public awareness (The Herpetological Conservation Trust 2009).

One of the objectives in the SAP reflects the UK's obligation to continually monitor the conservation status of the sand lizard under Article 17 of The Habitats

Directive and the research in this thesis is conducted in line with this objective. The conservation status of a species is a measure of its stability and is evaluated considering its surface range, population size, habitat (extent and condition) and the future prospects. Each factor is deemed to have a conservation status of either: favourable (FV); inadequate (U1); bad (U2) or Unknown (Ukn) and the sum of these components result in the overall conservation status of the species. The first conservation status assessment of the UK's sand lizards was reported in 2008 as 'inadequate but improving' (table 1.1). Table 1.1 shows the components of the 2008 conservation assessment for the UK's sand lizards (*L. agilis*) alongside other priority herptiles. The range of the sand lizards has been deemed as inadequate but stable at 8850, with a favourable value of 9833; and a stable number of 580 populations with 645 populations required for the species to be favourable. However, discussions between conservation authorities as to how the terms and targets for 'favourable', 'inadequate' and 'bad' should be quantified and measured are still in development.

Table 1.1 The 2008 conservation status assessment of the UK's reptile and amphibians. The values in the ref. column refer to the value required for the species to be in a favourable conservation status.

Species		Range (km ²)				Population				Habitat (km ²)				Future prosp.	Overall asses.
		Surface	%XR	Trend	Ref.	Size&Unit	%XP	Trend	Ref.	Area	%XH	Trend	Suitable		
Bufo calamita	map	3694	1.7	=	4100	2500 - 2500 x	N/A	=	10000	100	0.6	=	N/A	Good	U2+
Coronella austriaca	map	4289	3.5	=	4760	354 - 354 x	N/A	=	395	238.5	1.7	+	N/A	Good	U1+
Lacerta agilis	map	8850	6.6	=	9833	580 - 580 x	N/A	=	645	35	0.1	=	N/A	Good	U1+
Rana lessonae	map	100	0.2	+	N/A	1 - 1 x	N/A	+	N/A	0.125	0	X	N/A	Unk.	U2+
Rana temporaria	map	240916	38.9	=	240916	2149 - 2149 x	N/A	=	2149	N/A	N/A	X	N/A	Good	FV
Triturus cristatus	map	157749	44.3	=	157749	75000 - 75000 loc.	N/A	-	100000	N/A	N/A	X	N/A	Good	U1

The recent conservation status assessment for sand lizards of 'inadequate but improving' is fair. The results of the early species action plans to protect and limit habitat loss and degradation and increase the range of the sand lizards through re-introductions (to areas where local extinctions had occurred) are reflected in the stability of the habitat and range trends (table 1.1). The future prospects of the sand lizards do appear positive as the major threats to the populations and habitats have been identified and measures are in place or in progress to limit

potential negative impacts (see later). The population status assessment should be interpreted with caution, especially the assumption that the number of sand lizard populations and the number of individuals within each population are stable as the evidence supporting this claim is inconsistent.

The national sand lizard records database is held and managed by The Amphibian and Reptile Conservation Trust (ARC) and was used for the population assessment for the sand lizards conservation status assessment. The database consists of sand lizard records submitted by herpetologists, ARC field staff, students and volunteers. The records held on the database are of limited conservation use as, to my knowledge there is little sampling consistency between surveys and observers. Absence records (surveys where zero sand lizards were recorded) are rarely submitted and so the information held in the database predominantly contains presence records making it difficult and near impossible to identify populations which are declining or extinct. For these reasons the use of the database to evaluate the population status of sand lizards is questionable, but it is the only resource available. To this end there is a need to ensure consistency between sand lizard surveying methods for the comparison of survey results and the collected survey data must be of a suitable nature so that inferences regarding the population status of the sampled populations can be made.

'Rare' is used to describe animals with a low abundance or restricted geographical distribution (either clustered or not) or both and elusive refers to a low probability of detection for whatever reason (Thompson 2004). A major difficulty facing herpetologists in evaluating the number of sand lizard populations and the number of individuals within each population is their elusive nature and rarity. The sand lizard is a difficult species to monitor and a frequent problem encountered when conducting sand lizard census counts is variability in numbers observed. A herpetologist and volunteers can survey an area which is known to contain several individuals and observe zero lizards on survey day one and on survey day three observe several (House & Spellerberg 1982; House 1980; NCC 1983). At present, simple census counts conducted by herpetologists are inconsistent and

incomparable and as such all existing records for sand lizard observations can and should only be used as an indication of population presence.

Sand lizards respond to different environmental variables in particular temperature and solar radiation (Avery 1979; Cowles & Bogerts 1944; Dent 1986; Spellerberg 1982) which could account for some of the variability between census counts. Their response to these variables appears to be seasonal with slightly different activity patterns observed between males and females (Beebee & Griffiths 2000; Dent 1986; NCC 1983; Nicholson 1980; Smith 1973). Little published research has investigated how male and female lizards respond to different environmental variables throughout their seasonal cycle especially concerned with when and in what conditions the lizards are visible. Understanding how and which environmental variables influence the behaviour of the lizards can assist us with identifying the appropriate times of year and weather conditions in which to conduct surveys. Further, this could also allow us to standardised surveys which could then allow comparison of survey results allowing us to make more accurate inferences relating to population trends.

Reptiles exploit the temperatures in their surrounding environment through thermoregulation to maintain their body temperature. It is important not only to consider how environmental variables could influence sand lizard behaviour to but also whether the microclimatic temperatures of their immediate environment i.e. the vegetation could play a role. The temperatures within different structures of heathland vegetation could account for some of the spatial and temporal variation encountered when conducting sand lizard surveys. Sand lizards are only going to be observed when they are out in the open at times when it is thermally or behaviourally advantageous. If we can quantify the range of temperatures available within different heather structures these values can be compared to the temperatures that sand lizards are known to favour, and we can determine whether there is a relationship exists between the times lizards are observed and temperatures within the vegetation structures. It will also be valuable to establish whether a relationship exists between the temperatures of the vegetation with respect to the times when lizards are or are not observed in the open. Should any

relationship be found we can then speculate as to how sand lizards may shuttle between different habitats, identifying the times when they are mostly likely to be observed in the open which can be used to improve survey methods.

The sand lizard conservation assessment also requires information about population sizes. There has not yet been a study which has successfully estimated the size of a wild sand population (House & Spellerberg 1982; House 1980; NCC 1983; Nicholson 1980) primarily because of the variability encountered in census counts (Foster & Gent 1996; House & Spellerberg 1982; House 1980; NCC 1983; Nicholson 1980). With the UK's obligation to continually monitor and report to Europe on the conservation status of sand lizards and their population sizes there is a need to develop a long term monitoring method for the UK's sand lizard populations. A long term monitoring method needs to be able to detect trends in population size, either by abundance estimation or other means, and must be suitable for use by volunteers, students and more experienced herpetologists. This is an objective specified in the current Species Action Plan (The Herpetological Conservation Trust 2009).

So, this doctoral study was conceived with the aim of increasing our understanding of the elusive nature of the sand lizards to identify ways and methods to work towards the standardisation of field survey methods and population size estimation. The first part of this thesis (Chapters 2 and 3) investigates whether environmental and habitat variables influence the chance of a sand lizard observation and if, so to what extent and how?. The second half (Chapters 4 and 5) explores methods using new technology to estimate the number of sand lizards in isolated populations. It is suggested that future surveys for sand lizards should be standardised and related recommendations are presented in the discussion (Chapter 6). Field work took place on nine areas of heathland located in Dorset near the Dorset/Hampshire county border (details of the study areas can be found in Appendix A).

The remainder of this chapter provides context for the research questions addressed in the rest of this thesis. Geographical, physical, biological and

ecological characteristics of the UK's sand lizards and sand lizard populations are reviewed, and the difficulties encountered to date in sampling or surveying sand lizard populations are discussed. This chapter also explores the challenges in sampling rare and elusive species and draws parallels between sand lizards and other species. The concept of detection probabilities as a component of population size estimation is introduced, and methods to maximise the detection probability of sand lizards are discussed in relation to their biological and ecological characteristics. The aims of this thesis are described at the end of this chapter.

Distribution and habitat of the sand lizard

In the UK the sand lizard is at the North West limit of its range, which extends over the greater part of continental Europe and east into South West Asia. In Britain sand lizards have the most restricted distribution of the British herpetofauna and are confined to lowland sandy terrains of heathland and coastal dune areas. There are inconsistencies between reports which detail historical distribution of sand lizards in the UK (Arnold 1973; Arnold 1995; Corbett 1988a; Simms 1969, 1976; Smith 1951, 1973; Taylor 1948, 1963) and so it is difficult to accurately quantify the decline of sand lizard populations. However it is possible to grasp the extent of their decline by evaluating the loss of their habitat. The areas of heathlands in the Poole Basin (their UK stronghold) have declined in the last 200 years: 30,400 were hectares present in 1811, but by 1978 this area was reduced to 5,832 hectares (Rose *et al.* 2000; Webb & Haskins 1980, 1990). An intensive lowland heathland survey of the Poole Basin was conducted in 1996 but the results are not publicly available (Rose 2009 pers. comms.) and we are unable to confirm how the areas of lowland heathland in the Poole Basin may have changed since the 1978 survey. The survey did reveal that the number of heathland fragments in Dorset increased from 137 in 1978 to 151 in 1996 while the mean fragment size decreased steadily with the increasing number of fragments (Rose *et al.* 2000). Sand lizards surviving on these often isolated fragments of habitat are under huge pressures directly resulting from the urbanisation of these heaths. These secondary pressures have continued to cause local extinctions of sand lizards and still threaten many populations (Edgar 2002). Many of these pressures are caused directly by public access (Corbett 1997; De Molenaar 1998; Haskins 2000) and the populations persisting in these fragments are also considered at a risk from competition from invasive species such as the wall lizard (*Podarcis muralis*) (Edgar & Bird 2006) and the Allee effect (Stephens & Sutherland 1999) (see discussion).

The loss and fragmentation of habitat has led to the extinction of native (those indigenous to the region) populations in Berkshire, Cheshire, Cornwall, Devon, East Sussex, Hampshire, Kent, West Sussex and Wiltshire and the species also became extinct in Wales with colonies (defined as areas with at least twelve adult

animals (NCC 1983)) in Surrey and Dorset reduced by 96.5% and 85.5% respectively (Corbett 1988a; Corbett & Tamarind 1979; Edgar 2002; Jackson 1979; NCC 1983). Today, native populations (those indigenous to the region) can be found in Surrey, Dorset, Hampshire and Merseyside (Beebee & Griffiths 2000; Corbett 1988a, 1988b; Corbett & Tamarind 1979; Smith 1951) and sand lizard populations have been re-introduced in the West Country, West Sussex and Wales (Beebee & Griffiths 2000). So, attention and effort is required to ensure existing populations of sand lizards are managed appropriately and effectively, and a standard survey methodology should be established to enable the development of monitoring programmes to categorise the conservation status of our remaining populations. This study investigates how aspects of sand lizard ecology, behaviour and habitat use can assist in developing such a program.

Sand lizards are commonly observed in areas of dry heath with high levels of structural diversity. This typically comprises of open ground and heather stands of different ages in areas with local topographical variation and warm south facing slopes, such as banks, ridges, tumuli, pits and cliffs (Corbett & Moulton 1998; Dent 1980, 1986; Foster & Gent 1996; House 1980; NCC 1983; Spellerberg 1975). Female sand lizards usually lay their eggs in areas of bare sand (see below) and hence no UK breeding colonies of sand lizards have been recorded in areas lacking unshaded bare sand (NCC 1983). Individual sand lizards can also be found in other habitats bordering heathland consisting of wet heath or bog, rough grassland and scrub, mineral working, hedgerows, railway embankments, roadside verges and urban gardens (NCC 1983). Sand lizards are probably present in these areas as they have most likely been colonised by the dispersal of sub-adults, or they are used for foraging and feeding by adults, or the original heathland habitat has changed through urbanisation or habitat management. Thus the lizards have been forced to persist in these peripheral habitats. This research is concerned with the investigation of sand lizard populations in their preferred habitat on the Dorset and Hampshire heathlands (Beebee & Griffiths 2000; Corbett & Tamarind 1979).

Detailed research into the specific preference of heathland habitat by sand lizards has shown that they are most frequently associated with structurally diverse areas of heathland (Dent 1986; House & Spellerberg 1983; House 1980; Moody 2007; NCC 1983; Nicholson 1980). Sand lizards have a preference for areas containing a high number of interfaces (a boundary of marked height change between vegetation and bare ground or two types of vegetation structure), breaks in the dense heather canopy and areas of bare ground (House & Spellerberg 1983; Moody 2007). Areas containing several interfaces or boundaries are often described as 'mosaics of heathland vegetation' (Corbett & Tamarind 1979; House & Spellerberg 1983; Moody 2007; NCC 1983) and believed to provide ideal year round conditions for basking, foraging, feeding, resting and thermoregulation (Amat *et al.* 2003; Corbett & Tamarind 1979; Foster & Gent 1996; House & Spellerberg 1983; Moody 2007; NCC 1983; Nicholson 1980). Nicholson (1980) believed that sand lizards preferred these structurally diverse areas as they contained the highest numbers of their prey items. As shuttling heliotherms sand lizards behaviour is strongly linked to temperature regulation, but as yet no research has investigated or quantified the range of temperatures provided by these mosaic areas of heathland and demonstrated whether the temperatures within these structurally diverse areas do indeed offer year round conditions advantageous to the thermoregulatory behaviour of sand lizards, or whether the prey availability as suggested by Nicholson (1980) is the sole explanation to their habitat preferences. In this thesis I consider whether the temperature ranges (microclimates) within these structures can predict how the lizards use the different structures and thus allow us to identify the probable locations of sand lizards at different times of the year. A better understanding of this aspect of their behaviour will allow us to start making recommendations to improve the consistency of sand lizard surveys conducted by conservationists and site managers. This is explored in Chapter 3.

Diet

Sand lizards forage on the ground and within the canopy, selecting prey items greater than 2mm in length (Nicholson 1980). Their diet consists mainly of arthropods: Coleoptera (beetles and weevils), Orthoptera (grasshoppers and

crickets), Diptera (flies), Hymenoptera (wasps, ants and bees), Heteroptera (true bugs), Lepidoptera (butterflies and moths), Araneae (spiders) and Opiliones (harvestmen), Crustacea (woodlice), and *Bombus spp.* (bumblebees) (NCC 1983; Nicholson 1980). This assemblage of invertebrates is associated with heathland habitats with areas of structural variety, bare ground, rabbit disturbance, nectar and pollen sources, flowering heather, dung and patches of scrub (Drake *et al.* 1998). The diet of sand lizards reflects the seasonal abundance of prey items (Nicholson 1980). Most invertebrates are not dependent on the *Calluna* (heather) plant, but favour the structural diversity and range of microclimates available within the different phases of *Calluna* growth (Corbett & Moulton 1988; Telfer 2006). The highest numbers of invertebrates are found in the 'ecotone' or 'interface' areas of heathland between different structures in a 'mosaic' or habitat types (eg. heathland/grassland), which are also where sand lizards are most commonly observed (House 1980; Moody 2007).

Threats to sand lizards

Heath dwelling sand lizards are prey to aerial predators such as kestrels: (*Falco tinnunculus*); harriers (*Circus sp.*); mistle thrushes (*Turdus viscivorus*); crows (*Corvus corone*); magpies (*Pica pica*) and even robins (*Erithacus rubecula*) (NCC 1983; Simms 1969). Ground dwelling species which prey on sand lizards include; the domestic dog (*Canis lupus familiaris*); domestic cat (*Felis silvestris catus*) (Henshaw 1998); stoat (*Mustela erminea*); weasel (*Mustela nivalis*); adder (*Vipera berus*); badger (*Meles meles*); fox (*Vulpes vulpes*); hedgehog (*Erinaceus europaeus*); and pheasant (*Phasianus colchicus*) and the smoothsnake (*Coronella austriaca*) (Najbar 2001; NCC 1983; Simms 1969; Strijbosch & Creemers 1988; Van Bree *et al.* 2006).

Sand lizard populations are also at risk from anthropogenic pressures including development and urban pressure, habitat management, fire and climate change. Each of these threats are revisited in the general discussion with specific references to the findings presented in the experimental chapters of this thesis.

Ecology of sand lizards

The sand lizard (*Lacerta agilis*) is a stocky, short legged member of the Lacertidae. Adult sand lizards range up to 20-24cm of which the tail can make up 11-15cm (NCC 1983). The background colour of male and female sand lizards is varied but is generally grey or brown with a complex pattern of ocellate spots, blotches and dorsal lines which extend the full length of the body, perfectly camouflaging them against a back group of heather vegetation. In the breeding season the males develop a green colouration which is most prominent on their flanks, making them easily distinguishable and easier to observe in comparison to females (Beebee & Griffiths 2000; Dent 1986; NCC 1983). The underside of both sexes can be white or cream with a small number of black spots. Hatchling sand lizards emerge with the same ocellate spots and blotches as adults and immature sand lizards generally resemble the females in colouration until the males reach maturity (Beebee & Griffiths 2000). Males are known to live up to 12 years and the life expectancy of female sand lizards is on average higher than males (Strijbosch & Creemers 1988) with the highest mortalities to populations arising in the juvenile stage and at first reproduction (Strijbosch & Creemers 1988). Males have been shown to have a home range between 1780m² to 2130m², and the home range of females is lower with estimates ranging from 489m² to 1924m²: all of these values are expected to be underestimates based on sample size and field observations (Nicholson & Spellerberg 1989). Previous studies have not considered that males are easier to observe in the wild when attempting population estimates, and hence the derived abundance estimates and sex ratios may be unintentionally biased (Dent 1986; NCC 1983; Nicholson 1980; Strijbosch & Creemers 1988). This research will consider how the reproductive stage of sand lizards, along with other seasonal changes could influence the number of males and females seen (see below section on detection probabilities).

Seasonal activity of the sand lizard

Adult sand lizards enter retreat underground for the winter between mid-August and mid-October, while juveniles remain active until November (NCC 1983). Male sand lizards emerge from their winter retreat in March, approximately two weeks before the emergence of the females (Beebee & Griffiths 2000; NCC 1983; Smith

1973). Males spend these first weeks basking to encourage the onset of spermatogenesis, which is linked to the development of their green flanks; this is perceived by some as an indication of their fertility level (NCC 1983). The females also bask to regain condition lost through the duration of their winter retreat. Mating occurs from late April until late May with males mating with several females and the females accepting several males (NCC 1983; Olsson & Madsen 2001; Olsson *et al.* 1996b; Olsson & Shine 1997). The larger males with greener flanks win altercations (and thus more mates) with smaller less green males (Olsson 1994). The females incubate their eggs internally by basking extensively (Beebee & Griffiths 2000; House 1980; NCC 1983) for 39 – 45 days (Rudeberg 1956) although there is much variation between internal incubation periods within years and between years. In June, the females excavate burrows of approximately 7cm in sandy substratum, with a large cavity at the base into which their eggs are deposited. The areas of sandy substrata selected for clutch deposition by females usually receive large amounts of sunlight and have an average moisture content of 18.3% (Beebee & Griffiths 2000; House 1980; NCC 1983). The average number of eggs deposited by female sand lizards ranges between 5.2 and 7 (House 1980; Simms 1969; Smith 1951). They hatch after an *in-situ* incubation period between 53-73 days (House 1980) and 7 – 12 weeks (Beebee & Griffiths 2000) at a median nest temperature of 16.5°C – 20.0°C (see general discussion for comments relating to nest incubation and climate change). After the deposition of their clutch it is thought the body weight of the females is reduced between 25 – 40% and this loss can be offset with feeding and basking to regain condition (NCC 1983). The first hatchling sand lizards are usually observed at the beginning of August (Beebee & Griffiths 2000; NCC 1983).

Thermoregulatory behaviour of sand lizards

Sand lizards are ectotherms (Spellerberg 1975, 1982) and maintain their precise or preferred body temperature (PBT) through exploitation of external heat sources by basking for solar radiation (heliothermic behaviour) or through direct contact with heat sources (thigmotheric behaviour) (Avery 1979; Dent 1986; Spellerberg 1975, 1982). Reptile species use thigmotheric and heliothermic behaviour for temperature rise or reduction (Cowles & Bogerts 1944) and each reptile species

has a preferred body temperature which is optimum for the animal's physiological processes and enzyme production (Avery 1979). A species' PBT is constant but may vary over its geographical range (Avery 1979). Active UK sand lizards have been shown to have a preferred body temperature 31 °C - 32°C with a recorded range of 12.5°C - 34.0°C (Spellerberg 1988). The ecologically lethal critical minimum temperature is 5.9°C (Spellerberg 1988), and the maximum ecologically lethal critical temperature of 43.9°C (Bauwens *et al.* 1995); beyond this range normal physiological functions will cease. Sand lizards shuttle between areas of habitat which offer them opportunities keep themselves as close to their PBT as possible, or at least within their preferred thermoregulatory range, avoiding the lethal minima and maxima values.

Very little research has been carried out to explore how sand lizards exploit the microclimates available in structurally diverse areas of vegetation, especially in relation to their preferred body temperatures. This is surprising given that such a heterogeneous environment is a main objective of site managers. Areas of structurally diverse heathland will have different heating and cooling rates providing multiple microclimates. In Chapter 3 the range of temperatures of different heathland structures are explored in relation to the PBT of sand lizards and time of day (in relation to sunrise and sunset). Exploration into how the lizards may utilise their preferred areas of habitat to maintain their PBT may reveal some important insights as to where lizards are most likely or least likely to be found through the year and these finding could be used to improve survey efficiency and consistency.

The seasonal cycle of sand lizards is known to influence their thermoregulatory behaviour: males bask intensively once emerged from their winter retreat to encourage the onset of sperm production (see above) and females are frequently found basking while gravid. Again, no research has attempted to quantify whether the lizards are openly basking to exploit the thermal conditions most complimentary to their requirements, or whether the lizards have chosen to bask openly because they are responding to a different environmental variable: light. Previous studies have found that the activity of lizards is strongly associated with

surface temperature, time, direct sunshine, solar radiation and humidity (Avery 1979; Ceirans 2006; Dent 1986; House *et al.* 1980; Jackson 1978; Korsos & Gyovai 1988; NCC 1983; Spellerberg 1974). The research presented in this thesis not only quantifies the range of temperatures available in mosaic areas of heathland, but also investigates which environmental variables are most strongly associated with the presence of sand lizards at different times of the year; contributing to our limited knowledge of the ecology of the sand lizards. By furthering our understanding of how sand lizards respond to different measurable environmental variables and temperatures within heathland vegetation structures we can identify optimal conditions in which to maximise the chance of a sand lizard encounter for male and female lizards at different stages of their season cycles (Chapter 2). This in turn can contribute to the development of a survey methodology which will improve our ability to make accurate inferences on the conservation status of sand lizard populations.

Sand lizard population estimates and monitoring

As discussed, the seasonal and thermoregulatory behaviour of sand lizards is reflected in their patchy spatial and temporal distribution. We are unable to confidently predict where a sand lizard is likely to be observed; in what weather conditions, and also how long the lizard is likely to remain in that fixed location; and if the location is in the open, whether the lizard is likely to be observed during census surveys. These compounding factors lead to the unpredictable spatial and temporal distributions of sand lizard observations which are commonly observed with other species, and collectively these animals are described as rare, cryptic and elusive species (Thompson 2004). For species of this nature, adequate sampling of populations, and hence abundance estimation is problematic. Sampling and statistical methods to overcome the obstacles encountered when sampling and monitoring rare, elusive and cryptic species is a pressing area of research, as several of the world's most endangered species are data deficient (typically only basic descriptive data on the species itself is available) and these are the species which we believe require immediate conservation measures to ensure their survival (IUCN 2009c).

Detection probabilities

One of the most important research developments concerning the sampling and analysis of data concerning rare and elusive species is the identification of detection probability, and the role this can play in generating confident estimates of animal abundance. Perhaps this is the reason why previous attempts at population size estimation for isolated colonies of sand lizards (Amat *et al.* 2003; Dent 1986; House 1980; Nicholson 1980) have been unsuccessful. The detection probability has been identified as a component of population size estimation whereby the population size can be generated by the formula:

$$\text{Population estimate} = \frac{\text{number of individuals observed}}{\text{detection probability}}$$

The detection probability is the probability that a member of the population of interest appears in a count of a surveyed area, if present (Thompson 2004), and for rare and elusive species the detection probability is never consistent. The estimation of population abundance of rare and elusive species critically depends on the estimation of detection probabilities under a particular sampling method. Detection probabilities are made up of two components – availability and unavailability. Availability refers when the animal is available for detection (with sand lizards when they are above ground, usually basking in the open available for detection by observers). Unavailability is the time when an animal is not available for detection for example when a sand lizard has retreated for the winter, under vegetation, or underground. If we ignore the issue of an animal not being available for detection (e.g. retreated underground for the winter) and conduct a census count we will only obtain an estimate of the size of the available component of the population (which during the winter retreat would be zero) rather than the total population size (Pollock *et al.* 2004; Thompson 2004) leading to inaccurate abundance estimates.

The fundamental problem encountered and acknowledged in each previous population study (Dent 1986; House 1980; Nicholson 1980; Nicholson &

Spellerberg 1989) was the low recapture rate of individuals, resulting in population estimates with large confidence limits. In my opinion the low recapture rates reported in these population studies could be a result of genuine low abundance of individuals, ineffective sampling or low and variable detection probabilities. This is a clear example of why detection rates for rare and elusive species must be considered when formulating population estimates and making inferences from these estimates about population trends. Measures to understand and maximise the detection probabilities while sampling rare and elusive species should be encouraged and employed.

In the case of sand lizards, we assume that the reason male and females are observed basking openly at different times of the year is driven by their reproductive cycles, but in addition their detection probabilities are influenced by thermoregulatory behaviour which is often governed by weather conditions at, or recently before, the time of survey. We have no quantitative or scientific data in support of these observations, and this highlights our limited understanding of the thermal and behavioural ecology of sand lizards. If we can increase our level understanding as to when, and in what conditions sand lizards are found basking openly, we may be able to derive more appropriate sampling methods to generate reliable and confident estimates of population size. Chapters 2, 3 and 5 investigate how weather conditions, temperatures and seasonality could influence the basking behaviour, and hence detection probabilities of sand lizards.

The records held within the central ARC database can only be interpreted for conservation purposes as records of reported sand lizard presence. Records of absence are not logged with the database and if absence records were included, as there is no consistency in sampling methodology, many of these absences could be a result of sampling when a sand lizard is unavailable for detection or a low detection rate, rather than a 'true' absence. In conservation terms this means that even establishing the presence of sand lizards on a site is problematic. This has further implications when there is a requirement to continually report on the population status of a species. We need to consider how to improve current sand lizard sampling and recording methods based on scientific rather than anecdotal

evidence to allow conservation bodies such as ARC to make meaningful and reliable inferences on the status of sand lizard populations from the survey data and hence to direct conservation resources appropriately. Also, the limitations of current recording methods and the central database need to be recognised and all future inferences made relating to the conservation status of sand lizards should acknowledge the shortfalls of current surveying and recording methods.

There has not yet been a successful attempt to estimate the number of sand lizards in isolated populations because the influence of detection probabilities on the population estimates is a relatively new research area. As we need to evaluate the conservation status of the UK's sand lizard populations we need to determine whether it is possible to accurately estimate the number of lizards within several small populations once detection probability is estimated or whether once detectability is accounted for, the recapture rates of sand lizards are still too low to perform confident population analysis. If this is the case then we need to direct research effort towards alternative methods of census surveys to detect trends in the population status of sand lizards. An exhaustive sampling approach was adopted in this study to provide us with further information into the ecology of the sand lizard to help address some of the outstanding issues relating to sampling rare and elusive species.

Thesis Aim

In my opinion sand lizards are a challenging species to monitor because of their elusive and unpredictable behaviour, which could be governed by external factors. Thus the major challenge facing herpetologists is to link the number of sand lizards observed during field work to the true number present and with this. To date, the UK sand lizard monitoring scheme is restricted to count surveys, which given a strong influence of external variables on the 'detectability' of these lizards (see Chapter 2 and 3), are of limited use as an indication for population size, or indeed, species presence, especially as zero count surveys are not confirmation of absence (see Chapter 5). The aim of this thesis covers some of the research and

scientific objectives detailed in the current sand lizard action plan and such it is hoped will improve the quality of information reported to Europe relating to the conservation status assessment of the UK's sand lizard populations under Article 17 of the Habitats Directive. The aim of this research thesis is to further our understanding of the elusive nature of the sand lizard to identify ways and methods to work towards the standardisation of field surveying methods and population size estimation.

The thesis aim will meet by the following chapter objectives:

The influence of weather and seasonality on the detectability of sand lizards is explored in Chapter 2. The objective of this chapter is to investigate whether time and environmental variables influence the detection probability (the chance of a sand lizard observation) of male and female sand lizards, and if so to what extent, how? To meet this objective a population of sand lizards was monitored over a year and the visible presence of lizards was considered with respect to measured environmental variables using regression models. The findings from this chapter assist with the interpretation of the results from the intensive capture-mark-recapture (CMR) study in Chapter 5.

Chapter 3 investigates the annual and daily temperature variation in successional stages of *Calluna vulgaris* (common heather) in the field. The chapter objective is to investigate the range of thermal conditions available to sand lizards in the microhabitats of different heather structures through the year. These temperature profiles are then used to predict when it is thermally advantageous for sand lizards to be above ground and in the open, hence available for detection; and conversely when it is advantageous for lizards to remain in the vegetation or underground, thus unavailable for detection.

Chapter 4 explores the use of automated pattern matching software to identify individual lizards from digital images of their dorsal markings. The main objective of this chapter is to evaluate the performance of the software using *in situ* field images (which are often inconsistent or imperfect) of lizards and consider whether

this identification tool could be used in a large scale reptile monitoring scheme. The software also provides verification of the individual identification of sand lizards made by eye in Chapter 5.

The objective of chapter 5 is to attempt abundance estimation of wild sand lizard populations using CMR methodology. The lizards will be 'marked' from non-invasive digital images of their natural patterning and population estimates derived from photographic history of each recorded lizard. The identification of individual lizards from digital images by eye was verified using the software tested in the previous chapter. Factors which affect the population estimates are identified, and the difficulties and challenges faced in the survey methodology and data analysis are presented and discussed. The application of this method for population size estimation at a larger scale is discussed with reference to the development of a sand lizard monitoring scheme.

Chapter 6 reviews the main findings of this thesis and discusses the difficulties and challenges in sampling, understanding and turning sand lizard count data into meaningful population estimates on small scale studies, and in the broader context of monitoring schemes. These issues are then considered in relation to the future conservation of UK sand lizard populations and how herpetologists can best meet the EU reporting requirements for the conservation assessment of sand lizards as governed by the EU Habitats Directive.

2 The influence of weather and seasonality on the detectability of sand lizards, *L. agilis*, in a captive population

2.1 Introduction

The work in this chapter models the activity of sand lizards in a captive population in response to seasonality, diurnal variation and climatic variables. Research is needed to identify these relationships to help interpret field observations as a measure of population size, and ultimately conservation status, to comply with the UK's reporting requirements of the EU Habitats Directive (92/43/EEC), Articles 11 & 17. Understanding how male and female sand lizards respond to environmental variables (individually, and in combination) is also vital in the development of a reliable quantitative survey methodology to enhance the basic presence or absence records currently gathered by herpetologists. Developing this methodology (Chapter 5) will directly contribute towards the sand lizard monitoring scheme under the National Amphibian and Reptile Recording Scheme (NARRS) which is currently being piloted by the Amphibian and Reptile Conservation Trust (ARC) in partnership with the Amphibian and Reptile Groups in the UK (ARG UK) (The Herpetological Conservation Trust & ARG UK 2008). This chapter reviews the limited literature linking the presence of sand lizards to temporal and climatic factors, presents the methods and statistical tools used to explore and quantify these variables on a captive population, and closes with a discussion of the value of the new findings.

Sand lizards have seasonal and daily cycles, and their activity is strongly influenced by environmental variables (Avery 1979; Dent 1986; House *et al.* 1980; Jackson 1978; Korsos & Gyovai 1988; NCC 1983). Sand lizards are shuttling heliotherms (Avery 1979) and adjust their behaviour to exploit sources of thermal energy including solar radiation, hot ambient air and substratas, and the surrounding vegetation (Avery 1979; Ceirans 2006; Dent 1986; Foster & Gent 1996; Herczeg *et al.* 2003; House *et al.* 1980; Jackson 1978; Korsos & Gyovai 1988; Porter *et al.* 1973; Spellerberg 1974). The males and females have different

activity patterns governed by their reproductive behaviour (Amat *et al.* 2000, 2003; Beebee & Griffiths 2000). As a result, their “detectability” varies between sexes and these differences have not yet been investigated. Understanding the factors driving this variation is essential if the collection of field census data is to lead to accurate population estimates. Estimation of both absolute and relative abundance of rare and elusive species requires information about detection probability (MacKenzie *et al.* 2006). By measuring sand lizard activity with a suite of potential explanatory variables, we can model the relationships between sand lizard presence and combinations of climatic variables with time. The findings can then be used to inform field surveyors on the optimum conditions to survey; simple presence/absence data can then be gathered more effectively or used to provide more accurate estimates of population sizes under field conditions. Even the establishment of the presence or absence of sand lizards means that surveys should be timed when the chance of encounter (detection probability) for this rare and elusive species is maximised. This will reduce the chances of existing or decreasing populations going undetected, and will make reported absence more meaningful.

The optimal time to observe sand lizards in the UK is believed to be within the first few weeks after emergence from their winter retreat in spring, in temperatures between 10°C and 18°C (JNCC 2003). In early spring sand lizards spend large amounts of time basking to regain their condition, and for males this basking induces the onset of sperm production (Foster & Gent 1996; JNCC 2003; Nicholson 1980). With the progression of the season, the optimum temperature window in which to conduct lizard searches is generally believed to be between the hours of 0900-1100 and 1600-1900 in the UK (Brana 1991; Dent 1986; JNCC 2003). This evidence is not a result of any scientific study and is largely based on experience and anecdote.

Detectability is a tool to assist in the estimation of animal abundance. It is defined as the probability that a member of the population of interest appears in a count (Thompson 2004). In this chapter the strength of single environmental variables and combinations several will be analysed with *L. agilis* counts with respect to their

seasonality. The detection probabilities of male and female sand lizards are a function of their local environment, their seasonality and the prevailing weather conditions. These are all dynamic factors and will be subject to constant variation, and thus the importance lies in establishing which environmental factors are associated with positive lizard counts. The detection probabilities of both male and female sand lizards will be calculated and quantification of the environmental factors linked to their presence at these different stages will be discussed. Chapter 5 builds on the findings of this chapter and presents the results from an intensive CMR study in which the detection probabilities of wild male and females sand lizards are calculated, discussed and used in the estimation of *L. agilis* abundances.

The work described by this chapter was carried out on a closed captive population at Marwell Zoological Park, Hampshire, UK. Monitoring this closed and contained population controlled spatial variation and the visibility of the sand lizards was assumed to be a product of their behavioural response to seasonality and environmental variables.

2.2 Methods

The population of *L. agilis* at Marwell Zoological Park near Winchester, at the time of study consisted of approximately 22 adults. The vivarium at Marwell was established in 1989 (Edgar 1990) and is approximately 60m² (12m x 5m) on a south facing slope (figures 2.1 and 2.2). The vegetation is typical lowland heathland vegetation H2 *Calluna vulgaris* – *Ulex minor* as defined by the National Vegetation Classification (Rodwell 1995). The vivarium is enclosed by acrylic sheeting approximately 60cm high within a fruit cage to eliminate avian and small mammal predation, and is proofed against burrowing rats (*Rattus norvegicus*) at ground level. There is no evidence that predators have gained access in recent years, and neither is there evidence that *L. agilis* can escape. There is no public access to the enclosure or its surrounds, so human disturbance is minimal. The sand lizards' diet is supplemented by additional feeding due to the limited availability of natural prey items in the vivarium. This was not thought to impact on

the collection of data as no supplementary feeding took place during data collection. In essence the captive population is closed with no recruitment. Eggs are removed before hatching for incubation, rearing and release for conservation purposes (including re-introductions) and losses to the population can only arise from natural mortality.

A wireless Davis Vantage Pro2 weather station (Prodata Associates) recorded air temperature, humidity, wind speed, solar radiation and ultraviolet index (on a scale of 0 (minimum exposure) to 10 (maximum exposure)) at thirty minute intervals throughout the year. The weather station also recorded the maximum and minimum value for each variable within each thirty minute interval. Ground and soil temperatures were recorded manually by soil/air thermometers in the sun and shade and manual light readings were recorded using a Hanna LUX light meter to compliment the data logged from the weather station. The positioning of equipment is detailed in figure 2.2. Timed surveys were conducted around the enclosure noting the location and sex of each lizard observed (see figure 2.3) and readings from the soil/air thermometers and the light meter were noted. Surveys were conducted from May 2005 – June 2006, at least once a week for a minimum of four hours between 0700 and 2000. It was assumed there was no bias between observers, all visible lizards at the time of survey were recorded and that the lizards remained undisturbed the observer.

It was anticipated the findings from this chapter could be incorporated into the sampling of wild populations of sand lizards in chapter 5. Unfortunately, the data analysis from this chapter was complex and the results were not available in readiness for the field work undertaken in chapter 5. With hindsight, this was an overambitious idea.

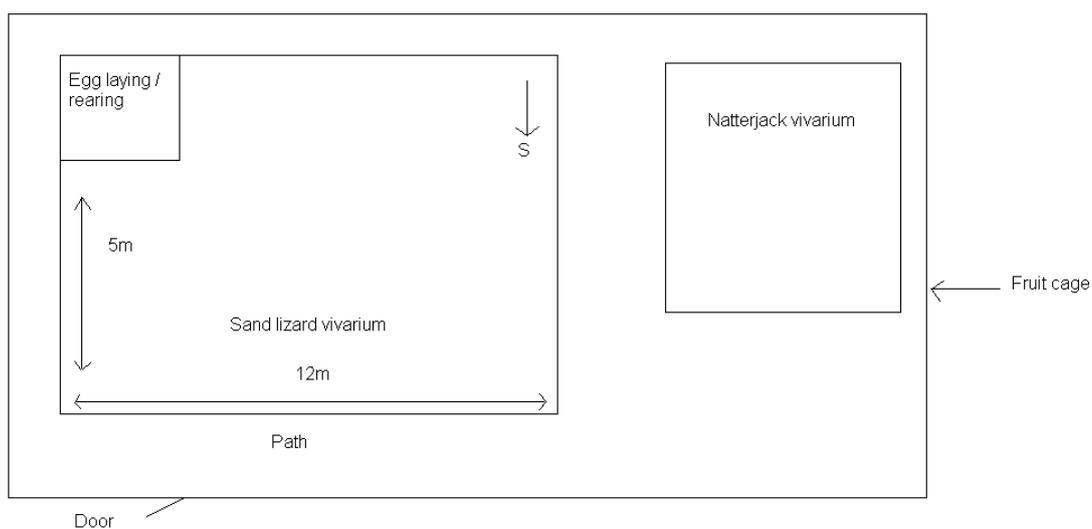


Figure 2.1. Design and dimensions of the vivarium at Marwell Zoological Park



Figure 2.2. The vivarium at Marwell. The weather station is located in the centre of the enclosure.

Data Analysis

Sand lizard activity was modelled in relation to environmental variables and time using the information-theoretic approach with Akaike's Information Criterion (AIC) (Akaike 1974). Recent literature recommends this as a superior method of analysis over hypothesis testing (Burnham & Anderson 2002; Whittingham *et al.* 2006) and Mazerolle (2006) proposes that its use in model selection should be adopted by herpetologists. The second order AICc criteria (used when the ratio of data points/number of parameters is <40) was used to evaluate the models based on the number of observations available (Burnham & Anderson 2002).

The aim of the analysis was to establish the weather conditions in which the most sand lizards were seen at different times of the season. Males will freely bask in the open in April but become harder to find after mating (JNCC 2003). Females, once mated, spend more time basking and we assume, for and feeding for egg development and when heavily gravid expose themselves as they search for suitable nesting sites and dig test burrows (Edgar 2002). After egg deposition, the now thin females spend a large amount of time basking and feeding to regain condition which in favourable conditions typically takes one week (Forster 2007; Foster & Gent 1996; NCC 1983) and are then elusive for the rest of the summer season. The data for both males and females were analysed with reference to these stages. Each stage was identified from observations in the vivarium during the count surveys (table 2.1).

The analysis investigated which single or combination of variables yielded the highest number of male and female sand lizards at their different life cycle stages. The count data was reduced for each seasonal stage (except the female, gravid) to ensure independence, which can be a known statistical problem when modelling count data under Poisson assumptions (Forster 2007). The female gravid data were not reduced as this would provide too few data points to generate models, the results of which should be interpreted with some caution. The variance inflation factor for each model was calculated by dividing the residual deviance of the model by the residual degrees of freedom (Mazerolle 2006) which

provides an indication as to whether the data are a good fit to the model, and also whether the data is subject to overdispersion. A model with a variance inflation factor of less than 1 and greater than 4 suggests that a Poisson model is not adequate at explaining the variation in the data (Burnham & Anderson 2002). An approximation to the R^2 value (the proportion of variability in a data set that is explained by the model) was also calculated to evaluate how well the regression line of each candidate model fits the lizard count and weather data.

Spearman's correlation coefficient was used to identify highly correlated weather variables (Table B.1, Appendix B) with a coefficient ≥ 0.7 (Field 2005). Variables with high coefficient values were not included in the same model. Temperature, time, ultra-violet light, wind speed (interpreted as an indicator of changeable conditions), solar radiation and humidity are included in the AIC modelling as single and paired predictors. In keeping with parsimony, only models with less than three parameters were considered for the analysis (Burnham & Anderson 2002).

Our understanding of how the detection rates of sand lizards fluctuate is limited. However, we believe the detection rate varies between the sexes and with seasonality but there is no supporting scientific evidence. We also assume that the detectability of lizards is influenced by a combination of or different environmental variables, which again lacks scientific support. The *a priori* models are formulated from our current understanding of the ecology of the species in that a combination of environmental variables, seasonality and sex could be accountable for the variations in detection probability of sand lizards. The possible relationship between lizard presence and environmental variables is represented in the candidate models as linear and quadratic. The quadratic models were based on the ecological assumption that the lizards, if linked to an environmental variable, may only be visible only over a selected range of values. The evaluated AIC models in table 2.1 consider the possible influence of all these factors.

Matrix plots of the raw data were generated to determine whether the relationships between the predictor variables and sand lizard observation were best described

as linear or quadratic. The models were run in S-Plus version 7.0 using the assumption of a Poisson distribution from the log-linear (Poisson) model function and relative AICc values were calculated using the following script:

```
aic.pois = function(mod){aic <- mod$deviance - (2 * mod$df.residual)return(aic)}
```

Detection Probabilities

The detection probabilities for male and female sand lizards were calculated for each seasonal stage using the formula from Thompson (2004):

Number of animals in population = count total / detection probability

The exact number of individual sand lizards in the vivarium at Marwell is unknown. The values for the maximum number of males (9) and females (13) seen at any one time were substituted for population size, hence the detection probabilities quoted are maximum values. The data for males and females were analysed independently from the same reduced data set used in the regression analysis.

Table 2.1. *A priori* models evaluated (indicated by X) using AICc for male and female sand lizards at each stage of their reproductive cycle.

Variable / Seasonal stage	Male		Female			
	Pre mating	Post mating	Pre mating	Gravid	Egg laying / regain condition	Rest of season
Temperature	X		X			
Temperature + Temperature ²	X	X	X	X	X	X
Temperature + Time	X					
Temperature + Wind + Time	X					
Ultra-violet Index	X		X			
Ultra-violet Index + Ultra-violet Index ²	X	X	X	X	X	X
Ultra-violet Index + Ultra-violet Index ² + Wind		X				X
Ultra-violet Index + Ultra-violet Index ² + Time	X	X				
Solar Radiation + Solar Radiation ²	X	X	X	X	X	X
Solar Radiation + Solar Radiation ² + Wind		X		X		
Solar Radiation + Solar Radiation ² + Time		X				
Humidity + Humidity ²	X		X	X	X	X
Humidity + Humidity ² + Wind speed					X	
Air temperature in sun + Air temperature in sun ²			X	X	X	
Air temperature in sun + Air temperature in sun ² + Wind speed				X		

2.3 Results

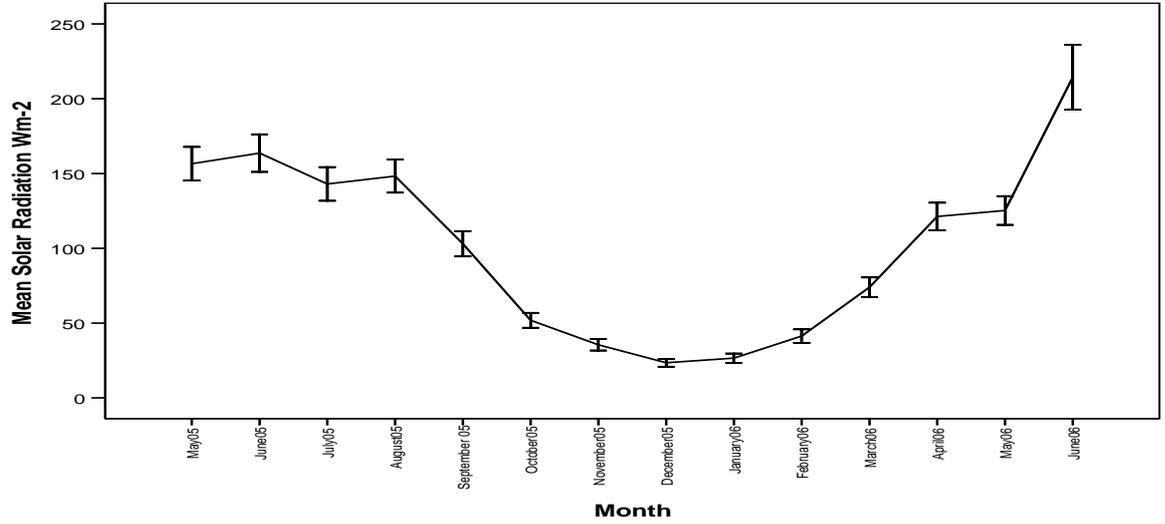
Weather data summaries

Table 2.2 presents summary values of recorded weather variables in the Marwell vivarium during the study period. Monthly averages for solar radiation, temperature, UV index, humidity and high wind speed recorded in the Marwell vivarium are presented in figures 2.3a, b, c, d & e. The figures were produced from the entire weather data set (not just the weather data at the time of count). The light and temperature related variables display the same pattern of lower values over the Autumn / Winter period rising in Spring and peaking in Summer. Wind speed peaked in Spring 2006, and humidity was highest between October 2005 and January 2006, reaching a minimum in June 2006.

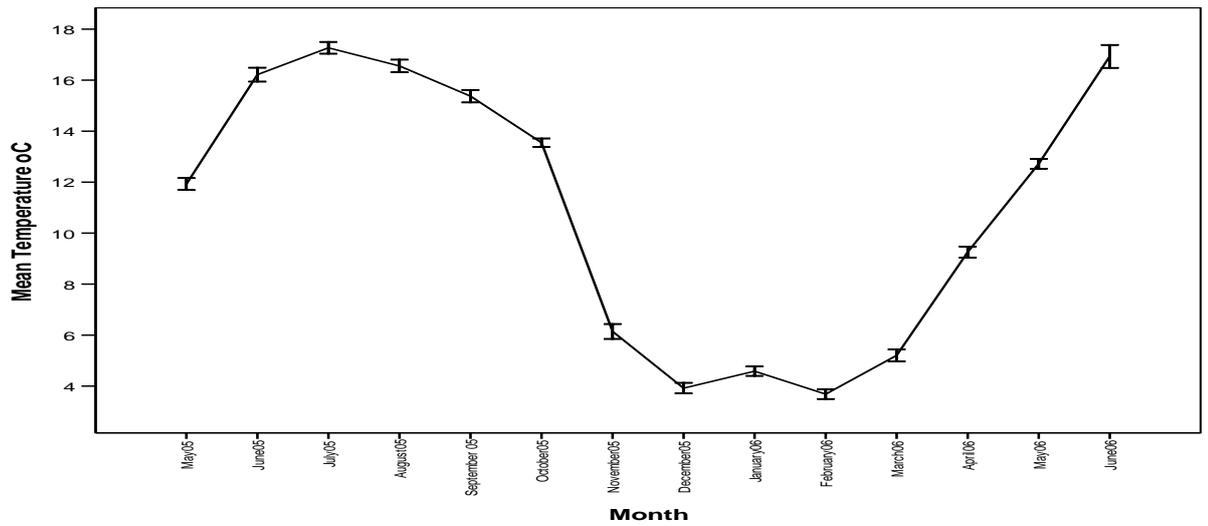
Table 2.2. Summary of weather conditions in the Marwell vivarium between May 2005 and June 2006.

<i>N= 19539</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Mean</i>	<i>Std. Deviation</i>
Temperature (°C)	-7.4	30.8	10.7	6.7
Highest Temperature (°C)	-7.3	31.0	11.0	6.8
Lowest Temperature (°C)	-7.6	30.3	10.5	6.7
Humidity (%RH)	26.0	100.0	81.1	14.8
Wind Speed (ms ⁻¹)	0.0	9.7	0.4	0.9
High Wind Speed (ms ⁻¹)	0.0	38.6	2.8	3.9
Pressure (mb)	738.9	1040.4	969.9	98.8
Rain (mm)	0.0	14.2	0.0	0.2
Solar Radiation (Wm ⁻²)	0.0	950.0	97.6	176.2
High Solar Radiation (Wm ⁻²)	0.0	1230.0	147.5	255.9
UV Index	0.0	7.5	0.5	1.1
High UV Index	0.0	8.6	0.7	1.4

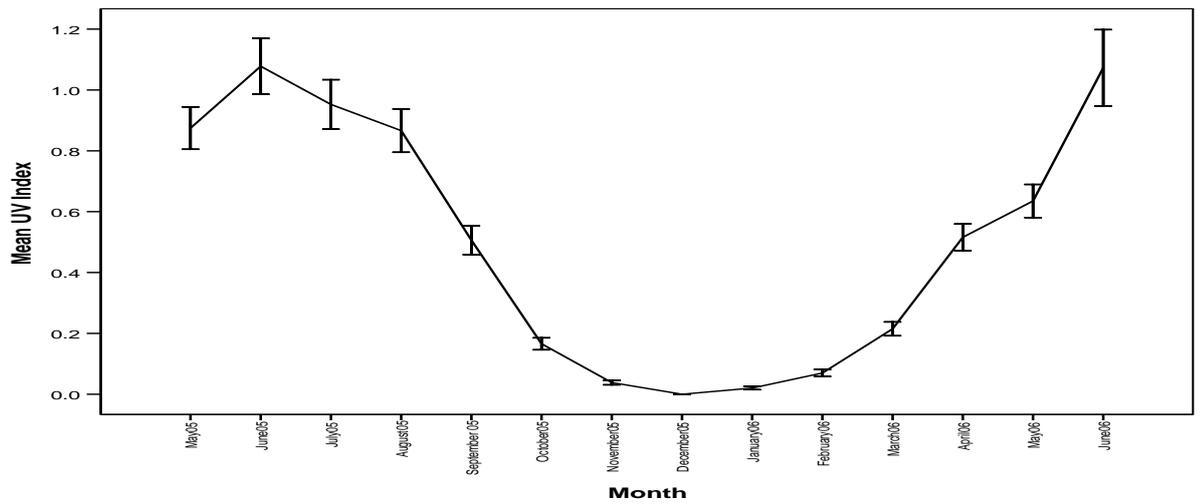
Figure 2.3 a, b, c, d & e. Monthly mean solar radiation, temperature, UV Index, wind speed and humidity values with 95% confidence limits recorded in the Marwell vivarium between May 2005 and June 2006.



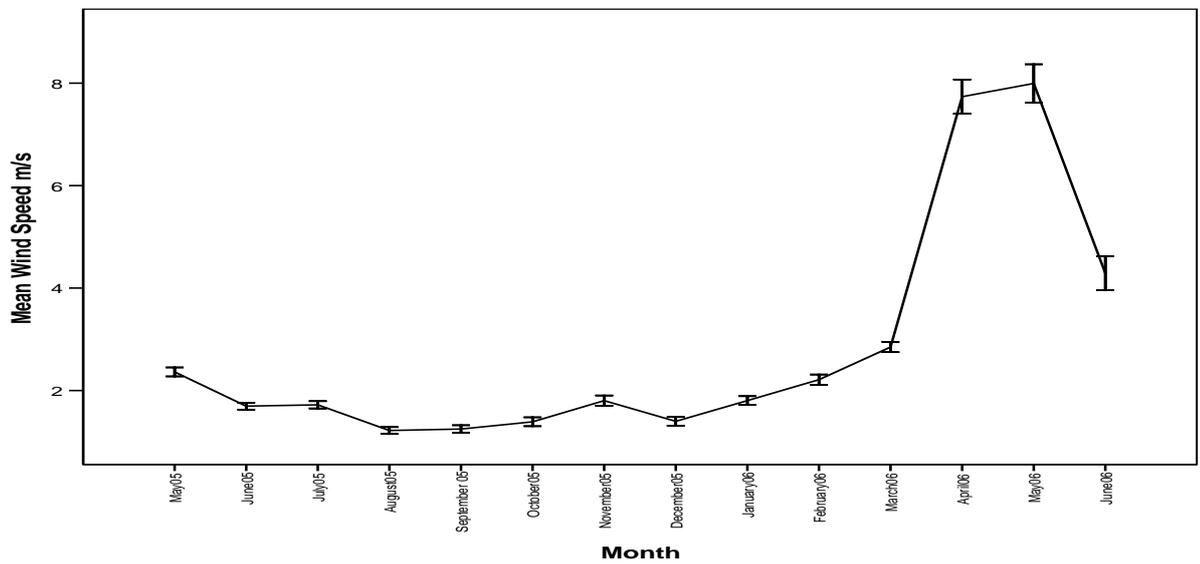
Solar Radiation.



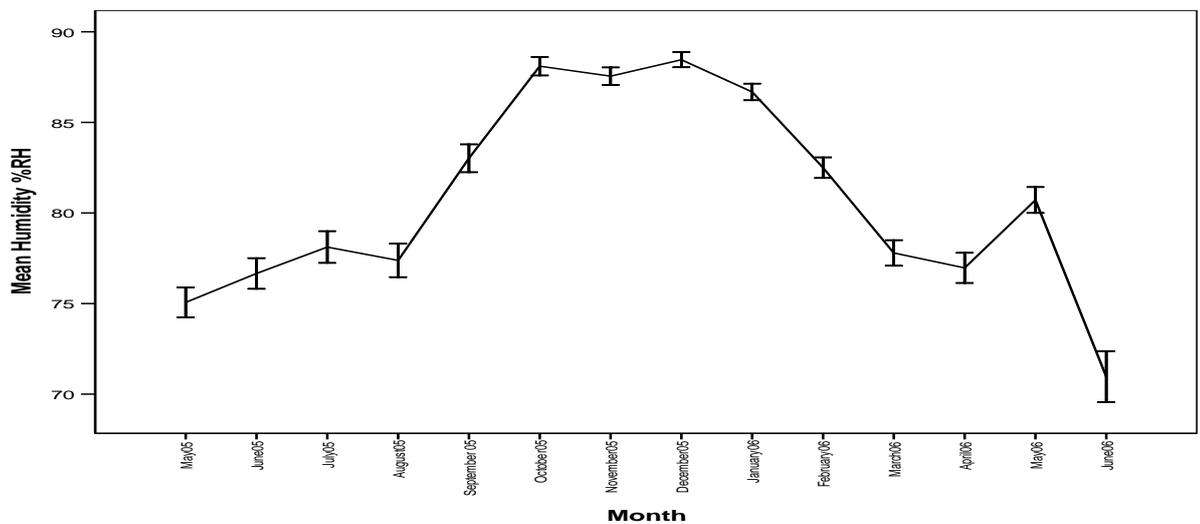
Temperature.



UV Index.



Wind Speed.



Humidity.

Sand lizard summaries

A total of 836 count surveys were conducted with 119 surveys returning zero counts. The earliest sightings in the calendar year were, for males 15/3/2006, and for females 4/4/2006, and the latest for both sexes was 11/10/2005. The number of male sand lizards peaked in May for both 2005 and 2006, and the highest number of females was recorded in June for 2005 and May during 2006. No lizards were recorded after the 11th October 2005 until the 15th March 2006 (figure 2.4).

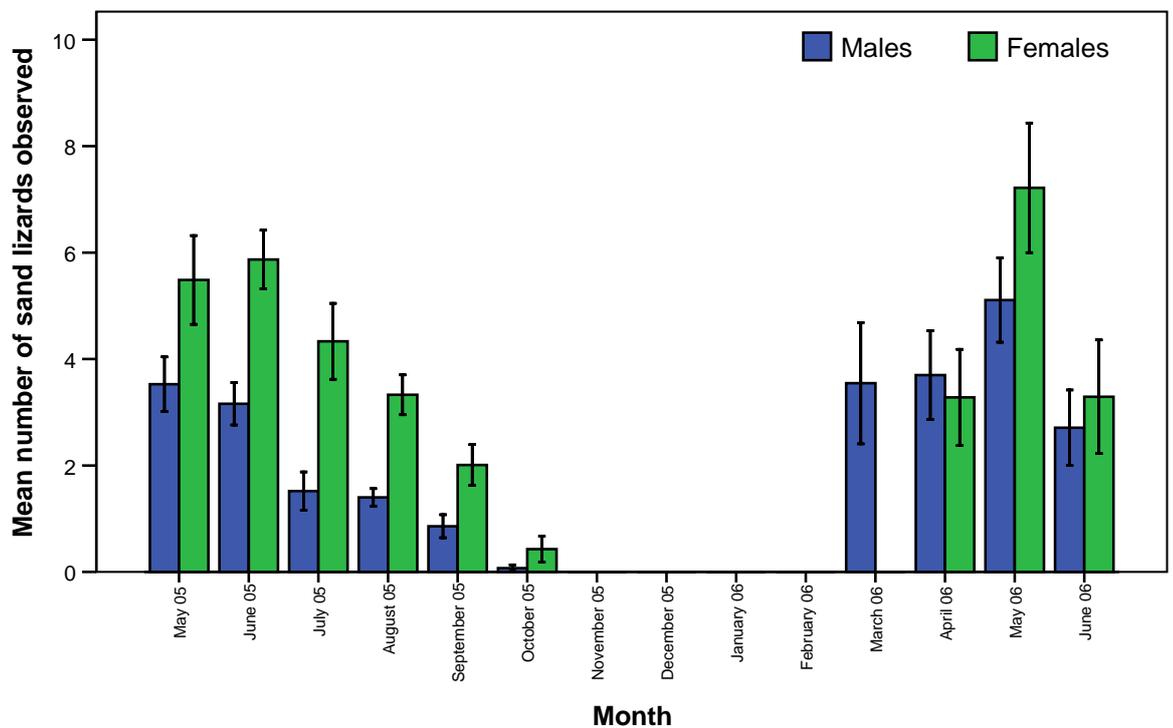


Figure 2.4. Mean monthly sand lizard totals observed at Marwell vivarium between May 2005 and June 2006. The error bars represent 95% confidence limits.

The weather conditions in which male and female sand lizards were observed were consistently of warmer temperatures, higher wind speed (changeable) and lighter and brighter conditions in comparison to conditions in which no sand lizards were recorded table (2.3).

Table 2.3. Recorded values of environmental variables in which sand lizards were recorded in the Marwell vivarium compared to weather conditions in which no lizards were recorded.

	<i>Positive Counts - A least one lizard observed</i>				<i>Counts where no lizards seen</i>			
	mean	std error	min	max	mean	std error	min	max
Temperature (°C)	19.0	0.2	3.1	29.7	14.5	0.3	2.8	27.1
High Temperature (°C)	19.3	0.2	3.3	30.1	14.8	0.3	2.8	27.3
Lowest Temperature (°C)	18.3	0.2	3.1	28.9	14.2	0.3	2.3	26.8
Humidity (%RH)	62.6	0.6	26	99	81.1	0.9	46.0	99.0
Wind speed (ms ⁻¹)	0.6	0.0	0.0	8	0.5	0.1	0.0	6.4
High wind speed (ms ⁻¹)	3.7	0.2	0.0	25.7	2.8	0.3	0.0	24.1
Pressure (mb)	977.2	3.7	743.8	1037.4	1004.0	3.9	759.7	1031.0
Rain (mm)	0.0	0.0	0.0	0.51	0.0	0.0	0.0	1.5
Solar radiation (Wm ⁻²)	373.8	8.6	0.0	899	103.1	7.8	0.0	593.0
Hi Solar radiation (Wm ⁻²)	564.4	11.5	0.0	1230	155.9	11.6	5.0	800.0
UV index	2.4	0.1	0.0	6.9	0.4	0.0	0.0	3.9
High UV	3.2	0.1	0.0	7.8	0.5	0.1	0.0	4.8
Light reading (LUX)	37.6	1.0	1.2	118.3	10.4	0.8	0.0	69.9
Soil Temp in sun (°C)	20.5	0.2	3.0	36.5	14.2	0.4	3.0	28.0
Air Temp in sun (°C)	24.2	0.3	4.5	39.5	16.8	0.7	5.0	25.0
Soil Temp in shade (°C)	17.2	0.2	3.0	29	12.9	0.3	3.0	21.5
Air Temp in shade (°C)	20.2	0.3	4.0	129	14.6	0.3	4.0	27.0

Modelling sand lizard activity in relation to environmental variables

Plots of selected environmental variables and male and female counts from the AICc analysis are located in Appendix B, figures B.1-B.7. The fitted regression line is the default least squares regression generated by SPSS v14.0.

Summary tables 2.4 to 2.9 rank the models in order of best fit. In these tables the column titled “res dev / red df” (residual deviance of model / degrees freedom of the model) is equivalent to the variance inflation factor (\hat{c}) which can be used as a measure of over dispersion (Mazerolle 2006). The data are considered over dispersed if $\hat{c} > 1$ and under dispersed if < 1 . The estimated over dispersion parameter \hat{c} should generally be $1 \leq \hat{c} \leq 4$ (Burnham & Anderson 2002) and provided $\hat{c} \leq 3$ Cooch & White (2007) state one should feel relatively safe progressing with the model structure as long as issues relating to lack of fit are fully considered. The \hat{c} values of the top two models at different reproductive stages of male and female lizards range between 0.78 and 1.89 (tables 1.4 – 2.9) and are within the acceptable \hat{c} limits.

Males

Prior to mating (table 2.4), the best model for male lizard presence is the linear model of temperature and time (model 1), which explains 46.10% of the variation in the data and is 2.84 times a better fit to the data than model 2 the linear model for temperature (model 2, figure B.1, appendix B). Model 3 (quadratic ultra-violet index) would suggest that the lizards have a preferred range of ultra violet light values between 1.50 and 2.00 (figure B.2, appendix B).

Post mating (table 2.5), solar radiation + solar radiation² + wind speed (model 1) is clearly the best, explaining 18.66% of the variation and is 7.8 times more likely to fit the data than model 2, the quadratic for solar radiation. Post mated male sand lizards are seen in changeable conditions (model 1 contains wind speed) in which there appears to be an optimal solar radiation value which lies approximately between 200 – 700W m⁻² (figure B.3, appendix B). There is essentially no

evidence to suggest that models 4, 5, 6 and 7 are able to explain variation between the measured variables and male lizard counts as the Δ AICc values exceed 10 (Burnham & Anderson 2002).

Table 2.4. Candidate set of Poisson regression models for the number of male sand lizards in relation to weather and temporal variables, seen before mating took place in Marwell vivarium. Where K = number of parameters (including intercept), AICc value = approximation of AICc values calculated using script in section 1.2.

<i>Predictor – Males pre mating</i> <i>N=22</i>	<i>Model ID</i>	<i>K</i>	<i>AICc</i>	Δ <i>AICc</i>	<i>res dev /</i> <i>res df**</i>	<i>Likelihood</i>	<i>AIC weight</i>	<i>Evidence ratio</i>	<i>R^2 adj %</i>
Temperature + Time of day	1	3	-20.61	0.00	0.78	1.00	0.47	1.00	46.10
Temperature	2	2	-18.53	2.08	0.99	0.35	0.17	2.84	31.55
Ultra-violet Index + Ultra-violet Index ²	3	3	-17.55	3.07	1.01	0.22	0.10	4.63	28.53
Temperature + Temperature ²	4	3	-17.30	3.32	0.97	0.19	0.09	5.26	33.37
Ultra-violet Index + Ultra-violet Index ² + Time	5	4	-17.03	3.58	0.92	0.17	0.08	5.99	34.44
Temperature + Wind Speed	6	3	-15.90	4.72	1.04	0.09	0.04	10.57	28.01
Ultra-violet Index	7	2	-14.64	5.97	1.24	0.05	0.02	19.79	12.20
Humidity + Humidity ²	8	3	-13.71	6.91	1.16	0.03	0.01	31.62	20.00
Solar Radiation + Solar Radiation ²	9	3	-11.87	8.74	1.30	0.01	0.01	79.09	7.32

** res dev / res df is the residual deviance of the model divided by the residual degrees of freedom. It approximates to a measure of overdispersion (Mazerolle 2006).

Table 2.5. Candidate set of Poisson regression models for the number of male sand lizards seen post mating in relation to weather and temporal variables. Where K = number of parameters (including intercept), *AICc value = approximation of AICc values calculated using script in section 1.2.

<i>Predictor - Males post mating</i> <i>N=98</i>	<i>Model ID</i>	<i>K</i>	<i>AICc</i>	Δ <i>AICc</i>	<i>res dev /</i> <i>res df**</i>	<i>Likelihood</i>	<i>AIC weight</i>	<i>Evidence ratio</i>	<i>R^2 adj %</i>
Solar Radiation + Solar Radiation ² + Hi Wind Speed	1	4	-62.14	0.00	1.33	1.00	0.85	1.0	18.66
Solar Radiation + Solar Radiation ²	2	3	-58.05	4.10	1.39	0.13	0.11	7.8	15.49
Solar Radiation + Solar Radiation ² + Time of Day	3	4	-55.93	6.22	1.40	0.04	0.04	22.4	14.63
UV Index + UV Index ² + Hi Wind Speed	4	4	-49.07	13.08	1.47	0.00	0.00	690.7	10.18
UV Index + UV Index ²	5	2	-43.24	18.90	1.54	0.00	0.00	12731.7	5.91
UV Index + UV index ² + Time of Day	6	4	-40.94	21.21	1.56	0.00	0.00	40285.4	4.91
Temperature + Temperature ²	7	3	-33.08	29.07	1.65	0.00	0.00	2048300.1	0.53

** res dev / res df is the residual deviance of the model divided by the residual degrees of freedom. It approximates to a measure of overdispersion (Mazerolle 2006).

Table 2.6. Candidate set of Poisson regression models for the number of female sand lizards in relation to weather and temporal variables, seen before mating took place in Marwell vivarium. Where K = number of parameters (including intercept), *AICc value = approximation of AICc values calculated using script in section 1.2.

<i>Females - Pre mating</i> <i>N=22</i>	<i>Model ID</i>	<i>K</i>	<i>AICc</i>	Δ <i>AICc</i>	<i>res dev / res df**</i>	<i>Likelihood</i>	<i>AIC weights</i>	<i>Evidence ratio</i>	<i>R² adj %</i>
Ultra-violet Index + Ultra-violet Index ²	1	3	-4.53	0.00	1.73	1.00	0.34	1.00	39.74
Ultra-violet Index	2	2	-1.97	2.56	1.89	0.28	0.09	3.60	34.38
Humidity + Humidity ²	3	3	7.78	12.31	2.35	0.00	0.00	470.13	18.35
Temperature	4	2	9.24	13.77	2.42	0.00	0.00	975.49	15.83
Air Temperature in Sun + Air Temperature in Sun ²	5	3	10.59	15.11	2.49	0.00	0.00	1914.92	13.47
Temperature + Temperature ²	6	3	11.62	16.15	2.54	0.00	0.00	3215.53	11.67
Solar Radiation + Solar Radiation ²	7	3	14.28	18.81	2.67	0.00	0.00	12144.25	7.05

** res dev / res df is the residual deviance of the model divided by the residual degrees of freedom. It approximates to a measure of overdispersion (Mazerolle 2006).

Table 2.7. Candidate set of Poisson regression models for the number of female sand lizards in relation to weather and temporal variables when the females were gravid in Marwell vivarium. Where K = number of parameters (including intercept), *AICc value = approximation of AICc values calculated using script in section 1.2.

<i>Females – Gravid</i> <i>N=40</i>	<i>Model ID</i>	<i>K</i>	<i>AICc</i>	Δ <i>AICc</i>	<i>res dev / res df**</i>	<i>Likelihood</i>	<i>AIC weights</i>	<i>Evidence ratio</i>	<i>R² adj %</i>
Air Temperature in Sun + Air Temperature in Sun ² + Wind Speed	1	4	-8.69	0.00	1.74	1.00	0.83	1.00	34.23
Air Temperature in Sun + Air Temperature in Sun ²	2	3	-5.12	3.56	1.85	0.17	0.14	5.94	30.09
Solar Radiation + Solar Radiation ² + Wind Speed	3	4	-1.98	6.71	1.92	0.03	0.03	28.60	27.57
Solar Radiation + Solar Radiation ²	4	3	3.81	12.49	2.08	0.00	0.00	516.24	21.45
Temperature + Temperature ²	5	3	16.02	24.71	2.39	0.00	0.00	232150.57	9.63
Ultra-violet Index + Ultra-violet Index ²	6	3	20.50	29.18	2.51	0.00	0.00	2173602.38	5.30
Humidity + Humidity ²	7	3	22.17	30.85	2.55	0.00	0.00	5012655.80	3.69

** res dev / res df is the residual deviance of the model divided by the residual degrees of freedom. It approximates to a measure of overdispersion (Mazerolle 2006).

Table 2.8. Candidate set of Poisson regression models for the number of female sand lizards in relation to weather and temporal variables when the females were egg laying and regaining condition post egg lay in Marwell vivarium. Where K = number of parameters (including intercept), *AICc value = approximation of AICc values calculated using script in section 1.2.

<i>Females - egg laying / regaining condition</i> <i>N=50</i>	<i>Model ID</i>	<i>K</i>	<i>AICc</i>	Δ <i>AICc</i>	<i>res dev / res df**</i>	<i>Likelihood</i>	<i>AIC weights</i>	<i>Evidence ratio</i>	<i>R² adj %</i>
Humidity + Humidity ²	1	3	-43.94	0.00	1.03	1.00	0.58	1.00	38.29
Humidity + Humidity ² + Wind Speed	2	4	-42.67	1.27	1.03	0.53	0.31	1.88	38.38
Solar Radiation + Solar Radiation ²	3	3	-35.50	8.44	1.23	0.01	0.01	67.97	25.17
Ultra-violet Index + Ultra-violet Index ²	4	3	-34.70	9.24	1.25	0.01	0.01	101.39	24.14
Air Temperature in Sun + Air Temperature in Sun ²	5	3	-27.42	16.52	1.41	0.00	0.00	3860.07	14.74
Temperature + Temperature ²	6	3	-16.66	27.28	1.63	0.00	0.00	838189.93	2.89

** res dev / res df is the residual deviance of the model divided by the residual degrees of freedom. It approximates to a measure of overdispersion (Mazerolle 2006).

Table 2.9. Candidate set of Poisson regression models for the number of female sand lizards in relation to weather and temporal variables for the rest of the season in Marwell vivarium. Where K = number of parameters (including intercept), *AICc value = approximation of AICc values calculated using script in section 1.2.

<i>Females - rest of season</i> <i>N=42</i>	<i>Model ID</i>	<i>K</i>	<i>AICc</i>	Δ <i>AICc</i>	<i>res dev / res df**</i>	<i>Likelihood</i>	<i>AIC weights</i>	<i>Evidence ratio</i>	<i>R² adj %</i>
Ultra-violet Index + Ultra-violet Index ² + Wind Speed	1	4	-15.63	0.00	1.58	1.00	0.97	1.00	27.04
Ultra-violet Index + Ultra-violet Index ²	2	3	-7.83	7.80	1.79	0.02	0.02	49.40	17.33
Solar Radiation + Solar Radiation ²	3	3	-1.18	14.44	1.96	0.00	0.00	1369.57	9.87
Humidity + Humidity ²	4	3	1.62	17.25	2.02	0.00	0.00	5566.60	6.71
Temperature + Temperature ²	5	3	9.19	24.82	2.21	0.00	0.00	244942.79	1.90

** res dev / res df is the residual deviance of the model divided by the residual degrees of freedom. It approximates to a measure of overdispersion (Mazerolle 2006).

Females

Observations of pre-mated females were best predicted by the models containing the ultra violet parameter (table 2.6). Model 1 (ultra violet + ultra violet²) is the best fit to the data explaining 39.74% of the variation whereas the linear version of ultra violet index (model 2) explains 34.38% of the variation. Figure B.4, appendix B indicates that a minimum threshold value for ultra violet index of ~1.25 exists. Models 3, 4, 5, 6, and 7 can be discounted as either the evidence ratios are excessive in relation to the best fit or the Δ AICc values exceed 10 (Burnham & Anderson 2002).

Observations of gravid females were best predicted by models containing air temperature in sun (table 2.7). Model 1, the quadratic of air temperature in the sun and wind speed (essentially ground surface temperature and a measure of changeability) explains 34.23% of the variation in the data and model 2, the quadratic of air temperature in the sun accounts for 30.09% of the variation and is 5.94 times less likely to be the best fit model in comparison to model 1. Plots of surface temperature against counts of females imply gravid females are selecting ground surface temperatures between 17.5°C and 27.5°C (figure B.5, appendix B). Models 3, 4, 5, 6 and 7 are very poor models based on their Δ AICc values and evidence ratio values.

Observations of egg laying females and females post lay were best predicted by models containing humidity (table 2.8). Model 1, the quadratic of humidity explains 38.29% of the variation in number of egg laying and post egg laying females seen with higher number of females observed between relative humidity values of 50% - 70% (figure B.6, appendix B). The addition of the wind speed to the model marginally increases the fit of the model to 38.38%, but this increase is negligible as AIC selection process favours the most parsimonious model (Burnham & Anderson 2002); model 1 is 1.88 times better at explaining the variation in the data than model 2. Models 3, 4, 5 and 6 show little evidence to support the variation in the data from either their Δ AICc or evidence ratio values.

Observations of females for the rest of the season were best predicted by the quadratic of ultra-violet index and wind speed (model 1) explaining 27.04% of the

variation in the data set (table 2.9). Plots of the count data imply females are most frequently found basking in ultra-violet index values between 2.00 and 5.00 (figure B.7, appendix B). Models 2, 3, 4 and 5 are poor predictors based on their Δ AICc or evidence ratios values.

Detection probabilities

The mean detection probability of pre mated males is higher than those of post-mated males (0.39 and 0.33, table 2.10). On average 39% of pre mated males present will be seen (with ranging values of 0% – 78%) and 33% (with ranging values of 0% - 89%) of all post mated males. The average detection probability for male sand lizards through the whole season was calculated as 0.34 with ranging values from 0.00 to 0.89.

The detection probabilities of female sand lizards were wide ranging at each stage of their life cycle. Pre-mated females averaged 0.25 with a range of 0.00 – 0.62 thus on average 25% of the female population were observed prior to mating. Gravid females averaged a detection probability of 0.41 with a range of 0.00 – 1.00 and at this stage, on average, 41% of the female population were observed. The detection probabilities of egg laying females and those regaining condition averaged 0.42 with a range of 0.00 – 0.85 and on average 42% of the female population were recorded during this time. Post egg laying and regaining condition the average detection probability of female sand lizards drops to 0.36 with a range of 0.00 – 0.85. The detection probabilities for males and females are increased when the reproductive stage of each sex is taken into account in comparison to the annual mean detect rate (table 2.11). This evidence clearly shows that the detection probability of each sex does not remain constant through the season.

Table 2.10. The mean detection probabilities of male and female sand lizards at each seasonal stage from count data collected at the Marwell vivarium between May 2005 and June 2006. The total number of males and females in the vivarium was taken as 9 and 13, respectively.

	<i>Minimum</i>	<i>Maximum</i>	<i>Mean detection probability</i>	<i>Standard error</i>
Males - Pre mated	0.00	0.78	0.39	0.05
Males - Post mated	0.00	0.89	0.33	0.02
Females - Pre mated	0.00	0.62	0.25	0.04
Females - Gravid	0.00	1.00	0.41	0.04
Females - Egg laying/regaining condition	0.00	0.85	0.42	0.03
Females - Rest of season	0.00	0.85	0.36	0.03

Table 2.11. The mean detection probabilities of males, females and the total population over the whole season, from count data collected at the Marwell vivarium between May 2005 and June 2006. The total number of males and females in the vivarium was taken as 9 and 13, respectively.

	<i>Minimum</i>	<i>Maximum</i>	<i>Mean detection probability</i>	<i>Standard error</i>
Males	0.00	0.89	0.34	0.02
Females	0.00	1.00	0.36	0.02
Total	0.00	0.95	0.36	0.02

At each reproductive stage for males and females zero counts of lizards were frequently recorded. This illustrates that even through the lizards are present they are often not recorded because the detection probability is 0.00 (table 2.10) and conversely the maximum values of the detection probabilities range from 0.62 – 1.00. The maximum detection probability of 1.00 was only observed for gravid females.

2.4 Discussion

Sand lizards in the vivarium were observed in air temperatures of 3.1°C – 30.1°C with a mean of 19.0°C (table 1.4) which deviate somewhat from the temperature range of 18.0°C - 43.0°C, mean of 26.3°C in House *et. al.* (1980) and the range of 12°C - 20°C quoted by Nuland & Strijbosch (1981). House *et. al.* (1980) collected their data between May and August while Nuland and Strijbosch (1981) carried out their study between March and November in favourable weather conditions. Limiting lizard counts to these months and ‘favourable’ weather conditions would give rise to higher temperatures with reduced ranges.

The reproductive cycle of the sand lizard determines a difference in activity patterns for males and females (Amat *et. al.* 2003) which this chapter has also found. The detection probability of males and females varied with their reproductive stage and the lizards also respond to different environmental variables during each stage. The climatic variables in which male and female lizards are most frequently observed at different stages of their reproductive cycle are summarised in table 2.12.

Table 2.12. Summary of the two best fit candidate Poisson regression models from the Marwell count data with R^2 (adj) values.

<i>Life stage and sex of lizard</i>	<i>Best fit Poisson model</i>	<i>R² (adj) %</i>
Males - pre mating	Temperature + Time of day	46.10
Males - pre mating	Temperature	31.55
Males - post mating	Solar Radiation + Solar Radiation ² + Hi Wind Speed	18.66
Males - post mating	Solar Radiation + Solar Radiation ²	15.49
Females - pre mating	Ultra-violet Index + Ultra-violet Index ²	39.74
Females - pre mating	Ultra-violet Index	34.38
Females - gravid	Air Temperature in Sun + Air Temperature in Sun ² + Wind Speed	34.23
Females - gravid	Air Temperature in Sun + Air Temperature in Sun ²	30.09
Females - egg laying / regaining condition	Humidity + Humidity ²	38.29
Females - egg laying / regaining condition	Humidity + Humidity ² + Wind Speed	38.38
Females - rest of season	Ultra-violet Index + Ultra-violet Index ² + Wind Speed	27.04
Females - rest of season	Ultra-violet Index + Ultra-violet Index ²	17.33

Existing literature encourages sand lizard surveys to be conducted in 'favourable weather conditions' without elaborating on the definition of 'favourable' (Foster & Gent 1996; JNCC 2003; NCC 1983). This chapter has provided the first scientific evidence that defines 'favourable weather conditions'.

Between emergence from overwintering and mating (in early spring), the presence of male sand lizards was strongly linked to temperature and time of day (table 2.12). The linear model suggests the males were not selecting a specific range of temperatures in which to bask (figure B.1, appendix B) but that more males were seen at higher temperatures. This fits in with findings by House & Spellerberg (1983) that males need to elevate their body temperatures before mating to increase the rate of sperm development during spermatogenesis before mating. Time of day strengthens the fit of the linear temperature model (table 2.12) and so influences the number of males observed. Later in the season day length is longer so the lizards have a longer time period to be selective about the specific conditions in which they bask. This could explain why time of day does not feature in any of the best predictor models for either male or female sand lizards later in the season. Earlier in the season the lizards could be constrained by the short day length and forced to maximise their basking opportunities during daylight or alternatively earlier in the season the warmest temperatures could be associated with a certain time of day.

The visibility of post-mated males was best predicted by the quadratic model of solar radiation and wind speed (table 2.12) and the models which contained temperature as a predictor of male sand lizard presence were poor fits to the data (table 2. 5). I suggest that wind speed reduces the ambient temperature, providing more favourable conditions for the lizards to bask openly in sunny conditions. This would agree with findings from Amat *et. al.* (2003) that more sightings of male sand lizards later in the season are found at lower temperatures. After sand lizards have mated the ambient temperatures are not restricted to the lower levels recorded in March and April and the lizards do not have to bask openly in direct sunlight for thermoregulation. The lizards can regulate their temperatures by exploiting the warmer ambient air temperatures and bask in the small pockets of light which penetrate the vegetation, which would also reduce their exposure to

predation. Models containing air temperature after the lizards have mated are very poor indicators of lizard presence for both sexes (tables 2.5, 2.7, 2.8, 2.9) adding some scientific support to the anecdotal evidence that sand lizards are not commonly seen in continuous hot and bright conditions typical of the summer months in southern England. Instead the lizards are likely to be selecting areas where the temperatures are cooler such as the shaded canopies and burrows beneath ground (see Chapter 3), and if the lizards are indeed seeking a temperature reduction they will be unavailable for detection resulting in the observed zero counts.

The presence of female sand lizards between emergence from their winter retreat and mating in early spring is positively linked to the quadratic model of ultra-violet levels, and indicates the females are selecting basking conditions with higher UV levels (table 2.12). This could be linked to the synthesis of vitamin D3 which in reptiles requires UVB light to produce pre-D3. The conversion of pre-D3 vitamin into D3 is a slow, heat-dependent process. During the conversion to D3 some pre-D3 vitamin is also converted into the hormone calcetriol which is essential for calcium regulation, and is vital to maintain organ functionality (Baines *et al.* 2006). Perhaps the females are basking in conditions suitable for the synthesis of pre-D3 for production of calcetriol prior to egg fertilisation. Once mated, the gravid females are then most strongly associated with the quadratic model for surface temperatures in the sun and wind speed. The females could now be synthesising D3 for growth, using the warmth from the soil surface, and also producing calcetrol as egg development in lizards requires a lot of calcium (Herbert *et al.* 2006).

Egg laying is a physically demanding task for females and we can speculate that to minimise the risk of overheating females would choose cooler conditions in which to exert themselves and the best predictor model contains humidity (table 2.12) which has a strong negative correlation with solar radiation (appendix B, table B.1). For the remainder of the season the presence of females is positively linked to the quadratic form of ultra-violet light and wind speed (table 2.9). Although wind speed reduces the ambient temperature it will not necessarily be associated with light levels. Hence it appears that the females are selecting

changeable conditions within their preferred ultra-violet range as in the summer months the UV index often exceeds these values (figure B.7, appendix B).

This study shows (with the exception of egg laying females) that light and temperature variables as those most strongly associated with sand lizard presence and table 2.3 shows that lizards are seen in warmer, brighter and windier conditions, in comparison to those in which no lizards were observed.

The weather conditions leading up to the time of survey are also believed to have an influence on the presence or absence of sand lizards (Ceirans 2006; Dent 1986; Foster & Gent 1996; Herczeg *et al.* 2003; Strijbosch & Creemers 1988). A relatively high number of sand lizards can often be observed openly basking in the first clear, sunny and dry conditions after periods of continuous rain. The influence of historic weather conditions on the presence of male and female sand lizards was deemed beyond the scope of this chapter, but nevertheless would be a valuable future research project.

Detection probabilities

The detection probability of males decreases after mating. This was anticipated based on personal field observations, and it was further emphasised by the large amount of time the males spend openly basking in preparation for mating and also competing for mates. After mating the males no longer need to bask to develop sperm, and since emergence from overwintering the ambient temperatures will have increased. In fact, the male lizards are probably avoiding the higher temperatures and light levels found in the warmer months, and instead are selecting basking conditions with lower temperatures and light levels (early morning sun and late afternoon) which are nearer to the environmental conditions found in spring.

The detection probability of females is higher after mating, in agreement with the previously published studies which have found that gravid females are more frequently observed basking than non gravid females (Dent 1986; Edgar 2002; Foster & Gent 1996; JNCC 2003; Robert *et al.* 2006). However, the high detection probability (85%) observed for egg laying females is unlikely to be observed in the

field. The number of females in the vivarium is artificially high and the perimeters of sand are clearly visible, so several egg laying females can be simultaneously observed within a few seconds, this would be a highly unusual occurrence in the field.

Sand lizards are a difficult species to survey because of their fluctuating detection rate. This chapter has shown that the detection probabilities of males and females vary at different stages of their reproductive cycle (tables 2.10 & 2.11) and are influenced by different environmental variables. Future sand lizard surveys should aim to monitor populations at times of year and in conditions that maximise the detection probabilities of both male and female sand lizards, which will ultimately increase the chance of an observation. The times and conditions which maximise the detection probabilities of male and females sand lizards differ. Simply, surveys should be conducted for males before the mating season and surveys for females should be conducted after the mating season.

Several surveys from the captive population returned zero counts even though we know they are present! This is an illustration of how sand lizard census surveys could easily provide false absence records for this species when it is actually present. This emphasises the need to record additional co-variables (environmental variables) when conducting sand lizard surveys to identify areas that were surveyed in conditions where the detection probabilities were likely to be low, or the animal unavailable for detection. Conversely this will also assist in identification of true species absence in areas surveyed in optimal conditions and times of the year without an observation.

This chapter has investigated how the detection probabilities of male and females sand lizards varies with reproductive stage and which environmental variables are most strongly associated with the presence of male and female sand lizards at each reproductive stage. Future monitoring methods need to be able to either consistently direct sampling effort at times and in conditions which maximise the detection probabilities of sand lizards; or alternatively, develop a method to interpret survey results taking account of the factors presented in this chapter which influence the detection probabilities. This could be implemented by

recording environmental variables at the time of survey and creating an index based measure linked to the detectability of the lizards. Adopting these sampling strategies would start to introduce survey consistency between census counts and allow comparative analysis between results.

3 Temperature variation in heathland vegetation structures and the behaviour of sand lizards.

3.1 Introduction

Reptiles are ectotherms and manage their body temperatures behaviourally by orientation, posturing, shuttling (heliothermic behaviour) and they obtain heat from direct contact with their surroundings (thigmotheric behaviour). Sand lizards can survive over a relatively wide range of body temperatures. Like all species of reptile it has a 'preferred or voluntary body temperature' (PBT) which it endeavours to maintain even though the actual temperature of the individual may fluctuate dependent on external conditions (Pianka 1986; Spellerberg 1982). Table 3.1 summarises the published research relating to sand lizard body temperatures and the range of air temperatures in which they have been observed in Europe.

Critical and voluntary minima and maxima temperatures have been identified for several reptile species. Values which exceed the critical are lethal, and body temperatures within the voluntary range will force the animal to seek either a temperature rise or a reduction (Cowles & Bogerts 1944; Spellerberg 1982). The maintenance of a body temperature within a species' voluntary range is essential for basic functions including digestion, reproduction, chemosensory activity, locomotion and metabolism (Avery 1979; Bauwens *et al.* 1995; Ceirans 2006; Nicholson 1980; Spellerberg 1974, 1982).

The selection of microhabitats, hence microclimates, plays an important part in temperature regulation of ectotherms. Reptiles are rarely encountered basking in the same location at different times of the day as thermal conditions associated with a particular microhabitat are not constant. Sand lizards are commonly observed in areas of dry heath with high levels of structural diversity comprising open ground and heather stands of different ages in areas with local topographical variation and warm south facing slopes (Corbett & Moulton 1998; Dent 1980, 1986; Foster & Gent 1996; House 1980; NCC 1983; Spellerberg 1975). Research suggests that the association of *L. agilis* with these structurally complex areas

(Foster & Gent 1996; House 1980; JNCC 2003; Moody 2007) is caused by high numbers of invertebrates (Nicholson 1980) and the range of available microclimates (Amat *et al.* 2003; Dent 1986; Foster & Gent 1996; House 1980; NCC 1983). As sand lizards have a limited home range on heathlands (Nicholson & Spellerberg 1989) they need to exploit the characteristics of localised vegetation in combination with abiotic features to meet their thermoregulatory needs.

Table 3.1. Summary of published temperatures in relation to *L. agilis* in European countries.

Reference	Temperature detailed in study
House <i>et al.</i> (1980) (UK)	Mean body temperature of sand lizards 25.3°C: Range of recorded values 12.5 °C – 34.0 °C. Mean air temperature lizards observed 18.9 °C; Range 7.0 °C – 28.5 °C. Mean ground surface temperatures in which lizard observed 21.9 °C; Range 11.0 °C – 38 °C. March –May mean body temperatures of <i>L. agilis</i> 25.4 °C and June – September mean <i>L. agilis</i> body temperature 29.0 °C.
Spellerberg (1976) (UK)	<i>L. agilis</i> mean basking temperature 26.3 °C: Range 18.0 °C - 43.0 °C <i>L. agilis</i> mean body temperature in normal activity 31 °C - 32 °C. Critical minimum temperature 5.9 °C or 3.0 °C when acclimated.
Lieberman & Pokrovskaja (1943) (Russia)	Body temperature for active <i>L. agilis</i> of 33°C
Bauwens <i>et al.</i> (1995) (SW Europe)	Critical maximum temperature of 43.9 °C. Median preferred body temperature of 34.7 °C. Lower preferred body temperature of 32.0 °C. Optimal temperature for maximum sprint speed 36.5 °C

Barclay-Estrup (1971) investigated surface and underground temperatures and light ranges associated with different aged heather stands (pioneer, building, mature and degenerate phases) in a heath community. Minimum and maximum surface temperatures were recorded weekly for each heather phase and continual temperature readings were obtained, from which weekly minima and maxima and daily mean values were calculated. Instrumental and technological constraints

restricted the recording of hourly temperatures in each heather phase to a single 24 hour period in June 1965. Any conclusions drawn from this work must be interpreted with some caution as the data are weekly or mean daily readings from a single day. The results indicate differences in temperature associated with different heather phases and further exploration into these temperature differences may assist our understanding of how sand lizards use the different structures for thermoregulation. In turn, if it is possible to identify which structures provide optimal microclimates for sand lizards at different times of the day and year, survey effort can be directed towards these heathland increasing the detection probability, providing more realistic abundance estimates (see Chapters 1 & 2).

The work in this chapter considerably expands on the work of Barclay-Estrup (1971) by continually recording, every 15 minutes, the temperature below, at the surface and within the canopies of different aged heather structures (which sand lizards are known to frequent) over a period of 22 months.

This chapter explores the thermal properties and temperature ranges of different heather structures with season and time of day. The range of temperatures in different heather phases and strata is then compared to the temperatures of substrata selected by basking sand lizards. Sand lizards inhabit areas of heathland with high degrees of structural diversity comprising of mosaics of different aged heather stands and areas of open ground. Between them these diverse structures offer a range of thermal gradients and variety of microhabitats (Amat *et al.* 2003; Corbett & Tamarind 1979; Dent 1986; House & Spellerberg 1982, 1983; House 1980; JNCC 2003; Moody 2007; Nicholson 1980; Strijbosch 1986; Strijbosch & Creemers 1988). These diverse mosaics are the 'target' habitat of heathland management for *L. agilis* in the UK but there is little understanding of why lizards favour structural diversity. This investigation provides the first temperature-based evidence as a supporting explanation. The chapter also explores whether there is a relationship between underground, surface and canopy temperatures and the observed presence of *L. agilis*. The discovery of such a relationship could be used to formulate guidelines on when to conduct census work and where to direct survey effort (where to look) to increase the

possibility of observing a basking lizard. This is currently a major challenge facing herpetologists.

Thus the aims of this chapter are to describe and characterise the thermal properties of key heathland vegetation structures and to interpret these in terms of the thermoregulatory requirements and behaviours of sand lizards.

3.2 Methods

Data collection was carried out at Merritown Heath (appendix A for site description) and underground, surface and canopy temperatures were logged for open ground (figure 3.1), in heather stands classified as mature (figure 3.2) and on degenerate heather (areas of mature heather with large dense canopies with no die back, figure 3.3) (cf. Barclay-Estrup, 1971). Temperatures were recorded by the Tiny Talk2 TK4014 temperature loggers every 15 minutes between February 2007 and December 2008. Figure 3.4 shows the location of the loggers. The temperatures of each stratum were measured at four different locations for replication and a total of 24 loggers were placed *in situ* in areas of Merritown Heath where sand lizards were present.



Figure 3.1. Data loggers *in situ* in open ground. The location of the loggers is shown by the red sticks



Figure 3.2. Data loggers *in situ* for a mature heather stand. The loggers are located in the canopy, at the soil surface and 10cm under the vegetation.



Figure 3.3. Data loggers *in situ* in a degenerate heather stand with a moss understorey. The location of the loggers is shown by the red sticks.

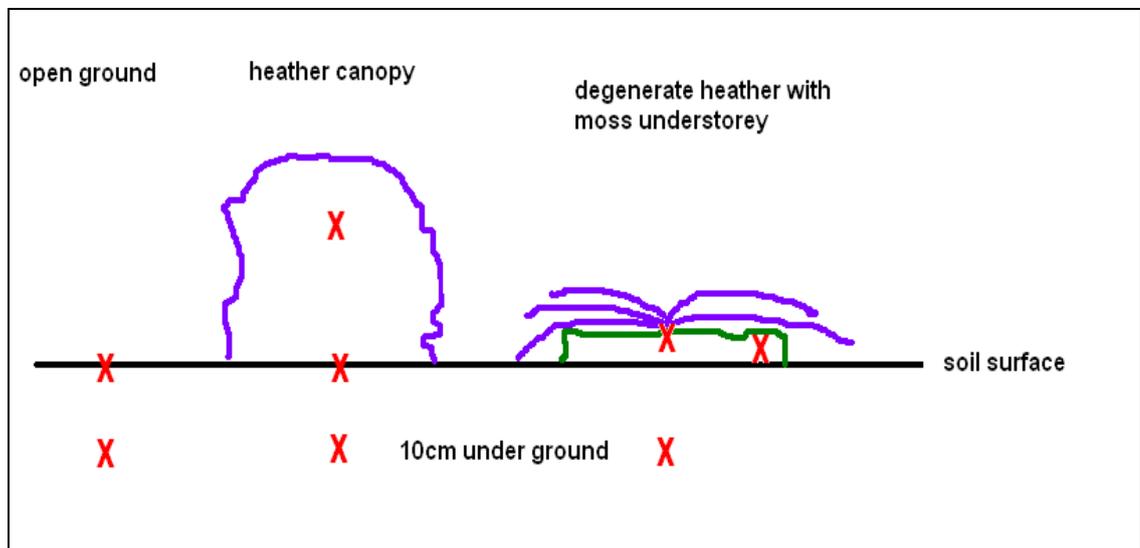


Figure 3.4. Schematic representation of the location of data loggers (red crosses) in heathland.

Monthly summary data were generated using all temperatures logged in the sand lizard active season between March 2007 and August 2007 between the hours of 6am and 10pm (night time records were excluded). *L. agilis* survey work was conducted during 2005, 2006 and 2007 where the substrata temperature where

sand lizards basked was recorded using a Mannix DLAF-8000 hand held electronic thermometer. These values were benchmarked against the monthly summary data from the temperature loggers.

To quantify the effect of strata and vegetation cover on temperature the data were split and considered with respect to time from sunrise and time to sunset (Pianka 1986). The monthly times for sunrise and sunset were taken on the 15th day of each month as detailed by Thorsen (2007) and for analysis all times were adjusted for British Summer Time.

The temperatures recorded by the data loggers within each heather phase were examined to describe the influence of strata on temperature. The variation in temperature between the vegetation structures was considered by direct comparison at fixed times. The range of temperatures recorded over a 24 hour period in 2007 are compared to those recorded over the same 24 hour period by Barclay-Estrup (1971) to determine whether an increase in temperature recording frequency using more advanced equipment increased the observed range, minimum or maximum values of the temperatures readings within the vegetation structures. Finally, the substrata temperatures on which basking sand lizards were observed were analysed against the mean temperatures from the replicates (at 15 minutes intervals between 6am and 10pm) for each vegetation structure by month, using the non-parametric Mann-Whitney U test (Fowler & Cohen 1990). This would allow us to identify whether the median temperatures within a specific strata and vegetation type were statistically different to the median temperatures the lizards were selecting each month. The Mann-Whitney U test was selected as it does not require the distributions of the two comparative data sets to be similar, the sample sizes to be equal or the data to be paired (Fowler & Cohen 1990). Further analysis of the data set was problematic and complex due to issues with the independence of the nature of continuous temperatures and would require highly advanced time series analysis which is beyond the scope of this chapter (Forster 2007). The results of the Mann-Whitney U-test (table 3.3) should be interpreted with some caution as the continuous temperature readings from the vegetation are not entirely independent (they depend on previous measurements

and restricted seasonally) and as such could be viewed by some to violate an assumption of independence (Forster 2007).

3.3 Results

Monthly mean temperature summaries and basking sand lizard substrata temperatures

The monthly mean, minimum, maximum and range of temperatures recorded in different strata of open ground, mature and degenerate heather varied over the survey season, with the highest monthly mean temperatures for open ground, mature and degenerate heather recorded in June, and the lowest in March (table 3.2).

Strikingly, the temperature within the degenerate canopy consistently had the largest range and the lowest minimum value every month. The lowest minimum recorded was -5.1°C and the maximum 38.8°C , both from the degenerate canopy and both in April. With the exception of August, the degenerate canopy provided the largest maximum temperature value in each month (table 3.2). However, the temperatures under the soil surface of the degenerate heather stands consistently had the smallest temperature range of each vegetation cover and stratum each month, with the largest being 6.7°C in April ranging between 6.5°C and 13.2°C .

The minimum temperature readings recorded at the soil surface for each canopy cover were always lower than the minimum values 10 cm below the soil surface. Consistently the largest underground temperature range was recorded under mature heather (table 3.2).

The monthly mean canopy temperatures of the mature and degenerate heather phases were consistently higher (per month) than the monthly mean surface and underground values. The monthly mean surface temperatures were consistently higher than the monthly mean underground temperatures despite the lower minimum values (table 3.2).

Table 3.2 shows *L. agilis* are basking over a wider range of temperatures in April and May in comparison to other months of the year, and basking at temperatures higher than the monthly mean temperatures recorded in the vegetation.

There appears to be no relationship or overlap between the minimum temperature recorded per month for each vegetation type and stratum with the temperature of substrata that the lizards select for basking (figure 3.5), suggesting that the minimum temperatures of vegetation should not be used to predict when and where *L. agilis* are likely to be observed basking. The lowest temperatures were recorded in the canopies of the mature and degenerate heather with the surface temperatures underneath the canopies only slightly higher (figure 3.5) suggesting that these canopies are unable to retain much heat.

The mean basking temperature of lizards recorded between 2005 and 2007 was significantly greater than the mean temperatures of each type of vegetation cover and strata recorded by the data loggers in 2007 (figure 3.6). The temperatures recorded in the vegetation were significantly different from the temperatures of substratum on which basking lizards were observed for each month (Mann-Whitney U test, $P < 0.0001$ in all cases, table 3.3. In March none of the mean temperatures approached the minimum observed substratum temperature on which basking lizards were observed. Thus, the monthly mean temperatures of vegetation are not good indicators as to where basking lizards are likely to be observed.

Although the relationships appear complex, the maximum temperatures recorded per month in the vegetation cover of different heather phases and strata are closer to the temperatures of the substrata used by basking *L. agilis* (figure 3.7). Their preferred basking temperature was generally below those recorded in the canopies and above those recorded underground. We can infer that the lizards may select microclimates with higher temperatures when the underground temperatures are below the temperature of substratum they select for basking.

Table 3.2. Mean monthly temperatures ($^{\circ}\text{C}$) 6 am – 10 pm, recorded in different heathland vegetation strata on Merritown Heath, Dorset, March – August 2007 and monthly mean temperatures of substrata of basking lizards observed during 2005, 2006 and 2007.

	<i>Substratum of basking L. agilis</i>	<i>Open Ground - Underground</i>	<i>Open Ground - Surface</i>	<i>Degenerate - Underground</i>	<i>Degenerate - Surface</i>	<i>Degenerate - Canopy</i>	<i>Heather - Underground</i>	<i>Heather - Surface</i>	<i>Heather - Canopy</i>
MARCH n=1984 (vegetation) n=32 (substrata temperatures)									
Mean	20.9	8.3	9.1	7.6	8.0	9.7	8.4	8.7	8.9
Range	8.9	8.8	15.8	3.9	15.6	33.9	17.8	22.4	24.7
Minimum	16.9	3.6	1.5	5.2	0.2	-4.5	0.3	-1.3	-1.8
Maximum	25.8	12.4	17.3	9.1	15.9	29.4	18.1	21.1	22.9
APRIL n=1920 (vegetation) n=226 (substrata temperatures)									
Mean	20.9	12.5	15.2	9.9	13.3	16.7	13.3	14.4	14.8
Range	16.0	12.8	24.2	6.7	26.5	44.0	25.7	32.1	33.9
Minimum	12.3	6.0	3.2	6.5	-0.7	-5.1	0.2	-1.9	-2.3
Maximum	28.3	18.7	27.4	13.2	25.8	38.8	26.0	30.2	31.7
MAY n=1984 (vegetation) n=194 (substrata temperatures)									
Mean	23.0	14.5	16.4	12.2	14.1	16.2	14.2	14.8	15.1
Range	15.5	12.4	23.4	4.9	24.4	38.4	22.6	28.5	29.8
Minimum	15.9	8.6	5.7	9.9	4.1	0.2	4.7	3.0	2.6
Maximum	31.4	21.0	29.1	14.7	28.5	38.6	27.3	31.5	32.5
JUNE n =1920 (vegetation) n=34 (substrata temperatures)									
Mean	26.0	17.6	19.6	14.6	16.5	18.8	16.6	17.3	17.6
Range	6.9	10.7	20.0	4.4	17.2	31.5	17.7	22.1	23.8
Minimum	16.6	12.4	10.4	11.9	8.0	4.8	8.3	7.0	6.7
Maximum	32.8	23.0	30.4	16.3	25.3	36.3	26.0	29.2	30.5
JULY n =593 – 1981 (vegetation) n=17 (substrata temperatures)									
Mean	27.3	16.9	18.3	14.8	15.6	16.7	15.7	16.0	16.1
Range	6.9	8.3	17.1	3.3	13.5	25.9	14.2	17.8	19.3
Minimum	23.2	12.7	10.2	13.0	7.5	3.1	7.9	6.1	5.7
Maximum	30.1	20.9	27.3	16.3	20.9	29.0	22.1	24.0	25.0
AUGUST n=1984 (vegetation) n=15 (substrata temperatures)									

Mean	27.3	17.1	18.8	14.6	15.9	16.8	15.8	16.2	16.3
Range	5.8	10.3	19.5	3.9	16.8	24.9	15.2	19.0	19.7
Minimum	23.6	12.5	10.4	12.5	7.9	4.3	8.2	6.8	6.4
Maximum	29.4	22.9	29.9	16.4	24.7	29.2	23.4	25.8	26.1

Table 3.3. Mann-Whitney U test statistics for the comparison of temperatures of substratum of basking lizards with those recorded in different strata of vegetation between March and August 2007. All comparisons were significantly different at $P < 0.0001$.

<i>Mann-Whitney test statistics for the temperatures at which basking lizard were observed against the temperatures recorded in the different strata.</i>	Open Ground - Underground	Open Ground - Surface	Degenerate Heather - Underground	Degenerate Heather - Surface	Degenerate Heather - Canopy	Mature Heather - Underground	Mature Heather - Surface	Mature Heather - Canopy
Mann-Whitney U – March Vegetation n = 1984, Lizard n = 32	0.00	19.00	0.00	0.00	3252.00	0.00	0.00	73.00
Mann-Whitney U – April Vegetation n = 1920, Lizard n = 226	8442.00	84092.00	155.00	50669.00	149315.00	51.00	13930.00	98020.00
Mann-Whitney U – May Vegetation n = 1984, Lizard n = 194	6368.00	50792.00	0.00	18587.00	63819.00	0.00	4796.00	47256.00
Mann-Whitney U – June Vegetation n = 1920, Lizard n = 34	2572.00	8338.00	0.00	2040.00	8985.00	0.00	1433.00	7279.00
Mann-Whitney U – July Vegetation n = 593-1981, Lizard n = 15	0.00	307.00	0.00	0.00	60.00	0.00	0.00	66.00
Mann-Whitney U – August Vegetation n = 1984, Lizard n = 15	0.00	1367.00	0.00	10.00	465.00	0.00	0.00	411.00

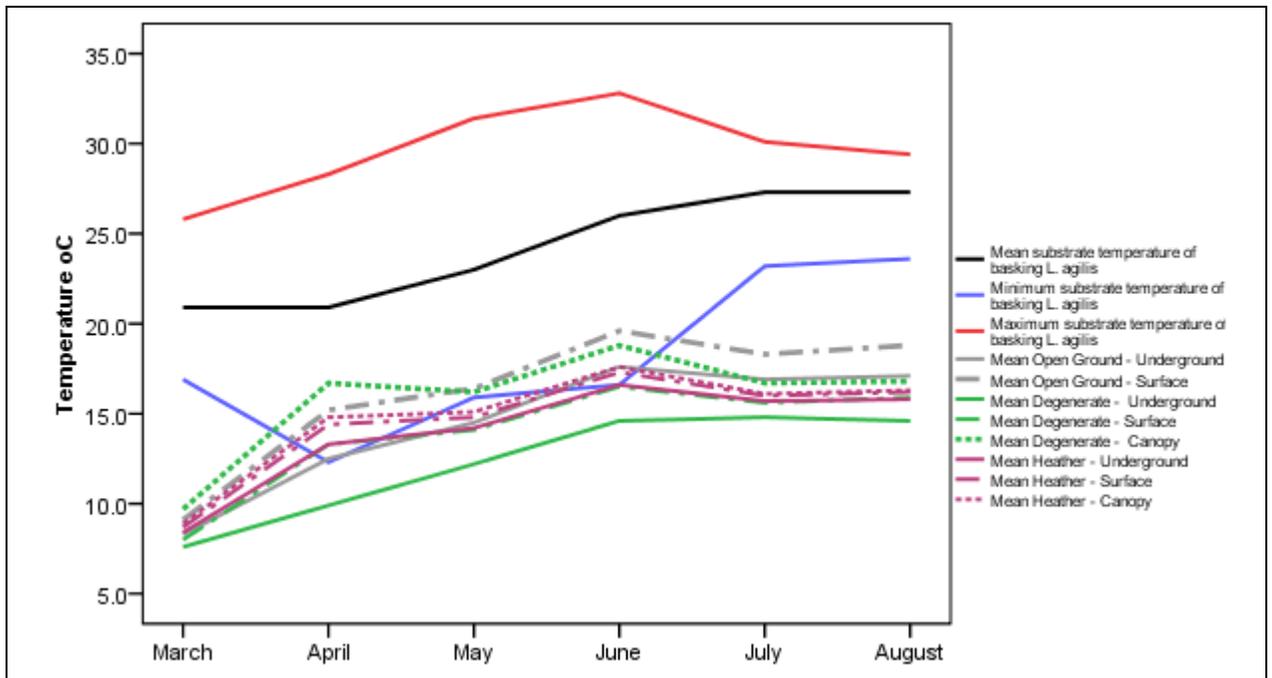


Figure 3.5. Monthly minimum temperatures recorded over different vegetation cover and strata between 6 am and 10 pm at Merritown Heath during 2007. Also shown are the mean, minimum and maximum temperatures of the substratum on which basking *L. agilis* were observed during 2005, 2006 & 2007.

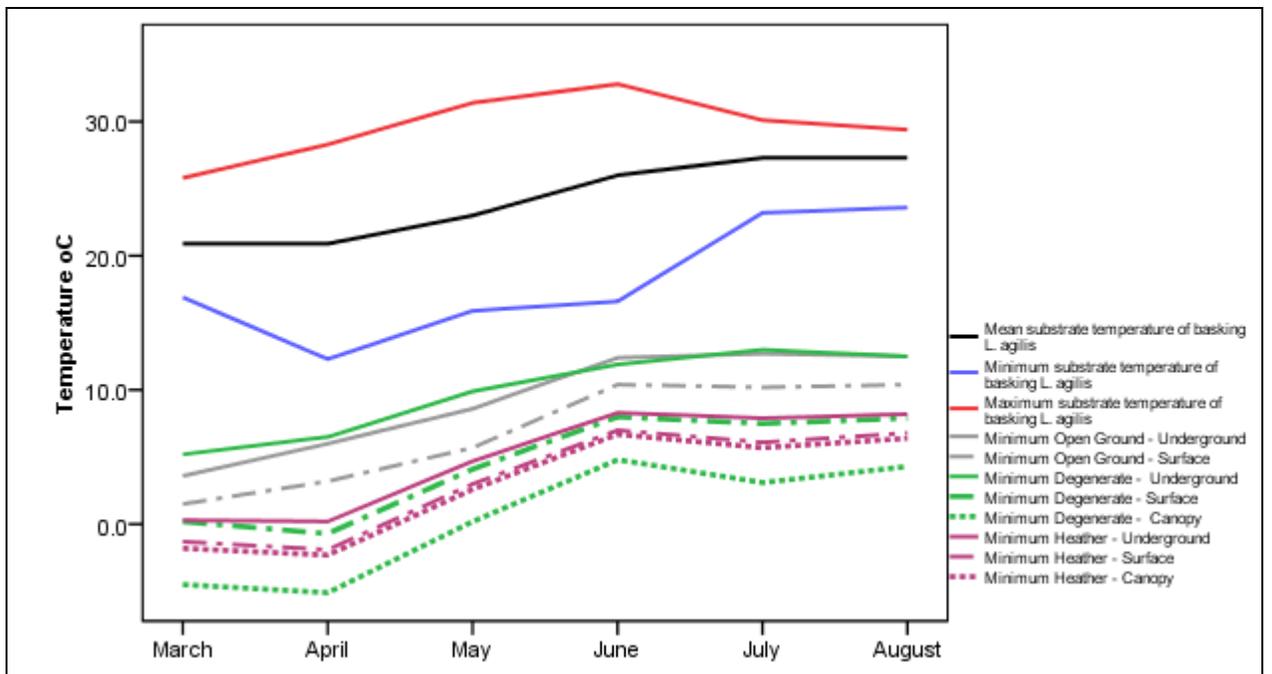


Figure 3.6. Monthly mean temperatures recorded over different vegetation cover and strata between 6am and 10pm at Merritown Heath during 2007. Also shown are the mean, minimum and maximum temperatures of the substratum on which basking *L. agilis* were observed during 2005, 2006 & 2007.

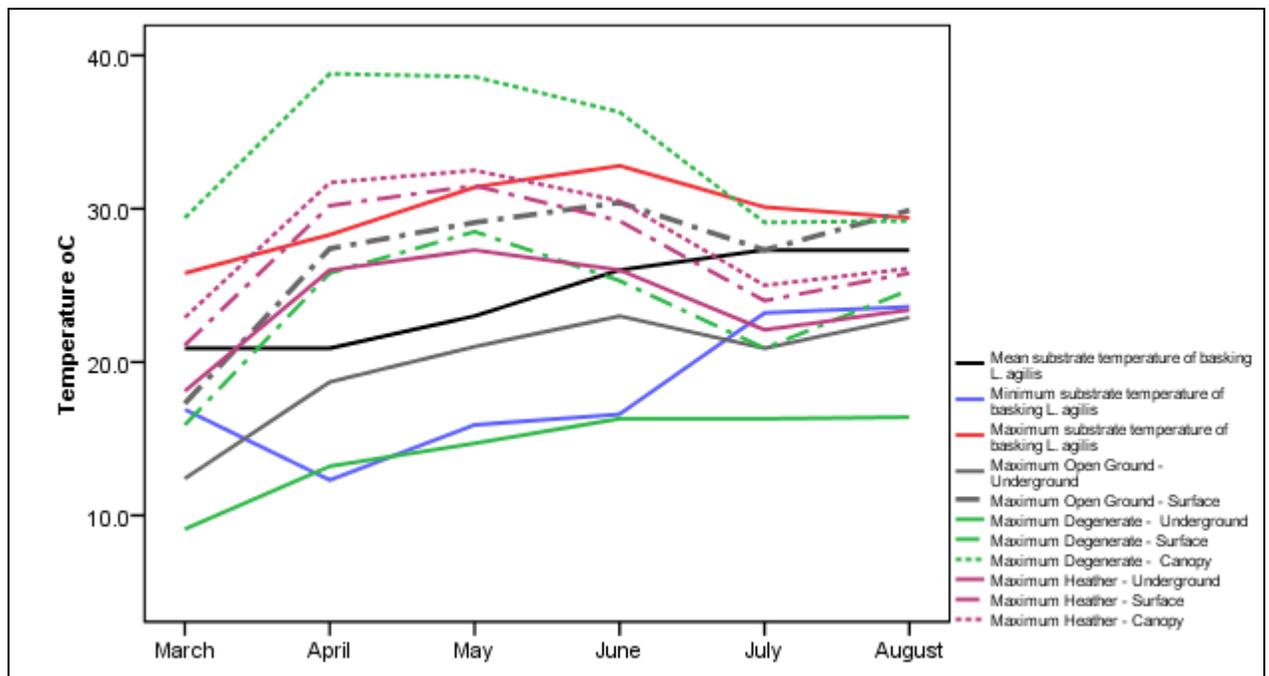


Figure 3.7. Monthly maximum temperatures recorded over different vegetation cover and strata between 6am – 10pm at Merritown Heath during 2007. Also shown are the mean, minimum and maximum temperatures of the substratum on which basking *L. agilis* were observed during 2005, 2006 & 2007.

Monthly and daily temperature summaries

Figures 3.8 a-r show the mean temperatures from the replicates recorded every 15 minutes according to strata and time period. Figure 3.9 a-r shows the mean monthly temperatures recorded between March and September 2007 in relation to sunset and sunrise for each habitat and strata under study. Detailed observations from these two figures are presented in table C.1 Appendix C and summarised with the key interest points in table 3.5.

General observations for open ground

Not surprisingly, the temperatures recorded on and beneath the soil surface increase between March and August. A larger range of temperatures was recorded at the soil surface and underground at sunset – 4 hours, midday, and sunset -1 hours, than those recorded nearer sunrise (figures 3.8 & 3.9 a, d, g, j, m, p). After midday, the recorded soil surface temperatures are consistently higher than the underground temperatures. At sunrise, sunrise + 2 hours and sunrise + 4 hours the underground

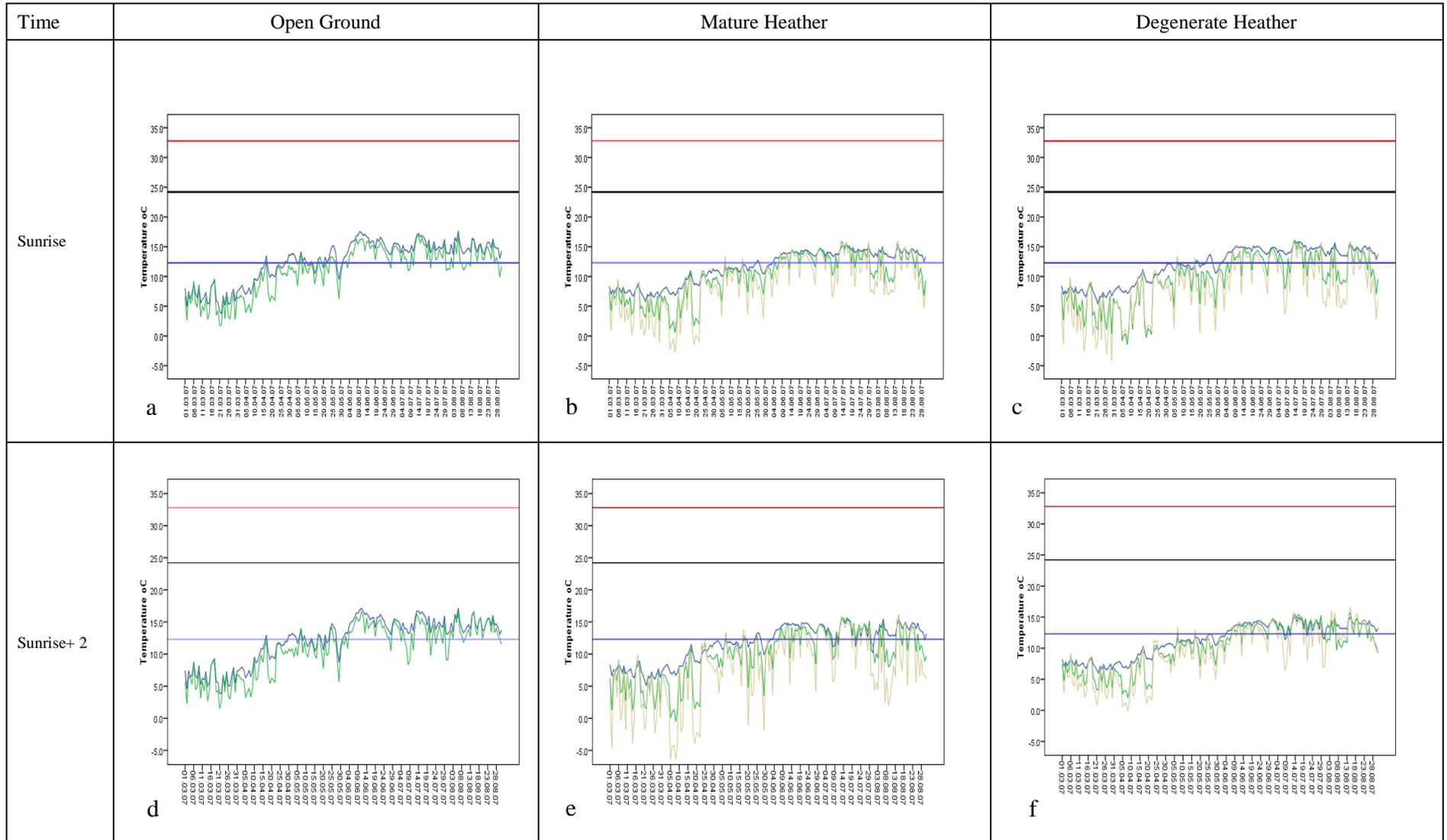
temperatures are consistently higher than the soil surface temperatures (figures 3.8 & 3.9 a, d and g).

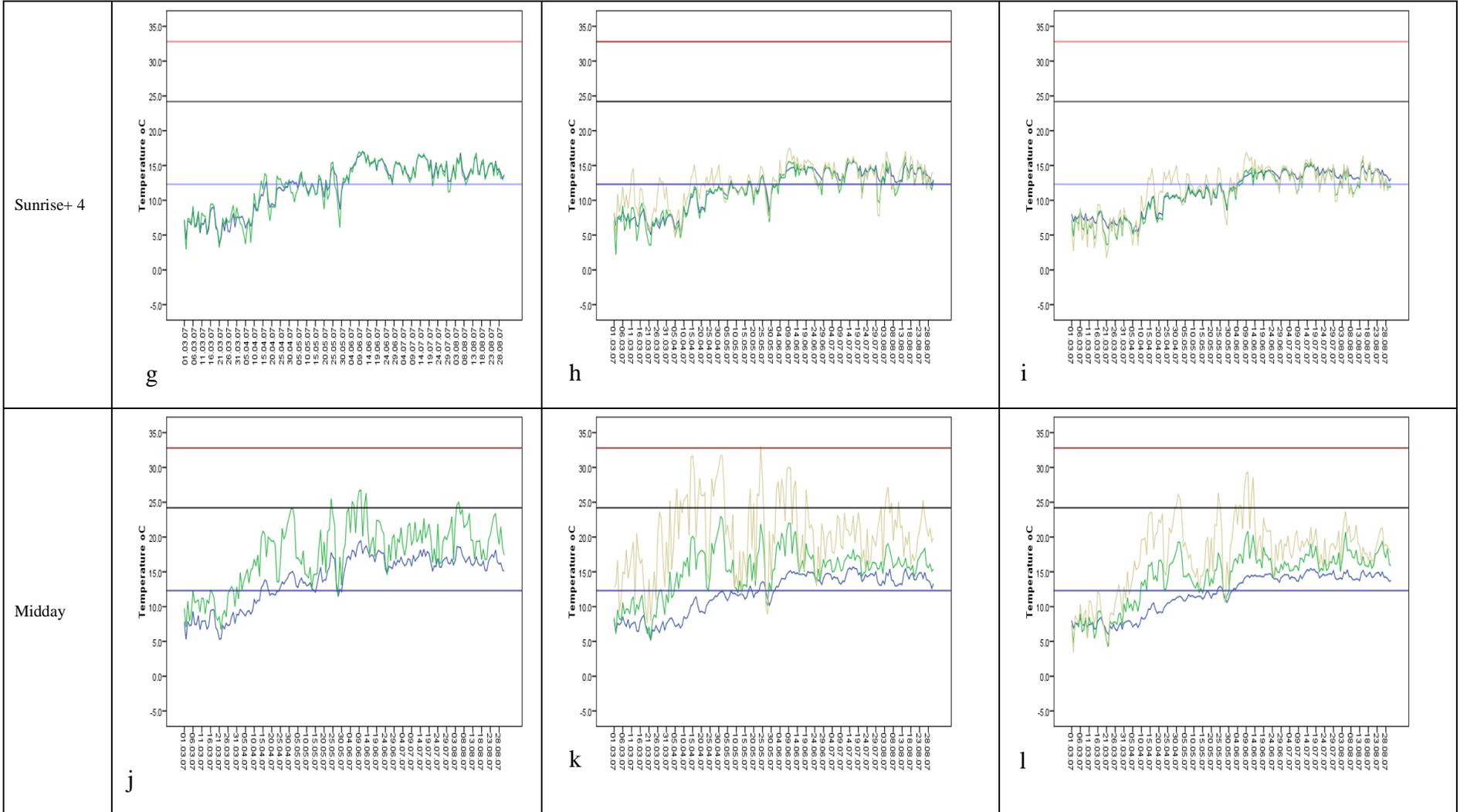
General results for mature heather

The temperatures recorded at the surface and underground demonstrate an increasing trend as the season progresses. The temperatures recorded in the canopy have the most amplitude and the extreme minima at sunrise, sunrise + 2 hours (figures 3.8 & 3.9 b and e) with the extreme maxima at midday, sunset – 4 hours and sunset – 1 hour (figures 3.8 & 3.9 n and q). The temperatures recorded between each stratum at sunrise + 4 hours (figures 3.8 & 3.9 h) display the least difference and those recorded at midday (figures 3.8 & 3.9k), sunset – 4 hours (figures 3.8 & 3.9n) and sunset – 1 hour (figures 3.8 & 3.9q) have the largest temperature variation.

General results for degenerate heather

The daily temperatures at the surface and underground gradually increase each month between March and August. The temperatures of each stratum follow the same trends for each time period (figures 3.8 & 3.9 c, f, l, o and r). At midday and sunset – 4 hours there is a larger difference in temperatures between strata, and at these times the degenerate canopy shows the largest temperature variation and range (figures 3.8 & 3.9 l and o).





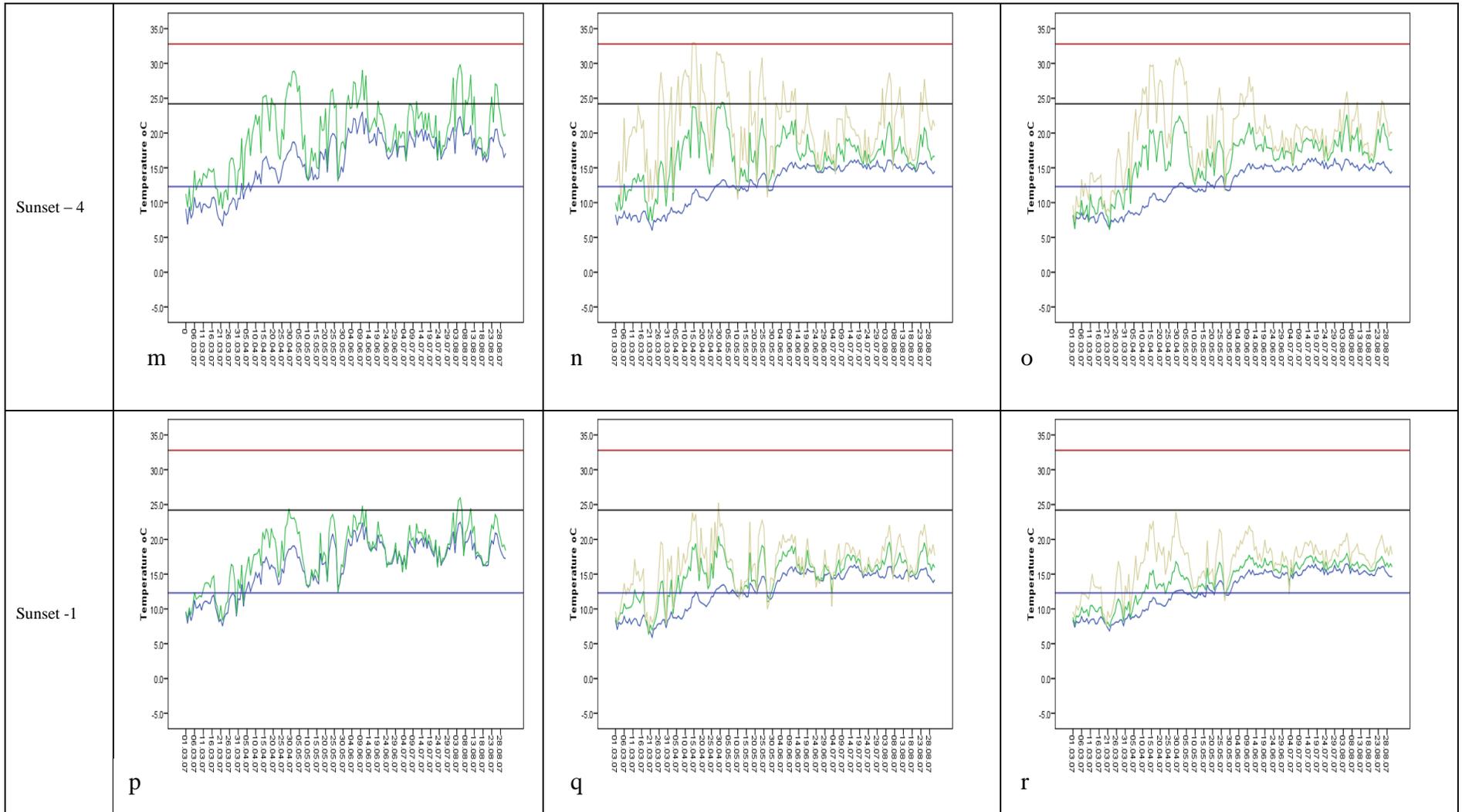
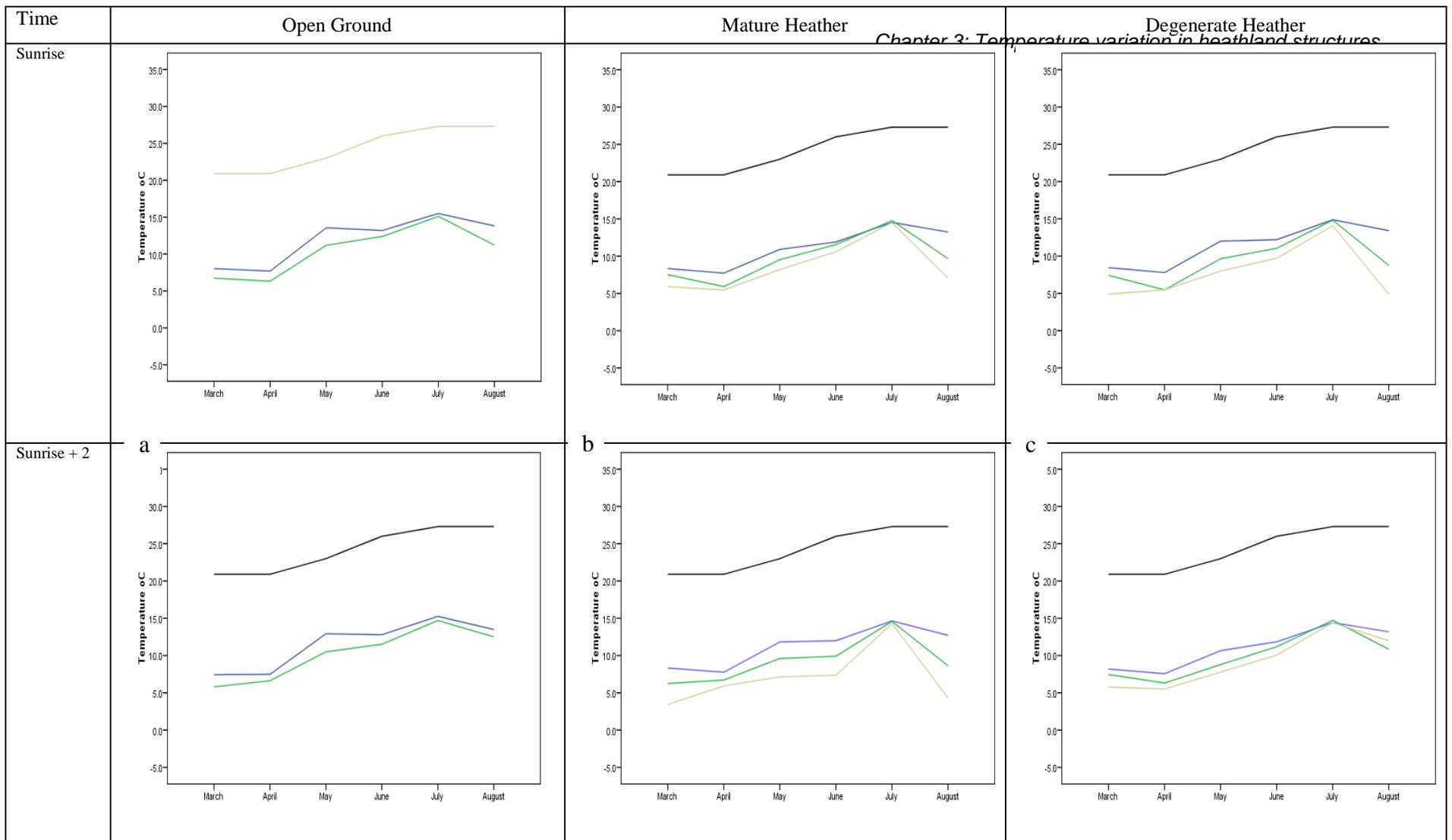
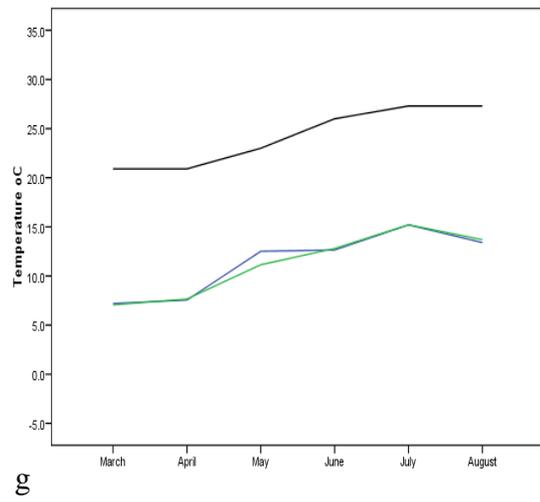


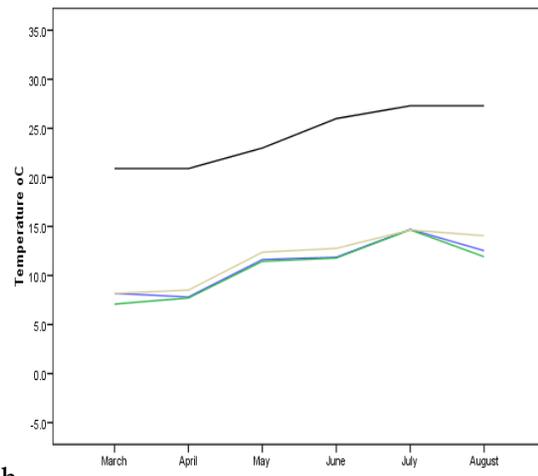
Figure 3.8. Mean temperatures (n=3) recorded every 15 minutes for each stratum for fixed time periods in relation to sunrise and sunset. The underground temperatures are represented by the blue line, surface by the green line and canopy temperatures by the beige line. The horizontal lines represent the minimum (blue) substratum temperature (12.3°C), the mean (black) temperature (24.2°C) and the maximum (red) temperature (32.8°C) at which basking *L. agilis* were observed during census counts during 2005, 2006 & 2007.



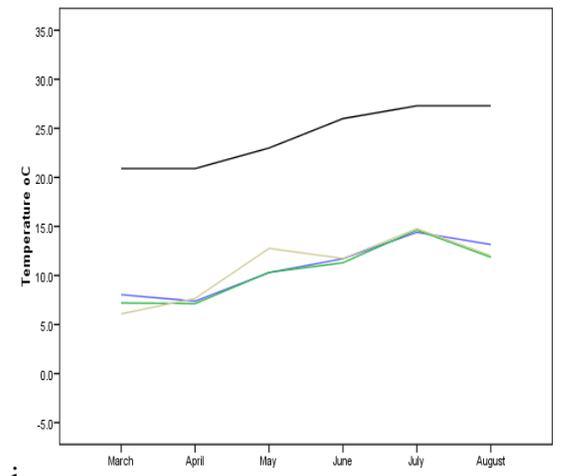
Sunrise + 4



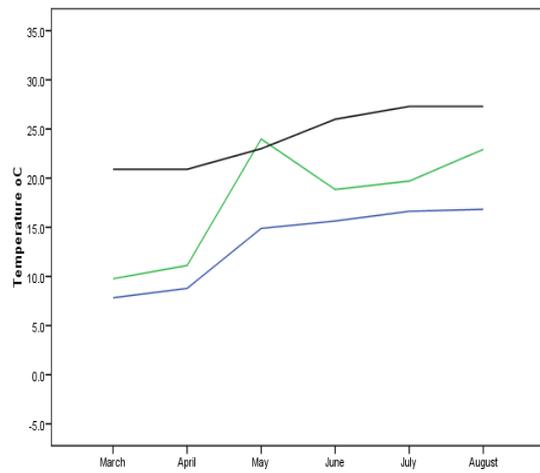
h



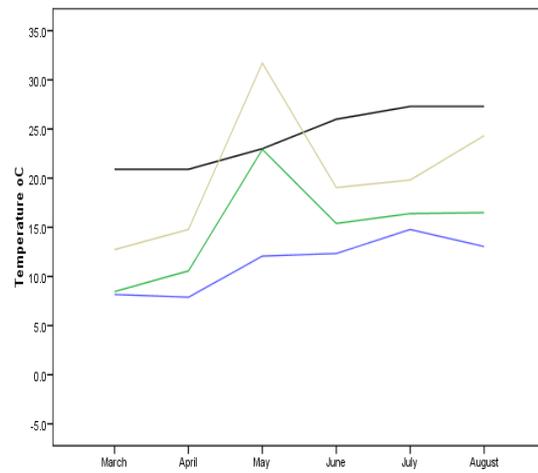
i



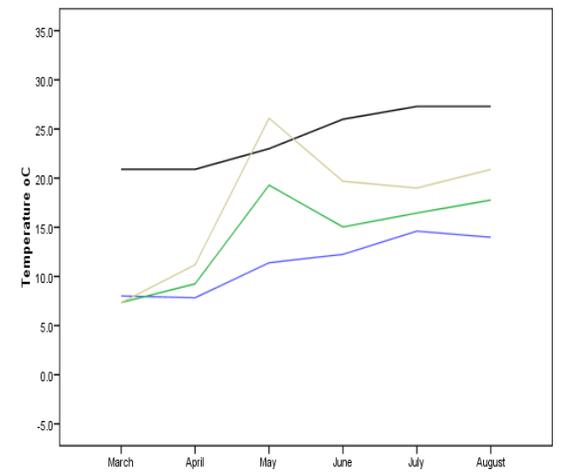
Midday



h



i



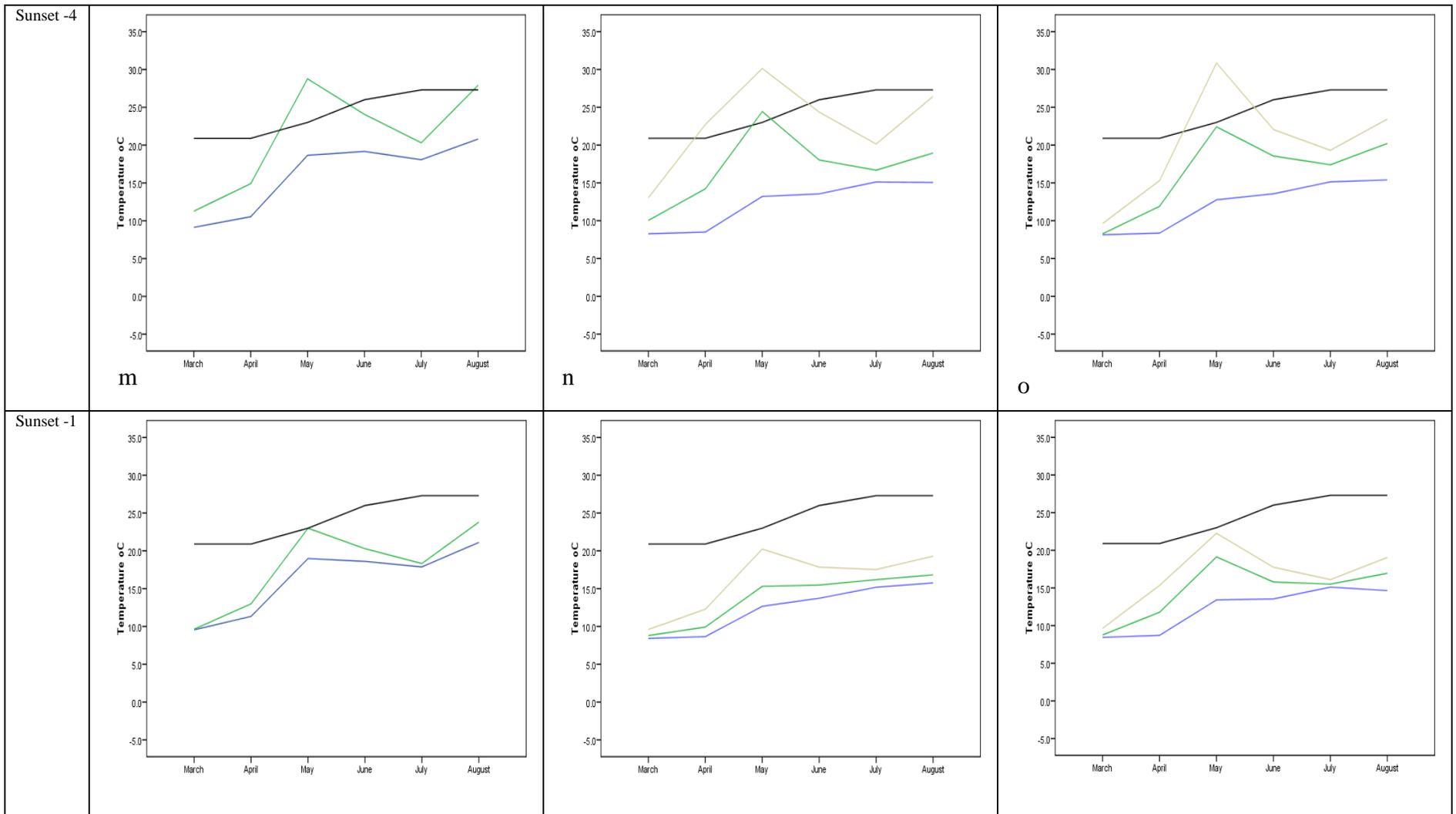


Figure 3.9. Mean monthly temperatures (n=3) for each stratum at different time periods in relation to sunrise and sunset. The blue lines represent the underground, the green the surface and the beige the canopy temperatures. The mean monthly substratum temperature which basking *L. agilis* were observed during census counts undertaken in 2005, 2006 & 2007 is represented by the black line.

Table 3.4 summarises the key points of interest from Table C.1 (appendix C) which include: High temperatures in the mature heather canopy early in the season at sunrise + 4 hours and high temperatures at midday and sunset – 4 hours; low and most varied temperatures at the surface and canopy of the mature and degenerate heather at sunrise and the highest surface and underground temperatures at midday on open ground.

Table 3.4. Observations of note when contrasting the temperatures recorded in different vegetation cover and strata at fixed times of the day

	<i>Sunrise</i>	<i>Sunrise + 2 hours</i>	<i>Sunrise + 4 hours</i>	<i>Midday</i>	<i>Sunset - 4 hours</i>	<i>Sunset -1 hour</i>
General Observations			Minimal temperature difference between vegetation cover and strata, temperature plots follow similar patterns (figures 1.8g, h and i)		Temperature plots within each vegetation type are similar and only differ in amplitude explicable by strata (figures 1.8m, n and o)	
UNDERGROUND						
Open Ground		Most frequent temperature fluctuations (figure 1.8d)		Highest underground temperatures (figure 1.8j)	Highest underground temperatures (figure 1.8m)	Highest underground temperatures (figure 1.8p)
Degenerate Heather				Similar temperatures as found for mature heather underground (figures 1.8 k and l)		
Mature Heather	Lowest underground temperatures			Similar temperatures as found for degenerate underground (figures 1.8 k and l)		
SURFACE						
Open Ground	Lower and more fluctuating temperatures than recorded underground for open ground (figure 1.8a)	Most frequent temperature fluctuations (figure 1.8d)		Highest surface temperatures (figure 1.8j)	Highest surface temperatures (figure 1.8m)	Highest surface temperatures (figure 1.8p)
Degenerate Heather	Large amount of temperature variation with minima extremes (figure 1.8c)					
Mature Heather	Large amount of temperature variation with minima extremes (figure 1.8b)					Temperatures are higher and of greater range than those recorded at the surface of the degenerate heather (figures 1.8q and r)
CANOPY						
Degenerate Heather	Large amount of temperature variation with minima extremes (figure 1.8c)			Higher temperatures than recorded at the surface and underground for degenerate heather cover (figure 1.8l)		
Mature Heather	Large amount of temperature variation with minimum extremes (figure 1.8b)	Greatest range of temperatures with extreme minima (figure 1.8e)	Highest temperatures of all strata and covers early in the season (figure 1.8h)	Very high temperatures (figure 1.8k)	Very high temperatures (figure 1.8n)	

3.4 Discussion

This chapter investigated the influence of vegetation cover on underground, surface and canopy temperature for three types of heathland habitat: open ground, degenerate heather and mature heather. Each habitat type and stratum had a temperature range which differed seasonally and daily when considered in relation to sunrise and sunset times (table 3.2 and figures 3.8a-r – 3.9a-r). Combined, these structures offer a range of different microclimates which not only provide a constant source of prey items (Nicholson 1980; Telfer 2006) but also offer a range of conditions suitable for thermoregulation through the season. I believe this to be the main explanation as to why sand lizards are most commonly associated with mosaics of different aged structures of heathland vegetation

Reptiles actively maintain their preferred body temperatures by thermoregulation in favourable environmental conditions. In conditions unsuitable for thermoregulation they assume the temperature of the environment; that is, they thermo-conform (Avery 1979). The visibility of *L. agilis* could be predicted in part by behavioural thermoregulation and thermo-conformity. If the temperatures in combination with the environmental factors of areas are not able to offer any thermoregulatory opportunities, *L. agilis* will remain undetected (most likely in their underground burrows) and assume the temperature of the surrounding environment.

This discussion will consider how sand lizards may use the different microclimates available in different heather structures seasonally and diurnally to predict where an observer is most likely to spot a sand lizard. Notable observations regarding the thermal properties of the different heather structures are highlighted. Other factors which could affect the seasonal location of lizards are discussed and comparisons are made between this and the only previous heathland vegetation temperature study, by Barclay-Estrup (1971).

Selection of basking areas by sand lizards

Here, I consider how sand lizards may shuttle between microclimates available through the different vegetation types and strata to either raise or lower their body temperatures (Avery 1979; Spellerberg 1982). These predictions are formulated by month, from the temperature data collected in this study and interpreted with respect to the temperatures of substratum on which basking lizards were observed. I have assumed the lizards will select the available microclimate(s) which provide a temperature range between the minimum and maximum (favouring those nearer the mean) substratum temperatures on which they were observed in the field. The monthly summary predictions of where sand lizards are likely to be observed are found for March in table 3.5, April in table 3.6, May in table 3.7 and June, July and August in table 3.8. This is evidence that structurally complex areas of heathland provide a large range of thermal gradients through the day which can be exploited by sand lizards regardless of the prevailing weather conditions. The availability of microclimates within the thermoregulatory range of sand lizards changes spatially and increases through the active season.

March

In the first week of March at midday and sunset-1, sand lizards should bask in the mature heather canopy as this is the only habitat that exceeds the minimum basking temperature threshold. It is very difficult to spot a sand lizard in the mature canopy and at this time of year many sand lizards were observed basking in the open. From the third week of March until the season ends, at sunset – 4 hours sand lizards would be basking on the surface of open ground and on the degenerate canopy (tables 3.5 – 3.8). In March none of the temperatures underground exceed the minimum recorded threshold, implying that once emerged from their winter retreat it would be thermally advantageous for the lizards to be above ground. *L. agilis* are often observed basking in the open in March before midday (Corbett & Moulton 1988; Dent 1980; Dent & Spellerberg 1987; Foster & Gent 1996; JNCC 2003; NCC 1983). This

implies that at this time of year sand lizards do not select the basking conditions primarily on ambient temperatures of the habitat. More critical, perhaps, is the incoming amount of solar radiation (Spellerberg 1982) to regain condition post overwintering by vitamin D3 synthesis (Nicholson 1980) and spermatocytosis and spermatogenesis. Chapter 2 indicates that this is how the females are behaving as prior to mating female sand lizards are most strongly associated with UV light (table 2.6, Chapter 2) but however, it the males are still responding strongly to temperature rather than light related variables (table 2.4, Chapter 2).

Chapter 2 identified a linear temperature model as the best predictor of male sand lizard presence suggesting that temperature does have a stronger influence over the presence of male sand lizards than solar radiation basking in the open. The presence of females

April

As with March, no minimum threshold values are exceeded prior to midday. Thus it can be inferred any lizards observed basking in the morning are not responding to the temperature of the vegetation but, more likely, light or perhaps light in combination with other environmental, biotic and behavioural factors (prey availability, humidity (water gain), territory establishment and mate searching). At midday *L. agilis* could be seen basking on open ground and the degenerate canopy but favouring the thermal conditions in the mature heather canopy. At sunset – 4 hours and sunset – 1 hour, the daytime underground temperatures for open ground exceed the minimum threshold from the first week of April and for the remainder of the season (tables 3.6 – 3.9) which implies that sightings of lizards will become less frequent as they spend more time below ground.

During the first week of April *L. agilis* are most likely to be observed in the mature heather canopy and from the second week are also seen basking on the degenerate heather canopy. By the final week they are also basking on open ground (but not under the mature canopy as the temperatures exceed the maximum threshold)

because the temperatures in these habitats are favourable (table 3.6). According to table 3.6, at sunset -1 hour in the last week of April *L. agilis* could be seen basking in the mature heather canopy, an observation recorded several times during field work over the three years.

May

From midday in week one of May (and from this point onwards) *L. agilis* could be seen on the open ground and also at the surface underneath the mature and degenerate canopies. By week two they should be visible on the degenerate canopy and mature heather canopy as the temperatures in these habitats are favourable, and by the third week in May (and for the rest of the season) the mature heather canopy temperatures regularly exceed the maximum threshold at which lizards have been seen basking. In week four the open ground surface and degenerate canopy temperatures are the most favourable at midday are favourable.

At sunset – 4 hours during May and for the rest of the season several habitat covers and strata provide temperatures fluctuating around the mean value at which basking *L. agilis* have been observed. This makes interpretation of where a lizard is likely to be observed a more complex matter as several places offer ideal thermal ranges (table 3.7). This supports both anecdotal and published (Corbett & Moulton 1988, 1998; Dent 1986; Edgar 2002; Foster & Gent 1996; House 1980; JNCC 2003; Nicholson 1980; Spellerberg 1974, 1975) evidence that *L. agilis* become harder to observe basking (either mosaic or in the open) after April.

June, July and August

The same comments for May are applicable for the remainder of the season (tables 3.8 & 3.9). Several habitat covers and strata exceed the minimum basking temperature and are favourable, making it difficult to reliably predict where lizards are most likely to be observed as the vegetation covers and strata offer a variety of ideal thermal ranges for thermoregulation. The presence of post-mated males and post-

egg laying females was not linked to temperature (table 2.5, Chapter). Perhaps because the temperature ranges within majority of microclimates are now favourable to their PBT's allowing the lizards to thermoregulate while remaining hidden by the vegetation. This could also provide the opportunity for the lizards to seek prey items and reduce the risk of predation. Predictions of where lizards are most likely to be observed depend not only on time of day but also season, the temperatures below ground and of the surrounding vegetation, and the prevalent weather conditions. All these factors will interact with prey availability and behavioural thermoregulation.

Season summary

Finally table 3.9 summarises the microclimates of the habitat types in relation to the time of year the minimum, mean and maximum temperatures of basking sand lizards were exceeded. Until the temperatures below ground exceed the minimum day time threshold it is advantageous for *L. agilis* to be above ground in the sun or in habitat areas with higher temperatures. Once the underground temperatures exceed the minimum basking temperature at it can be inferred that sand lizards do not need to be above ground for heat gain. The temperature underground then meets their thermoregulatory requirements and the risk from above-ground predators is minimised, this occurs from June (table 3.9). From midday in April the minimum basking temperature of sand lizards has been exceeded in several vegetation types and strata and so the sand lizards could be present in several of these habitats. Conversely at sunset -4 and sunset -1 in March and April the sand lizards are likely to basking on open ground and on the degenerate heather canopy. Both these habitat types are open and hence the detection of sand lizards is much easier.

Perhaps the most relevant findings to the visibility of *L. agilis* in areas of structurally complex habitat are those concerning the open ground surface and degenerate heather canopy temperatures as it is much easier to spot a lizard in open habitat (NCC 1983). Once the minimum basking temperature is exceeded, these areas provide a heat source for thermoregulatory behaviour should it be required. At midday, *L. agilis* should be most visible on open ground and on the degenerate

canopy between the first week of April and the fourth week of April. After this time of year the midday underground temperatures exceed the minimum threshold (table 3.5). At sunset–4 hours *L. agilis* should be most visible basking on open ground and the degenerate canopy between the third week of March and the first of April (table 3.5). This generally concurs with the timings of sand lizard surveys from anecdotal observations by the herpetological community (Edgar & Bird 2006; Foster & Gent 1996; Moulton 2006). After these dates it is assumed that the lizards will spend more time thermoregulating underground and under the canopies, as these temperatures exceed the minimum thresholds. These microhabitats provide cover to minimise their risk of predation when feeding above ground (Huey 1974).

Table 3.5. How *L. agilis* may shuttle through the day between different habitat types in March according to the temperatures available within the vegetation. The ticks are area where it would be thermally advantageous for *L. agilis*. The blue ticks represent areas where minimum temperature threshold exceed, the black the mean.

Week in March	Strata and vegetation cover	Sunrise			Sunrise + 2 hours			Sunrise + 4 hours			Midday			Sunset - 4 hours			Sunset - 1 hour		
		Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather
I	Underground																		
	Surface																		
	Canopy											✓				✓			✓
II	Underground																		
	Surface																		
	Canopy											✓				✓			✓
III	Underground																		
	Surface													✓					
	Canopy											✓			✓		✓		✓
IV	Underground																		
	Surface													✓					✓
	Canopy											✓			✓		✓		✓

Table 3.6. How *L. agilis* may shuttle through the day between different habitat types in April according to the temperatures available within the vegetation. The ticks are area where it would be thermally advantageous for *L. agilis*. The blue ticks represent areas where minimum temperature threshold exceed, the black the mean and red the maximum.

		Sunrise			Sunrise + 2 hours			Sunrise + 4 hours			Midday			Sunset - 4 hours			Sunset - 1 hour		
Week in April	Strata and vegetation cover	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather
I	Underground													✓			✓		
	Surface										✓		✓	✓		✓	✓		
	Canopy											✓	✓		✓	✓		✓	✓
II	Underground													✓			✓		
	Surface										✓	✓	✓	✓	✓	✓	✓	✓	✓
	Canopy											✓	✓		✓	✓		✓	✓
III	Underground													✓			✓		
	Surface										✓	✓	✓	✓	✓	✓	✓	✓	✓
	Canopy											✓	✓		✓	✓		✓	✓
IV	Underground										✓			✓			✓		
	Surface										✓	✓	✓	✓	✓	✓	✓	✓	✓
	Canopy											✓	✓		✓	✓		✓	✓

Table 3.7. How *L. agilis* may shuttle through the day between different habitat types in May according to the temperatures available within the vegetation. The ticks are area where it would be thermally advantageous for *L. agilis*. The blue ticks represent areas where minimum temperature threshold exceed, the black the mean and red the maximum.

Week in May	Strata and vegetation cover	Sunrise			Sunrise + 2 hours			Sunrise + 4 hours			Midday			Sunset - 4 hours			Sunset - 1 hour		
		Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather
I	Underground										✓			✓			✓		
	Surface										✓	✓	✓	✓	✓	✓	✓	✓	✓
	Canopy														✓	✓		✓	✓
II	Underground										✓			✓			✓		
	Surface										✓	✓	✓	✓	✓	✓	✓	✓	✓
	Canopy											✓	✓		✓	✓		✓	✓
III	Underground										✓			✓			✓		
	Surface										✓	✓	✓	✓	✓	✓	✓	✓	✓
	Canopy											✓	✓		✓	✓		✓	✓
IV	Underground										✓			✓			✓		
	Surface										✓	✓	✓	✓	✓	✓	✓	✓	✓
	Canopy											✓	✓		✓	✓		✓	✓

Table 3.8. How *L. agilis* may shuttle through the day between different habitat types in June according to the temperatures available within the vegetation. The ticks are area where it would be thermally advantageous for *L. agilis*. The blue ticks represent areas where minimum temperature threshold exceed, the black the mean and red the maximum. From Week II in June no new thresholds were exceeded for remainder of the study period thus the data are identical for July and August.

		Sunrise			Sunrise + 2 hours			Sunrise + 4 hours			Midday			Sunset - 4 hours			Sunset - 1 hour		
Week in June	Strata and vegetation cover	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather	Open Ground	Degenerate Heather	Mature Heather
I	Underground	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Surface	✓			✓			✓			✓			✓			✓		
	Canopy												✓						✓
II	Underground	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Surface	✓	✓		✓	✓		✓	✓		✓	✓		✓	✓		✓	✓	
	Canopy					✓			✓			✓			✓			✓	
III	Underground	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Surface	✓	✓		✓	✓		✓	✓		✓	✓		✓	✓		✓	✓	
	Canopy					✓			✓			✓			✓			✓	
IV	Underground	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Surface	✓	✓		✓	✓		✓	✓		✓	✓		✓	✓		✓	✓	
	Canopy					✓			✓			✓			✓			✓	

Table 3.9. Weeks when temperatures of 12.3°C, 24.2°C, 32.8°C (minimum, mean and maximum temperature of substratum on which *L. agilis* were observed basking) were exceeded for each category of vegetation cover and strata at fixed times of day between March and August 2007 at Merritown Heath. (*) denotes the temperature threshold was exceeded during this week and regularly exceeded value, but did not consistently remain above the threshold.

	Sunrise			Sunrise + 2 hours			Sunrise + 4 hours			Midday			Sunset - 4 hours			Sunset - 1 hour		
	12.3°C	24.2°C	32.8°C	12.3°C	24.2°C	32.8°C	12.3°C	24.2°C	32.8°C	12.3°C	24.2°C	32.8°C	12.3°C	24.2°C	32.8°C	12.3°C	24.2°C	32.8°C
UNDERGROUND																		
Open ground	I June			I June			I June			IV April			I April			I April		
Degenerate Heather	II June			II June			II June			I June			I June			II May		
Mature Heather	I June			I June			I June			I June			II May			II May		
SURFACE																		
Open ground	I June			I June			I June			I April	IV May*		III March	IV April*		I April		
Degenerate Heather	II June			II June			II June			II April			II April			II April		
Mature Heather							I June			I April			IV March	I May*		II April		
CANOPY																		
Degenerate Heather				II June			II June			I April	I May*		III March	II April*		I April		
Mature Heather							I June			I March	I April*	III May*	I March	IV March*	IV April*	I March	IV April*	

Structures of heathland vegetation and their importance for sand lizard thermoregulation

The mature heather stands exceed the minimum lizard basking temperature early in the first week in March at least two weeks before any of the other habitat types reach this temperature. Sand lizards were rarely observed in the mature heather canopy either because they were not present or they were well camouflaged. The lizards were often observed basking at the soil surface under the mature canopy at the edges of mature heather stands. This is of particular interest because sand lizards emerge from their winter retreat at this time, and spend time thermoregulating to regain condition (Amat *et al.* 2000; Dent 1980, 1986; Foster & Gent 1996; House 1980; JNCC 2003; Nicholson 1980; Nicholson & Spellerberg 1989; Spellerberg 1975, 1988; Strijbosch 1988) especially the males (see Chapter 2). In April the surface temperature under the mature canopy peaked, which was unexpected, but perhaps the dense canopy of woody mature heather is very effective at absorbing solar radiation in comparison to the other vegetation types under investigation.

The inclusion of degenerate and mature heather canopy temperatures has extended the work of Barclay-Estrup (1971) and revealed there is a greater temperature range within these two structures than previously thought (Barclay-Estrup 1971). The temperatures recorded in the canopies were the most extreme with the greatest minima and maxima (table 3.2, figures 3.5 & 3.7). The canopy temperatures fluctuated most readily and reached the highest values (in comparison to other strata) earlier in the year, at the time when sand lizards are most frequently observed basking in the open. It would be safe to say the greater temperature range found from this investigation can probably be attributed to an increase in temperature recording frequency and more accurate equipment. The temperature within different vegetation types and strata is in a constant state of daily and seasonal flux and the lizards will select the most favourable conditions in which to bask, which may not be representative from a single averaged reading, potentially resulting in misleading inferences in the 1972 study. This highlights potential sources of error in studies

which link the presence of animals to an averaged temperature recorded for a single habitat type.

Chapter 2 has illustrated that temperature is not the only environmental variable which can be linked to the presence of sand lizards, they are also linked to light. Barclay-Estrup (1971) confirmed light penetration in degenerate heather was significantly greater than that in mature heather stands and there is also a direct link between the light levels and moss cover under heather stands (Stoutjesdijk 1959) which accounts for the presence of certain invertebrate species within the degenerate canopy and their absence in mature heather canopy. Light penetrates the *Calluna* canopy through the irregular pattern of gaps in the dense canopy (Barclay-Estrup 1971). When referring to butterflies, these patches are termed 'sun-spots' and sand lizards have been observed during the warmer months basking within these pockets of light ('mosaic basking' (NCC 1983)). The greatest values of illumination beneath the mature heather stand peak at 25% in comparison with 57% for degenerate heather (percentages calculated with respect to the maximum illumination of open ground) (Barclay-Estrup 1971). The highest insolation values beneath the canopies were recorded during June and July when the sun is near its zenith (Barclay-Estrup 1971). This supports the finding that lizards are rarely observed basking in the open at this time of year. If up to 25% of the available light is able to penetrate the mature heather canopy during the warmer months, there is less necessity for sand lizards to bask openly and increase the risk of predation.

The trend of decreasing temperature differences between strata through the season between surface temperatures of open ground, mature and degenerate heather was also noted by Barclay-Estrup (1971). However, Barclay-Estrup (1971) noted the temperatures 10cm under the different vegetation cover types were quite similar; this study found soil temperature differences under different vegetation covers. In this study the highest temperatures were recorded under the degenerate heather, perhaps because of the insulation provided by the moss that is prevalent under the degenerate canopy and the maximum temperatures recorded beneath the mature

heather are higher than the equivalent temperatures for open ground (figure 3.7). This suggests that the vegetative cover of the soil influences the temperatures 10cm underground. The high temperatures under the mature heather stands could be caused by radiation and insulation of heat from the mature canopy not available beneath open ground or degenerate heather and the root system may even conduct heat below ground keeping temperatures higher overnight. This may be important to the thermoregulatory behaviour of *L. agilis* as they select well drained and well-insulated sites (NCC 1983) often densely vegetation banks or knolls for overwintering (House 1980).

The diet of *L. agilis* changes with time and reflects the seasonal abundance of prey items (Nicholson 1980). In spring the number of invertebrates in heather is low in comparison to those present in late Summer (Nicholson 1980). Sand lizards are rarely seen basking in the open or on the degenerate canopy in the warmer months, a finding that can be explained by their feeding ecology or the high temperatures of the habitat (table 1.6). In the summer months if the lizards are foraging within or underneath the canopies for mobile prey items such as wasps (*Hymenoptera*), moths (*Heterocera*) and true bugs (*Heteroptera*) they are less likely to be detected by the observer. Areas of open, undisturbed bare ground are of great thermoregulatory importance for most invertebrate species and are often where most lizards are observed (Telfer 2006). The lizards could be seen in these areas because they are easily visible to the observer; it is thermally advantageous or perhaps because of the high number of prey items present. Most invertebrates are not dependent on the *Calluna* plant itself but favour the structural diversity and range of microclimates available within the different phases of *Calluna* growth (tables 1.2 – 1.8). Sand lizards are associated with the structural diversity of heather plants (Amat *et al.* 2003; Corbett & Tamarind 1979; Dent 1986; House & Spellerberg 1982, 1983; House 1980; JNCC 2003; Moody 2007; Nicholson 1980; Strijbosch 1986; Strijbosch & Creemers 1988) and the strong association is probably explained by a combination of the prey items and range of microclimates available within the canopies (Nicholson 1980).

Female sand lizards lay their eggs in burrows under open sandy ground and they require warmth for incubation (House 1980; NCC 1983). The median temperature of sandy loam at egg clutch depth (7.2cm) (House 1980) is 17.9°C (NCC 1983) and in this study the mean temperatures 10cm under open ground during the incubation period of June and July were 17.6 °C and 16.9°C respectively (table 3.2). The temperatures recorded 10cm beneath the mature heather stands have much lower minima values than those recorded for open ground and the temperatures beneath the degenerate heather canopy have a restricted range, and lower maxima values, than those for beneath open ground, so could be unsuitable for egg incubation. This illustrates the importance of maintaining areas open ground where sand lizards are present for continued recruitment to the sand lizard populations (Corbett & Tamarind 1979; House 1980; NCC 1983).

Temperature regulation is essentially driven by solar radiation (Spellerberg 1982) and exploited through orientation, posturing and shuttling. This chapter has made inferences as to how sand lizards may move between the microclimates provided by the different vegetation structures which can be used to help us predict areas of habitat where lizards are most or least likely to be observed and hence increase the probability of an observation. Aspects of sand lizard behaviour such as mate seeking, mating, feeding, egg laying, predator avoidance and drinking could also influence the location of a sand lizard and these factors are likely to account for sand lizards which are observed in locations which are of limited thermal advantage. As Chapter 2 has showed the presence of basking male and females lizards is linked to different environmental variables through their seasonal reproductive cycle and to understand fully the thermoregulatory behaviour of sand lizards we need to take account of factors such as sex, behaviour, age, prevailing weather conditions and the immediate microclimate (Amat *et al.* 2000, 2003; Bauwens *et al.* 1995; Corbett & Tamarind 1979; Dent 1980, 1986; House 1980; House *et al.* 1980; JNCC 2003; Nicholson 1980; Nicholson & Spellerberg 1989; Spellerberg 1974, 1975, 1982, 1988; Strijbosch 1988). This chapter has illustrated the importance of structural diversity by quantifying the range of microclimates available to sand lizards through the year. I believe that it is

this range of temperatures which accounts for the strong association of sand lizards with structurally diverse areas of heathland.

4 Exploring the effectiveness and suitability of automated photo-identification software to pattern match dorsal markings of individual sand lizards.

4.1 Introduction

Photographs are an excellent permanent record of an individual's unique natural markings. In many species these markings (or patterns) do not change significantly and over time and have been used for the identification of individuals (Arzoumanian *et al.* 2005; Dudgeon *et al.* 2008; Foster *et al.* 2006; Gamble *et al.* 2008; Harmsen 2006; Henle *et al.* 1997; Karanth 1995; Karlsson *et al.* 2005; Kelly 2001; Schofield *et al.* 2008; Steinicke *et al.* 2000; Van Tienhoven *et al.* 2007). The use of natural markings to identify individuals from photographs has been applied to several aquatic and terrestrial species. If individuals from a population can be recognised from their natural patterning capture-mark-recapture methodology can be applied to estimate population size without needing to physically catch and mark each observed animal. This has its obvious ethical and practical benefits. These in combination with current advances and accessibility to digital products make this an attractive method of population size estimation.

This chapter explores the use of patterning matching software to identify individual lizards from digital images of their dorsal markings. The ability of the software to match images of the same lizard observed and photographed in the wild is evaluated as is the possible use of this software in a large scale monitoring scheme. The population estimates generated from the results of the pattern matching software are reported and discussed in chapter 5.

Images from camera traps have been used to identify re-encounters of jaguars (*Panthera onca*) (Harmsen 2006) and tigers (*Panthera tigris*) (Karanth 1995). Photographs from handheld cameras were used in the identification of sea otters

(*Enhydra lutris*) (Gilkinson *et al.* 2007), zebra sharks (*Stegostoma fasciatum*) (Dudgeon *et al.* 2008), cheetahs (*Acinonyx jubatus*) in the Serengeti, Tanzania (Kelly 2001), marbled salamanders (Gamble *et al.* 2008) and loggerhead sea turtles (*Caretta caretta*) (Schofield *et al.* 2008). Video stills were used in the identification of zebras in Amakhala Game Reserve in South Africa (Foster *et al.* 2006). Individuals were either identified by eye (Dudgeon *et al.* 2008; Gilkinson *et al.* 2007; Harmsen 2006; Schofield *et al.* 2008) or by auto match software with varying degrees of success (Foster *et al.* 2006; Gamble *et al.* 2008; Karanth 1995; Kelly 2001), see chapter discussion for details.

The use of auto match software to pattern match species in the marine environment has received the most attention and has resulted in an online database 'Ecocean Whale Shark Photo-identification Library' which encourages the submission of whale shark images to monitor individuals and migration patterns (Arzoumanian *et al.* 2005; Ecocean 2008). As a concept, an interactive database similar to this could be ideal for a future sand lizard monitoring scheme and population size estimation.

The first suggestion that lizards could be identified from their natural markings was documented by Carlstrom & Edelstam (1946) from research on the populations of Swedish common lizards (*L. vivipara*) and slow worms (*A. fragilis*). Nicholson (1980) and Dent (1986) successfully explored this technique to identify individual sand lizards in Southern England, and Martens & Grosse (1996) applied it to sand lizards in Germany. Head shield patterns have also been used to identify other lizard species including *L. viridis* (European green lizard) (Elbing & Rykena 1996) and *Podarcis muralis* (common wall lizard) (Schmidt-Loske 1996). However, these investigations were all short term studies and as it has not been confirmed whether the dorsal patterning of Lacertids remains constant over several years. The dorsal patterning may vary slightly with reproductive condition, age (Henle *et al.* 1997) and general body condition. However, at present the view of the herpetological community is these slight variations are not so significant as to result in the misidentification of individuals.

No published literature exists using photo identification (automated or by eye) of wild reptiles or amphibians *in situ* (Carafa & Biondi 2004; Gamble *et al.* 2008; Hiby 2008; Perera & Perez-Mellado 2004; Steinicke *et al.* 2000) perhaps because of some practical problems. Firstly the individuals need to be observed (see Chapter 5) and photographed without disturbance. The images then need to be in focus, of consistent quality (specifically the patterned areas for comparison and identification between individuals), and free from obscurities such as overhanging vegetation. This provides an ideal opportunity to test the performance of the pattern matching software from non invasive images of wild population of sand lizards.

The aim of this thesis is to work towards the standardisation and improvement of sand lizard survey methods and population estimation. Thus, the objective of this chapter is to evaluate the performance of an auto match photo identification software program developed by Conservation Research Limited to identify sand lizards from non-invasive photographs of their dorsal patterning taken in the field. The use of the software as a tool in converting digital images to data suitable for population size estimation, and its use within a future sand lizard monitoring scheme will be considered. The results from the auto matched identification of lizards will be compared to the identification results by eye with any anomalies presented and discussed.

4.2 Methods

The dorsal lizard images taken from the 56 surveys conducted in 2005, 2006 and 2007 from the study sites with the largest number of re-sighted lizards (see Appendix A for site descriptions -Town Common plot A (TA), Town Common plot C (TC), Merritown Heath plot A (MA) and Merritown Heath plot C (MC)), see Chapter 5, were used to test the effectiveness and suitability of the automated photo identification software developed specifically for *L. agilis* identification by Conservation Research

Ltd. Four independent databases were created within the software and the results presented are unique to each dataset of images.

The pattern matching procedure involves three processes. The first is image extraction where the dorsal patterning is 'extracted' from the image of a lizard. The second is where the extract is compared to other back pattern extracts in the database library and matches confirmed by the operator. The final stage is testing the software performance where extracts from matched pairs of lizards are ranked. Summaries of the stages involved in each process with relevant screen shots (as the software is still in development) are detailed.

Pattern extraction and match confirmation

The dorsal images were loaded into the database ready for extraction (figure 4.1a). The midline of the lizard was highlighted with purple dots, the right body side with blue and the left with red. Obscurities to the image such as vegetation were blocked out with shading and the image was pixel colour sampled (areas of dark and light patterning are selected) (figure 4.1b). The 3-D model 'net' was fitted to the dorsal image (figure 4.1c) which at times required adjustment by moving the midline, left or right points to ensure the 'net' was a good fit over the dorsal area of the imaged lizard. The pattern was extracted (figure 4.1d) and saved (figure 4.1e). Three algorithms then compare the extracted pattern of the new image to patterns already in the library. The program analyses the pattern of each image using three-dimensional co-ordinates and creates an identifier array which is a numerical description consisting of grey-scale intensities which are read from the image and stored as a matrix of numbers in relation to the central dorsal line of each lizard. The algorithms then compares the identifier arrays between images and scores the correlations between the pairs of photographs (Hiby & Lovell 1990). The program then ranks the library images by best fit to the newly entered image and the similarity (correlation coefficient) between the new image and a library images (from the identifier array) is given a patterning matching score determined by the algorithms, between 0.00 and

1.00 (a perfect fit). The user confirms any matches with library entries using the rank, score and visual inspection (figure 4.1f); this process is not automated.



Figure 4.1. Screen prints of pattern extraction process from dorsal images of sand lizards using automated photo-identification software.

The image is entered into the database (a), the dorsal and flanks are marked with the dots and obscuring vegetation banked out (b), the three dimension net is fitted over the body of the lizard and adjusted (c), the image is extracted (d), the algorithm identifies unique patterns within the natural patterning of the lizard (e) and the image is compared to those in the database (f).

Performance testing

Testing was applied to all the images in the library and is part of the automatch software. It allows the user to evaluate how well the pattern matching software performed comparing the image matching results from the algorithms to the image matching results confirmed by the operator. Testing also allows the user to identify specific sets of images the software failed to accurately match or sets of images the software incorrectly matched. The user is able to review the images which the software struggled to match and determine whether there was any consistency between the sets of images the software struggled to match.

4.3 Results

Individual lizards can be identified within and between field seasons from images of their dorsal markings using automated photo-identification software (table 4.1). In total 333 images were taken of sand lizards and 11 images were unsuitable for entry into the database. A total of 161 images were of re-encounters. Figure 4.2 shows screen shots of the extracted photographs and matches of the same male (M10 from site MC) initially sighted in 2005, re-sighted twice in 2006 and four times in 2007. The re-sights of this animal were matched rank 1 with high scoring values >0.77 by the automated software, after the first re-encounter. The first sighting of an individual can not be matched but future re-sights will be matched to the image of the initial encounter (top left image in figure 4.2).

Table 4.1. A summary of the images entered into each database and the corresponding results for each site.

Site	Year	Number of images entered into database	Number of identified lizards	Number of identified lizards re-sighted within year	Number of lizards re-sighted from		
					2005	2006	2005 & 2006
TC	2005	7	5	2			
TC	2006	19	15	4	5		
TC	2007	17	11	6	3	6	3
MC	2005	28	22	6			
MC	2006	19	13	6	10		
MC	2007	18	13	5	4	5	4
MA	2005	16	12	4			
MA	2006	32	19	13	5		
MA	2007	24	12	12	2	4	2
TA	2005	40	31	9			
TA	2006	46	29	17	9		
TA	2007	56	32	24	7	13	6



Figure 4.2. Matched pattern extracts from field photographs of the same male M10 from Merrittown Heath plot C sighted in 2005 and re-sighted in both 2006 and 2007.

It was not possible to extract patterns from every photograph nor was the software able to match every extracted pattern from re-sighted sand lizards (figure 4.3a-f and table 4.1). The software struggled to fit the 3-D model net over the backs of lizards in a very curled posture and pattern extraction from these images was not possible. The extracts created from photographs in which the dorsal patterning was obscured by a significant amount of vegetation were poor. The number of unsuitable photographs for pattern extraction due either to posture or obscurities ranged between 1% and 8% of the total number of sand lizard photographs dependent on site (table 4.1). The software performed very well on images of sand lizards where the posture of the lizard was straight and little or no vegetation was obscuring the dorsal area (figure 4.4a & b).

The percentage of sand lizards reencountered at each site over three years was not greater than 53% (table 4.3). There was no significant difference between the number of lizards re-sighted to those encountered once between sites ($\chi^2= 2.55$, $d.f.=3$, $P>0.05$). Hence there is no significant difference between the number of lizards encountered once while sampling each site to the number of lizards recaptured.

The software performed well in identifying re-sights of sand lizards from patterns extracted from field photographs. A mean percentage of 68% (range 52% - 79%) of re-sighted lizards were correctly identified by rank 1 and 2 matches using the software with a mean score of 0.84 (range 0.78 - 0.88), (table 4.3). There was no significant difference between the number of correct lizards matched at rank 1 and 2 and those matched at rank 3 and above between sites ($\chi^2= 7.45$, $d.f.=3$, $P>0.05$) suggesting that the ranks allocated by the software are not a good indication of match. The scores are more reliable.

The software was unable to match on average 32% (range between 21% and 48%) of extracted images within the first two ranks from lizards which had been re-sighted.

The scores of these images to their true matches were low (mean = 0.22, range 0.15 – 0.39) compared to the scores with their false matches (false positives) (mean = 0.59, range 0.45-0.68), (table 4.3, figures 4.5a-d, 4.6a & b and 4.7a & b). The scores for the false positive matching of lizards encountered once (mean = 0.48, range 0.39 -0.59) were consistently lower than the scores for false positive lizard re-sights (mean 0.59, range 0.45-0.68). The software scores the false positive matching of re-sighted lizards higher than the false positive matching of lizards encountered once.

date	ID	gender	age	image	AutoMatch	location
05-Apr-07	M9	Male		TA070405_M10d_M9_DV	LC	TA
02-Apr-07	M19	Male		TA070402_M9_M19_DV	LC	TA
02-Apr-07	M37	Male		TA070402_M6c_M37_DV	LC	TA
02-Apr-07	M38	Male		TA070402_M7c_M38_DV	LC	TA
02-Apr-07	F14	Female		TA070402_F4g_F14_DV	LC	TA
27-Apr-06	M28	Male		TA060427_M15d_M28_DV	S	TA
28-Apr-07	M49	Male		TA070428_M27c_M49_DV	S	TA

a

b

c

d

e

f

Figure 4.3. Images from which dorsal patterns could not be extracted because of the lizards' posture (a) and (b) and images of the same individual lizards the software failed to match (c), (d), (e) and (f).

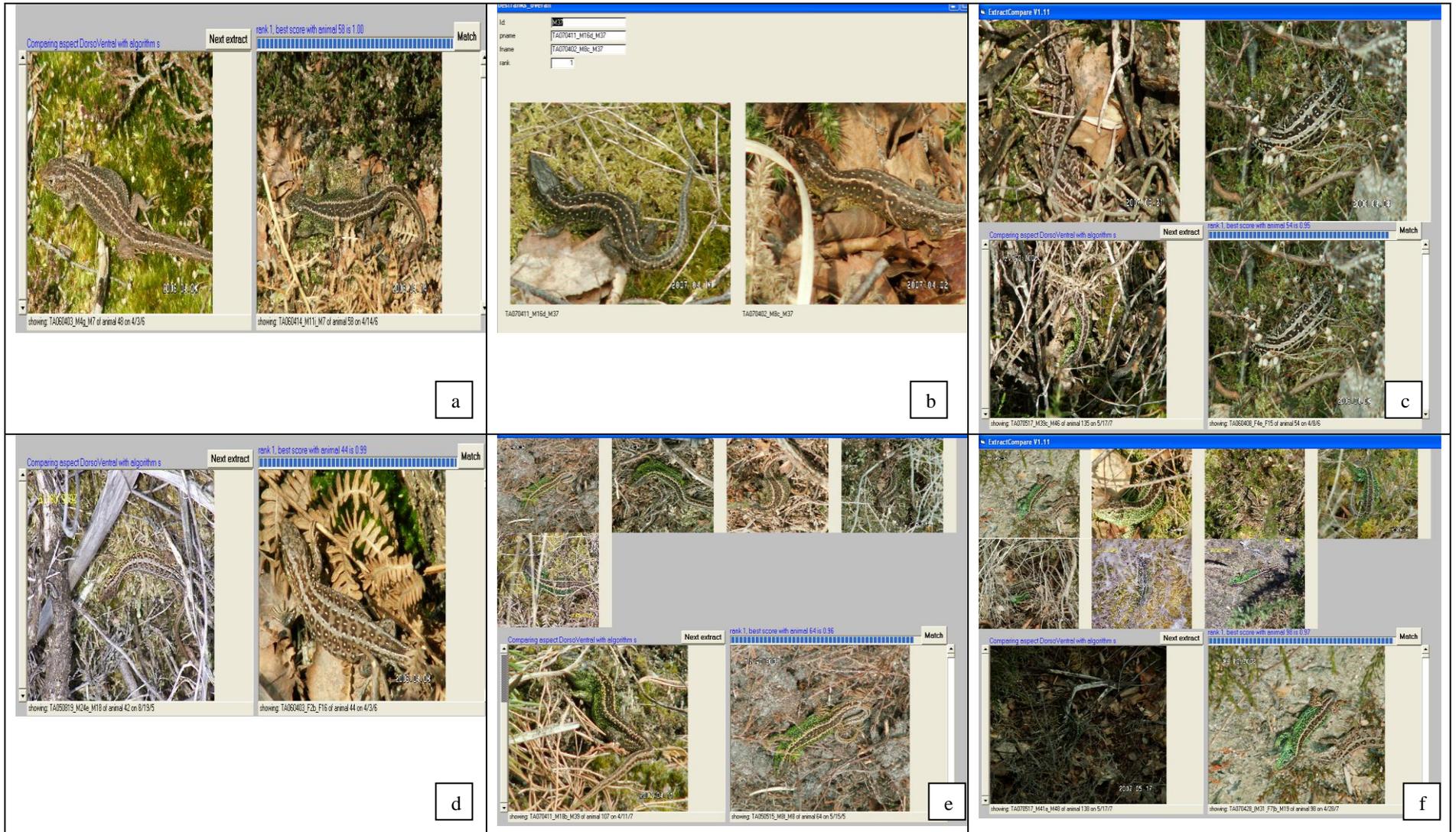


Figure 4.4. The software performed very well in identifying sand lizards from the patterns extracted from these images: (a) rank 1 with 1.00 score for identification; (b) rank 1 match from testing output; (c) and (d) males incorrectly identified by eye as females early in the season; (e) and (f) males unidentified by eye

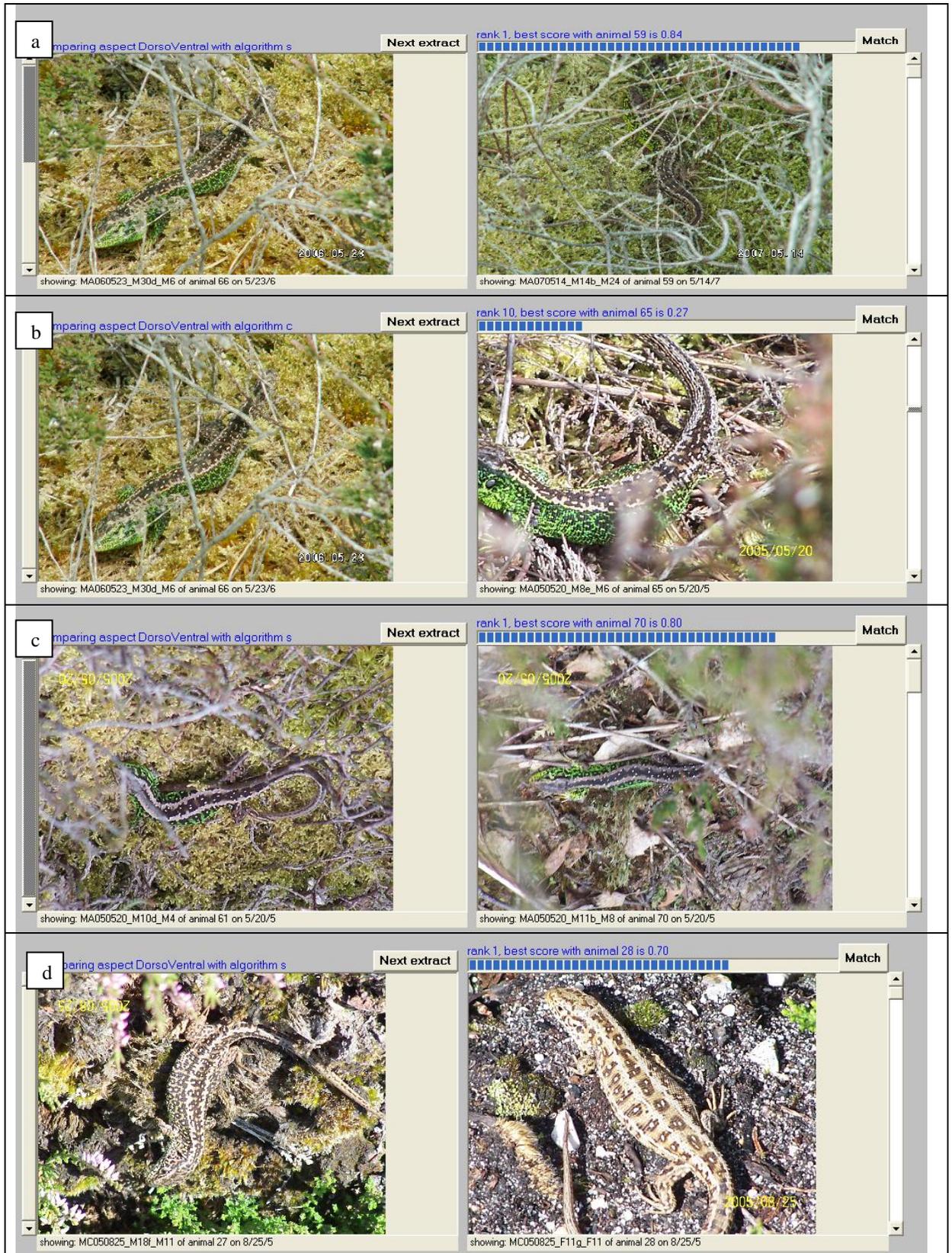


Figure 4.5. Examples of false positive matches by the auto match software a) false positive match with rank 1 and score of 0.84 b) is the true match of a, with a rank of 10 and match score of 0.27. c) false positive software match with rank 1 and 0.80 score d) false positive match with rank 1 and score 0.70. Incorrect matches are probably due to similarities in either the posture or dorsal markings of the lizard.

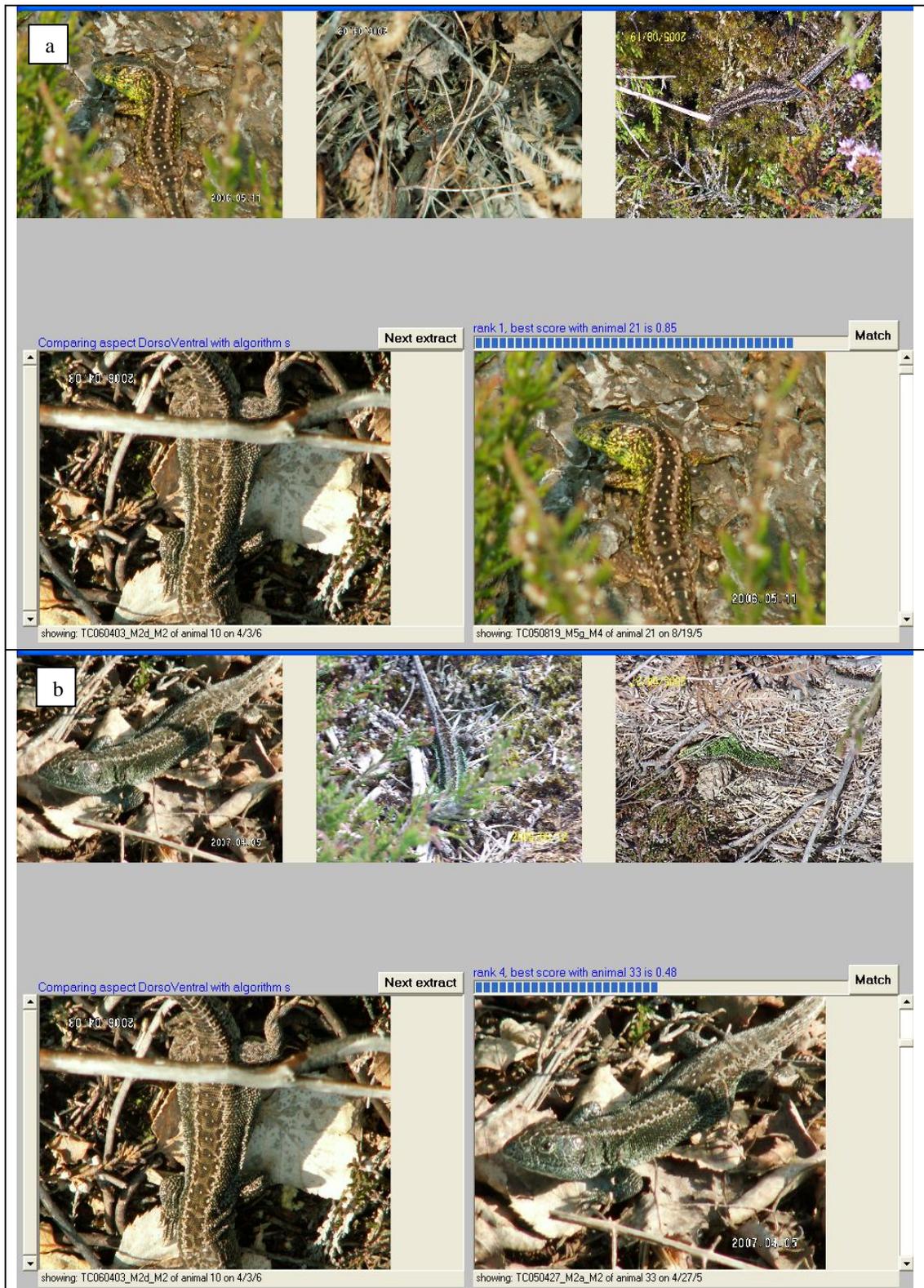


Figure 4.6. a) The false positive identification of the bottom left hand lizard with the lizard in the library (all other images are re-sights of the same lizard) with rank 1 and score of 0.85. b) Correct match of the lizard in figure 10a) with rank 4 and score of 0.48.

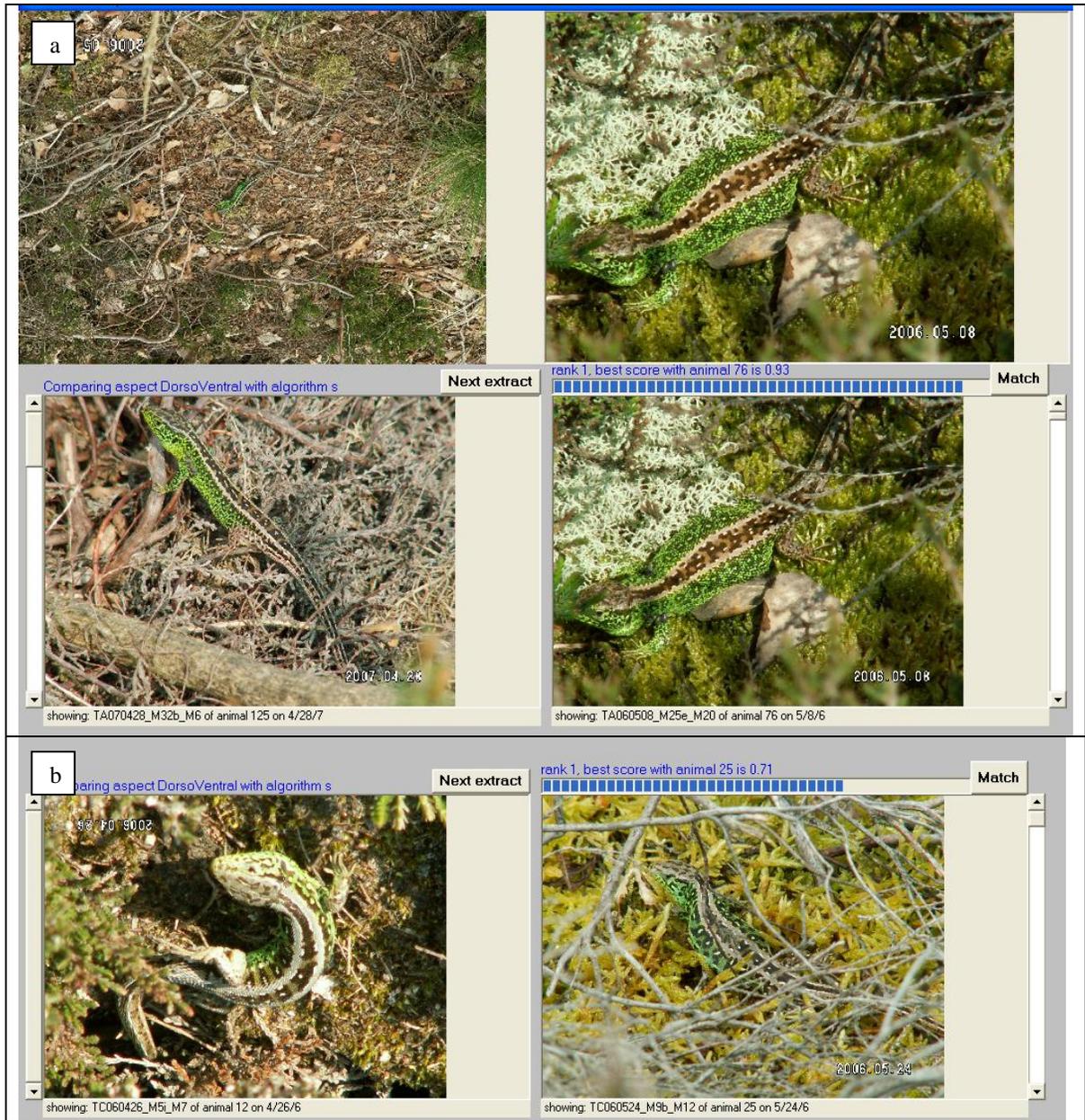


Figure 4.7. a) A false positive identification by the auto match software with a very high score of 0.93 and rank of 1. The image in the bottom left corner is being compared to the library image (bottom right). The top images are re-sights of the library image. At an initial glance the patterning on both lizards looks similar, but in fact they are different individuals. b) A false positive identification by the software with rank 1 and score 0.71.

Table 4.2. Summary of photographs from which suitable and unsuitable (due to obscurities and posture limitations) patterns were extracted for inclusion in the dataset for the auto match photo-id software.

	<i>Total number of initial images for database input</i>	<i>Number of images unsuitable for pattern extraction</i>	<i>Number of images entered in database for pattern extraction</i>	<i>% of initial images unsuitable for pattern extraction</i>
TC	44	1	43	2%
MC	71	6	65	8%
MA	74	2	72	3%
TA	144	2	142	1%

Table 4.3. The percentages of re-sights and single encounters of patterns extracted from lizard images in the database

	<i>Percentage of images of lizards re-sighted</i>	<i>Percentage of images of lizards encountered once</i>	<i>Number of images entered in database for pattern extraction</i>
TC	49%	51%	43
MC	42%	58%	65
MA	53%	47%	72
TA	53%	47%	142

Table 4.4. Summary of the percentage of re-sighted lizards correctly matched to the initial sightings by ranks 1 & 2 and ranks 3 and above with their associated mean scores by site. The false positive identification of missed matched lizards with rank 1 and false positive identification of lizards encounter only once are included with corresponding scores.

<i>Site</i>	<i>Percentage of lizards correctly auto matched by rank 1 or 2 with software</i>	<i>Mean score of correctly matched lizards with rank 1 and 2 by software</i>	<i>Percentage of lizards auto matched by rank 3 and above with software</i>	<i>Mean score of true match of lizard by software at rank 3 and higher (poor fit)</i>	<i>Mean false positive rank 1 scores for lizards matched at rank 3 and higher by software</i>	<i>Mean score of rank 1 match lizard encountered once, false positive</i>
TC	52%	0.78	48%	0.19	0.45	0.40
MC	78%	0.88	22%	0.17	0.62	0.39
MA	63%	0.82	37%	0.15	0.59	0.53
TA	79%	0.87	21%	0.39	0.68	0.59
Mean values across all sites	68%	0.84	32%	0.22	0.59	0.48

Table 4.5. Number and percentage of missed matches or false positive identification of re-sighted lizards and those encountered once by the auto match identification software. Only the scores of the false positive matches which exceeded the average site score (for matches at rank 1 and rank 2, see table 4.3) are considered. (*) is illustrated by figure 8a, an example of (**) by figure 9a and see figure 10a for an example of (**).

Site	Average site score for rank 1 and rank 2 matches by the auto match id software	Number of false positive identifications of lizards sighted only once which exceed the site average score for rank 1 and rank 2 matches	Number of images of re-sighted lizards identified as matches above rank 3 as a percentage of the total number of images per site	Number of extracts of re-sighted lizards identified as matches above rank 3 as a percentage of the total number of images per site which exceed the site average for rank 1 and rank 2 matches	Number of matches rank 3 and above exceeding site average score for rank 1 and rank 2 matches
TC	0.78	0	23%	2%	1(*)
MC	0.88	0	9%	0%	0
MA	0.82	0	19%	3%	2(**)
TA	0.87	0	11%	1%	2(**)

Testing

The testing applies to pairs of images of the same lizard where matches have been confirmed by eye. Between 42% and 53% (table 4.3) of the extracted patterns were of re-sighted lizards and only these images were tested as testing could not be run on unmatched images. Images of the same lizard were matched correctly with a rank 1 (figure 4.1b) and other pairs of images were ranked with a lower match (figures 4.3c, d, e & f). Testing was performed on every matched image in the library. The results show between 44.2% and 49.5% of extracted images are matched by the automated first rank as identified by the spatial patterning algorithms and between 69.5% and 83.1% are matched within the first 10 automated ranks (figure 4.8a-d).

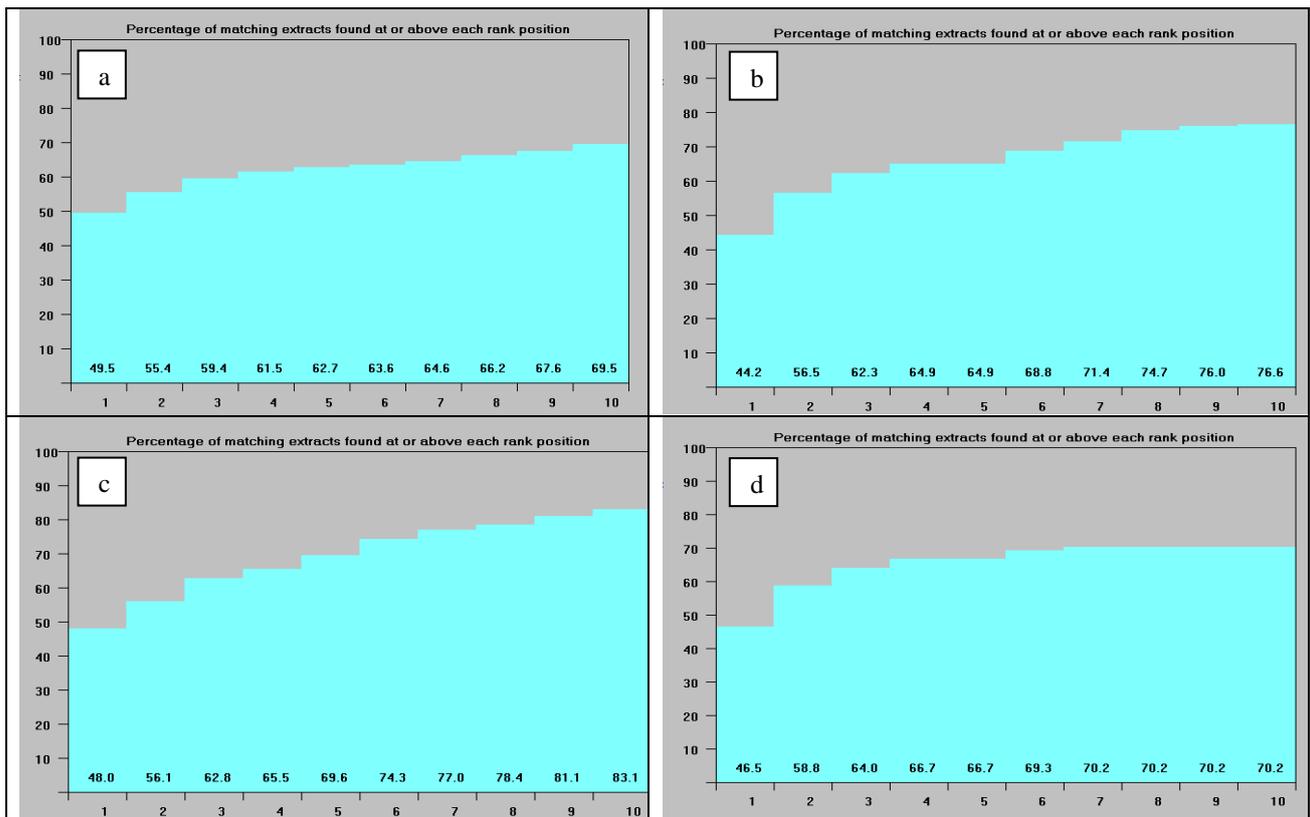


Figure 4.8. Testing output for the four independent sites where a=TA (Town Common A) where n=75, b=MA (Merritown Common A) where n=38, c=MC (Merritown Common C) where n=27, d=TC (Town Common) where n=21 (x axis represent rank, 1-10; y axis represent cumulative percentage with increasing rank).

4.4 Discussion

The dorsal patterning of sand lizards remains constant and can be used to identify individual sand lizards between years and within seasons following intensive surveys over a three year period on small (circa 0.25 Ha) independent areas. Patterns extracted from photographs taken of undisturbed lizards in the field are suitable for pattern analysis using auto match identification software developed by Conservation Research Limited. The software performed best when the image of the lizard was free from obscurities and straight in posture.

The success of the auto match software varied between the sites and values ranged between 52% and 79% with an overall mean of 68% (table 4.3) of extracted patterns correctly matched by a rank 1 or 2. Other studies which have evaluated the use of auto match software to assist with the identification of individuals include: Van Tienhoven *et al.* (2007) who report a 72% rank 1 success rate (one library reference image) which increases to 91.7% success (with three library reference images) of the spotted raggedtooth shark (*Carcharias taurus*); Gamble *et. al.* (2008) who produced a 70% successful return rate for the top-ranked images of the marbled salamander (*Ambystoma opacum*) and Arzoumanian *et. al.* (2005) generated a 92% success rate for the identification of whale sharks (*Rhincodon typus*). The use of automatch software to identify sand lizards falls slightly below the success rates quoted in other studies which may be because it is difficult to obtain consistency between images of a small, cryptic and secretive species.

The high identification rate of images taken from *in situ* wild sand lizards was not expected, as the image acquisition in other comparative studies was standardised (Gamble *et. al.* (2008). The back patterns of sand lizards photographed in this study were often obscured in parts with vegetation or the lizard was observed in a posture which made pattern extraction difficult or impossible (figures 4.3a, b and e). The high success rate could either be a product of the sample size n=75 (for sand lizards at all sites), in comparison to n=1000 for the salamanders, or that the

three dimensional algorithm used in the auto match software developed by Conservation Research Limited is more suited to pattern recognition of small reptiles and amphibians than the multi-scale algorithms used to identify the salamanders.

There was no significant difference between the number of re-sighted lizards and those encountered once and the number of lizards ranked 1 and 2 and those ranked 3 and above those, between sites. This implies that image quality and software performance were consistent between sites and sample size, and that sand lizards have a low recapture rate which is independent of site and sample size.

The software identified two incorrect image matches made by eye of females which were actually males. The misidentification arose as the images taken early in the season were catalogued as females since those lizards had no hint of green colouration. Later in the year (as figures 4.4c and d illustrate) the green colouration was evident. In essence this fits with comments by Henle *et al.* (1997) that reproductive condition can effect the dorsal patterning, but in this case the patterning of *L. agilis* remained consistent. The colouration was different, yet the images were identified as the same individual with high pattern match ranks and very high scores, which illustrates the value of using patterns over colours for identification and this could be important too if we are studying sex ratios or population dynamics, see Chapter 5. The other two missed identifications which the software highlighted were simply due to human error (figures 4.4e & f).

The ability of the software to match new pattern extracts to those in the database library is dependent of the number and quality of library images (Arzoumanian *et al.* 2005; Gamble *et al.* 2008; Hiby 2008; Kelly 2001; Van Tienhoven *et al.* 2007). The more images of an individual in the library the higher the chance of a high rank match. Likewise, a high quality clear image of an individual will increase the chance of a correct match and conversely a low quality image with a poor pattern extract will increase the chance of a poor match (Arzoumanian *et al.* 2005; Gamble *et al.* 2008; Hiby & Lovell 1990; Van Tienhoven *et al.* 2007). Low ranked

matches can be a result of a poor pattern extract from an out of focus image, a partially obscured dorsal pattern (figures 4.3e & 4.5a) or a curled posture (figure 4.3a & b). The ability of the software to correctly identify matches is dependent on the order images are entered into the database, a surprising weakness of the software. The best, clear images of lizards with 'standard posture' should be entered first to improve the software performance. In this study the images were entered chronologically. The success of the software as measured by rank and score could be improved by re-entering the images in a different order. Other studies have graded images on quality before matching (by eye or using software) and report significantly better matching results deemed from high quality, clear images (Gilkinson *et al.* 2007; Kelly 2001).

An area of concern when exploring the use of auto match software for any species is that of missed matches and false positive identifications. For every image of a lizard encountered once, there will be a match, a false positive identification representing the best possible match available in the database, even if false (see figure 4.2 top left image for example). This false positive identification will have an associated similarity score and for every image of a re-sighted lizard which is not correctly matched by rank 1 (missed matches) there will also be a false positive rank 1 match with associated score. These matches can be identified by the operator and corrected but this can be a time consuming process.

The similarity scores of false positive identifications of the single encounters are consistently less than those for the missed matches (table 4.3). When the mean similarity score for correct rank 1 and rank 2 matches is used as a threshold value for matches, the false positive of identification of lizards encountered once is eliminated (table 4.4) and the percentage of false positive identification of re-sighted lizards is substantially reduced. Kelly (2001) found a threshold of 0.50 reduced the probability of a false positive identification to 2.5% when exploring the use of earlier versions of this software with images of Serengeti cheetahs (*A. jubatus*). The application of these thresholds reduces the number of false positive identifications which saves time when visually checking the auto matches, but it does not assist with increasing the low similarity scores and ranks of the missed

matches. This illustrates the importance of an operator confirmed match. Despite the time taken to inspect the pairs of images this process is essential to reject false positive identifications and missed matches which with further analysis would generate inaccurate population estimates and confidence limits.

The results from the testing application within the auto match software do not agree with findings from previous studies (Gamble *et al.* 2008; Hiby 2008) where the accuracy of the auto match software decreases with number of individuals in the database (figure 4.8). Perhaps the number of lizard images entered into the database from each site is too similar for the testing to detect any obvious changes in accuracy. The testing application only evaluates the ability of the software to match pairs of images and cannot provide any data on the false positive identifications of lizards encountered once, which in this study was between 47% and 51% of the images in each database (table 4.2). This low lizard recapture rate could also contribute to the discrepancy between the accuracy rate of this and the salamander study.

The auto match software was not able to successfully match images of the same lizard in different postures (figures 4.3c, d, e & f and 4.5c). The algorithms look for spatial relationships between pattern extracts, as the body of the lizard curves so does the spatial relationship between two or more points and the pattern extracts from lizards in different postures are going to be, at some level, spatially different. It would appear that the software cannot fully compensate for this and highly ranks and scores pairs of lizard images with similar postures (figures 4.5c and 4.6a). The incorrect match of the lizard in figure 4.5c could be caused by the animals posture but also the markings of both individuals at a glance look spatially similar. The software also incorrectly rank 1 matched the lizard in figure 4.5a to a different lizard, the true match is figure 4.5b with rank 10. Figures 4.7a and b are also false positive matches with a high rank and score where at an initial glance the patterning also looks similar. It could be that the lizards in these figures are genetically linked and as such have similar spatial patterning which is reflected by the high similarity scores.

The sand lizard populations studied in this chapter were located on fragmented areas of heathland. No lizards were re-encountered across sites and plots when all the sand lizard images were compared in a central database which confirms each population under study was independent to the others either because the study areas of the site were outside the largest home range estimate of 2130m² for sand lizards (Nicholson & Spellerberg 1989) (Town Common) or isolated by a stream and tree line (Merritown) (see Appendix A site descriptions). This highlights the potential for false positive matches using the software as there are likely to be similarities in the back patterns of genetically linked lizards. With further fragmentation of small isolated populations of sand lizards this could become more of an issue.

The auto match software performed well identifying re-encounters successfully and correcting misidentifications made by eye. However, the use of this software for individual identification of sand lizards should be discouraged. The problems are not with the capability of the software to match individuals; the problems are with the suitability of the species for use with this software. The low recapture rates of sand lizards result in an immediate loss of 50% of the initial data collected (table 4.3). The quality of the images is the major variable which has the largest influence on the performance of the auto match software and ultimately, sand lizards are very difficult to consistently photograph in the field. The identification of individual lizards from photographs in my opinion is best conducted by eye but this is a very time consuming process.

There are currently no formal monitoring programmes for sand lizards whereas schemes for adders (*Vipera berus*) 'Make the Adder Count' and slow worms (*Anguis fragilis*) 'slow worms in compost bins' have proved successful and greatly benefited from public participation and record submission (HCT 2007). These schemes are concerned with mapping the distribution of these species rather than attempts at abundance estimation. The concept of an interactive on-line database working towards the estimation of sand lizard population nationally, although a good idea, is totally unworkable at present. The issue again is not with the capability of the software to identify individuals from good quality images, it is

obtaining these images which cause the most problems, even for experts. However, species which are currently trapped or handled for identification (toads, salamanders, frogs and newts) could be consistently photographed by any surveyor and would be ideal candidates to trial this type of database in the field of herpetology.

5 Estimation of sand lizard population sizes using photo recognition with capture-mark-recapture methodology

5.1 Introduction

The populations of the sand lizard *Lacerta agilis* in the UK declined with the loss of lowland heathland and coastal dune areas between 1811 and early 1980s (Corbett 1988a; Jackson 1979) (see page 3 of introduction). The decline of *L. agilis* in the UK has been effectively halted (Edgar & Bird 2006). Attention and effort is still required to ensure existing populations of sand lizards are managed appropriately and effectively starting with the development of a standard survey methodology (Edgar & Bird 2006) which will then lead to the development of monitoring programmes to categorise the conservation status of the existing populations which is required under EU law (see introduction). Sand lizards are rare, elusive, well camouflaged and easily disturbed (Chapter 2; Beebee & Griffiths 2000; JNCC 2003). The combination of these factors poses major challenges to conservation workers and researchers investigating the relationships between their behaviour and environmental variables (see Chapter 2; Foster & Gent 1996; JNCC 2003).

There is a modest amount of published literature regarding sand lizard population studies (Dent 1986; Foster & Gent 1996; House 1980; Nicholson 1980). These studies involved conducting surveys to record sand lizard presence and absence, but to date there is no established methodology for conducting surveys to estimate the size of populations. This is a well documented issue in the field of herpetology and a larger scale project NARRS (National Amphibian and Reptile Recording Scheme) has recently started to work toward the standardisation survey methodology for all six native herptiles. NARRS is a volunteer based monitoring scheme concerned with establishing the presence or absence of the native reptiles and amphibians of the UK. The monitoring scheme consists of the national amphibian survey where ponds are surveyed for species presence and the national reptile survey where a randomly selected square is monitored. Both surveys require three visits to the sample area in early Spring in appropriate weather conditions and times of day. The aim of NARRS is to gather species

presence and absence data and other variables that affect population viability and to generate percentage species occupancy estimates and national trends for the UK as a whole (The Herpetological Conservation Trust & ARG UK 2008). Only anecdotal information is available for volunteers advising when and in what conditions to conduct the surveys. NARRS is aimed at sampling the more widely distributed native reptile and will be of limited use for monitoring of sand lizards as they are confined to lowland heathlands, coastal dune and adjacent peripheral areas which will not be adequately represented by the selection of random grid squares. A supplementary sand lizard monitoring scheme is required.

The literature is unanimous in acknowledging the difficulties in conducting meaningful reptile surveys and interpreting the data gathered appropriately; reptile population estimates are typically reported as some form of unadjusted raw count statistic intended to reflect population size (e.g., (Dent 1986; Foster & Gent 1996; JNCC 2003; NCC 1983). Reptiles in general are difficult creatures to detect in their natural environment because of their cryptic behaviour, camouflage markings and because they are only available for detection when above ground (constrained by the time of year and weather conditions (see Chapters 2 & 3) (Dent 1986; Foster & Gent 1996; House 1980; NCC 1983; Nicholson 1980; Nicholson & Spellerberg 1989; Strijbosch & Creemers 1988; The Herpetological Conservation Trust & ARG UK 2008; Van Nuland & Strijbosch 1981). Hence, the number of sand lizards observed will rarely, if ever, be representative of the number of sand lizards present.

Three previous studies have attempted to estimate the density of sand lizard populations. Nicholson (1980) used pitfall traps in an area of dry heathland in Dorset, UK and calculated the sand lizard density by dividing the area laid with traps by the number of lizards caught. The estimates have limited value, however; they were not made over successive years and difficulties were encountered with the physical capture of this species. House (1980) and Dent (1986) estimated population size using CMR data in conjunction with sightings/frequency analysis, and again commented on the difficulties of capture, the time involved and the low recapture rate. None of these studies produced population estimates as individual

lizards were not comprehensively identified and those caught only once were excluded from the analysis (Nicholson 1980). Several other small scale studies have collected sand lizard census and habitat data, but none have attempted to estimate the number of individuals present, other than to make inferences from counts. However, these publications all acknowledge the difficulties in conducting census surveys, with low recaptures a common theme (Amat *et al.* 2003; Ceirans 2006; Glandt 1995; Herczeg *et al.* 2003; Korsos 1986; Nemes *et al.* 2006; Strijbosch 1988; Trakimas 2005; Van Nuland & Strijbosch 1981) and where estimates are stated their derivation is not clear (Corbett 1988a; Gullberg *et al.* 1998; Jackson & Yalden 1977; Tertyshnikov 1978).

The obstacle stopping herpetologists from linking the number of sand lizards observed to the true number present is 'the chance of encounter'. This chance is biometrically termed the 'detection or recapture probability' and is currently a developing area in ecological research concerning species which are rare, elusive and problematic to survey, as we lack reliable information on the population status and trend of these difficult to detect, yet often endangered species (Bailey *et al.* 2004a; Bailey *et al.* 2004b; Dodd & Dorazio 2004; Farnsworth *et al.* 2002; Mazerolle *et al.* 2007; Schmidt 2004; Thompson 2004; Thompson 2002). The 'detection or recapture probability' is defined as the probability of correctly noting the presence of an individual (or species) within some area and time period (Thompson 2004) and despite the best efforts of the investigators it is very common for individual animals and even entire species to be missed (Mackenzie *et al.* 2006).

Establishing and quantifying how the detection probability fluctuates will bring us closer to estimating the true number of sand lizards from the number of individuals observed. When individual animals encountered on a sample area can be identified, CMR methods can be used to estimate detection probabilities and also population size (Thompson 2004). This is especially important for species which have a low or fluctuating probability of detection, as exclusion of this parameter can result in a significant underestimate of population size (Dodd & Dorazio 2004; Grant & Doherty 2007; Mazerolle *et al.* 2007; Pollock *et al.* 2002; Schmidt 2004).

Analysis of herpetological data sets which have considered and modelled detection rates have found seasonal differences in detection probabilities and differences between cohorts (of *L. vivipara*: Lebreton *et al.* (1992) and illustrated that the observer (in a study where there were several surveyors), in addition to environmental and temporal variation, influences the detection rates (flat-tailed horned lizards, *Phrynosoma mcalli*: Grant & Doherty 2007). Both studies report wide confidence limits in the calculation of the detection rates, which is typical of reptile species and highlights the importance of considering this parameter in future studies. This chapter will investigate whether detection probabilities differ between the sexes, and within and between season, as the variation in detection probability alone could account for the annual variation in numbers of male and female lizards observed. Previously variations in count statistics have been used as indications of population stability (Mazerolle *et al.* 2007; Schmidt 2004). Clearly this could be flawed.

Distance sampling by transect was considered to estimate animal abundance and density. However, the detection probability is not fully considered in relation to external variables but to the chance of encounter as a function of distance from the transect line or point (Buckland *et al.* 2004). The cryptic nature and our limited knowledge of sand lizard behavioural ecology requires a more intensive approach to abundance estimates where the detectability and the survivorship of sand lizards can be fully explored. The limited home range of sand lizards (Nicholson & Spellerberg 1989) could also cause bias in abundance estimates if sampling was conducted by transects. The heathland habitat does not lend itself well to transect surveys for small, territorial ground dwelling lizards in densely vegetated terrains (Corbett 1974) as the visibility to the ground adjacent to a transect is as low as a few centimetres, or even effectively zero and a fundamental assumption of distance sampling is that the detection probability of individuals on the transect line is equal to one would not be met (Kacoliris *et al.* 2009). Of additional concern, rigid adherence to a straight line transect through heathland vegetation can damage the heather (Corbett 1974) altering the habitat. Distance sampling by transect was deemed unsuitable for the estimation of lizard abundance and density in their

heathland environment and so CMR methodology was used to estimate the size of the lizard populations.

CMR methods require the marking hence recognition of encountered individuals. Historically sand lizards have been marked using toe clipping for identification (Berglund 2000b; Dent 1986; House 1980; Nicholson 1980; Strijbosch 1988). Other published marking methods for the identification of individual amphibians and reptiles include paint, marker tag and dye marking branding, tattooing and laser markings (Ferner 1979; Fox 1978; Jenssen 1970; Neitfeld *et al.* 1994; Perret & Joly 2002; Tinkle 1973; Zwickle & Allison 1983), insertion of passive integrated transponder (PIT) tags (Camper & Dixon 1988; Dixon & Yanosky 1993; Germano & Williams 1993; Perret & Joly 2002) and use of natural markings (Carlstrom & Edelstam 1946; Dent 1986; Nicholson 1980). A marking technique needs to be permanent (for annual identification) and with professional and ethical considerations the only two marking methods suitable for use in this population study are the insertion of PIT tags and using the individuals natural markings.

Little research has been undertaken on the impact of tags on the reproductive output of females and egg development. Tagged newts were found to lay a higher number of eggs which suggests an adaptive induced reproductive response caused by stress (Perret & Joly 2002). As the sand lizard is a European Protected Species we would need to be confident the tags do not cause any negative impacts to the reproductive output of the females or damage to the lizards internal organs or skin through migration as has been reported for some small lizard species (Camper & Dixon 1988; Germano & Williams 1993)..Financial investment is also required to fund the equipment. The use of the lizards dorsal patterning was seen as the best marking method for individuals and it did not require the initial capture of the lizard. One objective of this research is to work towards the development of a large scale monitoring method for sand lizards. This scheme needs to be accessible to students, volunteers, herpetologists and consultants. It is not feasible to develop a monitoring program which requires capture and tagging of every lizard observed but it is feasible to ask surveyors to supplement their survey data with an image of the lizards observed.

The previous chapter has shown the dorsal patterning remained constant over the study period and proved that individuals can be recognised and identified within and between seasons. A CMR method is applied to the images gathered from wild populations already verified by pattern matching software (Chapter 4) to generate population estimates of the nine sand lizard populations under study.

With research and technological advances, capture histories of individual lizards can be analysed to generate estimations of detection and survivorship rates (Cooch & White 2007). Program MARK (Cooch & White 2007) was used in this chapter for generating population estimates. Program MARK is a free Windows-based application which can be a powerful modelling tool to estimate variations in survivorship and detection rates. The open population Cormack-Jolly-Seber (CJS) (Lebreton *et al.* 1992; Pollock *et al.* 2002) CMR method was selected for analysis (see methods). Program MARK, supports model averaging of the best fit models evaluated by the information theoretic approach using AIC criteria (Akaike 1974) (refer to Chapter 2 for detail), which is good practice if there is evidence to suggest model selection uncertainty (Mazerolle *et al.* 2007). However, model averaging is seldom considered or reported in herpetological population studies (Mazerolle *et al.* 2007) and hence the work described in this chapter is novel.

This chapter's objective is to evaluate the success of CMR methodology to estimate the size of nine sand lizard populations from digital images of their dorsal patterns. This chapter then considers whether this method of abundance estimation is suitable for this species and whether this methodology should form part of a larger scale sand lizard monitoring scheme. In addition, we hope that by conducting these population estimates we will further our ecological understanding of how the detection and survivorship probabilities of this difficult to monitor species fluctuate. This will enable us to make valuable suggestions towards the development of future monitoring methods to fulfil our reporting commitments to Europe regarding the conservation status of the UK's sand lizard populations.

Several areas of heathland were surveyed intensively (34 times over three field seasons) for sand lizards to quantify the detection probabilities, and these were then used to generate population estimates and densities for each sampled plot.

The detection and survival rates of male and females lizards were compared and possible explanations for differences between the two discussed. Parallels are drawn between the variation in recapture rates between males and females from a captive population (Chapter 2) to those in wild populations. The reliability of the population estimates is considered and sources of error within these are identified. Finally, the difficulties in establishing a robust method to quantify the number of sand lizards present in an area over a limited number of visits (in line with the National Reptile and Amphibian Recording Scheme, NARRS) are evaluated.

5.2 Methods

Surveys

Nine plots at three heathland sites selected by ARC (appendix A) were surveyed intensively (34 times over three field seasons) for sand lizards by walking slowly in an indiscriminate fashion around all areas of the plot. Likely basking locations and interfaces between habitat types or structures were given the most attention.

When a sand lizard was observed an image was taken using a Konica Minolta DiMAGE Z5 digital camera. The location of the lizard was recorded by a Garmin Etrex 12 channel GPS and the temperature, wind speed and direction, humidity and light reading (at observer height and lizard location) was taken using a Mannix DLAF-8000 handheld environmental meter.

A total of 126 field surveys were conducted from April–November in 2005 (14 surveys), March–July in 2006 (10 surveys) and February–July in 2007 (10 surveys). The time taken to survey each area was kept constant over the field seasons to maintain a consistent sampling effort. The aim was to survey each plot at least once a week.

Capture histories of sand lizards

Individual sand lizards were identified by eye from their dorsal patterning using the digital images and each of these is considered 'marked' in the results.

Comparisons were made between pairs of images by matching distinctive patterning and islanding of dots and the patterning and bleeding of colour into the dorsal stripes. Capture histories of mismatched lizards (where the same lizard was not paired by eye), were corrected by the automated photo identification software developed by Conservation Research Ltd. (Chapter 4) and were updated. The combined results of the pattern matching by eye and by the software were entered into Program MARK (White & Burnham 1999) to generate the survivorship and detection rates and the sand lizard population estimates.

A pilot radio tracking study was undertaken at Merritown plot C to further our understanding of sand lizard movements. The data from the pilot study was not sufficient for the intended analysis, see Appendix D.

Data analysis

The sampling method for the population data was designed to allow the analysis of the lizard's capture histories using the robust models in Program MARK.

Population estimates using the robust method account for and quantify temporary emigration and immigration of individuals within the estimates. This is possible by considering sampling sessions as primary and secondary occasions where the secondary sampling occasions are close together, to minimise any temporary immigration and emigration. In this case the primary occasions would be the year and the secondary periods would be the surveys conducted within each year (Cooch & White 2007). However, the low recapture of the sand lizards meant that meaningful data analysis could only be conducted using the most basic model: the Cormack-Jolly-Seber (CJS) population model in Program MARK. It was not possible to conduct analysis on the raw data set because of the low recapture rates so the individual plot data were condensed and reduced to annual encounter occasions (i.e. was the lizards observed in 2005, 2006 or 2007?), which increased the recapture rate. Where possible, the condensed data for each individual plot was analysed and the condensed data from the four individual plots with the most recaptures were pooled and collectively analysed. All data sets were evaluated against the candidate models described below using Program MARK.

The CJS model does not assume animals are randomly sampled (Amstrup *et al.* 2005) and allows the estimation of capture and survival rates based on the only the recapture histories of marked lizards (Amstrup *et al.* 2005). The CJS model is open to gains resulting from in situ reproduction and immigration and to loss from death and emigration (Amstrup *et al.* 2005), but unable to account for temporary immigration or emigration. The following assumptions must be valid before a *priori* model selection is made, and violation of these assumptions should be discussed in relation to lack of model fit (Cooch & White 2007).

1. Every marked animal present in the population at time (i) has the same probability of recapture (p_i).
2. Every marked animal in the population immediately after time (i) has the same probability of surviving to time ($i + 1$).
3. Marks are not lost or missed.
4. All samples are instantaneous relative to the interval between occasion (o) and ($i + 1$) and each release is made immediately after the sample.

Program MARK was used to quantify any constants or differences in sex dependent survivorship between years and sex and time dependent detectability/recapture. As such the following set of *a priori* models were run through program MARK. Survivorship was not predicted to vary with time or group, as the analysed data consisted of three encounter occasions on consecutive years. Model notation followed that of Lebreton *et al* (1992) as follows:

- Φ_i = survival probability from time i to time $i+1$
 p_i = probability of detection (recapture rate) at time i
 g = group (sex)
 t = time
 $.$ = constant

The following models were run through Program Mark. The general model predicted to be the best fit and with the most parameters was model 1.

1. $\Phi (g) p (g*t)$ – survival varies by group, detection varies by both group and time
2. $\Phi (g) p (g)$ – survival varies by group, detection also varies by group
3. $\Phi (g) p (.)$ – survival varies by group, detection is constant
4. $\Phi (g) p (t)$ – survival varies by group, detection varies with time
5. $\Phi (.) p (g)$ – survival is constant, detection varies by group
6. $\Phi (.) p (g*t)$ – survival is constant, detection varies by both group and time
7. $\Phi (.) p (.)$ – survival and detection are constant

The general model (with the most parameters and predicted best fit) was tested for goodness of fit and where necessary adjusted to correct for over or under dispersion as reflected by the variance inflation factor (\hat{c}). The data are considered over dispersed if $\hat{c} > 1$ and under dispersed if < 1 . The estimated over dispersion parameter \hat{c} should generally be $1 \leq \hat{c} \leq 4$ (Burnham & Anderson 2002) and provided $\hat{c} \leq 3$ Cooch & White (2007) state one should feel relatively safe progressing with the model structure as long as issues relating to lack of fit are fully considered. Adjustments to \hat{c} were calculated using the bootstrap Goodness of Fit (GOF) option in MARK and run for 500 simulations. The average \hat{c} from the simulations was used to correct the \hat{c} from the general model for any over or under dispersion.

Model fit was evaluated using Akaike's Information Criterion (AIC) or, in the case of adjustments quasi-likelihood Akaike's Information Criteria (QAIC) (Akaike 1974). Where two or models account for a large proportion of the variation of the data, the models were averaged using functions within Program MARK.

Population and density estimates

Population numbers for males and females were estimated collectively for all surveyed sites and each individual site (where possible). The estimates were calculated by using the number of individual sand lizards seen during surveying at the site multiplied by 1/detection rate. The number of lizards present during 2005 was not estimated as previous observations are required to calculate this parameter. The density of sand lizards on each site was calculated by dividing the population estimate by the plot area (estimated using GIS) (Appendix A, table A.1).

5.3 Results

The total number of sand lizard observations varied by year and by plot (tables 5.1 – 5.3). The most encounters occurred at Town Common plot A (table 5.1) and the least at Parley Common plot B (table 5.3). In total 544 observations of sand lizards were made in the course of this study. The values in tables 5.1 and 5.3 differ slightly from those reported in table 4.1 (see Chapter 4) as the same lizard was often encountered more than once in a single survey and photographed. In table 4.1, these duplicates were excluded from the database.

Table 5.1. Summary of sand lizards encounters at Town Common A, B and C over the study period. Marked males and females were those photographed. Unmarked individuals were not photographed but recorded in the field.

Town	2005			2006			2007			Totals
	A	B	C	A	B	C	A	B	C	
Marked males	29	1	6	38	11	15	48	5	15	168
Marked females	14	0	2	9	1	4	8	2	2	42
Total marked	43	1	8	47	12	19	39	7	17	193
Unmarked males	9	0	0	2	1	2	0	2	2	18
Unmarked females	4	1	0	2	0	1	1	0	0	9
Total unmarked	13	1	0	4	1	3	1	2	2	27
Total lizard encounters	56	2	8	51	13	22	57	9	19	237
Unidentified	0	0	0	0	0	0	0	0	0	0

Table 5.2. Summary of sand lizard encounters at Parley A, B and C over the study period. Marked males and females were those photographed. Unmarked individuals were not photographed but recorded in the field.

Parley	2005			2006			2007			Totals
	A	B	C	A	B	C	A	B	C	
Marked males	13	2	3	23	4	13	3	3	4	68
Marked females	5	1	0	3	1	1	1	2	0	14
Total marked	18	3	3	26	5	14	4	5	4	82
Unmarked males	6	0	3	0	0	4	1	0	2	16
Unmarked females	0	0	1	0	0	1	1	0	1	4
Total unmarked	8	0	4	0	1	1	2	0	3	19
Total lizard encounters	26	3	7	26	6	15	6	5	7	101
Unidentified	2	0	0	0	1	1	0	0	0	4

Table 5.3. Summary of sand lizards encountered at Merritown A, B and C over the study period. Marked males and females were those photographed. Unmarked individuals were not photographed but recorded in the field.

Merritown	2005			2006			2007			Totals
	A	B	C	A	B	C	A	B	C	
Marked males	12	4	19	25	12	18	17	6	13	126
Marked females	6	6	13	8	10	6	7	1	3	60
Total marked	18	10	32	33	22	24	24	7	16	186
Unmarked males	4	1	0	2	1	0	1	1	2	12
Unmarked females	2	1	2	2	0	1	0	0	0	8
Total unmarked	6	2	2	4	1	1	1	1	2	20
Total lizard encounters	24	12	34	37	23	25	25	8	18	206
Unidentified	0	0	0	0	0	0	0	0	0	0

Not all selected study areas had a consistent number of sand lizard sightings. Only the four sites with the highest number of sand lizard observations and re-encounters were considered for further analysis, these were: Town Common plots A and C and Merritown Heath plots A and C. The number of individuals recaptured each year varied between plots ($\chi^2=245.4$, $d.f.=24$, $P<0.01$) and years ($\chi^2=61.98$, $d.f.=14$, $P<0.01$). The first year of the study (2005) had the lowest number of recaptures across all study plots (figures 5.1 – 5.3).

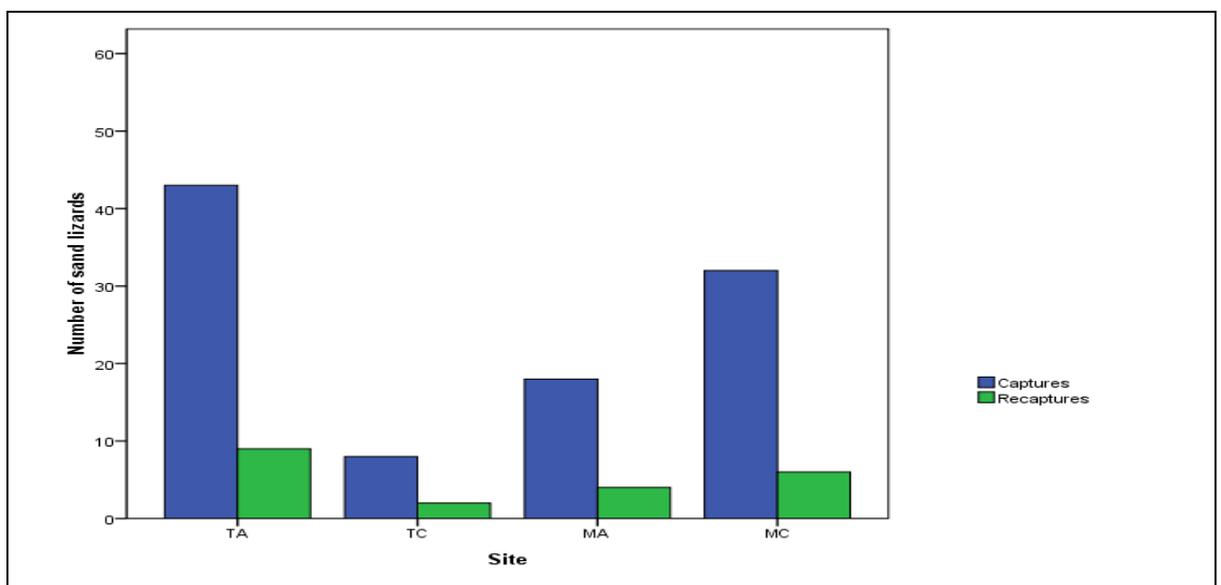


Figure 5.1. Total number of captures and recaptures of individual sand lizards during 2005 from the four study areas with the largest number of sand lizard observations. TA = Town Common plot A, TC = Town Common plot C, MA = Merritown plot A and MC = Merritown plot C.

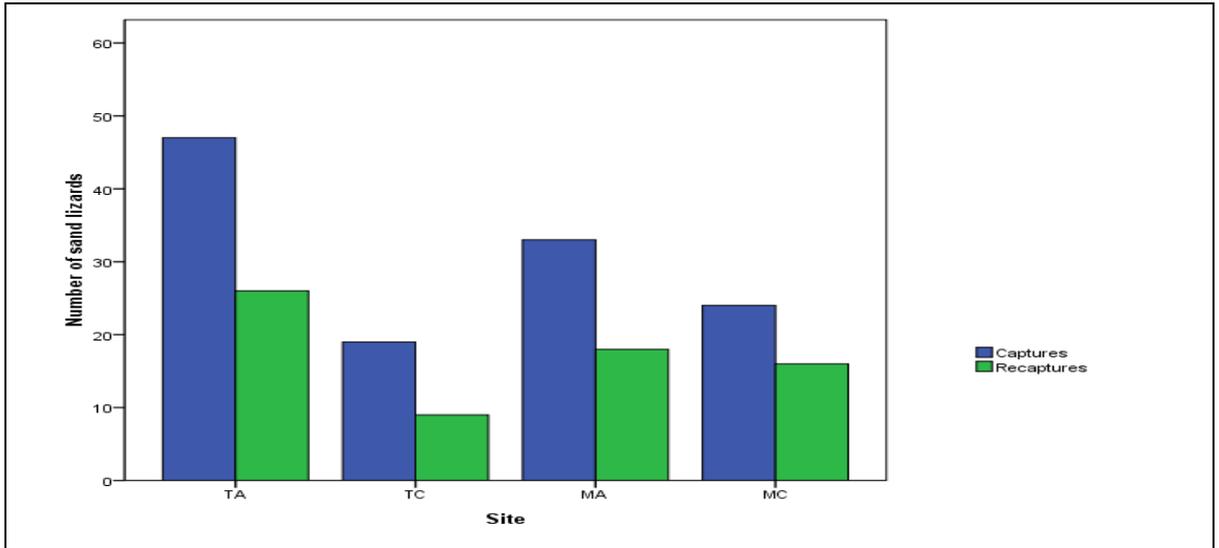


Figure 5.2. Total number of captures and recaptures of individual sand lizards during 2006 from the four study areas with the largest number of sand lizard observations. TA = Town Common plot A, TC = Town Common plot C, MA = Merritown plot A and MC = Merritown plot C.

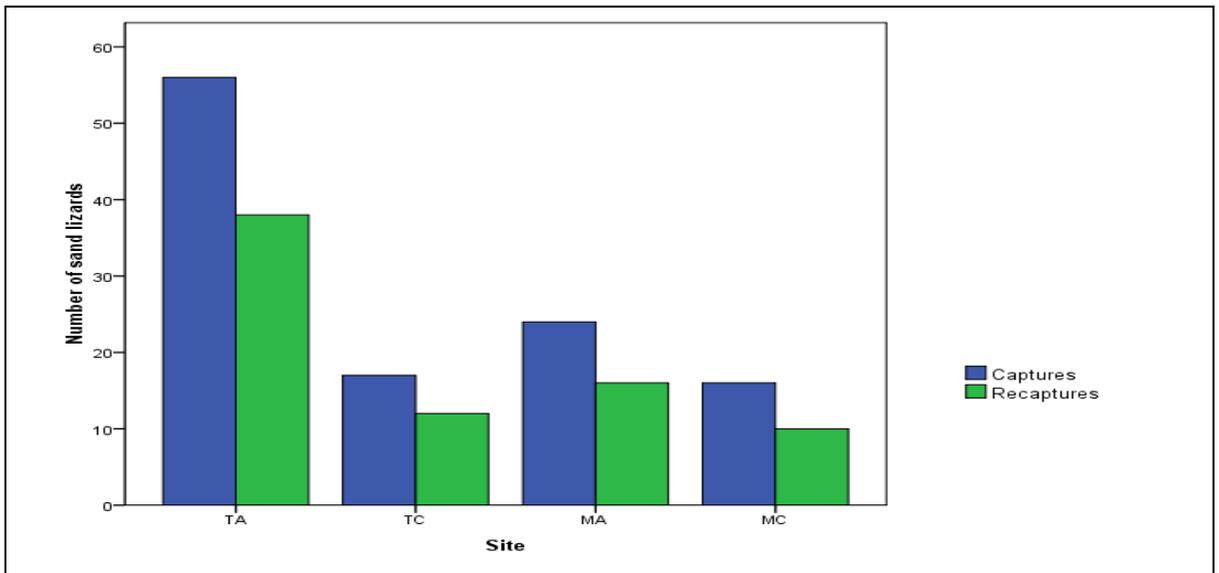


Figure 5.3. Total number of captures and recaptures of individual sand lizards during 2007 from the four study areas with the largest number of sand lizard observations. TA = Town Common plot A, TC = Town Common plot C, MA = Merritown plot A and MC = Merritown plot C.

The numbers of re-encountered sand lizards as a proportion of the total seen over the survey period was much lower than anticipated (figures 5.1-5.3). Analysis of the recapture data from each individual plot would yield invalid and uninterpretable results and hence only the datasets from TA and MC were analysed through MARK (see figures 5.5-5.8 for low count values).

Pooled data from four sites with three encounter occasions

The variance inflation factor (\hat{c}) of the general model $\Phi(g)p(g^*t)$ (where survivorship varies with sex and detectability varies with sex and time) was 2.8241 which reflects some over dispersion and lies near the upper level of acceptability of $1 \leq \hat{c} \leq 3$ (Burnham & Anderson 2002; Cooch & White 2007). The \hat{c} value was corrected to account for over dispersion in the dataset using the median \hat{c} function based on multiple simulations (\hat{c} adjusted = 1.8773) available in MARK as the general model was not fully time dependent (Cooch & White 2007).

The best models for the data suggest that the survivorship is different for males and females. The model which fits the data best (model 1) is that of survivorship varying with sex, and detectability varying with time. This best model is only 1.54 times better at explaining variation in the data than the second best model (model 2) where survivorship varies with sex and detectability remain constant (table 5.4). In this example the most parsimonious model was not the model with the highest likelihood. This suggests the inclusion of the addition time parameter in model 1 strengthens the fit of model 2.

Models 1-5 were averaged to produce parameter estimates (table 5.5). The condensed data set show that male survivorship is greater than female survivorship and the recapture rates of males and females differ between sexes and time. This was predicted with the *a priori* general model.

Table 5.4. Model output for survivorship and recapture of sand lizards from condensed data with three sampling occasions. Models were run using adjusted over dispersed data by the median \hat{c} value within MARK.

<i>Model using $\hat{c} = 1.8773$</i>	<i>Model ID</i>	<i>K</i>	<i>QAICc</i>	Δ <i>QAICc</i>	<i>Model likelihood</i>	<i>QAICc weights</i>	<i>Evidence ratio</i>	<i>Model Deviance</i>
Φ (sex) p (time)	1	4	112.09	0.00	1.00	0.38	1.00	3.48
Φ (sex) p (constant)	2	3	112.95	0.87	0.65	0.25	1.54	6.46
Φ (sex) p (sex*time)	3	5	113.76	1.67	0.43	0.16	2.31	3.01
Φ (sex) p (sex)	4	4	114.76	2.67	0.26	0.10	3.81	6.15
Φ (constant) p (sex)	5	3	115.07	2.99	0.22	0.09	4.45	8.58
Φ (constant) p (constant)	6	2	118.17	6.09	0.05	0.02	20.96	13.76
Φ (constant) p (time)	7	3	119.29	7.20	0.03	0.01	36.63	12.79

Table 5.5. Parameter estimates from model averaging of models 1-5 (Table 5.4) within MARK.

<i>Parameter</i>	<i>Estimate</i>	<i>Standard Error</i>	<i>Lower 95% C.I.</i>	<i>Upper 95% C.I.</i>
Female Φ	0.264	0.141	0.080	0.597
Male Φ	0.666	0.140	0.367	0.873
Female p for 2006	0.831	0.219	0.189	0.990
Female p for 2007	0.709	0.389	0.057	0.990
Male p for 2006	0.827	0.146	0.391	0.972
Male p for 2007	0.650	0.212	0.229	0.920

Table 5.6. Population estimates for the number of lizards present at all of the four survey sites during 2006 & 2007.

<i>Sex and Year</i>	<i>Number of individual lizards observed</i>	<i>Population estimate with 95% confidence intervals</i>
Males 2006	90	109 (93 – 230)
Females 2006	27	32 (27 – 143)
Males 2007	86	132 (94 – 376)
Females 2007	19	27 (20 – 333)

The confidence intervals for the population estimates are wider in 2007 than 2006 despite the observation of similar numbers of individuals sand lizards during sampling. The anecdotal observation of spotting more males than females when conducting surveys is supported by the output of the population estimates in table 5.6, that more males are present in the population than females, although the high upper confidence intervals for females reflect the low parameter estimates for detection in the MARK models. These detection estimates as calculated from pooled annual data are annual estimates and their detection is known to fluctuate significantly with their seasonal cycle (see Chapter 2).

Individual Plot analysis

The same set of *a priori* models applied to the pooled data were run through MARK for Town Common A and Merritown C. Models which included more than four parameters failed due to small sample size. The general model used for this analysis was $\Phi(\text{sex}) p(\text{sex})$ for which $\hat{c} = 1.4042$ (Town Common A) and $\hat{c} = 1.5147$ (Merritown Common C) indicating a model good fit with no required correction for overdispersion (Burnham & Anderson 2002; Cooch & White 2007).

Town Common A – MARK model outputs and population estimates

The best fit model to the data illustrates that survivorship of male and female sand lizards are different at this site. The second best model indicates that the detectability of each sex is more important in explaining the variation in the data than the difference in survivorship (Table 5.7). Models 3 and 4 (general model) which were predicted to be the best fit to the data are not ranked as highly as anticipated but AIC model selection favours the most parsimonious models (Akaike 1974).

Models 1 – 4 were averaged using Program MARK as combined they account for 97% of the variation in the data from the models under consideration. The

parameter estimates show male survivorship is higher than female survivorship at this site, and detectability differs by sex and also by year (table 5.8).

Table 5.7. Model output from three encounter occasions for lizards encountered at Town Common A during 2005, 2006 and 2007.

<i>Model using $\hat{c} = 1.4042$</i>	<i>Model ID</i>	<i>K</i>	<i>QAICc</i>	Δ <i>QAICc</i>	<i>Model likelihood</i>	<i>QAICc weights</i>	<i>Evidence ratio</i>	<i>Model Deviance</i>
Φ (sex) p (constant)	1	3	67.81	0.00	1.00	0.42	1.00	2.09
Φ (constant) p (sex)	2	3	68.78	0.97	0.62	0.26	1.62	3.06
Φ (sex) p (time)	3	4	69.94	2.13	0.34	0.15	2.90	1.94
Φ (sex) p (sex)	4	4	70.00	2.19	0.33	0.14	2.99	2.00
Φ (constant) p (constant)	5	2	73.88	6.07	0.05	0.02	20.79	10.37
Φ (constant) p (time)	6	3	76.04	8.23	0.02	0.01	61.35	10.32

Table 5.8. Parameter estimates from model averaging of models 1-4 for Town Common A. Upper limits of the estimates were calculated using the lower 95% confidence limits (LCI) and the lower limits using the upper 95% confidence limits (UCI) estimated from the MARK models.

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>LCI</i>	<i>UCI</i>
Female Φ	0.291	0.269	0.031	0.841
Male Φ	0.698	0.152	0.361	0.905
Female p for 2006	0.604	0.341	0.085	0.961
Female p for 2007	0.590	0.343	0.082	0.959
Male p for 2006	0.725	0.183	0.304	0.941
Male p for 2007	0.711	0.196	0.275	0.941

Table 5.9. Population estimates for Town A from model averaging. Upper limits of the estimates were calculated using the lower 95% confidence limits (LCI) and the lower limits using the upper 95% confidence limits (UCI) estimated from the MARK models.

	<i>Number individual lizards observed</i>	<i>Population estimate</i>	<i>LCI</i>	<i>UCI</i>
Males 2006	38	52	125	40
Females 2006	9	15	105	9
Males 2007	31	44	123	33
Females 2007	8	11	98	9

Merritown Common C - MARK model outputs and population estimates

The model output identifies the difference in male and female survivorship as the best explanation for the variation in the data (table 5.10) with the survivorship of males higher than that of females (table 5.11).

There were problems determining the parameter estimates for male detectability using MARK. At this site, a high number of male lizards were encountered during the first year of sampling (Table 5.3, figure cumulative graph for Merritown C) and in the following years these lizards and only a few new individuals were observed. The reduction of the data into three annual encounter occasions created a perfect detection probability of 1 (Table 5.11, 5.12 & 5.13). The number of males present on Merritown C was equal to the number observed. This problem was not foreseen and the further estimates of male sand lizard from this site should be interpreted with caution.

Table 5.10. Model output from three encounter occasions for lizards encountered at Merrittown C during 2005, 2006 and 2007.

Model using $\hat{c} = 1.5147$	Model ID	K	QAICc	Δ QAICc	Model likelihood	QAICc weights	Evidence ratio	Model Deviance
Φ (sex) p (constant)	1	3	35.36	0.00	1.00	0.41	1.00	2.00
Φ (constant) p (sex)	2	3	36.36	1.00	0.61	0.25	1.65	3.00
Φ (constant) p (constant)	3	2	36.76	1.40	0.50	0.20	2.01	5.77

Table 5.11. Number of lizards per hectare at Town Common A and Merrittown plot C based on population estimates from Program MARK. Upper limits of the estimates were calculated using the lower 95% confidence limits (LCI) and the lower limits using the upper 95% confidence limits (UCI) estimated from the MARK models.

Survey Area	2006						2007					
	Males	LCI	UCI	Females	LCI	UCI	Males	LCI	UCI	Females	LCI	UCI
Town Common A	159	378	122	45	319	28	205	530	155	34	297	26
Merrittown C	30	30	30	25	173	10	30	30	30	13	173	10

Table 5.12. Parameter estimates from model averaging from lizards encountered at Merrittown C during 2005, 2006 and 2007. The estimation of the male detection rates did not perform well, perhaps because of the low male recapture rates.

Parameter	Estimate	SE	LCI	UCI
Female Φ	0.325	0.192	0.080	0.728
Male Φ	0.503	0.147	0.242	0.762
Female p for 2006	0.793	0.347	0.058	0.996
Female p for 2007	0.793	0.347	0.058	0.996
Male p for 2006	1.000	0.000	1.000	1.000
Male p for 2007	1.000	0.000	1.000	1.000

Table 5.13. Population estimates for MC from model averaging. **Estimates for males are the number of males encountered within year defined as detection probability = 1.

	<i>Number individual lizards observed</i>	<i>Population estimate</i>	<i>LCI</i>	<i>UCI</i>
Males 2006**	9	9	9	9
Females 2006	6	8	104	6
Males 2007**	9	9	9	9
Females 2007	3	4	52	3

Densities of sand lizards

Town Common area A has a much higher density of female sand lizards per hectare than Merritown C. The comparison between the numbers of males is not reliable because of the difficulties in estimating the detection rate of males in Merritown C, with confidence the number of males per hectare at Town Common plot A is much greater than the number present at Merritown plot C (table 5.11).

There is a higher density of females at Town Common A and Merritown C during 2006 when compared to 2007 and a higher density of males at Town Common A in 2007 when compared with 2006.

It was anticipated that the presence of sand may be linked to the number of females observed on each plot as gravid females deposit their egg clutches (for incubation) in sandy soils (table 1.14). However there was no significant correlation between the number of females observed in each plot and the area of sand was found (Spearman's rank correlation co-efficient $r=0.30$, $P=0.44$, $n=9$).

Table 5.14. Area of sand suitable for *L. agilis* egg clutch deposition with the number of different females observed on each site. Sand area data after Plowman (2007), unpublished data.

<i>Plot</i>	<i>Area of sand on plot (m²)</i>	<i>Number of female sand lizards</i>
MA	0.4	11
MB	0.0	10
MC	37.0	17
PA	35.0	6
PB	22.0	4
PC	0.0	4
TA	95.0	20
TB	29.0	2
TC	75.0	4

Cumulative totals of individual lizards compared to count data observed per sampling period

The number of lizards observed per survey (counts) and the cumulative total of individual sand lizards observed over the sampling period were plotted for all nine sample sites (figures 5.4 - 5.8). The lizard counts on all nine plots over the three years are subject to a high degree of variation. Zero count surveys (no lizards observed) occurred at every site on more than two occasions each field season.

More male than female sand lizards were observed at all nine plots with new male and female lizards observed each year (figures 5.4 – 5.8). At the start of each season there was a rapid increase of the new males observed. The number of lizards recorded during count surveys cannot be interpreted or used as an indicator of the true number of individual lizards present per sampled area. The figures suggest the number of individuals present on the intensively surveyed sites of low population size required fewer visits (as the graphs plateau earlier) to establish the true number present (figures 5.5d, 5.7d and 5.8b), than at the site with the largest number of lizard observations (figure 5.4b). There are no similarities between the count data and the cumulative number of individual lizards present across the nine plots.

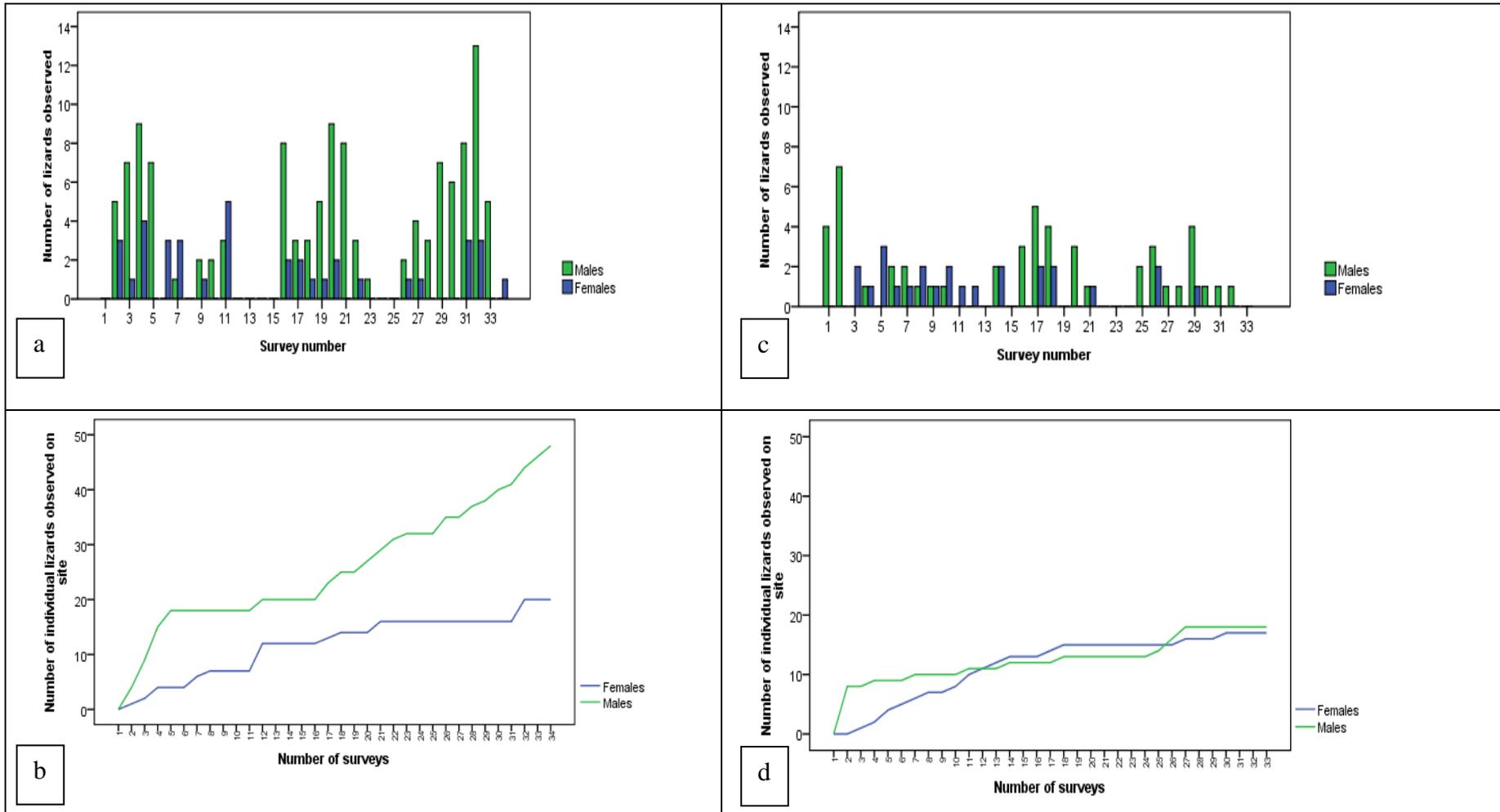


Figure 5.4. Number of sand lizards observed per survey for Town Common plot A (a) and Merritown plot C (c) and the cumulative total of individual sand lizards present at Town Common plot A (b) and Merritown plot C (d) in 2005 (surveys 1-14), 2006 (surveys 15-24) and 2007 (surveys 16-34).

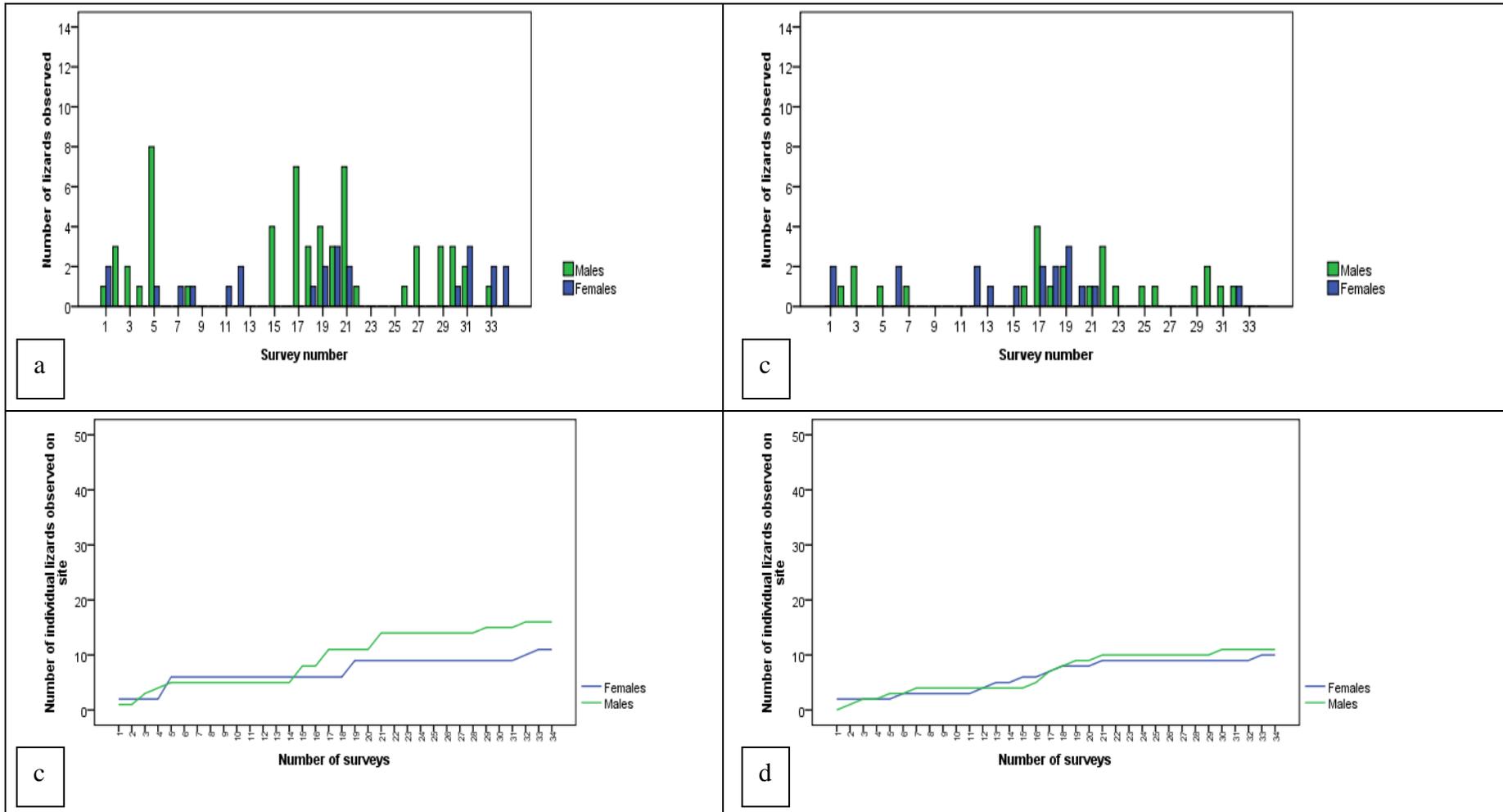


Figure 5.5. Number of sand lizards observed per survey for Merrittown plot A (a) and Merrittown plot B (c) and the cumulative total of individual sand lizards present at Merrittown plot A (c) Merrittown plot B (d) in 2005 (surveys 1-14), 2006 (surveys 15-24) and 2007 (surveys 16-34).

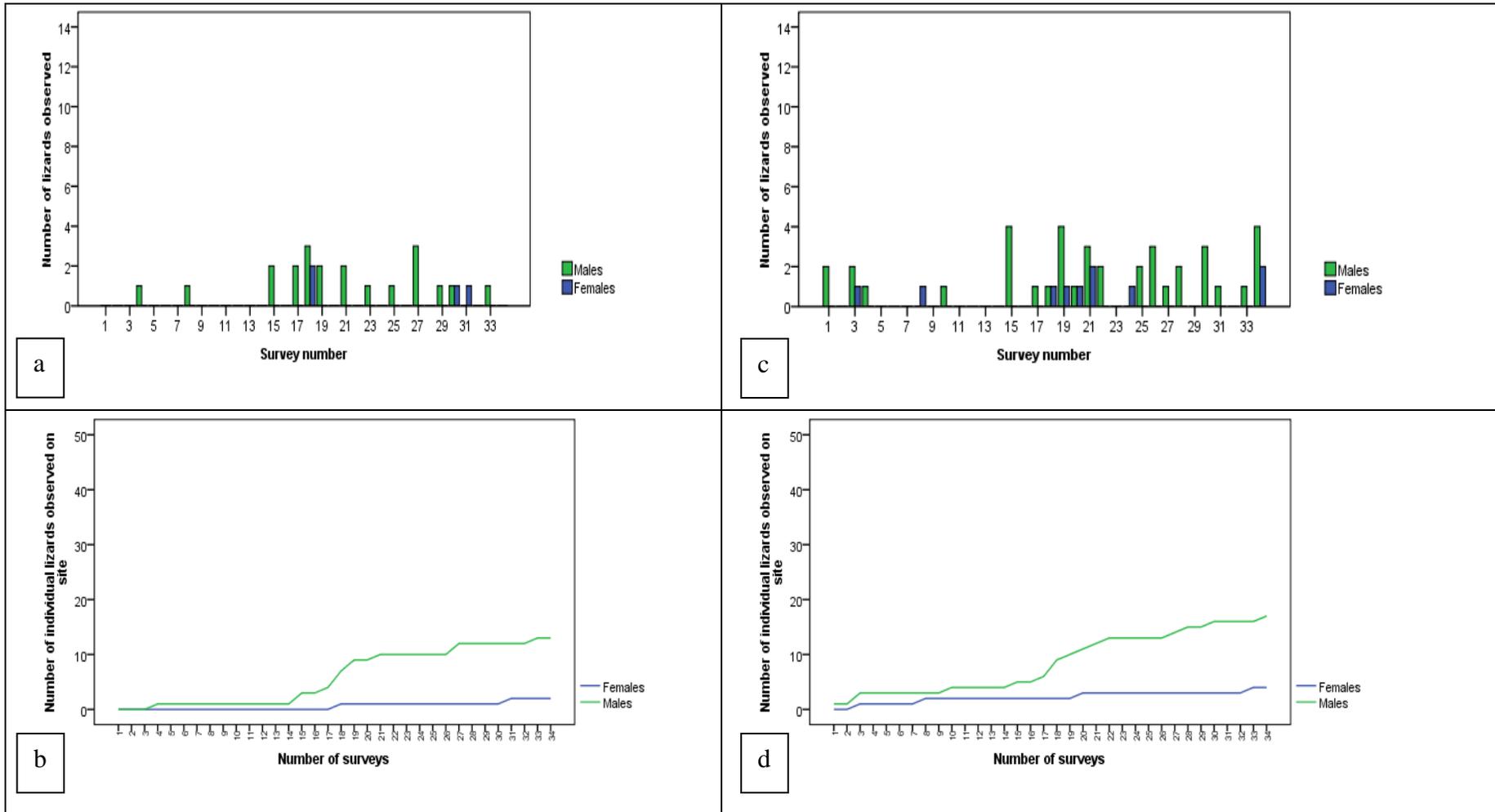


Figure 5.6. Number of sand lizards observed per survey for Town Common plot B (a) and Town Common plot C (c) and the cumulative total of individual sand lizards present at Town Common plot B (b) and Town Common plot C (d) in 2005 (surveys 1-14), 2006 (surveys 15-24) and 2007 (surveys 16-34).

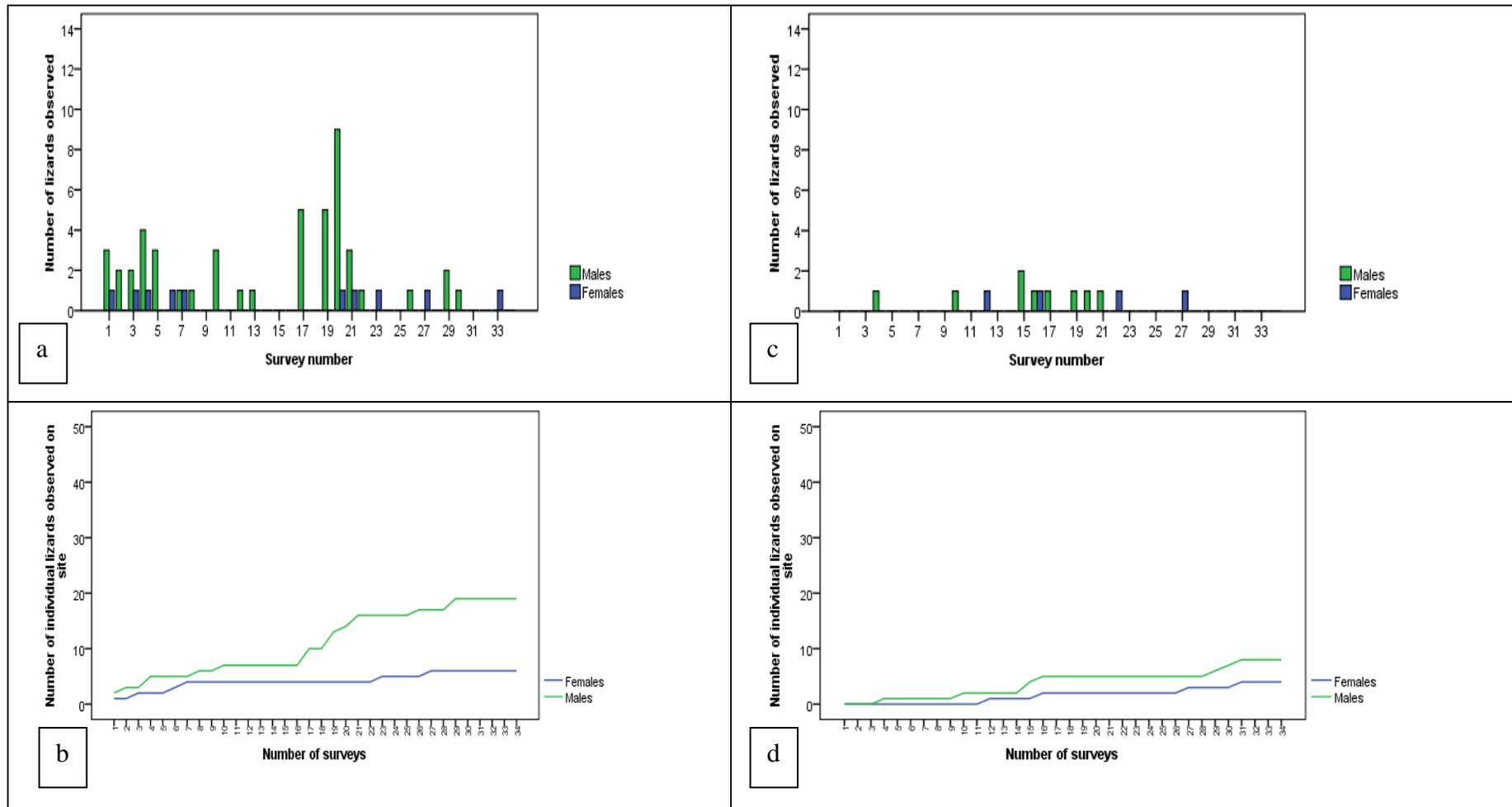


Figure 5.7. Number of sand lizards observed per survey for Parley Common plot A (a) and Parley Common plot B (c) and the cumulative total of individual sand lizards present at Parley Common plot A (b) and Parley Common plot B (d) in 2005 (surveys 1-14), 2006 (surveys 15-24) and 2007 (surveys 16-34).

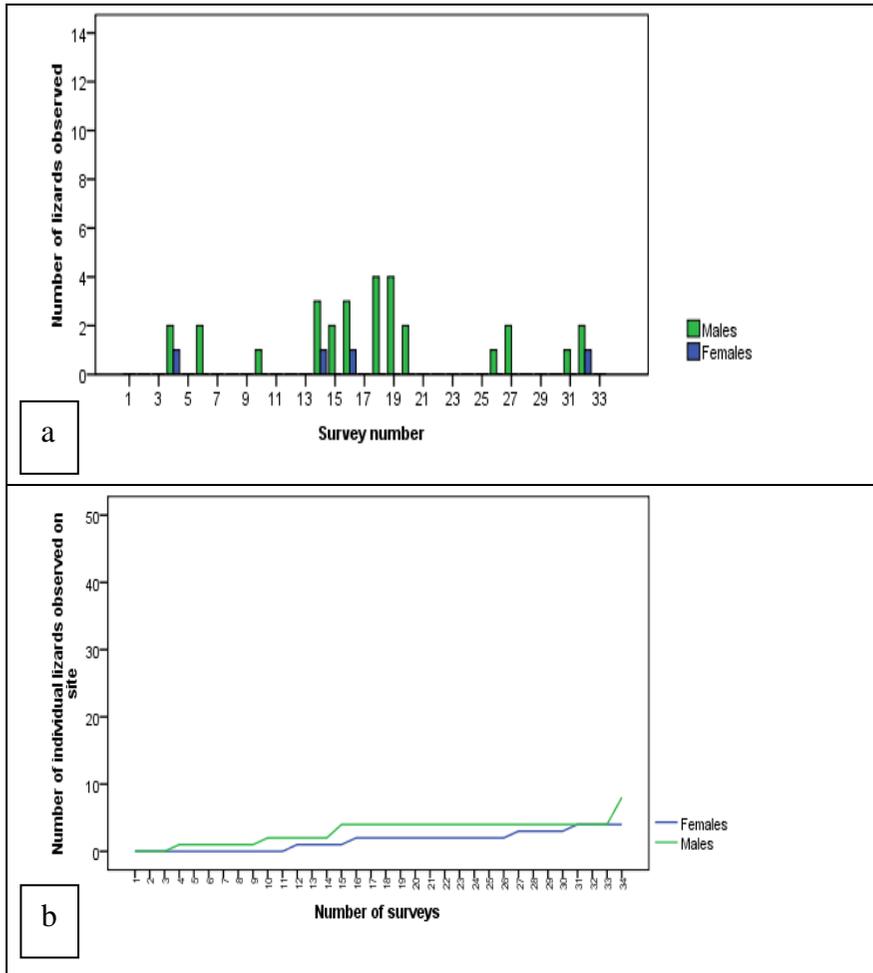


Figure 5.8. Number of sand lizards observed per survey for Parley Common plot C and the cumulative total of individual sand lizards present at Parley Common plot C in 2005 (surveys 1-14), 2006 (surveys 15-24) and 2007 (surveys 16-34).

Annual cumulative totals for Town Common plot A and Merritown plot C

The cumulative totals of individual lizards observed for the two sites with the highest number of lizards were analysed further to investigate whether any trends for the detection of new individuals occurred annually. The survey data were divided by year and independent (totals were not carried over from previous years) cumulative totals plotted.

The total number of new individual lizards observed each year at Town Common plot A is not consistent, nor is the rate at which they are detected (figures 5.9 – 5.11). The number of new individual lizards encountered in 2005 and 2006 appears to stabilise at visit 12 (2005) and visit 22 (8th visit in 2006) but this is explained by the zero count totals of these surveys (figure 5.4a). As such, there is no indication of a levelling of the cumulative total curves which implies additional surveys may be required to ensure every lizard present is detected.

The annual totals of number of different sand lizards present on Merritown are more consistent between years in comparison to those observed on Town Common A (figures 5.9 – 5.14). The cumulative curves are much flatter as fewer new individuals are seen on each survey. The reduced encounter rate of new individuals would be expected at a site with a lower population size. The totals also show less variation than those observed over the years on Town Common plot A, again explained by the lower population size and density estimates (table 5.11 & 5.12). The levelling to the cumulative curve is again a result of the zero surveys present nearing the end of the field season (figure 5.4c).

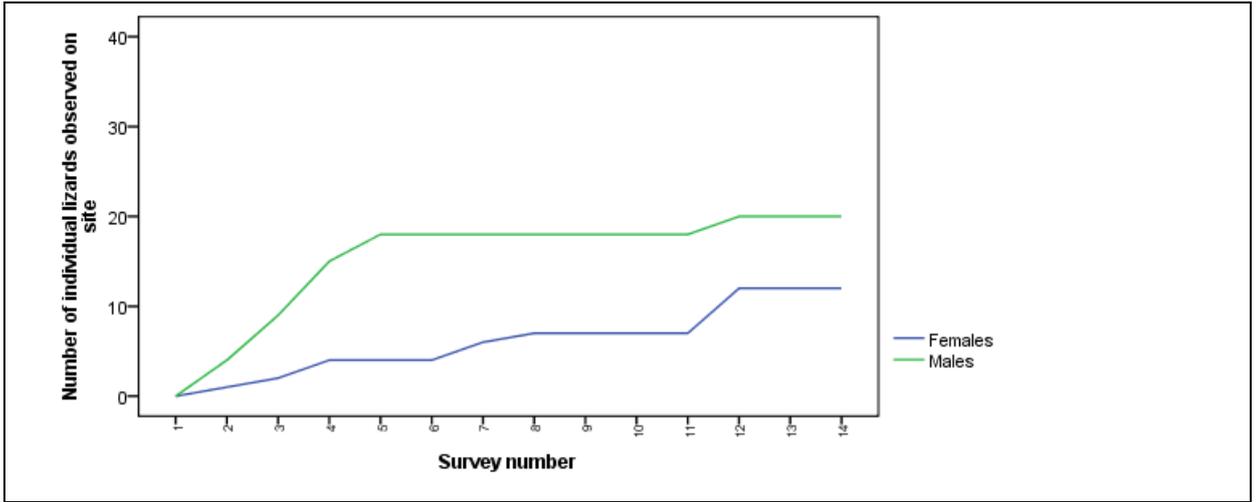


Figure 5.9. Cumulative number of different lizards observed during 2005 at Town Common plot A.

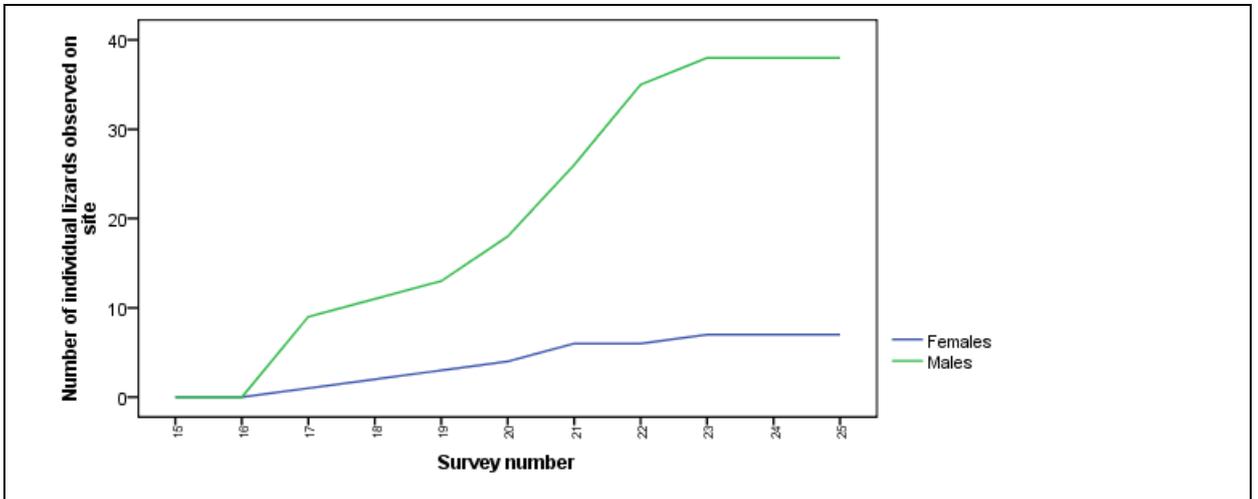


Figure 5.10. Cumulative number of different lizards observed during 2006 at Town Common plot A.

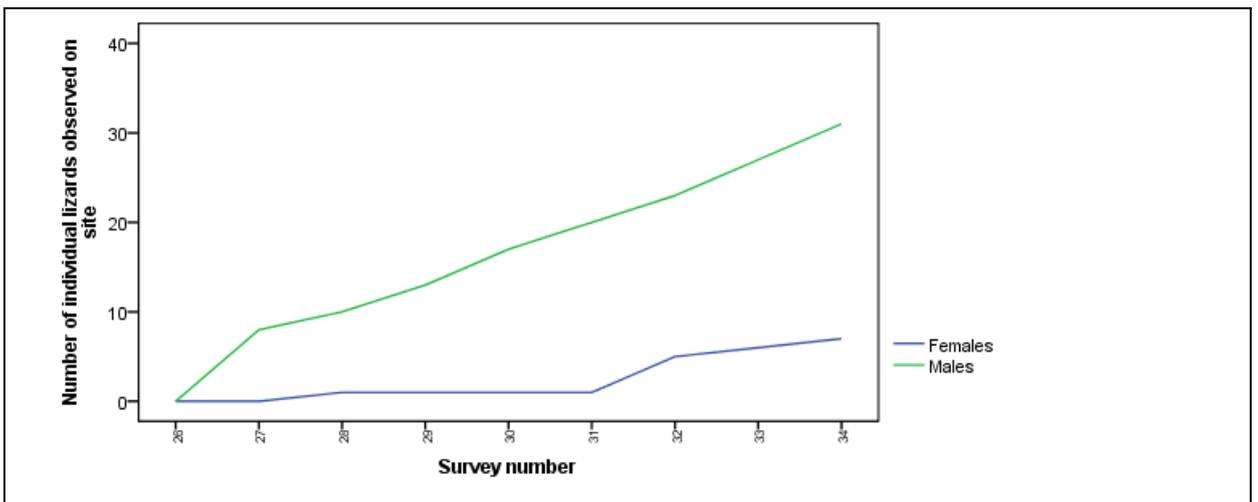


Figure 5.11. Cumulative number of different lizards observed during 2007 at Town Common plot A.

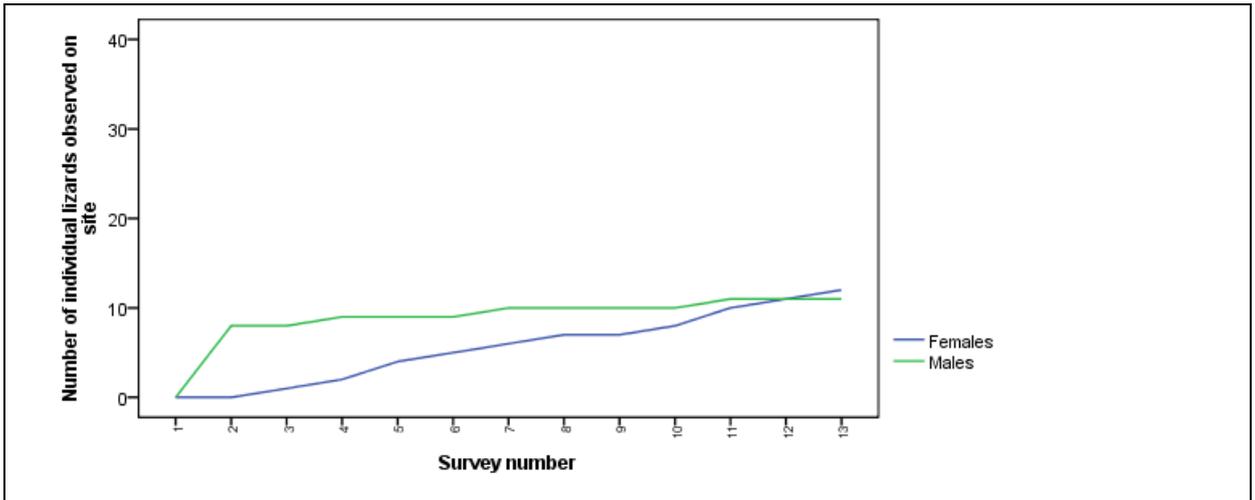


Figure 5.12. Cumulative number of different lizards observed during 2005 at Merrittown plot C.

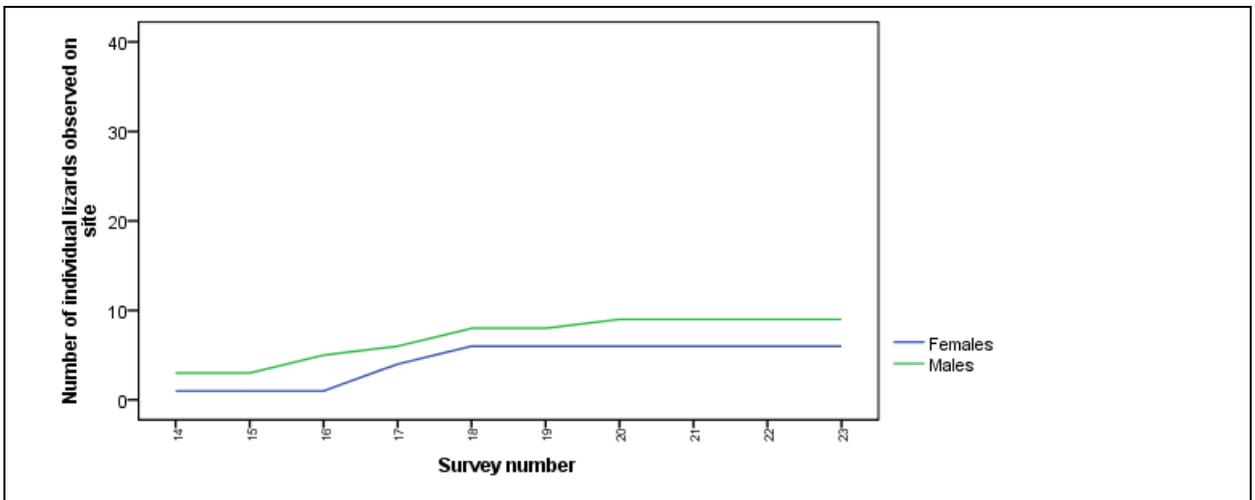


Figure 5.13. Cumulative number of different lizards observed during 2006 at Merrittown plot C.

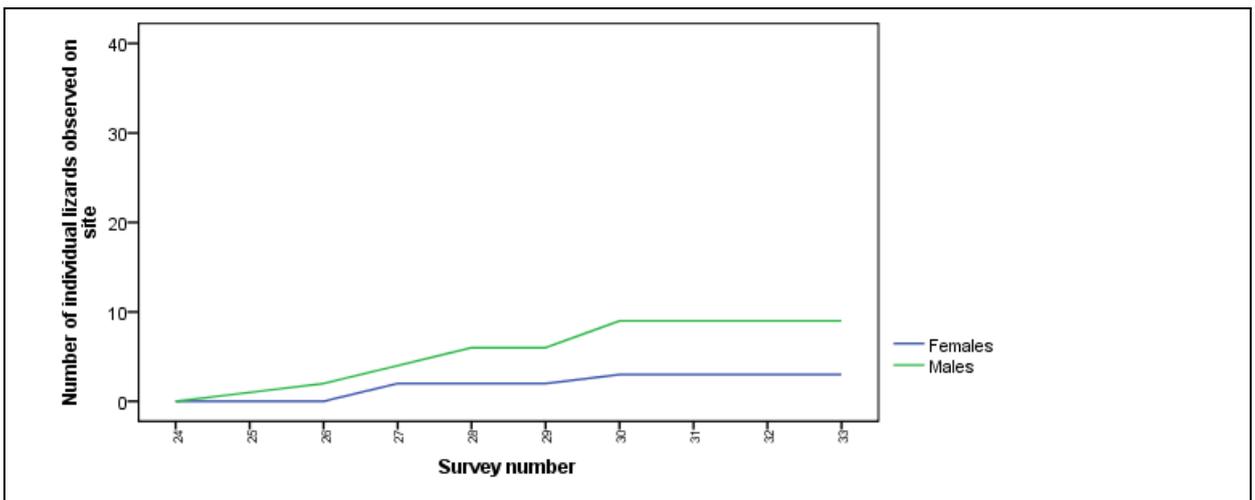


Figure 5.14. Cumulative number of different lizards observed during 2007 at Merrittown plot C.

5.4 Discussion

Detection rates

Intensive sampling was adopted to investigate the fluctuation of sand lizard detection probabilities within a single season and between years. The recapture rate of sand lizards at all plots was low and robust analysis from the raw survey data was not possible. The data from the four sites (TA, TC, MA & MC) with the most reencounters were pooled and collectively analysed. Although the recapture rate of sand lizards differed between the sites it was not thought that pooling the data would create additional sources of error. The pooled data contained a single annual record indicating whether or not the lizard had been observed during the season which would have eliminated any survey specific variables that could also have influence the detection probability of the sand lizards. Pooling of the data increased the number of data points increasing the reliability of the estimates and condensing the data decreased the zero records, thus making the data suitable for estimation of an annual detection probability estimate. It was not the intension of this study to reduce the field data for analysis, but as the recaptures rates of individuals were low investigation into the within season variation in of detection probability was not viable but with data reduction investigation was possible into how the detection probabilities vary between season and site and attempts at population size estimation were made possible.

The lack of re-encounters of sand lizards on each site was unpredictable as the number of lizards present was unknown at the start of the study, but the sites were known to have lizards present (data supplied by ARC from their sand lizards database, see introduction and chapter discussion for limitations of the records contained within the database). The aggregations of seasonal to annual records compressed the capture histories of individual lizards to a single encounter a year. Although this eliminated the seasonal (within year) variability in detection rates of males and females it ensured the data adhered to assumption 1 - 'same probability of recapture' of the Cormack-Jolly-Seber model (Cooch & White 2007).

Chapter 2 showed that the detection rate of sand lizards varied seasonally with environmental and temporal conditions. Initially it was hoped to model these seasonal variations in detectability using field data, but the data were not suitable for such a comprehensive exploration despite 126 intensive surveys taking over 320 hours. This remains a difficult issue for a rare and elusive species (Thompson 2004) such as *L. agilis* where the populations are small and clustered.

The estimates of male and female detection probabilities from wild population were different and higher than expected, despite the large confidence intervals (table 5.5 & 5.8).

The detection probability of females was slightly higher than that of males (from the pooled data, table 5.5) and at Town Common A the detection rate of males was slightly higher than that of females (table 5.8). In both cases, the confidence interval of the detection probability was narrower for males with the lower limit noticeably higher than the lower limit for females. It appears the detection probability of females is subject to more variation than that of males which is understandable given the reproductive nature of this species (Chapter 2). The mean detection probabilities of the captive lizards are notably lower than those calculated in the wild populations (table 2.10, 5.5 & 5.8). For captive males the mean values were closer to the lower limits of the confidence intervals from wild populations and the mean detection rate of captive females was also much lower than the annual mean from wild populations. The high detection rates of wild lizards were most likely a result of condensing the data into an annual encounter occasion, thus increasing the recapture/detection rate. However, this was necessary to enable exploration of robust population models and estimates. The parameter estimates from the pool data imply approximately 80% of available sand lizards were observed during the sampling (table 5.5), which shows a large proportion of the lizards present were observed. This is a positive result, especially considering the intensity of the sampling regime and the elusive and cryptic nature of sand lizards (Foster & Gent 1996; NCC 1983).

The detection probabilities of both males and females for all the sites differ (pooled data, table 5.5, Town Common A (table 5.8) and Merritown C (table 5.11), indicating this probability varies with site. This is a valid hypothesis, as the opportunity for an observer to detect a sand lizard at a site where sand lizards are known to be present, is in part a function of the habitat. The more open and accessible the habitat, the more likely an observer is to see a lizard (personal observation). In addition an observer is more likely to detect a sand lizard in its optimal habitat (assuming optimal habitat supports a high density of lizards). Also population density will affect detection probability (the more that are present, the more likely you are to encounter a lizard in suitable conditions and habitat) along with other site specific factors including level of site disturbance from public pressure, habituation and threat of predation. These combined factors probably account for the significant difference in the number of sand lizards recaptured between plots and years (figures 5.1-5.3).

Survivorship rates

The estimation of the survivorship parameters was kept constant with time to reduce the number of parameters: it is problematic to run and evaluate models with a high number of parameters when the sample size is small (Burnham & Anderson 2002; Cooch & White 2007). Thus, the survivorship of sand lizards was assumed to be constant between years even though female survivorship is known to vary between ages classes and sites (no estimates for males were reported) (Berglind 2000a). This is arguably unrealistic, but was the most robust analysis which could be conducted, and the first of its kind in generating estimates of male and female survivorship over seasons for this species.

Male survivorship was consistently higher than female survivorship, which could be influenced by the higher number of males observed and reencountered on each plot or by the behaviour of the sand lizards. Female sand lizards require more sunlight for egg development once gravid and so spend more time basking later in the season. This increase in exposure could also increase their likelihood of predation. During clutch deposition the females dig a burrow in the open sand; this process can take several hours and leaves the female lizards at further risk of

predation. After laying, the females spend time regaining their lost condition with increased basking and feeding prior to overwintering, which again exposes them to an increased risk of predation in comparison to males at the end of the season. The lower survivorship of females at Town Common A compared to Merritown C could be related to mortality during egg laying as more sand is present at Town Common A than Merritown C (table 5.13).

Population estimates and densities

An estimate of the number of sand lizards present on all nine sites was successful. The large confidence intervals were expected, as the number of lizards observed is subject to variation in time, weather conditions and season (Dent 1986; Foster & Gent 1996; House 1980; House *et al.* 1980; Nicholson 1980). Two of the plots studied yielded population estimates once the data were reduced and the recapture rate at the remaining seven sites was too low to produce any meaningful results following manipulation. Other recent studies involving lizards have also reported this problem and condensed or amalgamated their datasets to enable sand lizard population analysis (Berglund 2000b), common lizard (Clobert *et al.* 2001) and the flat tailed horned lizard, *P. mcallii* (Grant & Doherty 2007).

The sand lizard densities calculated for Town Common A and Merritown C (table 5.11) lie within the boundaries of previous published estimates ranging from 1.2 lizards per hectare (House 1980) to 300 lizards per hectare (NCC 1983) depending on the habitat and location of the site. Given the age of these density estimates it is likely that these sites have come under increased pressure from fragmentation, development and public pressure and contemporary density estimates are now likely to be lower than the published values. This highlights the ecological value of Town Common plot A as a high density area of sand lizards. Two busy bridle paths divide the plot which assist in keeping the sandy tracks open from encroaching vegetation which is beneficial as females favour open exposed sandy patches for clutch deposition (Corbett & Tamarind 1979) but also creates a moderate amount of disturbance. Anecdotally enthusiasts speculate that the area of sand present on a site can be used as an indication of population size as continued recruitment to the population is dependent on the presence of

suitable egg laying substratum. There is a larger area of sand present at Town Common A (95.0m²) in comparison to Merritown C (37.0m²) and perhaps this could account for the higher density of female sand lizards at Town Common A (tables 5.11). This evidence is based on observations from only two sites and would benefit from further investigation.

The previous attempts to estimate sand lizard density and population have noted that while many lizards are resident in a study area, others encountered only once were probably non resident, indicating high emigration and immigration rates (House 1980; Leeuwen & Hoef 1976; NCC 1983; Nicholson 1980). These high rates of movement could be accounted for by an insufficient number of survey visits in these studies, or, as the cumulative total graphs (figures 5.4-5.8 b & d) indicate, there is indeed a lot of movement of individual sand lizards to and from a survey area. The movement of females has been linked to the deposition of egg clutches in sand patches where they have been observed to move outside their normal home range especially when there are no areas of suitable substratum within their home range area (House 1980; Nicholson 1980) and anecdotal evidence suggests that males will move outside of their home range to find a female with which to mate. Juvenile male sand lizards disperse further from their natal sites than do juvenile females (Olsson *et al.* 1996a)

The population estimates of *L. agilis* should be interpreted with some caution and used as an indicator of the number of lizards which use the sampled area. The results from this study can not be used to indicate whether there are genuinely high rates of immigration and emigration of male and females sand lizards in and from the survey areas, or whether the continually increasing number of newly detected lizards is a product of the survey methodology and not enough repeat visits.

The major drawback of the population estimates of rare and elusive species critically depends on the estimation of the detection probability under a particular sampling regime (Thompson 2004). This has been achieved but not at the depth with which the sampling regime was designed. Careful planning needs to be given

when attempting to sample rare, elusive and cryptic species and *a priori* consideration and attention should focus on how to analyse the potentially problematic data sets. This is not easy because it is hard to predict the sample size (number of lizards present) and the number of recaptures (encounters of the same lizard) will consist of before you start sampling.

Cumulative numbers of new lizards and lizard counts – dominance and dispersal

An important finding from this investigation was the large number of new individual lizards observed on each site per year. The cumulative graph for Town Common plot A (figure 5.4b) illustrates that after 34 surveys over three years new individual lizards consistently observed. These lizards could be new individuals to the area, recently mature adults or simply, lizards that for some reason or another (territory, weather conditions, movement into the plot boundaries) had not been previously detected. This observed increase in new animals applied to both males and females.

Sand lizards are territorial animals and frequently compete for favourable basking spots in their home range. As the day progresses different locations within a site will offer favourable basking spots and perhaps the dominant males are observed basking in the favourable locations at the time they offer the best thermoregulatory opportunities. When the conditions are less favourable in these locations the dominant lizards will relocate to another basking spot and a less dominant lizard could then occupy the now less favourable basking location. If this is the case, only dominant individuals will be seen in the best basking locations on a plot (especially if these are limited), and secondly, several lizards which have not yet been encountered could present in the survey area but remain undetected. The continued presence of new males and females in this study could be a reflection of change in dominance and thus detectability of individuals.

During field work it was noted that the lizards observed in prominent basking positions were larger, so it can be inferred, older individuals; smaller younger individuals (less dominant) were rarely observed in these locations. Again this

indicates that perhaps the survey methodology only sampled the dominant males and females at each site or produced a sample skewed in favour of those individuals. This magnifies the numerical gap between the number of individuals seen and true number of lizards present. These compound factors, if theoretically viable, make the population estimates in this study difficult to interpret and perhaps the most conservative interpretation is to use these values as the known number of dominant individuals present at each site and accept that several other less dominant lizards will remain undetected every season. Again this poses further complications for any future researchers attempting to quantify these values for other territorial lizards.

Dispersal of sand lizards from their nest site and beyond the known home range (NCC 1983) could also account for the large number of new individuals observed only once or twice in a season. Dispersion would be advantageous for the juvenile and sub adult lizards to minimise competitor presence, reduce inbreeding risk (Begon *et al.* 1996) and avoid cannibalism from adult lizards (NCC 1983). The home range of juveniles and immature sand lizards does not overlap with the home ranges of their adults (Strijbosch 1978) and anecdotal and personal observations indicate that juveniles and immature sand lizard are seen in younger, less structurally diverse habitats, surrounding the areas of mixed ages and structured heathers where adults lizards are most frequently observed.

The research conducted on the captive population of sand lizards (Chapter 2) revealed that males have a higher detectability earlier in the season (March - May) which declines as the season progresses and females are more readily detected after mating (June). This pattern is reflected in the male count data observations made on Town Common A in 2005 (figure 5.4a), Merritown C during 2005, 2006 and 2007 (figure 5.4c), and Parley A in 2006 (figure 5.7a). In females the patterns are visible from Town Common A in 2006 & 2007 (figure 5.4a), Merritown A in 2006 & 2007 (figure 5.5a), Merritown B in 2006 (figure 5.5b) and Town Common C in 2006 (figure 5.6a). This is further evidence for site specific and annual variation in count totals and when considered there is probably no display of dominance or territory. The densities of captive bred populations are artificially high so the

extrapolation of the Marwell findings to wild populations of sand lizards needs careful and considered attention.

There is no unexpected relationship between the lizard count totals and the population estimates. Census data cannot be derived from counts of lizards and only when the detection probability of species remains constant can inferences be made on its abundance (Thompson 2004). This study has illustrated that after three years of regular intensive sampling we are still some distance away from linking the number of sand lizards seen during a survey to the true number present. Perhaps for the moment, working towards the estimation of site occupancy may be a better investment of research time, *see general discussion*.

Habitat management, population dynamics and monitoring

The number of unidentified and unmarked sand lizards decreased annually perhaps a reflection of increasing field experience (tables 5.1- 5.3) which indicates observer experience contributes to the number of sand lizards photographed, and it can be inferred detected.

The number of sand lizard encounters at Town Common plot B increased after 2005 post construction of a large pond adjacent to the plot. The pond restricted the ability of the sand lizards to migrate from the ridge as freely as they were previously able. This resulted in a higher number of lizard observations the following two years with several new individuals detected in 2006 which were recaptured in 2007. It is plausible that the creation of the large pond caused individual displacement of lizards and reduced emigration resulting in increased detectability.

The decrease in sand lizard observations on Parley plot A during 2007 can be attributed to the habitat management undertaken during winter 2006 where large areas of the plot were cleared of vegetation and the lizards probably moved to adjacent areas out of the defined survey area into patches of vegetation which support their behavioural and thermoregulatory needs. If major habitat management is required then, ideally, heath corridors should be left for the sand

lizards to migrate. At the very least, refuge areas of uncut vegetation should be left to provide cover for the lizards to reduce the exposure to predation and preserve some localised invertebrate communities. This technique has been adopted by the agricultural community to reduce chick and predation mortality of corncrakes (*Crex crex*) (Broyer 2003) by the RSPB in Oronsay, Scotland (RSPB 2009).

The results of this chapter have identified some limitations with the species database maintained and managed by the Amphibian and Reptile Conservation Trust. The selection of survey sites and plots was based on records held in the species database so that areas where several sand lizard records existed were chosen for further investigation. It was anticipated that plots containing several presence records would contain a high number of sand lizards. On reflection, the records held on the database are not an indication of population size and if interpreted as such are misleading for several reasons: the database is a collation of co-ordinated species records provided by different enthusiasts with misidentification of species a possibility; the same individual lizard could have been rerecorded several times by different observers, with each observation providing a new sighting; many of the records on the database are location biased (only adjacent to sandy path or artificial refugia), these issues are further explored and discussed in the final chapter of this thesis.

This chapter has addressed some of the anecdotal difficulties in attempting a sand lizard census. In particular, the number of lizards observed on a single survey is not related to the number of different individuals present on an area. After 35 repeat visits to an area, new lizards were still being encountered and it was not possible to establish whether this was due to lack of sufficient repeat visits or movement of individuals to and from the survey areas. The detection and survivorship rates of males and females differed and the survivorship of males was consistently higher than that of females. More males were encountered than females while sampling, but whether more males are actually present remains to be seen. This chapter has estimated the size of different sand lizard populations and highlighted the sampling and analytical difficulties encountered in the population estimation of species with low detection and recapture rate. Further

research should build on the findings of this investigation and develop a more efficient method to monitor the UK's populations of sand lizards (see general discussion).

6 General Discussion

Introduction

The aim of this thesis has been to increase our understanding of the elusive nature of the sand lizard and to identify methods to work towards the standardisation of field survey techniques and population size estimation. The aim of this chapter is to discuss the results from the previous experimental chapters and identify the significant findings which need to be included and considered in the development of a future monitoring scheme for the UK's sand lizard populations in preparation for the next conservation status assessment in 2012. It is hoped that the findings presented in this document will help conservationists identify how best to invest financial resources, research effort and time to benefit progress in the development of a monitoring scheme and hence conservation of this species. Many of the presented findings will be of general relevance for rare and elusive species of conservation importance.

Monitoring and population estimation

Population estimates that do not properly account for detection probability lead to biased estimators and misleading estimates of population sizes and trends (Thompson 2004) which can lead to misinformed management decisions and implementation of inappropriate policies. The major challenge with sand lizard census work is linked to their detection probabilities and for the first time we have established that the detection probabilities of male and female sand lizards differ and also fluctuate with respect to seasonality and environmental variables (Chapter 2). A large part of this study has been directed towards estimating the detection probability of sand lizards to produce more reliable population estimates and to evaluate how observers can adapt their survey technique to maximise the chance of an observation.

The detection rates for captive and wild sand lizards differed between the sexes (Chapters 2 and 5). The detection rate of male and female lizards differed when reproductive cycle was taken into account but the mean annual detection rate was the same between the sexes. The investigations into wild populations of sand

lizards found that the annual detection rate of males and females differed but the results were not as clear cut as anticipated and the data were condensed and pooled to allow a reliable analysis (Chapter 5). The detection rates of captive males and females were found to be different before and after the mating (Chapter 2), but it was not possible to investigate how this could affect the detection rate of wild populations because of the low recapture rates (Chapter 5). The detection rates of sand lizards not only vary between the sexes and in space and time (and at different times of the reproductive cycle), but also in response to environmental and habitat variables (Chapters 2, 3 and 5). There is no simple formula for converting observations into population estimates and thus data collected from ad hoc count surveys are of limited use in monitoring schemes for rare and elusive species. However, if the count surveys can be standardised by controlling the timing of surveys or the conditions in which they are undertaken, the results could be weighted to account for variations in detection probabilities allowing comparison of count records. Alternatively, the count surveys could be supplemented by the measurement of variables known to influence the detection probability of sand lizards. Either way, the use of count data from surveys which do not account for variation in detection rates to make inferences regarding sand lizard population stability and size is strongly discouraged.

The detection probabilities of sand lizards are dependent on several external variables and this study has explored and considered how and to what extent those measurable factors could influence the likelihood of observing a sand lizard. The work from the captive population showed that male sand lizards are more likely to be observed prior to mating, and their visibility during that period is linked with temperature and time of day. The detection of post-mated males is linked to changeable weather conditions (Chapter 2). Females are more likely to be encountered post-mating, linked to ground surface temperatures and changeable conditions (Chapter 2). The investigation into the thermal properties of different structures of heathland vegetation in Chapter 3 adds further complexity when proposing recommendations on the best seasonal and diurnal times to detect sand lizards because each structure provides a variation of thermal gradients during a single day, which again differs seasonally. This research has revealed the range of

temperatures recorded in the different vegetation structures were much greater than predicted which allowed us to consider in detail how the lizards may shuttle between vegetation types from a thermoregulatory perspective. In early Spring (March) the temperatures recorded underground are lower than the minimum substratum temperature on which basking sand lizards were observed and hence in good light conditions it is advantageous for the lizards to be above ground, and thus available for detection. At that time of year lizards are most likely to be observed in the mature heather canopy, on open ground and on the degenerate canopy, as in these heathland components temperatures are within their preferred range, but these temperatures are usually only reached later in the day. Although the range of microclimatic temperatures available within the different heather structures may account for the lizards thermoregulatory behaviour, the lizards will also select locations within the vegetation to satisfy their feeding habits (Nicholson 1980) and perhaps their retreat into the canopy in the warmer months of the year is not only driven by temperature but also the abundance of prey items.

It is difficult to predict when is the best time on a given day to survey for sand lizards as their behaviour, and the temperatures available within the vegetation (Chapter 3), depend on the recent and current weather conditions (for detailed breakdown see tables 3.5 – 3.9). The detection of sand lizards should not be based solely on temperature, as they also require sunlight for synthesis of D3 vitamin. Pre-mated male sand lizards may be detected at a temperature lower than their preferred range when there are large amounts of ultra-violet light, and post-mated males are detected in conditions where the incoming solar radiation ranges between 200 – 700 Wm^{-2} (Chapter 2 & Appendix B). Pre-mated females have an association with UV light and this study indicated a minimum threshold value of 1.25 (on the index scale). Gravid females were most strongly associated with the temperature in direct sunlight and were most frequently observed at temperatures ranging between 17.5°C and 27.5°C (Appendix B). Females laying their eggs and regaining their condition were associated with humidity and their detectability is maximised when the humidity is between 50% and 70% (Appendix B). Behaviour could also influence the conditions in which lizards are observed; for

example males holding or losing territories or females that need to deposit their clutches (Chapter 2).

My research confirms that the detection probabilities of males and females differ and these probabilities vary with reproductive stage and in response to environmental variables. Sand lizard surveys should be conducted at times when the detection probability is maximised which for males is prior to mating, in March and in good light conditions later in the day, paying attention to areas of open ground. In April the surveys should be earlier in the day focussing on open ground and the degenerate heather canopy (Chapter 3). Females are best surveyed post-mated later in Spring (May); their colouration makes them more difficult to detect than males and the conditions which they select to bask are dependent on their reproductive stage. This makes recommendations of habitat specifics difficult to clarify. Generally, females can be found in early May basking on the open ground in the earlier morning or late evening and in late May and June, under the edges of vegetation adjacent to sand strips (while they are preparing to deposit their clutches). Surveys for male and female sand lizards outside these recommended periods will have a much reduced probability of a sand lizard observation. To the experienced herpetologist these survey guidelines may appear to be nothing new, but this is the first time these recommendations have been supported by scientific evidence. The concern for conservationists is not whether the sand lizards are present but whether the surveys used for monitoring could reflect a false absence of the species. Such surveys would need to state clearly that the sampling had been conducted outside of the recommended conditions and should detail the date, time and weather conditions of when the sampling was undertaken. This could be used as a measure of likely detection probability at the time of sampling which could help ascertain whether the recorded absences were true or false.

Methods used to estimate population size must account for the two components of detection probability:- *the unavailability of animals* (for detection), which is especially important if this proportion of unavailability fluctuates in space and time (Thompson 2004); and the *likelihood of detecting an animal if it is available* (for detection). The robust design in CMR methodology (see Chapter 5) can be used

to quantify non-availability as can supplementing sampling by CMR analysis with radio telemetry (Thompson 2004) from which you can locate the individual and determine whether it is available or unavailable for detection. Both these methods were used in this study to estimate the unavailability of lizards but were unsuccessful. The low recapture rates of lizards (a reflection of their elusive behaviour) required the pooling of the data from all sites, thus eliminating analysis using the robust design. The results from a pilot radio tracking study illustrated that the technique was not sensitive enough to provide the detail required to estimate unavailability (Appendix D). The population estimates presented in Chapter 5 account for the likelihood of detecting an available lizard, but not the unavailability of a lizard. Nevertheless, despite this shortfall this is the first time population estimates have been produced for wild sand lizards which include the estimation of detection probability as a factor in population size.

Future attempts at population estimation should attempt to quantify the unavailability component of the detection probability for sand lizards. I suggest this should be estimated at different stages of the male and female reproductive cycle, since the findings presented in this thesis indicate that the unavailability of sand lizards varies through space and time. It is unlikely that the results of a survey programme to monitor the size of populations through time, or to map the distribution of cryptic animals will be reliable or useful without separating and estimating these two components of detection probability (Thompson 2004).

A new technique for sampling sand lizards and method for analysing the CMR data was explored in Chapter 4. This technique used images taken of the dorsal patterning of individual lizards for identification and these data were analysed through new software program through pattern matching. Both proved a success. The use of digital images to identify individual lizards in the field worked successfully and the future use of this method is endorsed as it does not require the capture or permanent marking of lizards. The software performed well in the identification of lizards from their images. However, to achieve the best results with the software the digital images of the dorsal patterning need to be consistent and of good quality (see Chapter 4). Overall, the exhaustive sand lizard surveys

produced a valuable data set which allowed analysis using these new identification techniques. Although successful within the context of this research project, the intensity of the sampling regime and time taken to analyse the images using the software deem these methods unsuitable for a larger scale monitoring scheme.

Monitoring

It was not difficult to maintain a constant survey effort for each plot over the study period, but at sites with public access the survey results could have been biased towards a reduced number of sand lizard encounters. Infrequently at Parley Common, members of the public were encountered walking across the study area with their dogs (*Canus lupus*) off-lead and foraging through the vegetation. This could have had an influence on the results of the unsurveyed areas (i.e. areas not surveyed on that day before the encounter with the public/dog), and to minimise any influence of disturbance to the basking lizards the survey was stopped for approximately 20 minutes and then resumed. This reflects the importance of the heathland areas as leisure spaces for the public and recreation use: urban heaths are particularly heavily used. Future monitoring programmes of heathland species should not conflict with the public use of these reserves and the potential disruption to strict survey methodology needs consideration.

The surveys conducted in Spring: (March, April and early May: at the start of each field season), had a higher number of observations than those from later in the year. This is because the sand lizards are more frequently encountered owing to their seasonal nature (Chapters 2 and 5) and the range of temperatures available within the heathland canopies (Chapter 3). As the season progressed, not only did the sightings of lizards decrease but the vegetation became drier and crunched under foot, creating noise and vibration which was not present during surveys in the wetter cooler months of the year. This factor probably did not affect the number of lizards encountered; it just encouraged careful manoeuvring through the vegetation and additional concentration in locating the lizards at a greater distance. The summer field surveys created an additional difficulty highlighted by the use of the automated photo identification software in Chapter 4, whereby the images taken of lizards were often obscured by pieces of vegetation as the lizards

are not basking in the open but in the cooler more shaded areas of vegetation (Chapter 3). This made the identification of individual lizards from their dorsal patterning more challenging and time consuming. If future sand lizard monitoring projects using CMR with dorsal images are considered, I would recommend that summer surveys are avoided and effort is directed towards monitoring populations from March to early June when encounters and clear photographic opportunities are most likely.

Generally male lizards are much easier to detect than the females because of their lucid green colouring combined with their territorial behaviour (Edgar & Bird 2006; Fearnley 2002) prior to mating. As mentioned in Chapter 4, I incorrectly identified a small number of male sand lizards (which had not yet developed any green colouration) as females at the start of the season. The results from Chapter 5 suggest that more males are observed than females leading to the assumption that more males are present in a sand lizard population than females. But females are harder to detect as their colouration camouflages them very effectively within the *C. vulgaris* stands and they probably spend less time out in the open for much of the year; so it remains to be seen whether there are actually more males than females or whether the observations of sand lizards are biased towards the males, which is something this research has been unable to quantify.

Surprisingly, the sex ratio of sand lizard populations has received little attention. Strijbosch & Creemers (1988) conducted the most comprehensive investigation into the ratio of males to females from a single population in the Netherlands and reported annual differences in the male:female sex ratio from a seven year mark-recapture study in which individuals were physically captured and marked by toe clipping. Only data from recaptured lizards were included in the analysis. The ratios varied significantly between 1:2 to 1:1 (male:female) and agreement with a 1:1 ratio was observed during only one particular year. The mean sex ratio over the study period favoured females 0.74:1.0 and the authors suggest this is due to the longevity of females in comparison to males (Strijbosch & Creemers 1988). The main obstacles in determining the sex ratio in sand lizard populations are related to sampling and detecting all individuals present in an area. This thesis has

shown that male and female sand lizards respond to different environmental variables at different stages of their reproductive cycle (Chapter 2) which in turn influences the detection rate. Unless sampling is strictly controlled and variations in detectability accounted for, variations in the sex ratios are to be expected. Most studies report either an equal sex ratio or one in favour of females (Berglind 2000a; Dent 1986; House 1980; Martens 1996; Strijbosch 1988; Strijbosch & Creemers 1988). However, all these studies did not make the assumption that all lizards present in an area had been observed and did not consider detection probability, and thus the sex-ratios reported should be interpreted with caution. This is an area which should be considered for further research (see climate change discussion section below).

The problems encountered with detecting sand lizards and the analysis of sparse data sets are typical of those associated with rare (low abundance and a restricted geographical distribution) and elusive (those with a low detection probability) species (Thompson 2004). Sand lizards are both. '*The reality of rare is we don't know anything about the particular species*'- Charles Bomar in Thompson (2004). At most our ecological understanding of the species is limited - this is the critical aspect in population estimation of sparsely distributed and elusive species. To overcome the sparse data sets, methods to increase the detection probability of animals need to be developed, and if this is not possible, techniques to estimate the unavailability of animals for detection should be researched. Combined, these elements will at least contribute to the ecological understanding of rare species and provide more confident, and therefore valuable, estimates of abundance.

A novel method to quantify the availability of the marine mammal dugong (*Dugong dugon*) was described by Pollock *et al.* (2004). The density and population size of dugongs was estimated from aerial surveys once artificial dugongs had been used to determine the availability of the animals in different conditions (water clarity, depth and sea state). Accounting for this variation in availability greatly improved the population estimates (Pollock *et al.* 2004). A population study of plethodon salamanders (*Plethodon sp.*) by Bailey *et al.* (2004a) ran several different models through Program MARK (see Chapter 5), using the robust design to investigate

different factors which influence the detectability and availability, and found that overall the salamanders displayed a trap-shy response of 63.5% as they spent longer underground to avoid recapture which resulted in an overall probability of detection of 0.04 (Pollock *et al.* 2004) and greatly improved the confidence of the abundance estimates Bailey *et al.* (2004).

Big brown bats (*Eptesicus fuscus*) have been successfully fitted with PIT (passive integrated transponder tags) tagged and transponders placed at the entrance to their roost sites resulting in a detection rate of this species ten-fold of that derived from manual capture and banding (O'Shea *et al.* 2002). PIT tags were explored as an option for the population aspect of this study but rejected following a thorough literature search. Hydro-acoustics have been used to improve sampling of rockfish populations (Hanselman & Quinn 2002) and non invasive genetic sampling of hair, urine, sloughs, feathers and egg shells have all been used to increase the detection rates and to generate more robust abundance and sex ratios of rare wildlife species (Waits 2002). Bioacoustics using the vocal signatures of frogs (Bee *et al.* 2001) and owls (Delport *et al.* 2002) has been used to assist with the identification (and location) of individuals and thus increase the detection rates. None of these techniques were suitable to increase the detection rates of sand lizards.

Several lessons can be learned from Ganey *et al.* (2004) who conducted a large scale CMR pilot study of the Mexican spotted owl (*Strix occidentalis lucida*) in Colorado. The pilot study was to evaluate the use of CMR methods to generate abundance estimates for the owls over large sample areas (40-75km²), and in turn use these estimates to identify population declines. Ganey *et al.* (2004) concluded that large scale sampling of rare and elusive species which have a low detection rate makes the task of confident population estimates very complex. Abundance estimates from these large scale studies do not provide confident estimates making it impossible to identify population declines. The lack of confidence in the abundance estimates is linked to high degrees of spatial and temporal variation, which is lost if sampling is conducted over a large scale (Ganey *et al.* 2004; Mackenzie *et al.* 2006; Thompson 2004). Ganey *et al.* (2004) are now currently

developing a method to monitor the owls using simple presence-absence monitoring on a large number of smaller areas (1km^{-2}), which should allow identification of localised extinctions and colonisations. Although these trends are not quantitative, they may be more useful to conservationists than inaccurate abundance estimates. Parallels can be made between this pilot study and the development of a national sand lizard monitoring scheme. As Chapter 5 has shown, there is a large amount of temporal and spatial variation in the detection rate of sand lizards over intensively sampled small survey areas. Reliable estimates of population size were only possible when the data were amalgamated over the three year sample period. I feel that the level of survey effort required to generate detailed abundance estimates for rare and elusive species is not justified; identifying genuine trends in presence and absence is a much better investment of resources, and will ultimately provide the conservationist with more useful information regarding the species distribution.

An alternative approach to reduce the intensive labour associated with CMR field work is the estimation of occupancy (Mackenzie *et al.* 2006). Occupancy is the probability that a randomly selected site or sampling unit in an area of interest is occupied by a species (Mackenzie *et al.* 2006). Occupancy estimation is concerned with whether an individual of a species is present or absent from a sampling unit (whether the unit is occupied or unoccupied). Visits to a sampling unit need to establish presence or absence which reduces survey effort in comparison to intensive count surveys. Occupancy estimation also accounts for imperfect detection rates which are calculated as a function of the number of times the species has been observed in the sampling unit (Mackenzie *et al.* 2006). Additional covariates such as habitat, environmental and temporal variable can be used to improve the accuracy of the occupancy models. Occupancy estimation would be more appropriate to identify trends in species presence and absence. However, the same issues encountered with low and fluctuating detection rates of sand lizards as described in Chapter 2 and 5, especially false absences (non-detection of a lizard when it is present) will still pose the same obstacles but other indications of a species presence (e.g. a lizard burrow, egg clutch or slough) could be used to reduce this likelihood. The analysis of more complex occupancy

models to account for variations in detection probability are still in their infancy and researchers advocating the use occupancy modelling are keen to develop this technique as an alternative to the labour intensive CMR for rare and elusive species (Mackenzie *et al.* 2006).

Thompson (2004) sums up his thoughts towards improving the abundance estimation of rare and elusive species – Innovation, Technology and Software. Innovative ideas need to be developed by researchers who understand the difficulties in sampling their rare and elusive species, the use of technology (PIT tags, non-invasive genetic sampling, digital images) can provide novel methods which help improve the chance of detecting an individual and analytical methods should be developed in parallel to support the needs of the ecologists who are investigating and working towards abundance estimates of rare and elusive species. Statisticians are currently developing new methodologies to assist with the analysis of low recapture dataset which are incorporated into statistical packages by regular updates (Cooch & White 2007; Thompson 2004). At present much more effort is dedicated to the statistical and sampling methods of moderately abundant and abundant species than to those species currently defined as rare (Thompson 2004), which may be misguided as the rare species are often those most in need of well-informed conservation intervention. The sand lizard is certainly such a species, and under considerable threat in the UK.

Threats to sand lizards

The decline of the sand lizard populations in the UK has been attributed to the loss and fragmentation of heathland and dune habitat caused by a change in land use for urban development, agriculture, afforestation, mineral extraction and roads (House & Spellerberg 1982, 1983; NCC 1983; Prestt *et al.* 1974; Spellerberg 1975). The decline of population numbers due to land use change has lessened (Edgar & Bird 2006) but the remaining areas of habitat are now effectively islands in a hostile matrix (Laurance 2008). Dispersal between sites and colonisation of new areas is limited or impossible. The distribution of sand lizards on the remaining heathland sites is not uniform (Edgar 2002); they favour areas where the architecture of the immediate landscape and vegetation is diverse as this

provides a variety of microclimates which meet their thermal requirements through the year (Chapter 3). These isolated populations of sand lizards within the remnant fragments of heathland are inherently more vulnerable to decline and extinction from localised pressures. Isolated populations are at a higher risk of a population bottleneck (Stephens & Sutherland 1999); predation and the increased cannibalism of hatchlings caused by the inability of juveniles to disperse, habitat degradation by inappropriate management or fire and competition from introduced lizard species (Edgar & Bird 2006).

There are four main types of anthropogenic pressures to the persisting sand lizard population on the Dorset heaths: those associated with development and urban pressure, habitat management, and climate change. These are the immediate threats to the heathland sand lizard populations and it is possible to mitigate against each of these human pressures.

Development and urban pressure

The draft South West Regional Development Strategy (RSS) has identified the potential for approximately 25,000 new dwellings by 2026 in the Bournemouth, Poole and Christchurch areas (approximately 1,295 dwellings a year) and acknowledges the presence and extent of the Green Belt and the environmental and wildlife areas designated under the European Habitats Directive (South West Regional Assembly 2006). However with the need for long term development there are exceptional circumstances to justify revisions to the extent of the Green Belts to deliver the most sustainable longer term development options (South West Regional Assembly 2006). Although the remaining areas of heathland are unlikely to be developed, future developments may encroach or occur adjacent to heathland areas. This will require mitigation measures for the negative impacts of increased pressure on the isolated sand lizard populations, and also heightens the need for continual monitoring of the existing populations.

The urban pressures do not exclusively affect sand lizards. The heathland habitat itself is susceptible to trampling damage caused by public access especially around viewpoints and inappropriately located car parks (Edgar 2002) and can be

devastated by fires from which regeneration can take decades (see below). Dogs (*Canus lupus*) off lead are an intrusive species where disturbance to heath dwelling species is concerned especially for reptiles (smooth snakes – *Coronella austriaca*, adders – *Vipera berus*, grass snakes – *Natrix natrix*, common lizards) and ground nesting birds (e.g. nightjar - *Caprimulgus europaeus*). Their fouling also releases additional nutrients into the nutrient poor soil underlying heathlands, contributing to habitat changes. Recruitment to sand lizard populations is also at risk from disturbance as sand lizard eggs are laid on bare ground in soft sandy substratum and are highly vulnerable to damage. The nests can withstand light trampling by people but the shod hoof of a horse and rider, or a mountain or motor bike, would destroy the nest (Edgar 2002). Site managers often restrict access by signage along some open sandy paths in which sand lizards are known to deposit their clutches to prevent damage to the nests, which are often ignored by horse riders, mountain bikers and motor bikers (Stride 2001). Fly tipping and the release of introduced amphibian species into heathland ponds, and introduced lizard species on cliff habitats is occasionally observed (Edgar & Bird 2006). If future development adjacent to heathland is expected mitigation for these issues should be vigorously negotiated as early as possible by conservation agencies.

Other than direct development or land use change, the most potentially damaging pressure from an increase in public use of heathlands and adjacent urban development is fire. This is detrimental for both the habitat and invertebrate communities (Telfer 2006) and the sand lizard populations themselves. If the intense heat and toxic fumes from the fire do not kill the lizards above ground or in their burrows (Edgar 2002) the lizards are unlikely survive long as their habitat has been destroyed: they are on the open ground with no prey available, and themselves open to predation unless they can move to an unburned areas. It takes a particularly long time for sand lizards to recolonise burnt areas and can only do so if they remain nearby, as it takes so long for the vegetation structure the sand lizards favour to be restored (Corbett & Moulton 1988; Edgar 2002). Fires that occur during the sand lizard season have a devastating effect on the localised populations. The vast majority of heathland fires between March and September are started deliberately (Table E.1, Appendix E). The County Fire Service

confirmed that between March and September in 2005, 2006, 2007 and 2008 they had sent fire crews to 559 heathland fires (The County Fire Service 2009) in Dorset, 19 of which occurred on the sites I was monitoring (but not the actual plot areas). This is an exceptionally high number of fires which with the proposed increase in the number of dwellings can only be expected to increase if they are adjacent, or in the vicinity of, Dorset's heathlands. This presents the question of whether financial resources should be allocated towards preventing these fires rather than research into monitoring methods if we are looking to secure the future of the localised and isolated populations of sand lizards.

Sand lizards are known to suffer more from human recreational pressures than the common lizards (Strijbosch 1988) as they spend more time basking in the open. This also makes them an easy prey target for the domestic cat which has been observed killing and eating sand lizards (Henshaw 1998). Herpetologists are concerned about the level of cat predation from developments adjacent to sites where sand lizard populations are present. This has been recognised through the mitigation measures initiated by a local council (Poole Borough) and Natural England under a Section 106 agreement under the Town and Planning Act 1990 planning application reference 07/0686/021F for the demolition of five bungalows and rebuilding of 32 flats at Alington Close and Shore Road, Poole Dorset adjacent to Luscombe Valley SSSI. Luscombe Valley SSSI supports a high density of sand lizards (Fearnley 2002) and the mitigation measures include cat proof fencing around the reserve and a cat covenant in the lease agreement of the new flats, whereby residents are forbidden to have cats. The risk to the sand lizard population by damage caused by cats has been recognised but it is yet to be seen whether the fencing will prevent cats accessing the site, and indeed how the local council will enforce the covenant. Initially these mitigation measures are steps in the right direction.

Habitat Management

The lowland heathlands of the Poole basin are home to several threatened plants (e.g. marsh gentian (*Gentiana pneumonanthe*)), invertebrates (e.g. green tiger beetle (*Cincindela campestris*)) and vertebrates (e.g. wood lark (*Lullula arborea*)).

The management of each heathland area needs to accommodate the requirements of all the species present. At times this can result in a conflict of interest as to the best management practice especially when resources are financially constrained.

The majority of habitat management (burning, felling and major clearances) on heathland sites where reptile populations are present is undertaken during the winter months when the animals are overwintering. Management is aimed at reducing the encroachment of scrub, maintaining the structural diversity of the lowland heathlands and preserving the areas of bare ground and open sandy paths and patches (Corbett & Moulton 1988, 1998; Corbett & Tamarind 1979; Foster & Gent 1996; House & Spellerberg 1983; NCC 1983). The removal of vegetation to create fire breaks in larger areas of mature heath is encouraged (NCC 1983) not only for the preservation of the habitat in such an event but to increase the diversity of the vegetation which reptiles and invertebrates are known to favour.

Habitat management for enhancing sand lizard populations involves small scale 'grooming or gardening' of areas where the localised populations are present. The structural diversity of the vegetation and areas of bare ground are maintained by scrub clearance and mowing. Sandy tracks and patches are managed by rotovation which also benefits some threatened invertebrates including the heath tiger beetle (*Cicindela sylvatica*) and the ladybird spider (*Eresus sandaliatus*) (Telfer 2006) and Chapter 5 found that a higher density of female sand lizards was found at the site with larger area of sand. These small scale practices are labour intensive and costly, and often are not a viable option on large sites. Chapter 3 has shown the importance of maintaining a variety of microhabitats and their associated climates for sand lizards.

On large heathland sites there is a progression towards sustainable habitat management, and grazing is currently encouraged and funded by Natural England as it can maintain a high diversity of plant species and structures while helping to control scrub (Lake 2006). Grazing of sites should not cause any concern for

populations of sand lizards if the grazing intensity, species and breed of livestock has been fully researched and is appropriate. Grazing could have a negative impact on the delicate mature and degenerate heather stands through livestock poaching and resting which is of concern as and these structures take years to regenerate. The level of disturbance to populations of sand lizards is also a concern especially if the grazing intensity of the site is too high. Herpetologists have encountered surfaced clutches of sand lizard eggs caused by poaching on grazed sites but fencing and gates, cattle licks, freshwater sources and shelters can be used to discourage livestock from grazing certain areas of a site at sensitive times of the year (Lake 2006). Parley Common has been identified as a site by Natural England which would benefit from grazing; the livestock are to be introduced during the Winter of 2009 - 2010.

The management of lowland heathlands is a balancing act between multiple species, finances, councils, conservation organisations and the public. It is very rare that all parties involved are in agreement as to the best way to manage these areas for all species concerned, which inevitably leads to a conflict of interest where one species may lose against another. It is important to recognise that conservation bodies will not get the habitat management right for all species all of the time but with the continual monitoring of populations negative trends can be identified and appropriate remedial measures implemented. The monitoring of all BAP species on heathland sites is now of increasing importance, especially given the severe fragmentation of the heathlands which lowers the genetic diversity of a population and restricts the dispersal ability of many species (Offer *et al.* 2003).

Climate change

The effect climate change will have on heathland habitat is unknown but with an 0.8°C increase in global average temperature since the 19th Century and an observed temperature increase of 0.2°C per decade over the past 25 years (Jenkins *et al.* 2009) the temperatures of the microclimates within the vegetation structures is increasing with the rising ambient temperatures. By 2080 the UK climate is predicted to be warmer with a mean predicted 3°C temperature increase

in winter and a 3.9°C temperature increase in the summer for the South of the UK (DEFRA 2009).

The predicted increase in temperatures is likely to extend the Northern geographical limit of sand lizards in UK. The northwards movement of sand lizards between the severely fragmented heathland habitats is very unlikely. Investigations into butterfly range (driven by an increase in global temperatures) in heavily fragmented landscapes found that the potential for expansion of ranges was limited because of the severity of the fragmented habitat and their small dispersal capacity (Opdam & Wascher 2004). No parallel research has been carried out on sand lizards but they are unlikely to disperse successfully or relocate through urban areas or agricultural land. It is probable they will move into peripheral habitats adjacent to heathlands such as urban areas, disused mineral extraction pits, sub urban gardens (Corbett 1988a), old railway lines, field banks and forest ride edges (Dent 1986). These areas need to be sampled in a large scale monitoring scheme and if populations are present, they are those most vulnerable to local extinction, and will require attention from conservation bodies to ensure they are able to persist.

The warm south facing slopes currently favoured by sand lizards (NCC 1983) are unlikely to remain as important to the populations in the light of increasing temperatures and to enhance and reduce the temperatures on these slopes, shading through habitat management could be considered. An increase in growth rate of the heathland vegetation should be anticipated which may need for more frequent habitat management to maintain the structural diversity preferred by sand lizards.

Chapter 3 has illustrated the range of microclimates provided by different structures of heathland vegetation. Shifts in the seasonal and daily activity patterns in light of a predicted temperature rise should also be anticipated. The range of temperatures available within the different microclimates of heathland structures will expand (tables 3.5 – 3.8). I would predict that the lizards will emerge from their winter retreat earlier and immediately bask openly for longer in the

warmer more favourable conditions. The temperatures within the vegetation will also increase earlier in the year which may mean that the lizards do not need to bask to maintain their temperature but can thermoregulate effectively under the canopies avoiding predation. This could condense the time that sand lizards would bask openly and thus reduce the length of time surveyors have to monitor this species. The spread of temperature ranges within the heathland vegetation structures noted in June (table 3.8) should be expected earlier in the year and as such, we may also find that sand lizards are observed later in the season nearer sunrise and sunset when ambient air temperatures are cooler. It is likely that sand lizards will easily adapt to small rises in temperature by favouring the cooler microclimates within the diverse structures of the heathland which may result in them being less available for detection. However, the primary concern for the UK's sand lizard populations should be the habitat and appropriate management should take active measures to prevent successional habitat change and spread of accidental fires.

Environmental sex determination occurs in both plants and animals (Shine 1999) where incubation temperatures determine the sex of hatchlings in many reptiles (Janzen & Paukstis 1991) and some fish species (Warner & Shine 2008). Squamates (lizards and snakes) and turtles exhibit both environmental sex determination (ESD) in the form of temperature sex determination (TSD) and genetic sex determination (GSD) (Janzen & Phillips 2006). The Charnov-Bull model (Charnov & Bull 1977) provides the overall frame work for TSD and considers that the sex which benefits most from enhanced growth should be produced at incubation temperatures that most improves post-hatching growth (Janzen & Paukstis 1991). So, eggs should develop into males when developing under conditions that promote high fitness for males, and eggs that encounter female favourable conditions develop as daughters (Warner & Shine 2008).

The role of TSD in sand lizards has not been studied but the recent evolutionary origins of TSD in lacertid lizards have been identified (Janzen & Phillips 2006) although studies regarding the adaptive significance of TSD in lizards are still in their infancy (Janzen & Phillips 2006). However, the notion that a female can

adjust her offspring's sex to their incubation temperatures and enhance her own genetic fitness (Shine 1999) confounded with increasing global temperatures gives rise to some interesting yet concerning questions regarding the future sex ratio of new hatchlings to the sand lizard populations (see previous discussion section on sex ratios). The warmer summer temperatures predicted by DEFRA (2009) could bias the sex ratio of new hatchling sand lizards in favour of females. As there is limited reliable research for the sex ratios of sand lizards across its range we do not know whether the sand lizard populations in warmer Mediterranean climates are already skewed towards females. It remains to be seen whether the females themselves will adapt their selection and excavation of nest sites in response to increasing temperatures and also whether thermally based nest-site selection by sand lizards may be a strategy adapted by TSD when the sex ratio of sand lizards is perturbed (Janzen & Phillips 2006). Site managers should be encouraged to create sand patches with different aspects with varying degrees of shade to provide a choice of suitable nest sites with a variety of thermal conditions, so if gravid females do show adaptive responses to increased temperatures in nest site selection suitable substratum is available.

As well as an increased risk of fire, the adverse effects of increased temperature on lowland heathland operate mostly through the increased availability of nutrients and in such cases it is possible that grasslands may replace heathlands (Wessel et al. 2004) and this would render some areas unsuitable for sand lizards. In drought conditions, however, heather would be better able to compete with the encroachment of grasses (Wessel et al. 2004) but much more vulnerable to competition from with *P. aquilinum* (for water) (Gordon et al. 1999). The latter is of more significance than other changes given a slow rate of global warming (Gordon et al. 1999). Wessel et al (2004) recommend burning, sod cutting, clipping and grazing to reduce the build up nutrients on heathlands.

Monitoring requirement under the Habitats Directive

The sand lizard is a European Protected Species and under Article 17 of The Habitats Directive, Member States are required to report the implementation

progress of the Directive every six years. The overall objective of the Directive is to achieve and maintain favourable conservation status (FCS) for all habitats and species of Community interest and to contribute towards maintaining biodiversity of natural habitats and of wild fauna and flora in the European territory of the Member States. Monitoring must therefore lead to a clear picture of the actual conservation status and its trends on various levels and indicate the effectiveness of the Directive in terms of approaching and reaching this objective (Europa 2009). It is the responsibility of a country's government to ensure this takes place through domestic habitat and conservation regulation.

The current conservation status of the sand lizard is inadequate but improving, but in reality the population assessment of 'stable' lacks evidence (table 1.1). In reality the true number and size of sand lizard populations is unknown. This thesis has contributed to our understanding of why the estimation of the number of sand lizards in a population is so difficult and perhaps provides an answer as to why we are currently unable to meaningfully monitor our populations. Here I have shown that abundance and population estimates for this species are problematic from both a sampling and analytical perspective and despite three years of exhaustive sampling of some sites population estimates could not even be calculated (Chapter 5). Yet, inferences have been made regarding the population status of sand lizards from the count records held on the central sand lizard database. This is of concern as chapters 2 and 5 have shown that the detection rates between male and female sand lizards differs and are also influenced heavily by seasonality, environmental variables and the localised habitat and so unstandardised count surveys are unlikely to provide a representation of population size (Mazerolle 2006; Mazerolle *et al.* 2007). This illustrates some difficulties encountered with the implementation of the Directive. However, these problems will not be exclusive to sand lizards but applicable to many data deficient rare and elusive European Protected Species.

This research has presented the shortfalls of the UK's current sampling of sand lizard populations and limitations of the existing data. There are several variables which require consideration when interpreting sand lizard count data and this research has identified that; seasonality, time of day, temperature, solar radiation,

humidity, wind speed and local habitat all influence the detection probability sand lizards. All these variables are subject to local variation and conditions will differ between sampling sites which makes the design of a standard survey method more complicated. In terms of developing a long term monitoring scheme I think the best allocation of effort is to improve our capability to accurately report the conservation status of sand lizards is a 'back to basics' approach directed at establishing where sand lizards are present or more importantly where they are absent. I would suggest that sampling for sand lizards is limited to a specific time frame and surveys are encouraged at times when the detection probability is maximised. It would also be valuable to supplement survey data with the measurement of environmental variables known to have an influence on the detection rate of lizards.

Once we can establish whether lizards are present or absent in sampled areas we can then dedicate research effort into developing methods which can identify population trends. Whatever methods are considered, they need to be capable of detecting population trends, practical and suitable for use by the individuals conducting the surveys (experienced herpetologists, consultants, volunteers and students). There is little advantage in developing a sampling method without the resources to manage and interpret the field data. Both aspects should be considered when exploring possible methodologies detection population trends.

The issues and difficulties in sampling sand lizard populations presented in this thesis need to be addressed otherwise the data we report back to Europe may be misleading and as a consequence the conservation of this species will suffer. We need to acknowledge that our current recording methods (sampling, data management and interpretation) are not adequate and serious consideration should be given to a 'back to basics' approach which would establish a baseline on which to build a reliable long term monitoring methods.

Chapters 2, 3, 4 and 5 have highlighted the complexity of sampling, analysis and interpretation of survey data for sand lizards. Heeding advice from Ganey *et al.* (2004), and reflecting on the experience of this study, efforts to conduct a large scale CMR study as part of a national monitoring scheme of this rare and elusive

species are discouraged. The low and fluctuating detection rates of sand lizards pose logistic and analytical issues for which there is no immediate solution.

Although the estimation of occupancy does not provide abundance values it will allow conservationists to map the distributions of sand lizards and identify areas of local extinctions and colonisations. Many conservationists and herpetologists, myself included, feel that current monitoring methodology and recording of sand lizard records is inadequate. At present, monitoring is most frequently conducted by volunteers and herpetologists on areas known to support sand lizard populations by volunteers and herpetologists, but areas of non-typical habitat (road verges, urban areas, gardens and disused railway lines) within the vicinity of these existing populations remain unsurveyed. A national monitoring scheme should include sampling of these peripheral areas. We know the preferred habitat of sand lizards, but I do not think we have been sufficiently open-minded to consider that although these peripheral areas may not offer the preferred sand lizard habitat they may be suitable to support small numbers of individuals, or have potential as corridors to link to other heathland sites. We need to identify whether lizard populations are using areas of non typical habitat and if this is evaluated using occupancy models with carefully considered habitat variables, we may indeed learn more information about the specific habitat requirement of this species.

Relevance and limitations of this research

My research involved the investigation of one captive population of sand lizards in Hampshire and nine independent wild populations on the Dorset heathlands. Although the sampling was limited to ten populations the broader findings are of use to the herpetological community especially when developing methods for sampling rare and elusive reptiles. I consider the detailed findings from this study of particular relevance to the sand lizard populations found at the northern limit of their distribution as opposed to those located in Mediterranean climates.

Chapters 2, 3 and 5 both illustrate that several variables which influence the likelihood of sand lizard observations are localised and linked to the immediate microclimates. The lizards will exploit the immediate microclimates for their thermal advantage. In structurally diverse areas of heathland I have predicted where the lizards are most likely observed. Although the detail within these findings may not specifically relate to other heathland sand lizard populations as the habitats may differ, the principals remain the same. The lizards will shuttle between vegetation types which offer favourable thermoregulatory opportunities. The movement of sand lizard between different microclimates on dune or peripheral habitats can be speculated based on their preferred basking temperatures but this study is unable to offer any specific recommendations. The findings from the captive population about how male and female sand lizards respond to different environmental variables at different reproductive stages and in turn how these can influence their detection probability are relevant to all populations of sand lizards at their Northern most limit. Those working with and monitoring sand lizard populations should consider these findings when interpreting field results or developing further methods for census work.

Further research

Chapter 2 has illustrated how the detection rates of males and females vary with temporal and environmental variables. There is scope to build on the results of this chapter by continuing this monitoring of the captive population at Marwell (but elsewhere too if possible) and supplementing the data collected with dorsal images of lizards. Analysis of the environmental and temporal conditions in which individual male and female lizards are observed would allow a more detailed analysis into the specific variables that influence the detection rates of males and females.

Historic weather conditions also have a significant influence on the detection rates of sand lizards. It would be worthwhile to explore the extent to which these influence the detection rate.

Future intensive CMR

Chapter 5 investigated the use of CMR methods in the estimation of sand lizard populations on nine independent areas. In my opinion, an avenue worth exploring would be an analysis of this data set estimating the occupancy rates at each of the field sites.

Also worthy of future consideration would be a study similar in method, but across fewer sites in areas where there are believed to be a high density of individuals (which itself is subjective), where the sampling is conducted twice daily during the defined seasonal stages of the males and females. This would allow investigation into how the daily detection probabilities of male and female sand lizards vary with seasonality and enable covariates (of environmental variables) to be factored into the models which could potentially reveal undetected relationships. This research in chapter 5 was unable to investigate these relationships in detail because of the low recapture rate of individuals and because survey effort was distributed over several sites. A more intensive approach of surveying on fewer sites would also allow exploration of sand lizard movements between areas of prime habitat and sub-optimal areas which could also be used as covariates in population modelling and may reveal relationships between sand lizard observations and habitat quality.

Improving our understanding of potential relationships between habitat quality and sand lizard observations would help with the development of monitoring strategy and improve our methods of assessing the conservation status the sand lizard populations and the habitat.

Conclusions

I feel that perhaps conservation organisations have placed too much emphasis on levels of detail from survey results and attempts at population size estimation and neglected effort in tackling the simpler questions of ‘where do and don’t we find sand lizards?’. I imagine that these organisations are keen to keep interest levels of volunteers high and would perhaps lack confidence in asking volunteers to dedicate their time towards surveying non-typical habitat for sand lizards as volunteers are often motivated visual sightings of lizards. Regardless, we need to practice forward thinking and try new approaches towards a structured national monitoring program for sand lizards as previous recording methods have not been successful in producing consistent, meaningful and useful results.

I support the view of Thompson (2004) in that innovative and creative ideas are needed to overcome sampling and analytical issues when researching rare and elusive species. Investigators need to apply their ecological understanding of a species and incorporate this into a suitable and practical sampling regime. New technology may assist overcoming some sampling limitations and analytical techniques for rare and elusive species are constantly being improved. This thesis has considered and explored a variety of techniques to overcome issues relating to lizard ecology and low detection rates for the estimation of sand lizard population sizes. Simply there is no ‘quick-fix’ solution to these issues. The way forward needs to involve further research, the use of scientific and robust methodologies and patience.

The obstacles identified in this thesis (some of which have been overcome, and others indignantly remain) of working towards a sampling method for sand lizards has given rise to more research questions than any of those involved (experienced

herpetologists, professors of statistics and research academics) in this project could have imagined. There is a strong legislative requirement (under Article 17 of the Habitats Directive) to develop a reliable method with which to monitor the existing sand lizard populations. I believe the best way forward is to consider and pilot the use of occupancy estimation, using the recommendations made in this thesis to maximise the detection probability of sand lizards.

The application of CMR methodology using dorsal images and photo-identification software to identify individual sand lizards to generate population estimates was successful. However, the method was not without problems and the large confidence intervals and low recaptures reflect this. The results also identify previously unrecognised difficulties in obtaining abundance estimates for sand lizard populations. Further research addressing the sampling and statistical issues identified here is needed before conducting future field work aimed at confident sand lizard abundance estimates.

7 Appendix A

Selection of the sites

Three sites were selected for study. Each site needed to be under management from an organisation which worked in collaboration with or by the ARC. Each site needed to be large enough to select three independent sample areas between which the movement of lizards was non-existent and located near each other so the three sites could be visited in a day a (prerequisite of the funding conditions). Town Common, Merritown Heath and Parley Cross were identified as suitable study sites with assistance from the ARC.

The plot selection within each site was made with guidance (from the ARC) based on records held by their rare species database which consists of presence records submitted by herpetologists. Although the database is not a reliable source of abundance estimates it provides location details for historical sightings of sand lizards. Areas where sand lizards records were present were selected for intensive monitoring. The rare species database is the central resource for the UK's sand lizard records. The shortfalls and limitations of this recording system are discussed in context the of site selection and in relation to abundance estimates at the end of this chapter and the final discussion (Chapter 6).

Site locations

Parley Common and Merritown Heath are north of Bournemouth Airport, Dorset and Town Common is to the east> Each site is located within 5 kilometres of Bournemouth airport (figure A.1). The locations of the plots surveyed on each site are detailed in figure A.2 (Parley Common), figure A.3 (Merritown Heath) and figure A.4 (Town Common) with the historic sand lizards records marked. Geographical specifics of each survey plots are detailed in Table A.1.

Town Common and Parley Common

Both Town Common and Parley Common are designated Sites of Special Scientific Interest (SSSIs) under the Wildlife and Countryside Act 1981 (part II), Special Protection Areas (SPAs), Special Areas of Conservation (SACs) and the wetland areas of Town Common also protected by the Ramsar Convention (1971). Town Common is 146 Ha of predominantly lowland heathland within the Poole Basin lying on bagshot beds. It is owned by the Malmesbury Estate and managed by the ARC. Parley Common is approximately 114 Ha of lowland heathland and under multiple ownership by the Canford Estate, the ARC, Ferndown golf club, Diocese of Salisbury and East Dorset District Council and Dorset County Council. The ARC own 107 Ha of Parley Common. Both reserves are managed by the ARC and seasonal work consists of heathland habitat maintenance and clearance of pine (*Pinus sp.*), birch (*Betula pendula*), bracken (*Pteridium aquilinum*) and rhododendron (*Rhododendron sp.*). Rotovation of sand strips and paths is undertaken and patches of heather are regularly mown to maintain a diverse range of habitats for sand lizards and invertebrates. Town and Parley Common contain several public footpaths and permissive bridle ways all of which are used frequently by the public. All the areas selected for sampling are outside of the home range of 2130m² for individual sand lizards (Nicholson & Spellerberg 1989) and thus considered independent sites.

Merritown Heath LNR

Merritown Heath is 90 Ha of predominantly dry lowland heathland owned by Manchester Airports Ltd and managed by Dorset County Council under a wildlife enhancement scheme funded by Natural England. The site is categorised of high national importance for sand lizards. Merritown Heath is a SSSI, SPA, SAC and is managed under advice from The ARC to provide adequate representation of age structures of heathland vegetation and maintaining areas of open ground. Merritown Heath although managed by the council has no public access and therefore no public pressure. The plots selected for sampling at Merritown heath are outside the home range of 2130m²

for sand lizards(Nicholson & Spellerberg 1989) and MA is separated from MB and MC by a stream and tree line.

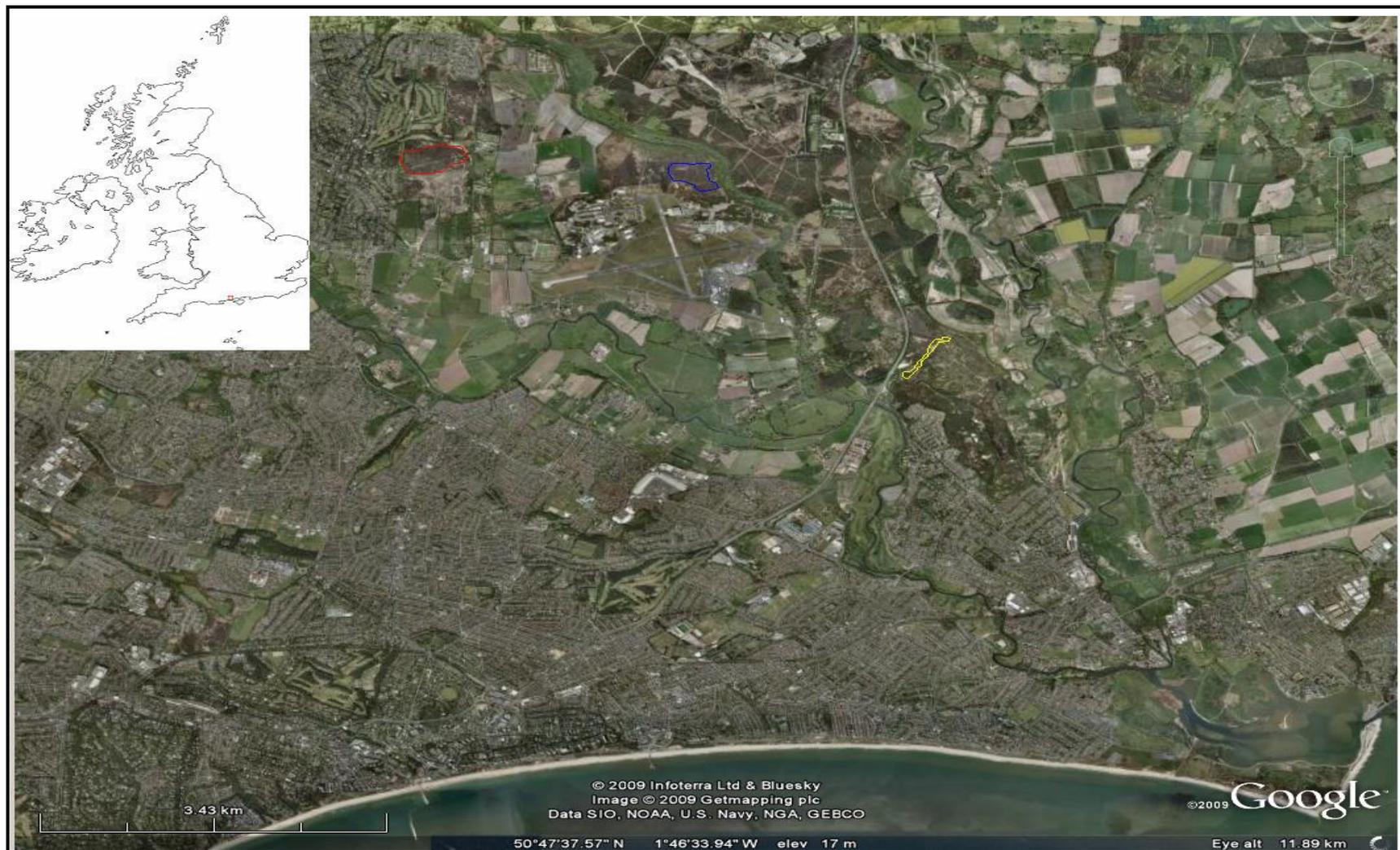


Figure A.1. Location of field sites indicated by the insert and aerial photo outlines Parley Common (red), Town Common (yellow) and Merritown Heath (blue). The urban area of Bournemouth is to the South West of the field sites. Image taken from Google Earth (2009).



Figure A.2 Aerial Photograph of Parley Common, Dorset with plots A, B & C annotated with historic *L. agilis* records (orange dots) and tins (brown squares) and orientated North.

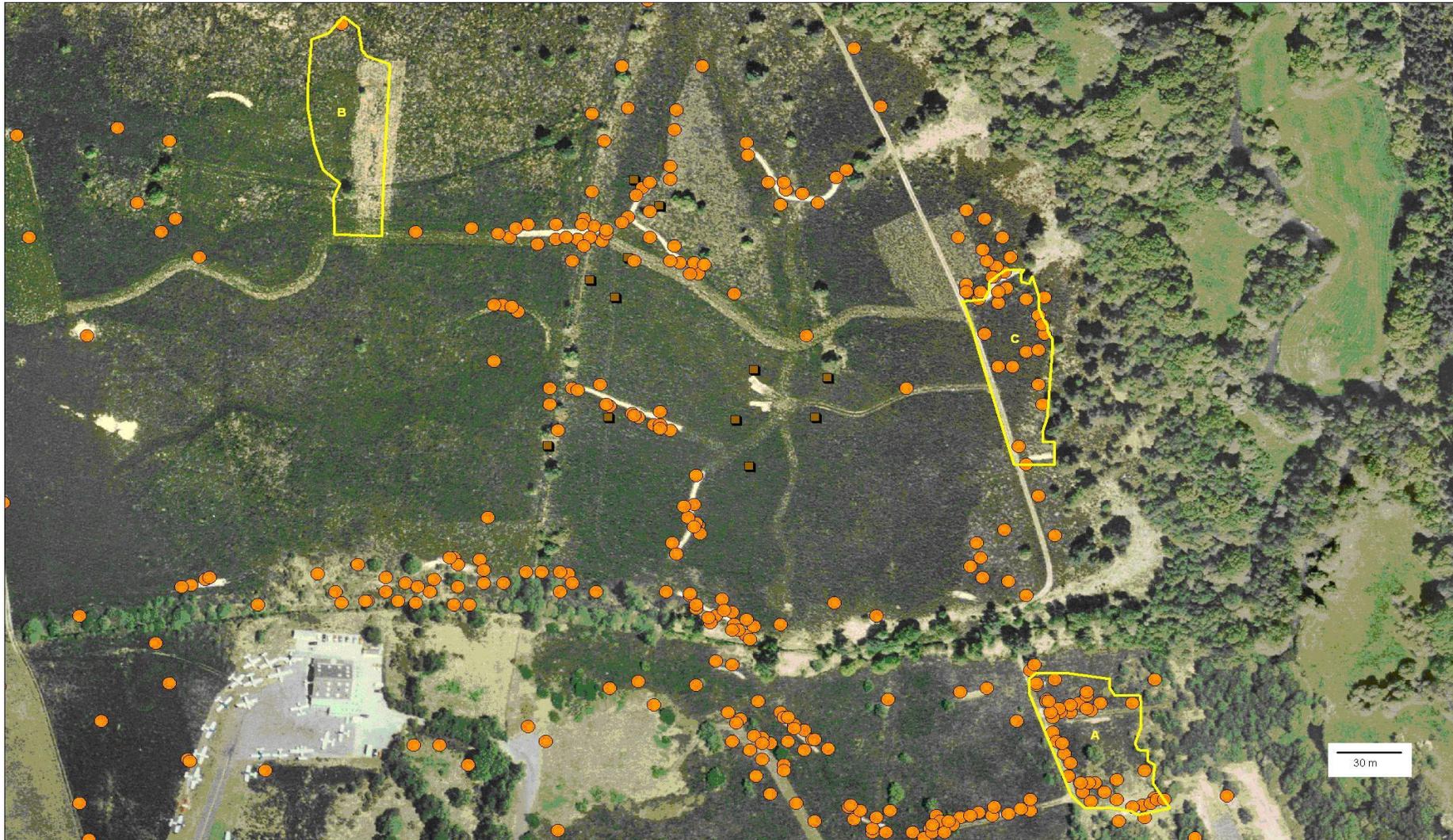


Figure A.3. Aerial Photograph of Merritown Heath, Dorset with plots A, B & C annotated with historic *L. agilis* records (orange dots) and tins (brown squares) and orientated North.

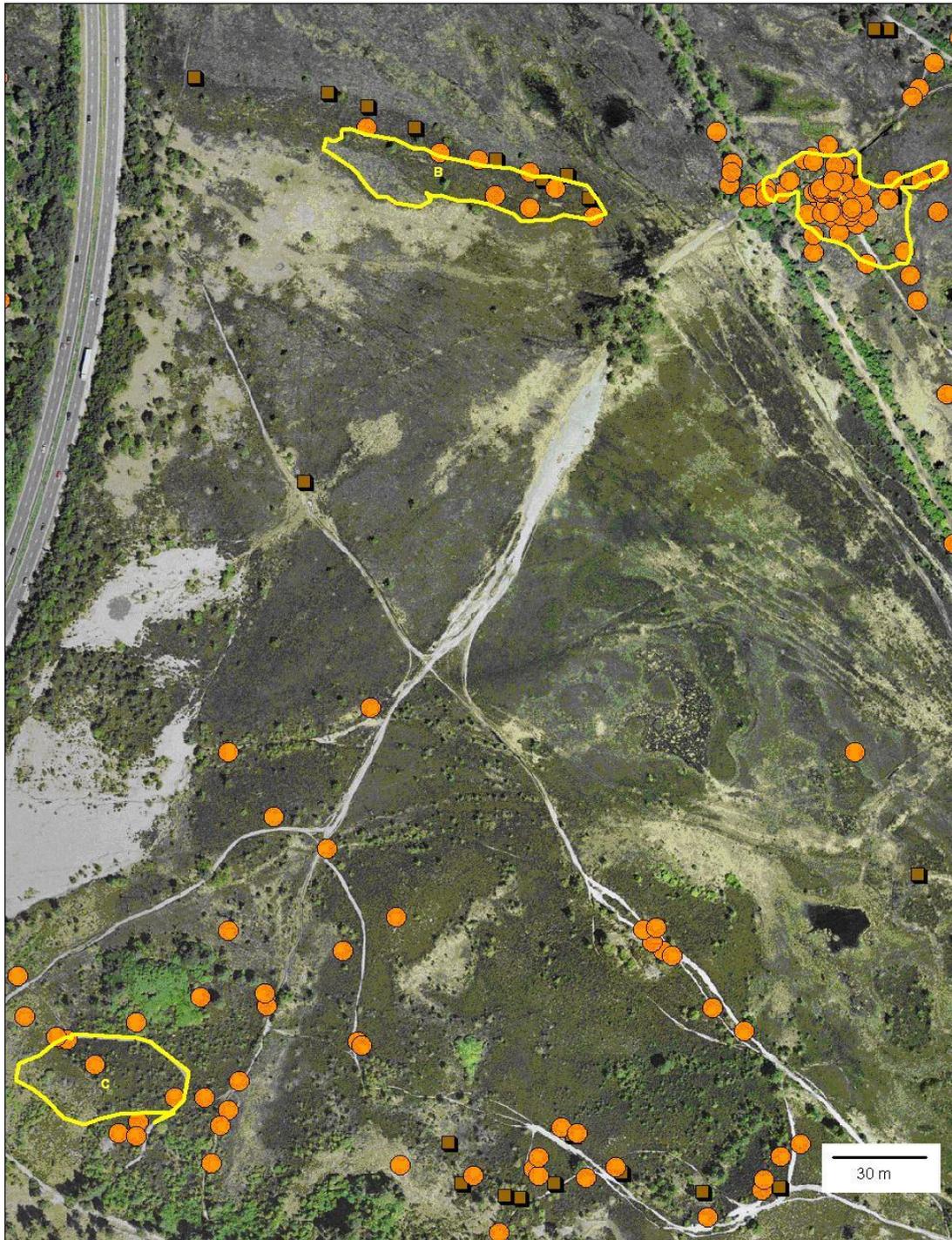


Figure A.4. Aerial Photograph of Town Common, Dorset with plots A, B & C annotated with historic *L. agilis* records (orange dots) and tins (brown squares) and orientated North.

Table A.1. Details of the survey plots selected on Town Common, Merritown Heath and Parley Common.

Feature	Town Common			Parley Common			Merritown Heath		
	Plot A	Plot B	Plot C	Plot A	Plot B	Plot C	Plot A	Plot B	Plot C
Perimeter length (m)	316.6	358.5	233.9	231.4	214.7	262.4	256.4	290.0	280.9
Area (Ha)	0.33	0.36	0.34	.033	.026	0.34	0.34	0.36	0.30
Centre point of plot co-ordinates SZ	414142.6	413929.2	413731.1	408886.3	408942.9	409104.3	411805.3	411430.7	411759.8
X	96804.7	96823.6	96317.0	99079.9	99340.1	99182.5	98875.31	99214.8	99082.8
Y									

8 Appendix B

Table B.1. Spearman's correlation coefficient values for weather variables recorded in the Marwell vivarium between May 2005 and June 2006. Variables with a positive or negative value of 0.7 or above are highly correlated.

Spearman's correlation coefficient values	Time (decimal)	Day	Cumulative time (decimal)	Temperature	High Temperature	Lowest Temperature	Humidity	Wind Speed	High Wind Speed	Pressure	Rain	Solar Radiation	Solar Energy	High Solar Radiation
Time (decimal)	1.0													
Day	0.0	1.0												
Cumulative time (decimal)	0.0	1.0	1.0											
Temperature	0.3	-0.3	-0.3	1.0										
High Temperature	0.3	-0.3	-0.3	1.0	1.0									
Lowest Temperature	0.3	-0.3	-0.3	1.0	1.0	1.0								
Humidity	-0.3	0.2	0.2	-0.6	-0.6	-0.6	1.0							
Wind Speed	0.2	0.0	0.0	-0.2	-0.1	-0.1	-0.2	1.0						
High Wind Speed	0.1	0.2	0.2	-0.2	-0.2	-0.2	-0.1	0.8	1.0					
Pressure	0.1	-0.4	-0.4	0.2	0.2	0.2	-0.3	-0.3	-0.4	1.0				
Rain	0.0	0.0	0.0	-0.1	-0.1	-0.1	0.2	0.0	0.0	-0.1	1.0			
Solar Radiation	0.0	-0.2	-0.2	0.6	0.6	0.5	-0.8	0.2	0.1	0.2	-0.2	1.0		
Solar Energy	0.0	-0.2	-0.2	0.6	0.6	0.5	-0.8	0.2	0.1	0.2	-0.2	1.0	1.0	
High Solar Radiation	0.0	-0.2	-0.2	0.5	0.5	0.5	-0.7	0.3	0.2	0.1	-0.2	0.9	0.9	1.0
UV Index	0.0	-0.3	-0.3	0.6	0.6	0.6	-0.7	0.2	0.1	0.2	-0.1	0.9	0.9	0.9
High UV	0.0	-0.3	-0.3	0.5	0.5	0.5	-0.7	0.3	0.2	0.1	-0.1	0.9	0.9	0.9
Light reading	-0.1	-0.2	-0.2	0.5	0.5	0.5	-0.6	0.2	0.1	0.1	-0.2	0.8	0.8	0.8
Soil Temperature in Sun	0.2	-0.4	-0.4	0.9	0.9	0.9	-0.6	-0.1	-0.2	0.2	-0.1	0.6	0.6	0.6
Air Temperature in Sun	0.1	-0.3	-0.3	0.9	0.9	0.9	-0.7	0.0	-0.1	0.2	-0.1	0.8	0.8	0.7
Soil Temperature in Shade	0.2	-0.5	-0.5	0.9	0.9	0.9	-0.6	-0.1	-0.2	0.2	-0.1	0.6	0.6	0.5
Air Temperature in Shade	0.2	-0.4	-0.4	0.9	0.9	0.9	-0.7	-0.1	-0.1	0.2	-0.1	0.7	0.7	0.6

Table B.1 continued. Spearman's correlation coefficient values for weather variables recorded in the Marwell vivarium between May 2005 and June 2006.

Variables a positive or negative value of 0.7 or above are highly correlated.

Spearman's correlation coefficient values	UV Index	High UV	Light reading	Soil Temperature in Sun	Air Temperature in Sun	Soil Temperature in Shade	Air Temperature in Shade
Time (decimal)							
Day							
Cumulative time (decimal)							
Temperature							
High Temperature							
Lowest Temperature							
Humidity							
Wind Speed							
High Wind Speed							
Pressure							
Rain							
Solar Radiation							
Solar Energy							
High Solar Radiation							
UV Index	1.0						
High UV	1.0	1.0					
Light reading	0.8	0.8	1.0				
Soil Temperature in Sun	0.7	0.7	0.6	1.0			
Air Temperature in Sun	0.8	0.7	0.7	0.9	1.0		
Soil Temperature in Shade	0.6	0.6	0.5	1.0	0.9	1.0	
Air Temperature in Shade	0.7	0.7	0.6	0.9	0.9	0.9	1.0

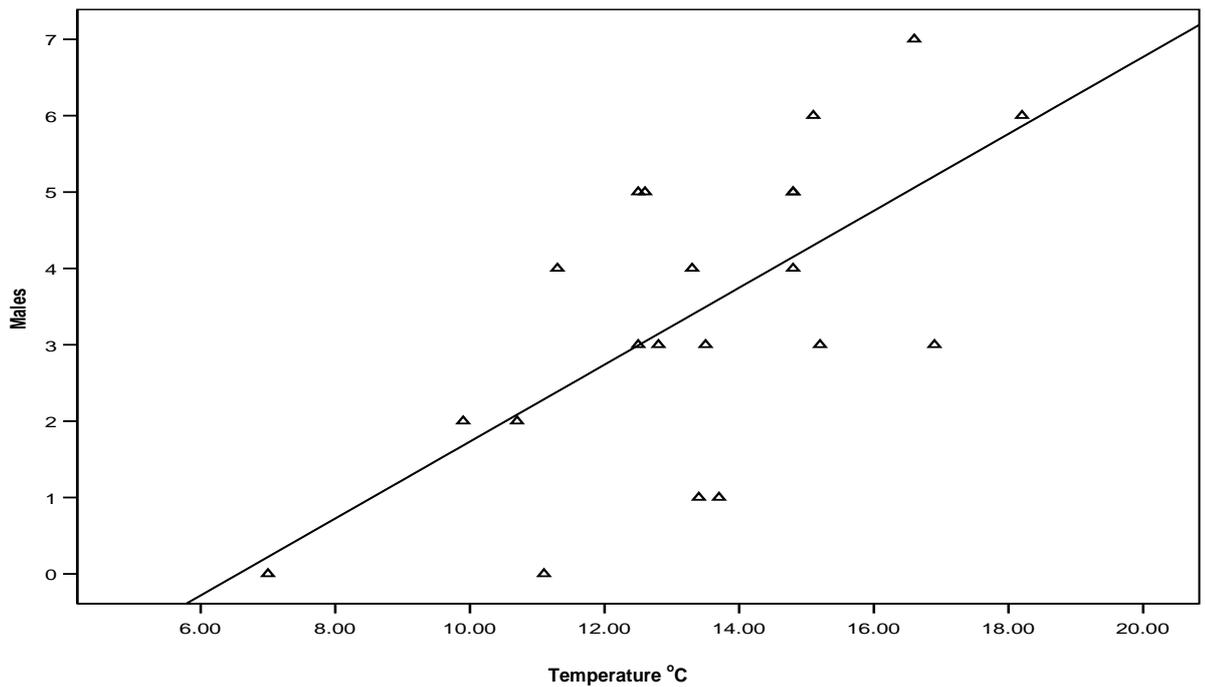


Figure B.1. Range of temperature values with corresponding male lizard count values for pre mated males. Temperature + Time of day was the best fit model to the data based on AIC evidence.

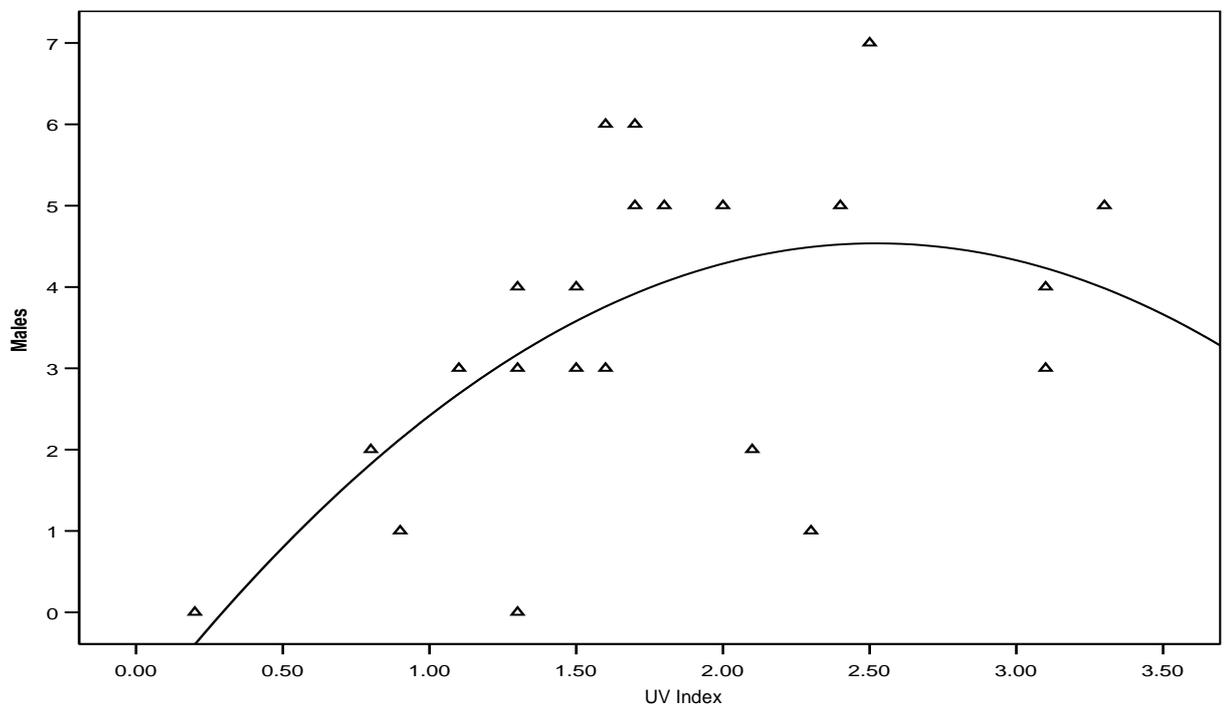


Figure B.2. Range of UV index values with corresponding male lizard count values for pre mated males. The optimum value appears to lie between 1.50 and 2.00.

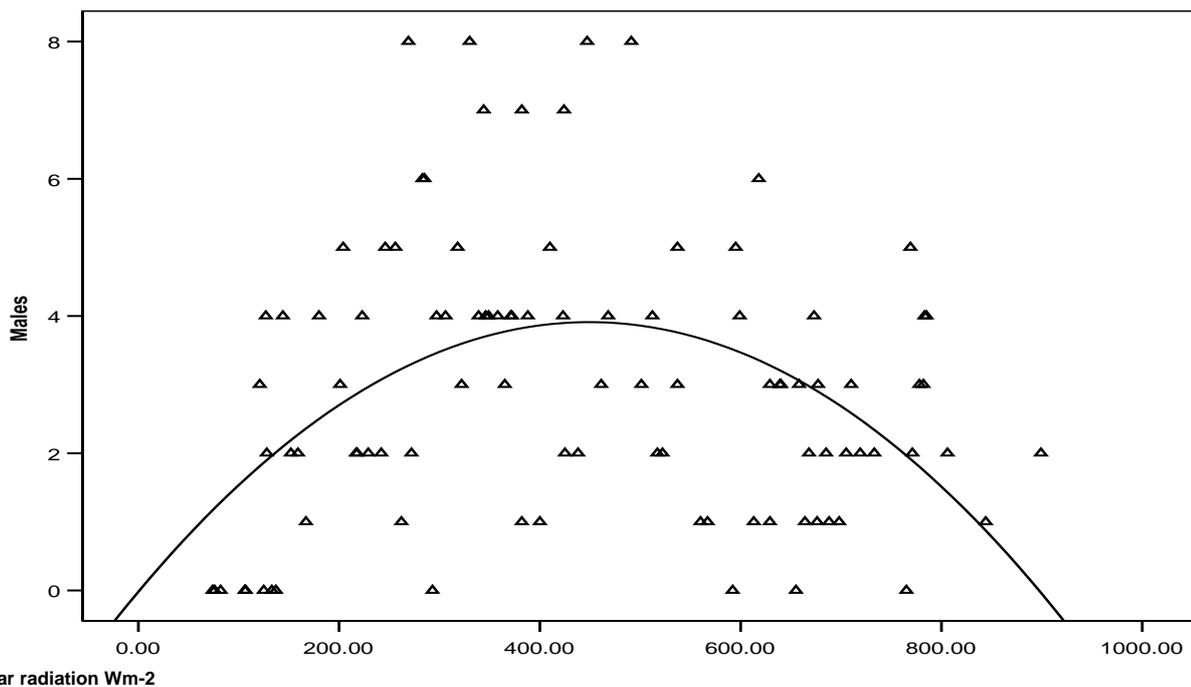


Figure B.3. Range of solar radiation values with corresponding male lizard count values for post mated males. The optimum range appears to be between (300 – 700 Wm⁻²). Solar radiation + solar radiation² + Hi wind speed was the best fit model to the data based on AIC evidence.

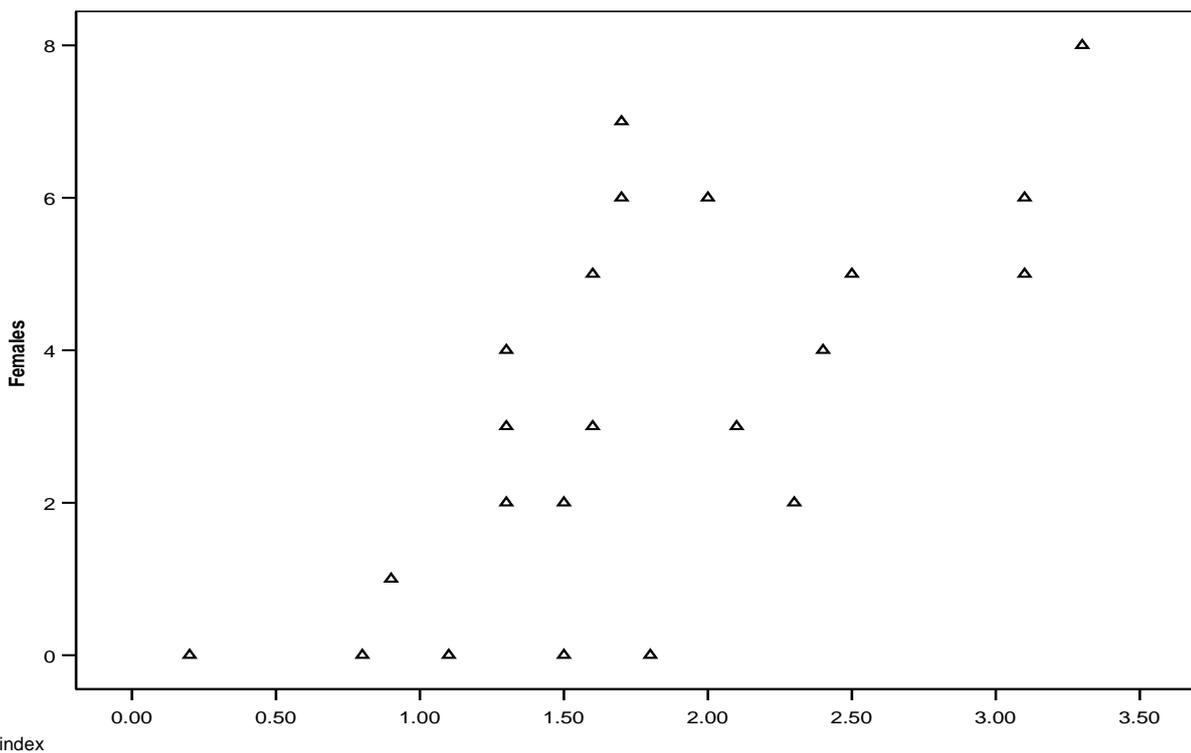


Figure B.4. Range of UV Index with corresponding pre mated female count. Ultraviolet Index + Ultraviolet Index² is the best fit model selected using AIC. The data suggest that a threshold value of 1.25 may exist

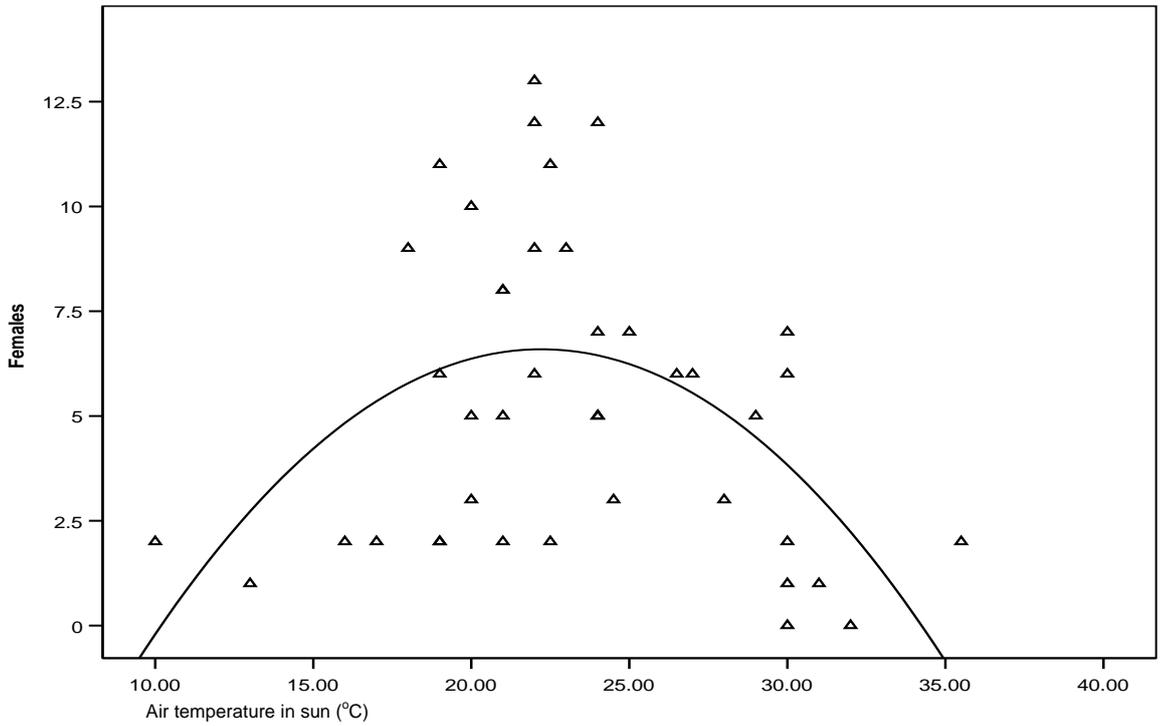


Figure B.5. Range of air temperature in sun values with corresponding gravid sand lizard counts. The relationship is quadratic with the preferred range lying between 17.5°C and 27.5°C.

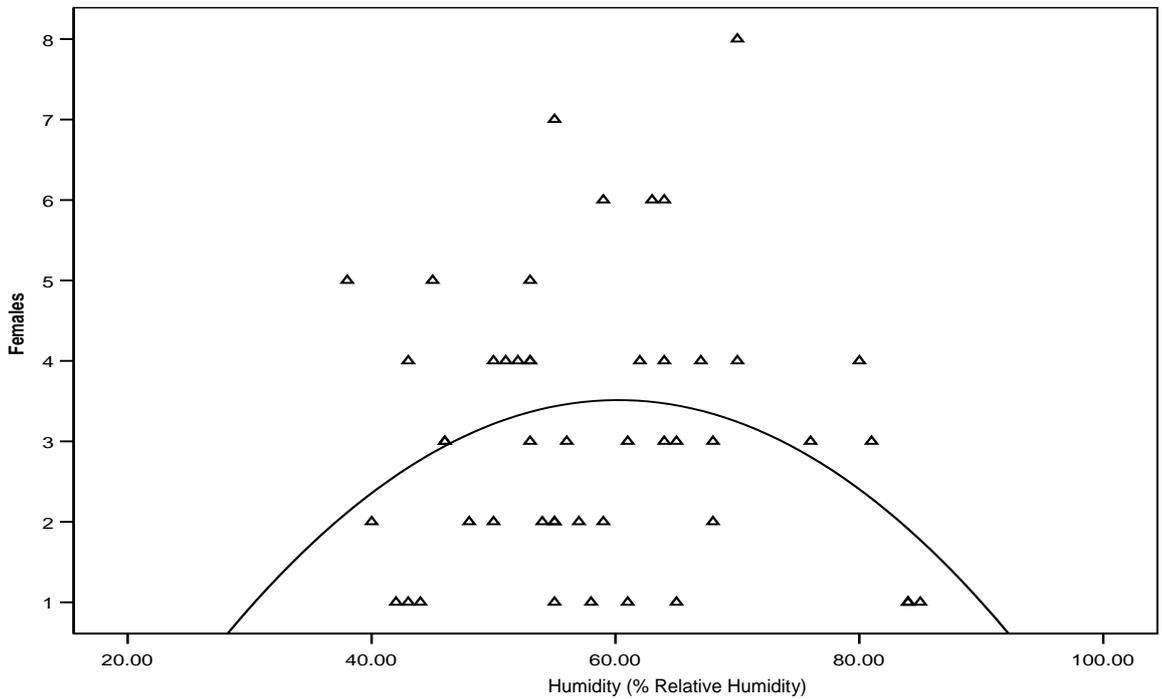


Figure B.6. Range of humidity values with corresponding egg laying and regaining condition females. The best model to fit the data is $\text{Humidity} + \text{Humidity}^2$ with the preferred range of humidities lying between 50% and 70%.

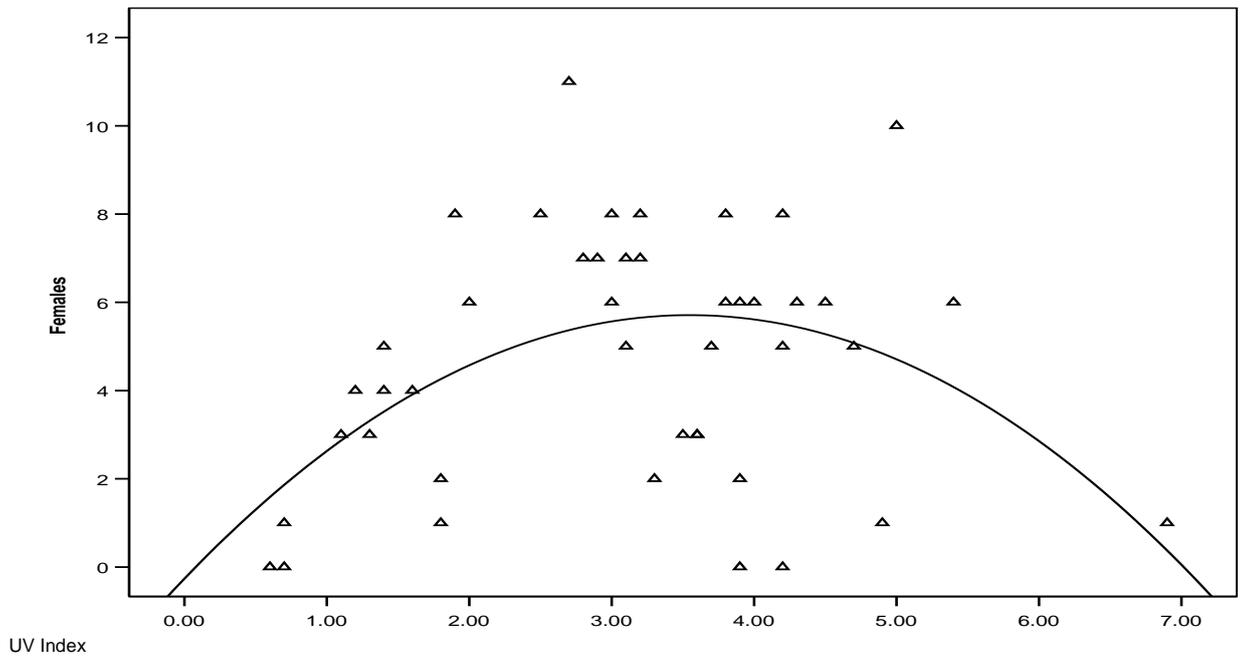


Figure B.7. Range of UV index values with corresponding counts of females for the rest of the season post egg laying and regaining condition. The data indicate the optimum range of values lies between 2.00 and 5.00.

9 Appendix C

Table C.1. Summary of the key interest points from figures 1.8a-r and figures 1.9a-r relating to the thermal properties of heathland strata at different times of the day.

Time / strata	Open Ground	Mature Heather	Degenerate Heather
Sunrise	<p>The daily underground temperatures in the last week of April exceeded the minimum sand lizard basking temperature. From June, the daily surface temperatures also exceed this threshold. At no time in the season do the daily or mean monthly temperatures recorded underground or at the surface approach the mean basking temperature.</p> <p>The mean monthly surface temperatures were consistently lower than the mean monthly underground temperatures and both were lower than the mean lizard basking temperature. (Figures 3.8a & 3.9a).</p>	<p>The daily underground temperatures fluctuated less and were higher than those recorded in the canopy and at the surface, (figure 3.8b). In June, the underground temperatures exceeded and remained above the minimum basking temperature while the surface and canopy temperatures fluctuated around this threshold for the rest of the season (figure 3.8b).</p> <p>The monthly mean temperatures were consistently lower than the mean lizard basking temperature. The highest temperatures were recorded in July. The canopy temperatures are lower than the underground temperatures. (Figure 3.9b).</p>	<p>The monthly mean temperatures for each stratum were consistently below the mean basking temperatures recorded for basking lizards (Figure 3.9c). The minimum daily temperatures were subject to the most fluctuation (Figure 3.8c). The highest temperatures were recorded beneath the ground where the minimum basking temperature of lizards was exceeded from June (Figure 3.8c).</p>
Sunrise + 2	<p>The underground monthly mean and daily temperatures were consistently higher than the surface temperatures, and both lower than the mean lizard basking temperature (Figures 3.9d & 3.8d). From June, the daily temperatures underground exceeded and remained above the minimum basking temperature (Figure 3.8d).</p>	<p>The daily canopy temperatures recorded were lower than those recorded at sunrise (Figures 3.8e & 3.8b) and as such there is a greater temperature difference between those recorded beneath ground and the canopy. The canopy temperatures were rarely higher than the underground temperatures. The temperatures beneath ground exceeded the minimum lizard basking temperature from June. The temperatures recorded in the canopy are not consistently above the minimum basking temperature.</p> <p>The mean monthly temperatures for all strata were below the mean monthly basking temperatures. The mean monthly underground temperatures were the highest and the monthly mean temperatures for all strata were similar in July (figure 3.8e).</p>	<p>The daily surface and underground temperatures exceeded the minimum basking temperature from the second week of June.</p> <p>The monthly mean temperatures for each stratum are similar in July are consistently below the mean basking temperature recorded for basking lizards (figure 3.9f) The daily underground temperatures were the most stable (figure 3.8f).</p>

<p>Sunrise + 4</p>	<p>The mean monthly surface and underground temperatures were consistently below the mean basking lizard temperature. The daily and mean monthly underground and surface temperatures appear very closely related (figures 3.9g – 3.8g). From June, the temperatures recorded at the surface and beneath ground exceed the minimum basking temperature of sand lizards.</p>	<p>The daily canopy temperatures were consistently higher than the underground and surface temperatures in March and April and at times exceeded the minimum basking temperature of the sand lizards (figure 3.8h). From June, the surface and underground temperatures were consistently above the minimum basking temperature. There is little difference between the temperatures recorded within each stratum. The canopy temperatures have dramatically increased between sunrise + 2 hours (figure 3.8e) and sunrise + 4 hours (figure 3.8h)</p> <p>The mean monthly temperatures for all strata remained below the mean lizard basking temperature, (figure 3.9h). The canopy temperatures are slightly higher than those recorded at the surface and underground.</p>	<p>Post 10th April the daily canopy temperatures exceeded the daily underground and surface temperatures. The underground temperatures exceeded this minimum value in the first week of June (figure 3.8i). At this time there is little amplitude between the temperature values in comparison to other time periods (figures 3.9a - 3.9r).</p> <p>The monthly mean temperatures for each stratum were consistently below the mean basking substratum temperature for lizards (figure 3.9i). The mean canopy was higher than the underground and surface means temperatures in May.</p>
<p>Midday</p>	<p>The daily surface temperatures exceeded the minimum lizard basking temperature by March end and the daily underground temperatures exceeded this value by May. There are five occasions between late May and August end when the daily surface temperatures exceeded the mean lizard basking temperature (figure 3.8j).</p> <p>The mean monthly and daily surface temperatures were consistently higher than the underground temperatures (figures 3.9j & 3.8j). With the exception of May, the monthly mean underground and surface temperatures were below the mean lizard basking temperature (figure 3.9j).</p>	<p>The mean monthly temperatures recorded in the canopy were the highest and exceeded the mean basking temperature in May (figure 3.9k). There is a large amount of temperature variation between the strata at midday (figure 3.9k) in comparison to the difference between the temperatures recorded at sunrise + 4 hours (figure 3.9h).</p>	<p>There is a greater difference between the daily and monthly mean temperatures recorded in each stratum (figures 3.8l & 3.9l) in comparison to the temperatures recorded at earlier times of the day (figures 3.8c, 3.8f & 3.8i). The daily canopy consistently reached higher temperatures than the surface and underground temperatures. The canopy temperatures exceeded the minimum basking temperature at the beginning of April, approached the mean basking temperature in mid-April and exceeded the mean basking temperature in May and June. The daily surface and underground temperatures exceeded the minimum basking temperature in second week of April and June respectively.</p> <p>The monthly mean underground and surface temperatures were lower than the mean lizard basking temperature. The monthly mean canopy temperatures were highest exceeded the mean lizard basking temperature in May (figure 3.9l).</p>

<p>Sunset – 4</p>	<p>The daily surface temperatures were consistently higher than the daily underground temperatures, with surface temperatures exceeded the minimum basking temperature in early March and the underground temperatures exceeded this value in early April. The daily surface temperatures exceeded the mean basking temperature by mid April. The daily underground temperatures always remain below the mean sand lizard basking temperature figure 3.8m).</p> <p>The mean monthly surface temperatures were consistently higher than monthly mean underground temperatures (figure 3.9m). The monthly mean surface temperatures exceeded the mean basking temperature in May and August (figure 3.9m). The daily temperatures (figure 3.8m) show the mean basking value was again exceeded in June and August, but this is not reflected in the monthly mean summary data (figure 3.9m).</p>	<p>The daily canopy temperatures exceeded the minimum in March and approach the maximum basking temperature in April. The surface temperatures mirror those present in the canopy with less amplitude. In May the underground temperature exceeded the minimum lizard basking temperature.</p> <p>The mean monthly canopy temperatures were the highest and exceeded the mean basking temperature in April, May and June (figure 3.8k) There is greater amplitude in the temperature difference between the three strata in April, May and June than the remainder of the year. The monthly mean temperatures recorded at sunset – 4 (figure 3.9n) in the canopy are much higher than those at midday in April and June (figure 3.9h)</p>	<p>The daily canopy temperatures exceeded and remained above the minimum basking temperature in early March. The temperature range in the canopy was large with a drop of 15°C between the beginning of and mid May (figure 3.8o). The surface temperatures exceeded and remain minimum lizard basking temperature from the beginning of April which is mimicked by the daily underground temperatures in June (figure 3.8o). From mid June the daily canopy temperatures were not as high or extreme as those recorded earlier in the season.</p> <p>The monthly mean canopy temperatures were consistently higher than the mean monthly underground and surface temperatures. The mean lizard basking temperature was exceeded by the monthly mean canopy temperature in May when the mean surface temperature was approaching this value (figure 3.9o).</p>
<p>Sunset -1</p>	<p>The daily surface and underground temperatures follow a similar pattern, with a smaller temperature difference between the two strata than noted in the previous two time periods midday (figure 3.8j) and sunset – 4 hours (figure 3.8m). The daily soil surface temperatures exceeded the minimum basking temperature and by the second week of April so had the underground temperatures.</p> <p>The monthly mean soil surface temperatures were consistently higher than the mean monthly underground temperatures and both below the mean lizard basking temperature. In May the mean surface temperature was equal to the mean basking temperature of <i>L. agilis</i>, figure 3.9p.</p>	<p>The mean monthly canopy temperatures were the highest yet and remained below the mean lizard basking temperature (figure 3.9q). The highest monthly mean canopy and surface temperatures were recorded in May and the highest underground temperatures in July (Figures 3.9q & 3.8q).</p>	<p>The daily temperatures from stratum follow a similar pattern with the canopy temperature only once approaching the mean basking temperature at the end of April (figure 3.8r). The minimum basking temperature were exceeded in March by the canopy temperatures; April by the surface temperatures and May by the underground temperatures.</p> <p>The monthly mean temperatures recorded in the three strata were consistently lower than the mean basking temperature (Figure 3.9r). The daily and monthly canopy temperatures were consistently higher than mean monthly and daily surface temperatures which in turn are higher than those reached beneath the ground (Figures 3.9r & 3.8r).</p>

10 Appendix D

Introduction

Radio telemetry has previously been used to investigate the movements of sand lizards (Dent 1986) with limited success which was attributed to the heavy tags. With the rapid advance in technology over the past two decades radio telemetry tags are now available which weigh <5% of the animals body mass (Kenwood 2001) and this provides an ideal opportunity to re-trial this technique on sand lizards.

Chapters 2, 3 and 5 have considered how seasonality, environmental variables and habitat can influence the detection rate of sand lizards. However, we still do not know the exact location of lizards when they are not visible and hence unavailable for detection. The use of radio telemetry will allow us to locate and quantify the length of time the lizards are unavailable. This will assist with the derivation of a standard sampling methodology where survey effort can be directed to times when a lizard is available for detection. In addition, radio tracking will provide us with much needed information relating to the movements of sand lizards between different vegetation types and structure and draw parallels between these movements and the microclimatic temperature ranges quantified in Chapter 3.

A large scale radio tracking study requires significant financial and labour investment and to produce statistically reliable data, a minimum number of 30 individuals need to be tagged (Kenwood, 2001). This study aimed to trial radio tracking with wild sand lizards, evaluate the quality of the data gathered and determine whether a larger scale radio tracking study would prove viable and likely to yield new information relating to the movements, and home ranges of wild sand lizards.

Methods

The equipment was sourced from Biotrack Ltd. in Wareham and PIP3 single cell tags were used, with a mass of 0.5g dimensions of 5.5mm x 2.2mm and a battery life of approximately 3 weeks with 20ms pulses at 50 beats per minute. A Mariner 57 Yagi and a Vega 173 receivers were used.

A number of captive lizards were fitted with dummy radio tags (identical in size and mass to the live tags) and monitored over a 7 day period to ensure there were no adverse effects resulting from tagging. This trial was successful. Three male sand lizards at Merritown Common (Appendix A) were fitted with radio tags and their locations tracked every 30 minutes during daylight hours by two field workers. Simultaneously a weather station located near the tagged lizards recorded the same environmental variables as detailed in Chapter 2. Further details regarding methods of sand lizard capture, tag attachment and trials on stationary radio tags are detailed in Appendix A by Moody (2007).

Results

Three male lizards were tagged on 20th June 2006 (male 1), 1st July 2006 (male 2) and 11th July 2006 (male 3). The tracking duration of each lizard ranged between 1 hour and 17 days. The movement of each individual was scarce. Male 1 was tracked 148 times and only 25 movements were detected (table D.1) and male 2 moved 12 times (table D.2) during 101 tracking occasions. The activity was recorded in the mornings or late afternoons.

Table D.1. Details of the 25 movement records from the tracking pilot of M1.

Date	Time	Tracking ref	Visual	Observer Height		Light (X10 lux)	Wind Speed	From Direction	Canopy		Ground		Canopy thermometer		Open ground thermometer		Lizard Status Active/Stationary/Unknown	Signal strength weak fluctuating normal strong	Location from burrow	
				Air temp oC	Humidity %RH				Temp oC	Humidity %RH	Temp oC	Humidity %RH	Temp at 5cm oC	Soil temp oC	Temp at 5cm oC	Soil temp oC				
21/06/2006	10:00	M1062101	N	17.5	44.5		3.3	W	20.6	58.5	22.5	68.5						S	W	
21/06/2006	10:30	M1062102	N	18	34.6		3.3	W	22.1	46.4	26.6	33						A	N	2M WEST
21/06/2006	11:00	M1062103	N	19.5	30.1		3.4	W	35.8	13.3	34.7	25.6						A	N	4M WEST
21/06/2006	15:00	M1062111	N	19	40		2.9	W	24.8	43.5	24.6	42.1						A	N	5M NORTH EAST
21/06/2006	17:00	M1062115	N	17.9	40.8		1.8	SW	22.4	43.9	21.4	41.6						A	N	0
22/06/2006	10:30	M1062205	N	18.4	22.4		1.7	W	31.3	13.4	30.7	6.5	28					S/A	N	WEST
22/06/2006	11:00	M1062206	N	18.2	33.4		2.5	W	33.9	7.4	31.1	13.3	28					S	F	WEST
22/06/2006	14:30	M1062213	N	19.5	30.6		3.3	W	26.5	31.2	26.9	31	32	23	24	25		A?	F	0
22/06/2006	15:00	M1062214	N	19.5	30.8		6.4	W	23.9	38.2	23.4	32	35	22	21	26		S	W	0
23/06/2006	11:00	M106062303	N	28.9	1.40		0.0		37.5	6.4	38.1	12.4	31.0	19.0	25.0	23.5		U	F	0
23/06/2006	11:30	M106062304	N	19.5	20.1		1.2	SE	28.4	28.2	28.5	15.8	26.0	17.5	22.0	21.0		A	F	0
23/06/2006	12:00	M106062305	N	23.5	34.7		0.5	W	25.6	45.6	28.4	36.5	29.0	19.0	25.0	23.0		A	F	2M SWEST
23/06/2006	12:30	M106062306	N	22.6	11.7		1.5	W	29.4	30.3	33.7	33.7	30.0	23.0	28.0	27.0		S	F	NE OF BURROW
23/06/2006	13:00	M106062307	N	23.5	27.1		0.7	SE	31.4	35.6	32.8	20.0	31.0	27.0	26.0	27.0		A	F	4M WEST
23/06/2006	14:00	M106062309	N	20.6	22.7		2.0	SW	27.6	43.0	31.0	25.6	33.0	25.0	26.0	29.0		S	F	0
23/06/2006	17:00	M106062315	N	20.6	35.7		0.6	E	23.5	49.8	23.7	51.0	23.0	18.0	21.0	21.5		A	F	2M EAST
24/06/2006	09:00	M106062404	N	18.5	59.6		0.4	NW	19.8	71.5	20.3	74.5	18.0	16.0	17.0	16.0		A - Posture change only	F	1M SOUTH
26/06/2006	08:30	M106062601	N	17.8	70.7		1.3	N - NE	16.6	78.5	16.7	78.5	15.0	14.0	15.0	13.5		S	F (WEAK)	0
26/06/2006	13:30	M106062611	N	16.9	74.8	1203	1.2	SE	17.1	82.3	17.1	86.1	15.5	14.5	14.0	14.0		S	F (WEAK)	0
28/06/2006	09:30	M106062804	N	20.2	54.6		0.7	SE	22.8	65.9	23.7	61.8	22.0	16.0	21.0	20.0		S	WF	0
28/06/2006	11:00	M106062807	N	24.7	21.7		0.0		30.3	34.6	28.5	29.0	25.0	18.0	22.0	21.5		S	W	0
28/06/2006	12:30	M106062810	N	21.8	35.3		0.5	SE	28.2	46.7	28.6	43.7	32.0	21.0	26.5	25.0		S	F	0
28/06/2006	13:30	M106062812	N	23.1	46.7		2.5	SE	25.8	57.8	27.5	46.7	32.0	22.0	27.0	24.0		S	N/W	0
28/06/2006	15:00	M106062815	N	21.2	41.8		1.1	SE	24.9	53.0	25.1	53.7	31.0	18.0	26.0	25.5		S	W	0
30/06/2006	13:30	M106063006	N	24.5	38.5		1.6	S	31.3	39.7	37.2	18.7	36.0	24.5	28.0	28.0		S	F	0

Table D.2. Details of the 12 movement records from the tracking pilot of M2.

Date	Time	Tracking ref	Visual	Observer Height		Light (X10 lux)	Wind Speed	From Direction	Canopy		Ground		Canopy thermometer		Open ground thermometer		Lizard Status Active/Stationary/Unknown	Signal strength weak fluctuating normal strong	Location from release site
				Obs air temp oC	Humidity %RH				Temp oC	Humidity %RH	Temp oC	Humidity %RH	Temp at 5cm oC	Soil temp oC	Temp at 5cm oC	Soil temp oC			
01/07/2006	14:30	M206070101	N	28.3	30.2		2.0	S	30.5	30.9	32.0	27.4	34.0	18.0	39.5	37.5	A	F	0
02/07/2006	10:00	M206070202	N	27.7	35.2		0.2	S	32.6	33.4	31.7	36.2	32.0	24.0	25.5	16.5	S / F	F	0
02/07/2006	19:00	M206070213	N	26.6	36.8		0.9	S	28.2	36.0	28.5	34.8	28.0	23.0	27.5	25.0	S	V.W	0
03/07/2006	16:00	M206070318	N	28.4	29.2		1.6	S	31.4	27.6	33.2	28.1	34.0	27.0	36.0	28.0	S	V.W	0
04/07/2006	08:30	M206070401	N	23.7	48.7		0.8	SE	26.3	45.2	26.7	46.7	30.0	23.0	22.0	18.5	S	N/F	0
04/07/2006	11:00	M206070406	N	28.8	37.9		1.3	S	30.7	33.2	31.3	32.1	33.0	23.0	31.0	27.0	S	N	S
04/07/2006	15:30	M206070409	N	26.3	36.7		1.5	S	27.9	42.2	31.4	33.2	34.0	29.0	35.0	37.0	S	F	0
04/07/2006	16:30	M206070411	N	26.4	42.3		1.5	S	27.3	42.6	28.7	49.4	33.5	24.0	32.0	24.0	S	N	W WTS - 5M WEST
06/07/2006	13:30	M206070601	N	20.9	70.3	1964	0.4	NW	22.6	71.8	23	72.9	21	19	20	18	S	N	4M WEST
06/07/2006	14:00	M206070602	N	22.6	72.1		0		22.8	77	23.4	81.4	22	19	20	18.5	A	F	
06/07/2006	14:30	M206070603	N	22.2	71		0.7	NW	23.2	73.8	23.5	77.8	21	19	20	18	A	F	0
08/07/2006	15:00	M206070805	N	21.6	42.9		2.2	SW	24.7	41.6	25.9	42.6	24.0	18.0	25.0	20.0	S/A	F	0

11 Appendix E

Table E.2. Fires on or adjacent to heathlands to which Dorset and Hampshire Fire Crews were sent between February 2005 and September 2008. Data provided by The County Fire Service.

Incident number	Incident Date	Motive	Location
014406	01/02/2005 11:34:14	Malicious	CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN,POOLE
014494	02/02/2005 20:08:04	Malicious	TURBARY COMMON,CANFORD AVENUE,WALLISDOWN,REDHILL PARK
014509	02/02/2005 20:31:00	Accidental	TALBOT HEATH,REDHILL PARK
014510	02/02/2005 20:31:00	Accidental	TALBOT HEATH,REDHILL PARK
014511	02/02/2005 20:31:00	Accidental	TALBOT HEATH,REDHILL PARK
014497	02/02/2005 20:31:00	Accidental	25 ISAACS CLOSE,TALBOT HEATH,REDHILL PARK
014600	04/02/2005 18:11:51	Accidental	CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN,POOLE
014640	05/02/2005 13:46:07	Accidental	ALDERHILLS NATURE RESERVE,ALDER PARK,BOURNE VALLEY,WESTBOURNE
014782	09/02/2005 10:50:04	Malicious	20 MONKTON CRESCENT,BLOXWORTH ESTATE,REDHILL PARK
014796	09/02/2005 16:29:07	Malicious	WHITE & CO,ELLIOTT ROAD,WEST HOWE INDUSTRIAL ESTATE,WALLISDOWN,REDHILL PARK
014803	09/02/2005 17:23:45	Malicious	UPTON HEATH,UPTON,HAMWORTHY
014806	09/02/2005 18:51:13	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
014828	10/02/2005 13:15:05	Malicious	BOURNE BOTTOM,BENBOW CRESCENT,WALLISDOWN,REDHILL PARK
014836	10/02/2005 18:15:44	Malicious	CANFORD HEATH,CANFORD HEATH,POOLE
014922	12/02/2005 15:08:48	Malicious	END OF,BELBEN ROAD,ALDERNEY,POOLE
014944	12/02/2005 17:49:15	Malicious	CANFORD HEATH,BELBEN ROAD,ALDERNEY,POOLE
015030	14/02/2005 20:02:20	Malicious	CHERFORD ROAD,ENSBURY PARK,REDHILL PARK
015120	16/02/2005 16:43:18	Malicious	SHARP ROAD,BOURNE VALLEY,WESTBOURNE
015127	16/02/2005 19:14:57	Malicious	CANFORD HEATH,STEEPLE CLOSE,CANFORD HEATH,POOLE
015132	16/02/2005 20:04:41	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
015149	17/02/2005 10:55:00	Malicious	ALDERNEY WEST COMMON,BELBEN ROAD,ALDERNEY,POOLE
015169	17/02/2005 18:05:02	Malicious	TURBARY COMMON,TURBARY CLOSE,ROSSMORE,REDHILL PARK
015198	18/02/2005 12:58:16	Malicious	CANNON HILL WOODS,COEHILL,WIMBORNE
015202	18/02/2005 13:52:06	Malicious	REAR OF,TAMAR CLOSE,FERNDOWN,FERNDOWN
015254	19/02/2005 19:28:03	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,WEST HOWE,REDHILL PARK
015274	19/02/2005 22:00:20	Accidental	GALLOWS HILL,BOVINGTON CAMP,WAREHAM

015322	20/02/2005	14:42:10	Malicious	TOLLARD CLOSE,ROSSMORE,REDHILL PARK
015328	20/02/2005	15:22:48	Malicious	UPTON HEATH,UPTON,HAMWORTHY
015329	20/02/2005	15:42:33	Accidental	47 LONE PINE DRIVE,WEST PARLEY,FERNDOWN
015334	20/02/2005	16:47:45	Malicious	BOURNE BOTTOM,SOUTH PARK ROAD,WALLISDOWN,REDHILL PARK
015370	21/02/2005	20:29:20	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
015481	24/02/2005	11:42:41	Malicious	FERNDOWN LEISURE CENTRE,CHERRY GROVE,FERNDOWN,FERNDOWN
015511	25/02/2005	09:33:37	Accidental	ACTON,LANGTON MATRAVERS,SWANAGE
015524	25/02/2005	16:50:55	Malicious	TURBARY CLOSE,ROSSMORE,REDHILL PARK
015527	25/02/2005	17:42:39	Accidental	ST CATHERINES HILL,ST CATHERINES,CHRISTCHURCH
015532	25/02/2005	19:39:24	Malicious	MELBURY AVENUE,ROSSMORE,REDHILL PARK
015536	25/02/2005	20:00:34	Malicious	PARVALUX ELECTRIC MOTORS LTD,WALLISDOWN ROAD,WALLISDOWN,REDHILL PARK
015585	26/02/2005	15:32:16	Accidental	UPTON HEATH,BEACON ROAD,UPTON,HAMWORTHY
015602	26/02/2005	17:53:22	Malicious	PARRS PLANTATION,OAKDALE,POOLE
015608	26/02/2005	19:27:07	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
015642	27/02/2005	04:28:53	Malicious	STOBOROUGH,WAREHAM
015653	27/02/2005	12:47:50	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
015654	27/02/2005	13:09:43	Malicious	BOURNE VALLEY COMMON,TOLLARD CLOSE,ROSSMORE,REDHILL PARK
015664	27/02/2005	13:40:39	Malicious	BOURNEVALLEY COMMON,63 BENBOW CRESCENT,WALLISDOWN,REDHILL PARK
015672	27/02/2005	16:15:04	Malicious	REAR OF 67,BENBOW CRESCENT,WALLISDOWN,REDHILL PARK
015690	27/02/2005	19:05:53	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
015732	28/02/2005	14:26:30	Malicious	TURBARY CLOSE,ALDERNEY,WESTBOURNE
015738	28/02/2005	16:18:47	Malicious	TURBARY ROAD,ROSSMORE,WESTBOURNE
015751	28/02/2005	16:57:16	Malicious	REAR OF,MONKTON CRESCENT,BLOXWORTH ESTATE,REDHILL PARK
015769	28/02/2005	19:20:38	Malicious	BOTTOM OF/,TURBARY CLOSE,ALDERNEY,WESTBOURNE
015771	28/02/2005	20:15:26	Malicious	REAR OF KEMP WELCH SCHOOL/,TURBARY CLOSE,ALDERNEY,WESTBOURNE
015773	28/02/2005	21:02:50	Malicious	TOLLARD CLOSE,BLOXWORTH ESTATE,REDHILL PARK
015783	28/02/2005	22:23:36	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,ENSBURY PARK,REDHILL PARK
015809	01/03/2005	15:26:52	Malicious	REAR OF,37 MILBORNE CRESCENT,ROSSMORE,REDHILL PARK
015870	03/03/2005	12:00:54	Malicious	FERNDOWN LEISURE CENTRE,CHERRY GROVE,FERNDOWN,FERNDOWN
015936	04/03/2005	15:03:25	Accidental	HIGHER BLANDFORD ROAD,CORFE MULLEN,POOLE
015952	04/03/2005	21:42:30	Malicious	REAR OF TURBARY PARK,HERBERT AVENUE,ALDERNEY,WESTBOURNE
015983	05/03/2005	12:19:38	Malicious	BOURNE BOTTOM,OFF BLOXWORTH ROAD,BOURNE VALLEY,WESTBOURNE
015994	05/03/2005	13:37:44	Accidental	HIGHER HYDE HEATH,HYDE,BERE REGIS

016010	05/03/2005	17:24:16	Malicious	RUSHCOMBE BOTTOM HEATH,DIANA WAY,CORFE MULLEN,HAMWORTHY
016056	06/03/2005	17:44:27	Malicious	TALBOT HEATH,TALBOT HEATH,TALBOT HEATH,REDHILL PARK
016103	07/03/2005	17:30:27	Malicious	PARRS PLANTATION,OAKDALE,POOLE
016110	07/03/2005	18:36:29	Malicious	FRANCIS AVENUE,CANFORD HEATH,WALLISDOWN
016117	07/03/2005	20:02:29	Malicious	BLOXWORTH ROAD,BOURNE VALLEY,REDHILL PARK
016125	07/03/2005	20:22:58	Malicious	TALBOT COMBINED SCHOOL,TALBOT DRIVE,TALBOT HEATH,REDHILL PARK
016126	07/03/2005	20:26:36	Malicious	MARTIN KEMP-WELCH SCHOOL,HERBERT AVENUE,ALDERNEY,WESTBOURNE
016166	08/03/2005	19:21:07	Malicious	TURBARY CLOSE,ALDERNEY,WESTBOURNE
016170	08/03/2005	19:51:37	Malicious	OLD WAREHAM RD RBT to HOLES BAY NORTH R` ABOUT,A3049,DORSET WAY,CANFORD HEATH,POOLE
016179	08/03/2005	20:16:29	Malicious	OAKDALE PUB/DORSET WAY,DORSET WAY,A3049,OAKDALE,POOLE
016192	08/03/2005	23:15:00	Malicious	TALBOT HEATH/,TALBOT DRIVE,TALBOT HEATH,REDHILL PARK
016200	09/03/2005	09:08:50	Malicious	SOUTH PARK ROAD,WALLISDOWN,REDHILL PARK
016243	10/03/2005	08:39:24	Malicious	TALBOT COMBINED SCHOOL,TALBOT DRIVE,TALBOT HEATH,REDHILL PARK
016275	10/03/2005	19:54:42	Malicious	TURBARY COMMON,WALLISDOWN ROAD,WALLISDOWN,REDHILL PARK
016302	11/03/2005	13:18:16	Accidental	WAREHAM FOREST,BERE ROAD,COLD HARBOUR,WAREHAM
016308	11/03/2005	14:30:35	Malicious	EVERING AVENUE,ALDERNEY,POOLE
016355	11/03/2005	18:00:22	Malicious	REAR OF/ROSSMORE COMMUNITY CENTRE,TURBARY CLOSE,ROSSMORE,REDHILL PARK
016383	12/03/2005	13:11:38	Accidental	A35,UPTON ROAD,CREEKMOOR,HAMWORTHY
016396	12/03/2005	16:17:57	Malicious	LYTCHETT WAY,UPTON,HAMWORTHY
016431	13/03/2005	11:39:39	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
016478	13/03/2005	16:12:35	Malicious	110 SCARF ROAD,CANFORD HEATH,POOLE
016511	13/03/2005	20:00:18	Malicious	REAR OF/20 BERKELEY AVENUE,ALDERNEY,POOLE
016533	14/03/2005	10:41:21	Accidental	WEST MOORS PLANTATION,WEST MOORS,FERNDOWN
016537	14/03/2005	11:40:26	Accidental	BALLARD DOWN,STUDLAND,SWANAGE
016540	14/03/2005	12:28:31	Malicious	ROSSMORE COMMUNITY COLLEGE,HERBERT AVENUE,ALDERNEY,WESTBOURNE
016552	14/03/2005	18:01:37	Malicious	KEMP WELCH LEISURE CENTRE,BOROUGH OF POOLE,HERBERT AVENUE,ALDERNEY,WESTBOURNE
016555	14/03/2005	18:43:53	Malicious	KEMP WELCH LEISURE CENTRE,KEMP WELCH LEISURE CENTRE,HERBERT AVENUE,ALDERNEY,WESTBOURNE
016558	14/03/2005	18:53:22	Malicious	SCOTT CLOSE,WALLISDOWN,REDHILL PARK
016622	15/03/2005	15:25:03	Malicious	TURBARY CLOSE,ALDERNEY,WESTBOURNE
016638	15/03/2005	20:01:28	Malicious	KEMP WELCH SCHOOL,TURBARY CLOSE,ROSSMORE,REDHILL PARK
016646	15/03/2005	21:07:39	Malicious	SHERBORN CRESCENT,CANFORD HEATH,POOLE
016666	16/03/2005	14:09:47	Malicious	KEMP WELCH LEISURE CENTRE,KEMP WELCH LEISURE CENTRE,HERBERT AVENUE,ALDERNEY,WESTBOURNE

016758	18/03/2005	15:31:50	Malicious	CANFORD WAY,A3049,ALDERNEY,POOLE
016816	19/03/2005	16:55:05	Accidental	MORETON PLANTATION,MORETON,BERE REGIS
016830	19/03/2005	19:56:00	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
016862	20/03/2005	13:36:03	Malicious	BRANKSOME HILL ROAD,BRANKSOME,WESTBOURNE
016893	20/03/2005	16:30:23	Accidental	WHITE SHEET PLANTATION,HOLT,WIMBORNE
016897	20/03/2005	16:48:03	Accidental	NIGHTJAR,6 RAVINE ROAD,CANFORD CLIFFS,WESTBOURNE
016899	20/03/2005	17:21:19	Malicious	KEMP WELCH LEISURE CENTRE,KEMP WELCH LEISURE CENTRE,HERBERT AVENUE,ALDERNEY,WESTBOURNE
016902	20/03/2005	19:32:52	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
016906	20/03/2005	20:16:04	Malicious	KEMP WELCH LEISURE CENTRE,KEMP WELCH LEISURE CENTRE,HERBERT AVENUE,ALDERNEY,WESTBOURNE
016932	21/03/2005	16:09:40	Malicious	WINSTON AVENUE,BOURNE VALLEY,WESTBOURNE
016995	23/03/2005	14:36:49	Malicious	PARRS PLANTATION,DALE VALLEY ROAD,OAKDALE,POOLE
017000	23/03/2005	16:24:31	Malicious	PARRS PLANTATION,DALE VALLEY ROAD,OAKDALE,POOLE
017008	23/03/2005	20:11:16	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
017095	25/03/2005	13:33:32	Accidental	AARON CLOSE,CANFORD HEATH,POOLE
017098	25/03/2005	13:42:07	Malicious	FERNDOWN COMMON,FERNDOWN,FERNDOWN
017104	25/03/2005	14:05:57	Malicious	PARRS PLANTATION,DALE VALLEY ROAD,OAKDALE,POOLE
017186	26/03/2005	19:45:02	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
000056	02/04/2005	14:34:31	Malicious	27 DUNCAN CRESCENT,BOVINGTON CAMP,WAREHAM
000067	02/04/2005	17:25:09	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,ENSBURY PARK,REDHILL PARK
000076	02/04/2005	20:16:07	Malicious	TURBARY COMMON,DOWNEY CLOSE,WALLISDOWN,REDHILL PARK
000165	04/04/2005	20:34:48	Malicious	26 RIGGS GARDENS,WALLISDOWN,REDHILL PARK
000186	05/04/2005	16:15:37	Malicious	HURN FOREST,HURN,FERNDOWN
000204	05/04/2005	20:50:49	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
000246	06/04/2005	17:51:53	Malicious	ALDERNEY RECREATION GROUND,TURBARY ROAD,ALDERNEY,WESTBOURNE
000310	08/04/2005	15:18:02	Malicious	TURBARY PARK AVENUE,ENSBURY PARK,REDHILL PARK
000322	08/04/2005	20:12:33	Malicious	HASKELLS ROAD,NEWTOWN,POOLE
000372	09/04/2005	20:21:07	Malicious	HIGHER BLANDFORD ROAD,CORFE MULLEN,POOLE
000409	10/04/2005	12:22:22	Malicious	KINSON COMMON,PAGET ROAD,WEST HOWE,REDHILL PARK
000419	10/04/2005	12:55:51	Accidental	DORSET WAY,A3049,CANFORD HEATH,POOLE
000430	10/04/2005	16:08:15	Malicious	HAYMOOR MIDDLE SCHOOL,ASHDOWN CLOSE,CANFORD HEATH,POOLE
000437	10/04/2005	18:21:44	Malicious	ASHDOWN SCHOOL,ADASTRAL ROAD,CANFORD HEATH,POOLE
000449	10/04/2005	20:18:37	Malicious	146 TURBARY PARK AVENUE,WEST HOWE,REDHILL PARK

000498	11/04/2005	16:06:10	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
000509	11/04/2005	19:55:37	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,ENSBURY PARK,REDHILL PARK
000557	12/04/2005	20:19:10	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
000629	13/04/2005	20:23:52	Malicious	TURBARY PARK AVENUE,ENSBURY PARK,REDHILL PARK
000733	16/04/2005	14:40:33	Malicious	KINSON COMMON,SOUTH KINSON DRIVE,KINSON,REDHILL PARK
000807	18/04/2005	20:17:19	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
000844	19/04/2005	20:08:34	Malicious	FRANCIS AVENUE,CANFORD HEATH,WALLISDOWN
001016	24/04/2005	13:09:01	Malicious	KEMP WELCH LEISURE CENTRE,KEMP WELCH LEISURE CENTRE,HERBERT AVENUE,ALDERNEY,WESTBOURNE
001021	24/04/2005	14:03:00	Malicious	TRENT WAY,FERNDOWN,FERNDOWN
001057	25/04/2005	19:01:35	Malicious	TURBARY CLOSE,ALDERNEY,WESTBOURNE
001109	26/04/2005	18:25:26	Malicious	30 RIGGS GARDENS,WALLISDOWN,REDHILL PARK
001148	27/04/2005	15:14:59	Malicious	CANFORD HEATH,FRANCIS AVENUE,CANFORD HEATH,POOLE
001258	30/04/2005	20:12:22	Malicious	TURBARY HEATH,CANFORD ROAD,WALLISDOWN,REDHILL PARK
001316	02/05/2005	12:55:44	Malicious	CANFORD HEATH,BELBEN ROAD,ALDERNEY,POOLE
001365	03/05/2005	16:53:56	Malicious	REAR OF,TURBARY CLOSE,ALDERNEY,WESTBOURNE
001384	03/05/2005	19:43:04	Malicious	15 MONKTON CRESCENT,BLOXWORTH ESTATE,REDHILL PARK
001399	03/05/2005	19:57:03	Malicious	TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
001432	04/05/2005	00:17:43	Malicious	65 BENBOW CRESCENT,WALLISDOWN,REDHILL PARK
001506	04/05/2005	21:00:06	Malicious	TURBARY COMMON,TURBARY ROAD,ALDERNEY,WESTBOURNE
001524	05/05/2005	11:13:14	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
001525	05/05/2005	11:30:08	Malicious	KINSON COMMON,GLENMEADOWS DRIVE,KINSON,REDHILL PARK
001573	06/05/2005	11:43:27	Malicious	KINSON COMMON,SOUTH KINSON DRIVE,KINSON,REDHILL PARK
001593	06/05/2005	21:28:28	Malicious	FERNHEATH COMMON,MOORSIDE ROAD,WEST HOWE,REDHILL PARK
001608	07/05/2005	00:33:00	Malicious	ASHDOWN SCHOOL,ASHDOWN CLOSE,CANFORD HEATH,POOLE
001620	07/05/2005	07:23:26	Malicious	KINSON COMMON,KINSON,REDHILL PARK
001674	08/05/2005	08:09:04	Accidental	KINSON COMMON,SOUTH KINSON DRIVE,KINSON,REDHILL PARK
001680	08/05/2005	13:19:44	Malicious	TOLLARD CLOSE,BLOXWORTH ESTATE,REDHILL PARK
001696	08/05/2005	17:22:00	Malicious	EGMONT ROAD,TURLIN MOOR,HAMWORTHY
001753	09/05/2005	18:14:00	Malicious	POOLE LANE,KINSON,REDHILL PARK
001798	10/05/2005	13:14:12	Malicious	PARRS PLANTATION,DALE VALLEY ROAD,OAKDALE,POOLE
001820	10/05/2005	20:02:07	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
001839	11/05/2005	12:08:02	Malicious	KINSON COMMON,OUTSIDE,84 SOUTH KINSON DRIVE,WEST HOWE,REDHILL PARK

001910	12/05/2005	19:57:38	Malicious	TURBARY COMMON,CANFORD AVENUE,WALLISDOWN,REDHILL PARK
001920	12/05/2005	21:00:46	Malicious	PARRS PLANTATION,PARRS PLANTATION,DALE VALLEY ROAD,OAKDALE,POOLE
001945	13/05/2005	15:51:17	Accidental	HADRIAN WAY,CORFE MULLEN,HAMWORTHY
002018	15/05/2005	13:37:12	Malicious	TRICKETTS CROSS COMMUNITY CENTRE,BARNS ROAD,FERNDOWN,FERNDOWN
002037	15/05/2005	20:12:44	Malicious	BELBEN ROAD,ALDERNEY,POOLE
002108	17/05/2005	16:48:26	Malicious	REAR OF,WARBURTON ROAD,CANFORD HEATH,POOLE
002133	17/05/2005	20:12:04	Malicious	FRANCIS AVENUE,CANFORD HEATH,WALLISDOWN
002142	18/05/2005	04:23:14	Malicious	WEST MOORS PLANTATION,ELMHURST ROAD,WEST MOORS,FERNDOWN
002175	18/05/2005	19:35:14	Deliberate	WHEELERS LANE,CANFORD HEATH,REDHILL PARK
002309	21/05/2005	21:25:52	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
002353	23/05/2005	10:51:35	Malicious	KINSON COMMON,KINSON,REDHILL PARK
002428	25/05/2005	11:41:03	Malicious	KINSON COMMON,KINSON,REDHILL PARK
002486	26/05/2005	16:05:27	Deliberate	STEEPLE CLOSE,CANFORD HEATH,POOLE
002499	26/05/2005	18:21:29	Malicious	BELBEN ROAD,ALDERNEY,POOLE
002505	26/05/2005	21:04:42	Malicious	MANNINGS HEATH R`ABOUT to ALDERNEY R`ABOUT,CANFORD WAY,A3049,ALDERNEY,POOLE
002555	27/05/2005	18:22:17	Malicious	KING GEORGE V PLAYING FIELD,CHERRY GROVE,FERNDOWN,FERNDOWN
002566	27/05/2005	19:50:16	Malicious	MILLHAMS ROAD,KINSON,REDHILL PARK
002597	28/05/2005	11:34:31	Malicious	KINSON COMMON,KINSON,REDHILL PARK
002709	30/05/2005	12:59:38	Malicious	KINSON COMMON,GLENMEADOWS DRIVE,KINSON,REDHILL PARK
002715	30/05/2005	15:32:13	Deliberate	SIKA TRAIL,WAREHAM FOREST,GREAT OVENS DRIVE,NORTHMOOR PARK,WAREHAM
002729	30/05/2005	16:28:20	Malicious	SOUTH KINSON DRIVE,KINSON,REDHILL PARK
002781	31/05/2005	07:13:13	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
002813	31/05/2005	15:38:53	Deliberate	78 PILSDON DRIVE,CANFORD HEATH,POOLE
002961	02/06/2005	22:23:37	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
003038	04/06/2005	20:42:54	Malicious	PALMERSTON ROAD,UPTON,HAMWORTHY
003053	05/06/2005	07:42:18	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
003150	08/06/2005	08:25:21	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
003206	08/06/2005	19:32:16	Accidental	PARRS PLANTATION,PARRS PLANTATION,DALE VALLEY ROAD,OAKDALE,POOLE
003208	08/06/2005	20:47:57	Malicious	DIANA WAY,CORFE MULLEN,HAMWORTHY
003235	09/06/2005	14:31:14	Accidental	KINSON COMMON,KINSON,REDHILL PARK
003286	10/06/2005	21:28:01	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
003295	10/06/2005	21:43:33	Malicious	TURBARY PARK AVENUE,WEST HOWE,REDHILL PARK
003349	11/06/2005	21:18:25	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK

003393	12/06/2005	22:55:15	Malicious	TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
003401	13/06/2005	07:06:18	Malicious	TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
003433	13/06/2005	20:47:45	Malicious	TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
003474	14/06/2005	20:11:50	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
003704	19/06/2005	09:27:58	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
003812	21/06/2005	16:33:44	Accidental	DAGGONS ROAD,ALDERHOLT,VERWOOD
003814	21/06/2005	16:59:01	Accidental	BOVINGTON CAMP,KING GEORGE V ROAD/,BOVINGTON CAMP,WAREHAM
003822	21/06/2005	18:33:43	Malicious	SIKA TRAIL,WAREHAM FOREST,COLD HARBOUR,WAREHAM
003834	21/06/2005	21:28:44	Accidental	SIKA TRAIL,WAREHAM FOREST,COLD HARBOUR,WAREHAM
003935	23/06/2005	15:38:46	Accidental	KINSON COMMON,KINSON,REDHILL PARK
003945	23/06/2005	17:54:24	Accidental	HARDOWN HILL,MORCOMBELAKE,CHARMOUTH
004155	26/06/2005	18:13:56	Malicious	HEATHERLANDS COMMUNITY CENTRE,BARNS ROAD,FERNDOWN,FERNDOWN
004340	29/06/2005	17:16:58	Accidental	RINGWOOD ROAD,VERWOOD,VERWOOD
004415	01/07/2005	14:40:11	Accidental	LONG ISLAND,THE ISLANDS,LONG ISLAND,POOLE HARBOUR
004676	07/07/2005	19:06:30	Accidental	BUGDEN COPSE,MANOR ROAD,VERWOOD,VERWOOD
004682	08/07/2005	00:34:06	Accidental	DACOMBE DRIVE,UPTON,HAMWORTHY
004705	08/07/2005	19:43:58	Malicious	KINSON COMMON,SOUTH KINSON DRIVE,KINSON,REDHILL PARK
004808	10/07/2005	22:24:56	Malicious	KINSON COMMON,KINSON,REDHILL PARK
004840	11/07/2005	14:02:19	Accidental	BAKERS HANGING,ASHLEY HEATH,FERNDOWN
004856	11/07/2005	20:16:51	Accidental	HAM COMMON,HAMWORTHY,HAMWORTHY
005007	14/07/2005	11:04:37	Accidental	KINSON COMMON,KINSON,REDHILL PARK
005022	14/07/2005	16:18:58	Accidental	THAMES CLOSE,FERNDOWN,FERNDOWN
005085	15/07/2005	17:47:57	Malicious	UPTON HEATH,UPTON,HAMWORTHY
005118	16/07/2005	09:48:49	Accidental	CANNON HILL PLANTATION,COLEHILL,WIMBORNE
005219	17/07/2005	21:24:08	Malicious	REAR OF,177 VERITY CRESCENT,CANFORD HEATH,POOLE
005274	18/07/2005	19:49:45	Malicious	KINSON COMMON,REAR OF SOUTH KINSON DRIVE,KINSON,REDHILL PARK
005328	19/07/2005	18:21:11	Malicious	KELLAWAY ROAD,CANFORD HEATH,POOLE
005337	19/07/2005	18:53:54	Malicious	SOUTH KINSON DRIVE,KINSON,REDHILL PARK
005357	20/07/2005	10:35:07	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
005383	20/07/2005	20:47:37	Malicious	CANNON HILL PLANTATION,PILFORD HEATH ROAD,COLEHILL,WIMBORNE
005389	20/07/2005	23:10:21	Malicious	KINSON COMMON REAR OF,102 SOUTH KINSON DRIVE,WEST HOWE,REDHILL PARK
005405	21/07/2005	09:29:27	Malicious	KINSON ROAD,KINSON,REDHILL PARK
005490	22/07/2005	08:23:36	Malicious	DUMBARTON ROAD,WYKE REGIS,WEYMOUTH

005569	23/07/2005	19:02:05	Malicious	CANFORD HEATH,BELBEN ROAD,ALDERNEY,POOLE
005889	29/07/2005	15:06:01	Accidental	EAST LULWORTH to WEST HOLME (3.5M),B3070,TYNEHAM,WAREHAM
006140	04/08/2005	09:11:31	Malicious	SOUTH KINSON DRIVE,KINSON,REDHILL PARK
006370	08/08/2005	17:41:23	Accidental	WAREHAM FOREST TOURIST PARK,COLD HARBOUR,WAREHAM
006404	09/08/2005	13:29:18	Malicious	ALDER HILLS NATURE RESERVE,ALDER ROAD,BOURNE VALLEY,WESTBOURNE
006467	11/08/2005	10:30:00	Malicious	34 GLENMEADOWS DRIVE,KINSON,REDHILL PARK
006500	12/08/2005	10:02:06	Malicious	KINSON COMMON,KINSON,REDHILL PARK
006521	12/08/2005	15:28:10	Malicious	KINSON COMMON,KINSON,REDHILL PARK
006699	16/08/2005	13:36:50	Accidental	ST ANNS HOSPITAL,69 HAVEN ROAD,CANFORD CLIFFS,WESTBOURNE
006833	18/08/2005	18:46:58	Accidental	EAST RAMSDOWN HEATH,AVON CAUSEWAY,HURN,CHRISTCHURCH
006847	18/08/2005	20:57:57	Malicious	REAR OF,MILBORNE CRESCENT,ROSSMORE,REDHILL PARK
006897	19/08/2005	14:52:58	Malicious	24 BRINSONS CLOSE,BURTON,CHRISTCHURCH
006925	20/08/2005	03:09:24	Malicious	LAKE PIER,HAMWORTHY,HAMWORTHY
007083	23/08/2005	15:32:50	Accidental	OUTSIDE/2B ROUNDWAYS,INITIAL CITY LINK BOURNEMOUTH,TURBARY COMMON,WEST HOWE INDUSTRIAL ESTATE,WALLISDOWN,REDHILL PARK
007168	25/08/2005	18:16:41	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
007197	26/08/2005	17:24:31	Accidental	KINSON COMMON,KINSON,REDHILL PARK
007232	27/08/2005	15:08:05	Accidental	BOURNE BOTTOM,EVERING AVENUE,ALDERNEY,POOLE
007264	27/08/2005	17:19:59	Malicious	SAINSBURY,ALDER ROAD,BOURNE VALLEY,WESTBOURNE
007319	28/08/2005	08:14:50	Accidental	KINSON COMMON,KINSON,REDHILL PARK
007398	29/08/2005	06:33:29	Malicious	WEST MOORS PLANTATION,WEST MOORS,FERNDOWN
007592	01/09/2005	12:52:40	Malicious	UPTON HEATH,HEIGHTS ROAD,UPTON,HAMWORTHY
007598	01/09/2005	16:15:38	Malicious	KINSON COMMON,KINSON,REDHILL PARK
007668	02/09/2005	17:16:31	Malicious	KINSON COMMON,KINSON,REDHILL PARK
007670	02/09/2005	18:12:50	Malicious	CANFORD HEATH FROM CANFORD HEATH ROAD,TO DARBYS LANE NORTH,CANFORD HEATH,POOLE
007748	03/09/2005	11:52:04	Malicious	CANFORD HEATH,BELBEN ROAD,ALDERNEY,POOLE
007755	03/09/2005	14:44:20	Deliberate	CANFORD HEATH ROAD,CANFORD HEATH,POOLE
007815	03/09/2005	16:44:04	Malicious	CANFORD HEATH ROAD,CANFORD HEATH,POOLE
007828	03/09/2005	18:19:30	Malicious	KINSON COMMON,KINSON,REDHILL PARK
007833	03/09/2005	20:36:20	Accidental	HAM COMMON,HAMWORTHY,HAMWORTHY
007851	04/09/2005	10:35:21	Accidental	HAM COMMON,NAPIER ROAD,HAMWORTHY,HAMWORTHY
007924	05/09/2005	18:30:49	Malicious	CANFORD HEATH,PLANTATION ROAD,CANFORD HEATH,POOLE
008114	09/09/2005	17:17:00	Malicious	KINSON COMMON,KINSON,REDHILL PARK

008471	16/09/2005	21:02:10	Malicious	KNIGHTON HEATH GOLF COURSE,WHEELERS LANE,CANFORD HEATH,REDHILL PARK
008500	17/09/2005	15:07:46	Accidental	FOOTBALL PITCH AT END OF/,FORD LANE,FERNDOWN,FERNDOWN
008513	18/09/2005	02:50:48	Malicious	COVE COTTAGES,FORTUNESWELL,PORTLAND
008521	18/09/2005	10:26:08	Accidental	KNIGHTON HEATH GOLF CLUB,FRANCIS AVENUE,CANFORD HEATH,WALLISDOWN
008546	18/09/2005	18:12:38	Malicious	KINSON COMMON,KINSON,REDHILL PARK
008573	19/09/2005	11:37:40	Malicious	KINSON COMMON,KINSON,REDHILL PARK
008577	19/09/2005	13:41:04	Accidental	CANNON HILL PLANTATION,COLEHILL,WIMBORNE
008593	19/09/2005	17:37:27	Malicious	KINSON COMMON,KINSON,REDHILL PARK
008689	21/09/2005	08:00:00	Malicious	KINSON COMMON,KINSON,REDHILL PARK
008738	21/09/2005	17:48:07	Malicious	MEADOW,NORMANDY DRIVE,PUREWELL,CHRISTCHURCH
008775	22/09/2005	15:37:32	Malicious	HAM COMMON,HAMWORTHY,HAMWORTHY
008788	22/09/2005	17:36:21	Malicious	KINSON COMMON,KINSON,REDHILL PARK
008891	24/09/2005	17:39:04	Malicious	TURBARY COMMON,TURBARY PARK AVE,WALLISDOWN,REDHILL PARK
009017	26/09/2005	19:12:32	Malicious	KINSON COMMON,KINSON,REDHILL PARK
009022	26/09/2005	20:14:53	Malicious	BOURNE BOTTOM END OF,TURBARY CLOSE,ALDERNEY,WESTBOURNE
009026	26/09/2005	21:34:03	Malicious	ROCKLEY PARK HOLIDAY CENTRE,NAPIER ROAD,HAMWORTHY,HAMWORTHY
009051	27/09/2005	17:42:57	Malicious	KINSON COMMON,KINSON,REDHILL PARK
009086	28/09/2005	09:30:59	Malicious	KINSON COMMON,KINSON,REDHILL PARK
009092	28/09/2005	14:00:45	Malicious	KINSON COMMON,KINSON,REDHILL PARK
009336	03/10/2005	17:08:40	Malicious	KINSON COMMON,SOUTH KINSON DRIVE,KINSON,REDHILL PARK
009470	06/10/2005	12:20:55	Accidental	CANNON HILL WOODS,MIDDLEHILL ROAD,COLEHILL,WIMBORNE
009689	10/10/2005	19:05:33	Malicious	TURBARY PARK COMMON,TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
010132	20/10/2005	15:34:06	Malicious	REDHILL COMMON,REDHILL,REDHILL PARK
010294	23/10/2005	20:47:14	Accidental	EAST OVERCLIFF DRIVE,TOWN CENTRE,SPRINGBOURNE
010490	27/10/2005	15:17:09	Malicious	KINSON COMMON,KINSON,REDHILL PARK
010497	27/10/2005	19:53:44	Accidental	KINGS PARK/ FITNESS FIRST STADIUM,A F C BOURNEMOUTH,DEAN COURT,SPRINGBOURNE,SPRINGBOURNE
010600	30/10/2005	11:03:41	Accidental	BRANKSOME DEAN CHINE,CASSEL AVENUE,WESTBOURNE,WESTBOURNE
010660	31/10/2005	15:16:30	Accidental	ST BRELADES AVENUE,ALDERNEY,POOLE
010668	31/10/2005	20:32:39	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
010902	05/11/2005	18:00:14	Accidental	KEMP WELCH SCHOOL FIELD,HERBERT AVENUE,UPPER PARKSTONE,WESTBOURNE
010937	05/11/2005	21:51:33	Malicious	FERNDOWN COMMON,CHERRY GROVE,FERNDOWN,FERNDOWN
010938	05/11/2005	22:16:33	Accidental	CANFORD HEATH,KNOWLTON ROAD,CANFORD HEATH,POOLE

011262	13/11/2005	02:08:49	Malicious	HEATHERLANDS COMMUNITY CENTRE,SEVERN ROAD,FERNDOWN,FERNDOWN
011588	16/11/2005	16:41:51	Accidental	ISAACS CLOSE,TALBOT HEATH,REDHILL PARK
011632	17/11/2005	16:52:10	Malicious	VALLEY VIEW,TALBOT HEATH,REDHILL PARK
011691	18/11/2005	17:20:36	Malicious	FRANCIS AVENUE,CANFORD HEATH,WALLISDOWN
011960	25/11/2005	01:48:45	Malicious	77 TAMAR CLOSE,FERNDOWN,FERNDOWN
012007	26/11/2005	12:10:28	Malicious	VALLEY VIEW,TALBOT HEATH,REDHILL PARK
012017	26/11/2005	14:13:44	Malicious	THAMES CLOSE,FERNDOWN,FERNDOWN
012093	28/11/2005	09:11:23	Malicious	NEAR TO,FERNDOWN LEISURE CENTRE,CHERRY GROVE,FERNDOWN,FERNDOWN
012458	06/12/2005	15:00:59	Malicious	FERNDOWN UPPER SCHOOL,CHERRY GROVE,FERNDOWN,FERNDOWN
012461	06/12/2005	15:37:13	Malicious	FERNDOWN LEISURE CENTRE,CHERRY GROVE,FERNDOWN,FERNDOWN
012613	10/12/2005	13:18:16	Malicious	78 FITZPAIN ROAD,WEST PARLEY,FERNDOWN
012619	10/12/2005	17:47:13	Malicious	KING GEORGES PLAYING FIELDS,CHERRY GROVE,FERNDOWN,FERNDOWN
012821	15/12/2005	07:01:16	Malicious	TURBARY PARK,TURBARY PARK AVENUE,WEST HOWE,REDHILL PARK
012840	15/12/2005	14:54:48	Malicious	A35,UPTON BY PASS,UPTON,HAMWORTHY
012974	17/12/2005	06:57:04	Malicious	TURBARY COMMON,ACCESS OFF TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK
013031	17/12/2005	23:43:41	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
013042	18/12/2005	06:54:38	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
013122	20/12/2005	07:02:26	Malicious	MOORSIDE ROAD,WEST HOWE,REDHILL PARK
013282	24/12/2005	12:08:48	Malicious	TALBOT HEATH,LAIDLAW CLOSE,TALBOT HEATH,REDHILL PARK
013308	25/12/2005	07:37:30	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
013485	29/12/2005	21:27:21	Malicious	TURBARY COMMON,WALLISDOWN ROAD,WALLISDOWN,REDHILL PARK
013641	02/01/2006	19:59:06	Malicious	TURBARY CLOSE,ALDERNEY,WESTBOURNE
013766	06/01/2006	12:45:08	Malicious	ROSSMORE COMMUNITY COLLEGE,HERBERT AVENUE,ALDERNEY,WESTBOURNE
014600	29/01/2006	09:54:37	Malicious	END OF,BELBEN ROAD,ALDERNEY,POOLE
014612	29/01/2006	11:10:36	Accidental	ST CATHERINES HILL,ST CATHERINES HILL LANE,ST CATHERINES,CHRISTCHURCH
014628	29/01/2006	16:55:48	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
014641	30/01/2006	11:07:38	Malicious	KINSON COMMON,SOUTH KINSON DRIVE,KINSON,REDHILL PARK
014651	30/01/2006	14:22:49	Malicious	TURBARY CLOSE,ALDERNEY,POOLE
014661	30/01/2006	15:53:28	Malicious	4 ALDER PARK,J SAINSBURY PLC,ALDER ROAD,BOURNE VALLEY,WESTBOURNE
014670	30/01/2006	15:56:59	Accidental	REAR OF,28 BURLINGTON ROAD,SWANAGE,SWANAGE
014778	01/02/2006	12:14:56	Accidental	TAMAR CLOSE,FERNDOWN,FERNDOWN
014849	03/02/2006	09:06:28	Malicious	FERNDOWN LEISURE CENTRE,CHERRY GROVE,FERNDOWN,FERNDOWN
014916	04/02/2006	14:34:46	Malicious	SHELL BAY,STUDLAND,SWANAGE

014921	04/02/2006	17:35:13	Malicious	FERNDOWN COMMON,FERNDOWN,FERNDOWN
014922	04/02/2006	17:38:38	Malicious	UPTON HEATH,UPTON,HAMWORTHY
014931	04/02/2006	19:44:18	Malicious	LEESON DRIVE,FERNDOWN,FERNDOWN
014975	05/02/2006	16:46:23	Malicious	PINEWOOD CLOSE,WALKFORD,CHRISTCHURCH
015027	06/02/2006	16:29:36	Malicious	CULLIFORD CRESCENT,CANFORD HEATH,POOLE
015114	07/02/2006	19:12:54	Malicious	CULLIFORD CRESCENT,CANFORD HEATH,POOLE
015178	08/02/2006	17:39:38	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
015477	14/02/2006	15:04:55	Accidental	CANFORD HEATH,WHEELERS LANE,CANFORD HEATH,REDHILL PARK
015740	21/02/2006	07:49:07	Accidental	KINSON COMMON,KINSON,REDHILL PARK
015761	21/02/2006	17:41:51	Malicious	KINSON COMMON,ROCHESTER ROAD,WEST HOWE,REDHILL PARK
015882	25/02/2006	13:42:58	Malicious	UPTON HEATH,UPTON,HAMWORTHY
015893	25/02/2006	17:43:45	Malicious	KINSON COMMON,KINSON,REDHILL PARK
015924	26/02/2006	07:21:12	Malicious	KINSON COMMON,KINSON,REDHILL PARK
015926	26/02/2006	09:53:21	Accidental	BLOXWORTH ROAD,BOURNE VALLEY,REDHILL PARK
015933	26/02/2006	11:48:54	Malicious	KINSON COMMON,ADJACENT KINSON CEMETERY,KINSON,REDHILL PARK
015979	27/02/2006	07:09:43	Malicious	KINSON COMMON,KINSON,REDHILL PARK
016043	28/02/2006	18:09:23	Malicious	KINSON COMMON,KINSON ROAD,EAST HOWE,REDHILL PARK
016078	01/03/2006	14:15:09	Malicious	REAR OF,18 MONKTON CRESCENT,BLOXWORTH ESTATE,REDHILL PARK
016082	01/03/2006	14:17:29	Malicious	NEAR THE SEWAGE WORKS,THAMES CLOSE,FERNDOWN,FERNDOWN
016086	01/03/2006	14:36:33	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,WEST HOWE,REDHILL PARK
016148	02/03/2006	17:45:27	Malicious	NEAR THE SEWAGE WORKS,TRENT WAY,FERNDOWN,FERNDOWN
016150	02/03/2006	18:56:03	Malicious	KINSON COMMON,SOUTH KINSON DRIVE,KINSON,REDHILL PARK
016161	03/03/2006	06:55:36	Malicious	KINSON COMMON,KINSON,REDHILL PARK
016174	03/03/2006	11:57:53	Malicious	TALBOT HEATH,BLOXWORTH ROAD,BLOXWORTH ESTATE,REDHILL PARK
016230	04/03/2006	14:03:15	Accidental	HENGISTBURY HEAD,HENGISTBURY,CHRISTCHURCH
016248	04/03/2006	23:04:33	Malicious	ST ALDHELMS C OF E COMBINED SC,WINSTON AVENUE,BRANKSOME,WESTBOURNE
016272	05/03/2006	12:45:15	Malicious	KINSON COMMON,KINSON,REDHILL PARK
016280	05/03/2006	16:13:07	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
016282	05/03/2006	18:06:49	Malicious	KINSON COMMON,KINSON,REDHILL PARK
016283	05/03/2006	18:50:40	Malicious	KINSON COMMON,KINSON,REDHILL PARK
016316	06/03/2006	18:43:05	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
016500	11/03/2006	16:12:59	Malicious	PARLEY COMMON,HUMBER ROAD,FERNDOWN,FERNDOWN
016516	11/03/2006	19:04:52	Malicious	KINSON COMMON,KINSON,REDHILL PARK

016517	11/03/2006	19:07:35	Accidental	CANFORD HEATH,CANFORD HEATH,POOLE
016546	12/03/2006	14:39:10	Malicious	FERNDOWN COMMON,FERNDOWN,FERNDOWN
016566	13/03/2006	07:08:38	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
016589	13/03/2006	18:41:50	Malicious	KINSON COMMON,POOLE LANE,KINSON,REDHILL PARK
016625	14/03/2006	17:37:05	Malicious	KINSON COMMON,KINSON,REDHILL PARK
016652	15/03/2006	12:00:40	Malicious	FERNDOWN COMMON,FERNDOWN,FERNDOWN
016670	15/03/2006	14:26:19	Malicious	PARLEY COMMON,FERNDOWN,FERNDOWN
016682	15/03/2006	15:56:16	Malicious	KINSON COMMON,KINSON,REDHILL PARK
016697	15/03/2006	17:43:43	Accidental	LULWORTH ARMY RANGES,TYNEHAM,WAREHAM
016783	17/03/2006	12:18:29	Accidental	ABBOTSBURY HILL (TOP),ABBOTSBURY,WEYMOUTH
016806	17/03/2006	20:00:22	Malicious	40 TURBARY PARK AVENUE,WEST HOWE,REDHILL PARK
016832	18/03/2006	07:06:34	Malicious	KINSON COMMON,KINSON,REDHILL PARK
016953	19/03/2006	17:57:16	Malicious	BISHOP OF WINCHESTER SCHOOL,MALLARD ROAD,STROUDEN,SPRINGBOURNE
016959	19/03/2006	19:08:28	Deliberate	CULLIFORD CRESCENT,CANFORD HEATH,POOLE
017193	19/03/2006	22:59:05	Malicious	ARROWSMITH ROAD,CANFORD HEATH,POOLE
017309	21/03/2006	19:39:03	Malicious	TURLIN MOOR,EGMONT ROAD,TURLIN MOOR,HAMWORTHY
017321	22/03/2006	06:49:12	Malicious	KINSON COMMON,KINSON,REDHILL PARK
017342	22/03/2006	16:53:50	Malicious	EVERING AVENUE,ALDERNEY,POOLE
017385	23/03/2006	12:28:39	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
000015	01/04/2006	14:28:19	Malicious	CHEWTON COMMON ROAD,WALKFORD,CHRISTCHURCH
000052	02/04/2006	13:43:53	Malicious	TOLLARD CLOSE,ROSSMORE,REDHILL PARK
000139	04/04/2006	09:01:31	Malicious	EVERING AVENUE,ALDERNEY,POOLE
000149	04/04/2006	13:03:52	Malicious	PARLEY COMMON,DUGDELL CLOSE,FERNDOWN,FERNDOWN
000155	04/04/2006	15:21:10	Malicious	26,CHEDDINGTON CLOSE,CANFORD HEATH,POOLE
000165	04/04/2006	17:21:21	Malicious	REAR OF,CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN,POOLE
000249	06/04/2006	13:40:09	Malicious	HOLTON HEATH,HOLTON HEATH,HAMWORTHY
000397	09/04/2006	18:56:05	Malicious	TURBARY CLOSE,ALDERNEY,WESTBOURNE
000408	10/04/2006	10:43:14	Malicious	SOUTH KINSON DRIVE,WEST HOWE,REDHILL PARK
000415	10/04/2006	14:22:57	Deliberate	CANFORD HEATH,MANNINGS HEATH R` ABOUT to ALDERNEY R` ABOUT,A3049,CANFORD WAY,ALDERNEY,POOLE
000512	10/04/2006	16:19:11	Malicious	TURLIN ROAD,TURLIN MOOR,HAMWORTHY
000519	10/04/2006	18:42:36	Malicious	EGMONT ROAD,TURLIN MOOR,HAMWORTHY
000549	11/04/2006	11:44:52	Malicious	KINSON COMMON,KINSON,REDHILL PARK

000616	13/04/2006	11:15:07	Malicious	KINSON COMMON, POOLE LANE, KINSON, REDHILL PARK
000620	13/04/2006	15:26:38	Malicious	CANFORD HEATH, CANFORD HEATH, POOLE
000635	13/04/2006	21:02:39	Malicious	TURBARY COMMON, DOWNEY CLOSE, WALLISDOWN, REDHILL PARK
000650	14/04/2006	06:48:32	Malicious	KINSON COMMON, POOLE LANE, KINSON, REDHILL PARK
000866	17/04/2006	15:08:48	Malicious	KEMP WELCH LEISURE CENTRE, BOROUGH OF POOLE, HERBERT AVENUE, ALDERNEY, WESTBOURNE
000876	17/04/2006	15:51:24	Malicious	KNIGHTON HEATH, BEAR WOOD, REDHILL PARK
000915	18/04/2006	11:04:29	Accidental	UPTON HOUSE, POOLE ROAD, UPTON, HAMWORTHY
000933	18/04/2006	12:18:30	Malicious	SCOTT ROAD, WALLISDOWN, REDHILL PARK
001109	22/04/2006	14:01:32	Deliberate	ALDER PARK NATURE RESERVE, SAINSBURY, ALDER ROAD, BOURNE VALLEY, WESTBOURNE
001129	22/04/2006	14:38:24	Deliberate	UPTON HEATH, UPTON, HAMWORTHY
001266	23/04/2006	20:46:44	Malicious	TURBARY COMMON, TURBARY PARK AVENUE, WALLISDOWN, REDHILL PARK
001363	26/04/2006	15:48:03	Malicious	LOUVIERS ROAD, LITTLEMOOR, WEYMOUTH
001449	28/04/2006	13:38:38	Malicious	TURBARY COMMON, WALLISDOWN, REDHILL PARK
001485	28/04/2006	20:20:08	Malicious	TURBARY COMMON, WALLISDOWN, REDHILL PARK
001511	29/04/2006	14:46:47	Malicious	MOORS VALLEY COUNTRY PARK, HORTON ROAD, ASHLEY HEATH, FERNDOWN
001515	29/04/2006	16:17:13	Malicious	WEST MOORS PLANTATION, EDGEMOOR ROAD, WEST MOORS, FERNDOWN
001581	30/04/2006	21:26:34	Malicious	BOURNE BOTTOM, REAR OF LEISURE CENTRE, ALDERNEY, POOLE
001604	01/05/2006	01:29:29	Malicious	FERNDOWN UPPER SCHOOL, CHERRY GROVE, FERNDOWN, FERNDOWN
001607	01/05/2006	07:00:23	Malicious	REDHOAVE ROAD, CANFORD HEATH, POOLE
001629	01/05/2006	16:54:52	Accidental	CALLER FROM/, 10 SANDY LANE, ST CATHERINES, CHRISTCHURCH
001670	02/05/2006	13:05:58	Malicious	PARLEY COMMON, PARLEY COMMON, WEST PARLEY, FERNDOWN
001733	03/05/2006	21:03:08	Accidental	TURLIN MOOR, TURLIN MOOR, HAMWORTHY
001735	03/05/2006	22:02:25	Malicious	EVERING AVENUE, ALDERNEY, POOLE
001759	04/05/2006	12:51:27	Malicious	CANFORD HEATH, SHERBORNE CRESCENT, CANFORD HEATH, POOLE
001804	04/05/2006	16:10:52	Malicious	CANFORD HEATH, CANFORD HEATH, POOLE
001876	06/05/2006	12:52:52	Malicious	BOURNE BOTTOM, SOUTH PARK ROAD, WALLISDOWN, REDHILL PARK
001883	06/05/2006	17:07:10	Malicious	ALDER HILLS NATURE RESERVE, OFF SHARP ROAD, BOURNE VALLEY, WESTBOURNE
001891	06/05/2006	20:47:24	Malicious	WALLISDOWN ROAD, WALLISDOWN, REDHILL PARK
001896	06/05/2006	20:57:46	Malicious	EVERING AVENUE, ALDERNEY, POOLE
001918	06/05/2006	22:05:00	Malicious	TURBARY COMMON/, TURBARY CLOSE, ALDERNEY, WESTBOURNE
001938	07/05/2006	18:00:01	Malicious	DOVER ROAD, WYKE REGIS, WEYMOUTH
002040	09/05/2006	20:16:14	Malicious	LONGHAM BRIDGE, LONGHAM, FERNDOWN
002191	12/05/2006	16:54:15	Malicious	DARBYS LANE NORTH, CANFORD HEATH, POOLE

002300	14/05/2006	18:37:38	Malicious	BEACON ROAD,CORFE MULLEN,HAMWORTHY
002303	14/05/2006	20:21:39	Malicious	REAR OF COMMUNITY CENTRE,DUGDELL CLOSE,FERNDOWN,FERNDOWN
002363	16/05/2006	09:00:53	Malicious	BOURNE VALLEY,BLOXWORTH ROAD,BOURNE VALLEY,REDHILL PARK
002898	29/05/2006	18:27:57	Accidental	EGMONT ROAD,TURLIN MOOR,HAMWORTHY
002945	30/05/2006	16:27:22	Malicious	TURBARY CLOSE,ROSSMORE,WESTBOURNE
003016	01/06/2006	10:46:55	Malicious	BARNS ROAD,FERNDOWN,FERNDOWN
003049	01/06/2006	22:00:29	Malicious	TOLLARD CLOSE,ROSSMORE,REDHILL PARK
003072	02/06/2006	14:49:22	Malicious	CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN,POOLE
003108	02/06/2006	17:50:02	Malicious	ROUNDAABOUT CANFORD HEATH ROAD,JUNCTION ADASTRAL ROAD,CANFORD HEATH,POOLE
003194	04/06/2006	11:29:08	Accidental	WAREHAM FOREST TOURIST PARK,COLD HARBOUR,WAREHAM
003281	05/06/2006	14:40:47	Malicious	LONGMEADOW LANE,CREEKMOOR,HAMWORTHY
003312	06/06/2006	10:50:49	Accidental	29 WOODLANDS DRIVE,SANDFORD,WAREHAM
003376	07/06/2006	19:20:10	Malicious	CANFORD HEATH/,STEEPLE CLOSE,CANFORD HEATH,POOLE
003409	08/06/2006	20:57:49	Malicious	SCARF ROAD,CANFORD HEATH,POOLE
003416	08/06/2006	21:19:07	Malicious	OLD WAREHAM ROAD,CANFORD HEATH,POOLE
003419	08/06/2006	21:22:42	Malicious	SCARF ROAD,CANFORD HEATH,POOLE
003473	09/06/2006	17:48:43	Malicious	ASHDOWN SCHOOL,ADASTRAL ROAD,CANFORD HEATH,POOLE
003497	09/06/2006	18:42:04	Malicious	KELLAWAY ROAD,CANFORD HEATH,POOLE
003513	09/06/2006	19:05:56	Malicious	REAR OF,WITNEY ROAD,CANFORD HEATH,POOLE
003591	11/06/2006	00:02:20	Malicious	CHEWTON COMMON,PINEWOOD CLOSE,WALKFORD,CHRISTCHURCH
003613	11/06/2006	14:01:48	Malicious	CHEWTON COMMON,CHEWTON COMMON ROAD,WALKFORD,CHRISTCHURCH
003810	16/06/2006	20:38:32	Malicious	AVON VALLEY COUNTRY PARK,BIRCH ROAD,ST IVES,FERNDOWN
003827	17/06/2006	08:35:20	Malicious	AVON HEATH COUNTRY PARK,BIRCH ROAD,ST IVES,FERNDOWN
003843	17/06/2006	16:32:14	Accidental	PORTESHAM WAY,CANFORD HEATH,POOLE
003983	19/06/2006	22:04:31	Accidental	MATCHAMS VIEWPOINT CARPARK,MATCHAMS LANE,MATCHAMS,FERNDOWN
003991	20/06/2006	07:47:54	Accidental	WATTONS FORD,WATTONS LANE,MATCHAMS,FERNDOWN
004137	23/06/2006	19:11:23	Malicious	ASHDOWN SCHOOL,ADASTRAL ROAD,CANFORD HEATH,POOLE
004139	23/06/2006	19:27:47	Malicious	TURBARY PARK COMMON,TURBARY PARK AVENUE,WEST HOWE,REDHILL PARK
004187	24/06/2006	14:39:58	Malicious	TRENT WAY,FERNDOWN,FERNDOWN
004297	27/06/2006	22:20:41	Malicious	FERNDOWN COMMON,FERNDOWN,FERNDOWN
004369	29/06/2006	17:56:20	Malicious	BOURNE BOTTOM,BOURNE VALLEY,WESTBOURNE
004423	30/06/2006	19:24:17	Accidental	DARBYS LANE NORTH,CANFORD HEATH,POOLE
004451	01/07/2006	09:05:20	Malicious	TURBARY COMMON,TURBARY PARK AVENUE,WALLISDOWN,REDHILL PARK

004477	01/07/2006	23:55:01	Malicious	BOURNE BOTTOM/,ST BRELADES AVENUE,ALDERNEY,POOLE
004859	11/07/2006	21:23:59	Malicious	STEAMER POINT NATURE RESERVE,FRIARS CLIFF,CHRISTCHURCH
005077	15/07/2006	15:38:30	Malicious	PARLEY COMMON,PARLEY COMMON,WEST PARLEY,FERNDOWN
005083	15/07/2006	15:48:59	Accidental	HUMBER ROAD,FERNDOWN,FERNDOWN
005095	15/07/2006	19:24:18	Accidental	PARLEY COMMON,PARLEY COMMON,WEST PARLEY,FERNDOWN
005096	15/07/2006	20:12:00	Accidental	HEATHERLANDS CENTRE,BARNS ROAD,FERNDOWN,FERNDOWN
005197	16/07/2006	13:17:37	Accidental	STUDLAND FERRY,FERRY ROAD,STUDLAND,SWANAGE
005207	16/07/2006	16:30:33	Accidental	NUTFORD FARMHOUSE,PIMPERNE,BLANDFORD
005268	16/07/2006	23:36:15	Malicious	PARLEY COMMON,LONE PINE DRIVE,WEST PARLEY,FERNDOWN
005292	17/07/2006	16:43:35	Accidental	KINGS PARK,REAR OF,53 LITLEDOWN AVENUE,LITLEDOWN,SPRINGBOURNE
005344	17/07/2006	22:15:50	Malicious	HEATH LAND OFF/,25 DIANA WAY,CORFE MULLEN,HAMWORTHY
005385	18/07/2006	14:11:03	Accidental	SHAGGS COTTAGE,SHAGGS,EAST LULWORTH,WAREHAM
005396	18/07/2006	16:30:45	Malicious	SHAGGS COTTAGE,SHAGGS,EAST LULWORTH,WAREHAM
005552	20/07/2006	19:12:08	Accidental	REDHILL COMMON,REDHILL DRIVE,REDHILL,REDHILL PARK
005578	21/07/2006	10:42:53	Unknown	GATEMORE ROAD,WINFRITH NEWBURGH,WAREHAM
005625	21/07/2006	13:30:31	Accidental	RHODODENDRON MILE,PUDDLETOWN,DORCHESTER
005707	21/07/2006	21:01:06	Malicious	KINSON COMMON,KINSON,REDHILL PARK
005744	22/07/2006	11:03:25	Malicious	KINSON COMMON,KINSON,REDHILL PARK
005842	23/07/2006	14:23:39	Accidental	HAM COMMON,HAMWORTHY,HAMWORTHY
006136	27/07/2006	05:50:48	Accidental	UPTON HEATH,UPTON,HAMWORTHY
006227	28/07/2006	07:15:58	Accidental	SHAGGS COTTAGE,EAST LULWORTH,WAREHAM
006258	28/07/2006	16:14:09	Malicious	BOURNE VALLEY,MONKTON CRESCENT,BLOXWORTH ESTATE,REDHILL PARK
006406	30/07/2006	23:52:50	Accidental	BOURNE VALLEY RESERVE,81 ST BRELADES AVENUE,ALDERNEY,POOLE
006462	01/08/2006	15:07:00	Accidental	RINGWOOD ROAD,ALDERNEY,POOLE
006515	02/08/2006	15:43:23	Malicious	EGMONT ROAD,TURLIN MOOR,HAMWORTHY
006530	02/08/2006	19:27:32	Accidental	TURLIN MOOR/,TURLIN ROAD,TURLIN MOOR,HAMWORTHY
006536	02/08/2006	19:42:40	Malicious	PARLEY COMMON/,BARRACK ROAD,FERNDOWN,FERNDOWN
006538	02/08/2006	20:02:37	Malicious	TAMAR CLOSE,FERNDOWN,FERNDOWN
006551	03/08/2006	06:41:27	Malicious	PARLEY COMMON,TAMAR CLOSE,FERNDOWN,FERNDOWN
006553	03/08/2006	07:04:52	Malicious	KINSON COMMON/,SOUTH KINSON DRIVE,KINSON,REDHILL PARK
006578	03/08/2006	14:36:36	Accidental	94 EVERING AVENUE,ALDERNEY,POOLE
006579	03/08/2006	14:38:47	Accidental	VERITY PARK,VERITY CRESCENT,CANFORD HEATH,POOLE
006617	04/08/2006	11:36:58	Accidental	FERNHEATH,WEST HOWE,REDHILL PARK

006770	06/08/2006	20:09:22	Accidental	BOURNE BOTTOM,COSTCUTTERS (PRIMEX),2 BELBEN ROAD,ALDERNEY,POOLE
006785	06/08/2006	21:52:28	Malicious	TURLIN MOOR,FORELAND ROAD,TURLIN MOOR,HAMWORTHY
006863	08/08/2006	12:34:32	Malicious	76 MOORSIDE ROAD,WEST HOWE,REDHILL PARK
006873	08/08/2006	14:07:43	Malicious	ROSSMORE COMMUNITY COLLEGE,HERBERT AVENUE,ALDERNEY,WESTBOURNE
006963	09/08/2006	14:07:01	Malicious	FERRY ROAD,STUDLAND,SWANAGE
007070	10/08/2006	22:33:01	Malicious	PARLEY COMMON,BARNES RD/PARLEY COMMON,WEST PARLEY,FERNDOWN
007091	11/08/2006	01:26:16	Malicious	PETWYN CLOSE,FERNDOWN,FERNDOWN
007135	11/08/2006	19:53:20	Accidental	REAR OF HEATHERLANDS CENTRE,BARNES ROAD,FERNDOWN,FERNDOWN
007168	12/08/2006	11:03:11	Deliberate	HEATHERLAND COMMUNITY CENTRE,SEVERN ROAD,FERNDOWN,FERNDOWN
007204	12/08/2006	16:18:39	Malicious	PARLEY COMMON,PARLEY COMMON,WEST PARLEY,FERNDOWN
007249	12/08/2006	19:39:52	Malicious	PALMERSFORD TREATMENT WORKS,TRENT WAY,FERNDOWN,FERNDOWN
007276	12/08/2006	23:57:30	Malicious	PARLEY COMMON,PETWYN CLOSE,FERNDOWN,FERNDOWN
007282	13/08/2006	09:15:55	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
007285	13/08/2006	09:51:54	Malicious	KINSON COMMON,OPP 101/POOLE LANE,KINSON,REDHILL PARK
007290	13/08/2006	10:22:32	Malicious	TURBARY COMMON,CANFORD AVENUE,WALLISDOWN,REDHILL PARK
007315	14/08/2006	12:50:29	Deliberate	PARLEY COMMON,BARNES ROAD,FERNDOWN,FERNDOWN
007451	16/08/2006	11:05:51	Malicious	TURBARY PARK AVENUE,WEST HOWE,REDHILL PARK
007454	16/08/2006	13:21:02	Accidental	LAWSONS CLUMP CAR PARK/,MORDEN ROAD,SANDFORD,WAREHAM
007659	20/08/2006	12:31:51	Accidental	BURTON COMMON,WATERY LANE,SOMERFORD,CHRISTCHURCH
007746	21/08/2006	14:33:04	Accidental	LITTLE COURT HOTEL,5 WESTLEAZE,LOWER BURTON
007971	26/08/2006	20:39:45	Accidental	TADNOLL,CHALDON HERRING,WEYMOUTH
007998	27/08/2006	12:06:28	Accidental	UPTON HEATH,MAXWELL ROAD,CORFE MULLEN,HAMWORTHY
008039	27/08/2006	18:49:33	Malicious	REAR OF/,28 GROSVENOR CLOSE,ASHLEY HEATH,FERNDOWN
008102	28/08/2006	16:22:41	Malicious	TURBARY ROAD,ROSSMORE,REDHILL PARK
008161	29/08/2006	15:52:06	Unknown	RINGWOOD FOREST,ST STEPHENS LANE,VERWOOD,VERWOOD
008414	02/09/2006	10:50:55	Accidental	CANNON HILL ROAD,COLEHILL,WIMBORNE
008471	03/09/2006	10:20:07	Malicious	59 BENBOW CRESCENT,WALLISDOWN,REDHILL PARK
008479	03/09/2006	12:10:17	Malicious	LORD CLOSE,CANFORD HEATH,POOLE
008531	03/09/2006	19:54:58	Accidental	DEWLANDS COMMON,VERWOOD,VERWOOD
008593	04/09/2006	15:39:50	Malicious	21 BISHOP CLOSE,TALBOT HEATH,REDHILL PARK
008899	10/09/2006	07:00:39	Accidental	PARLEY COMMON,FERNDOWN,FERNDOWN
009393	20/09/2006	19:23:49	Malicious	PARLEY COMMON,REAR OF,BARRACK ROAD,WEST PARLEY,FERNDOWN
010483	14/10/2006	15:12:12	Malicious	KELLAWAY ROAD,CANFORD HEATH,POOLE

010839	23/10/2006	17:33:24	Malicious	CANFORD HEATH,KELLOWAY ROAD,CANFORD HEATH,POOLE
011594	07/11/2006	13:27:40	Malicious	ST BRELADES AVENUE,ALDERNEY,POOLE
012495	30/11/2006	19:28:53	Malicious	FERNDOWN FOREST OPPOSITE,COLONIAL GARAGE,WIMBORNE ROAD EAST,FERNDOWN,FERNDOWN
012712	06/12/2006	17:55:31	Malicious	DURDELLS AVENUE,WEST HOWE,REDHILL PARK
013239	19/12/2006	16:26:11	Accidental	ROCKLEY PARK HOLIDAY CENTRE,NAPIER ROAD,HAMWORTHY,HAMWORTHY
013286	20/12/2006	22:32:38	Malicious	ROCKLEY PARK HOLIDAY CENTRE,NAPIER ROAD,HAMWORTHY,HAMWORTHY
014233	15/01/2007	13:49:48	Malicious	CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN,POOLE
014941	31/01/2007	23:30:12	Malicious	ST CATHERINES HILL,DUDMOOR LANE,ST CATHERINES,CHRISTCHURCH
016026	03/03/2007	11:19:28	Accidental	NORDEN FARM,CORFE CASTLE,SWANAGE
016510	13/03/2007	11:40:39	Accidental	AILWOOD FARM,AILWOOD,WOOLGARSTON,SWANAGE
016629	16/03/2007	12:48:00	Accidental	VIEWPOINT,CORFE ROAD,STUDLAND,SWANAGE
016824	20/03/2007	16:44:54	Deliberate	BROADSTONE RECREATION GROUND/,THE BROADWAY,BROADSTONE,POOLE
017019	24/03/2007	08:02:48	Accidental	HAM COMMON,HAMWORTHY,HAMWORTHY
017039	25/03/2007	00:58:37	Malicious	TURBARY COMMON,DOWNEY CLOSE,WALLISDOWN,REDHILL PARK
017057	25/03/2007	15:54:57	Malicious	POOR COMMON,84 FITZPAIN ROAD,FERNDOWN,FERNDOWN
017333	31/03/2007	15:29:18	Accidental	THE COTTAGE/WATTONS FORD,WATTONS LANE,MATCHAMS,FERNDOWN
000034	01/04/2007	19:57:44	Malicious	BRANKSOME WOODS,LEICESTER ROAD,BRANKSOME PARK,WESTBOURNE
000221	05/04/2007	11:19:28	Accidental	ST STEPHENS LANE,VERWOOD,VERWOOD
000273	06/04/2007	16:01:39	Accidental	OLD SEWAGE WORKS/LYTCHETT HEATH,SANDY LANE,UPTON,HAMWORTHY
000365	08/04/2007	14:53:37	Deliberate	20 LOWER CRANESMOOR,BOVINGTON CAMP,WAREHAM
000495	10/04/2007	18:45:26	Malicious	ADJ/,17 WILLOW TREE RISE,WEST HOWE,REDHILL PARK
000551	12/04/2007	10:25:00	Accidental	HEATHLANDS AVENUE,WEST PARLEY,FERNDOWN
000615	13/04/2007	18:14:57	Accidental	HAM COMMON,HAMWORTHY,HAMWORTHY
000624	13/04/2007	18:28:31	Malicious	RIGGS GARDENS,WALLISDOWN,REDHILL PARK
000737	15/04/2007	08:38:03	Accidental	WAREHAM FOREST,COLD HARBOUR,WAREHAM
000871	16/04/2007	20:55:23	Malicious	RO/4 MONKTON CRESCENT,BLOXWORTH ESTATE,REDHILL PARK
000943	18/04/2007	17:59:48	Accidental	TURBARY COMMON/,CANFORD AVENUE,WALLISDOWN,REDHILL PARK
001021	20/04/2007	13:09:59	Malicious	BRACKEN ROAD,FERNDOWN,FERNDOWN
001136	22/04/2007	18:44:05	Accidental	CANFORD HEATH,WHEELERS LANE,CANFORD HEATH,REDHILL PARK
001153	23/04/2007	10:20:09	Accidental	FRANCIS AVENUE,CANFORD HEATH,WALLISDOWN
001167	23/04/2007	17:46:03	Accidental	TAMAR CLOSE,FERNDOWN,FERNDOWN
001503	01/05/2007	12:10:08	Malicious	WAREHAM FOREST,COLD HARBOUR,WAREHAM
001534	01/05/2007	16:59:39	Malicious	EVERING AVENUE,ALDERNEY,POOLE

001547	01/05/2007	18:48:37	Accidental	HIGHER BLANDFORD ROAD,CORFE MULLEN,WIMBORNE
001562	02/05/2007	04:13:28	Malicious	ST CATHERINES HILL,MARSH LANE,FAIRMILE,CHRISTCHURCH
001665	03/05/2007	17:53:15	Accidental	ASHDOWN SCHOOL,ADASTRAL ROAD,CANFORD HEATH,POOLE
001673	03/05/2007	19:21:03	Malicious	DUDMOOR LANE,ST CATHERINES,CHRISTCHURCH
001682	03/05/2007	20:14:08	Accidental	MARSH LANE,FAIRMILE,CHRISTCHURCH
001691	03/05/2007	23:21:58	Malicious	WHITECROSS CLOSE,CANFORD HEATH,POOLE
001707	04/05/2007	11:30:07	Accidental	CLOUDS HILL COTTAGE,CLOUDS HILL,CROSSWAYS,DORCHESTER
001909	07/05/2007	06:41:22	Accidental	KINSON COMMON,SOUTH KINSON DRIVE,KINSON,REDHILL PARK
001928	07/05/2007	15:30:54	Malicious	TURBARY COMMON,TOZER CLOSE,WALLISDOWN,REDHILL PARK
002377	18/05/2007	17:26:16	Malicious	54 EGMONT ROAD,TURLIN MOOR,HAMWORTHY
002391	19/05/2007	05:39:01	Malicious	LODMOOR COUNTRY PARK,LODMOOR,WEYMOUTH
002431	20/05/2007	02:44:59	Malicious	CANFORD HEATH ROAD,CANFORD HEATH,POOLE
002634	24/05/2007	05:07:17	Malicious	TOWER PARK ROUNDABOUT,DORSET WAY,A3049,NEWTOWN,POOLE
002640	24/05/2007	09:21:20	Malicious	FRANCIS AVENUE,CANFORD HEATH,WALLISDOWN
002760	26/05/2007	17:45:51	Malicious	MANNINGS HEATH R`ABOUT to TOWER PARK R`ABOUT,DORSET WAY,A3049,CANFORD HEATH,POOLE
003102	02/06/2007	17:26:02	Malicious	TURLIN ROAD,TURLIN MOOR,HAMWORTHY
003216	05/06/2007	11:58:57	Accidental	LULWORTH RANGES,B3070,TYNEHAM,WAREHAM
003258	06/06/2007	11:03:31	Accidental	FIVE TIPS FIRING RANGE,EAST STOKE,WAREHAM
003293	07/06/2007	10:56:59	Accidental	SOPLEY COMMON,HURN,CHRISTCHURCH
003734	16/06/2007	14:24:38	Accidental	CULLIFORD CRESCENT,CANFORD HEATH,POOLE
003738	16/06/2007	19:01:51	Malicious	REDHILL COMMON,REDHILL,REDHILL PARK
005241	26/07/2007	21:26:30	Malicious	OPPOSITE,67 CANFORD AVENUE,WALLISDOWN,REDHILL PARK
005615	03/08/2007	18:41:36	Malicious	77 SEVERN ROAD,FERNDOWN,FERNDOWN
005674	05/08/2007	02:52:39	Malicious	117 PILSDON DRIVE,CANFORD HEATH,POOLE
006666	29/08/2007	19:00:29	Malicious	MONKTON CRESCENT,BLOXWORTH ESTATE,REDHILL PARK
006697	29/08/2007	19:24:03	Malicious	TURBARY CLOSE,ALDERNEY,WESTBOURNE
006955	03/09/2007	15:59:58	Malicious	EPIPHANY SCHOOL,SHILLINGSTONE DRIVE,MUSCLIFF,REDHILL PARK
007004	04/09/2007	14:55:21	Accidental	LODGE,WAREHAM FOREST TOURIST PARK,COLD HARBOUR,WAREHAM
007187	07/09/2007	18:38:27	Malicious	FORD LANE,FERNDOWN,FERNDOWN
007272	09/09/2007	06:58:31	Malicious	REDHILL COMMON,REDHILL AVENUE,REDHILL,REDHILL PARK
007273	09/09/2007	08:25:34	Accidental	EBBLAKE INDUSTRIAL ESTATE,BLACKMOOR ROAD,VERWOOD,VERWOOD
007626	16/09/2007	12:43:15	Deliberate	TALBOT HEATH,TALBOT HEATH,TALBOT HEATH,REDHILL PARK
007784	19/09/2007	09:21:26	Accidental	VALLEY VIEW,TALBOT HEATH,REDHILL PARK

008089	24/09/2007	19:36:36	Malicious	OUTSIDE/,63 TAMAR CLOSE,FERNDOWN,FERNDOWN
008336	30/09/2007	19:18:43	Accidental	FURZELANDS ROAD,THREE LEGGED CROSS,VERWOOD
008592	07/10/2007	14:23:49	Accidental	FERRY ROAD,STUDLAND,SWANAGE
009259	22/10/2007	13:12:15	Malicious	ALDER HILLS,BOURNE VALLEY,REDHILL PARK
009263	22/10/2007	16:44:50	Malicious	47 BENBOW CRESCENT,WALLISDOWN,REDHILL PARK
009797	03/11/2007	21:34:38	Accidental	REAR OF/47 BENBOW CRESCENT,WALLISDOWN,REDHILL PARK
009870	05/11/2007	18:48:12	Malicious	BENBOW CRESCENT,WALLISDOWN,REDHILL PARK
010048	09/11/2007	16:55:57	Malicious	BOURNE VALLEY NATURE RESERVE,ALDER ROAD,BLOXWORTH ESTATE,REDHILL PARK
010135	11/11/2007	16:30:32	Malicious	TURBARY COMMON,WALLISDOWN,REDHILL PARK
010271	14/11/2007	17:00:20	Accidental	WHITE SHEET PLANTATION,HOLT,WIMBORNE
012207	01/01/2008	12:32:13	Malicious	CANFORD WAY,A3049,ALDERNEY,POOLE
012926	20/01/2008	14:22:23	Malicious	BEHIND MILLHAMS TIP,MILLHAMS ROAD,KINSON
013317	31/01/2008	19:53:40	Malicious	7 KEYES CLOSE,WALLISDOWN
013582	07/02/2008	15:31:15	Accidental	BELBEN ROAD,ALDERNEY
013868	13/02/2008	12:59:49	Malicious	HAYMOOR MIDDLE SCHOOL,ASHDOWN CLOSE,CANFORD HEATH
013878	13/02/2008	21:06:55	Malicious	FRANCIS AVENUE,CANFORD HEATH
014038	16/02/2008	17:50:46	Malicious	HEATHERLANDS CENTRE,BARNES ROAD,FERNDOWN
014093	17/02/2008	17:50:01	Accidental	FURZEBROOK ROAD,EAST CREECH
014317	21/02/2008	19:17:23	Malicious	EGMONT ROAD,TURLIN MOOR
014546	26/02/2008	21:42:16	Malicious	30 MONKTON CRESCENT,BLOXWORTH ESTATE
015159	12/03/2008	16:48:48	Malicious	CORFE MULLEN HEATH,SPRINGDALE ROAD,CORFE MULLEN
015327	17/03/2008	14:30:29	Malicious	ASHDOWN SCHOOL,ADASTRAL ROAD,CANFORD HEATH
015571	24/03/2008	12:34:14	Accidental	SLOP BOG,WEST MOORS ROAD,FERNDOWN,FERNDOWN
015581	24/03/2008	13:35:40	Malicious	32 SANDYHURST CLOSE,CANFORD HEATH
015613	25/03/2008	11:19:54	Malicious	CANFORD HEATH,CULLIFORD CRESCENT,CANFORD HEATH
015876	30/03/2008	23:10:45	Accidental	BOURNE VALLEY COMMON,MILBORNE CRESCENT,ROSSMORE
000064	02/04/2008	19:10:41	Malicious	RUSHBCOMBE BOTTOM/,CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN
000181	05/04/2008	13:59:43	Accidental	HAM COMMON,HAMWORTHY
000233	06/04/2008	19:02:30	Accidental	TURBARY COMMON,WALLISDOWN
000243	06/04/2008	20:42:27	Malicious	HEATHERLANDS COMMUNITY CENTRE,SEVERN ROAD,FERNDOWN
000300	07/04/2008	17:22:53	Malicious	ALDERNEY COMMON,TURBARY ROAD,ALDERNEY
000351	08/04/2008	20:05:02	Malicious	DURDL E DOOR HOLIDAY PARK,WEST LULWORTH
000380	09/04/2008	19:39:41	Malicious	HEATHERLANDS CENTRE,BARNES ROAD,FERNDOWN

000419	10/04/2008	16:50:08	Accidental	BLOXWORTH ROAD/SCOTT CLOSE,BOURNE VALLEY
000423	10/04/2008	19:02:53	Malicious	TRENT WAY,FERNDOWN
000455	11/04/2008	17:04:21	Malicious	BOURNE VALLEY NATURE RESERVE,EVERING AVENUE,ALDERNEY
000647	15/04/2008	14:33:07	Malicious	CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN
000654	15/04/2008	15:30:33	Malicious	ALLENS LANE,UPTON
000683	16/04/2008	16:55:56	Malicious	KEYES CLOSE,WALLISDOWN
001641	10/05/2008	11:05:35	Malicious	MANNINGS HEATH ROAD,MANNINGS HEATH,POOLE
001902	14/05/2008	21:01:54	Malicious	CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN
002041	18/05/2008	11:22:35	Malicious	CANNON HILL,COLEHILL,WIMBORNE
002120	20/05/2008	13:49:32	Accidental	STUDLAND ROAD,CORFE CASTLE
002227	21/05/2008	18:19:09	Malicious	KEYES CLOSE,WALLISDOWN
002318	24/05/2008	00:19:31	Malicious	CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN
002352	24/05/2008	06:53:19	Accidental	TREE HAMLETS,UPTON
002367	24/05/2008	16:07:23	Unknown	ROCKLEY PARK HOLIDAY CENTRE,NAPIER ROAD,HAMWORTHY
002389	24/05/2008	17:48:17	Accidental	CANNON HILL,COLEHILL
002449	25/05/2008	18:19:17	Accidental	ISOLATION COTTAGE,ARNE
003146	08/06/2008	21:56:58	Accidental	CORFE HILLS SCHOOL,HIGHER BLANDFORD ROAD,CORFE MULLEN
003181	09/06/2008	13:01:45	Malicious	OAKDENE CARAVAN SITE,ST LEONARDS
003666	18/06/2008	17:26:31	Malicious	CANFORD HEATH,FRANCIS AVENUE,CANFORD HEATH
004080	28/06/2008	16:30:35	Malicious	DUNYEATS HILL,GRAVEL HILL,CANFORD HEATH
004141	29/06/2008	09:59:55	Malicious	LAKE DRIVE,HAMWORTHY
004323	03/07/2008	11:55:12	Malicious	HAM COMMON,HAMWORTHY
004343	03/07/2008	18:11:32	Accidental	ASHDOWN LEISURE CENTRE,BOROUGH OF POOLE,ADASTRAL ROAD,CANFORD HEATH
004546	08/07/2008	16:42:08	Malicious	BOURNE VALLEY,REDHILL PARK
004706	12/07/2008	22:14:43	Malicious	CANFORD HEATH,BELBEN ROAD,ALDERNEY
004872	16/07/2008	13:39:33	Malicious	KNIGHTON HEATH,OFF/FRANCIS AVENUE,BOURNEMOUTH
004935	18/07/2008	17:48:24	Malicious	BEAR WOOD WOODLAND,WHEELERS LANE,BEAR WOOD
005347	26/07/2008	23:28:55	Malicious	BOURNE BOTTOM,BENBOW CRESCENT,WALLISDOWN
005448	28/07/2008	17:11:02	Malicious	LOWER CRANESMOOR,BOVINGTON CAMP
005876	08/08/2008	14:03:00	Accidental	ALDER HILLS NATURE RESERVE,ALDER ROAD,ALDER PARK,BOURNE VALLEY
006955	03/09/2008	18:38:54	Malicious	REAR OF ALDERNEY SCHOOL BOTTOM/,EVERING AVENUE,ALDERNEY
007585	17/09/2008	12:10:42	Malicious	MARSHWOOD AVENUE,CANFORD HEATH
007694	19/09/2008	17:08:03	Accidental	BOURNE VALLEY,EVERING AVENUE,ALDERNEY

007882 24/09/2008 08:51:00 Accidental TURBARY ROAD,ALDERNEY

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