Ecology and Conservation of High Altitude Amphibians

Christabel Geland

A thesis submitted in fulfillment of the requirements for the degree of *Magister Scientiae* in the faculty of Natural Sciences, University of the Western Cape.

August 2002

Supervisor: Prof. Alan Channing

Keywords

Anuran, high altitude, vocalisation, tadpoles, temperature, rainfall, conservation, monitoring, riparian, terrestrial

Abstract

Ecology and Conservation of High Altitude Amphibians

C. Geland

MSc thesis, Department of Zoology, University of the Western Cape.

This study looked at the breeding ecology of the anurans, found in the Landdroskop mountain range in Grabouw, and some recommendations as to their conservation are made. There is very little known about the frogs in South Africa and this study aims to elucidate some of the factors that influence the vocalisation of these frogs and the periods that these frogs breed.

In the southwestern Cape frogs breed in the winter months when there is a large supply of available water and the temperatures are low. They start calling at the start of the heavy rains usually in April / May and continue into October / November. We know that the vocalisation in frogs plays a crucial role in their mating success and that various reproductive strategies are employed to ensure survival of the larvae. The Landdroskop mountain range is known for having a high diversity of anurans. There are twelve known species that occur on these mountains and they range from being riparian, moss, and marsh to truly terrestrial frogs.

Amphibian declines have been reported from all over the world and various initiatives are being undertaken to establish long-term data sets in order to set up suitable monitoring programs. This study serves as a baseline study to set up a monitoring program in the Landdroskop mountain range in order to preserve the diversity found here.

This study took place over a five-month period (June to October). Seven sampling stations were set up along the hiking trail in the study area, to include all available habitats of the frogs. Weekly visits were made to the field and a total of 52 man-hours were spent in the field studying the frogs. Presence / absence records were made with regards to vocalisation, individual frogs and tadpoles. I also looked to see if there was any difference in the calling activities of congenerics at different temperatures and precipitation levels.

I found eight out of the twelve species of frogs in the study area during the study period. These species were *Afrana fuscigula*, *Arthroleptella villiersi*, *A. landdrosia*, *Breviceps montanus*, *B. acutirostris*, *Strongylopus grayii*, *S. bonaespei* and *Heleophryne purcelli*. These were located by one of the above-mentioned methods. Tadpoles of the riparian species, *Afrana fuscigula* and *Strongylopus bonaespei* were found in the permanent water bodies at different stages of development throughout the study period. Chi-square tests for two independent samples showed no significance in calling for congenerics at different temperatures or precipitation levels.

From the field observations it is clear that there is differential use of habitat between congenerics, which is especially clear in the terrestrial groups, *Arthroleptella* and *Breviceps*. These species were the species that were most frequently encountered in the field and thus make good candidates as indicator species for the aquatic and terrestrial habitats and for a monitoring program.

August 2002

Declaration

I declare that *Ecology and Conservation of High Altitude Amphibians* is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Christabel Geland August 2002

Signed:

Acknowledgements

I would like to thank my supervisor, Prof. Alan Channing, for his guidance. Special thanks to Gordon Harkins for being there for me, pushing me when I needed it and always making time to discuss various aspects of the work as well as trekking with me into the field so often. To my family a special thanks for their understanding their faith and being there when I needed them most. I would also like to thank the National Research Foundation and the Royal Society of London, for financial support throughout my studies. To Cape Nature Conservation for allowing me to work in Hottentots Holland Nature Reserve, thank you.

CONTENT PAGE **PAGE NUMBER**

List of Figures

List of Tables

1 INTRODUCTION

1.1 Background

Anurans occur on all continents with the exception of Antarctica. As frogs are distributed across the world they are exposed to a wide range of climates and habitats. They are found in all terrestrial plant biomes and inhabit the full range of altitudes, for example they have been reported from coastal regions – *Bufo marinus* – to altitudes as high as 5 000 meters in the Himalayan and Andean mountains (Duellman, 1992). Globally frogs inhabit extremely diverse environments ranging from deserts to rainforests to the coastal regions and within these environments the range of habitats utilised varies from streams and rivers, leaf litter and trees to underground burrows to name but a few. The variety of climates and environments has led to many different morphological and reproductive adaptations.

Worldwide there are 47 anuran families of which 15 are represented in sub-Saharan Africa. Of these, nine are endemic to sub-Saharan Africa (Duellman, 1993). Morphological, physiological and behavioural adaptations of frogs as well as the evolution of different life cycles allow them to exist in the very extreme conditions that some of these environments present. The variety of life histories observed in anurans is an interesting phenomenon, which has resulted in much research.

Duellman (1992) stated that "frogs are never-ending sources of fascination" and "they adhere to few conventions". This is reflected in the ability of frogs, since they have emerged from a predominantly aquatic to a terrestrial environment, to exploit all potential habitats.

1.2 Literature Review

To truly understand high altitude anurans Navas (1997) highlighted the need to study the physical nature of these regions.

1.2.1 *Montane Habitats and Climates*

Mountain regions occupy approximately one fifth of the earth's surface distributed across all continents and are global centers of biodiversity, with some of the most fragile ecosystems on earth (Price, 1997). These regions are distinguished by high thermal variability, frequent low temperature peaks, high evaporation rates due to low relative humidity, reduced atmospheric pressure and intense solar radiation (Bradford, 1984; Navas, 1997). Decreasing temperatures and oxygen levels and a concomitant increase in the amount of moisture, as a result of mists, are common patterns observed with increasing altitude. The physical nature of this environment presents a harsh terrain for human inhabitants, but can often serve as refugia for many types of animals and plants. Human habitation is mainly confined to the lower slopes although higher altitudes are often utilised for food production either through the cultivation of plants as in the Sierra Nevada in southern Spain or as grazing land for cattle as in the Moroccan High Atlas (Douglas, 1997; Parish and Funnell, 1999). Climatically, conditions in montane habitats may vary significantly with latitude and altitude both important factors that will influence the amount of available water, and type and composition of animal and plant communities (Navas, 1996).

High elevation regions may also provide a variety of habitats to anurans, including still or running water, rocks, grasslands and bare soil. High elevation anurans fit a variety of ecological niches from fully aquatic to fully terrestrial, nocturnal to diurnal, sluggish to active and opportunistic to selective foragers (Navas, 1997). The isolated nature of mountain peaks can also serve to a great extent, as centers of speciation and endemism, as there is often very little contact with species at the lower slopes of the mountain and between species on different peaks.

As body temperature is coupled to substrate temperature the choice of a microhabitat is usually based on the activity temperature of the anuran. The microhabitat reduces the exposure of an anuran to cold temperatures of the high altitude environment and is associated with the time of day that the anuran is active. Some ranid frogs are largely restricted to substrates with high water potential. The nocturnal terrestrial frogs face the coldest temperatures whilst the diurnal terrestrial frogs face the most variable temperatures. Fully aquatic frogs face the least variable temperatures at any given time. Navas (1996) claims that it is the more diverse lowland genera that have exploited the high elevation regions.

1.2.2 *Physiology and Behaviour*

Physiologically, montane frogs are adept at surviving in their habitat, even though Tracy *et. al.* (1992) state that anurans in comparison to reptiles have little control over temperature changes. The harshest factors that are faced by frogs in a high elevation area are the low temperatures, high incidence of ultra violet radiation, acid deposition at high altitudes and in some regions of the world semi or permafrost conditions (Bradford, 1984; Bradford *et. al.*, 1992; Corn and Vertucci, 1992; Blaustein *et. al.*, 1994; Navas, 1996, 1997; Licht and Grant, 1997).

As frogs are ectothermic they employ various methods of gaining heat. In many cases they use methods such as heliothermy (basking in the sun) or thigmothermy. Amphibians have a limited capacity to thermoregulate, as there is a trade off between maintenance of body temperature and evaporative loss of water over the semi permeable skin (Navas, 1996), with the exception of some arboreal species that are resistant to cutaneous water loss. Basking behaviour has been observed in several species of anurans at high elevations, for example *Rana muscosa*, where they change their position relative to the sun and move between land and water to maintain a reasonably positive water balance (Bradford, 1984). *Rana muscosa* is almost exclusively diurnal, as are most other anurans that bask. However, whilst basking the anuran risks water loss by evaporation with very little change in body temperature. From mid to high elevations heliothermy induces increased diurnality and thigmothermy results in the selection of warmer and less variable microsites for activity. When employing thigmothermy an anuran finds a rock or other substrate that is usually damp, to sit on and will avoid the dry parts of the rock as much as possible. This it does in its efforts to avoid loss of water and to achieve the preferred temperature and maintain water balance (Bradford, 1984).

Frogs such as *Bufo spinulosis* and *Hyla labialis* employ heliothermic and thigmothermic behaviour (Sinsch, 1989; Navas, 1996), however, Tracy *et. al.* (1992) reported that smaller frogs are not able to increase their body temperatures using thermoregulatory behaviour and are possibly active mainly at night. Water relations influence thermoregulatory activities of an anuran, therefore ranid frogs are largely restricted to substrates with high water potential (Bradford, 1984).

In some species, such as *R. muscosa* aggregative behaviour occurs in both the adults and larvae. Aggregation allows for the head and back of the individual to be exposed to the sun, the ventral side is adpressed against the substrate surface and the sides are pressed against individuals adjacent to the frog, minimizing water loss and heat loss from the sides of each animal (Bradford, 1984). In these environments it is quite often that one will observe aggregative behaviour in tadpoles of *R. muscosa* in warm isolated shallow waters. Hutchison and Hill (1977) showed thermal selection in *R. catesbeiana* tadpoles could be observed and that there is plasticity among these tadpoles to change their activity temperatures and to remain at the lower end of the thermal spectrum, while maintaining optimum conditions for growth and development. In other species, however, selection of the microsite would include going under the river or stream banks to avoid the excessive cold and maintain heat. Other than being good mechanisms for heat absorption, aggregative behaviour and thermal selection by tadpoles have other physiological advantages as well. Aggregative behaviour can maximise predator avoidance, prevent desiccation, increase insulation and reduce heat loss as well as increase metabolic rate, improve locomotion and coordination, accelerate feeding, digestion and assimilation and thereby facilitate growth and development (Stebbins and Cohen, 1995).

The above are all mechanisms to deal with loss of water in terrestrial environments. Additionally, some anurans achieve this by behavioural means, such as only being active at night. Another mechanism employed by anurans is the alternation between entering the water at various intervals during the day to absorb water. Some anurans, for example the arboreal frog *Phyllomedusa sauvagei*, conserve water by methodically spreading a lipid substance over their bodies and can then bask in the sun for a very long time. Some frogs deal with high temperatures by burrowing into the ground until more favourable conditions arise at which time they will resurface to feed or breed.

High altitudes present a special problem as cold, usually snowy, winters or even semi permanent snow cover is experienced and is typical for these environments. Costanzo *et. al.* (1999) studied inoculative freezing in the freeze-tolerant wood frog, *Rana sylvatica*, and showed that these frogs can survive low temperatures by inducing inoculation at higher temperatures. It would thus seem that anurans (amphibians) are capable of partially controlling their physiological responses to temperature to some extent.

1.2.3 *Morphology*

An animal's morphology can play a big role in its survival in any given habitat. The wide spectrum of habitats that are utilised by anurans reflects how these animals have adapted morphologically to get the maximum out of their habitat without compromising their survival. It is easy to tell from an anuran's morphology what type of habitat it lives in. Mostly an anuran's habit can be determined by whether it has strong hind limbs, for jumping or swimming, or the amount of webbing present on the toes are an indication of whether they are swimmers or not. *Xenopus laevis* has strong hind legs and webbed feet and other morphological and physiological features that are evidence for its completely aquatic habit. Some frogs have strong hind limbs, little webbing on the feet that allows for jumping, and are found in grasses adjacent to rivers. An example of this type of frog is *Strongylopus grayii*. Some frogs even though they have the above features would have intermediate amounts of webbing, which would still make them strong swimmers, for example *Afrana fuscigula*. Both *Afrana fuscigula* and *Strongylopus grayii* are also strong jumpers. Some frogs, such as *Breviceps spp.*, have short stubby hind legs, which are indicative of a 'walking' frog. *Pseudacris streckeri* have stout forelimbs, which are well adapted for burrowing. *Breviceps spp*., like other fossorial frogs burrow using their hind limbs. Another burrowing frog is *Hemisus sp*., which does not burrow with its forelimbs but rather uses its head, which is in the shape of a shovel. In arboreal frogs it is easy to see how a frog can sit on a leaf and not fall off, as in these specialised frogs there are small discs at the tips of their toes that make use of the surface tension to stick to the leaves.

Frogs have semi-permeable skin, which acts as a gaseous exchange medium in terrestrial species. The skin on the belly and lateral sides of the riparian species of frogs is smooth while the skin on the belly and proximal ventral surfaces of terrestrial anurans is granular and some may have areolate and granular skin on the flanks. This skin type increases the surface area that comes into contact with the substrate and makes it an ideal water collecting mechanism (Duellman and Trueb, 1986). This is clearly demonstrated by *Breviceps macrops* found in the Namaqualand region in the Northern Cape (pers. obs.). These frogs would come out at night and sit facing the sea with their abdomens, which are granular, pressed into the sea sand as it is via the venter that most of the water is absorbed from the sand (Duellman and Trueb, 1986).

1.2.4 *Life Histories*

The life history of an animal includes all aspects of an animal's life cycle from egg to death. Life history patterns of anurans include all aspects of reproduction, including vocalisation and larval metamorphosis. There are many other aspects that should be considered when regarding an animal's life history as certain constraints may be placed on the animal which are influenced by the genotype, the environment or a combination of both (Begon *et. al.*, 1986). A combination of all of these factors will act to influence a particular organism's life history pattern. In the following paragraphs I shall concentrate on the mechanisms employed by anurans to acquire mates paying particular attention to vocalisation and reproductive strategies. This will be followed by a brief discussion on parental care and tadpole behaviour in some anuran species.

1.2.4.1 *Vocalisation*

The utilisation of sounds is a very important aspect of communication in many terrestrial and aquatic animals. Animals use vocalisation to exchange information about danger, availability of food, to determine distances and for advertisement of reproductive readiness. Amphibians are thought to be the first vertebrates that developed the ability to produce sounds (Duellman and Pyles, 1983) and although salamanders have a small degree of vocalisation, Anura is the only group of amphibians that have widely developed this ability (Duellman and Trueb, 1986). Acoustics in frogs is less diverse than those of birds or insects. However, acoustics serve a function equally important and calling is regarded to be a pre-mating isolation mechanism used by anurans during the mating season (Duellman and Pyles, 1983; Duellman and Trueb, 1986; Gerhardt, 1994). Advertisement calls of anurans are species-specific and this makes them valuable characters in taxonomic, systematic, evolutionary and behavioural studies (Duellman and Pyles, 1983). Interspecific differences in advertisement calls have been observed between both sympatric and allopatric species and experiments have demonstrated that frogs reared away from conspecifics, or in heterospecific communities in the absence of conspecifics, still produce the specific call (Gerhardt, 1994).

Most calls, regarded as mating calls, are produced at the beginning and during the breeding season. To reduce the incidence of predation frogs usually call in choruses or on their own from concealed positions (Brooke *et. al.*, 2000). It is not certain, however, which factors initiate frog calling or migration to the breeding site. Social factors are regarded as being important, as other frogs will join in the chorus once there is an initiator (Stebbins and Cohen, 1995). Several other factors that have been proposed to explain this behaviour include environmental and micro-environmental physical factors such as temperature and day-length and water availability, humidity respectively (Duellman and Trueb, 1986 and Brooke *et. al.*, 2000). It was thought that odours given off by algal blooms initiate this behaviour in the species *Rana temporia* and odours given off by upland forest vegetation were responsible in the species *Pseudacris triseriata* (Duellman and Trueb, 1986). Another important question is how frogs find the breeding site. It has been suggested that some amphibians use celestial or olfactory cues to orient themselves to the breeding site as in the natal homing behaviour observed in *Bufo bufo* and other amphibian groups such as newts (Brooke *et. al.*, 2000).

Historically, all calls produced by frogs were regarded as being mating calls (Blair, 1958), but a review of available evidence at the time, by Straughan (1973), suggested that certain calls had different characteristics and that these calls served a purpose other than just attracting females. More recently research has demonstrated that frogs do in fact have a range of distinctly different calls in their vocabulary including calls that act as an advertisement to attract females, an aggressive call to ward off intruding males, and a release call uttered by both males and spent females in response to other males attempting amplexus. There are a number of species that are known where the female produces a reciprocal call in response to the male advertisement call, common examples are *Alytes obstetricans*, *Tomodactylus angustidigitorum, Rana blythi, R. virgatipes* and *Xenopus laevis* (Picker, 1980; Duellman and Trueb, 1986; Emerson and Inger, 1992; Gerhardt, 1994; Haddad and Giaretta, 1999).

The advertisement call is aimed solely at conspecifics and may have a dual purpose. For example, in the leaf-folding frog *Afrixalus delicatus* (Backwell and Passmore, 1990), it is used to attract the female and help locate the male, but also to help partition resources between the males (Stebbins and Cohen, 1995). The advertisement call is given at a particular frequency and in some species, such as *Rana catesbeiana*, females respond to the pulse repetition rate of the call (Duellman and Trueb, 1986). Female frogs, even in a heterospecific community, have the ability to identify and only respond to conspecific males (Duellman and Pyles, 1983). The advertisement calls of each species in a multispeciose community differ considerably on the basis of their frequency, pulse repetition rate and note repetition rate. The advertisement call can be changed to become more attractive to females by the addition of notes to a call thereby lengthening the call or by adding a pulse to the call.

In a study done on the green frog, *Rana clamitans*, it was found that territorial males could distinguish between their adjacent territorial neighbours and strangers based on the individual variation in the call (Bee *et. al*., 2001). Schiøtz (1973) noted that in breeding aggregations individual frogs would have a vocal fight, which could lead to physical combat, to protect territories against other males. The aggressive call of an anuran can be distinguished from the advertisement call by the frequency, repetition rate and the amount of notes of the call given as in *Afrixalus delicatus* (Backwell and Passmore, 1990). Usually the aggressive call has a more shrill quality than the advertisement call. The frog uses this call for two purposes: (1) territoriality, whereby it lets other conspecifics know that they are invading its territory and (2) antagonistic call, which is supposed to warn intruders to avoid entering the territory of the resident male. In the non-aggregative breeder, *Eleutherodactylus coqui*, both the male and female utilise the aggressive call (Stewart and Rand, 1991) to protect retreat sites. In another study, Stewart and Rand (1992) found that these frogs actually utilise the call at dawn and dusk and sporadically during the day as protection of their retreat sites and as a warning to conspecifics. It has been shown in certain species of anurans that only a slight adjustment to the advertisement call is necessary to produce a compound call that includes the aggressive call.

The advertisement call is an indication of male fitness and in some species is the only criterion the female uses to choose her mate. Females prefer males' calls that have high repetition rates. In the study by Docherty *et. al.,* (2000) it was found that *Hyperolius m. marmoratus* males that mate usually do so in the early evening and thus produce fewer calls than those that do not mate. Body size and relative size of the vocal apparatus have an effect on the acoustic properties of anuran calls. A larger frog's call would be characterised by a longer call, higher pulse rate and lower dominant frequency. In *Rana clamitans* a smaller frog would lower the dominant frequency of its call in response to larger intruding males, giving a false indication of its actual size (Bee *et. al.*, 2000). A male's success at finding a mate is also influenced on the number of nights that he spends calling at the breeding sites. This is especially true for the aggregative breeders. Explosive breeding frogs form dense aggregations around a pond. Here they call for the attention of the females, but frequently search actively for females occasionally resulting in amplexus with another male. Prolonged breeders, on the other hand, call from stationary positions, maintaining some form of inter-male spacing. In non-aggregative frogs the female would choose the male with most energetically expensive call but there are also other factors that make the female decide whether or not she wants to breed with the specific male. A female from the species *Hylodes asper* would first inspect the underwater nest provided by the male before mating with him (Haddad and Giaretta, 1999). This species is found in the splash zone of waterfalls and currents and the ambient noise levels make it tremendously difficult for this frog to rely solely on acoustics for attracting a mate. This is due to the sound pressure levels of the waterfall and the advertisement call being similar even though the high-pitched calls are spectrally different. *Hylodes asper* have therefore developed another mechanism, whereby females get to choose their mate, called foot-flagging (see Haddad and Giaretta, 1999 for details). Visual communication is also reported for various other groups of anurans, where there is sufficient humidity and light in the habitat and where there is a reduction in the use of vocalisation.

Some frogs do not possess the ability to produce sound and have reduced tympanums. Studies have shown that these frogs use other means of identifying conspecifics. Voiceless frogs have been identified in various parts of the world. *Rana blythi* from Southeast Asia and *Capensibufo rosei* from the southwestern Cape, South Africa, are usually associated with extremely noisy habitats, the lack of closely related cogeners or the use of permanent breeding sites (Emerson and Inger, 1992; Channing, 2001).

A study by Emerson and Inger (1992) showed that males of *R. blythi* do not aggregate in high densities and that the male - female distribution at breeding sites are unlike other ranids because there exists a female bias. In some species satellite behaviour can be observed, which reduces the energetic costs of calling for the satellite males (Ovaska and Hunte, 1992).

1.2.4.2 *Reproductive Strategies*

The life histories of anurans vary considerably and this is reflected in the range of reproductive strategies displayed in this group. Duellman and Trueb (1986) listed a total of 29 different reproductive modes for anurans around the world. They define a reproductive mode as "a combination of ovipositional and developmental factors, including ovipositional site, ovum and clutch characteristics, rates and duration of development, stage and size of hatching and type of parental care if any". Reproductive strategies range from the generalised aquatic mode to the terrestrial mode, where an aquatic stage may or may not be present. It is known that various reproductive modes, such as the specialised terrestrial modes, have developed in various groups of unrelated lineages (Bogart, 1981 and Duellman and Trueb, 1986). It is thought that the change from the aquatic mode of reproduction to terrestrial mode represents an escape mechanism developed by anurans to ensure high survival rates of their offspring (Duellman, 1992).

The generalised aquatic mode is the mode that includes the eggs and larval stages in the water. Since frog eggs are vulnerable to desiccation frogs have to lay their eggs in areas where there is sufficient moisture to prevent this, even in terrestrially adapted species. Therefore terrestrial breeding species reproduce where there is sufficient moisture or high levels of moisture available. To overcome the danger of desiccation a wide range of reproductive modes has been adopted in anurans to ensure that the eggs remain moist.

Some aquatic species attach their eggs to rocks or vegetation or have special nests dug into a little pond adjacent to the main stream, such as *Hyla vasta*. Other frogs make a foam-like nest, as in *Chiromantis xerampelina*, which when dry forms a hard outer core but provides enough moisture inside to prevent desiccation of the eggs. These nests are usually found in the riverbanks attached to exposed roots, so that when the eggs hatch, the tadpoles drop into the river and become free-swimming larvae. Some arboreal species lay their eggs on vegetation overhanging rivers or ponds. This ensures that tadpoles once hatched are sufficiently close to the water body where the next stage in their life cycle will be spent. *Hemisus*, an African frog, lays its eggs in a subterranean nest approximately one meter from a body of water. Duellman (1992) thus states that these frogs are not truly terrestrial.

In truly terrestrial species the eggs do not develop into free-swimming larvae and have the complete transition from egg to froglet out of water. Terrestrial frogs can be classified as oviparous as in most aquatic and riparian species, but also truly terrestrial species, ovoviviparous such as *Nectophrynoides tornieri* and *N. viviparus* or viviparous such as *Nimbaphrynoides liberiensis* and *N. occidentalis*. In these frogs the clutch size is reduced to a few eggs (six to ten) from thousands of eggs, because there is a greater input of energy by the female in the form of yolk production in the eggs. This yolk is protein rich and provides the larva with food while it is developing in the egg. The eggs produced by these anurans are also relatively larger compared to those of aquatic or semi-aquatic species. Oviparous species have developed various modes from laying their eggs on rocks or between vegetation (leaf litter) and digging underground burrows. In these species the eggs develop into froglets omitting a free-swimming tadpole stage (Brown *et. al.*, 1972).

1.2.4.3 *Parental Care*

Parental care in anurans has been noted in various groups of anurans and can include either one or both parents (Duellman, 1992). It is one of the mechanisms that animals make use of to ensure that there is a high survival rate of the offspring. Parental care ranges from protecting the nest, to carrying the brood on the back of a parent at various stages. Various methods of parental care are described in Duellman and Trueb (1986). Even though it is thought that parental care is a phenomenon just associated with terrestrial, direct developing, frogs it has been shown to occur in the aquatic species *Pipa carvalhoi* where the female carries the eggs on her back (Duellman, 1992). In the Puerto Rican cave dwelling frog, it is the male's task to look after the eggs in the nest and sometimes there are multiple clutches, from different females, that it has to protect (Burrowes, 2000). This is an energetically expensive way of protecting the offspring, but in taxa such as *Alytes obstetricans* less energy is spent as eggs are carted on the parent's back (Duellman and Trueb, 1986).

1.2.4.4 *Tadpoles*

Hatching tadpoles have a body plan that has a superficial resemblance to fish (Duellman and Trueb, 1986). However, the striking differences are that the body is short and generally ovoid. The tail is long and compressed with a caudal musculature, having dorsal and ventral fins. Many different types of tadpoles can be identified, from the common pond-type to the more specialised tadpoles. From the behaviour it is possible to note whether tadpoles prefer flowing water, still water, whether they are pelagic or bottom dwelling (van Dijk, 1972). The position of the mouth and the morphology of the mouthparts and the position of the eyes can also act as an indicator as to the type of habitat the tadpoles are found in and the type of feeding habits they exhibit, for example if they are filter feeders or prefer macroscopic vegetation.

A tadpole on its own is vulnerable to predation (Duellman and Trueb, 1986), however in groups such as *Bufo rufus* tadpoles form aggregations of various sizes (Eterovick and Sazima, 1999). In this group aggregations are formed at night when tadpoles become inactive and it is not unusual to find a group of the same age class (stages) forming aggregations. The older tadpoles usually form bigger aggregations, which help to minimise the amount of individuals taken as prey by a predator. Cannibalism was observed in a group of *B. rufus* tadpoles (Eterovick and Sazima, 1999).

1.3 Conservation and Monitoring

1.3.1 *Amphibian Declines*

In the past two decades or so there have been many reports of amphibian decline in the world. A meeting held by herpetologists in the latter part of 1989 made it apparent that there was cause for concern as numerous reports of declines was presented (Barinaga, 1990). What was particularly worrying was that frogs were disappearing from seemingly pristine environments in montane regions. The reasons for the decline in amphibian populations have been attributed to a variety of different factors such as habitat loss, disease, environmental contaminants and climate changes (Beebee, 1996; Licht and Grant, 1997; Alford and Richards, 1999).

Their ectothermic nature and the fact that the eggs of amphibians are naked make them vulnerable to all changes in the climate. Thus the depletion of the ozone can have many deleterious effects on species that are more susceptible to change than others (Blaustein *et. al.*, 1994). These authors looked at 10 different species of amphibians and found that there was a high degree (>80-fold) of variation in their response to ultra violet B (UVB) radiation. Licht and Grant (1997) found that UVB exposure resulted in irreparable damage to the eggs and larvae of amphibians, whereas exposure to UVA (visible light) resulted in little damage that was repaired by the enzyme photolyase. Abiotic factors, such as water depth, water colour and dissolved organic content in the oviposition sites, and biotic factors, such as jelly capsules surrounding the eggs, melanin pigmentation of the eggs and colour of the larvae and juveniles can reduce the effects of UVB. However, long-term exposure to UVB can result in high mortality of amphibians. Other abiotic factors affecting amphibians are acid depositions at high elevations and low pH and aluminium. Corn and Vertucci (1992) looked at the effects of acid (sulphate) during snowmelt on six amphibian species of which five were anurans and one salamander. They found that no definite conclusions could be made about the effects on *Bufo boreas*, and *Rana pipiens* and proposed that the present levels of acid deposition in the Rocky Mountains are not a threat at present. Bradford *et. al.* (1992) found that acid deposition in the surface waters of the Sierra Nevada changes the chemistry of the water making it more acidic and that this decreases the pH of the water, resulting in increased amounts of dissolved aluminium. When they tested for sublethal limits of acidity in *Rana muscosa* and *Bufo canorus*, they found that the sublethal pH limits in the laboratory for embryos and tadpoles of *R. muscosa*, 4.4 and <4 respectively and 4.7 and 4.3 respectively, *for B. canorus*. This resulted in reduced body size of both species' embryos and tadpoles. Biotic factors blamed for the amphibian decline include bacterial and fungal infections. The red leg disease, *Aeromonas hydrophila*, a bacterial disease, seems to be a large factor to the mortality of *Rana muscosa* in Kings Canyon, California (Bradford, 1991). The other pathogen receiving attention is the fungal infection Chytridiomycosis, which was originally isolated in anuran species from Australia, has a presence in Central American anurans (Berger *et. al.*, 1998) and has recently been identified in *Afrana fuscigula* and *Xenopus laevis* from around South Africa (Weldon, pers. comm.). Other factors blamed for the amphibian decline are the introduction of non-indigenous fauna, such as the Cane Toad and fish in Australia (Hero, 1996).

The big question that most herpetologists are asking then: "are these factors working on their own?" Most agree though that these factors have to be acting synergistically to have the profound effect that is observed. The main factor still responsible for the loss of habitat is the encroachment of humans onto the habitat of amphibians (Hero, 1996). A particular case is what is happening in Tanzania (Newmark, 2002), where the spray zone of *Nectrophrynoides asperginus*, the viviparous frog, was nearly completely destroyed when the construction of a hydroelectric power station cut off the water supply that feeds the spray zone where these frogs live. However, there is evidence that humans not only affect the habitats of amphibians directly but also indirectly, as with the depletion of the ozone layer – resulting in increased levels of UVB and pollution, both air and water – but where air pollution results in acid deposition at high elevations. Other factors such as the construction of roads are also aiding, perhaps not to the same extent, to the destruction of amphibian habitat (Forman and Alexander, 1998).

1.3.2 *Monitoring*

Recently the term monitoring has taken on a more definitive meaning (Hellawell, 1991). In this paper Hellawell (1991) describes the definitions of three strategies used to design a monitoring program. These are as follows: 1) the survey, where a set of quantitative or qualitative data is collected in a prescribed period of time using standardised procedures, 2) the surveillance, where the survey program is extended to provide a time series and to ascertain variability and 3) the actual monitoring, where intermittent surveillance is carried out. Biological monitoring programs have been set up in practically the entire biosphere, such as the air, terrestrial, marine and freshwater ecosystems. In these systems various aspects are monitored using abiotic indicators, such as soil or water quality, or using biotic aspects such as indicator species (Spellerberg, 1991). Two questions that most people would ask however, is 1) why monitor and 2) what does one monitor?

Even though there are a number of reasons why one should monitor, Hellawell (1991) lists three generalised categories, such as 1) assessing the effectiveness of policy or legislation, 2) regulation and 3) detecting incipient change. Biological monitoring is important because having long-term data sets one can make assertions about whether a population is stable or not and with the influx of reports of population declines in both plants and animals this information becomes invaluable (Spellerberg, 1991).

Blaustein *et. al.* (1993) stresses the importance of long-term data in the study of amphibians as they are regarded as 'model vertebrates' for studying complex life cycles, aquatic communities and mating patterns in the field. Usher (1991) shows that there is a pattern in the way of setting up a monitoring program. He shows that there are five questions that the researcher should ask. These questions are: 1) the purpose of the monitoring, 2) the methodology used, 3) how the data will be analysed, 4) how the data will be interpreted and 5) when the aim of the project is achieved.

As far as amphibians are concerned, laws have been stipulated which are specifically aimed at their protection (see details in Beebee, 1996; Baard *et. al.*, 1999). These laws aim to protect their present status and to maintain their habitats. The use of amphibians as biological indicators has recently received much attention. This is because they have a semi-permeable skin, which allows water and gases to pass through freely. Also the fact that they spend at least a part of their life cycle, the larval stages, in water makes them suitable agents for predicting water quality (Channing, 1998).

1.3.3 *Rationale*

For any long-term monitoring project the role of baseline data is invaluable. Not many data sets exist to make accurate distinctions of whether a population is declining because of extrinsic factors, for example biotic or abiotic, or whether it is just natural fluctuations of populations (Blaustein *et. al.*, 1993; Pechmann *et. al.*, 1991). This could be that the time span needed for any reasonable assumptions to be made about a population is longer than the time period in which most studies take place (Blaustein *et. al.*, 1993). Unfortunately there exist very little ecological data on the anuran species of South Africa (Channing, 1999) and other regions of the African continent (van Djik, 1981).

The reason for this project is two fold: 1) the need for detailed information on the ecology of frogs found in the southwestern Cape and 2) to gather information to set up a monitoring program in the mountain range where this study took place.

1.4. Research Questions

This project is aimed at establishing a long-term monitoring program in the Landdroskop mountain range, which forms part of the Cape Fold Mountain Range, in the western Cape. This project will thus serve to collect baseline data for the larger project planned for the Landdroskop Mountain Range in this region. The aim of this project is to provide data on the breeding ecology of these winter breeding frogs. In order to get these baseline data I set a series of questions.

1) What species occur on this mountain? It is important to know what species one will be dealing with to establish a program to suit them. Very recently (Dawood and Channing, 2000) a new moss frog species, *Arthroleptella landdrosia*, was described from this locality.
2) What are the habitats of the different species encountered here? As this is a seepage area with several hiking trails I wanted to establish their distribution patterns, and see if their distribution was uniform. There are 12 known species from this mountain range, with 4 terrestrial species and 8 riparian species.
3) Which species is most frequently encountered?
4) When do the frogs start and stop calling? I wanted to find out if the different species displayed any differences in the time periods when calling is initiated, both intra and interspecifically.
5) What influences the frogs' calling? Are there any differences in the calling patterns displayed by conspecifics with regards to temperature and rainfall?
6) What reproductive patterns are displayed by the species found here?

2 MATERIALS AND METHODS

2.1 Study Site

This study was conducted on the Landdroskop mountain range (figure1) in the Hottentots Holland Nature Reserve, Grabouw (33°45' - 34°23' S and 18°50' - 19°12' E) South Africa. This area forms part of the Cape Fold Mountains. The highest peak in the Landdroskop mountain range is 1515 m. On the southwest side of the mountain rainwater runoff in winter is channeled through a seepage area, which consequently leads to the formation of several semi-permanent water bodies. These water bodies, even though they do not dry up completely in summer, have very low water levels in the dry season. This region is very water stressed in the summer months because of the typical drought-like conditions that are experienced. The region itself is rocky and the hiking trails that run along the mountain serve as water channels during the winter rainfall, directing the water into the seepage area (vlei).

2.1.1 *Climate*

The climate of this region is similar to other countries dominated by the Mediterranean regime, which is characterised by hot, dry summers, and cold, wet winters (Gasith and Resh, 1999). Most of the rainfall, in the region and surroundings, is received between July and August, with rainfall levels varying between 700 mm per annum near Stellenbosch to 3300 mm on the Dwarsberg Plateau (Meyer and du Preez, 2000). Cold fronts in winter are common in this region and are associated with gale force winds and occasional snow falls which can last up to 2 weeks at a time (Meyer and du Preez, 2000). During the summer, when dry conditions prevail, mists that are blown in over the

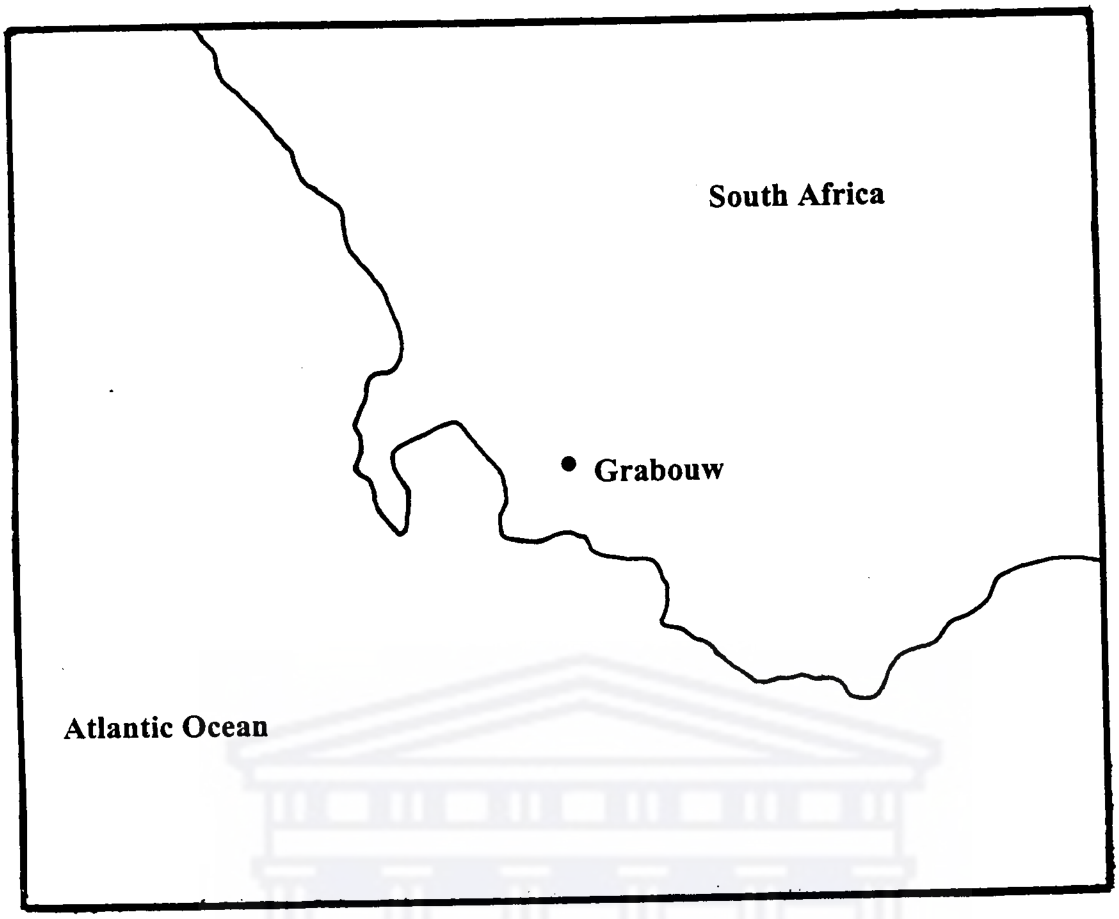

Figure 1. Landdroskop mountain range is situated in the Hottentots Holland Nature Reserve near Grabouw (33° 45' - 34° 23' S and 18° 50' - 19° 12' E), South Africa.

mountains by the prevailing southeast winds provide the main source of moisture in this area.

2.1.2 *Weather conditions experienced in the field*

Typical of mountain environments, weather conditions can change drastically within a short time span. Temperature drops as great as 2 °C in an hour were not unusual. Weather conditions experienced during visits to the study site are presented in table 1.

Table 1. Weather conditions experienced on visits to the area over the study period

Date	Weather Conditions
6-Jun-01	sunny - icy wind
7-Jun-01	very cold - overcast – rain - windy
20-Jun-01	sunny – breezy
1-Jul-01	sunny - gusty winds
20-Aug-01	strong, gusty winds – overcast
19-Sep-01	misty but warm
20-Sep-01	Warm
26-Sep-01	cold, overcast, gusty winds, rain, hail
27-Sep-01	clear skies, icy wind
10-Oct-01	warm, slight breeze
17-Oct-01	cloudy, cold, overcast
18-Oct-01	cloudy, no rain, bursts of sun
25-Oct-01	misty and very cold

2.1.3 *Vegetation*

The dominant vegetation is typically Restionaceae (grasses / reeds/ sedges), Proteaceae (proteas) and Asteraceae (daisies), which is characteristic of mountain fynbos that forms part of the Cape floristic region (CFR). The CFR is unique in that it is the smallest of the world's six floral kingdoms being located solely in the Western Cape Province of South Africa. In summer when rainfall levels are low there is little evidence of the rich nature of this flora, but at the onset of the winter rains there is a rapid increase in this flora and the view is changed into a panorama of lush reeds, daisies and proteas.

2.2 Study Methods

2.2.1 *Study Period*

The research was carried out between June and October 2001 during which time nine visits were made to the study site with a total of 13 survey days. Initially visits were made to the study site every two weeks, which later changed to weekly visits as seasonal increases in frog activity became apparent. Two researchers walked through the study sites twice a field visit and each investigation was 3-5 hours long, which amounted to a total of approximately 52 man-hours.

2.2.2 *Sampling Stations*

Seven sampling stations (figure 2) were established for the current study, chosen for practicality, but also because they represent the variety of microhabitats and microclimates that are available to frogs in this area. Geographical co-ordinates and

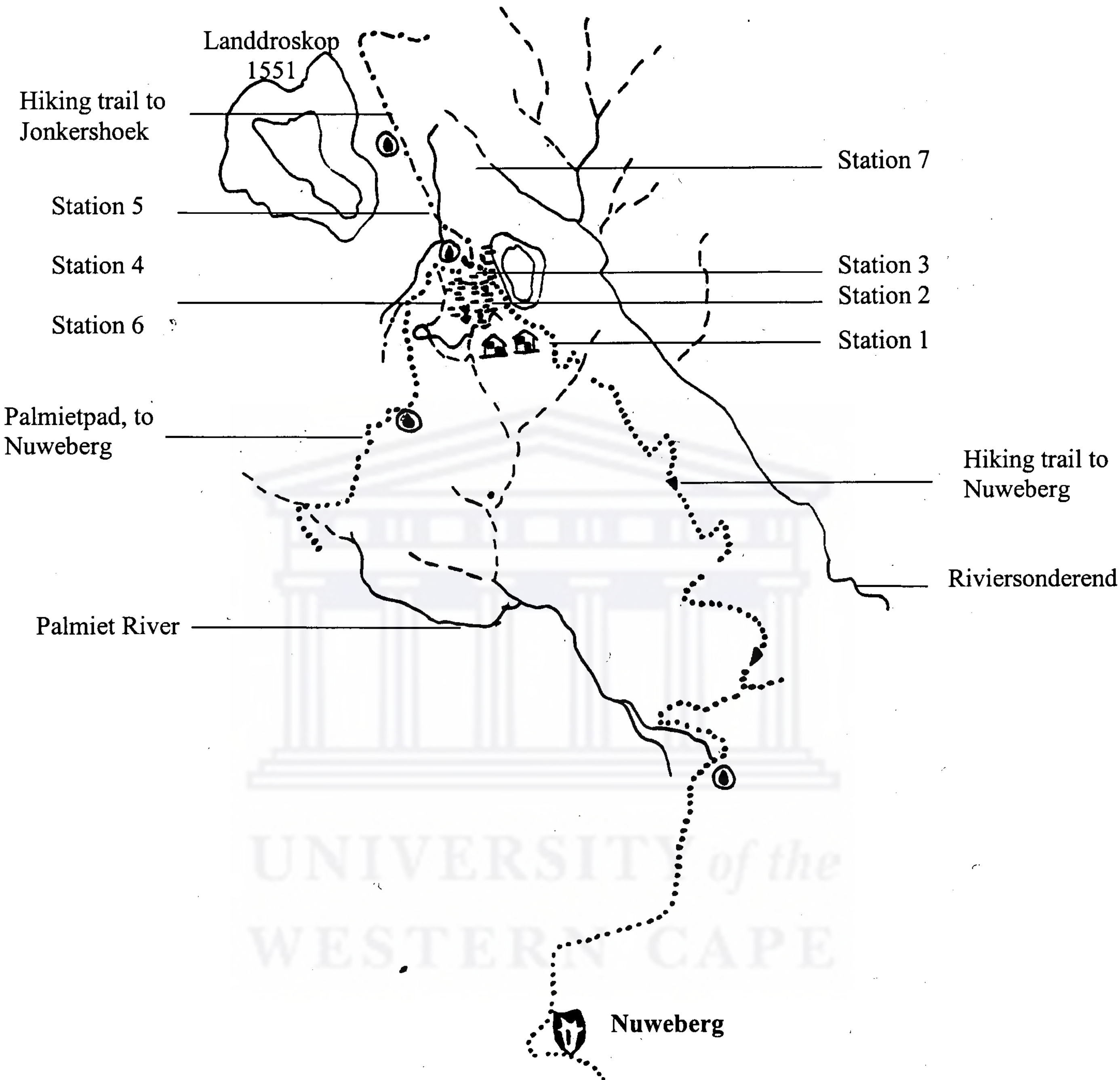

Figure 2. The seven sampling stations along the hiking path at the study site, Landdroskop Mountain range.

altitude information obtained using Geographical Positioning System (GPS) for the seven stations is presented in table 2.

Table 2. Geographical co-ordinates and elevation details of the seven sampling stations.

Sites	Co-ordinates	Altitude (m.a.s.l)
1	34°02'55.6"S 19°00'32.6"E	1059
2	34°02'55.7"S 19°00'27.2"E	1068
3	34°02'55.6"S 19°00'29.9"E	1063
4	34°02'54.8"S 19°00'23.5"E	1068
5	34°02'57.8"S 19°00'19.2"E	1080
6	34°02'58.7"S 19°00'30.0"E	1044
7	34°02'51.6"S 19°00'07.4"E	1084

Of the seven stations, stations 1 (figure 3) and 5 (figure 7), although at different altitudes (see table 2), were similar with respect to topological, hydrological and vegetative characteristics. For example they were situated adjacent to the hiking trail with a gentle slope above and below, had little pools of water forming during the rainy season and they also became overgrown with a high density of Restionaceae and Asteraceae. Stations 2 (figure 4) and 3 (figure 5), like stations 1 and 5, were also situated along the path, but differed in that no standing pools formed at these sites probably because the slopes on either side were far steeper. Proteaceae and clumps of grass were the dominant flora and no apparent seasonal differences in the vegetative cover were observed during the study period. The altitudinal differences between these two stations were relatively small.

Figure 3. Station 1: The dominant species are *Arthroleptella villiersi* and *Afrana fuscigula.*

Figure 4. Station 2: The dominant species is *Arthroleptella landdrosia*.

Figure 5. Station 3: The dominant species are *Arthroleptella landdrosia* and *Breviceps acutirostris*.

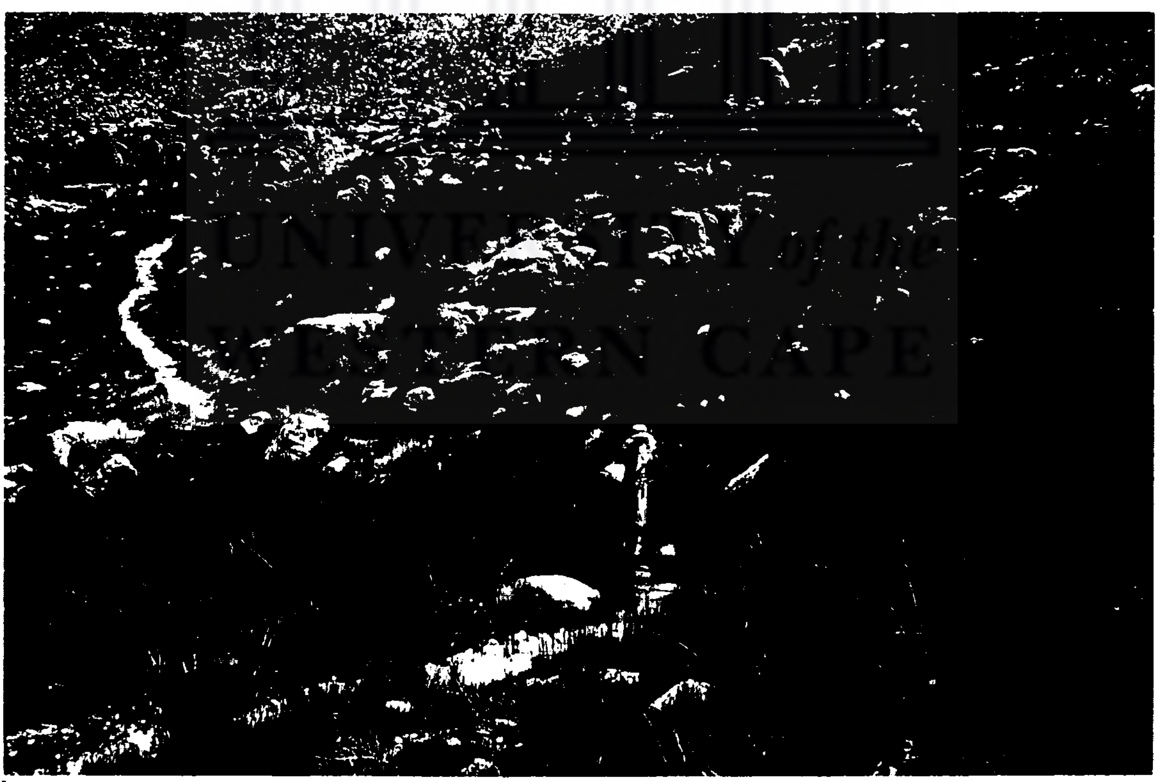

Figure 6. Station 4: The dominant species is *Afrana fuscigula*.

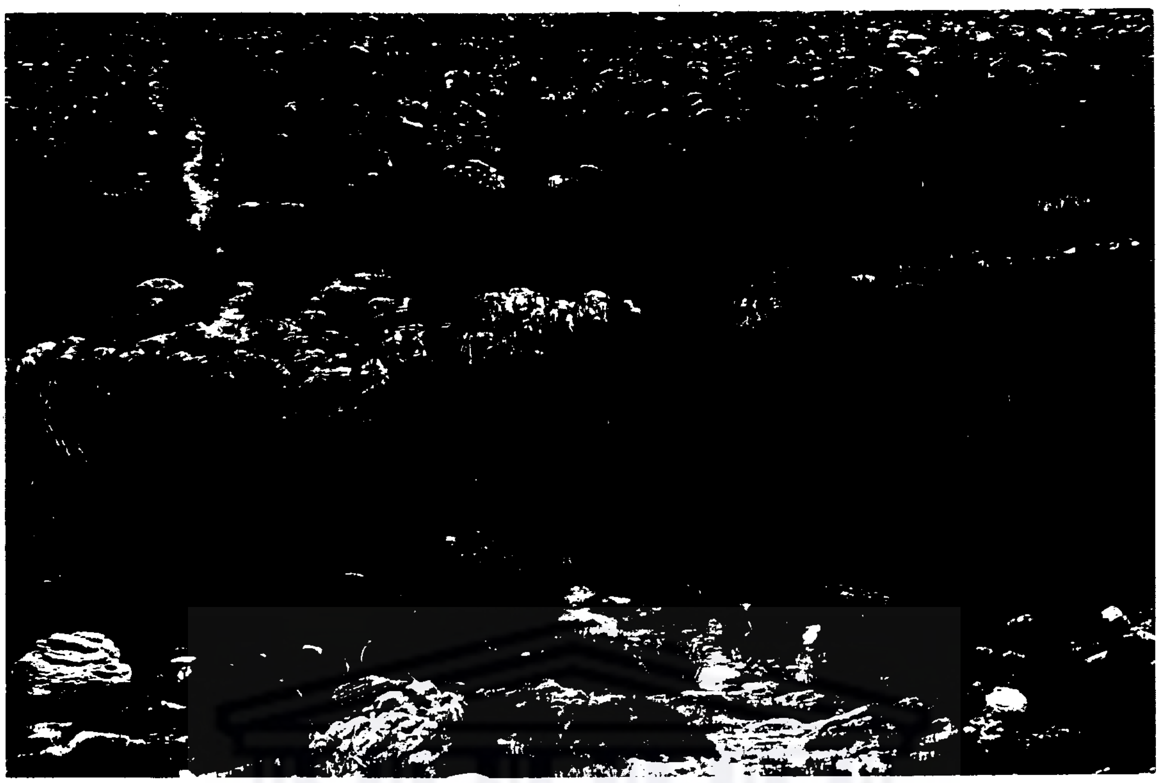

Figure 7. Station 5: The dominant species are *Arthroleptella villiersi*, *Afrana fuscigula* and *Strongylopus grayii* on the periphery of the station.

Figure 8. Station 6: The dominant species are *Afrana fuscigula*, *Strongylopus grayii*, *S. bonaespei* and *Breviceps montanus*.

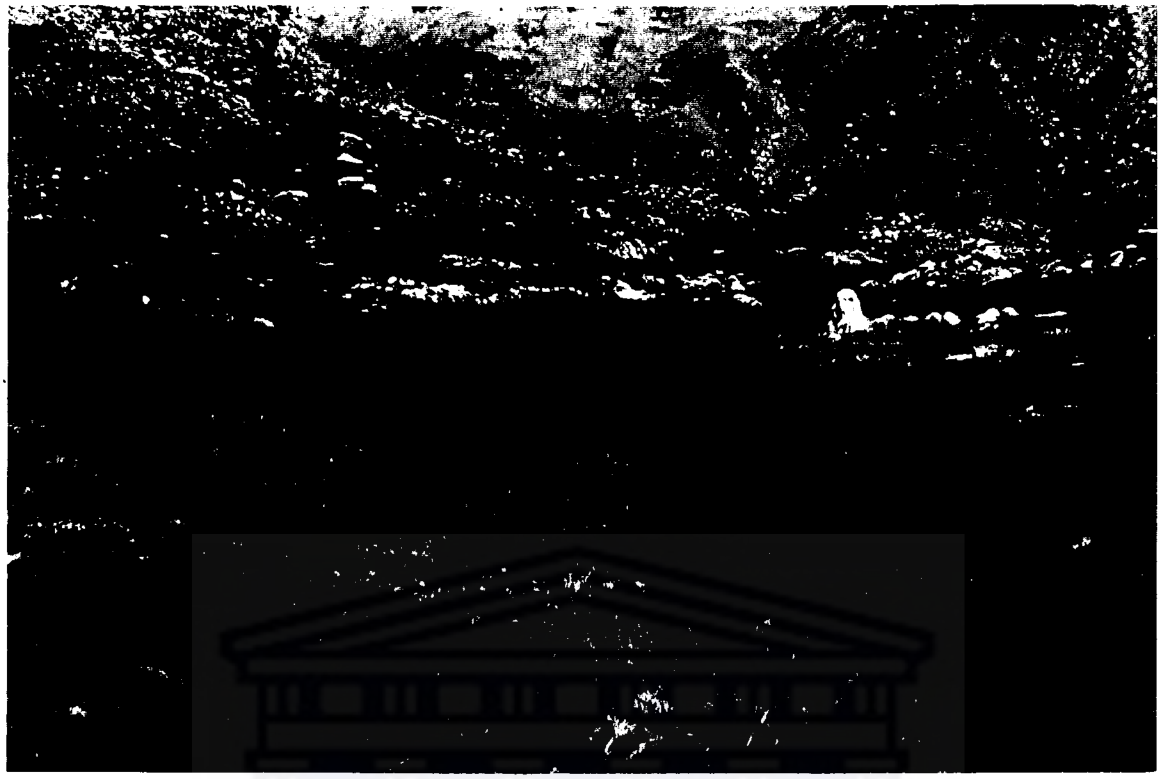

Figure 9. Station 7: The dominant species are *Afrana fuscigula*, *Strongylopus grayii*, *S. bonaespei*, *Breviceps montanus* and *B. acutirostris*. One adult and tadpoles of the species *Heleophryne purcelli* were encountered.

During the wet season at station 4 (figure 6), a stream formed that connected station 4 to the stream flowing towards station 6 (figure 8), which in summer dried up and formed a standing pool. Even though station 4 and station 2 are at the same altitude, they have no other common characteristics. The dominant vegetation type during the wet season was Restionaceae at this station.

Stations 6 and 7 differed from all the other stations in that both were seepage areas made up of a network of slow flowing streams and little pools. At these sites Restionaceae and Asteraceae formed a dense growth on the banks of the streams. Water flow rates were generally faster at site 6 where the slope was greater.

2.2.3 *Temperature and Rainfall*

Temperature was measured using a mercury thermometer held at shoulder height to standardise data. Water temperature was measured by placing the thermometer toward the center of the pool and at a depth of at least 2 centimeters (where possible). Rainfall data were obtained from the rainfall station at Nuweberg as well as from one of the Jonkershoek (station identity: Jonkr2c) weather stations, which was closest to my study site. Rainfall was calculated by taking the average cumulative rainfall, from both rainfall stations, for the week preceding a visit to the study site, which was about 7 days. Any rain experienced on one of the days spent in the field was added to this to give a comprehensive picture of the moisture levels experienced in the field.

During the study ambient air temperatures in this area ranged from a minimum of 5 °C in August to a maximum of around 21 °C in October. Details of the temperature and rainfall profiles for each study visit and are shown in table 3.

Table 3. Average ambient and water temperature (taken when possible) and actual rainfall (for week preceding and including day of sampling) data. *N/A means that no water temperature measurements were taken on that particular day

Date	T_{air} (°C)	T_{water} (°C)	Rainfall (mm)
6-Jun-01	14	12	83
7-Jun-01	9	10	99
20-Jun-01	19	9	40
1-Jul-01	10	9	32
20-Aug-01	5	7	106
19-Sep-01	15	13.5	56
20-Sep-01	13	12	56
26-Sep-01	6.5	10	67
27-Sep-01	10	13	67
10-Oct-01	21	12	1
17-Oct-01	11	11	35
18-Oct-01	13	11	35
25-Oct-01	13	*N/A	41

2.2.4 *Frogs and Tadpoles*

A total of 12 frog species (table 4) were expected to be located in the study area as previously reported by Passmore and Carruthers, 1979; Channing *et. al.*, 1994; Dawood and Channing, 2000. These species range from being riparian to completely terrestrial, and having aquatic larvae to being direct developers. However, it is possible that not all of these species might be present at this site.

Table 4. List of potential species to be located in the Landdroskop Mountain Range and their common names, with references.

Species Name	Common Name	Riparian / Terrestrial / Marsh	Reference
Afrana fuscigula	Cape river frog	Riparian	Passmore and Carruthers, 1979
Arthroleptella landdrosia	Moss frog	Terrestrial	Dawood and Channing, 2000
Arthroleptella villiersi	Moss frog	Terrestrial	Channing *et. al.*, 1994
Breviceps acutirostris	Strawberry rain frog	Terrestrial	Passmore and Carruthers, 1979
Breviceps montanus	Cape mountain rain frog	Terrestrial	Passmore and Carruthers, 1979
Breviceps rosei	Sand rain frog	Terrestrial	Passmore and Carruthers, 1979
Bufo rangeri	Raucous toad	Riparian	Passmore and Carruthers, 1979
Capensibufo rosei	Cape mountaintoad	Terrestrial	Passmore and Carruthers, 1979
Heleophryne purcelli	Cape ghost frog	Riparian	Passmore and Carruthers, 1979
Poyntonia paludicola	Marsh frog	Marsh	Passmore and Carruthers, 1979
Strongylopus bonaespei	Banded stream frog	Marsh	Passmore and Carruthers, 1979
Strongylopus grayii	Clicking stream frog	Terrestrial	Passmore and Carruthers, 1979

Frogs were located by sight and sound and captured by hand or by a net. Frogs were identified on site and tadpoles were identified and staged on site using a magnifying glass. Gosner (1960) was used to stage the tadpoles. To identify tadpoles in their early stages, oral mouthparts and other features described by van Dijk (1966) were used. In the latter stages of development the amount of webbing between the toes is a better feature to use for identification. For genera such as *Strongylopus* and *Afrana* this was helpful, as *Strongylopus* has less webbing between its toes than *Afrana* (Channing, 1979).

2.3 Statistics

The chi-square test for two independent samples (Siegel, 1956) was used to test for any differences between conspecifics as well as to test whether there was any difference between the two most frequently encountered species with regards to temperature and rainfall. The alpha level for this test was set at $\alpha = 0.05$. Chisquare values obtained and P-values are presented in tables 5 (a) and (b).

Table 5 (a). Chi-square for conspecifics and for the two most frequently encountered species, *Afrana fuscigula* and *Arthroleptella villiersi*, at different temperatures. The alpha level was set at $\alpha = 0.05$ and the $df = 1$.

Species	Chi square	P- value
Breviceps montanus *Breviceps acutirostris*	1.37	$.20 \leq P \leq .30$
Arthroleptella villiersi *Arthroleptells landdrosia*	0.18	$.70 \leq P \leq .50$
Strongylopus grayii *Strongylopus bonaespei*	0.08	$.80 \leq P \leq .70$
Afrana fuscigula *Arthroleptella villiersi*	0.75	$.80 \leq P \leq .70$

Table 5 (b). Chi-square for conspecifics and for the two most frequently encountered species, *Afrana fuscigula* and *Arthroleptella villiersi*, at different rainfall levels. The alpha level was set at $\alpha = 0.05$ and the $df = 1$.

Species	Chi square	P- value
Breviceps montanus *Breviceps acutirostris*	0.48	$.50 \leq P \leq .30$
Arthroleptella villiersi *Arthroleptells landdrosia*	0.43	$.70 \leq P \leq .50$
Strongylopus grayii *Strongylopus bonaespei*	4.57	$.05 \leq P \leq .02$
Afrana fuscigula *Arthroleptella villiersi*	0	

3 RESULTS

3.1 Effects of Temperature and Rainfall on Frog Species

A total of eight frog species were frequently found in the study site and these are listed in table 6 along with information on the three main methods of identification; presence of adults, recording of species-specific calls, the presence of tadpoles and the number of stations in which they were found.

Table 6. The different species identified in the field, the identification method used and the number of stations these were found in.
[a]Species found in the field after the study period (June 2002)

Species	Adults	Calling	Tadpoles	# of Stations
Afrana fuscigula	*	*	*	5
Arthroleptella landdrosia	*	*		2
A. villiersi		*		5
Breviceps acutirostris	*	*		4
B. montanus		*		4
Heleophryne purcelli	*		*	1
Strongylopus bonaespei	[a]*	[a]*	*	2
S. grayii		*		3
[a]*Capensibufo rosei*	*			1
[a]*Poyntonia paludicola*		*		2

The eight frog species encountered during the study period belong to five genera distributed among three families. The family Ranidae contains the genera *Afrana*, *Arthroleptella* and *Strongylopus*. The family Microhylidae contains *Breviceps* and Heleophrynidae contains *Heleophryne*. Of the species identified, *Afrana fuscigula* and *Arthroleptella villiersi* were present at most of the sites in the study region, whereas other species such as *Heleophryne purcelli* were only found at one location (see table 6) possibly reflecting the habitat-specific requirements of the latter or alternatively its relative rareness and cryptic habits or both. Other cryptic species, such as *Strongylopus grayii*, *Arthroleptella villiersi* and *Breviceps montanus*, were identified by their calls only, and *Strongylopus bonaespei*, from tadpoles, (table 7).

Table 7: Species distribution among the different stations

SPECIES	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**	**Station 7**
Afrana fuscigula	*			*	*	*	*
Arthroleptella landdrosia		*	*				
A. villiersi	*	*			*	*	*
Breviceps acutirostris	*		*		*		*
B. montanus	*				*	*	*
Heleophryne purcelli							*
Strongylopus bonaespei						*	*
S. grayii					*	*	*

Of the eight species, two *Afrana fuscigula* and *Arthroleptella villiersi* were active across the full range of temperatures recorded during the study period in this area, while the remaining six displayed more restricted ranges. The temperatures at which the eight different species were active, either as calling or being visible are presented in figure 10.

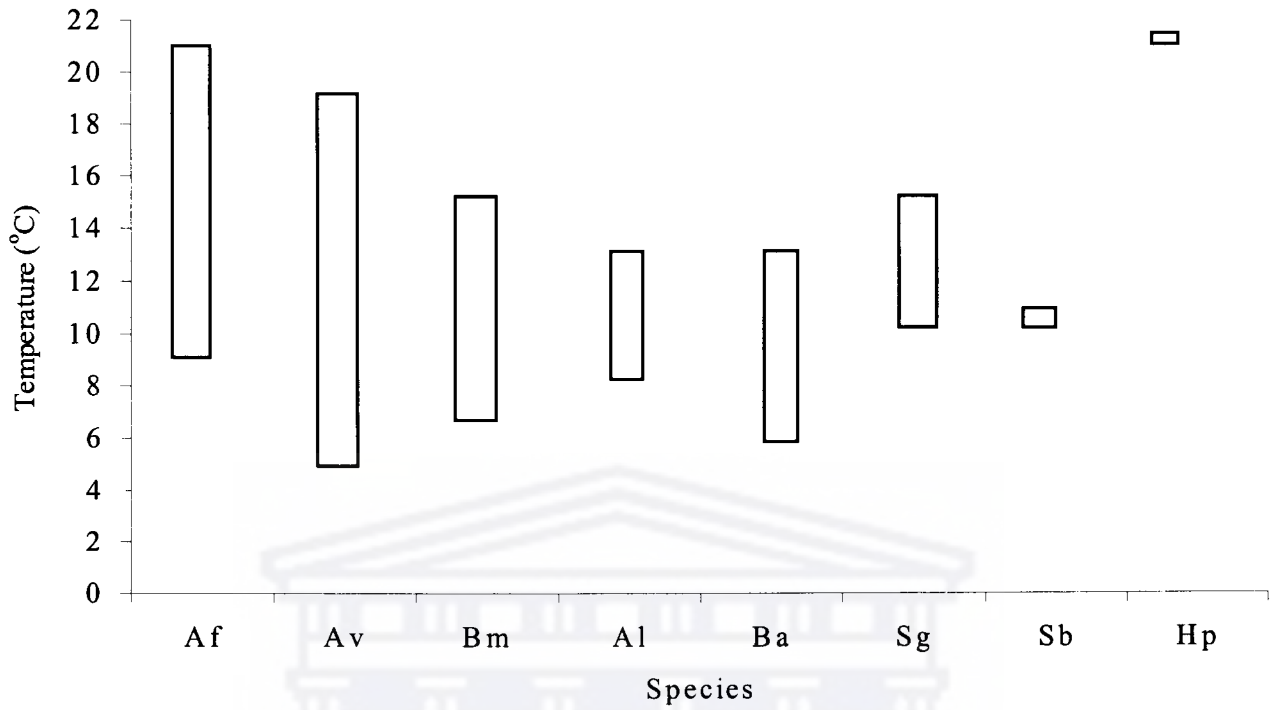

Figure 10. Temperature ranges at which the different frog species were active. Species name abbreviations are as follows: Af = *Afrana fuscigula*, Av = *Arthroleptella villiersi*, Bm = *Breviceps montanus*, Al = *Arthroleptella landdrosia*, Ba = *Breviceps acutirostris*, Sg = *Strongylopus grayii*, Sb = *S. bonaespei*, Hp = *Heleophryne purcelli*.

As can be seen from figure 10 *Arthroleptella landdrosia* and *Breviceps acutirostris* were only recorded in the temperature range of 8 - 13 and 6 – 13 °C respectively, *Strongylopus grayii* between 10 – 15 °C and *Heleophryne purcelli* at 21 °C. *Afrana fuscigula* and *Arthroleptella villiersi* show the broadest temperature ranges for activity. It should be considered though that these were only temperatures recorded when it was possible to go into the field and that there may still be more variation in the temperature ranges that certain species, for example *H. purcelli* could display. However, since no adult *S.*

bonaespei and only one adult *H. purcelli* was found, it is hard to draw conclusions about the preferred temperature range. From the graphs it would seem that there are interspecific differences in the activity temperature preferenda of *Arthroleptella*, *Breviceps* and *Strongylopus*. However, when using the chi – square test the values showed no significant differences for *Arthroleptella* (χ^2 = 0.18, NS), *Breviceps* (χ^2 = 1.37, NS) and *Strongylopus* (χ^2 = 0.08, NS). There was no significant difference between *Afrana fuscigula* and *Arthroleptella villiersi* (χ^2 = 0.75, NS) that showed the widest ranging temperatures. Furthermore, table 8 shows how many species could be heard calling on a particular day at a particular temperature. In this figure any other aspect, such as basking individuals or tadpoles, is ignored.

Table 8. Different species calling at different air temperatures and the total number of species calling at a particular temperature. Abbreviations for species names are as follows: Af = *Afrana fuscigula*, Al = *Arthroleptella landdrosia*, Av = *A. villiersi*, Ba = *Breviceps acutirostris*, Bm = *B. montanus*, Hp = *Heleophryne purcelli*, Sb = *Strongylopus bonaespei*, Sg = *S. grayii*

	Temperature (°C)																	
Species	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Af		*			*	*			*	*	*				*		*	
Al					*				*									
Av	*				*	*	*		*	*	*				*			
Ba		*			*		*		*									
Bm		*				*	*		*		*							
Hp																		
Sb																		
Sg						*	*		*		*							
Total	1	3			4	4	4		6	2	4				2		1	

As can be seen from table 8, most species of frogs called at 13 °C, whilst at the lowest and highest temperatures recorded in the field only one species were calling at each. It would seem that the average number of species would call when temperatures ranged between 9 and 15 °C.

These species also displayed various activity patterns in the different rainfall experienced in the study area. Figure 11 shows the species that were active in these rainfall levels.

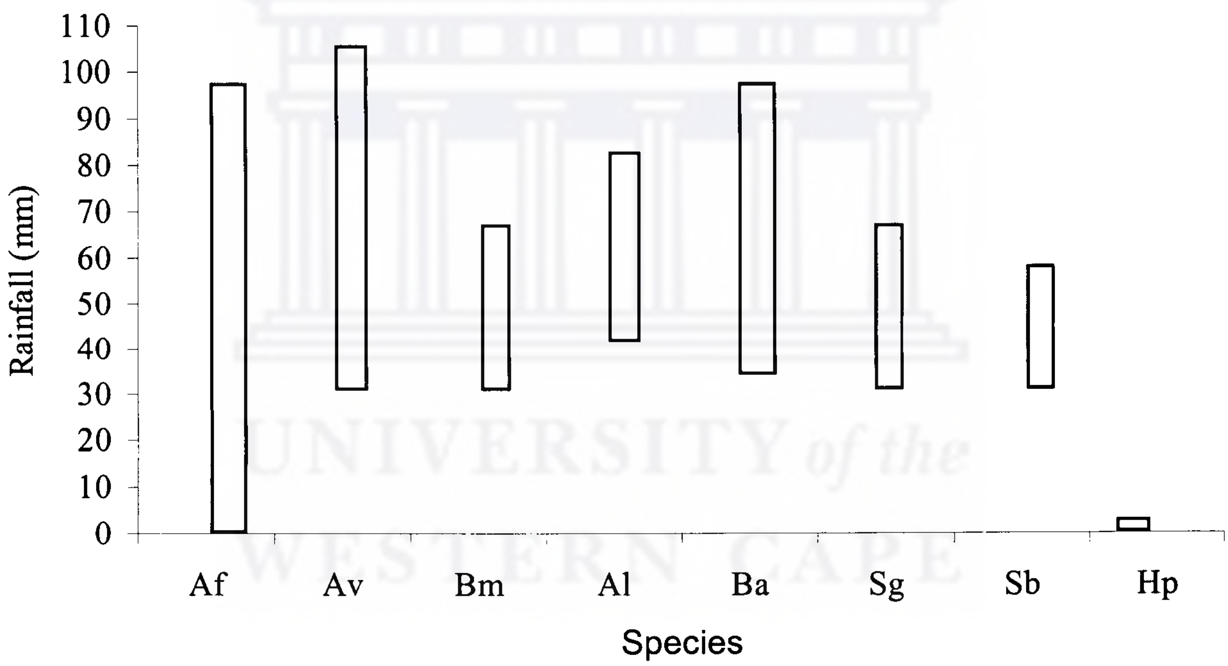

Figure 11. The different rainfall values, cumulative rainfall values recorded from the preceding week, at which the frog species were found active.

Species names are the same as in figure 10

As can be seen from figure 11 *Afrana fuscigula* is active from low rainfall to relatively high rainfall (1 – 99 mm) as recorded in the field. *Arthroleptella villiersi* is the next species that has a broad range of rainfall values that it can be active at (32 – 106 mm). However, there has to be sufficient moisture in the vegetation or soil to encourage activity for this species as well. *Arthroleptella landdrosia* and *Breviceps acutirostris* displayed similar patterns of activity in similar rainfall values (35 – 99mm of rain). This figure (11) shows that *B. montanus* and *S. grayii* have similar preferences of rainfall capacities (32 – 67 mm). There can be no conclusive ideas about *Heleophryne purcelli* and *Strongylopus bonaespei*. It would seem that there are interspecific differences in the activity patterns of *Arthroleptella*, *Breviceps* and *Strongylopus*. However, when using chi – square the values showed no significant differences for *Arthroleptella* ($\chi^2 = 0.43$, NS), *Breviceps* ($\chi^2 = 0.48$, NS) or *Strongylopus* ($\chi^2 = 4.75$, NS) in response to temperature and rainfall. There was no significant difference between *Afrana fuscigula* and *Arthroleptella villiersi* ($\chi^2 = 0.75$ NS), which again displayed the widest ranging rainfall levels. As with temperature, table 9 shows how many species could be heard calling at a particular precipitation level. In this figure all basking individuals were ignored, as well as tadpoles.

Table 9. Different species calling at different precipitation levels and the total number of species calling at a particular precipitation. Abbreviations for species names are as follows: Af = *Afrana fuscigula*, Al = *Arthroleptella landdrosia*, Av = *A. villiersi*, Ba = *Breviceps acutirostris*, Bm = *B. montanus*, Hp = *Heleophryne purcelli*, Sb = *Strongylopus bonaespei*, Sg = *S. grayii*

	Rainfall (mm)											
Species	0	10	20	30	40	50	60	70	80	90	100	110
Af	*			*	*		*	*	*		*	
Al					*						*	
Av				*	*		*	*	*		*	*
Ba					*			*			*	
Bm				*	*		*	*				
Hp												
Sb												
Sg				*	*		*	*				
Total	1			4	6		4	5	2		4	1

The highest and lowest precipitation levels each have only one species calling. The highest species numbers were recorded when precipitation levels were relatively low (40 and 41 mm). Average numbers of frogs called at precipitation levels between 30 and 70 mm.

While it is of interest to investigate the effects of the individual variables, temperature and rainfall separately, activity patterns are probably better explained by a combination of these two factors and indeed many others such as habitat, vegetation, soil type etc. In reality the activity patterns of the eight species in the seven sites are likely to be correlated in a complex way with both rainfall and temperature. The activity patterns, whether the frogs were calling or not, of the eight species among the seven sites in relation to both temperature and rainfall over the study period are shown in figure 12.

In the following paragraphs I shall present the results for each of the eight species individually in terms of temporal-spatial patterns of presence and abundance and attempt to elucidate on some of the ecological factors likely to have an influence on such patterns.

3.1.1 ***Species***

Afrana fuscigula was the most common species in the present survey. This species was observed on 12 days out of 13 with 22 records at five, 1, 4, 5, 6 and 7, out of the 7 stations investigated (see figure 12). *A. fuscigula* was present throughout the study period at all these stations, only becoming more common at station 4 from the 27th September. On the 20th August and the 26th September, the two coldest days recorded, there was a general absence of this species from all stations.

The low rainfall for most of the month of September resulted in the pools at station 1 drying up and as a result this species was not recorded here subsequent to this event. However, after a brief spate of rain on the 26th September this species made an appearance for one day after which it disappeared from here again for the rest of the study period. On three occasions *A. fuscigula* pairs were observed either in amplexus or attempting amplexus. The first time the female was receptive. Amplexus lasted for 20 seconds before a second male came and displaced the first amplexing male. The second and third time, both females were unreceptive. The third female was observed shoving the male off and attempting to swim away.

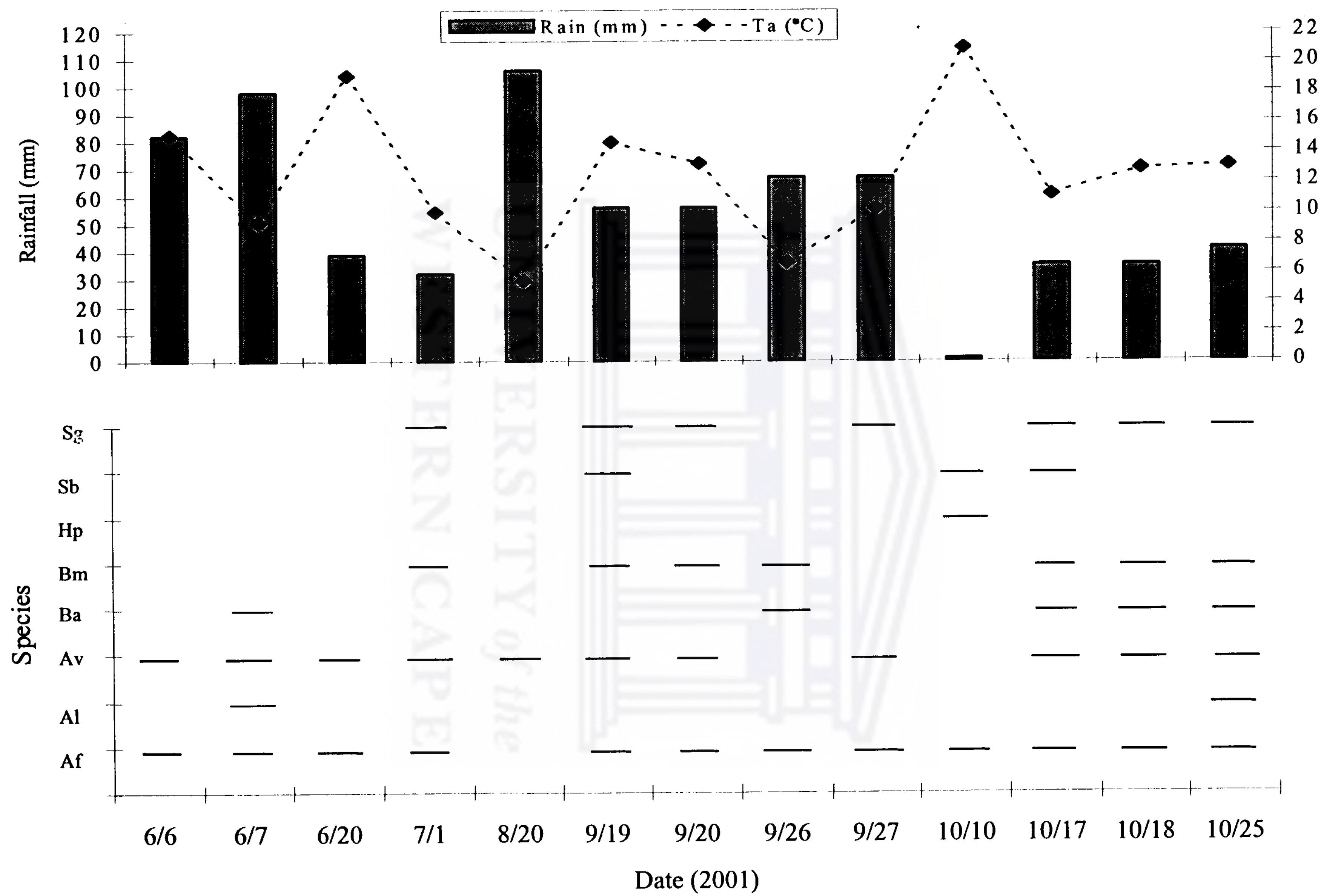

Figure 12. Species presence and absence in all stations (1 – 7) on 13 survey dates. Presence and absence are based on calling, individual sightings and tadpoles. Species name abbreviations as follows: Af = *Afrana fuscigula*, Al = *Arthroleptella landdrosia*, Av = *A. villiersi*, Ba = *Breviceps acutirostris*, Bm = *B. montanus*, Hp = *Heleophryne purcelli*, Sb = *Strongylopus bonaespei*, Sg = *S. grayii*

Arthroleptella villiersi was also present at five out of the seven stations, on 11 days out of 13. It was recorded from stations 1, 2, 5, 6 and 7, on 20 occasions (see figure 12). Figure 4 shows station 2 where this species was recorded on a single occasion. However, its disappearance from station 1 after the 27th September is possibly because of the drying up of the soil water in the station, as it was still present in station 5 by the 18th October. *A. villiersi* was present at both these stations between 5 – 25 °C. It shared this pattern of temperature activity with *Afrana fuscigula* (figure 10) but has a wider temperature range with the lowest activity temperature for *Arthroleptella villiersi* at 5.5 °C (figure 10). No activity was observed on the 10th of October at either site. After the 17th of October, when the area received some precipitation, the activity of *A. villiersi* increased at station 5. Unfortunately the cryptic nature of this species resulted in this species not being found at any of these stations even after extensive searches.

Breviceps montanus was present at four out of seven stations, on seven days out of 13. They were recorded 15 times from stations 1, 5, 6, and 7 (see figure 12). This species had a relatively high presence on the periphery of stations 5, 6 and 7 on wet days and a slightly weaker presence at station 1. It would seem that as soon as some form of precipitation became available, even when temperatures were relatively high, this species became active, as on the 20th June (see figures 10 and12 and table 8). *B. montanus* was represented in stations 6 and 7 from the 19th September through to 25th October which could support the idea that breeding in this species occurs in the summer. This species has a wider temperature range than its congeneric, *B. acutirostris* (figure 10), and was heard calling more frequently. The cryptic behaviour and colouration could possibly explain why these frogs were never found.

Strongylopus grayii was present at three out of seven stations, on seven days out of 13. Recorded seven times from stations 5, 6 and 7 (see figure 12). Even though this species was heard calling quite often, no tadpoles were ever located. *Strongylopus grayii* was present at station 5 but not at station 1. *S. grayii* also had a narrow temperature range, between 10 – 20 °C, in this study (figure 10). *S. grayii* was found at both station 6 in September and at station 7 in September and October. The cryptic nature of this species made it difficult to locate as well.

Breviceps acutirostris was present at four out of seven stations, on five out of 13 days. They were recorded eight times from stations 1, 3, 5 and 7 (see figure 12). It was, however, recorded once (7th of June, see figures 10 – 12) from station 3. This species was first recorded on the 7th of June, but was not located again until the 26th of September. Two male individuals of the species *Breviceps acutirostris* were found at station 7, calling from a rocky perch on a very cold and misty day (17th of October). This species also has a narrower temperature range (figure 10) than *B. montanus.*

Arthroleptella landdrosia was present at two out of seven stations. On two out of 13 days they were recorded on three occasions from stations 2 and 3 (see figure 12). This is where the only specimen was found (see figure 4). It would also seem that *A. landdrosia* only become active at high precipitation levels (7th June) or when the mists in the area is heavy as on the 25th October. The temperature range as well as the rainfall activity patterns for this species is narrower than it is for its sister species *A. villiersi* (figure 10 and 11).

Heleophryne purcelli was present at one out of seven stations. On one out of 13 days it was recorded at station 7 (see figure 12). The individual was found on the substrate of a still pool on the 10th of October (see figure 12 for details on climate). No real activity was displayed as this frog was basking in the sun. This was an unexpected find as this species is thought to be adapted to fast flowing streams and water flow at site 7 at this time was negligible.

It would thus seem that from these data that the most frequently recorded species in this area is the riparian species *Afrana fuscigula*, followed by two terrestrial breeders, the moss frog *Arthroleptella villiersi* and the rain frog *Breviceps montanus*. Ratings of other frogs can be seen in table 10. Ratings were assigned as follows: most frequently encountered frogs were assigned a 3 and less frequent frogs were assigned a 1.

Table 10. Scores of most common species found in the study site.

Species	# of Days / 13	# of observations at stations	Individuals	Ratings
Afrana fuscigula	10	22	177	3
Arthroleptella villiersi	10	20	120	3
Breviceps montanus	7	15	96	2
Strongylopus grayii	7	7	23	2
Breviceps acutirostris	4	8	73	2
Arthroleptella landdrosia	2	3	3	1
Heleophryne purcelli	1	1	1	0

3.2 Tadpoles

Tadpoles were first sighted in station 6 on the 1st of July (table 11); perhaps not surprising they were *Afrana* tadpoles. At a later date *Afrana* and *Strongylopus bonaespei* tadpoles were recorded at both stations 6 and 7, in later stages of development. The location of *Strongylopus bonaespei* tadpoles was quite surprising, as this riparian species was never heard calling at either station 6 or 7. However, S*trongylopus bonaespei* was heard calling early in the season of 2002 (June).

Table 11. Tadpoles found at stations 6 and 7, with the date and the stages at the time of location.

Date	Station	Species	Stage
1-Jul-01	6	*Afrana fuscigula*	25
	7	*Afrana fuscigula*	25
19-Sep-01	6	*Afrana fuscigula*	34
			36
			37
			42
		Strongylopus bonaespei	39
			41
10-Oct-01	7	*Strongylopus bonaespei*	40
			41
			42
			43
18-Oct-01	7	*Strongylopus bonaespei*	45

3.3 Vocalisation

Frogs were heard calling from all the stations (figure 12) at most of the times during the study period. *Strongylopus grayii*, *Arthroleptella villiersi* and *Afrana fuscigula* were heard calling in the general study area from May on a preliminary visit to the study site. Various species were found to dominate certain areas according to their habitat preferences and the suitability of the habitat to the requirements of the particular species. For example at station 1 *Arthroleptella villiersi* was the dominant species and was heard calling from this station throughout the study period until the 27th September. Some species, such as *Breviceps acutirostris* and *Arthroleptella landdrosia*, would only start calling after a certain period, making it seem that a certain threshold of either temperature or more likely moisture needs to be reached before calling commences. It is unfortunate that I cannot show the effects of mist or have a value for the amount of mist experienced in this mountain range as observations show that mists in this region play a crucial role in the activities of frogs that are not active when there is a drop in the rainfall, especially with species such as *Breviceps acutirostris* and *Arthroleptella landdrosia*. These species were observed calling when the mists in the study area and surroundings were heavy, even though there was no actual rainfall. It was noted that most species in the study area would not call when the temperature was below 5 °C. They would start calling as soon as the temperature in the daytime was above this and end as soon as the night temperature would drop below this, as it normally does in the mountain. These frogs were observed to stop calling during hailstorms, as on the 26th September. At the other end of the spectrum *Afrana fuscigula* is the only species of frog that was active when temperatures were above 20 °C, as on the 10th October (figure 12).

4 DISCUSSION

4.1 Climate – Temperature and Rainfall

Conditions experienced in the Landdroskop mountain range were typical of mountain environments with regards to temperature and rainfall. Some visits to the study site proved to be quite challenging as adverse weather conditions made it impossible to go out into the field for data collection. On at least two occasions, 18 – 19 August and 27 – 28 August, collectors were unable to leave the base hut due to inclement weather conditions without risk to personal safety. This is also one of the few areas in the western Cape to receive snow in the wintertime, usually lasting for about two weeks at a time (Meyer and du Preez, 2000). Some visits to the study site were postponed during the winter months when snowfall was predicted for the area. Additionally, between July and August 2001 the heavy rains washed several stretches of the access road away.

Between-station variability with regards to weather conditions was negligible on any particular day. Where same day temperature differences among the various stations were observed, could be due to the differences in a combination of the amount of vegetation cover, the degree of exposure or protection from the wind and the proximity of water. *Afrana fuscigula* individuals were observed retreating under riverbanks on the colder days experienced in the field. As was reported temperature drops in the region were often rapid and when temperatures reached 5 °C, frog calling ceased and no tadpole activity was observed in the pools. The fact that water temperature, in general, was relatively stable I did not use this in my analysis of its effect on calling. This is due to the fact that when frogs call, they are not submerged in water but rather they are found on the banks of the river or clinging to vegetation. This and the activity/temperatures patterns presented suggest that even in these winter-breeding frogs there exists a minimum temperature below which all activity ceases. However, it is not clear where these frogs go or what they do to avoid the cold or snow. It is not known either whether these frogs like *Rana sylvatica* induce freeze inoculation (Costanzo *et. al.*, 1999). Navas (1996) claims that the range of body temperatures experienced by high elevation frogs in the Andean mountains is linked to the interaction between the microhabitat and the time of day that the amphibian is active. This could be true for these frogs but there is no direct evidence for this other than that these frogs would not be active after a certain temperature (~ 4 °C) and that tadpoles in the field would be found under the riverbanks.

4.2. Frogs

In general frogs were found in the whole study area where there was suitable habitat to fulfill their specific life cycle requirements. Eight out of the twelve expected species were found in the study area. The riparian species, *Afrana fuscigula*, *Strongylopus bonaespei*, *S. grayii* and *Heleophryne purcelli*, were found or heard calling in close proximity to water at all times. The terrestrial species, *Arthroleptella landdrosia*, *A. villiersi*, *Breviceps acutirostris* and *B. montanus*, were found or heard calling close to the type of habitats that are utilised by these frogs for breeding.

Afrana fuscigula is a riparian species and is found wherever there is a water body present. At all five stations where this species was present, 1, 4, 5, 6 and 7, standing pools were present for at least part of the year, providing suitable habitat for this riparian species. At stations 4, 6 and 7 the pools were permanent throughout the study period whereas at stations 1 and 5 they are seasonal occurring only in the rainy season between May and August. This species was found in higher densities at stations 6 and 7, which are permanent water bodies, than at the other stations as they have a high affiliation for water and their life history from embryo to adult is associated with it. Their need for relatively permanent water bodies could be a possible reason for its disappearance from station 1 after 10th October, when the lack of rain early in October and the warmer temperatures caused the pools to dry up and at station 5 the pools were stagnant at this time. However, as this species was only found at station 5 on two occasions (19th September and 10th October), it could mean that these frogs were not using this station for breeding. Interestingly, although station 4 appeared to be a suitable breeding site for this species and adults were usually present no breeding activity was observed here. Most of the frogs observed in this station were basking in the sun, either on the banks or in the water. The reason that these frogs did not use this station for breeding is not clear. The pool is relatively deep and as their eggs sink to the bottom of the pool once laid and tadpoles are bottom feeders (Channing, 1979), the over flow in the rainy season would not be sufficient to wash the eggs or larvae away. Basking activity was noted in the other stations as well for this species on the warmer days, for example in some stations individuals would bask on the rocks in the middle of a pool or hanging onto the vegetation with their limbs extended (figure 13). Basking behaviour is utilised by other frogs in tropical high altitude regions as well to maintain body temperatures (Bradford, 1984). A study by Navas (1996) reported that frogs associated with water bodies experience lower fluctuations in temperature than do terrestrial frogs. On the colder days

(a)

(b)

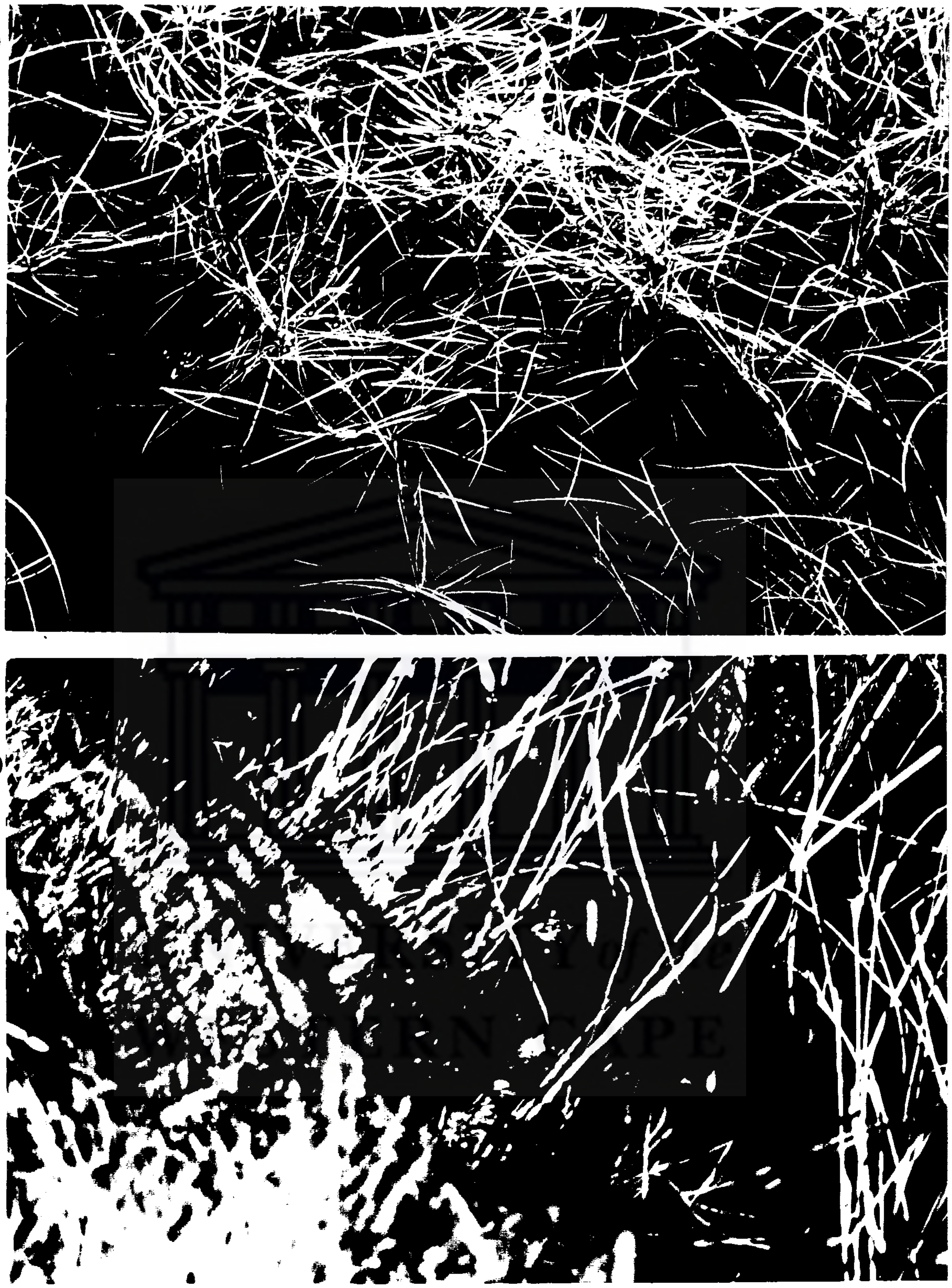

Figure 13. (a) *Afrana fuscigula* basking in the sun with its limbs extended between vegetation in the water. (b) *A. fuscigula* basking on a twig.

in the study area these frogs were observed thermoregulating by retreating under the banks of rivers.

Arthroleptella villiersi is found in seepage areas where the rainfall is high. They are winter breeders and are found on the Cape Fold Mountains as well as a population in the coastal strip near Rooi Els (Channing *et. al.*, 1994; Channing, 2001). This species is endemic to the southwestern Cape. The stations, 1 and 5 with the exception of station 2, where this species were found were densely covered in vegetation for most of the study period, hence providing the typical habitat of these moss frogs. The dense vegetation provides good coverage, increases the water holding capacity of the soil and helps to reduce water loss from the soil by lessening the effect of evaporation, thus providing sufficient moisture for extended periods of time. As the life history of this moss frog is not associated with water bodies, these stations, 1 and 5, provided ideal habitat for this frog.

Its disappearance from station 1 after the 27th September is possibly because of the drying up of the soil water in the station, as it was still present in station 5 by the 18th October. This indicates that it is not just temperature but also moisture in the environment that influenced the activity of this species. Also their breeding season is reported as being from July to November (Channing, 2001), which could mean that their calling cessation could just be a reflection that their breeding season has come to an end in station 1, but that moisture levels in station 5 remained sufficient to continue breeding. Station 2 differs from all the other stations where *A. villiersi* was found in several aspects, such as topography, geology and vegetative type and coverage and the moisture holding capacity species occurs in the summer (Channing, 2001). However, I believe that their breeding season occurs when there is sufficient moisture, but this could also be that the mating patterns of this species is a bit obscured as there is insufficient data on the breeding patterns of this species.

Heleophryne purcelli, or Purcell's ghost frog, was located only once throughout the study period and is classified as an incidental find. This is because it was found on a warm day basking on the substrate of a still pool. At the time of this find the water levels in station 7 had dropped considerably and the fact that it was found here cannot elucidate the type of habitat that it occupies in this area or give any indications of when the breeding season of this species takes place. However, the presence of this frog at this station does contradict the fact that it was reported to be restricted to fast flowing streams (van Djik, 1977).

Strongylopus grayii, also known as the clicking stream frog, has a more diverse distribution pattern than *A. fuscigula*, but in many instances it is found sympatric to *A. fuscigula* (van Djik, 1977). This species has little to no webbing on the toes (Channing, 1979), which helped to distinguish whether certain non-calling individuals were *Afrana* or *Strongylopus* (descriptions of the morphology can be found in Channing, 2001). As this species is represented in such a broad band in southern Africa and is also found at all altitudes, it has been suggested by Channing (1979) that *S. grayii* is a good colonising species. These frogs were present in stations 5, 6 and 7 and the common characteristics of these stations have been described above. This riparian species, however, is more cryptic and specialised than *Afrana fuscigula* and thus is not as common. This riparian species was not present in station 1 and this could be because this station does not have suitable habitat for this riparian species, whereas station 5 has some permanent water bodies on its periphery where these frogs were always heard calling. These frogs are reported to start calling before the winter rains set in (Channing, 2001) and was calling since the preliminary visit in April. The mode of breeding is described as incipient extra aquatic development, where eggs are laid in strings at the water's surface in shallow water, in shady sites under leaves of humus and under leaves (van Dijk, 1971; Channing, 1979). Unfortunately these frogs were never encountered in the field and none of the tadpoles either.

Strongylopus bonaespei adults, were never encountered during the study period, however, tadpoles were found in stations 6 and 7 on various occasions. The distribution of this species' tadpoles suggests that these frogs share similar patterns to that of *Afrana fuscigula*. However, on a visit to the study site in June 2002, this species was heard calling and an individual was observed in station 6.

4.3 Tadpoles

It is unfortunate that no tadpoles of the terrestrially breeding frogs were located to clarify more about these frogs' life history. However, the fact that aquatic tadpoles were found is not surprising as these types of tadpoles are usually the easiest to find. The different age groups could signify various clutches of offspring as it is reported that the *A. fuscigula* tadpoles could take anywhere between three months and three years to reach maturity (Channing, 2001). However, the drop in the water levels in summer would probably ensure that the tadpoles in this area would metamorphose faster as the ponds dry out. When there is plenty of water available for the tadpoles, a long tadpole stage is expected. *Strongylopus bonaespei* tadpoles reach maturity within a few weeks (Channing, pers. com.), so this could signify that all tadpoles of this species were from this breeding season. These tadpoles were usually found cohabiting the same pools and it is impossible to distinguish one species from the other by just looking at them in the water. Both species of tadpoles are what van Djik (1972) terms bottom dwelling or benthic and they have all the morphological traits associated with this type of behaviour. These tadpoles also displayed thermoregulatory behaviour, even though it is not as in *Bufo rufus* where the tadpoles will aggregate for both predator avoidance and thermoregulation (Eterovick and Sazima, 1999). In these species, however, the tadpoles would not aggregate but tend to orientate themselves under the riverbanks where the ambient water temperature would usually be higher than the temperature of the waters closer to the center of the pools. There did not seem to be any segregation of the age classes whilst thermoregulating as in *Rana catesbeiana* (Hutchison and Hill, 1977), where the different age classes display different preferred mean temperature and acclimation temperatures under laboratory conditions. No parental care was observed in these species and I would think that as in all other explosive breeding frogs it is to be expected.

The identification of *Strongylopus bonaespei* tadpoles is according to the description given in Greig *et. al*. (1979). This method was followed because most of the tadpoles were in the later stages of development and the bands on the tibia were already visible and easy to use as this feature helps to distinguish this species from *Strongylopus grayii*.

4.4 Vocalisation

As vocalisation usually indicates the start of the breeding season, it could be assumed that the breeding season for *Afrana fuscigula*, *Strongylopus grayii* and *Arthroleptella villiersi* started in April or May after the first heavy rains were experienced. It would seem that for *Breviceps montanus*, *B. acutirostris, Strongylopus bonaespei* and *Arthroleptella landdrosia* the breeding season started in June or July depending on the amount of moisture present. However, after analysing the data, it is indicated that there were no differences in preferred temperature and precipitation levels between *Breviceps spp*., *Arthroleptella spp*. and *Strongylopus spp*. It is not clear from the data collected what factors are responsible for the commencement of calling. There are many suggestions as to why and how frogs start calling (Duellman and Trueb, 1986; Stebbins and Cohen, 1995; Brooke *et. al*., 2000), it could be that the first rainfall acted as an initiating mechanism as well as the drop in temperature. Minter (1995) showed that for *Breviceps adspersus* call duration and call rate are strongly correlated to the air temperature and that they only commence calling after some form of precipitation is experienced. This is the same scenario that was observed by the *Breviceps spp*. found in this area. However, the temperature readings in the field for this species were lower than that recorded for the species used in the study by Minter (1995) this is due to the fact that the study area used lie in the summer rainfall region of South Africa.

The calls first heard during preliminary visits to the study site could be an indication that the different species were calling to attract the females to the breeding sites. This would then fit the reproductive isolating mechanism hypothesis suggested by Blair (1958), where the males start calling early in the season to ensure breeding success (Gerhardt, 1994). It is also known that frogs call from the beginning, throughout and at the end of the breeding season, this was clearly evident in all groups in this study. The continuance of calling could indicate a seasonal pattern of breeding in the winter season however, it could mean that when conditions are suitable, frogs will continue to breed as with *Afrana fuscigula,* that was still calling in October. It was noted in the field that frogs would stop calling in the field after a certain time and also when temperatures reached a certain minimum temperature (~ 5 °C), which usually occurred at night. As frogs are ectothermic, energy levels are too low to allow calling after this minimum ambient temperature. Navas (1996) reports that high altitude amphibians have a tendency towards being diurnal as this is when the temperatures are most suitable for them to have at least some form of control over body temperature. All the frogs found in this study area display a diurnal activity pattern.

The breeding times of *Heleophryne purcelli* are uncertain, as only one basking individual was located throughout the study (10^{th} October).

5 CONCLUSIONS

5.1 Monitoring Implications

Monitoring of herpetofauna has increased rapidly in the last two decades. Since 1989 (Barinaga, 1990), there has been an urgency to collect as much information as possible to preserve the herpetofauna of the world and where there was little known to gather as much information as possible. Many programs have been set up where herpetologists gather information to produce long-term data sets, as these are vital when setting up a monitoring program (Blaustein, *et. al.*, 1993) as they can give an indication of the natural cycles that occur in a population. Spellerberg (1991) lists a whole range of biological variables and processes that can be measured in order to set up a monitoring program, which includes species lists, occurrence of indicator species and rare species, as well as various other aspects that can be used.

Amphibian monitoring is very important, as there are many traits of these animals that can be associated with the health of the environment (Beebee, 1996). The semi-permeable skin of the adults and the aquatic tadpoles are useful indicators when testing for various pollutants and excessive radiation levels, especially in high altitude amphibians.

Pechmann *et. al.* (1991) states that the lack of long-term census data is one of the primary factors that hampers the setting up of monitoring programs in most instances.

The data gathered in this project could serve as baseline data for the establishment of a monitoring program in this area, Landdroskop mountain range, by considering their breeding periods, their calling times and the status of the tadpoles. A species list made up from all available data has been set up (table 4) and there are seven terrestrial, two marsh and three riparian species of frog in this area. As there is such high diversity in this area these frogs can be used in monitoring the environment as well. The most frequently encountered riparian species, *A.fuscigula*, can be used to monitor the health of the immediate environment surrounding the permanent water bodies. As *A. fuscigula* tadpoles have a larval stage, ranging between three months and three years depending on the availability of resources (Channing, 2001) these tadpoles can act as indicators to water quality (Chaning, 1998). Terrestrial species such as *Arthroleptella villiersi* and *Breviceps montanus* could be used to monitor the environment. It should be noted that monitoring of amphibians in this region should take place in the breeding season of the amphibians or frogs, as this is the only time that the frogs are visible. As comprehensive species lists of the frogs found in this region have already been compiled (Baard *et. al.*, 1999; Meyer and du Preez, 2000) and some baseline work has been done on the breeding ecology of these frogs (Channing, 2001 and this study), researchers or conservationists to the area can now start implementing monitoring that has been suggested by Cape Nature Conservation (Meyer and du Preez, 2000). This monitoring program should, however, not be exclusive to the most frequently encountered species, but should include species such as the Landdroskop moss frog, *Arthroleptella landdrosia*, and the Cape mountain toad, *Capensibufo rosei*, or the voiceless toad, which was not found in this study, but was found on a latter visit to the study site.

5.2 Conservation Recommendations

The high diversity of frogs in this area has been listed by Baard *et. al.* (1999) and it has been noted that it should be considered as a high conservation priority as recently described species, for example *Pseudocordylus nebulosus* – a crag lizard, *Arthroleptella landdrosia* – a moss frog and *Capensibufo rosei* – the Cape mountain toad are already at risk. However, currently the frogs found in this area do not seem to be in any immediate danger of over-exploitation of species, by diseases – even though there are tests for the chytrid fungus being done on the riparian species – pollution and habitat encroachment by humans. This tends to make one wonder why these recently described species, the crag lizard, the moss frog and the Cape mountain frog, are at risk if there are no definitive reasons. One possible reason given by Baard *et. al.*(1999), is that the area is easily accessible to hikers and most of the breeding areas is situated on or in relatively close proximity to the hiking trails.

Recommendation 1:

Population counts should be done during the breeding season, as these anurans are basically active and visible at this time.

Recommendation 2:

Stricter control should be practiced at this time of year, during the winter months, where essentially access to the mountain range is stopped until the breeding season has ended or unless otherwise decided by Western Cape Nature Conservation Board. This would ensure an uninterrupted breeding cycle as well as the survival of the larvae.

Recommendation 3:

I would highly recommend that certain areas be off limits to all hikers and people who use the facilities provided, because even though frogs will breed in the presence of humans, inadvertent habitat destruction and pollution are potential problems that could have many adverse effects both terrestrially and aquatically.

Recommendation 4:

It is highly advisable to keep a close eye on climate changes in the region as these frogs' life histories are closely linked to their ambient environment as well as their habitat. In order to fulfill this criterion I recommend that a weather station be placed in this mountain region, Landdroskop mountain range.

Recommendation 5:

I would suggest that census of calling frogs be taken at least on a weekly basis during the breeding season so that long term data sets can be produced. This data can eventually show the natural cycles that take place in the population or whether these populations are being threatened, once the data sets are large enough.

5.3 Future Work

There is very little known about the frogs found in this region, thus this study serves as a basis for future work. There are not many people that are doing work on these animals; hence it is vital that more people become involved. The diversity found in this region allows for much work to be carried out as the life histories of these frogs are not really well known or understood. I think this region would be an appropriate site to study the life histories, as well as the environmental effects on the frogs, as this area is in the confines of a Nature Reserve.

At present there is a German working group in East and West Africa, Madagascar, SE Asia / Australasia and South America called the Global Amphibian Diversity Analysis Group (GADAG). They are trying to implement standardised methodologies, including demographic and genetic population parameters, for monitoring projects (GADAG, 2002). In Cape Town there is a group working on the Frog Atlas Project that aims to map the distribution of frogs in southern Africa. Unfortunately, my project does not give any other details about the life histories of these frogs. This too serves as a baseline for work in the western Cape. However, it would be advisable to get in contact with GADAG to perhaps implement a standardised monitoring protocol.

Other interesting factors that could be investigated about these frogs are the activities employed to avoid the cold. It is already known that the tadpoles do not aggregate to thermoregulate but retreat under banks of pools or streams, but it is not clear as to the behaviour of the adult frogs. Since some of these species are not confined to this high altitude but do occur lower down on the mountain studies would be interesting to find if there is any physiological variation between the populations found here.

Very little is known about the breeding activities of *Breviceps spp.* other than the detailed work done by Minter (1995). It would thus be valuable if some effort were made to find out more about these frogs by studying these frogs in this area.

6 REFERENCES

1. Alford, R.A. & Richards, S. J. 1999. Global Amphibian Declines: A Problem in Applied Ecology. *Annual Review of Ecology and Systematics* 30: 133-165.

2. Baard, E. H. W., Branch, W. R., Channing, A. C., de Villiers, A. L., le Roux, A. and Mouton, P. le Fras. N. 1999. A review of the amphibians and reptiles in the Cape Floristic Region as indicators of centers of biodiversity, sensitive habitats and sites of special interest. Cape Nature Conservation. Published Report.

3. Backwell, P. R. Y. and Passmore, N. I. 1990. Aggressive interactions and intermale spacing in choruses of the leaf-folding frog, *Afrixalus delicatus*. *South African Journal of Zoolology* 25: 133-137.

4. Barinaga, M. 1990. Where have all the froggies gone? *Science* 247: 1033-1034.

5. Bee, M. A., Perrill, S. A. and Owen, P.C. 2000. Male green frogs lower the pitch of acoustic signals in defense of territories: a possible dishonest signal of size? *Behavioral Ecology* 11:169-177.

6. Bee, M. A., Kozich, C. E., Blackwell, K. J. and Gerhardt, H. C. 2001. Individual Variation in Advertisement Calls of Territorial Male Green Frogs, *Rana clamitans*: Implications for Individual Discrimination. *Ethology* 107: 65-84.

7. Beebee, T. J. C. 1996. *Ecology and Conservation of Amphibians*. Chapman and Hall. London.

8. Begon, M., Harper, J. L. and Townsend, C. R. 1986. *Ecology: Individuals, Populations and Communities 2nd Ed.* Blackwell Science. Massachusetts.

9. Berger, L., Speare, R., Daszak, P., Green, D. E., Cunningham, A. A., Goggin, C. L., Slocombe, R., Ragan, M. A., Hyatt, A. D., McDonald, K. R., Hines, H. B., Lips, K. R., Marantelli, G. and Parkes, H. 1998. Chytridiomycosis causes amphibian mortality associated with population declines in the rainforests of Australia and Central America. *Proceedings of the National Academy Science*, USA. 95: 9031-9036.

10. Blair, W. F. 1958. Mating Call in the Speciation of Anuran Amphibians. *The American Naturalist* 92: 27-51.

11. Blaustein, A.R., Wake, D. B. & Sousa, W.P. 1993. Amphibian Declines: Judging Stability, Persistence and Susceptibility of Populations to Local and Global Extinctions. *Conservation Biology*. 8: 60-71.

12. Blaustein, A.R., Hoffmann, P.D., Hokit, D.G., Kiesecker, J.M., Walls, S.C. & Hays, J.B. 1994. UV repair and resistance to solar UV-B in amphibian eggs: A link to population declines. *Proceedings of the National Academy Science*, USA. 91: 1791-1795.

13. Bogart, J. P. 1981. How Many Times has Terrestrial Breeding Evolved in Anuran Amphibians. *Monitore zoologico Italiano* (N. S.) Suppl.15 3:29-40.

14. Bradford, D. F. 1984. Temperature Modulation in a High-elevation Amphibian, *Rana muscosa*. *Copeia* 4: 966-976.

15. Bradford, D. F. 1991. Mass Mortality and Extinction in a High-elevation Population of *Rana muscosa*. *Journal of Herpetology* 25: 174-177.

16. Bradford, D.F., Swanson, C. & Gordon, M.S. 1992. Effects of Low pH and Aluminium on Two Declining Species of Amphibians in the Sierra Nevada, California. *Journal of Herpetology* 26: 369-377.

17. Brooke, P. N., Alford, R. A. and Schwarzkopf, L. 2000. Environmental and Social Factors Influence Chorusing Behavior in a Tropical Frog: Examining Various Temporal and Spatial Scales. *Behavior, Ecology, Sociobiology* 49: 79-87.

25. Corn, P. S. and Vertucci, F. A. 1992. Descriptive Risk Assessment of the Effects of Acidic Deposition on Rocky Mountain Amphibians. *Journal of Herpetology* 26: 361-369.

26. Costanzo, J. P., Bayuk, J. M. and Lee, R. E. Jr. 1999. Inoculative Freezing by Environmental Ice Nuclei in the Freeze-Tolerant Wood Frog, *Rana sylvatica*. *Journal of Experimental Zoology* 284: 7-14.

27. Dawood, A. & Channing, A. 2000. A Molecular Phylogeny of Moss Frogs from the Western Cape, South Africa, with a Description of a New Species. *Journal of Herpetology* 34: 375-379.

28. Docherty, S., Bishop, P. J. and Passmore, N. I. 2000. Consistency of calling performance in male *Hyperolius marmoratus marmoratus*: implications for male mating success. *African Journal of Herpetology* 49: 43-52.

29. Douglas, T. 1997. Land Use Change in the Sierra Nevada of Southern Spain. *Special Issue on Mountain Regions*. *The Globe* 39:8-9.

30. Duellman, W. E. 1992. Reproductive Strategies of Frogs. *Scientific American*, July 1992: 58-65.

31. Duellman, W. E. 1993. Amphibians in Africa and South America: Evolutionary History and Ecological Comparisons. In *Biological Relationships between Africa and South America*, pp. 200-243. Ed. Goldblatt, P. Yale University Press, New Haven.

32. Duellman, W. E. and Pyles, R. A. 1983. Acoustic Resource Partitioning in Anuran Communities. *Copeia* 3: 639-649.

33. Duellman, W. E. and Trueb, L. 1986. *Biology of Amphibians*. McGraw-Hill Book Company. New York.

34. Emerson, S.B. & Inger, R.F. 1992. The Comparative Ecology of Voiced and Voiceless Bornean Frogs. *Journal of Herpetology* 26: 482-490.

35. Eterovick, P. C. and Sazima, I. 1999. Description of the Tadpole of *Bufo rufus* with Notes on Aggregative Behavior. *Journal of Herpetology* 33: 711-713.

36. Forman, R.T.T. & Alexander, L.E. 1998. Roads and their major Ecological Effects. *Annual Review of Ecological Systematics* 29: 207-231.

37. Global Amphibian Diversity Analysis Group. 2002. http://www.gadag.org

38. Gasith, A. & Resh, V.H. 1999. Streams in Mediterranean Climate Regions: Abiotic Influences and Biotic Responses to Predictable Seasonal Events. *Annual Review of Ecologicy and Systematics* 30: 51-81.

39. Gerhardt, H.C. 1994. The Evolution of Vocalization in Frogs and Toads. *Annual Review of Ecologicy and Systematics* 25: 293-324.

40. Gosner, K. L. 1960. A simplified table for staging anuran embryos and larvae with notes on identification. *Herpetological* 16: 183-190.

41. Greig, J. C., Boycott, R. C. and De Villiers, A. L. 1979. Notes on the elevation of *Rana fasciata montana* Fitzsimmons, 1946 to specific rank, and on the identity of *Rana fasciata sensu* Burchell, 1824 (Anura: Ranidae). *Annals of the Cape Province Museum* (Natural History) Vol.13 Pt 1.

42. Haddad, C. F. B and Giaretta, A. A. 1999. Visual and Acoustic Communication in the Brazilian Torrent Frog, *Hylodes asper* (Anura: Leptodactylidae). *Herpetologica* 55: 324-333.

43. Hellawell, J. M. 1991. Development of a rationale for monitoring. In *Monitoring for Conservation and Ecology*, pp 1 – 14. Ed. F. B. Goldsmith. Chapman and Hall. London.

44. Hero, J. M. 1996. Where are Queensland missing frogs? *Wildlife Australia*. Winter 1996.

45. Hutchison, V. H. and Hill, L. G. 1977. Thermal Selection of Bullfrog Tadpoles (*Rana catesbeiana*) at Different Stages of Development and Acclimation Temperatures. *Journal of Thermal Biology* 3: 57 – 60.

46. Licht, L.E. & Grant, K.P. 1997. The Effects of Ultraviolet Radiation on the Biology of Amphibians. *American Zoology* 37: 137 – 145.

47. Meyer, A. and du Preez, J. 2000. Management Plan of Hottentots Holland Nature Reserve. Unpublished Report.

48. Minter, L. R. 1995. The advertisement call and other aspects of the reproductive biology of *Breviceps adspersus* Peters (Anura, Microhylidae). *Madoqua* 19: 37-44.

49. Navas, C.A. 1996. Implications of microhabitat selection and patterns of activity on the thermal ecology of high elevation neotropical anurans. *Oecologica* 108: 617 – 626.

50. Navas, C.A. 1997. Thermal extremes at High Elevations in the Andes: Physiological Ecology of frogs. *Journal of Thermal Biology* 22: 467 – 477.

51. Newmark, W. D. 2002. *Conserving Biodiversity in East African Forests: A Study of the Eastern Arc Mountains*. Springer – Verlag. Berlin.

52. Ovaska, K. and Hunte, W. 1992. Male mating behavior of the frog *Eleutherodactylus johnstonei* (Leptodactylidae) in Barbados, West Indies. *Herpetologica* 48: 40 – 49.

53. Parish, R. and Funnell, D. C. 1999. Climate Change in Mountain Regions: Some Possible Consequences in the Moroccan High Atlas. *Global Environmental Change* 9: 45 – 58.

54. Passmore, N. I. and Carruthers, V. C. 1979. *South African Frogs*. Witwatersrand University Press.

55. Pechmann, J. H. K., Scott, D.E., Semlitsch, R.D., Caldwell, J.P., Vitt, L.J. & Gibbons, W. 1991. Declining Amphibian Populations: The Problem of Separating Human Impacts from Natural Fluctuations. *Science* 253: 892 – 895.

56. Picker, M. 1980. *Xenopus laevis* (Anura: Pipidae) Mating systems – A preliminary synthesis with some data on the female phonoresponse. *Suid Afrikaanse Tydskrif vir Dierkunde* 15: 150 – 158.

57. Price, M. 1997. Special Issue on Mountain Regions: Introduction. *The Globe* 39.

58. Schiøtz, A. 1973. Evolution of anuran mating calls. Ecological aspects. In *Evolutionary Biology of the Anurans: Contemporary Research On Major Problems*, pp. 311-319. Ed. Vial, J. L. University of Missouri Press, Colombia.

59. Siegel, S. 1956. *Nonparametric Statistics for the behavioral sciences*. McGraw – Hill Kogakusha, LTD. Tokyo.

60. Sinsch, U. 1989. Behavioral thermoregulation of the Andean toad (*Bufo spinulosus*) at high altitudes. *Oecologica* 80: 32 – 38.

61. Spellerberg, I. 1991. *Monitoring Ecological Change*. Cambridge University Press. New York.

62. Stebbins, R. C. and Cohen, N. W. 1995. *A Natural History of Amphibians*. Princeton University Press. New Jersey.

63. Stewart, M. M. and Rand, A. S. 1991. Vocalization and the Defense of Retreat Sites by Male and Female Frogs, *Eleutherodactylus coqui*. *Copeia* (4): 1013 – 1024.

64. Stewart, M. M. and Rand, A. S. 1992. Diel Variation in the use of Aggressive Calls by the Frog *Eleutherodactylus coqui*. *Herpetologica* 48(1): 49 – 56.

65. Straughan, I. R. 1973. Evolution of anuran mating calls: Bioacoustical aspects. In *Evolutionary Biology of the Anurans*. Ed. Vial, J. L. University of Missouri Press, Columbia.

66. Tracy, C. R., Tracy, C. R. and Turner, J. S. 1992. Contrasting Physiological Abilities for Heating and Cooling in an Amphibian (*Rana pipiens*) and a Reptile (*Sauromalus obesus*). *Herpetologica* 48 (1): 57 – 60.

67. Usher, M. B. 1991. Scientific requirements of a monitoring programme. In *Monitoring for Conservation and Ecology*, pp 15 – 32. Ed. F. B. Goldsmith. Chapman and Hall. London.

68. Van Dijk, D. E. 1966. Systematic and field keys to families, genera and described species of southern African tadpoles. *Annals of the Natal Museum* 18: 231-286.

69. Van Dijk, D.E. 1971. Anuran Ecology in Relation Particularly to Oviposition and Development Out of Water. *Zoologica Africana* 6: 119 – 132.

70. Van Dijk, D.E. 1972. The Behaviour of Southern African Anuran Tadpoles with Particular Reference to their Ecology and Related External Morphological Features. *Zoologica Africana* 7: 49 – 55.

71. Van Djik, D. E. 1977. Habitats and Dispersal of southern African Anura. *Zoologica Africana* 12(1): 169 –181.

72. Van Djik, D. E. 1981. Some problems during a study of the literature on African anura. *Monitore Zoolologico Italiano* 22: 401 – 408.