COMPARISONS OF THE CLIMATES OF THE TWO HABITATS OF HAMILTON'S FROG (*LEIOPELMA HAMILTONI* (McCULLOCH))

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SUMMARY: Comparisons of climate data from the two known habitats of *Leiopelma hamiltoni* (a small deforested rock tumble near the summit of Stephens Island called the "frog bank" and a forest remnant on Maud Island) show that the two are remarkably similar, apart from greater extremes of temperature and humidity occurring at the open rock surface of the frog bank than on the surface of the Maud Island habitat. Furthermore, the air space between the rocks of the frog bank is significantly cooler, more humid and subject to less temperature fluctuation than the surface. The frogs, being nocturnal, shelter under these rocks during the day. This habit and the climate of the frog bank are the major factors permitting the survival of the frog on Stephens Island since the frog bank lost its forest cover. Climate data from a nearby remnant of the original forest suggest that the Stephens Island habitat would have been more suitable for frogs in its original forested form than in its present state. Although grasses and *Muehlenbeckia* vines are encroaching onto the frog bank and creating a more favourable micro-climate at the habitat's surface, such cover may eventually restrict the access of frogs to sheltering rock crevices.

INTRODUCTION

Hamilton's frog (*Leiopelma hamiltoni* (McCulloch, 1919)), one of three extant species of the endemic family Leiopelmatidae, is known to occur only on two islands: Stephens Island, 40° 40' S, 174° 00' E, in Cook Strait. where it is confined to a small (< 0.25 ha) rock tumble near the island's summit (300 m) called the "frog bank"; and Maud Island, 41° 02' S, 173° 54' E, in the Marlborough Sounds, where it is restricted to a 15 ha remnant of the original coastal forest (Crook *et al.*, 1971).

The frog bank was originally covered by a low but dense forest dominated by kohekohe *(Dysoxylum spectabile)*. This cover disappeared sometime during the period 1915-1927 when browsing by sheep and cattle apparently destroyed much of the forest, opening up the compact canopy and making the remaining patches of bush vulnerable to strong, salt-laden winds. From then until 1951 the bank was virtually devoid of vegetation, but in that year a fence was constructed by Wildlife Service staff to exclude livestock from the vicinity of the frog habitat. A plant cover of grasses and *Muehlenbeckia* vines (probably hybrids of *M. complexa* and *M. australis)* has since encroached onto the bank and an area of only about 20 m^2 now remains uncovered.

The effects of deforestation cannot be assessed in detail, but Crook *et al.* (1971) suggested two possible reasons for survival of the frog. Firstly, although the annual rainfall on the island averages only 863 mm, clouds tend to envelop the summit (and frog bank), helping to maintain moist conditions. Secondly, the layer of rocks or talus may have originated from slumping or block-sliding of the summit ridge. If this is so, rocky fissures may extend to considerable depth down the scarp face of the slump, thus providing a deep refuge for the frogs during droughts.

To examine these two hypotheses, and to gauge the effects of vegetation changes on the climate of the frog bank, comparative measurements were made of temperatures and humidities in different parts of this slowly changing habitat: on the surface of rocks and beneath them; below *Muehlenbeckia* vines that cover much of the bank; and on the ground in a forest remnant less than 100m from the bank. As a basis for comparison, similar measurements were made on the floor of the remnant forest on Maud Island. Finally, measurements were made also under standard meteorological conditions (screens on stands 1 m above ground level) in the vicinity of the two frog habitats.

This study does not claim to be a full analysis of the climate of the two islands and the micro-climates of the frog habitats. This would require the collecting of records over a period of several years from a greater number of recording stations. Rather, the object of collecting climate data has been to set

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broad guidelines for the further management of the frog bank and to aid in the evaluation of other areas that could be used for the establishment of new colonies of Hamilton's frog.

MATERIALS AND METHODS

The climate recording stations

Weekly recording ("kohari" pattern) thermohydrographs, which measure temperature through distortion of a bimetal strip and humidity by means of a hair hydrograph, were enclosed in double-louvred Stephenson screens at the following climate recording stations:

1. Stephens Island lighthouse. 200 m a.s.l. adjacent to the existing meteorological station with the screen at standard height.
2. Stephens Island frog bank basin (Fig. 1). 300 m a.s.l. adjacent to the frog bank with the screen at standard height.
3. Stephens Island frog bank. On the surface of bare rocks on the bank.
4. Stephens Island frog bank. 0.5 m below the surface of bare rocks on the bank.
5. Stephens Island frog bank. On the surface of rock beneath the cover of *Muehlenbeckia* vines.
6. Stephens Island forest floor. 300 m a.s.l. in a grove of remnant forest *ca*. 100 m from the bank.
7. Maud Island homestead. 30 m a.s.l. near a farmhouse with the screen at standard height.
8. Maud Island forest floor. 90 m a.s.l. on ground surface.

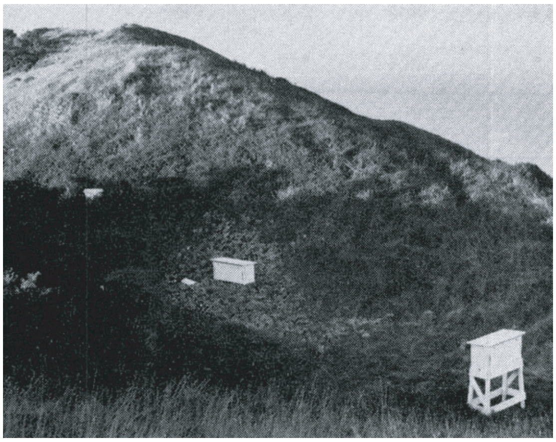

FIGURE 1. *Stephens Island frog bank showing part of the climate-measuring equipment. Screens from left to right: stations* 5,4,3 *and* 2 *(on stand).*

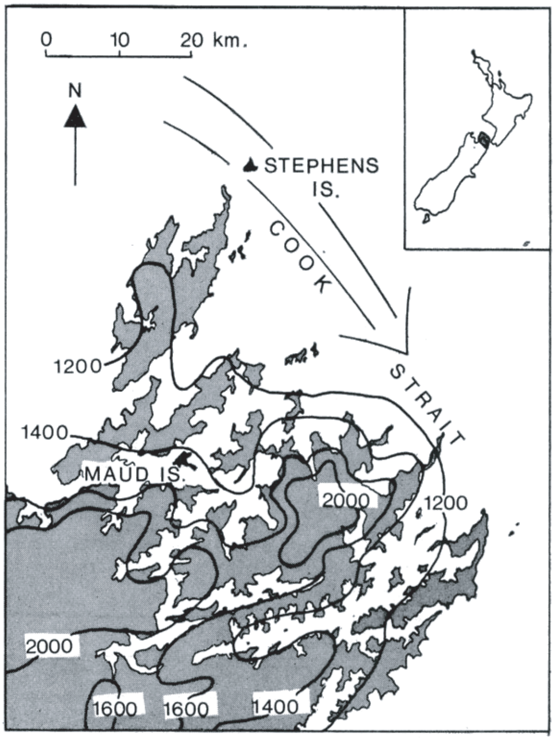

FIGURE 2. *Locality map showing rainfall in mm (isohyets) and prevailing air flow (arrow).*

Maximum and minimum thermometers were used to calibrate the weekly upper and lower limits of all temperature records. No temperature records were taken at station 5. Humidity records were checked using wet and dry bulb thermometers enclosed with the thermohydrographs.

Data processing

The data analysed in this paper were collected over the 12 month period September 1974 to August 1975.

Daily readings were transcribed from the thermohydrograph charts onto computer punch cards and these were subsequently loaded onto a magnetic tape. The information extracted from each chart for each 24 hour period consisted of:

1. Temperature and relative humidity taken at three-hour intervals.
2. Maximum and minimum temperatures and the times at which these were attained (to the nearest hour).
3. Number of hours when relative humidity exceeded 90%.

TABLE 1. *Mean seasonal temperature and relative humidity values recorded at the surface of the frog bank (station* 3) *and at the floor of the Maud Island remnant forest (station* 8).

	Temperature °C			Relative humidity%		
Season	Stephens Island	Significance	Maud Island	Stephens Island	Significance	Maud Island
SPRING						
Sep-Nov 1974	12.0		12.3	91.5		91.2
SUMMER						
Dec 1974-Feb 1975	18.0		17.9	87.1		87.5
AUTUMN						
Mar-May 1975	14.0	*	14.4	90.2	*	91.7
WINTER						
June-Aug 1975	8.3		8.6	88.4	***	91.9

* = p < 0.01, ** = p < 0.005, *.. = p < 0.001

TABLE 2. *Mean day and mean night seasonal temperature and relative humidity values recorded at the surface of the frog bank (station* 3) *and at the floor of the Maud Island remnant forest (station* 12).

(a) DAY

	Temperature °C			Relative humidity %		
Season	Stephens Island	Significance	Maud Island	Stephens Island	Significance	Maud Island
SPRING						
Sep-Nov 1974	13.4		12.9	87.6		88.5
SUMMER.						
Dec 1974-Feb 1975	20.1	***	18.9	78.8	***	83.1
AUTUMN						
Mar-May 1975	14.8		14.7	86.5	***	90.8
WINTER						
June-Aug 1975	9.1		8.9	86.4	***	92.1

(b) NIGHT

	Temperature °C			Relative humidity %		
Season	Stephens Island	Significance	Maud Island	Stephens Island	Significance	Maud Island
SPRING						
Sep-Nov 1974	10.6	***	11.6	95.4	*	93.9
SUMMER						
Dee 1974-Feb 1975	15.9	***	16.8	95.2	***	91.7
AUTUMN						
Mar-May 1975	13.1	***	14.1	93.7		92.6
WINTER						
June-Aug 1975	7.6	***	8.4	90.4		91.7

* = p < 0.01, ** = p < 0.005, *.. = p < 0.001

To analyse these data a programme was written that enabled us to test differences in climate (using Student's t and F ratio tests) between the various stations within 10-day, 1 month and 3 month time periods.

THE CLIMATES OF THE TWO HABITATS

No matter what the atmospheric conditions, any amphibian out of water will continuously lose water by evaporation through its skin (Porter, 1972); anurans do so at a rate that is nearly inversely proportional to the relative humidity of the ambient atmosphere (Adolph, 1932). As Stephens Island has been deforested, is subject to severe storms, and receives a lower annual rainfall than Maud Island, the frog bank would seem to be the less suitable of the two island habitats (Fig. 2). However, a comparison of records taken on the bare rock surface of the bank and on the forest floor of Maud Island suggests that the climates of the two habitats are very similar, although it is less humid at the bank during winter (Table 1). This similarity of climate is probably created by the topography and altitude of the frog bank, which forms the north-western side of a shallow depression or basin lying just below the summit of Stephens Island. It is thus partially sheltered from the prevailing winds and is often enveloped in cloud (Crook *et al.*, 1971).

The comparison made in Table 1 was repeated separately for "day" values (0900, 1200, 1500 and 1800 hours) and "night" values (2100, 2400, 0300 and 0600 hours) (Table 2). Although cooler and generally more humid than the Maud Island habitat at night, the climate at the bank is warmer and less humid by day. Conditions critical for frog survival, high temperatures coupled with low humidities, are therefore more likely to occur at the Stephens Island habitat.

SPECIAL FEATURES OF THE CLIMATE AT THE FROG BANK

To test the suggestion that the frog bank basin, as a consequence of topography and altitude, experiences a climate not typical of the island as a whole, records taken from this area were contrasted with those collected adjacent to an existing meteorological station operated by the Marine Division close to the lighthouse (Table 3).

The climate of the basin is, as expected, the cooler of the two and, during spring, it was more humid. A higher rainfall was recorded throughout the study period at the basin (914 mm) than at the lighthouse (813 mm). This may have been a consequence of the frequent enveloping of the basin by clouds. Separate comparisons of day and night values of temperature and relative humidity, recorded during summer at stations 1 and 2, show that conditions at station 2 are warmer and less humid during the day but cooler and more humid during the night (Table 4).

In summer, on fine days, the sun beating down on the unprotected rock surface of the bank can cause high temperatures that, when coupled with low humidities, must be approaching limits critical for frog survival. During regular, systematic, night searches, frogs, which are nocturnal, have been found on the surface of the bank when the temperature

TABLE 3. *Mean seasonal temperature and relative humidity values recorded at the frog bank basin (station 2) and at the station adjacent to the lighthouse (station 1) on Stephens Island, both screens at standard height.*

	Temperature °C			Relative humidity %		
Season	Lighthouse	Significance	Frog bank basin	Lighthouse	Significance	Frog bank basin
SPRING						
Sep-Nov 1974	12.9	***	12.0	90.3	***	93.3
SUMMER						
Dec 1974-Feb 1975	17.5		17.8	89.7		88.7
AUTUMN						
Mar-May 1975	15.0	***	14.4	90.1		91.4
WINTER						
June-Aug 1975	9.6	***	8.0	89.3		89.1

* = p < 0.01, ** = p < 0.005, *.. = p < 0.001

TABLE 4. *Mean day and night summer (Dec 1974-Feb 1975) values of temperature and relative humidity recorded at the frog bank basin (station 2) and at the station adjacent to the lighthouse (station* 1) *on Stephens Island, screens at standard height.*

	Temperature °C			Relative humidity %		
Period	Lighthouse	Significance	Frog bank basin	Lighthouse	Significance	Frog bank basin
DAY	18.5	***	19.6	86.6	***	82.7
NIGHT	16.5	***	16.0	92.8	*	94.5

. = p < 0.01, .. = p < 0.005, .** = p < 0.001

(recorded at station 3) has been as low as 4°C, but never when it was higher than 17°C. Throughout this study, the lowest temperature recorded at station 3 was 2°C (21 and 24 July 1975) and the highest was 30°C (4 January 1975). Therefore, summer maxima experienced at this habitat are more likely to be critical for frog survival than are winter minima.

Special Features of the Bank That Have Allowed the Frog to Survive

To support a population of frogs, a habitat such as the bank must provide shelter that will protect individuals from occasional harsh, potentially lethal, atmospheric conditions. Such conditions, on Stephens Island, are most likely to occur in mid-summer.

Throughout the course of this study the warmest and driest period occurred between 1-10 January 1975, during which the highest daily values of temperature and the lowest daily values of humidity were consistently recorded at 1500 hours N.Z.S.T. In an attempt to gauge the degree of 'protection offered to frogs, at this time, by fissures and crevices, the micro-climate recorded 0.5 m below the surface was contrasted with that recorded on the surface (Table 5).

During this period, the temperature was significantly lower and the humidity significantly higher 0.5 m below the surface than on the surface. The depth of the broken rock layer is not known, but it is possible that refuges deeper than 0.5 m could be even cooler and more moist. When sheltering through the day, frogs may descend to near the base of the rock layer during the hottest, driest, periods and gradually ascend as conditions become cooler and more moist. The layer of broken rock and the climate of the bank are, therefore. probably the most important features of the Stephens Island habitat allowing survival of the frogs.

The importance of the rock layer can be further emphasised by considering the apparent absence of frogs from a small area of remnant forest less than 100 m from the bank. Although experiencing a climate apparently suitable for survival, this forest lacks a rocky ground cover which could shelter frogs, not only from adverse weather, but also from predatory tuataras *(Sphenodon punctatus)* (Newman, 1977).

TABLE 5. *Mean temperature and relative humidity values recorded at 1500 hours during the period 1-10 January 1975 at stations on (station 3) and under (station* 4) *the surface of the frog bank, Stephens Island.*

	On surface of frog bank	Significance	0.5 m below surface of frog bank
Temperature °C	26.2	***	21.5
Relative humidity %	52.4	*	68.6

. = p < 0.01, .. = p < 0.005, .** = p < 0.001

EFFECTS OF VEGETATION CHANGES ON THE FROG BANK

The effects of deforestation can be gauged, to some extent, by comparing the climate at the surface of the bank with that at the floor of the nearby

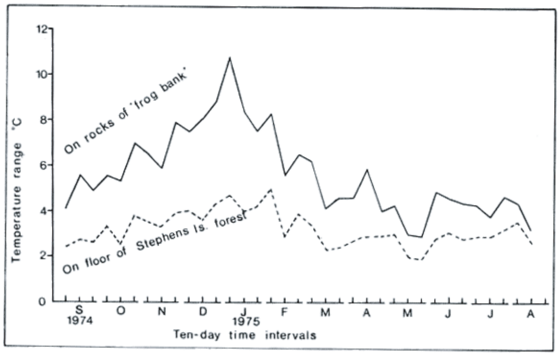

FIGURE 3. *Mean temperature ranges for 10-day periods (mean of differences between daily maximum and minimum temperatures) between September* 1974 *and August* 1975 *recorded at the unprotected surface of the frog bank (station* 3) *and at the floor of the remnant forest (station* 6) *on Stephens Island.*

remnant forest. Mean temperature ranges between daily maximum and minimum values are much wider on the unprotected surface of the bank (Fig. 3). Differences between the climates at the two sites are particularly marked in mid-summer. During this period, probably the most critical for frog survival, conditions at the forest floor are significantly cooler and more humid than those at the surface of the bank (Table 6).

To assess the effect of encroaching *Muehlenbeckia* vines on the climate at the surface of the bank, records taken under the vines have been compared with records from the surface of the bank and from the floor of the nearby forest. Between 1 and 10 January 1975 humidity under the *Muehlenbeckia* (61.0%) was higher than that on the bare rock surface (52.4 %, $p > 0.10$) but still very much lower than that recorded on the floor of the nearby forest (75.1 %, $p < 0.01$). Thus, while the encroaching *Muehlenbeckia* is influencing the climate at the surface of the bank by increasing humidity (and probably decreasing temperature fluctuations), it is not as effective in this function as would be a closed-canopied forest.

DISCUSSION

Regarding the frog's survival in its modified Stephens Island habitat, climate data support the two hypotheses proposed by Crook *et al.* (1971). The data indicate:

(a) that the climate at the bank, probably as a consequence of its altitude and topography, is similar to that occurring in the Maud Island forest, though greater extremes of temperature and humidity occur at the bank, and

(b) that the micro-climate 0.5 m below the surface of the bank is cooler, more humid and subject to less temperature fluctuation than that occurring on the surface.

Data also suggest that temperature and humidity extremes became greater at the bank following removal of the original forest and thus justify the existing management plan for Stephens Island which aims at the habitat's reafforestation.

It will obviously take some time to implement the management plan, but meanwhile encroaching grasses and *Muehlenbeckia* vines are having a beneficial effect on the surface micro-climate by raising humidity and probably reducing temperature fluctuations. Such cover, through its associated invertebrate fauna, may also increase the abundance and diversity of food species available to frogs. A thick mat of detritus, reinforced by vines, may develop beneath this cover and provide a suitable substrate for shade-tolerant forest seedlings. Such a mat may, however, restrict the access of frogs to sheltering rock crevices, and thick stands of *Muehlenbeckia* could actually choke the development of desirable seedlings. Perhaps the best short-term management

TABLE 6. *Mean temperature and relative humidity values recorded at 1500 hours during the period 1-10 January 1975 at the station on the surface of the frog bank and at that on the floor of the nearby remnant forest. Stephens Island.*

	On frog bank surface	Significance	On forest floor
Temperature °C	26.2	***	19.9
Relative humidity %	52.4	***	75.1

. = $p < 0.01$, .. = $p < 0.005$, ... = $p < 0.001$

technique would be to restrict partially the encroachment of *Muehlenbeckia* allowing small areas of bare rocks to remain. This would ensure that frogs had access to shelter.

While it may be possible to specify areas climatically suitable for frogs, their final presence or absence will probably depend on a combination of factors. The absence of frogs from the climatically suitable forest remnant near the bank on Stephens Island has, for instance, been largely attributed to the action of tuataras-insufficient shelter being available in this area to enable frogs to avoid this predator (Newman, 1977). Information derived from climate data could, however, be used to assist in the evaluation of sites to which the species could be introduced as a further conservation measure.

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