Monitoring the Cave Environment

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Abstract

A basic understanding of the mechanisms that control the microclimate of a cave can be a valuable tool in managing a cave. In many cases simple observations and measurements can be used to identify the general operation of the cave microclimate. Some types of cave microclimate are more susceptible to man-caused changes. In most cases a simple baseline study should be performed before and after any modifications, such as gates, are made to a cave. Various instruments that can be used are reviewed, including simple $25 thermometers and inexpensive data loggers.

With increased emphasis on cave management, resource managers are often called upon to make decisions that can have profound impacts on the climate and ecosystem. This paper presents a brief overview of cave climate and outlines simple methods and equipment for making rapid assessments of cave climate. Being able to recognize the basic controls on the climate of a cave or portion of a cave allows the resource manager to make better decisions.

Resource managers should be aware of activities that can change the cave environment. The most common cause is modifications to the entrance of a cave. This can include installation of gates, physical changes to cave passages, creation of new entrances, and blocking of existing entrances.

Caves are relatively static environments protected from the extremes of surface weather by relatively small entrances and insulated by thick layers of rock and soil. In caves where there is no large influx of surface water into the cave, temperature and relative humidity reach stable values within a few hundred feet of the entrance. In cave systems that contain flowing streams, the influence of surface temperatures can extend for many thousands of feet into the cave.

It is generally true that the temperature of a cave is the same as the mean annual surface temperature. This is a good starting point for any investigation of a particular cave's microclimate. Is it warmer or colder than would be expected based on the mean surface temperature? Figure 1 shows the correlation between mean surface temperature and elevation in Arizona. Plotted on the same graph is the temperature of many caves. A brief look shows that caves temperatures have a wide variation from the mean surface temperature. While caves are, on the average, at the mean surface temperature there are individual caves that are up to 15°F warmer or colder than expected.

By collecting temperatures from many caves in an area, one can construct a similar graph that is useful in picking out caves with unusual tempera-

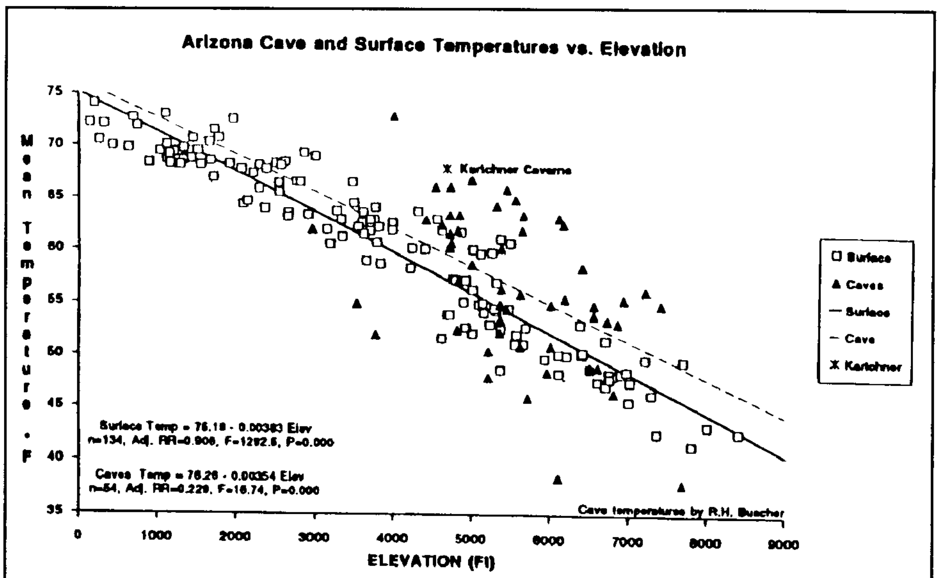

Figure 1. *Arizona surface and cave temperatures versus elevation.*

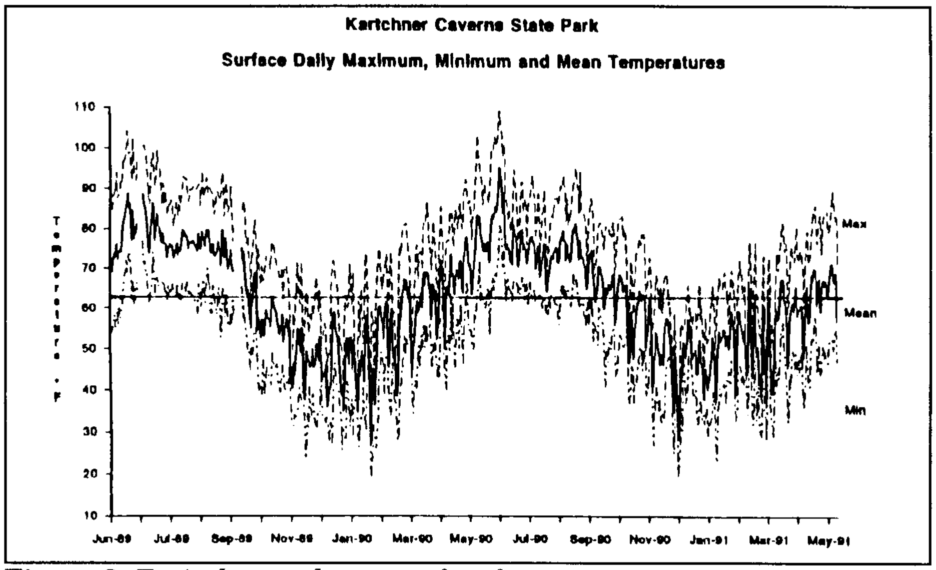

Figure 2. *Typical annual pattern of surface temperatures.*

tures. A similar graph of cave temperatures for a given area allows one to quickly determine which caves appear to have significantly warmer or colder temperatures. These are caves where the microclimate is most likely being dominated by other factors.

Based on this information, one can also make some generalizations about what to expect. For instance, caves which are unusually cold might be good places to look for bat hibernacula.

Almost all caves respond to surface temperatures to a certain degree and follow a muted pattern of seasonal changes. If we look at a graph of surface temperatures we see that there is also a considerable amount of variation in the temperature throughout the year and also on a daily basis. Figure 2 plots the daily maximum, mean, and minimum temperatures at Kartchner Caverns State Park. The mean surface temperature is 62.5°F but the daily temperature fluctuates over a range of 30°F. The yearly cycle of temperature can be roughly broken up into three phases. From May to September the outside temperature is almost always above the mean temperature, even during the coldest part of the night. From December through January the outside temperature is almost always colder than the mean, even during the warmest parts of the day. The remaining months, September through November and February through April, are transition periods when the daily range of temperatures can be above or below the mean surface temperature. Caves will show a more general response based on these three phases than to daily variations.

Cave-adapted organisms can be a very sensitive indicator of the microclimate. These organisms have evolved in the stable cave environment. A study by David M. Griffith shows how sensitive a species of cave-adapted beetle and cave cricket eggs are to the relative humidity of the soil.

Figure 3 is modified from a paper by Griffith ("The Effects Of Substrate Moisture On Survival of Adult Cave Beetles (*Neapha-enops Tellkempfi*) and Cave Cricket Eggs (*Hadenoecus Subterraneus*) In a Sandy Deep Cave Site," *NSS Bulletin*, V53, #2, Dec 1991). This illustrates the importance of substrate moisture can have on the mortality of cave-adapted invertebrates. As soil dries from 100% relative humidity to 99% the mortality increases from near zero to almost 100%. For these animals a change of 1% in relativehumidityiscatastrophic.Otherorganisms using caves have not been as well studied but may be similarly adapted to very narrow ranges in relativehumidityortemperature.

The typical methods of measuring relative humidity have a resolution of 0.5% to 2.5%. Such methods are incapable of accurately assessing changes that would affect such organisms. In fact a biologic survey of the species using a cave may be one of the most sensitive methods for monitoring the cave climate.

Figure 4 shows how relative humidity can be roughly correlated to the observable conditions in the cave. At relative humidifies below 97% to 98%

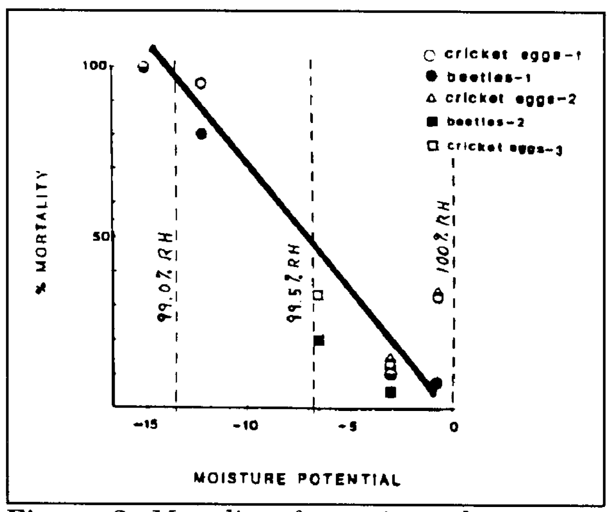

Figure 3. *Mortality of cave invertebrates as a function of soil moisture.*

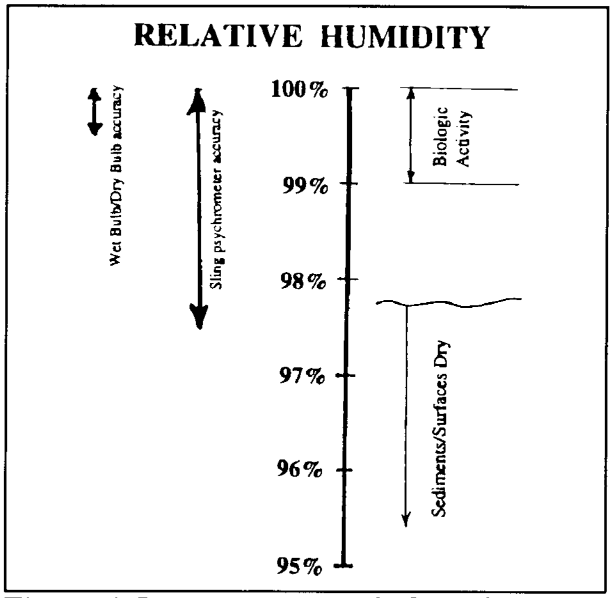

Figure 4. *Important ranges of relative humidity.*

rock surfaces and sediments exposed in the cave will begin to appear dry. Also plotted on the same figure are the range of accuracy that can be expected using a sling psychrometer reading to 0.5°F and using a wet bulb-dry bulb pair reading to 0.1°F. The range of humidity which is important for cave-adapted organisms is also shown. As can be seen, the available methods for monitoring moisture in the cave can give only a crude indication of this important variable. For most conditions where the cave surfaces are moist, the use of instruments for measuring relative humidity has very little benefit.

In order to anticipate the likely impacts of changes to the cave on the microclimate of the cave, we must first have a rudimentary understanding of the basic processes which influence cave microclimate. Knowing how the cave microclimate operates will aid in predicting the likely effects of changes to the cave.

Four basic types of airflow patterns found in caves are shown in Figure 5. Each pattern is determined largely by the geometry of the cave passages and the number of entrances. Simple inspection of a cave or even a cave map can allow one to make a reasonable decision as to what type of airflow pattern is likely to be dominant. Larger and more complex caves can be broken up into segments where each of these basic mechanisms is the dominant mode.

Chimney caves are caves with two or more entrances which lie at different elevations. During the year two patterns of steady airflow can develop due to the differences in air density between the two entrances and the air in the cave. The greater the elevation difference the more pronounced the air flow will be.

During the winter, cool air entering the lower entrance is warmed and rises to the top of the cave and exits as a plume of warm air at the upper entrance. During the summer, the air inside the cave is cooler and more dense than outside air and it flows out the lower entrance.

Cold-air-trap caves selectively capture and hold cold air. Typically these caves have entrances and initial passages which slope downward from the entrance. Usually there is only a single entrance and the cave volume is relatively small. At night or during the winter months, air that is colder and of greater density will flow into the cave, filling the areas lower than the entrance with cold air. During the warmer months of the year, a pool of colder dense air remains. The volume of cold air stored must be large enough to keep the area cool for several months.

Warm-air traps selectively capture and hold warm air. Warm air is less dense and will rise to the top of the passage or ceiling of a room. Caves that slope upward or have extensive areas lying above the elevation of the entrance are potential warm-air traps.

The fourth type of airflow is a barometric or wind driven resonance. Given a sufficiently large cave volume, small changes in air pressure due to wind gusts or approaching weather disturbances can cause the cave to breath in or out in order to come to equilibrium. This effect is more pronounced for very large cave volumes.

Caves may not be one simple form but rather a complex combination of several different types. Various passages and rooms may have separate airflow-dominated mechanisms. Small and moderately large caves usually have a single dominant control of the airflow pattern. Larger caves are more likely to have more complex behavior because of the increased likelihood of multiple entrances and larger volumes.

A comprehensive mathematical model of the temperature and relative humidity profiles at the entrances of caves was developed by Wigley and Brown ("Geophysical Applications of Heat and Mass Transfer In Turbulent Pipe Flows," *Boundary-Layer Meteorology*, 1971). An important aspect of the model is the concept of the "relaxation length (X_0)" as applied to the temperature and relative humidity profiles.

Relaxation length (feet) $X_0 = 63\ R^{1.2}\ V^{0.2}$
where R = passage radius in feet and
V = air velocity in feet per minute

the relaxation length is a measure of the rate of exponential damping of temperature differences as one proceeds deeper into the cave. At a distance into the cave of four or five times the relaxation length, temperatures remain constant year-round.

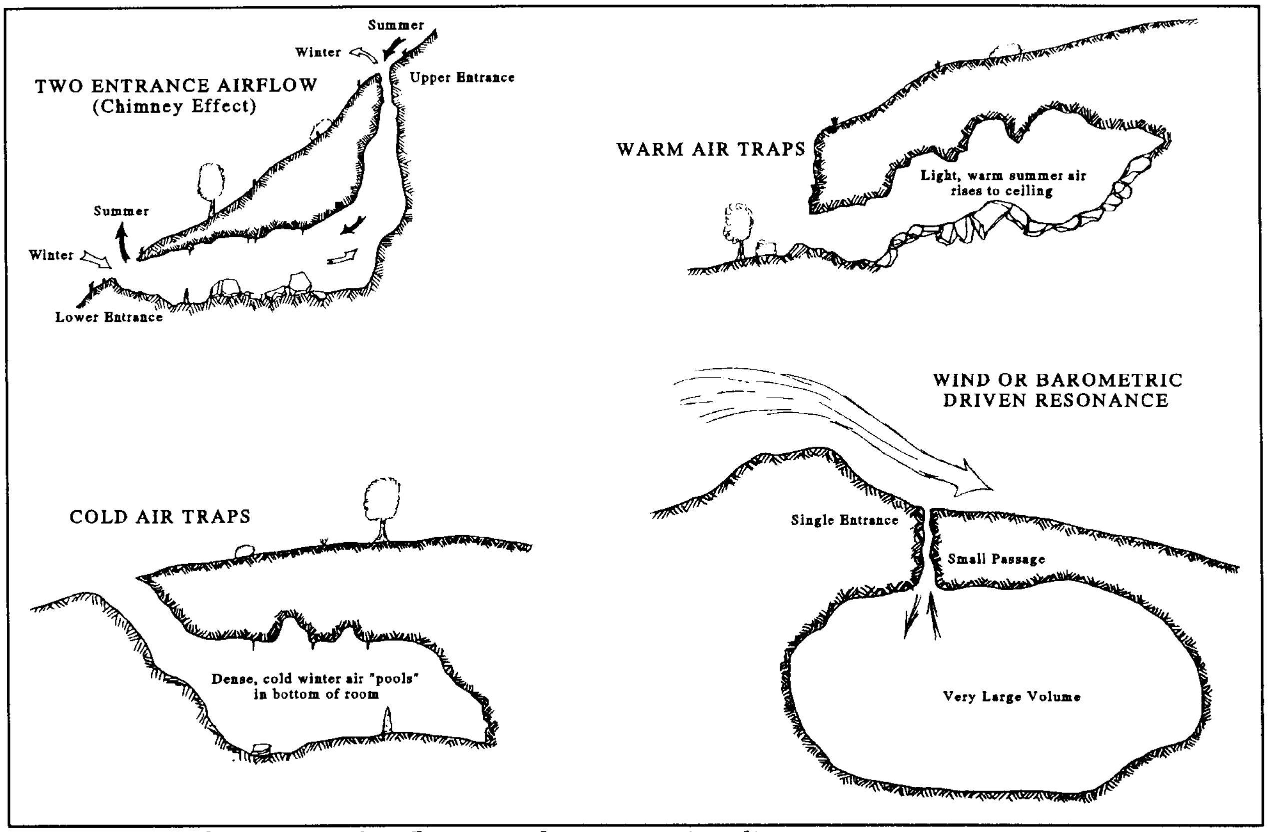

Figure 5. *Four basic types of airflow controls on cave microclimate.*

The model predicts the relaxation length based on air velocity and passage geometry. Passages are considered to be essentially circular pipes with moist walls. Air entering the cave gradually comes to thermal equilibrium with the walls through conduction with the walls and the gain or loss of water by evaporation or condensation.

Figure 6 is a graphical representation of the types of temperature profiles predicted by the Wigley-Brown equation. Several types of temperature profiles are possible and generally correspond with seasons on the surface.

The Wigley-Brown theory is very insensitive to changes in airflow, changing airflow velocity by a factor of two would change the relaxation length by only 15%. Changes in passage dimensions have a much greater influence. Here doubling the passage radius would increase the relaxation length by a factor of 2.3.

This equation allows us to make at least qualitative predictions about how changes in passage size and airflow will affect the cave environment. We can calculate that the relaxation length of a gravel plug is on the order of two to three feet. Digging out the plug to create a small human-sized entrance will increase the relaxation length to several hundred feet. For a small cave this may mean a total disruption of the cave climate.

Another important aspect of the Wigley-Brown equation is that the distance into the cave that surface conditions penetrate is described by a sin-

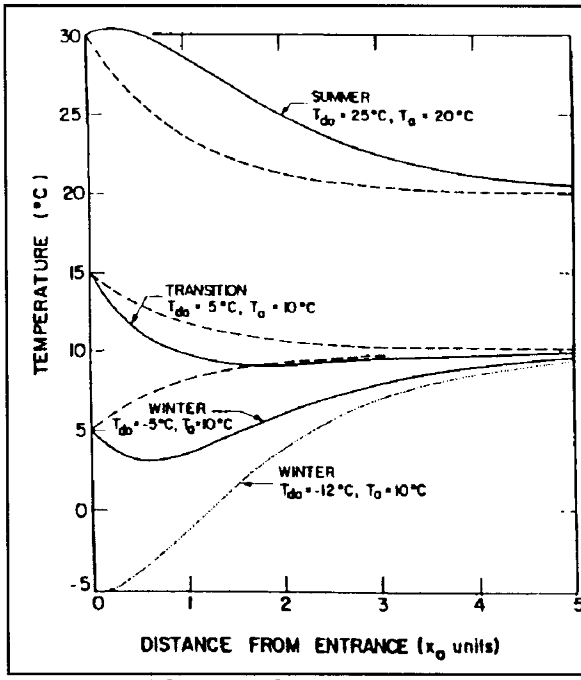

Figure 6. *Theoretical temperature profiles near cave entrances.*

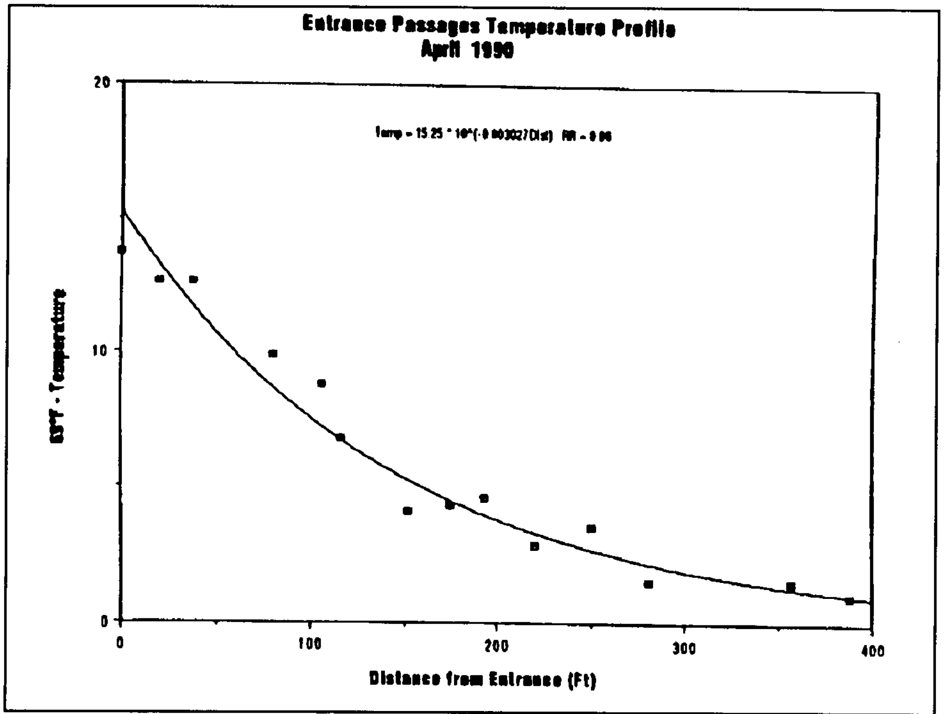

Figure 7. *Entrance passage temperature profile.*

gle number, the relaxation length. It is relatively easy to measure the relaxation length based on a simple temperature profile.

Figure 7 is a temperature profile taken of the entrance passages of Kartchner Caverns. The temperatures were taken in April during a transitional time of the year. The figure shows that temperatures steadily warm from the entrance into the cave. At a distance of 400 feet a stable temperature is being reached.

From this graph we can determine the relaxation length X_0 predicted by Wigley. For this example the relaxation length is 100 feet. This one number describes the distance over which the entrance influences the cave temperature. If changes were made to the entrance we would expect that the value of X_0 would also change. A follow-up temperature profile would show the effect of any modifications. This provides a simple descriptor and means of assessing entrance changes from a simple temperature profile.

The basic equipment needed to make a quick assessment of the microclimate is readily available. A simple but reliable thermometer is needed. A particularly good thermometer for use in caves is manufactured by Taylor, as a 1° digital stem thermometer. The cost is approximately $25. These thermometers have a temperature resolution of 0.1°F and remain stable over long periods of time. A poor choice is the max/min indoor/outdoor thermometer sold by Radio Shack. The chief drawback of this thermometer is a lack of stability which makes it impossible to obtain consistent results. There are also a range of good hand-held thermometers available at costs of $100 to $500. Of these, the best for cave use are thermister thermometers. Avoid using a thermocouple thermometer. Thermocouple thermometers are a universal type of thermometer for measuring a wide range of temperatures. This makes them less suitable for the narrow range encountered in cave studies.

Relative humidity is difficult to measure accurately in most caves. As we have seen, much of what we are interested in occurs at very high relative humidities, 95% and above.

Generally the least suitable instrument for measuring relative humidity is one of the newer, inexpensive hygrometers. Most are accurate only up to 90 to 95% relative humidity and so are useless in the high humidities encountered in caves. These types of sensors are also subject to large amounts of drift over time.

A simple sling psychrometer is suitable for general relative humidity measurements. A number of models are available such as Taylor or Bacharach. The Taylor stem thermometer can also be used to measure relative humidity by using a tubular wick and recording both a wet bulb and dry bulb temperature. It is still difficult to obtain relative humidity measurements with these methods that are accurate enough. Psychrometers with a temperature reading to 0.5°F have an accuracy of only 3% relative humidity. More accurate assessment of long-term relative humidity trends can be made with simple devices such as an evaporation pan or Piche evaporimeter.

The prices of data loggers has now reached the point where suitable inexpensive models are available for $100 to $200. The newest data loggers will operate for six months to one year on a single nine-volt battery. Temperature resolution should be at least 0.5°F and preferably better than 0.1°F. (See Dunlap 1996, this publication.) Unfortunately there are no models available with relative humidity sensors suitable for cave use. If relative humidity is to be measured, a better choice is to construct a wet bulb/dry bulb data-logger probe.

I generally recommend taking soil temperatures rather than air temperatures. In my experience it is very difficult to take air temperatures that are more accurate than ±0.25°F.

It takes over five minutes for most thermometers to come to thermal equilibrium and the presence of a person quickly elevates the local air temperature. Soil temperatures are much quicker to take and less disturbed by the observer.

A brief report of the environmental conditions should be made for each cave. This should include the date and outside weather conditions. Even simple observations made without any sort of instruments can provide useful information. Features of particular significance include entrance size, type, airflow direction, condensation on walls, presence of dry surfaces, and whether cave-adapted organisms are present.

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