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Effects of Climate Change on the Viability of the Devils Hole Pupfish

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Abstract

Devils hole is an unusual, cavernous, aquifer-fed spring in Death Valley National Park. It is the only home to a critically endangered species, *Cyprinidon diabolis*, a.k.a. The Devils Hole Pupfish. *C. diabolis* allows us a unique look at the impact of climate change on a species that has no gene flow and no possibility of escape from its current habitat. Climate change affects ectotherms (cold-blooded animals) tremendously since their body temperature is subject to changes in the temperature of their environment. In the case of *C. diabolis*, they are subject to high temperatures year round, around 33˚ C. The high temperatures cause an increase in oxygen needs for essential metabolic activity as well as an increase in energy needs. The limited energy and oxygen availability of Devils Hole means *C. diabolis* has to work harder to merely stay alive and has less energy to dedicate to reproduction. Most biologists will tell you that animals are adapted to thrive in their environment. But what happens when the environment changes quickly, the genes necessary for adaptation are unavailable in the population, and there is no chance for finding a new habitat? The answer is simple; the population declines rapidly until the stress or stresses they face are removed. In the case of *C. diabolis*, we are investigating just how much stress is being placed on this population by an increase in temperature. Recent climate change models predict a 5 – 6˚ C increase in average air temperatures across the southwest portion of the United States in the next 80 years (Meehl, et al., 2007). In biological systems, a 1˚ C change in body temperature may result in a >10% higher energy demand. Although we do not know what the effects of higher air temperatures will be on Devils Hole water temperature, it is likely that even a modest change in temperature will result in greater energetic demands.

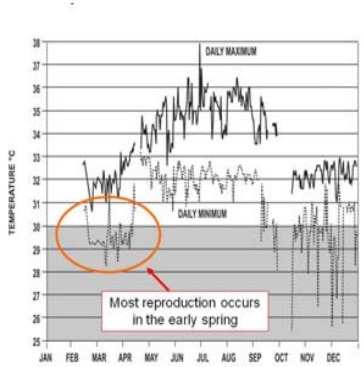
Methods

Our investigation includes measuring resting aerobic metabolic activity based on oxygen consumption at various temperatures. Due to the endangered nature of *C. diabolis*, we use a possible hybrid fish of *C. diabolis* and its closest relative, *C. nevadensis mionectes* for testing purposes. The basis of our experiments is flow-through respirometry. We place the fish in a clear plastic chamber that has water pulled through it by a peristalsis device and a series of tubes. An electrode that senses changes in oxygen pressure takes measurements before the fish enters the chamber to establish a baseline and then continually measures the oxygen pressure over a course of 2-5 hours to determine how much oxygen the fish requires at rest. After determining how much oxygen the fish consumed at rest at various temperatures, we chart those data to determine which temperatures are stressful for the fish in an acute setting. By using fish that are acclimated to different temperatures, 28 and 33˚ C, we can see what is happening to the fish metabolically under chronic conditions. We can also hypothesize what effects global climate change will likely have on this population and even use this species as a model for climate change's effects on fish population around the world.

Devils Hole is a unique pupfish habitat in the Mojave.

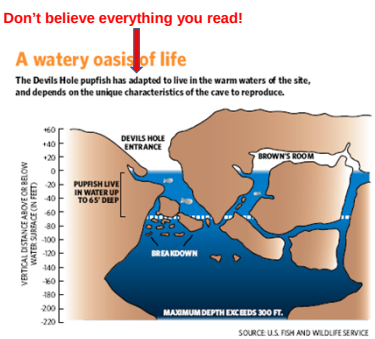
Cyprinidon diabolis is a critically endangered pupfish species that is only found in Devils hole. The population contained just 38 individuals in 2006. The current population is estimated at 120 individuals. Most breeding takes place on the shelf at the bottom center of the photograph.

Seasonal temperature variation on the breeding shelf.



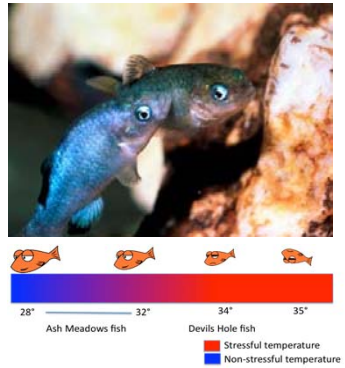
The breeding shelf is the only portion of Devils Hole that is exposed to the surrounding environment and the water temp. changes as the season changes.

Devils Hole's structure helps maintain a stable temperature of 33 – 34˚ C in the main pool.



The stable temperature in the main pool ensure that the fish are acclimatized to approximately 33˚ C. What if the fish are unable to thrive at this temperature? Evolutionary dogma says they should be adapted, but maybe they're not.

C. diabolis likely lives above its ideal temperature range.

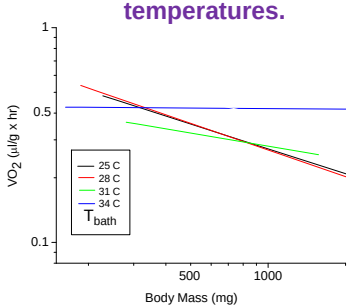


As water temperature increases, the oxygen demand of fish increases and the oxygen capacity of water decreases. This means the fish need more oxygen but there's less of it available.

Using flow-through respirometry, we determine oxygen consumption as a function of temperature and mass.

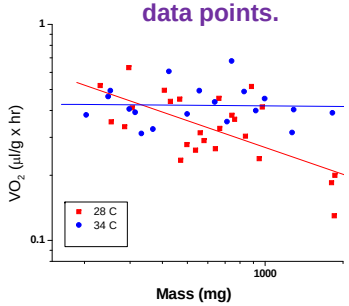
By controlling the temperature of the water in an aquarium, we can determine just how much oxygen *C. diabolis* uses at various temperatures both above and below the temperatures found in Devils Hole.

Pupfish acclimated to 28˚ C were tested at various bath temperatures.



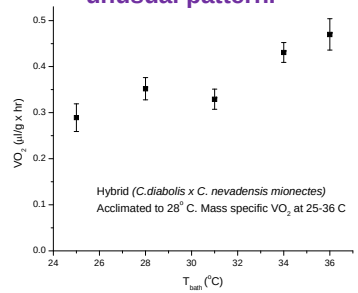
The above graph demonstrates that at temps. between 25 and 31˚ C, the mass-specific metabolic rate decreases, as expected; however, at 34˚ C, the rate is essentially flat, indicating that as mass increases, the fish struggle to meet oxygen needs.

A clear trend is seen when looking at the individual data points.



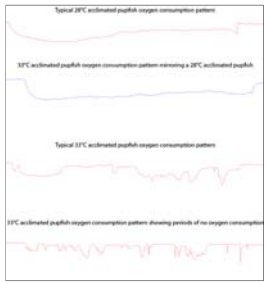
These data demonstrate that small fish appear to be unaffected by the 6˚ C difference. The medium and large fish show a significant increase in oxygen consumption as temperature increases.

Mass-specific oxygen consumption shows an unusual pattern.



In most biological systems, metabolic activity increases 2-3 fold per 10˚ C increase in temperature. We see almost no change between 25 and 31 ˚ C and a modest increase between 25 and 34˚ C.

Preliminary data show unusual oxygen consumption patterns for 33˚ C acclimated fish.



While most of the 28˚ acclimated fish showed consistent oxygen consumption patterns when tested at 28˚ C bath, early testing on 33˚ C acclimated fish shows erratic patterns and in some cases, a complete halt to all oxygen consumption for long periods of time.

Summary and Conclusions

- Increased metabolic activity in medium and large fish tested at 34˚ C suggests temperature may be limiting size, fecundity, and the ability to thrive in Devils Hole.
- A minimal change in mass-specific metabolic rate on the population level over a wide range of temperatures may indicate a redirection of metabolic resources in order to simply survive, precluding the ability to thrive.
- New data are showing that fish acclimated to 33˚ C are very unstable in their metabolic activity and a further increase in habitat temperature may lead to the extinction of *C. diabolis*.
- As a model, *C. diabolis* may tell us what will happen to fish populations around the world if human-caused climate change is not controlled.

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