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Daily and yearly movement of the Devil's Hole pupfish *Cyprinodon diabolis* Wales in Devil's Hole, Nevada

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DAILY AND YEARLY MOVEMENT OF THE DEVIL'S HOLE PUPFISH *CYPRINODON DIABOLIS* WALES IN DEVIL'S HOLE, NEVADA

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Abstract.— Past observations and ongoing population surveys indicate daily and yearly vertical movement of the Devil's Hole pupfish, *Cyprinodon diabolis* Wales, within the upper 27 m of the water column in Devil's Hole, Nevada. This movement involves occupying and leaving a 5 by 3.5 m rock shelf during daily and yearly periods of maximum light intensity.

Devil's Hole, located in the southeast quadrant of R50E, T18S, Sec. 36, in Ash Meadows, Nevada, at an elevation of 730 m, is the only natural habitat of the Devil's Hole pupfish.

The surface pool at Devil's Hole lies about 15 m deep in a roughly conical depression in a ridge of Cambrian carbonate rock (Winograd and Doty 1980) (Fig. 1). The pool is about 3.5 by 22 m in surface area with a natural rock shelf 5 by 3.5 by .3 m (deep) at one end. Water depth increases abruptly at the end of the shelf into a large and only partially mapped cavern system that interrupts the groundwater of the carbonate aquifer (Winograd and Doty 1980). Devil's Hole has no surface outlet.

The spring-line in Ash Meadows (including Devil's Hole) is tectonically controlled, containing Quaternary faults, with Devil's Hole on the upthrown side of the fault zone (Winograd and Doty 1980). Because of its recessed position, the entire water column in Devil's Hole receives significantly less direct and indirect light than the surrounding area. This situation has existed for millenia.

The Ash Meadows Ground Water Basin, of which Devil's Hole is a part, receives its water from the area of the Nevada Test Site north of Las Vegas. This is fossil water, with the transport process taking about 10,000 years from precipitation to outflow at Devil's Hole (Winograd and Doty 1980). The water in Devil's Hole remains a relatively constant 32 C to a depth of at least 27 m.

According to Minckley and Deacon (1975), diatoms are the most important food items of *C. diabolis* in the winter and spring, with the algae *Spirogyra* and *Plectonema* becoming most important in summer and fall. Although a majority of the food used by *C. diabolis* is available only on or near the shallow shelf, divers have confirmed, as late as mid-October, that algae covers about 80 percent of the available substrate from the area adjacent to and just below the shelf to a depth of about 12 m (35 ft), 15–20 percent from 12–17 m (35–50 ft), with only trace amounts below 17 m.

Dissolved oxygen concentration is relatively uniform at 2.5–3.0 ppm throughout the water column to a depth of about 22 m. Photosynthetic activity increases dissolved oxygen concentrations on the shelf during midday as a function of light intensity and duration. Maximum values of 6.0–7.0 ppm DO have been recorded on the shelf in June and July.

It is unlikely that *C. diabolis* movement from the shelf to the depths during periods of peak sunlight is in response to availability of dissolved oxygen. Such a movement would imply oxygen avoidance on the part of this species. Work with *Crenichthys* sp. by Hubbs et al. (1967) indicates increased activity and greater numbers of fish in areas of higher dissolved oxygen in the natural habitats of these species.

Daily Movement

James (1969) noted that as light intensity increased during the day at Devil's Hole the number of fish present on the shelf decreased

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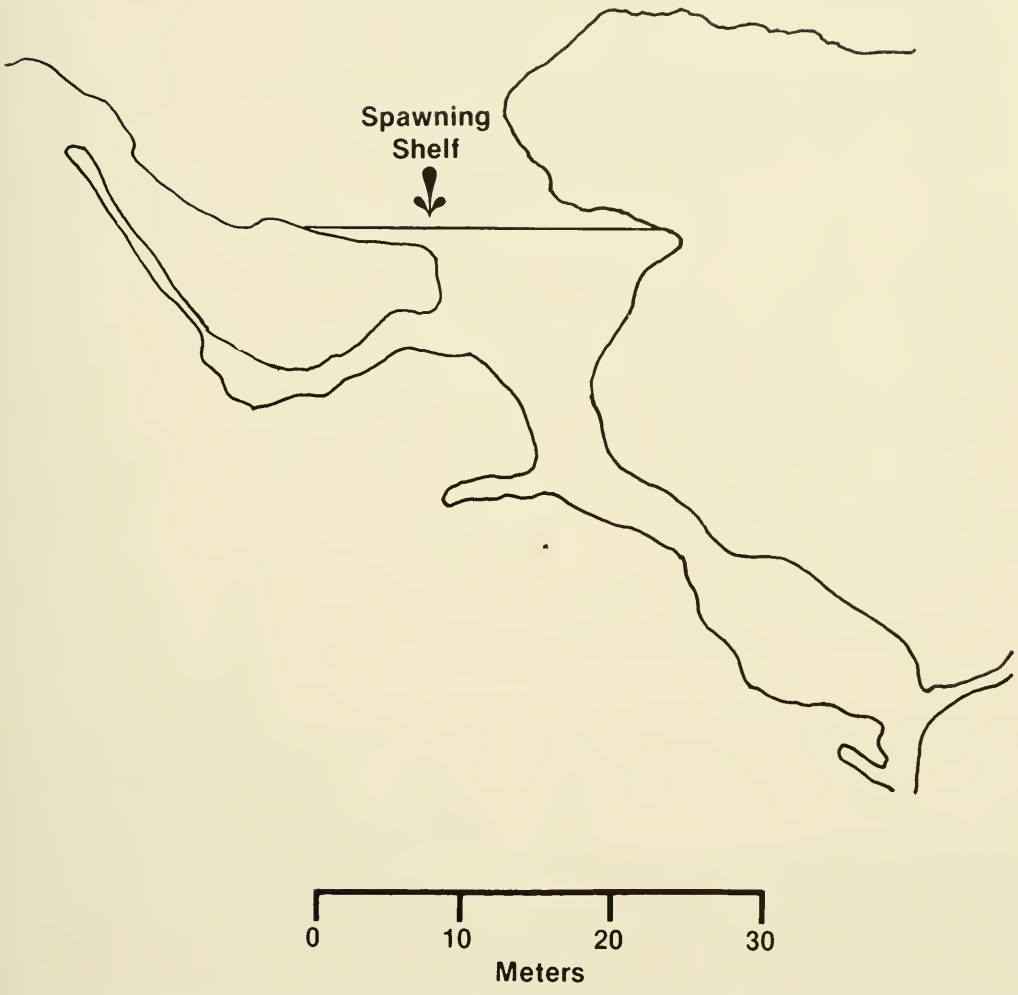

Fig. 1. Upper section of Devil's Hole, Ash Meadows, Nevada, showing shelf exposed to sunlight and upper portion of cavern system.

(Fig. 2). Since 1974, counts of fish in Devil's Hole have been made by both a surface team and a scuba dive team. From 1974 through 1978 counts were made in the morning around 0900 hr, near the period when maximum light falls on the shelf at about 1200 hr, and in the afternoon at about 1600 hr. Analysis of these population data (Fig. 3) tend to support the observations of James (1969) that the numbers of fish present on the shelf generally decrease around the noon period of maximum light intensity on the shelf. This tendency is most marked during the period of April through September, when light intensity and duration are the greatest. The lack of a sharply defined decrease in numbers on the shelf around noon in July is inconsistent. Whether it is real or an artifact is unknown. An increase in fish numbers on the shelf around noon usually does not occur during the period October through March, when sunlight reaches the water surface only briefly or not at all during midday. In fact, from December through March there is a regular increase in numbers of fish occupying the shelf as the day progresses.

Movement Within the Year

In addition to the diel rhythm noted by James (1969) and verified by ongoing population surveys, data were also analyzed to determine the relationship between duration and intensity of sunlight and fish numbers on

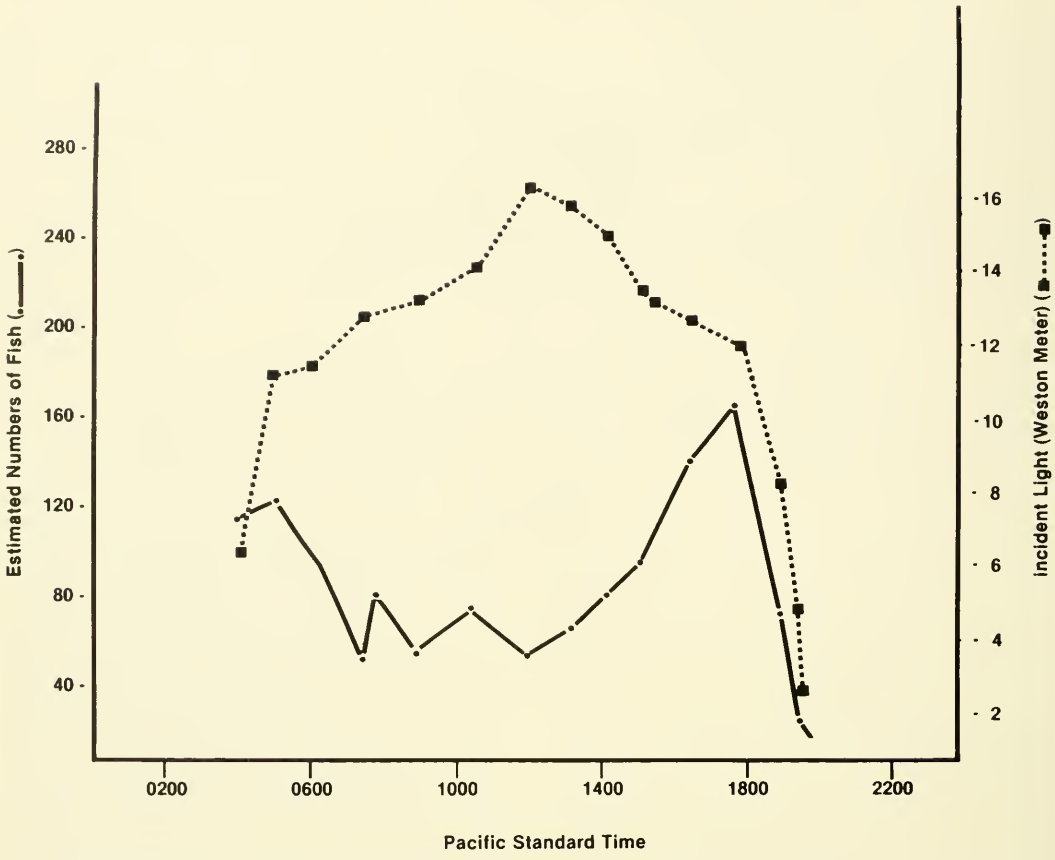

Fig. 2. Relationship of diel fluctuation in incident light with estimates of the fish population inhabiting the upper shelf (from James 1969).

Fig. 3. Fish on shelf as a percentage of total fish counted by period in day.

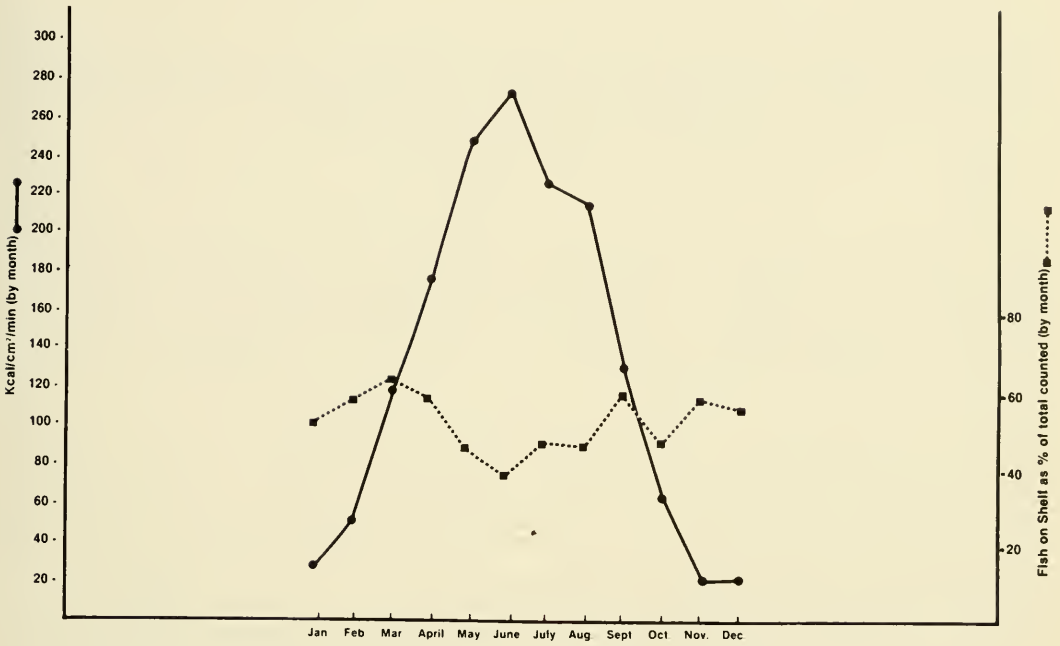

Fig. 4. Relationship of sunlight (kcal/cm²/min) to fish on shelf as percent of total fish counted.

the shelf through the year. The results of this analysis are presented in Figure 4 and indicate that the number of fish present on the shelf, as a percentage of the total fish counted, is inversely proportional to the intensity and duration of sunlight on the shelf over a twelve-month period. A one-way analysis of variance indicated that significant differences existed between monthly population counts presented in Figure 4.

While an inverse relationship between sunlight duration and intensity and percentage of the population occupying the shelf does exist, other factors may influence the relationship. For example, the increasing percentage of the population occupying the shelf from January through March may be related to spawning activities, which increase in intensity during this period and are concentrated on the shelf (James 1969, Minckley and Deacon 1975). The declining percentage of the population occupying the shelf from March to the annual minimum in June occurs during the time when fry and juveniles are increasing in abundance on the shelf. Although these events in the life cycle of *C. diabolis* may influence the pattern shown in Figure 4, with the exception of October, the relationship between sunlight and percentage of the population on the shelf is most striking and consistent.

Figure 5 profiles fish present at various levels in the water column as a percent of the total number of fish counted by month over the five-year study period. These data are consistent with those presented in Figure 4 and indicate a decrease in shelf population and an increase in population at depths with more sunlight.

With the exception of October, when population pressure on the shelf may contribute to recruitment to the next lowest level, the partial depopulation of the shelf does not appear to be a general function of population pressure. Analysis of population data for the period 1974–1978 indicates that the yearly population curve is essentially sinusoidal, reaching a low in March and April and a peak in August and September. Thus, the highest percentage of the population occurring on the shelf corresponds to both the maximum and minimum population densities.

SUMMARY

The Devil's Hole pupfish, *Cyprinodon diabolis* Wales, engages in movement from and to a narrow rock shelf at the surface of the

Fig. 5. Relationship of sunlight to fish occupancy of upper 27 m of Devil's Hole by level.

Devil's Hole system. Movement occurs daily and yearly during periods of maximum sunlight intensity and duration.

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