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INFECTION DYNAMICS OF *PLASMODIUM MEXICANUM*, A MALARIAL PARASITE OF LIZARDS[1]

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Abstract. A mark-recapture technique was used to evaluate variation in the course of infection of the malarial parasite, *Plasmodium mexicanum*, in its natural host, the western fence lizard (*Sceloporus occidentalis*) during the warm season in northern California, USA. These data were used to examine the hypothesis that the parasite modifies its reproductive schedule during the year to meet the challenges of a seasonal environment. Infections first became evident in the blood at various times during the warm season (May–September), then rose exponentially before leveling off to a constant parasite load. Parasite levels (parasitemia) declined during the winter, but rebounded rapidly the next spring, apparently once again to a steady level. Most infections studied were older ones remaining at a relatively constant level throughout the warm season. Exponential growth rate of rising infections varied over a fourfold range, and chronic infections varied greatly in parasitemia (over two orders of magnitude). The end of exponential growth, and the ultimate parasitemia level reached, were related to the timing of production of gametocytes (nondividing sex cells). Gametocytes appeared very early in an infection, then increased so that they eventually dominated the parasite population. The rate of increase of gametocytes varied greatly among infections, but was not clearly related to host age or to date the infection originated. Weak evidence suggests that the rate of asexual proliferation was more rapid in infections originating late in the warm season. Neither host sex nor age was associated with rate of parasite increase in growing infections. Maximum parasitemia was independent of sex or starting date of the infection, but was higher in juveniles than in adults. We conclude that during the warm season, the schedule of reproductive activities of *P. mexicanum* does not follow precisely the time of year or host quality, perhaps because of the developmental mechanism driving gametogenesis.

Key words: course of malarial infection; lizard malaria; mark-recapture; parasite ecology; Plasmodium mexicanum; Sceloporus occidentalis; *seasonal environments.*

INTRODUCTION

Malarial parasites (*Plasmodium*) have evolved a complex life cycle in which they alternate reproductive stages between vertebrate and insect hosts. Each species of *Plasmodium* typically infects only one or a few pairs of host species, but the overall geographic and host range of the genus is substantial. Approximately 130 described species of *Plasmodium* infect birds, mammals, and reptiles (most are parasites of lizards) over most of the world's warmer geographic regions (Garnham 1966, Ayala 1977, Carter and Diggs 1977, Seed and Manwell 1977). Presumably natural selection has molded the basic malarial life cycle to accommodate a wide variety of ecological contingencies. For example, the schedule of reproductive events within the vertebrate host might be seasonally modified to ensure maximal transmission between hosts, thus increasing the parasite's reproductive success.

Any theoretical consideration of the reproductive ecology of malarial parasites is greatly hindered by the paucity of information on *Plasmodium* in its wild hosts in a natural setting. Studies on the course of malarial infection in vertebrates typically involve artificial infections observed in a laboratory, usually with unnatural host species. The scant handful of field studies have been based on samples of unmarked animals periodically taken from naturally infected populations (Ayala 1970, Ayala and Spain 1976, Schall 1983*a*), or were primarily concerned with the host's ecology (Rand et al. 1983, Schall 1983*a*). Thus the nature of variation in malarial reproduction among hosts within a population is scarcely known, and interspecific comparisons are at best tenuous.

We studied the reproductive dynamics of *Plasmodium mexicanum* in its vertebrate host, the western fence lizard, *Sceloporus occidentalis*, in a seasonal temperate environment in northern California. The parasite must overwinter in *Sceloporus* because its putative insect host (a psychodid fly, *Lutzomyia vexatrix*) spends the winter as larvae (Chaniotis and Anderson 1968, Ayala and Lee 1970). This surely proves hazardous for *P. mexicanum* because of the high rate of lizard mortality during the cold months, especially among juveniles (Ruth 1977; J. J. Schall, *personal observation*). The quality of lizards as potential hosts therefore varies with their age and drops as winter approaches.

To meet these challenges *P. mexicana* might follow a "conditional" life history in which the schedule of reproductive events within the lizard differs, depending on the season and the host's expectation of future life. For example, infections that initiate asexual growth in

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blood early in the season might grow relatively slowly compared to those beginning in late summer. Slowly growing parasite populations could hold pathology to the host at a minimum, allowing the hematopoietic response of the lizard to keep pace with erythrocyte destruction. Later in the season, when biting flies are most abundant, the infection could switch to mass production of the nondividing transmission stage (gametocytes). In contrast, late season infections may have to race to produce gametocytes before the onset of winter.

We present here results of a mark-recapture study of a single population of *Sceloporus occidentalis* infected with *Plasmodium mexicanum,* aimed at characterizing the course of individual infections under field conditions. We attempted to discover the time at which infections became obvious in the blood, the variation in rates of asexual multiplication and ultimate parasite density in the blood (parasitemia), the point in each infection when production of gametocytes begins, changes in proportion of gametocytes and asexual stages, and indirectly to assess the comparative mortality of infected and noninfected lizards during the warm season. We use these data to test the hypothesis that *P. mexicanum* varies its reproductive schedule depending on time of year and condition (or quality) of its vertebrate host. These results represent the first study of infection dynamics of any malarial parasite of a nonhuman vertebrate host under natural conditions.

Study Site, Materials and Methods

Observations were conducted at the Hopland Field Station of the University of California near Hopland, Mendocino County, California. The regional climate is Mediterranean, with hot, dry summers and cool, wet winters. *Sceloporus occidentalis* is common on fallen logs and rocky outcrops, where it maintains territories for long periods during the warm season. Adult fence lizards at Hopland can be active from late April to mid-October, although the activity season is usually somewhat shorter. Approximately 25% are infected with *Plasmodium mexicanum* (Schall 1983*a*).

As there are specific foci of infection, we selected two areas where the parasite has been common for some years. The sites ranged from ≈200 to 400 m in elevation and totaled 12 ha of mixed oak-grassland, woodland, and man-made structures. Lizards were collected with a trifilament noose attached to a fishing pole. Collection began in mid-May 1982 and continued on a nearly daily basis until late September. Lizards had already been active for several weeks before our study began in 1982, so one author returned during mid-May 1983 to recapture as many marked animals as possible. Adult lizards were just emerging from winter dormancy at that time (many were encrusted with dirt and retained their visual identification numbers from the previous season). Very few unmarked adults were collected, confirming that we had examined nearly every animal on the study plots the preceding summer.

Once collected, lizards were kept in cloth sacks for processing the same evening. Each animal was marked by toe-clipping and a number painted on the back with Liquid Paper. Sex, mass, snout–vent length (SVL), tail condition, and any other distinguishing features were recorded. Blood smears were made at the time of toe clipping and later stained with Giemsa using standard techniques (Ayala and Spain 1976). We released lizards at the precise point of capture the next day.

Time between recapture attempts was kept at a minimum of 7 d for the first 11 wk of the study, then shortened to 5 d for the last 4 wk. The 1982 warm season was divided into three 5-wk segments: early (10 May to 21 June), middle (22 June to 31 July), and late (1 August to 7 September). Lizards with SVL <60 mm were considered juveniles.

Blood smears were examined under 1000–1250× for a minimum of 8 min, sufficient time to inspect at least 10 000 erythrocytes. If no parasites were seen, the animal was classified as uninfected on that date (although very low parasitemias and infections restricted to nonblood tissues would have yielded false negatives). Parasitemia was expressed as the number of parasites per 10 000 erythrocytes. If one to four parasites were seen, the parasitemia was recorded as <5 parasites per 10 000 erythrocytes. When five or more parasites were observed, an additional 2000 red cells were counted to quantify the infection more accurately. Counts were done 1000 cells at a time, with an effort to sample the entire smear randomly. Discrepancies required additional counts for verification. To facilitate certain analyses, three levels of parasitemia were defined: high (>250 parasites per 10 000 red blood cells), intermediate (30–250 parasites per 10 000 red blood cells), and low (<30 parasites per 10 000 red blood cells). Parasites were classified as either asexual cells or gametocytes. Rates of increase of parasitemia were calculated for those infections for which we have a series of recaptures without wide time gaps. For comparison among infections we used graphs with a $\log_{10}$ ordinate to provide straight lines. The rate of increase of the exponential growth equation, r, was calculated as the slope of the natural logarithm of parasitemia plotted against the date.

Results

Recapture success and lizard mortality

We marked 550 *S. occidentalis* during the course of this study. Most (57%) were marked during the 1st wk, and >80% within the 1st mo. We recaptured 334 animals at least once, including 104 (total of 505 blood smears) infected with *P. mexicanum.* Substantial information was obtained from 65 infections; these were in animals captured at least three times over at least half the warm season.

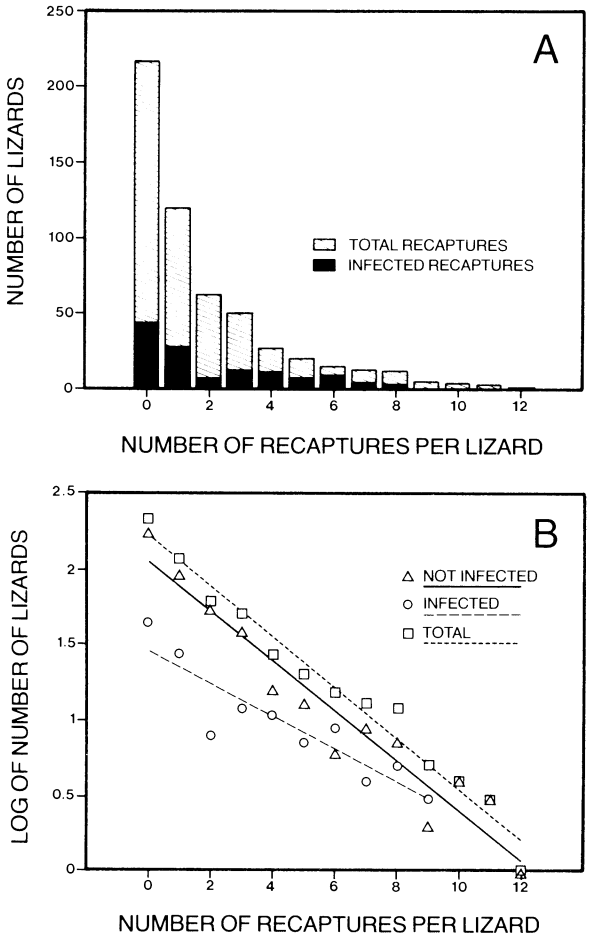

FIG. 1. Recapture success for marked *Sceloporus occidentalis* lizards, those infected and those not infected with *Plasmodium mexicanum*, during the warm season at Hopland, California. (A) Absolute number of recaptures. (B) Semilog plot comparing frequency of recaptures for noninfected lizards ($r = 0.97$, slope $= -0.17$), infected lizards ($r = 0.91$, slope $= -0.12$), and the combined sample ($r = 0.99$, slope $= -0.17$).

The likelihood of recapturing lizards, both infected and noninfected, declined dramatically with each recapture (Fig. 1A). Lizards became extremely difficult to approach as the season progressed; however, we compensated for this in part by increased stalking effort. The very regular exponential decline in multiple recaptures shown in Fig. 1B probably resulted, not from increasing wariness of the lizards, but from our catching a fairly uniform proportion of animals in the population each collecting day. If so, the probability of multiple recaptures is the constant likelihood of capturing an animal on any day raised to a power equal to the number of recaptures. Curiously, multiple recaptures were slightly more common for infected than noninfected lizards (Fig. 1; χ^2 goodness-of-fit test, $P < .05$). As there was no bias in amount of time spent stalking infected vs. noninfected lizards (we did not know which animals were infected during the field season), these results suggest that infected animals were easier to recapture. Schall et al. (1982) and Schall and Sarni (1986) demonstrated that malarial infection results in important behavioral alterations by *S. occidentalis* that might account for the apparent difference in recapture success.

Data on recapture success for infected and noninfected lizards provided weak evidence that malarial infection does not cause significant mortality in *S. occidentalis* during the warm season in the wild. To assess parasite-induced mortality more precisely, we randomly selected 46 adult male lizards that were infected at the time they were marked, and which maintained an infection throughout the spring and summer, and compared them with a similar group of 46 noninfected lizards. Mean number of days between first and last recapture for the two groups was nearly identical (58.9 vs. 57.8 d; *t* test, $P > .05$). Although *P. mexicanum* causes severe pathology in *Sceloporus* (Schall et al. 1982, Schall 1983*a*, *b*), there was no indication of increased mortality in these free-ranging lizards. We stress that these observations pertain only to the 1982 warm season, and do not bear on the effects of malaria in overwintering or recently emerged lizards during the early spring period of parasite recrudescence.

Classes of infection

The 65 infections studied in detail fell into three classes. Most (38, or 59%) maintained a stable level of parasitemia during the time they were observed (see Fig. 2 for some examples). In 26 infections (40%), parasitemia was clearly rising during the season (examples in Fig. 3), and only one infection showed progressive decline in parasite density. Stable infections were found in lizards with low, intermediate, or high levels of par-

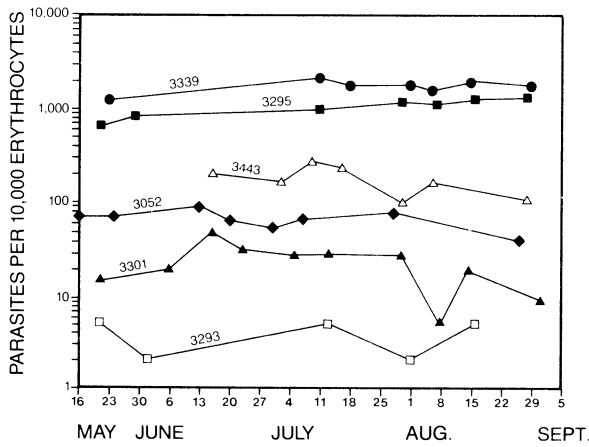

FIG. 2. Parasite loads (parasitemia) for six *Sceloporus occidentalis* individuals (identified by number) representative of those with stable infections of *Plasmodium mexicanum* in one warm season. Parasitemia varied over two orders of magnitude among stable infections. Temporal variation appears greater in low-level infections because of relatively greater error in counts made for such infections.

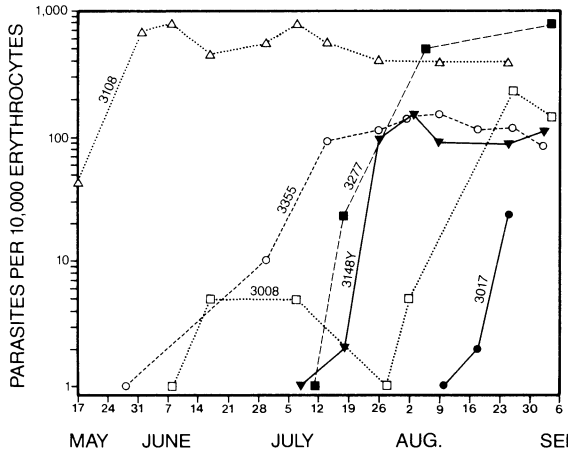

FIG. 3. Parasite loads (parasitemia) for six *Sceloporus occidentalis* individuals (identified by number) representative of those with *Plasmodium mexicanum* infections that were increasing over time in one warm season. Several of these individuals leveled off to a stable condition.

asitemia. Among chronic infections, six were low (from barely detectable to 0.3% of erythrocytes infected), 22 were middle-level infections (0.33 to 2.32% of red cells infected), and 10 infections harbored high-level parasitemia (2.54 to 18%).

The patterns of increase of the 26 rising infections also differed considerably (Fig. 3). Some went from barely detectable to high levels, some from low to middle levels, and others were at a stable middle level and rose to high levels. In 12 rising infections, parasitemia leveled off and then remained constant: 5 at intermediate and 7 at high levels. If any increasing infections leveled off at low levels, they would probably have been misclassified as being stable rather than exhibiting a rising course.

Infections consisting primarily of uninucleated asexual cells (trophozoites) were seen throughout the warm season (Table 1), although some were probably older infections undergoing a recrudescence. In 26 infections one or more early blood smears proved negative, even after careful search, but were followed by smears showing an increasing parasite population. We judged these to be new infections. Fig. 4 illustrates closest estimates for the starting date when the infection first entered blood tissue in each of these 26 individuals. Most starting dates were in midsummer, but some infections began very early, and others later in the season.

Vertical analysis

For comparison with other studies (Ayala 1970, Ayala and Spain 1976, Schall 1983*a*), we combined all our data and examined results as though representing a year's sampling of unmarked individual lizards. Fig. 5 illustrates mean parasitemia in infected lizards for 15 sampling periods and shows no significant variation in parasitemia over time (Kruskal-Wallis test, $P > .05$).

TABLE 1. Seasonal variation in the proportion of uninucleated trophozoites in *Plasmodium mexicanum* infections in 104 *Sceloporus occidentalis* (317 blood smears) during the warm season of 1982 at Hopland, California. Active infections, with rapid asexual proliferation, can occur anytime during the warm season.

	Time periods, in 2-wk intervals							
	May	June		July		August		September
% trophozoites	1	2	3	4	5	6	7	8
	Number of smears							
75–100	1	...	1	2	1	...	...	...
50–74	2	...	...	1	2	1	...	...
25–49	30	4	5	2	...	7	4	2
0–24	37	25	38	33	26	41	25	27
Total smears examined	70	29	44	38	29	49	29	29

Even when parasitemia over time was compared for infections known to be rising, there was no significant difference among samples. This spurious result is due to the asynchronous dynamics of individual infections.

The proportion of gametocytes among infected lizards varied among sampling periods (Fig. 6; Kruskal-Wallis test, $P < .05$), generally rising as the season progressed. A short decrease in mean gametocyte proportion in late June to early July corresponds with the period of increased asexual activity, when a majority of new infections became obvious in the blood (Fig. 4). These results reveal that, over time, infections switch from asexual proliferation to production of gametocytes. Vertical analysis, though, misses the fact that some infections maintain a quite stable gametocyte: asexual ratio during the entire warm season (see Longitudinal Observations, below). Gametocyte percentage was positively correlated with parasitemia ($r = 0.34$, $P < .001$; percentages arcsine-transformed).

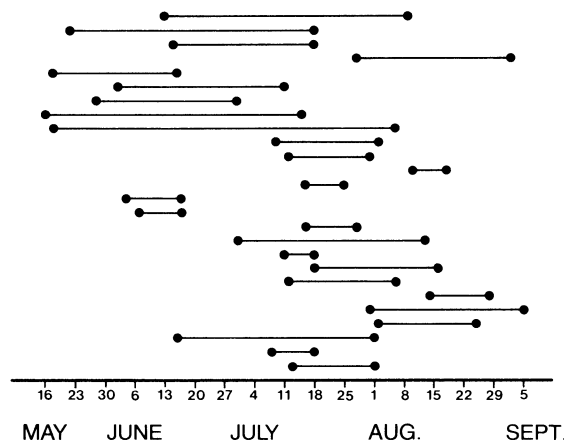

FIG. 4. Estimates of date of first appearance of malarial parasites in the blood of 26 *Sceloporus occidentalis* individuals during the 1982 warm season. Dates of last negative blood smear (left) and first positive smear (right) are shown.

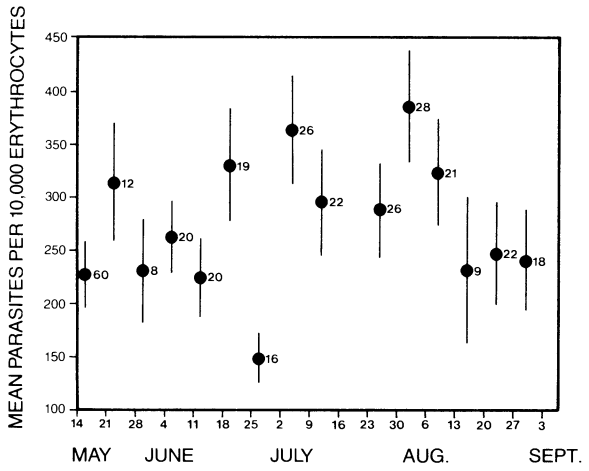

FIG. 5. Mean *Plasmodium mexicanum* parasitemia for all infections observed for each week during the warm season of 1982. Error bars indicate ±1 standard error of the mean; sample sizes (number of infected lizards) are also shown.

Longitudinal observations

Figs. 2 and 3 illustrate the great variation in types of malarial infection that coexist in the Hopland *Sceloporus* population at any one time. Understanding this variation requires that individual infections be followed closely over time.

Sufficient information was available for a reliable estimate of growth rate of the parasite population for 18 rising infections. The rate of increase, r, varied fourfold from the slowest growing infection (0.074 d^{-1}) to the one growing most rapidly (0.290 d^{-1}), although most infections varied from 0.092 to 0.207 d^{-1}, only a twofold variation (Table 2). Neither host sex nor host size (weakly correlated with age; Schall 1983*a*) were related to rate of parasite increase (Mann-Whitney U tests; $P > .05$ in each case).

Infections that first became obvious in the blood early in the season had the slowest mean rate of increase (0.132 d^{-1}, $N = 4$), those starting in midseason had a faster mean rate (0.189 d^{-1}, $N = 10$), and late starters showed the most rapid mean increase (0.213 d^{-1}, $N = 2$). However, the difference among means is not significant (Kruskal-Wallis test, $P > .05$). In the second spring of the study, 17 of the lizards captured with active malarial infection had been classified as uninfected the previous summer (Table 3). Their parasitemias ranged from scarcely detectable to very high levels. There was a significant positive relationship between the intensity of the spring infection and how late the previous year the animal was known to be uninfected (Spearman correlation, $r_s = 0.416$, $P < .05$). This suggests that animals acquiring infections late in the summer are more prone to support higher parasite loads the following spring, a situation that would result if late-season starters experienced more rapid asexual reproduction.

TABLE 2. Rate of increase (r) and final parasitemia in *Sceloporus occidentalis* lizards with rising *Plasmodium mexicanum* infections during the warm season of 1982 at Hopland, California.

Animal	Sex	Age*	Infection starting date†	Final parasitemia level‡	r (d^{-1})
3230	M	adult	early	?	0.101
3043	M	adult	early	?	0.092
3162	F	adult	early	high	0.175
3355	M	juv	early	intermediate	0.161
3392	M	adult	middle	intermediate	0.177
3277	M	adult	middle	high	0.223
3070	M	adult	middle	?	0.081
3372	F	adult	middle	?	0.168
3008	F	adult	middle	intermediate	0.180
3390	M	juv	middle	?	0.276
3510	M	juv	middle	high	0.290
3014	F	juv	middle	intermediate	0.207
3333	F	juv	middle	?	0.074
3148Y	F	juv	middle	intermediate	0.216
3017	F	adult	late	?	0.210
3326	F	adult	late	?	0.216
3307	M	juv	?	high	0.127
3025	F	juv	?	high	0.090

* Lizards with snout–vent length <60 mm were considered juveniles.

† Early: 10 May to 21 June; middle: 22 June to 31 July; late: 1 August to 7 September.

‡ High: >250 parasites per 10 000 erythrocytes. Intermediate: 30–250 parasites per 10 000 erythrocytes.

Maximum parasitemia reached during the infection could be reliably estimated for 45 infections and was independent of host sex or starting date of the infection (U tests, $P > .05$ in each case). However, maximal parasitemia was higher in juveniles than in adults (U test, $P < .05$). There was also a significant trend among the stable infections for larger animals to have lower parasitemias (<60 mm SVL, $\bar{X}$ parasitemia = 3.8%; 60–69 mm SVL, $\bar{X} = 1.3\%$; ≥70 mm SVL, $\bar{X} = 0.36\%$; Kruskal-Wallis test, $P < .05$). Although parasitemia

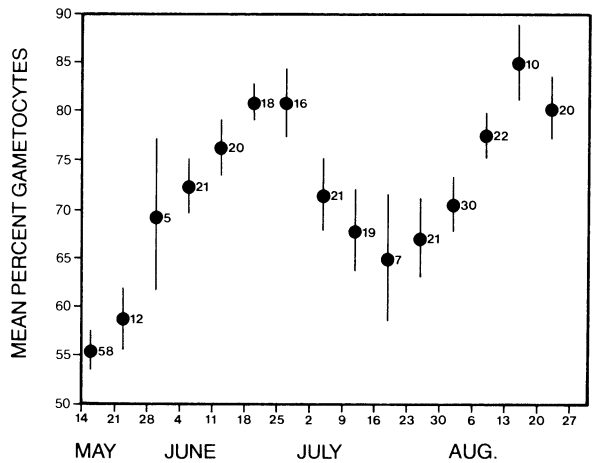

FIG. 6. Mean proportion of gametocytes in *Plasmodium mexicanum* infections for each week over the warm season of 1982. Error bars indicate ±1 standard error of the mean.

TABLE 3. Parasitemia (percent of erythrocytes infected) and percent gametocytes in *Plasmodium mexicanum* infections overwintering in *Sceloporus occidentalis* at Hopland, California during 1982–1983.

1982 infections			1983 infections		
Date last seen	Parasitemia (%)	Gametocytes (%)	Date first seen	Parasitemia (%)	Gametocytes (%)
22 May	2.9	71.0	13 May	0.3	0
2 Jul	0.8	94.4	17 May	<0.05	36.9
5 Jul	0.4	55.6	13 May	0.1	50.0
10 Aug	0.3	57.1	13 May	0.05	0
14 Aug	4.5	100.0	18 May	0.3	50.0
16 Aug	0.4	88.9	13 May	<0.05	0
16 Aug	0.05	50.0	21 May	<0.05	50.0
31 Aug	15.8	98.8	18 May	0.6	30.0
2 Sep	1.1	87.0	20 May	0.6	16.7
5 Sep	0.9	78.6	11 May	0.4	25.0
16 May	0	···	22 May	0.3	0
17 May	0	···	16 May	0.15	0
20 May	0	···	20 May	4.8	4.0
1 Jun	0	···	10 May	0.3	0
30 Jun	0	···	18 May	1.5	60.0
18 Jul	0	···	18 May	<0.05	0
18 Jul	0	···	16 May	1.0	30.0
3 Aug	0	···	16 May	2.0	14.6
10 Aug	0	···	16 May	2.9	36.7
11 Aug	0	···	16 May	0.6	0
16 Aug	0	···	20 May	0.9	0
18 Aug	0	···	18 May	0.15	0
26 Aug	0	···	11 May	3.5	8.3
26 Aug	0	···	11 May	5.2	23.6
2 Sep	0	···	10 May	3.9	53.7
2 Sep	0	···	13 May	4.3	18.0
4 Sep	0	···	11 May	0.5	0

rarely declined during the warm season from its maximal level, it did decline during winter: in all 10 infections followed from 1982 to 1983, parasitemia dropped over winter; half of these infections dropped to low levels (Table 3).

The dynamics of gametocyte proportion varied considerably among infections (see Figs. 7 and 8 for some examples). Among 31 stable infections, 15 (48%) had stable gametocyte levels >75%, 3 (9%) had intermediate stable levels of 50–65%, 8 (26%) had gametocyte levels that rose appreciably to a high stable proportion, and 5 (16%) had gametocyte percentages that continued to rise throughout the period of study. Thus, 90% of stable infections had gametocyte percentages that were either high and stable, or rose to high levels during the season. Among 24 rising infections, 22 (92%) demonstrated increasing gametocyte percentages as the season progressed.

Available data allowed an accurate estimate of the dynamics of initial gametocyte production for 11 rising infections, all probably new infections acquired during the study period. In 6 infections, gametocytes appeared shortly after the infection was first detected. In some of these, gametocytes rose to 50–90% of all parasite cells within only 7–10 d. In 5 infections gametocytes appeared 7–19 d after the infection became obvious in blood cells, while in one infection there was a delay of 78 d before any gametocytes were seen. (This infection was also unusual because it remained at low levels for 2 mo before experiencing substantial growth.) The time from first detection of infection until first appearance of gametocytes did not differ between infected juvenile and adult lizards, nor with date the infection originated. In all of the 12 infections for which we were able to determine the relationship between parasitemia and proportion of gametocytes, the increase in gametocytes was associated with a synchronous leveling off of parasite replication.

In summary, gametocytes in almost all infections appear to increase during the warm season if they are not already abundant in early spring. In May 1982 many infections already had high and constant gametocyte levels; perhaps the sampling program had begun after the older infections had already undergone their spring recrudescence. In contrast, 8 of 10 infections that were followed into May 1983 showed greatly decreased gametocyte proportions (Table 3), and in all of these the overall parasitemia had dropped. Thus gametocytes appear to be gradually cleared from the lizard's blood during the winter, to be replaced very quickly the next spring.

DISCUSSION

P. mexicanum appears to be a long-established and highly stable parasite of *Sceloporus* in some areas of western North America. The *Sceloporus-Plasmodium* association is an old one in northern California, probably existing there since at least the Pleistocene (Ayala 1970). Malarial prevalence at the Hopland Field Station has remained at ≈25% for 8 yr, and perhaps for longer than two decades despite substantial environ-

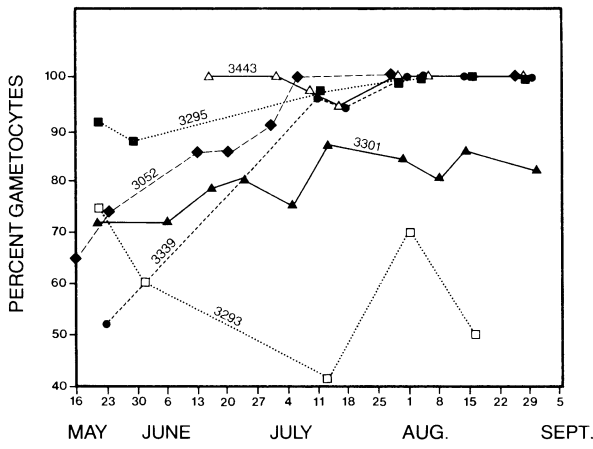

FIG. 7. Proportion of gametocytes in six *Sceloporus occidentalis* individuals representative of stable *Plasmodium mexicanum* infections over the warm season of 1982. See Fig. 2 for parasitemia data for these same infections. Four of the infections shown here reached 100% gametocytes in early August, remaining in this condition for the rest of the warm season.

mental fluctuations during that time (Ayala 1970, Schall 1983*a*; C.R. Bromwich and J. J. Schall, *personal observations*). We assume this success is derived in part from the parasite's specialized reproductive characteristics that ensure transmission between hosts in the seasonal environment of northern California. In response to the challenges of its seasonal environment, we expected that *P. mexicanum* would adjust its reproductive schedule to complement the vertebrate host's quality and the date of infection. This kind of conditional reproductive schedule occurs in nematode parasites of livestock in temperate regions (Schad 1977), and possibly also occurred in human malaria in northern Europe (Hackett 1937).

We found that new *P. mexicanum* infections can occur at any time during the warm season. Initially, the parasite population grows exponentially, but finally levels off to a stable level maintained during the rest of the season. Gametocytes eventually emerge in the blood and increase in abundance until they dominate the infection. As gametocytes do not reproduce in the blood, a switch to their production slows down the rise in parasitemia and probably causes the observed leveling off. Over the winter gametocytes are cleared from the lizard's blood and parasitemia declines. Asexual replication resumes early the next spring but appears short-lived because gametocytes quickly dominate the infection. We did not determine if infections undergoing a spring recrudescence rebound to their original maximal level, or reach a new constant condition.

These findings are in variance with the results usually reported for *Plasmodium* infections, including those of lizards, in which exponential rise is followed by a crisis, then precipitous decline (Boyd 1939, Coatney et al. 1971, Telford 1972). Also, the prevailing view holds that chronic malarial infections maintain low, constant parasitemia, whereas a large proportion of stable *P. mexicanum* infections were characterized by high parasite loads. (One of these remained at ≈18% of erythrocytes infected; humans infected with *P. falciparum* often die when parasitemia reaches only 2% [Belding 1942]!) Goodwin and Stapleton (1952) reported high stable infections of *P. floridense* in naturally infected *Sceloporus undulatus* kept in the laboratory, suggesting that the pattern seen for *P. mexicanum* may be typical for the malarias of lizards.

The general life history of *P. mexicanum* in the lizard host reported here also differs somewhat from earlier accounts on this same species (Ayala 1970, Schall 1983*a*). These authors used samples of lizards taken periodically throughout the season. As demonstrated here, *P. mexicanum* infections at the study area are pronouncedly asynchronous during the warm season. At any time some infections will be found at various stages in their exponential growth, whereas others maintain constant parasitemia that varies greatly in intensity among infections. Thus, vertical analysis can produce equivocal or even erroneous conclusions; only a mark-recapture study can provide reliable information on the dynamics of such a system.

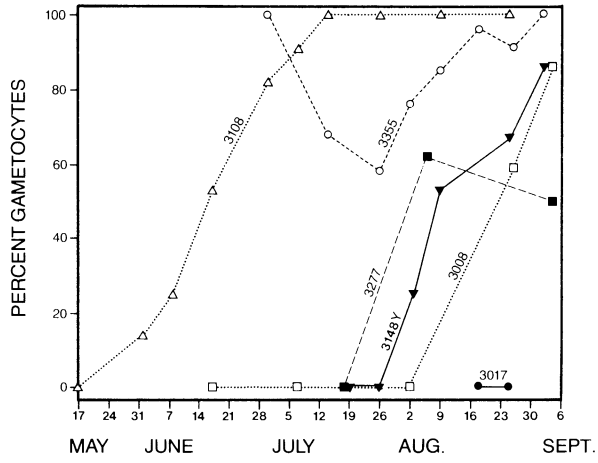

FIG. 8. Proportion of gametocytes in six *Sceloporus occidentalis* individuals representative of *Plasmodium mexicanum* infections increasing with time over the warm season of 1982. See Fig. 3 for parasitemia data for these same infections.

We examined three kinds of variation in the course of malarial infection in *Sceloporus*: rate of increase in parasitemia during exponential rise, maximum parasitemia, and dynamics of gametocyte production. This analysis provides little support for any precise adjustment of reproductive events by the parasite during the warm season. Rates of exponential increase range over much less than an order of magnitude and do not differ between juvenile and adult, or male and female lizards. Although some results suggest that infections starting late in the season grow more rapidly than early starting infections, the evidence is unconvincing because some infections display the opposite pattern. The ultimate level reached by infections before leveling off to a chronic condition varies greatly (over two orders of magnitude). No difference was found between male and female lizards, nor between early starting and late starting infections, but maximal parasitemia of all infections and mean parasitemia of stable infections was higher in smaller lizards. Perhaps this results from differing immune competency of adult and juvenile lizards, rather than any intrinsic alteration by the parasite of its reproductive behavior. If so, this suggests the odd conclusion that the ultimate parasitemia reached by *P. mexicanum,* but not the rate of increase, is influenced by the lizard's immune system. Unfortunately, little is yet known about the reptilian immune system (Sypek and Borysenko 1985), so its role in influencing malarial infection dynamics is now very speculative (but see Schall 1983*b*).

Maximal parasitemia is closely associated with an increase in gametocytes, so insight into the mechanisms of gametocyte production will be central to understanding the course of infection of *P. mexicanum.*

The switch from asexual replication to predominant production of gametocytes can occur very quickly, even in the early stages of infection, or it may be gradual. Early starting infections were not found to delay gametocyte production more than later infections. This was unexpected, as the optimal timing for the switch from asexual proliferation to gametocyte output was initially predicted to be late in the season when the insect host is abundant. Thus, although gametocytes gradually increase over time within any infection, the dynamics of gametocyte production seem to vary randomly among infections.

The developmental mechanism involved in a switch from asexual reproduction to gametogenesis in *Plasmodium* is still unknown. Early experiments suggested simple genetic control over the tendency for an infection to produce gametocytes (Huff and Gambrell 1934, Gambrell 1937), and later studies suggest that gametocytes and asexual stages are genetically uniform within a malarial clone (Walliker 1976). Inselburg (1983) demonstrated that within a single clone of *P. falciparum,* several distinct lineages emerged. Some produced a "fated" proportion of gametocytes, whereas others continued to yield only asexuals. Relative proportion of these two lineages appeared random. The gradual increase in gametocytes in infections of *P. mexicanum* may represent a replacement of lineages yielding predominantly asexual stages with those producing gametocytes. Once an infection consists primarily of gametocyte-producing lineages, a subsequent recrudescence in early spring should yield primarily gametocytes. This is what we observed in *P. mexicanum.* Perhaps variation in gametocyte dynamics, and consequently the entire course of infection, contains a significant random component resulting from the developmental mechanism driving gametogenesis.

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