2.11 BIOLOGY

Eggs of the genus *Aedes*, always require some form of stimuli for proper hatching. The effect of reduced ambient oxygen concentration was observed by Gjullin *et al.* (1941). Use of certain stimulating agents, viz., corn-broth, ascorbic acid and several others, were advocated for egg-hatching from time to time (Borg and Horsfall, 1953; Horsfall, 1956; Burgess, 1959; Judson, 1960). Clements (1963) was of the view that eggs of sandine mosquitoes undergo a developmental arrest. Some recent workers have also reported the problems of conditioning of *Aedes* eggs and related hatching stimuli (Muspratt, 1962; Judson, 1963; Quraishi *et al.*, 1963; Mallack *et al.*, 1964).

Imai and Maeda (1976) recorded high rate of hatching of *Aedes albopictus* eggs in water containing Chlorella or having a low concentration of dissolved oxygen (DO) than in distilled water or that containing a high DO concentration. During mass rearing of *Aedes aegypti* for field releases in Delhi, under a WHO/ICMR Project, Ansari *et al.* (1977 a) recommended the conditioning of eggs for 72 hours and obtained 95.96% hatch. In the three hatching media used i.e. dechlorinated water, rearing medium and reduced pressure, for a period of twenty minutes, no significant difference in hatchability was noted. Novak and Shroyer (1978) described a new hatching
technique involving biotic deoxygenation and confinement of
eggs in small glass tubes. Several geographical strains of
Ae. triseriatus and Ae. hendersoni were tried. Ninety five to
100% hatching was achieved. They considered this method as an
essential one for studies of egg hatching. These workers con­
cluded that egg-hatching did not occur in instalment in Ae.
triseriatus when eggs are properly conditioned and provided
with optimal hatching stimulus.

Aedes aegypti Linnaeus

Haddow and Gillett (1957) noted that eggs of Ae. aegypti
were laid mainly during the day with a well marked peak in the
afternoon as there was a definite diel cycle of oviposition in
this species. Light was considered to be the controlling factor
in the oviposition cycle (Gillett et al. 1959). Later on, labora­
ory observations on pupation and emergence were made by
Haddow et al. (1959). The existence of a diel rhythm in pupa­
tion or in emergence was not found by them. Further, they ob­
served that the male larval life was shorter than female by
about 8 - 10 hours. Male pupal life was also shorter
than female by about 2 - 3 hours. Moreover, it was noted that
all those specimens which spent longest time in larval stage
also spent longest time in pupal stage. Provost and Lum(1967)
also confirmed the earlier findings of Haddow et al (loc. cit.)
regarding absence of diel rhythm in pupation or in emergence,
in various strains of Ae. aegypti. Christophers (1960) studied
this species at 28°C, when the larvae hatched within 15 minutes
or less. He observed that the span of I, II and III instars was almost of 24 hours of duration each. The IV instar was of 50 hour duration.

Ansari et al (1977 a) perfected the procedures and techniques for mass rearing of Ae. aegypti at 28 ± 1°C and 80-85% RH. Twelve hundred male and 3600 female pupae were added daily to the adult colony cages on each alternate day. Eggs were collected daily in the morning and conditioned for 72 hours. Eggs were hatched in dechlorinated water at a temperature of 28 ± 1°C in enamel trays. Thirty thousand larvae were measured volumetrically and reared in plastic trays. Pupae were harvested on the day 6 and separated with a screen and cold water. Male pupae were sexed by using grids with 99.9% accuracy. During the mass rearing, it was noted that percent of egg hatching decreased steadily with age, but 2 and 4 weeks storage gave an acceptable level of hatching (95.95 and 87.09% respectively). Simultaneously, a device was developed to separate larvae from pupae of Ae. aegypti (Ansari and coworkers, 1977 b). The device consisted of a tray fitted with a perforated metal screen bottom which fitted into a separation chamber. Larvae and pupae were placed in the tray and the chamber was filled with water. The tray was kept in the chamber to allow larvae to pass through the holes. Pupae were then placed in chilled water in shallow enamel trays for completion of separation of pupae from the larvae.
**Aedes albopictus** Skuse

*Ae. albopictus* is known as a vector of dengue fever, and it is reported that this species played a major role in which the transmission of dengue fever prevailed in Japan during the World War II. Mori *et al* (1981) colonised *Ae. albopictus* under laboratory conditions at 25°C and 16 hours daylength at Nagasaki, Japan. Five hundred larvae were reared in a pan and were fed with 0.4 gms. of mixture of brewer's yeast and finely ground mouse pellets every day. Pupae were obtained on day 8 and transferred to laboratory dish containing clean water in a cage. The adults were given 2% sugar solution. Three days after emergence of the last female, a chicken was given for blood meal. Five days after feeding on blood meal, filter paper was fixed on inside of dish containing a little water to facilitate oviposition. Soon after the females laid eggs, the filter paper was taken away and the number of eggs were counted next day. The eggs on the filter paper were submerged in water in a glass vial and newly hatched larvae were taken out and counted every day. The water used in all experiments was the tap water.

Laboratory studies, done by Liu *et al* (1985), at 26 ± 1°C temperature and 60 - 90% RH showed one-fold population increase in 5.2 days. Rates of development of different stages, percentage of survival, reproductive capacity, sex ratios and life expectancy of both sexes were determined by these workers,
Aedes diantaeus H., D. & K.

Tamarina and Aleksandrova (1977) observed during laboratory colonisation of this mosquito that when females of first generation were given the opportunity to lay eggs on moist filter paper/ moist cheese cloth/ tap-water or an infusion of fallen leaves taken from the breeding places, they preferred to oviposit on fallen leaves. Females of next generations laid eggs on all those substrates. Oviposition took place on 13th day after blood meal provided and continued for 3 days thereafter. On the first occasion, 87 eggs were laid by the female. Eggs were treated with 1% solution of ascorbic acid, a week after they were laid. Larvae began to hatch a day after ascorbic acid treatment. Most of the eggs hatched within first 3 days. Percentage of hatching was 43. The males lived for about a week and females about a month.

Aedes taeniorhynchus Wiedemann

Nielsen and Haeger (1954) reared this species in laboratory and observed that at 30°C, 1st, 2nd and 3rd instars took 24 hours each while the 4th instar took 50 hours. Nielsen and Evans (1960) observed that adult emergence rhythm was dependent on the pupation rhythm which in turn was affected by temperature and not by photo-... Similar observations were made by Provost and Lum (1967). These two workers found that larval development rate is directly related to temperature and amount of food available. Nayar (1967) made the detailed studies on this species. He reported that eggs of Ae. taeniorhynchus underwent embryonic development immediately-after laying, if properly conditioned.
For completion of embryonic life, enough moisture (70-80% RH) and temperature (22-32°C) were required. The eggs hatched within 5-15 minutes in deoxygenated water. At 27°C, 1st to 3rd instars took 22, 18 and 22 hours respectively, while at 30°C, they took 19, 15 and 19 hours only. Duration of 4th instar was about twice that of 1st or 3rd instar, i.e., duration of 4th instar was 38 hours at 30°C. The results indicated that the amount of food was of no effect, provided temperature remained constant. Further studies made by Nayar (loc.cit.) revealed that temperature had a greater role to play in the regulation of moulting as well as the pupation process, in this insect Anopheles culicifacies Giles

Pal (1943 a, 1945 a & b) studied in detail the temperature conditions in Punjab which was directly associated with the various stages of this mosquito. The most favourable range of temperature for viability of eggs was 28 to 36°C. Larval development took 11-15 days at 32-37°C; the range of temperature from 28 to 32°C was, however considered to be most suitable for the various larval instars to grow. Further, he found that the temperature ranging from 28-32°C was quite favourable for pupal development. The rate of pupation was 30-40% at 36-40°C. Adult longevity was found to be 28 to 56 days at 12-18°C, while it was 14-28 days and 6-18 days at 25°C and 30°C respectively.

A. culicifacies was colonized, for the first time in
Delhi, India, by Ansari et al. (1977c). These workers established a colony of this species in laboratory cages by providing 15 hours of full day light with fluorescent tubes and special arrangement was made to create dusk and dawn conditions for a period of 80 minutes in the morning and in the evening. Afterwards, Das (1973) colonized this species using special techniques. Egg to egg cycle was found to be of 15 days at 25-27°C.

Tewari and Reuben (1979) studied the mating behaviour of A. culicifacies in small cages and improved certain methodologies of rearing this species at Salem, Tamil Nadu. They found that at a temperature of 22-29°C and 75-85% RH, the average daily egg production was 1900 while the average hatchability of eggs was 96%. An average daily pupal production numbering about 1300 (range 300-3025) was attained in the regular colony while the average pupation was 71%. Nine days were required, on an average, from hatching to pupation.

Further, laboratory studies on the biology of A. culicifacies were made by Das and Rajagopalan (1979) at 28±1°C and 75-80% RH. The average number of eggs laid by a female during the first oviposition was 52. Egg hatchability was 96.7%. The mean duration of each instar was: I instar-1 day; II instar-2 days; III instar-1-2 days; IV instar-3 days and pupa-1 day. High yield of pupae (average 74.5%) was obtained when trays were provided with a layer of sub-soil from paddy-fields, exposed to sunlight with proper arrangement for aeration of water surface for 3-4 hours. Adult survival was the highest with chicken blood and soaked raisins.
**Anopheles fluviatilis** James

Detailed studies on adult longevity of *A. fluviatilis* were made by Pal (1943a) in Lahore, Pakistan. Under laboratory conditions, the females of this species lived up to 18 days at 20°C at any relative humidity. The females survived for 17–18 days at 30°C and 60–80% RH and for 10 days only at 35°C, 100% RH. It was concluded that temperatures between 20–30°C and 50–80% RH provided optimum conditions for survival of adult mosquitoes.

**Anopheles minimus** Theobald

Muirhead Thomson (1940) studied the hatching of eggs of *A. minimus* experimentally and noted that hatching took 2 days at 30 and 35°C, 2.5 days at 25°C, 3.5 days at 20°C and 7 days at 16°C. Similarly, length of pupal stage also varied with temperature i.e., 1.25 days at 30°C, 1.75 days at 24°C, 2.75 days at 20°C and 4.5 days at 16°C. Further, Ribbands (1949) noted that in monsoon conditions, the life of egg was 2 days, of larvae 7 days, of pupae 2 days and of adults (upto first egg-laying) 3 days.

**Anopheles stephensi** Liston

Observations on caged mosquitoes, under field conditions, have shown that individual specimens of this species could live up to 32 days at 55% RH (*Mayne, 1936*). Similarly, *Strickland and Roy (1936)* had specimens living up to 36 days. These workers

*Original articles not seen. Quoted from Ramachandra Rao (1984).*
noted that at summer temperatures, the gonotrophic cycle took 4 to 11 days to mature a batch of eggs. However, under laboratory conditions, the gonotrophic cycle took 2-3 days, but the first cycle taking a day more (Russell and Mohan, 1939). In Iran, Quraishi et al (1966) noted that the first gonotrophic cycle in A. stephensi was completed in 3-4 days and the second in 6-8 days after eclosion.

**Anopheles subpictus** Grassi

Mehta (1934) undertook laboratory studies on this mosquito species in Karnal, Haryana and observed that the adult longevity increased at lower temperatures. The females survived up to 20 days at 25°C and up to 6-14 days at 30°C and 70% RH. The researcher felt that high humidity above 90% was injurious to this insect. In nature, he thought, *A. subpictus* lived from 5-11 days at 30°C.

**Culex (Lutzia) fuscanus** Wiedemann

This mosquito species is a predator of other mosquito larvae during its larval stage. The bionomics of this mosquito species, studied in Japan, have shown that it is a blood-sucking mosquito, but it does not feed on man (Ikeshoji, 1966). In India, a full fledged cyclic colony of *C. (L.) fuscanus* was established at Vector Control Research Centre, Pondicherry, for the first time (Panicker et al, 1982). Its detailed biology was studied at 28 ± 2°C, 60-75% RH, by Geetha Bai and her associates (1982). The mean number of eggs in each raft was found to be 124.8
(range 45-181). The egg stage lasted for 1-2 days. Egg hatch-
ability ranged from 32.6 to 96.0%. The mean duration of each 
larval instar was: I instar- 1-2 days; II instar- 1-2 days; 
III instar- 1-2 days and IV instar- 1-3 days. The duration of 
pupal stage averaged 1-2 days. The period from egg stage to 
adult emergence ranged from 7 to 10 days. Female longevity 
ranged from 2-63 days, while the corresponding figures for 
males were 2-60 days.

*Culex quinquefasciatus* Say

Qutubuddin (1953) studied the duration of pupal stages, 
adult emergence and sex ratio of this insect under laboratory 
conditions and reported that male and female pupal life were 
of the same duration. Walter and Hacker (1974) made life table 
studies of three strains of *C. quinquefasciatus*. The strains 
originated from Bangkok (Thailand), Vero Beach (Florida) and 
Houston (Texas). Eggs and larvae were collected from the 
respective fields and colonized in the laboratory. The mean 
number of eggs/raft were 108.1, 113.9 and 121.5 for Bangkok, 
Houston and Vero Beach strains respectively. The mean life 
time for male and female adults of 3 strains were 8.2 and 
17.57 days for Bangkok, 11.82 and 20.18 for Houston and 12.11 
and 22.60 for Vero Beach strains respectively.

In India, Singh and associates (1974, 1975) reared 
this species on a mass scale at 28 ± 1°C and 90%RH. The average
larval development time was 6-9 days. Pupal production was very uniform and pupal yield per tray ranged from 49.24 to 63.10%. Percentage of pupation was 32.61, 35.71, 20.48 and 6.19 on day 1, 2, 3 and 4 of pupation respectively. The male : female sex ratio was 85:15, 50:15, 20:50, 5:95 on 1st, 2nd, 3rd and 4th day of pupation. There was a noticeable size difference between male and female pupae. The first pupation (mainly of male pupae) was harvested on the 6th day. Sharma et al. (1972) developed a grid to sex male and female pupae. Since this technique involved considerable expenditure in maintaining temperature control system, Singh and Razdhan (1977) reared this species under ambient conditions. The four parameters, i.e. larval development period, daily pupal production, pupal yield per tray and sex ratio of pupae on different days, were studied. It was found that larval development was very irregular. It took 16-24 days in November, December and January (19-23°C ambient temperature), 7-11 days in February to April and October (23-40°C) and 6/7 days from May to September (31-42°C). Moreover, heavy larval mortality was noted. Pupal production was not uniform and pupal yield per tray ranged from 20-60%. Percentage of pupation was 6.43, 18.57, 18.09 and 6.76 on 1, 2, 3 and 4 day of pupation respectively. Similarly, male : female sex ratio under ambient conditions was 86:14, 45:55, 34:66 and 31:69 on day 1, 2, 3 and 4 of pupation respectively. Moreover, very little size difference was observed in late male and female pupae.
**Culex sitiens** Wiedemann

*C. sitiens*, a brackish water-breeding mosquito, has been successfully colonized in the laboratory at Pondicherry, at 28 ± 2°C and 60-75% RH (Panicker, Geetha Bai and Viswam, 1981). The number of eggs per raft ranged from 63 to 371 and hatchability was 30.2 to 98.7%. It was noted that hatchability of eggs was higher in tap water (73.3%) than in distilled water (68.8%). Both males and females developed from most egg rafts, while in 2 cases, only females were obtained. Normally, the female progeny outnumbered the males in all rafts.

The mean range of duration of each larval instar was:

- I instar, 1-4 days;
- II instar, 2-5 days;
- III instar, 1-4 days;
- and IV instar, 3-8 days.

It was noted that females lived for a longer duration, as compared to males. Longevity of females ranged from 3-34 days, while the corresponding period for males was 3-25 days only (Panicker et al., loc. cit.).

**Mansonla annulifera** Theobald

Chandrasekharan (1982) gave a general account of the biology of *Mansonla* mosquitoes. Detailed laboratory studies on the biology of *M. annulifera* were made by Srinivasan and Viswam (1986). The species has been colonized at Vector Control Research Centre, Pondicherry. A cyclic colony is being maintained at 28 ± 2°C and 60-75% RH. Studies were carried out on egg hatchability, immature developmental duration, insemination capacity, longevity, gonotrophic cycle and fecundity. The
number of eggs per cluster varied from 74-146 and the hatchability from 88.03 to 98.32%. The mean range of duration of each larval instar was: I instar- 2-4 days, II instar- 3-6 days, III instar- 4-7 days and IV instar- 7-11 days. Pupal stage lasted 2-3 days. Complete developmental duration from egg to adult was 22 to 35 days (average 28.5 days). The longevity of male and female varied from 2 to 27 days and 3 to 32 days respectively. Males emerged earlier than females. The male to female ratio at emergence was 1:3.5.

2.2. EFFECTS OF PHOTOPERIOD AND TEMPERATURE

Photoperiod and temperature are the most important factors in the regulation of growth and developmental processes of insects. Moreover, these two environmental conditions have different effects on different insects and even different individuals of a given species, sometimes, may react to these conditions differently in different geographical regions. In the light of these varying reactions, it will be interesting to see how different mosquito species referred to below, respond to light and temperature conditions. Sensitivity to photoperiod is never extended to the whole life cycle. All the stages may be receptive, but in most cases, the responsive period is limited to a particular stage or instar of an insect. In other words, the sensitive period of insects to light, temperature and humidity is far away from the responsive period (de Wilde, 1962).
Eggs of different mosquito species are highly susceptible to photoperiod and temperature. Short day-lengths and low temperature inhibit the egg hatching process. However, eggs of different mosquito species show variations to these effects under laboratory, as well as, in the field conditions. The following relevant review of literature will clarify the contentions.

**Aedes aegypti** Linnaeus (Yellow fever mosquito)

The eggs of this species and other aedine mosquitoes, after completion of embryonic development, enter a state of dormancy. These eggs hatch only after submersion in a medium with reduced oxygen content (Gjullin *et al.*, 1941; Borg and Horsfall, 1953). Male eggs hatch more readily than females from the same egg batch (Elzinga, 1961; Wood, 1962; Mayer, 1966). In Nagasaki, Japan, when the eggs of this species were kept dry during winter (sub-optimum temperature), a few eggs overwintered in outdoor conditions. These eggs, when kept in a sunny place in early March and soaked in water, hatching could be observed at 11.3 to 15.5°C, but most of the larvae hatched out in this way died soon. Only few could reach adult stage (Ofuji, 1963).

Weissman-Strum and Kindler (1963) advocated that 27°C and 90% RH were the most suitable conditions for egg hatching of *Ae. aegypti*. For mass production of *Ae. aegypti*, Ansari *et al.* (1977a) maintained the cycling colony cages at
28°C and 80-85% RH. Eggs were collected daily in the morning and conditioned for 72 hours. Eggs were hatched in dechlorinated water at 28°C and 80 ± 5% RH. However, these authors did not take into consideration the role of photoperiod on egg hatchability of this mosquito species.

*Aedes albopictus* Skuse

Ito (1959) had reported the variations in hatching phases due to weather conditions. Wang (1966) observed the role of light in hatching of eggs of this insect. He found only 21.9% hatching in short-day (8L:16D) illumination, while under constant illumination for a period of 24 hours, the hatchability was 86.45%. There was a clear difference in the rate of hatching between the two photoperiods. In both the light periods, temperature was 25°C. The critical photoperiod was between 13 and 14 hours. Imai and Maeda (1976) studied the effect of environmental conditions on hatching of eggs of *Ae. albopictus*. Results obtained by them were almost similar to those observed by Wang (1966) earlier. These workers obtained 67% of egg hatching received from parents reared at 27°C under 16 L:8 D period as compared to 10% at 20°C under 8 L:16 D and 14% at 27°C during 8 L:16 D photophase. It is clear from these experiments that photoperiod is much more effective than temperature in the induction of hatching process. Only a small number of eggs laid by females reared at 21°C in 10hr daylength, hatched between 6-11 days, while many eggs laid by female reared at 25°C in 16hr daylength, hatched between 4-16 days after oviposition (Mori et al., 1981).
Hawley et al (1987) tested 17 geographic strains of *Ae. albopictus* for egg diapause after exposing insects to short and long photoperiods. Adults were fed on human or mouse blood, held for 4 to 5 days, and then provided with an oviposition jar. Eggs were held for 6 to 8 days to allow completion of embryonation, percentage hatch was determined after flooding with deoxygenated water for 24 hours. Results showed a clear photoperiodic effect on the North American and northern Asian strains but no such effect on any strain of tropical or sub-tropical origin. It was concluded by these workers that North American strains of *Ae. albopictus* exhibit photoperiodic sensitivity and coldhardiness characteristics similar to strains originating from temperate zone of Asia.
Aedes atropalpus Coquillett (Rock pool mosquito)

Anderson (1968) reported a very peculiar effect of light and temperature on egg hatchability of this insect. He observed 95% hatching in a condition of 16L : 8D at 17.5°C, but the hatching was found to be as low as 1.1% in 12L : 12D at 27°C or below. Interestingly, an increase of temperature to 32°C retaining the same photoperiodic regime (12L : 12D), the hatchability was found to be as high as 90.9%. Kalpage and Brust (1974) studied the effect of temperature and photoperiod on embryonic diapause in Ae. atropalpus. Diapausing eggs which were kept at 23°C and 8L : 16D, hatched after exposure to 30°C for 20 days or exposure to 16L : 8D for 90 days. Most of the diapausing eggs hatched after only 5 days at 30°C, provided they were 60-90 days old. It was concluded by them that high temperature acts independently of photoperiod, as eggs kept at 30°C hatched at SD as well as LD regimes.

Beach and Craig (1977) were of the view that Ae. atropalpus deposited dormant eggs in response to short day photoperiods when temperatures were below certain limits. In further studies on the effect of three temperatures i.e. 22, 24 and 28°C on three geographical strains of Ae. atropalpus collected from three latitudes (i.e., 14°N, 34°N and 45°N), Beach (1978) concluded that both temperature and photoperiod play an active role in various geographical strains.

Aedes campestris Dyar and Knab

This species has been reported to be univoltine by a
number of workers (Mc Lintock, 1944; Rempel, 1950; Owen and Gerhardi, 1957; Nielsen and Rees, 1961). Chapman (1963) observed that in Nevada strain, only 53% of the freshly laid eggs hatch after a week at 23°C and suspected the species to be multi-voltine. According to Tauthong (1975), long photoperiod (16L: 8D) caused hatching of dormant eggs of *Ae. campestris*. Tauthong and Brust (1977) observed that short photoperiod of less than 14 hr induced the embryonic diapause in this insect.

*Aedes canadensis* Theobald

Newkirk (1955) was the first to note "facultative diapause" in this mosquito. However, there were no data available on the photoperiodic effects under laboratory conditions. Barr and Al-Azawa (1958) observed that eggs of *Ae. canadensis* - Kansas strain, failed to hatch under normal hatching conditions. Mallack et al (1964) got much variability in the hatchability of field collected eggs of this mosquito. Finger and Eldridge (1977) observed that eggs of this species, when subjected to a daily light regime of 9L : 15D for 14 days after oviposition, failed to hatch at all. Critical photoperiods were considered to be 13L : 11D and 14L : 10D.

*Aedes caspius* Pallas

This species is very widely distributed in the USSR and includes 2 sub-species: *Ae. caspius dorsalis* Meigen, predominant in the north and *Ae. caspius caspius* Pallas, prevalent in the southern parts of the country (Gutsevich and others, 1970).
More detailed experiments on the 2 sub-species were conducted at Washington (USA) by Mc Haffey and Harwood (1970). According to them, in short-day-lengths, the number of larvae hatched increased from 15 to 75% when the duration of exposure the mothers was increased from 13.5 to 16.5 hr. In other words we can say that there is a maternal effect of photoperiod which in turn regulates the egg hatching, in both the sub-species. Further studies on Ae. caspius caspius were undertaken at Leningrad (USSR) by Vinogradova (1975). She observed more egg hatching during LD (18L : 6D) than in SD (12L : 12D) photophases, the percentages being 98.9 and 92.9 at 25°C; 88.1 and 72.6 at 20°C and 38.7 and 27.4 at 15.5°C respectively. She concluded that photoperiodic influence was less significant than that of temperature in this species.

*Aedes sollicitans* Walker (Salt marsh mosquito)

Photoperiod had a very marked influence on the embryonic development of this species. More than 95% eggs hatched when the photoperiod was 15L : 9D at both, high (32°C) and low (18°C) temperature. Under short-day, virtually none of the eggs hatched at low temperatures. At high temperature and a photophase of 11L : 13D, 71% of the eggs hatched. Eggs maintained continuously under 10L : 14D at 23°C, failed to hatch for 87 days (Anderson, 1970).

*Aedes taeniorhynchus* Wiedemann (Southern salt-marsh mosquito)

Nayar (1967) stated that major factors controlling the development of eggs of this insect were the temperature and
humidity; light was not considered to be an important regulatory condition. Contrary to this, Parker (1985) observed that photoperiod and temperature interacted in the embryogenesis.

*Aedes triseriatus* Say (Eastern Tree hole breeding mosquito)

Baker (1935) reported that egg diapause could be induced in this mosquito by SD conditions and terminated by return to long days. Contrary to it, Love and Whelchel (1955) found no evidence of egg diapause in this insect. Due to difference of results between these workers, further detailed study was taken up by Kappus and Venard (1967) who found that direct photoperiodic treatment of eggs produced the most remarkable effect. However, the photoperiodic treatment of adults showed no effect. It was concluded that both temperature and photoperiod caused a significant effect in this regard. On the other hand, photoperiodic response was considered to be temperature dependent. Certain other workers also assumed that the sensitive stage in this species is restricted to the developing embryo (Anderson, 1968 & 1970; Pinger and Eldridge, 1977).

Shroyer and Craig (1980) observed a hatching latency, caused by photoperiod in *Ae. triseriatus*. Fully formed embryos were sensitive to shortday-lengths (10L : 14D) and only 3-6 shortday cycles were enough to block the hatching reflex. The second type of latency could be induced when the embryos (maintained at 16L : 8D) were transferred from 21°C to 10°C. These embryos became unresponsive to hatching stimuli after 7-14 days. This low temperature-induced latency could be
completely terminated 11 days after return to 21°C (Shroyer and Craig, loc. cit.). Further, it was observed that overwintered eggs in tree-holes hatched in instalments, because hatching stimuli and conditioning factors were sub-optimal and limited (Shroyer and Craig, 1981).

*Mansonia titillans* Walker

Influence of continuous light (LL), continuous darkness (DD) and 12L : 12D at 27°C was observed on egg hatchability of this insect. It was noticed that 12L : 12D photophase, led to synchronised hatching of the eggs, it is to be noted that hatching took place only during the scotophase. An endogenous circadian rhythm of egg hatching seemed to exist. The rhythm could be entrained by the light-dark regime. It was also observed that a single 12-hour light or dark period in the populations, resulted in distinct phase shift which could be initiated early in embryogenesis (Nayar et al, 1973).

**EFFECTS ON MOSQUITO LARVAE**

Different instars of mosquito larvae respond to various photoperiods and temperatures. Different geographical strains of the same species may also display much variations in their reaction to the environment.

*Aedes aegypti* Linnaeus

Ofuji (1963) investigated the possibility of establishment of this species in Japan by studying the ecological zero-point of larvae and their development in early spring. One
hundred larvae, soon after hatching at 25°C, were reared in 5 groups of 20 larvae each at 5 constant temperatures. Larvae took 13.3, 9.2, 6.5, 5.5 and 5.7 days for development at temperature 18, 22, 25, 27 and 30°C respectively. The development of the larvae was found to be slightly delayed at 30°C.

**Aedes atropalpus** Coquillet (Salt marsh mosquito)

Anderson (1968) studied the influence of photoperiod and temperature on the larvae of * Ae. atropalpus* under laboratory conditions. He observed that when the eggs/adults/1st and 2nd instars/1st to 3rd instars reared under LD (16L : 8D) were transferred to SD (12L : 12D), the rate of egg hatching was very poor; it ranged from 0.2 to 1.3% only. When the other stages were transferred from LD to SD, the rate of hatching ranged from 87.4 to 99.4%. In both the cases, temperature was maintained at 23°C. He, therefore, stressed the role played by photoperiod on development of this species.

**Aedes sierrensis** Ludlow (Western tree-hole breeding mosquito)

Studies undertaken at Central Oregon and Northern California, indicated that the development of 4th instar larvae of this mosquito species depended on photoperiod to initiate diapause at 16.5°C. Short days elicited 100% diapause among larvae from both the places, but the incidence of diapause declined with latitude so that only 35% of populations from Southern California entered diapause. It was concluded that among that portion of the population capable of responding to daylength, the critical photoperiod increased by 1 hour for each 4.8°
increase in latitude of origin (Jordon and Bradshaw, 1978). In further studies, Jordon (1980) pointed out that critical photo-period for 4th instar larvae varied among different geographic populations and thus suggested that there is a genetic divergence among various populations.

*Aedes triseriatus* Say

Love and Whelchel (1955) reported that this species overwintered at 4th instar stage, which pupated in spring when the photoperiod was lengthened. In southern part of USSR, SD (10L : 14D) resulted in long delay in development during 4th instar and this caused death to many of them at 15-20°C which was too high temperature (Vinogradova, 1967). Larvae from eggs kept under 10L : 14D during embryogenesis were allowed to develop in the same photoperiod. The arrested development was observed in the larvae of 4th stage. These larvae were seen active and consumed food. Wright and Venard (1971) noticed that photoperiods and temperatures experienced by the adults exhibited no influence on their progeny. Clay and Venard (1972) demonstrated that larvae of the Ohio strain, hatched from longday-exposed eggs, but entered diapause in a condition of a short-day, cool-temperature regime. However, under comparable photoperiod-temperature regime, diapause incidence was greater in the Alabama population. Sims (1982) observed that larvae of this species from 26 to 46°N latitude underwent 4th instar larval diapause in response to short-day-cool conditions. Both sub-tropical and northern populations had relatively greater incidence of
continuous development at SD while northern population exhibit greater diapause at LD as well. It was concluded that diapause intensity is relatively stronger in females and in central area of latitudinal range. There is intra-population variance at each end of the range of the species.

*Culex tritaeniorhynchus* Giles

Short photoperiod and low temperature completely stopped the breeding of this mosquito species (Eldridge, 1963; Ito et al, 1968; Kawai, 1969). Larval growth and pupation rate were, on the other hand, affected by high temperature (Yoshida et al, 1970). Wada and Omori (1971) observed that almost no larval growth took place at 16°C. Later on, detailed studies on *C. tritaeniorhynchus summorosus* Dyar, were taken up under various photoperiods and temperatures at Osaka, Japan, by Yoshida et al (1974). The larval growth was found to be delayed under SD (12L : 12D) as compared to LD (14L : 10D). The growth rate was further delayed under SD (10L : 14D). At 37.5°C, only 0.5% of the larvae pupated. All the larvae died at first instar stage at 44°C temperature.

In India also, prolonged larval development of this mosquito was observed in laboratory as well as under simulated conditions. Rahman et al (1981) were of the view that overwintering of *C. tritaeniorhynchus* took place in larval stage in Delhi from 1st week of December to 1st week of February.

*Culiseta melanura* Coquillett

The role of photoperiods (9L : 15D and 16L : 8D) and temperatures (28, 19, 10 and 4°C) was taken into account of this
insect. It was observed that at 28°C, all larvae completed development within the same time regardless of photoperiod. At 19°C pupation rate differed. All larvae reared under LD pupated, whereas under SD, approx 20-30% of the larvae became pupae within the test interval of 17 weeks. Regardless of photoperiod, the larval development was prevented by low temperature. These workers observed that one group of 4th instar larvae survived over 7 months at 4°C. Upon rewarming, a substantial number of the 4th instar larvae pupated and emerged (Maloney and Wallis, 1976).

Wyeomyia smithii Coquillett (Pitcher plant mosquito)

Laboratory studies undertaken by Lounibos and Bradshaw (1975) revealed that growth of 3rd instar larvae of this insect was checked by brief exposure to LD (17L : 7D) followed by SD (8L : 16D or 12L : 12D) at 25°C. In New Jersey, Bradshaw and Phillips (1980) found that larvae of this species overwintered due to low temperature and short day length under laboratory conditions. The larvae could be maintained in this state so long as these conditions prevailed; this situation could be reversed when the larvae were exposed to long day length.

EFFECTS ON MOSQUITO PUPAE:

Duration of pupal stage in most of the mosquito species is too short to be influenced by photoperiod, they are, therefore, reported to be temperature dependent (Provost and Lur., 1967; Nayar, 1967 & 1968).
This species deposited diapausing eggs in response to SD photoperiods when temperatures were below certain limits. The decision to diapause or continue development is mainly based on daylength measurements made by an endogenous circadian clock during the photosensitive 4th instar larva and pupae of the maternal generation (Beach and Craig, 1977). It was noted by Beach (1978) during subsequent studies that diapause was triggered in *Ae. atropalpus* from 14°N lat when 9 or more SD photoperiod cycles occurred during 4th the instar and pupa. Temperature of 22°C or more caused part or all of the population to complete the photosensitive period in less than 9 days thereby avoiding diapause.

*Oda and Wada (1972)* studied the effect of photoperiod on pupae of this insect by exposing them to short day regime (8L : 16D or 9L : 15D). It was observed that follicular development and feeding activity of females of *C.p.pallens* were inhibited due to short daylength exposure of the pupae. The more the pupae were exposed to short day, the greater was the effect on follicular development of adult females.

**EFFECTS ON ADULT MOSQUITOES**

There have been studies to show that photoperiod and temperature regulate normal development and feeding activity of female mosquitoes. The following account provides some examples.
Culex pipiens pallens Coquillett

Oda (1971) studied the effect of photoperiod and temperature on the feeding activity and follicular development of females of this species. It was concluded that effect of photoperiod decreases with rising temperature. Laboratory studies by Wang (1979) indicated that shortday-lengths could induce hibernation in newly emerged adults, but sensitivity to photoperiod never lasted throughout the entire life cycle. The successive growth started as photoperiod was cut down to 13.5hr/diel at 20-22°C temperature.

Culex pipiens pipiens Linnaeus

Spielman and Wong (1973) observed that less than 12 hours of light induced the entire mosquito population to overwinter. When these overwintered mosquitoes were again exposed to a light regime of 16hr/day, reproductive arrest was broken. Similar experiments also showed that both photoperiods and temperatures affected the development of ovarian follicles. Females reared under 15L : 9D at 22°C showed an increase in follicular size during first 8 days after emergence. On the other hand, females reared under 10L : 14D at 22°C, did not show any increase in follicular size. At photophases of 9-12 hours, follicles remained small, while at 13hr or more, the increase was noted. It was further noticed that an increase in temperature resulted in increase of follicle size regardless of photophase (Sanburg and Larsen, 1973). Contrary to it, Oda and Kuhlow (1974) were of the view that diapause in this insect was induced by shortdaylength and its development and termination were due to changing daylength rather than temperature.
Anopheles freeborni Aitken

A. freeborni adults overwinter during September to December in California (USA). It is characterised by suspension of reproductive activity. Field studies carried out by Washino (1970) indicated a strong possibility that decreasing photoperiod rather than low temperature initiated overwintering. In subsequent studies (Washino et al., 1971), it was noted that photoperiod and temperature affected the blood meal in this insect. It was also observed that a great proportion of adult females, reared under LD took a blood meal and developed matured eggs as compared to those reared under short daylengths.

2.3 MOSQUITO SURVEY IN INDIA

Regional surveys provide very useful information on the distribution and prevalence of various mosquito species. The results of such surveys offer valuable information of the vector species and their prevalence in the particular zone/region. Some of the important and comprehensive surveys of various States in general and of North Eastern Region of India, in particular have been mentioned.

Anopheline survey in relation to epidemiology and control of malaria in certain parts of Uttar Pradesh recorded a few anopheline species (Robertson, 1909; Cameron, 1921 and Phillips, 1924). Further, Clyde (1931), Srivastava (1950), Srivastava and Diwan Chand (1951), Issaris et al. (1953) and Rahman et al. (1956) reported the existance of 10-17 anopheline species and highlighted their roles in malaria transmission.
Showing Various States

India

200 100 0 200 km

Jammu & Kashmir
Himachal Pradesh
Punjab
Delhi
Uttar Pradesh
Haryana
Nepal
Sikkim
Bhutan
Arunachal Pradesh
Assam
Nagaland
Meghalaya
Assam
Manipur
Meghalaya
Tripura
Mizoram
Bihar
West Bengal
Karnataka
Andhra Pradesh
Orissa
Maharashtra
Gujarat
Madhya Pradesh
Rajasthan
Pakistan
Pakistan
Arabian Sea
Lakshadweep (India)
Sri Lanka
Andaman Islands
Nicobar Islands (India)
However, all these surveys were restricted to anopheline fauna only. Later, Wattal et al. (1967) carried out extensive survey and recorded 4 species of Anopheles, 6 of Culex and 1 of Aedes. Recently, Hagpal and associates (1983), reported 29 mosquito species from Nainital Terai (Uttar Pradesh), belonging to 8 genera, viz., Anopheles, Aedes, Aedeomyia, Armigeres, Coquille-ttidea, Culex, Mansonia and Mimomyia. Three species i.e. A.sitkarni, A.lincesayi and A.kochi were reported for the first time. A.karwari and A.minimus earlier reported, were found to be absent.

Fry (1912) undertook mosquito survey of Coastal Orissa and Chilka Lake areas and reported 5 anopheline species. Sarathy (1932) recorded 15 species of Anopheles from Puri district (Orissa), while Seni., White and Adhikari (1939) recorded 20 species from Chilka Lake, based on larval collection. A. sundaicus was reported for the first time there. In 1942, survey carried out by Covell and Singh recorded 17 anopheline species from the area. Recently, detailed mosquito survey was carried out in Coastal Orissa and a total of 32 species belonging to 6 genera i.e. Anopheles, Aedes, Aedeomyia, Armigeres, Culex and Mansonia were collected (Nagpal and Sharma, 1983 a). A.minimus and A. pulcherrimus were recorded for the first time from this region. Four species reported earlier i.e. A. jeypo-riniens, A. maculatus, A. sundaicus and A. theobaldi were found to be absent.
Afridi and coworkers (1938) studied the mosquito fauna of Kutch (Gujarat) and reported the presence of 7 species of anophelines. Pandya and Mehta (1975) gave a general account of haematophagous arthropods of Surat district, Gujarat. In all, 13 species of Culicidae were encountered. It consisted of 7 species of Anopheles, 3 of Culex, 2 of Aedes and 1 of Armigeres. Recently, Neeru Singh and her associates (1985) undertook a detailed survey in Kutch and recorded the occurrence of 14 species of mosquitoes belonging to 3 genera i.e. Anopheles (10 species), Culex (2) and Mansonia (2). A. aconitus, A. nigerrimus, A. pulcherrimus and A. sundaicus were collected for the first time from this region.

Mosquito survey carried out at various places in Mandla district, Madhya Pradesh, revealed the presence of 5 genera, viz., Anopheles (12 species), Aedes (2), Armigeres (1), Culex (2) and Mansonia (2). A. culicifacies was the most dominant species in this region (Neeru Singh and Nagpal, 1985). A. stephensi and A. varuna, earlier reported by Subramanian and Dixit (1948) from Nimar district (Madhya Pradesh), were not encountered by these investigators. Kulkarni and Rajput (1985) surveyed Bastar district (M.P.) for Culicine mosquitoes, between December, 1980 and January, 1982. A total of 4358 culicine mosquitoes belonging to 11 species i.e. 10 of genus Culex and 1 of genus Uranotaenia were collected. Recently, Kulkarni (1987) collected anophelines of Bastar district, between February, 1980 and January, 1981. He reported the presence of
19 anopheline species including *A. varuna*, which was found to be absent by Neeru Singh and Nagpal (*loc. cit.*). These researchers also failed to collect any specimen of *A. stephensi*.

Christopher (1912) reported 8 anopheline species from Andaman Islands. Coveil (1927a) also recorded 8 species, but with one new record and reported the absence of *A. altkeni* which was previously recorded by Christopher (loc. cit.). Basu (1958) reported only *A. sundalcus* and Culex species. His survey seems to fall short of, since it was restricted to only indoor collections from human dwellings. Krishnan and Halernkar (1967) recorded 9 anopheline species with 2 new records. Further, they observed the absence of *A. altkeni* and *A. umbrosus*. However, all these surveys indicate the species composition of only anophelines. Keeping this in view, extensive mosquito survey was undertaken by Nagpal and Sharma (1983b). These workers reported the presence of 5 genera—*Anopheles* (16 species), *Aedes* (1), *Armigeres* (1), *Culex* (4) and *Mansonia* (2). Seven *Anopheles* species—*A. annularis*, *A. nigerrimus*, *A. nivipes*, *A. karwari*, *A. stephensi*, *A. subpictus* and *A. varuna* were recorded for the first time from Andaman Islands.

In Goa, till 1963, a total of 24 species of anophelines were recorded (Borcar et al., 1967). During 1983, 5 species of anophelines (with an additional record of *A. leucosphearbus* group) and 10 species of culicines were recorded by Choudhary et al. Further, Kulkarni and his associates (1986) undertook a detailed survey of Goa and recorded 29 species. *C. tritaeniorhynchus* was the most abundant species. With this
study, the number of mosquito species recorded so far in Goa has risen to 51 comprising of Anopheles—25 species, Aedes—6, Culex—14, Heizmannia—1 and Mansonia—4.

Monographs on Indian anophelines and culicines were published by Christophers and Barraud in 1933 and 1934 respectively, where all up-to-date available records of mosquitoes were incorporated therein. These monographs contained various mosquito species of India, Pakistan (including Bangladesh), Ceylon (now Sri Lanka), Burma and adjoining countries with detailed ecological notes.

However, mosquito species of North Eastern Region of India which includes Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura, were not described in much detail. Later, only during 1966-1967, faunistic survey was carried out jointly by Zoological Survey of India and Field Laboratory, now Defence Research Laboratory, Tezpur, Assam, in Kameng and Subansiri divisions of North East Frontier Agencies (now Arunachal Pradesh) and in certain limited places of Assam. However, these observations have not been brought to the knowledge of general Entomologists.

Sarkar et al (1980) surveyed 5 places of Nagaland and reported the presence of 16 species of 4 genera, viz., Anopheles (8 species), Culex (6), Aedes and Armigeres (1 species each). Adult collection was mainly done with the help of sweepnets and aspirator tubes. Further, survey in Nagaland was undertaken by Malhotra and his associates (1982a) and recorded 30 species belonging to 6 genera, viz., Anopheles (10 species), Aedes (4),
Culex (12), Mansonia (2), Armigera and Tripetroides (1 sp. each). Adult mosquitoes were collected with the help of CDC Miniature light traps. Of the places surveyed, Mukokchung had the maximum mosquito infestation (530.12 per trap night). C. gelidus was the most dominant species encountered during the survey.

Mosquito survey of Mizoram (Malhotra et al., 1982b & 1984) revealed the presence of 41 species belonging to 6 genera, viz., Anopheles (15 species), Aedes (8), Armigera and Malaya (1 species each), Culex (14), and Mansonia (2). The recent survey carried out by Nagpal and Sharma (1987) has revealed the presence of 36 species of 7 genera in Mizoram. They are Anopheles (14 species), Aedes (5), Armigera (3), Culex (10), Malaya (1), Mansonia (2) and Toxorhynchites (1).

Anopheline survey at Manipur by Covell (1927b, 1931), Barraud (1933) and Puri (1936) revealed the presence of only 5 species from the State. Mortimer (1946) in his survey of anophelines during 1943-1944, collected 16 species with total absence of A. dirus and A. minimus. Mosquito survey in Manipur (Malhotra et al., 1983a), carried out at 3 places, revealed the presence of 23 species belonging to 6 genera i.e. Anopheles (7 species), Aedes (2), Culex (11), Armigera, Coquillettidae and Mansonia (1 species each). Recently, Rajput and Singh (1986) recorded 18 anopheline species from Manipur. Only one specimen of A. minimus could be collected during the entire survey period i.e. September, 1983 to October, 1985. Further study by Rajput and Singh (1987) on day-biting mosquitoes of
Manipur revealed the presence of 23 species of 6 genera i.e., Anopheles (1 species), Aedes (9), Armigeres (9), Heizmania (1), Mansonia (2) and Tripteroides (1).

The survey of various places, now included in Meghalaya, in early thirties, revealed the presence of 32 species belonging to 7 genera, viz., Anopheles (17 species), Culex (3), Aedes (6), Armigeres (3), Mansonia, Toxorhynchites and Urantanea (1 species each) (Christophers, 1933; Barraud, 1934). Rajagopal (1976) reported the presence of 14 Anopheles species from Burnihat (Meghalaya) and incriminated A. philippinensis as sole malaria vector. Recently, Das et al (1984a) undertook mosquito survey in Meghalaya and collected 42 species (and 2 varieties) belonging to 6 genera, viz., Anopheles (17 species and 2 varieties), Culex (11 species), Aedes (7), Armigeres (2), Mansonia (4) and Coquillettidia (1 species only). Recently, Nagpal and Sharma (1987) recorded 41 species of 6 genera from Meghalaya. The various genera were Anopheles (20 species), Aedes (5), Armigeres (2), Culex (11), Mansonia (2) and Toxorhynchites (1 species).

Misra and Dhar (1955) carried out a survey in Tripura during 1954 and collected 10 species of anophelines. Of these, A. minimus was incriminated as malaria vector. Much survey work has not been done in Tripura.

Misra (1956) described 6 anopheline species from Arunachal Pradesh and incriminated A. minimus as malaria vector. Sen and Coworkers (1973) reported 14 species from Tirap district,
Arunachal Pradesh, and incriminated *A. dirus* as sole malaria vector there. All these studies were restricted to anophelines only. Malhotra *et al* (1987), therefore, undertook extensive mosquito survey in Tirap and Subansiri districts of this State and reported 48 species of a genera. During another study, Nagpal and Sharma (1987) reported the presence of only 6 genera, viz., *Anopheles* (18 species), *Aedes* (6), *Armigeres* (1), *Culex* (10), *Mansonia* (3) and *Toxorhynchites* (1). These researchers failed to collect any specimen of genus *Malaya*, *Tripteroides* and *Cocullilletidae*, while Malhotra *et al* (*loc. cit.*) reported their presence very well. Recently, Dutta and Baruah (1987) established involvement of *A. minimus* as a vector of malaria in Arunachal Pradesh.

Earlier anopheline surveys carried out in Assam during forties, revealed the presence of 6 species of *Anopheles* with maximum density of *A. minimus*. This species occurred throughout the year with high densities from June to November. Malaria parasite injection was found in all the months (except in February) with a peak in March (Anderson and Vishwanathan, 1941; Clark and Choudhury, 1941; Vishwanathan *et al.*, 1941). Rajagopal (1979) collected 6 anopheline species from Nowgong district bordering Mikir Hills in Assam. *A. dirus* formed 82.7% of the total. The preponderance of *A. dirus* in the collection with a very high man-biting rate (43) indicated that this species was the most probable vector of malaria in forested areas of Assam. All these studies were mainly concerned with malaria transmission. Faunistic survey in certain places of
Dibrugarh district in Assam was initiated by Sarkar et al. (1981) during March-April 1978. In all, 27 mosquito species belonging to 8 genera, viz., Anopheles (6 species), Aedes (4), Armigeres (3), Culex (8), Mansonia (3), Malaya, Toxorhynchites and Coquillettidia (1 species each) were encountered. The maximum collection of a single species was of C. quinquefasciatus which formed 68% of the total catch. Kareem et al. (1983, 1985) undertook malaria transmission studies in Gokhalkhana, under Boko PHC, Goalpara district, Assam, and reported 21 anopheline species from there. A. minimus which was believed to have disappeared due to insecticidal spray, was encountered in unsprayed areas. Dissections results have shown sporozoites in one specimen of A. minimus in the study area during 1983. A. dirus was also captured. Among anophelines encountered, A. philippinensis was the most dominant (22.78%).

The latest available information of mosquito fauna of Assam, has been provided in a recent survey carried out by Nagpal and Sharma (1987). In total, 8 mosquito genera i.e., Anopheles (27 species), Aedes (9), Armigeres (3), Mansonia (3), Culex (13), Coquillettidia, Malaya and Toxorhynchites (1 species each) were captured by them.

However, most of these studies were restricted to adult collections only, which did not give the totality of mosquito fauna of a particular region. Furthermore, the details of different species, their seasonality, feeding behaviour, host preferences and breeding habits/habitats were not done by them.
2.4: SEASONALITY

Seasonal changes in environment always determine the physiological and behavioural conditions of animals in general and insects in particular. In other words, some specific functions of insects always synchronize with the changing conditions of the environment. Therefore, growth and developmental processes and for that matter, phenological adaptation of insects are always dependent on the prevailing conditions of the seasons of the year. As a consequence, recurring of any biological event, like development or arrest of development of insects synchronize with cyclic seasonal conditions.

A survey of literature concerning mosquitoes seasonality has been made hereunder:

*Aedes aegypti* Linnaeus

Seasonal prevalence of *Ae. aegypti* in Egypt revealed that adult mosquitoes were present in the houses throughout the year, although the density was not very high in winter (Kirkpatrick, 1925). In Spain, Clavero (1946) got adults of this species in abundance in summer and autumn, and were prevalent till the end of December. Marin (1957) observed high density of this species between October and December, in northern Morocco, larvae could be collected till the end of spring, notwithstanding. In Bangkok, this species occurred round the year, reached a peak after the onset of monsoon and gradually decreased to low levels from January to April (Scanlon, 1966). On the other hand, in tropical regions of
America, the effect of rainfall was very conspicuous, while in temperate regions of the US, the species almost disappeared in winter months and slowly increased its density in spring and early summer (Soper, 1967). In Southern Nigeria, West Africa, Surtees (1967) noted that mean weekly larval density of this species increased over 5 times during first 4 months of the year but declined sharply from May to July. This decline was followed by a decrease as the rainy season was over.

In India, Diwan Chand et al. (1961) undertook certain studies in Gorakhpur, Uttar Pradesh, and reported that adult density increased from June and reached its peak in August; it then came down from September onwards. In Vellore, Tamil Nadu, Reuben (1967) reported low adult density in July, 1964, which reached the peak in September and fell thereafter, being lowest during hot-dry season i.e. March-May 1965. In Delhi, population estimation of *Ae. aegypti* was made at 2 tyre-dumps by Reuben and her associates (1973) who showed that population increased with the onset of monsoon in June-July. From June to November, 1971, in Delhi, the monthly rainfall recorded was 46.8, 140.4, 424.1, 157.3, 7.8 and 0.0 mm respectively. During June and July, 1971, the monthly maximum and minimum temperatures were 37.5°C and 27°C and 34.1°C and 25.2°C respectively. The density then declined with the end of rains and beginning of cold season.

It is evident from the above that highest incidence of *Ae. aegypti* occurred during the monsoon months.
Aedes albopictus Skuse

In Japan, the successful overwintering, in the field could be seen only in egg stage (Abe et al., 1941; Nakata et al., 1953). Experimentally, it was possible to make the insect survive through winter in larval stage in certain region of Honshu, Japan (Ishii et al., 1954). Udaka (1959) pointed out that *Aedes albopictus* repeated 5 generations in a year in Shikoku district of Japan. His estimation was based on temperature summation. In Amami-Oshima Island of Japan again, overwintering larvae in the field were found by Takenokuma (1966). Ho et al. (1971) were of the view that the seasonal fluctuations of immature stages was closely related with the rainfall. Another Japanese worker (Makiya, 1973 & 1974) observed the population dynamics of various larval stages in water-holding concavities of grave-stones in a graveyard. However, this population variation was artificially affected by renewal of water in the water-holding concavities due to local custom. According to Wada et al. (1976), even the adult emergence occurs in winter.

Seasonal abundance of *Ae. albopictus* was studied in Nagasaki, Japan, for a period of 3 years (1974-76). High density of immature stages was observed in July-August during all the 3 years. The larval number fell gradually from September and only few larvae were found by the end of January next year. Number of early instar larvae was reported to be influenced by rainfalls. The largest number of pupae was observed in early May, 1975. However, fluctuations of the number of pupae were far less remarkable than those of larvae. Adult mosquitoes
started emerging during May/June and peak emergence was from July to September. From October onwards, the density declined very few adults were collected in November. From December to February/March, no adult could be collected. However, early instar stages were seen with very high mortality (Mori and Wada, 1978).

As far as we know, not much work has been done in India from the seasonality point of view on this insect.

* * *

*Aedes canadensis* Theobald

Morris and De Foliart (1971) found that adult population peak of this species occurred during mid-June and mid-July in Wisconsin, USA. In northeastern Pennsylvania, larvae of *Ae. canadensis* were collected in snow-melt peaks from mid-April till late June (Wills and Fish, 1973). Further, larval and adult mosquito surveys in woodland habitats near Ithaca in New York, have been done during summer of excessive rainfall in 1972 and during normal summer in 1973 by Magnarelli (1976). He observed that the cumulative rainfall during the period of mid-March-August, 1972, was 512.5 mm while during 1973, in the same period, it was only 398.3 mm. It is to be noted that the difference in rainfall had an impact on the seasonal occurrence of larvae and adult emergence of the mosquito. In 1972, *Aedes canadensis* was a big nuisance in woodland habitats from late-June to late-July, while during 1973, females were easily collected in mid-August.

Thus, there appears to be a direct correlation between excessive rainfall and adult mosquito density. However, there
might be certain other environmental factors such as temperature, relative humidity and food availability which might be associated with the phenomenon of seasonality.

*Aedes cantans* Meigen

Field studies carried out by Service (1977) in Southern England for a period of 6 years have shown that the females of *Ae. cantans* laid eggs from June to September. These eggs remained dormant till the beginning of January, mainly due to low temperature and short daylength. The larvae hatched in January and pupated in late April or early May. Larval mortality decreased progressively in late instars.

*Aedes triseriatus* Say

Population dynamics of *Ae. triseriatus* in Northern Indiana showed the variations in sex ratio of pupae, collected from tree-holes during various seasons. There were much more male pupae in spring, which reduced to 50% male during late July while female pupae were predominant later (Sinsko, 1976). Schall and De Foliart (1978) observed a similar seasonal change in adult population emerging from tree-holes.

Detailed studies on seasonal variations in sex ratio and its dependence on egg hatching behaviour were undertaken by Shroyer and Craig (1981). They observed that newly hatched larvae collected from tree-holes displayed a seasonally variable sex ratio. Initial spring hatches of overwintered eggs were predominantly males but subsequent hatches produced smaller proportions of male larvae until females were the predominant
Ovitrap studies showed that females deposited equal numbers of male and female eggs throughout the year.

**Anopheles annularis** Van der Wulp

It is regarded as a secondary vector of malaria in certain parts of India. Senior White *et al* (1943) recorded maximum abundance of this insect during autumn months in Orissa. Ghosh and Hati (1980) studied the seasonal man-biting activity of this species in rural West Bengal, from September, 1979 to August, 1980. The maximum collection could be made during September, 1979. Not even a single specimen could be met with in April, 1980; it again disappeared during the months of June to August, 1980. In contrast, Ramachandra Rao (1984) reported that this species occurred throughout the year with greater abundance in May–June, both in Bengal and South India. Further, he observed breeding of this mosquito all around the year with enormous breeding during April–June. All these 3 months are regarded as dry season in India. Similar observations were made by Karim and coworkers (1985). These researchers also noted the seasonal prevalence of this species throughout the year with preponderance during April–May, in malaria endemic areas of Kamrup district, Assam.

It is opined that this mosquito species breeds throughout the year in most parts of India with varying densities depending upon temperature and rainfall.
Anopheles culicifacies Giles

It is a common mosquito in most part of India and is a well known vector of malaria. In India, the actual seasons of prevalence of this species vary from place to place. In Punjab, Gujarat, Madhya Pradesh, Bihar and Eastern Uttar Pradesh, this mosquito species was found throughout the year but higher densities were recorded in March/April and September/October. In Madras and other southern States also, the species was reported throughout the year with high density from July to December; in Assam and Bengal, on the other hand, peaks were noted in December/January (Afridi and Puri, 1940). In Northern India, with the onset of monsoon, relative increase in its density was recorded, but during January/February, when the temperature ranged from 4.4 to 10°C, a sudden fall in density was observed (Afridi et al., 1940). Jaswant Singh and Jacob (1944) found largest number in April–June, while the lowest was recorded in October in North Kanara (Bombay).

In Punjab, highest prevalence of this insect was noted during hot-humid months i.e. June to September (Pal, 1945 b). Krishnan (1957) reported that this species occurred in significant numbers throughout the year with two peaks—one in March/April and the other in September; on the other hand, low density was observed in January/February and May/June. Sinha (1970) undertook seasonal studies in Bhagalpur and Chotanagpur divisions of Bihar during 1964 through 1969 and observed that the insect was prevalent throughout the year with density
fluctuations. The per man-hour density varied between 1.32 and 8.92. The lowest was in May/June and December/January, while the highest was during February to April and July to November. Thus, very low and very high density peaks have been recorded.

It is clear from the above that population density of this species fluctuated in various areas.

*Anopheles fluviatilis* James

Vishwanathan (1950) made an extensive study on this species in North Kanara (Bombay). The insects were found to be scarce during rainy season in mountainous zone with heavy rainfall, thick forests, deep valleys and streams. It was largely due to flushing of streams and canals. In these perennial streams, breeding commenced only after the end of monsoon (October/November) but reached its peak in April and May. In eastern plateau zone, with moderate rainfall and plentiful rice fields (monsoon from June to October), the species was in abundance. The mosquito became scarce from January to mid-June. Sharma (1961) felt that heavy rain was not suitable for this species. Sinha (1970) considered it as a winter species in the foot-hill areas of Bihar and its density buildup was observed from November to March with minor fluctuations. In Peninsular India, it may be present throughout the year depending upon climatic conditions. Its seasonality is mainly determined by the amount of rainfall and terrain (Ramachandra Rao, 1984).
Anopheles leyporiensis Koldzumi

Macan (1948) got this insect in abundance during rainy season in Kabaw and Kale Valleys of Burma. However, the same researcher (1949) noted its high density during April and May in Arakan region of Bengal and Burma, where the rainfall occurred from June to October. In Hongkong, Jackson (1951) observed little breeding of this species from May to October (which is considered as rainy season) and observed its very high density during October/November.

In India, Jaswant Singh and Jacob (1944) could not find this insect in North Kanara, Bombay, during the rainy season. They believed that this absence might be due to continuous flushing of larvae from the breeding streams. In Jeypore Hills, Orissa, the insect was in abundance from November to March, while it disappeared during rainy season i.e. August/September (Wattal, 1957).

It can, therefore, be concluded that seasonal fluctuations of this species seemed to be directly related to rainfall which ultimately controls the larval density.

Anopheles stephensi Liston

It is one of the major vectors of malaria in India and in neighbouring countries, like, Pakistan, Iran and Iraq.

In Bengal, this species was more prevalent in those regions which has average rainfall, not less than 50mm, 85% RH and temperature ranging from 25°C-32°C (Chowdhury, 1936).
Knowles and Basu (1943) reported maximum breeding of this species in Calcutta during July and, thereafter, it rapidly receded until December. In another study in South India, Russell and Ramachandra Rao (1941) collected large number of these mosquitoes in April and May than in other months. Bhaskar Rao and coworkers (1946) experienced the maximum density of adults from November to March in Madras. In Jamshedpur (Bihar), Sinha (1970) noted that the population density increased between April and December with minor fluctuations. The highest per man-hour density (2.4) was noted in October. Rajagopalan et al (1979) detected well breeding of this species in Pondicherry. It occurred in most of the months of the year except during rainy season.

**Culex annulirostris** Skuse

A light trap was used to study the seasonal distribution and prevalence of 13 mosquito species in Mildura area of Murray Valley, Victoria, Australia, in 1975-79. *C. annulirostris* was the most common summer species. Its population increased from late October until February and declined in March-April. Population growth increased when ambient temperatures exceeded 17.5°C and it was the greatest when temperature reached 25°C (Mc Donald, 1980).

**Culex pipiens** Linnaeus

Studies on *C. pipiens pipiens*, undertaken at Eastern Indiana, revealed the presence of only female mosquitoes during winter months. All the female dissected were found to be mated
and spermatozoa were usually active. There was no evidence of blood feeding in natural population during overwintering period (Shroyer and Siverly, 1972). Adult females of *C. pipiens* were found to be inactive at 21.5°C and below, but very active at 22.5°C and above in Southern Oregon (Hamrin, 1978).

The oviposition activity of *C. p. pipiens* in summer and autumn was investigated at 2 breeding sites in West and North of Federal Republic of Germany. Egg rafts were collected and counted daily on hourly basis. It was found that oviposition reached a high peak and then decreased sharply and ceased towards sunrise. There was a clear correlation between the hourly maximum number of egg-rafts deposited and nightfall. The peak of oviposition corresponded with sunset. The rhythm was shifted with the change in daylength, according to season and geographical latitude (Oda and Kuhlow, 1979).

*Culex quinquefasciatus* Say

Studies on this common mosquito species are getting momentum as more and more urban areas are coming up in different parts of the world. Seasonal variations in aquatic stages were observed in West Africa during 1970 by Subra. Neves and Da Silva (1973) made indoor catches at Belo Horizonte, Brazil, and found that *C. quinquefasciatus* were most plentiful in the months of highest rainfall and temperature. This is the period of maximum production of eggs by the mosquitoes. The egg rafts were present throughout the collection
period from April, 1971 to September, 1972, near Cedar Key, Florida. There were maximum egg rafts from May to August (Lowe et al., 1974).

A field study near Houston, Texas, showed that all stages of C. quinquefasciatus were present throughout the year. Despite severe cold weather (5°C or below) and snow falls, egg production seemed to be continuing. There was a slow but constant emergence of adults. Females were predominant during the colder months (5°C-15°C) and males in summer (20°C-30°C). In spring, there was an increase in the number of eggs per raft (Hayes, 1975). In subsequent studies, weather factors were correlated to egg production and duration of various larval stages (Hayes and Hsi, 1975). These workers were of the view that temperature might be a good indicator for predicting population density of C. quinquefasciatus. Hayes and Downs (1980), pointed out that during warm weather, oviposition reached its peak just after sunset and again near dawn. The pattern changed in cold weather with elimination of morning oviposition. It was confirmed further that all the stages of life-history of the mosquito were temperature dependent.

In India, studies on seasonal changes in populations of C. quinquefasciatus in two villages of Delhi, in 1971-72, showed a marked increase in its density in April and May. This was associated with a rise in temperature. Population density decrease with the onset of the rainy season (July to September). The number of adult females was greater than males in most
seasons. No seasonal trend was noted in the number of egg rafts or the hatching of eggs (Yasuno et al, 1977a). They reported shift of breeding sites depending on the concentration of organic matter in irrigation wells. The marked seasonal changes in population size was correlated with temperature. In coldest months i.e. in January (5°C or so), adult population was very small but it increased in the month of May (37°C-40°C). In rainy (July-August) and post-rainy seasons (end of September), the population was approximately half of that in hot season (Yasuno and coworkers, 1977b). Breeding of *C. quinquefasciatus* was also observed throughout the year in Tezpur, Assam. The lowest larval incidence was recorded during July, 1972 (28°C) and highest in February, 1973 (25°C). The low larval population during July (28°C) was probably due to heavy rainfall (420 mm) in preceding months which had flooded out the breeding sites (Sarkar et al, 1978).

It can be said that under Indian environmental conditions, *C. quinquefasciatus* breeding occurs throughout the year, however, the density appears to depend upon temperature and rainfall.

*Culex tritaeniorhynchus* Giles

Overwintering of adults of this species was worked out in detail in Japan (Bullock et al, 1959; Omori et al, 1967). Wada et al (1967) collected females of this species at the end of March and the insects were most active in late April. Males were first collected in mid-May. Population remained steady in June, increased to a maximum in July and August, decreased sharply in September when most females were presumed to have entered
hibernation. Daylength appeared to be the factor controlling reproductive activity in the females.

In India, studies on the mosquitoes of North Arcot district of Madras, Tamil Nadu, revealed the presence of *C. tritaeniorhynchus* throughout the year with varying densities (Reuben, 1971). In North India, the adult and larval density of this mosquito has been reported to be negligible during winter months (Menon and Rajagopalan, 1974; Rahman et al, 1978). Further studies, in and around Delhi area, showed the complete absence of adults of this mosquito species from 1st week of December, 1978 (Max. 21.8°C, Min. 9.4°C) to first week of February, 1979 (Max. 19.4°C, Min. 6.8°C). Contrary to this, 3rd and 4th instar larvae were collected in low density, throughout the winter season (Rahman et al, 1981). Obviously, the presence or absence of adult *C. tritaeniorhynchus* in South and North India during winter season was directly attributed to temperature. The minimum temperature in Delhi during winter remains 6°C or even lower, while in South India, the minimum temperature never goes down below 10-12°C or so.

In another South-East Asian country, Korea, adult *C. tritaeniorhynchus* were not detected in their natural habitats during winter (Ree et al, 1976). In Lahore, Pakistan, Reisen et al (1977) observed that during late autumn, there was a complete cessation of mating activity indicating to inactive period.
Culex univittatus Theobald

A study was made in May to October, 1967, near Johannesburg in the highveld region of South Africa. The four main species of Culex, viz., C. quinquefasciatus, C. p. pipiens, C. theileri and C. univittatus were studied. A small number of C. univittatus adults were collected in pigeon-baited traps during winter. The field results suggested that this species overwintered in adult stage only (Jupp, 1969). Further study on this species indicated that population of Culex univittatus increased during spring (September-October) when the mean maximum and minimum monthly temperature was 24.5° and 7°C respectively (Jupp, 1975).