DISCUSSION
The study was undertaken in the hilly district of Koraput in Orissa state which is hyperendemic for falciparum malaria (Rajagopalan et al., 1990) transmitted mainly by *A. fluviatilis* (Gunasekaran et al., 1989). This species was incriminated as a vector in this area for the first time by Perry (1914). Subsequently, Senior White (1937 & 1938) concluded that *A. fluviatilis* and the other two related species viz., *A. minimus* and *A. varuna* were responsible for malaria transmission. Based on the information gathered on the bionomics of *A. fluviatilis* it was suggested that species sanitation may control malaria in this area (Senior White 1938). Prior to the introduction of DDT residual spray through National programme for malaria control in 1958, preliminary trials with DDT were carried out in various parts of the country and one such trial was undertaken against *A. fluviatilis* in Rayagada area of this district (Weeks, 1951). Based on the encouraging results of these trials, National Programme of malaria control was implemented with DDT as the main weapon. While different levels of malaria control were achieved in many parts of India, no appreciable results were achieved in Koraput district and till today malaria continues to be one of the major public health problems. Though some studies were carried out prior to the launching of NMEP in this area, the causes for the persistence of the disease, particularly in relation to vectors, were not studied for the past four decades. The present study carried out in Koraput
district attempted to gather all the necessary information on ecology and behaviour of *A. fluviatilis*, which are the important aspects need to be considered in relation to malaria transmission and its control.

6.1. Prevalence and distribution of *A. fluviatilis*:

During the present study, a total of 22 anopheline species, including *A. fluviatilis* and one variety of *A. annularis* were recorded. In addition, four more species viz. *A. majidi*, *A. pulcherrimus*, *A. aitkeni* and *A. moghulensis* and three varieties viz. *A. jeyporiensis* var. candidiensis, *A. annularis* var. nagporei and *A. annularis* var. odissi were also reported from adjoining areas of this district (Gunasekaran, *et al.*, 1989 and VCRC Annual Report, 1990). Thus, 26 species and four varieties of anophelines were prevalent in this district. Out of 23 species reported during the pre-DDT era (Senior White, 1937 & 1938), *A. stephensi* was conspicuous by its absence. Present surveys showed the prevalence of four more species viz. *A. pulcherrimus*, *A. sergentii*, *A. ramsayi* and *A. peditaeniatus*. These species might have either been missed during identification in earlier studies or these anophelines might have got established in recent times due to the extensive development of irrigation system. It is reasonable to expect more number of species including rare ones if the survey is extensive based on different types of collections, as was done during the present study.
During the pre-DDT period, the indoor resting density (per man hour) of *A. funestus* group (which included *A. fluviatilis*, *A. minimus* and *A. varuna*) ranged from 1.7-15.9 in human dwellings and 0-5.8 in cattle sheds (Senior White, 1937), which was much higher than that observed in the present study. The prevalence of *A. minimus* was reduced to such a low level that it could not be collected in resting collections and only three specimens were recorded from man biting collections for the entire study period. *A. varuna* was also found in very low density.

Such a drastic reduction in *A. fluviatilis* population in this area may be due to environmental changes following extensive deforestation and prolonged use of insecticide under the malaria control programmes. Further, total annual rainfall has showed a decreasing trend over years (Anonymous, 1985) which might have resulted in the reduction of breeding sources.

Among the four ecotopes studied, top-hill village recorded the highest prevalence of *A. fluviatilis* followed by foot-hill village. In riverine and plain ecotopes this species was in very low densities. This difference in the relative density of this species can be attributed to the type and extent of breeding habitats available in these ecotopes. The presence of perennial streams and terraced paddy fields in stream beds may be responsible for the maintenance of its high prevalence in top-hill village. In other
regions also, the distribution of this species was reported to be closely associated with forested hilly areas where perennial streams are present (Ramachandra Rao, 1984).

6.2. Seasonality in prevalence:

The adult density was observed to increase during the rainy season. Its peak prevalence was noticed during October-November, the post rainy period (actually, October is the tail end of rainy season and November is the beginning of cold season). The increase during rainy months can be attributed to the breeding in terraced paddy fields as observed by Viswanathan (1950) in North Kanara district. This pattern of seasonal trend was similar in all ecotopes.

Seasonal prevalence of *A. fluviatilis* was reported to follow different patterns in different places. Rainfall has been attributed to such variations. In high rainfall areas, this species was reported to be extremely scarce during the rainy season because of the flushing of breeding habitats. In these areas the peak prevalence was noticed either during pre- or post-monsoon seasons (Bhombole et al., 1954, 1956) whereas in low rainfall areas the peak density was reported during the rainy months as the rains favoured the creation of large number of breeding habitats (Brooke Worth, 1953). In the present study the peak prevalence of *A. fluviatilis* was noticed during the post-rainy season and its prevalence at moderate levels
during the rainy months suggested that the rainfall was not high enough to flush away all the breeding habitats as observed by Viswanathan (1950) in the eastern plateau zone of North Kanara district. Thus, this area appears to occupy an intermediate position based on the effect of rainfall. Present observation on peak abundance of this species during October–November is in corroboration with an earlier study in Rayagada zone of this district (Weeks, 1951).

6.3. **Morphological variations in adults:**

Most of the morphological variations were observed for the first time in the present study. All these phenotypic variations were detected mostly in the mosquitoes collected from forested hilly areas. This might probably due to some micro-evolutionary process undergoing in this area to overcome environmental stress brought about by deforestation and prolonged use of insecticides.

6.4. **Breeding habitats and interspecific association:**

The study showed that streams, rivers, ponds and wells were the perennial breeding habitats and paddy fields and borrow pits were the seasonal breeding habitats. Though *A. fluviatilis* breeds in all habitats, the intensity of breeding was significantly higher in streams. This agrees with the earlier observation of Ramachandra
Rao (1945) in North Kanara district. When the larval habitats were ranked in terms of immature density of *A. fluviatilis*, it was in the order of streams, rivers, borrow pits, wells, ponds and paddy fields. Swamps were totally absent in this area. The intensity of breeding was relatively lesser in all flowing habitats during rainy season due to "flushing effect", whereas in wells it was higher as wells were left undisturbed. During the post rainy months (cold season) all the habitats recorded the highest density of *A. fluviatilis* immatures. A similar observation was made by Covell and Harbhagwan (1939) in Wynaad area (Kerala).

There are controversial reports on the breeding of *A. fluviatilis* in paddy fields. While some reports showed the breeding of *A. fluviatilis* in paddy fields (Russell and Jacob, 1942; Ramachandra Rao, 1945; Senior White, 1946c; Vedamanikkam, 1952; Bhombore et al., 1956), Covell and Harbhagwan (1939) stated that *A. fluviatilis* larvae were not found in paddy fields in Wynaad area. Present study revealed that breeding of *A. fluviatilis* occurred in paddy fields throughout the cultivation season. In this area paddy cultivation is done in terraced stream beds especially in top-hill ecotope and this association is the reason for maintaining perceptible flow of water which is the factor that has been reported to favour the breeding of *A. fluviatilis*. Though the per dip density of *A. fluviatilis* immatures was lower in paddy fields when compared with other habitats, its contribution to building up of adult density
particularly in top-hill village cannot be underestimated due to its vastness as reported by Ramachandra Rao (1984).

Interspecific association:

Degree of association and index of association are the indicators of biological interaction which can be used to predict the possible occurrence of different vector species together in a given habitat. Present study showed that *A. fluviatilis* was closely associated with *A. culicifacies* and *A. annularis* in streams as well as ponds, and it was with *A. vagus* and *A. subpictus* in paddy fields. In wells it was found to be least associated with other anopheline species. This study suggests that streams and ponds are the most important habitats to be considered in controlling the vectors of malaria in this area as there was positive association between the three vector species viz., *A. fluviatilis*, *A. annularis* and *A. culicifacies*. This type of analysis is first of its kind in anophelines which can be used to assess the qualitative and quantitative importance of various breeding habitats.

6.5. Adult density in relation to malaria transmission:

The per man hour density obtained from indoor resting collections is considered for monitoring the population fluctuation and to study the relationship between population levels and transmission
intensity. This figure alone will not give a correct indication on the population fluctuation in areas where the vector exhibits varying degree of outdoor resting habit (Rajagopalan, 1983). In this area, *A. fluviatilis* was found to be predominantly exophilic in its resting behaviour. Therefore, to measure the fluctuation in the density of *A. fluviatilis* and also to calculate the average density in different ecotopes, the density obtained from outdoor resting collections was considered along with indoor resting density. It is to be noted that the collection of anophelines in outdoor shelters is a difficult task (Ramachandra Rao, 1984) and the available techniques may not give a precise estimation (Rajagopalan, 1983). However, these problems were minimised in the present study by selecting adequate representation of different types of outdoor resting shelters and simultaneously monitoring the adult density in indoor and outdoor habitats. The overall (indoor and outdoor) density (per man hour) varied in different months and seasons. It is known that *A. fluviatilis* can transmit malaria even in low densities and the critical density at which it can effectively transmit malaria was calculated to be 0.4 per man hour (Viswanathan, 1946). This has been widely accepted and used even in assessing the effect of insecticidal spray (Sharma and Chauhan, 1959). In this area, the per man hour density was above 0.4 during rainy and cold seasons, ranging from 0.66 to 1.53. Malaria incidence was also high during these seasons (Jambulingam et al., 1991).
When the different ecotopes within the zone are considered, the average per man hour density was higher in top-hill village than other ecotopes and this is in accordance with the intensity of malaria transmission (Jambulingam et al., 1991).

6.6. Resting behaviour:

6.6.1. Endophily and Exophily:

*A. fluviatilis* generally rests in houses and animal sheds. It has also been reported to exhibit varying degree of exophilic behaviour in different areas (Viswanathan et al., 1944, Senior White, 1946d, Weeks, 1951, Ramachandra Rao and Rajagopalan, 1957, Mani et al., 1984; Shalaby, 1971). During the present study, *A. fluviatilis* was collected from both indoors and outdoors. As many as 324 females of *A. fluviatilis* were collected from outdoors by spending 313.5 man hours whereas in indoors only 159 were collected even after spending 1020 man hours. A similar result was obtained in North Kanara district by Viswanathan et al. (1944) who collected as many as 16 *A. fluviatilis* females by spending 19 man hours and only four specimens from houses during 34.5 man hours time. It has been reported that the numbers collected outdoors and indoors can not be compared directly because of the fact that adult anophelines could be collected from houses or cattle sheds with less effort as the adults tend to become concentrated in these indoor shelters whereas the
effort required is disproportionately more in outdoor shelters as the adults are scattered over wide areas (Ramachandra Rao, 1984; Service, 1976). Despite this, the density recorded from outdoors during the present study by spending less man hours was significantly higher than that of indoors and outdoor resting population was found to predominate in all seasons. This clearly indicates that A. fluviatilis is predominantly exophilic in nature.

The analysis of the abdominal condition of indoor resting population showed that though the proportion of semigravids was almost equal to fullfeds, the proportion of gravid females was remarkably low which suggests that a large proportion of mosquitoes leave indoors before the completion of gonotrophic cycle. A similar behavioural pattern was reported in North Kanara district (Karnataka) where it was observed that half gravid females were leaving the daytime indoor resting places to outdoor shelters to complete the remaining part of the gonotrophic cycle (Viswanathan et al., 1944). The exodus behaviour of this species in this area was further evidenced from the higher proportion of semigravids and gravidas (when considered together) compared to fullfeds in outdoor resting population.

6.6.2. Resting in human dwellings and cattle sheds:

The ratio of A. fluviatilis population resting in human dwellings
to cattle sheds was 0.71:1.00. Though relatively a higher resting density was recorded in cattle sheds it was not significant. In an earlier study in Jeypore hills, *A. fluviatilis* was reported to rest predominantly in human dwellings and only a very small numbers were obtained from cattle sheds (Perry, 1914). Subsequent studies have shown that the ratio of *A. fluviatilis* obtained in houses to cattle sheds was 25:1 (Senior White, 1937, 1938) and 2:1 (Weeks, 1951). Thus it is evident that there was a gradual increase in the proportion of mosquitoes resting in cattle sheds indicating a change in the resting behaviour of *A. fluviatilis* from human dwellings to cattle sheds in this area. This may reflect a change in its feeding behaviour also.

6.6.3. Preferential resting sites in human dwellings:

The percentage of *A. fluviatilis* resting on walls and roof was almost equal and a considerable proportion (27.72%) rests on unsprayable surfaces such as hanging objects and the objects kept on the floor. On walls, more than 50 percent was collected between 3 and 4 feet and above 4 feet. In night time also a similar trend was observed. From the epidemiological point of view, mud plastering the floor and inaccessibility of lower portion of the walls for spraying due to the household objects kept against it may not reduce/influence the effect of residual insecticides as the proportion of *A. fluviatilis* resting on the lower portion of the wall was negligible. On the other hand, the considerable proportion of this
species resting on unsprayable surfaces might escape the effect of
the spray to certain extent. However, the present observation was in
contrary to the earlier report by Weeks (1951) in Rayagada area of
this district who concluded that 64% of the females were found
resting on walls below 2 feet and only 3% preferred to rest on
unsprayable surfaces. Further, outer portions of the walls are not
covered for residual spray based on the fact that mosquitoes do not
rest in these portions due to the exposure to sunlight. But as
A. fluviatilis was observed to rest on outer portions of the walls
during night time, it will be more effective if these portions are
also included for residual spray.

6.6.4. Preferential outdoor resting shelters:

A. fluviatilis has been reported to rest in a variety of outdoor
shelters. However, its preferential outdoor resting shelters have not
been reported so far. The present study showed that pit shelters were
the most preferred outdoor resting shelter for A. fluviatilis as
these shelters recorded the maximum incidence of positive searches
(for this species) as well as the number per search. In hotter
months, resting density was however, more in tree hollows. Earlier,
artificially made pit shelters were reported to be very sensitive in
monitoring the outdoor resting population of A. fluviatilis even when
it was present in low densities (Shalaby, 1971). However, present
study shows that there is a shift in resting behaviour from pit
shelters to tree hollows during hotter months. Therefore, the relative abundance of this species in different seasons can be estimated by monitoring the density in pit shelters and tree hollows throughout the year.

6.7. Feeding behaviour:

6.7.1. Endophagy and Exophagy:

In this area, though feeding indoors was more common in A. fluviatilis, outdoor biting was also observed when hosts were available. Outdoor biting occurred in all seasons. During the hot season about 10-15 percent of the villagers sleep outdoors throughout the night. During this season, though the outdoor man biting rate was lower than that of indoors it was not significantly different. Therefore, in hot season, risk of transmission exists both indoors and outdoors considering the sleeping habit of the people. During the cold months, people sleep indoors after spending the early hours of the night outdoors keeping the fire nearby. In rainy season (July-October) nobody sleeps outdoors and hence the chances for outdoor transmission is very meagre. Other than the results obtained during the present study there is no information available on exophagic behaviour of A. fluviatilis except the report of Eshghy et al. (1972) who observed outdoor biting in Southern Iran.
Relatively a higher number of biting females was collected from indoors than outdoors suggesting that this species is more endophagic in its biting behaviour as reported in other areas (Ramachandra Rao, 1984). The peak biting density of *A. fluviatilis* in rainy season coincided with peak transmission of malaria (Jambulingam et al., 1991).

6.7.2. Biting periodicity:

The present study showed that biting of *A. fluviatilis* occurred throughout night and the mean biting density recorded in the I half of the night was relatively higher than that recorded in the II half, but it was not significantly different. However, in the earlier studies in this area, Senior White (1938) and Senior White and Venkat Rao (1944) observed the maximum feeding activity during the second half of the night. There were further conflicting reports on the biting periodicity of this species. While in some areas the entry and feeding were observed throughout the night, more or less in equal numbers (Jaswant Singh and Mohan, 1951), in some other places majority completed feeding before midnight (Viswanathan and Ramachandra Rao, 1943, Manouchery *et al.*, 1976, Bashghy *et al.*, 1976, Kulkarni, 1987). This variation, according to Ramachandra Rao (1984) might be either due to environmental factors or variations in habits of different strains. In the present study the shift observed in the biting activity to early hours of night during cold season indicates
that the environmental factor is responsible for such a change in the biting periodicity. Comparable observation was made also in Rayagada area of this district by Weeks (1951) who reported that biting was more during the first part of the night in cold season. Due to this biting behaviour in early hours, the risk of becoming infected before retiring to bed is great (Viswanathan and Ramachandra Rao, 1943). Under such circumstances, tools like insecticide impregnated mosquito nets may not interrupt the transmission during the cold season. However, during the other seasons these nets can be used effectively.

6.7.3. Pre- and post-feeding activity:

Though *A. fluviatilis* was found to be predominantly exophilic, the present observations on pre and post feeding activities suggested that *A. fluviatilis* enter the houses from their day time resting places and rest in the houses before feeding thereby facilitating this species to get exposed to the sprayed surfaces. Similar observations have been reported in this species earlier (Mohan, 1945; Weeks, 1951). Further, as they rest before feeding, chances for the infective mosquitoes to get killed even before they could infect the hosts are more. Also, there are evidences from night resting collections at different hours that this species rests indoors after feeding as considerable proportion of fullfeds was recorded from indoors. Thus, the pre and post feeding activity of *A. fluviatilis* suggests that the chances of its coming into contact with
insecticides are reasonably high.

6.7.4. Refeeding:

Though anophelines generally complete their gonotrophic cycle with a single blood meal, a proportion of females of certain species was reported to feed twice within one cycle (Ramachandra Rao, 1984). In the present study *A. fluviatilis* females of semigravid stages were encountered in man biting collections suggesting the occurrence of refeeding phenomenon. Observations on the ovarian development in these specimens showed different stages of egg maturation. However, it was difficult to know whether the previous blood meal was partial or full. Further, as there was progression in ovarian development in accordance with blood meal digestion the possibility of 'gonotrophic discordance' is remote. This natural phenomenon of refeeding increases the frequencies of man-vector contact and thereby the chances for the vector to get infected and to infect human host are expected to be enhanced. Thus the phenomenon of refeeding in *A. fluviatilis* is epidemiologically important in this area. In an earlier study, incidence of double blood meal within the same gonotrophic cycle was reported in *A. fluviatilis* and inadequate blood meal and gonotrophic discordance were attributed to such phenomenon (Jaswant Singh and Mohan, 1951). However, the phenomenon of gonotrophic discordance was not observed in the present study.
6.7.5. Host preference:

*Anopheles fluviatilis* has been recognised as predominantly anthropophilic mosquito. However, present study revealed that the anthropophilic index of this species is low (26.0%). In another adjoining zone (Malkangiri), the index was found to be 82.4% (VCRC Annual Report, 1990). Such variations in its anthropophilic index had already been reported not only in different ecological situations but also within the same hilly range. While a high anthropophilic index was known from several parts of western hill tracts (Covell and Harbhagwan, 1939; Jaswant Singh and Jacob, 1944; Viswanathan, 1950) as well as Chatikona Summit of Jeypore hills (Senior White, 1948), low values were recorded from plain areas (Brooke Worth and Sitaraman, 1952). The occurrence of this species with variations in feeding behaviour in the same hilly tract of Koraput district suggests the possible existence of two biological strains. Similarly, in Hassan district of Karnataka, which is situated in western hills, only a low anthropophilic index was recorded (Brooke Worth and Sitaraman, 1952). According to them there might be a mixture of anthropophilic and zoophilic races in *A. fluviatilis* in western hill tracts. Feeding behaviour is an innate character which is largely influenced by the availability of hosts. The cattle population in the study zone was compared with that of Malkangiri zone and found that it was relatively lower with a man to cattle ratio of 1.0:0.5, compared to Malkangiri zone where the ratio was 1.0:0.8 (VCRC
unpublished data). In spite of relatively a higher prevalence of cattle population in Malkangiri zone the anthropophilic index was as high as 82.4% and it was further supported by the results of simultaneous man and cattle biting collections. In the study area (Jeypore zone) the ratio of man to cattle biting mosquitoes was 1:3.8 whereas it was 1:0.12 in Malkangiri zone (VCRC unpublished data). However, further cytogenetic studies are warranted to answer this hypothesis of biological races. Though this species showed low predilection to man in the study area, the degree of its man-vector contact and its role in malaria transmission can not be underestimated since other anophelines were found to be more zoophilic when compared to A. fluviatilis.

6.7.6. Maxillary index and host preference:

It was proposed by Roubaud (1921) that the critical maxillary index for anophelines was 14 below which could be an indication of human biting population and above which an indication of cattle biting population. The overall maxillary index in A. fluviatilis calculated in the present study area was found to be 13.29 which is slightly higher than that (12.3) reported by Senior White (1937) in the same area. Though this index was within the man biting range, it was almost the same in cattle as well as man biting mosquitoes. This suggests that this index based on maxillary serrations is not characteristic for differentiating man biting and cattle biting population of this species.
6.7.7. Relationship between feeding and resting:

Earlier, it was believed that resting place of anophelines indicates the feeding behaviour (Perry, 1914). Later it was reported that *A. fluviatilis* may feed in one place and rest in another (Bhombore *et al.*, 1956). In the present study, though majority of the females collected from human dwellings was found to contain human blood, certain proportion was also found to have bovine blood. Similarly mosquitoes collected from outdoor shelters were shown to have fed on bovine as well as human. All the specimens collected from cattle sheds were positive only for bovine blood. However, sporozoite/oocyst stages were detected in the females collected from cattle sheds suggesting that preceding blood meals were of human source. Other workers had also shown that human fed mosquitoes of this species rest in cattle sheds also (Week, 1951; Senior White, 1943). This suggests that both human dwellings and cattle sheds are equally important as far as the resting habit of *A. fluviatilis* is concerned and therefore, cattle sheds can not be excluded from the residual spray in this area.

6.8. Natural survival:

6.8.1. Immatures:

Immature survival is one of the important factors that determines
the population size of adults. It is influenced by several physico-chemical and biological factors which are characteristic of breeding habitats. Ponds were found to be the favourable habitat for the survival of immatures as it recorded the maximum probability of immature survival which was about three times higher than that of streams and rivers. The survival of immatures was minimal in paddy fields. Occurrence of very low proportions of pupae in all the breeding habitats when compared to first instar larvae suggests a high mortality of immatures during development. This might be one of the reasons for the low prevalence of this species in this area.

6.8.2. Adults:

Physiological age:

In the present study, longevity of the natural population of *A. fluviatilis* was estimated from age-composition method as done by Sen and Azeez (1963b) and Eshghy et al. (1976). The maximum number of follicular relics recorded was seven and the maximum longevity of the natural population was calculated to be 24.5 days during cold and rainy seasons and 15.5 days during hot season. These values are relatively higher when compared to the earlier observation of Senior White et al. (1945) who reported a survival of more than 12 days in cold season, based on mark release recapture method.
**Calendar age:**

The estimation of calendar age for the vector population gives the actual proportion that reaches the potentially dangerous age required for the effective transmission. During the present study it was found that 4.5% of the population of *A. fluviatilis* had reached the potentially dangerous age of 10-12 days. This proportion is much lesser when compared to the findings of Sen and Azeez (1963b) and Achuthan and Sitaraman (1959) who respectively calculated that 23% in Dhanbad (Bihar) and 37% in Mandya (Mysore) attained the critical age of 10 days. The higher values observed in these earlier studies were due to over estimation of age by assuming longer duration for the Christophers' stages II (2 days) and III (3 days). In these studies, the duration of gonotrophic cycle itself was assumed to be 3 days and the same 3 days duration was considered for the stage III also, which must have been lesser than 3. However, in the present study, considering the gonotrophic cycle of 2 days in hot and 3 days in both rainy and cold seasons the duration for II and III stages was assumed to be 1 and 1.5 days for hot season and 1.5 and 2 days for rainy and cold seasons.

**Survival rate:**

Natural survival of adult population is known to influence the transmission potential of vectors. The probability of adult survival
of *A. fluviatilis* through one day was 0.86 in cold, 0.81 in rainy and 0.74 in hot seasons and this was found to be associated with seasons. Almost similar values had been reported from Bihar (0.83) (Sen and Azeez, 1963b) and Mandya in Karnataka (0.85) (Achuthan and Sitaraman, 1959).

6.9. Population growth:

The values of net reproductive rate and mean generation time were relatively higher during the cold season resulting in population increase at a rate of 1.051 females. In the rainy season these values were at their lower side and consequently there was a decrease in population growth. This might be the result of the cumulative effect of lower immature and adult survival rates. The predicted population trend was compared with the natural changes in the population size in relation to the preceding seasons. Hotter months recorded the lowest population density and with the onset of monsoon, population started building up and the rate of increase was slightly higher during the rainy season than the following cold season. Though the innate capacity of the population to increase was more in the cold season, the pattern of natural increase did not reflect this predicted trend though peak density was recorded during this season. This might be due to the limiting factors such as reduction in breeding surface areas especially that of terraced paddy fields which became dry during the cold season.
6.10. **Natural infection and vectorial capacity:**

Natural infection with malarial parasites was recorded in four anopheline species viz., *A. fluviatilis*, *A. annularis*, *A. culicifacies* and *A. aconitus*. Among these four species, both sporozoite and oocyst rates were recorded to be the highest in *A. fluviatilis* despite its low number dissected for natural infection. This supports the view that *A. fluviatilis* is the most efficient vector (Ramachandra Rao, 1984). The maximum number of infected females of *A. fluviatilis* was recorded in top-hill village where the incidence of malaria was also very high (Pani, 1990; Jambulingam et al., 1991). This was followed by foot-hill village which ranked second when the incidence of malaria cases was considered.

Studies on natural infection in *A. fluviatilis* were carried out extensively in several areas. Earlier studies in Jeypore hills showed that the sporozoite rates in *A. fluviatilis* were ranging from 1.5% (Perry, 1914) to 3.6% (Senior White, 1937). In a subsequent study Weeks (1951) recorded a sporozoite rate of 1.1%. However, recently a higher sporozoite rate of 5.09% was recorded in Malkangiri zone of this district (Parida et al., 1991) where the intensity of malaria transmission was also reported to be higher compared to Jeypore zone (Jambulingam et al., 1991). When compared to these reports, the sporozoite rate recorded during the present study (0.16%) was found
to be lower. This clearly shows that the infection rate in this species greatly varies in different physiographic regions within the same district which might be largely due to the difference in man biting rate and human blood index of *A. fluviatilis* as well as the difference in the parasitic load existing in the community in different zones as shown by Pani (1990).

Vectorial capacity is an epidemiological index to assess the potentiality of a vector species in disease transmission. Though *A. fluviatilis* has been incriminated as a major malaria vector in several parts of India, estimation of its vectorial capacity has not been attempted so far. Only critical densities expressed as number per man hour have been estimated based on indoor resting populations (Ramachandra Rao, 1984).

During the present study, the season-wise analysis showed that vectorial capacity was higher during rainy season followed by hot and cold seasons. There was an increase in number of malaria cases, particularly *P. falciparum*, with the vectorial capacity of *A. fluviatilis* in different seasons. Based on this relationship it is inferred that vectorial capacity can be used an indicator in assessing the malaria transmission potential in this area.

When the vectorial capacity of *A. fluviatilis* was compared between the study zone and the adjoining Malkangiri zone, the values
varied widely between these two zones. The value was higher in Malkangiri zone and this was attributed to the higher man biting rate and human blood index (VCRC Annual report, 1990). As already mentioned, it is possible for the existence of two biological races/strains in this area with different capacities in transmitting the disease as postulated by other workers (Viswanathan, 1950; Issaris et al., 1953; Kulkarni and Wattal, 1982).

The difference in the vectorial capacity calculated for different plasmodial species is a reflection of the difference in the estimated values of sporogonic period as other parameters were assumed to be the same for all parasite species. As a result, higher values of vectorial capacity have been obtained for \textit{P. vivax}, which has a shorter sporogonic period than \textit{P. falciparum}. However, there is a striking difference in the prevalence of parasite species in the study area. \textit{P. falciparum} has been the dominant species, constituting about 70–80% of the total malaria cases (Rajagopalan et al., 1990). Longer duration of \textit{P. falciparum} gametocytaemia compared to other plasmodial species in untreated persons and lesser stimulation of immune response particularly in areas where there is prolonged transmission (Bruce-Chwatt and Glanville, 1973) may enhance the chances of the vector getting infected with \textit{P. falciparum} parasites resulting in higher rate of \textit{P. falciparum} transmission. The vectors may also have different susceptibility to different plasmodial species (Ramachandra Rao, 1984). The susceptibility status of
A. fluviatilis to different human plasmodial parasites is not yet known, except for P. falciparum (Mohan, 1955) and hence variations in susceptibility of this vector species to different parasite species can not be ruled out. However, this factor is not considered for the estimation of vectorial capacity.

6.11. Dispersal:

Though direct experimental evidences on this aspect for A. fluviatilis are lacking, the indirect observations made in the present study, based on the presence of immatures of this species in breeding habitats at different distances from the nearest human habitation suggest that A. fluviatilis can disperse to a maximum distance of 1700 m for oviposition. However, there was no correlation between the distance and intensity of breeding. This range was higher than that reported by Adisubramaniam and Vedamanikkam in 1943 (300 m), Venkat Rao and Philip in 1947 (800 m) and Bhombre et al. in 1956 (400 m). The average flight range which is the distance upto which 50% of the total larvae collected, was 1000 m.

Adult mosquitoes were observed to disperse to a maximum distance of 1000 m for outdoor resting and the average flight range was found to be 500 m, the distance upto which more than 90% of the total females was collected.
Based on the dispersal of *A. fluviatilis* for oviposition, it was recommended to cover the area for antilarval measures up to a distance of 300 m around the village in Wynad area (Adisubramaniam and Vedamanikkam, 1943) and 500 m in North Kanara district (Ramachandra Rao, 1984). Present study suggests that for antilarval measures if attempted in this area it is necessary to carry out at least to a distance of 1000 m from human habitation.

6.12. Susceptibility status to insecticides:

*A. fluviatilis* was found to be susceptible to DDT, HCH, Malathion and Deltamethrin. Till date, DDT indoor residual spray has been used continuously from the beginning of National Malaria Eradication Programme in 1958 in this area. Despite this prolonged application, this species is still susceptible to DDT. As this species is susceptible to other insecticides as well, even a change in insecticide will not pose any technical problem. However, this species was reported to have developed resistance to HCH in the adjoining Malkangiri zone of this district (VCRC Annual Report, 1990) where DDT was replaced with HCH in 1972. It appears that the development of resistance to HCH by *A. fluviatilis* is rapid. Therefore, in areas where *A. fluviatilis* is a major vector and HCH is used for indoor residual spray, this insecticide can be replaced by DDT. Reports from other areas indicate that *A. fluviatilis* is still susceptible to DDT, though certain degree of tolerance had been
reported from Maharashtra and Karnataka (Raghavan et al., 1967; Vittal et al., 1982a). However, resistance to DDT is known from Punjab Province of Pakistan (Rathor et al., 1985).

6.13. Vector control perspectives:

Malaria has been stable in Koraput district. This district is one of the areas where malaria is persisting without any interruption inspite of control measures being carried out through National Programmes. This warranted a fresh look into the situation and the problems relating to the vector control strategy.

The success of any malaria control programme depends on effective interruption of transmission through vector control and early detection and liquidation of parasites in the human host. The extent of breeding habitats is so great that antilarval treatment with insecticides will be difficult, costly and may not be feasible. As environmental measures will also not be practicable considering the vastness of the breeding habitats some naturalistic methods of control such as keeping the streams free from vegetation near the villages, use of fishes in tanks could be revived since these methods have some utility. Such methods can not be expected to give excellent results but can help in reducing the vector density to certain extent. Man made borrow pits can be tackled with community involvement with proper motivation. However, its feasibility needs to be assessed.
Ponds are identified as one of the important breeding habitats, since *A. fluviatilis* and other two vector species namely, *A. culicifacies* and *A. annularis* breed with a high degree of association. Ponds in this area are perennial and vast. Polyculture with edible and fast growing fishes including larvivorous and phytophagous can be a good proposition to tackle the vector breeding in ponds. This will be also helpful in promoting the economic status of the beneficiaries. By linking vector control with such income generating schemes it can be expected to be viable and self perpetuating.

Though *A. fluviatilis* is predominantly an exophilic mosquito in this area, its pre- and post-feeding activities/behaviour facilitate the contact with sprayed surface areas in human dwellings and cattle sheds. Since this species is susceptible to DDT, indoor residual spray with this insecticide can be continued, but the operational deficiencies (Rajagopalan and Das, 1990) should be overcome. However, cultural practices/religious faith of tribal community such as mud-plastering and high rate of refusals for spraying are known to interfere in the operation and this needs to be tackled through health education.

Practice of personal protection methods such as impregnated mosquito nets and low cost repellents should also be encouraged and made available to the community. Community participation is often
discussed and seldom practiced. This can be brought to reality only when the community is given proper and adequate recognition and representation from the stage of planning through implementation in the control programmes.