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Abstract
Background: Blood feeding and resting behaviour of malaria vectors are the most influential factors in malaria transmission.

Aims: To measure blood feeding and resting behaviour, conventional mosquito sampling methods were performed in an area with potential for malaria transmission.

Methods: Adult mosquitoes were collected monthly from indoor/outdoor places by conventional sampling methods, and larval habitats were investigated. Enzyme-linked immunosorbent assay was used to measure the human blood index (HBI) of the mosquitoes.

Results: Anopheles stephensi, Anopheles culicifacies, Anopheles dthali and Anopheles fluviatilis, were collected. Overall, 1249 female Anopheles mosquitoes were captured on human and animal baits, but no human–vector contact occurred indoors. A. dthali, A. fluviatilis and A. culicifacies showed a greater tendency to outdoor resting places in contrast to A. stephensi, which had a propensity to indoor resting places. The seasonal biting activities of all species occurred at average temperatures between 23 and 27°C. HBI was measured as 27.2%, 20.7%, 19.1%, and 23.0% for A. fluviatilis, A. stephensi, A. culicifacies and A. dthali, respectively.

Conclusion: Vector control strategy depends upon mosquito behaviour. Therefore, using appropriate sampling methods based on mosquito behaviour is critical for malaria control planning. Exophilic/exophagic habit of mosquito vectors leads to fewer human bites, resulting in biting protection. Exophilic behaviour also requires specific larvicidal operations in order to prevent and control malaria transmission.

Keywords: Anopheles, malaria, vector behaviour, ecology, Islamic Republic of Iran

Introduction

To eliminate malaria transmission from potential zones is a big challenge, and understanding vector biology and ecology play a major role in the battle against malaria (1). The emergence of new behavioural patterns of mosquitoes may significantly increase the risk for malaria transmission and represents a new challenge for malaria elimination (2). To combat malaria transmission and vectors it is necessary to understand the behaviour of the vector species. Spatial distribution of mosquitoes depends on environmental and climatological factors, so each species has its own range in a given area (3). As seasonal fluctuations in vector populations act
to synchronize disease transmission, the patterns of anopheline mosquito population dynamics provide important data for understanding the epidemiology and control of malaria (4). However, human and mosquito contact is a major challenge in malaria areas (5,6).

The main malaria vector control tools are indoor residual spraying (IRS), and long-lasting insecticide-impregnated bednets. The correct use of these tools depends on mosquito biting and resting behaviour, as well as their susceptibility to the applied insecticides (7). Extensive and long-term use of chemicals in malaria vector control programmes leads to changes in vector behaviour (8).

Recently, the Islamic Republic of Iran reported fewer than 200 cases of malaria, which was confirmed based on the World Health Organization (WHO) classification (9). More than 90% of malaria cases were found in the south and southeast of the Islamic Republic of Iran, with a population of ~746 000 (10).

Among 25 species of Anopheles reported in the Islamic Republic of Iran, 7 are considered to be malaria vectors, and five of them, Anopheles stephensi, Anopheles fluviatilis, Anopheles culicifacies, Anopheles dthali and Anopheles superpictus, are present within the south and southeast of the country (11–13). Although, no insecticide resistance has been reported among A. fluviatilis and A. dthali in Southern Islamic Republic of Iran, A. stephensi became resistance to dichlorodiphenyltrichloroethane (DDT), dieldrin and β-cyhalothrin and tolerant towards deltamethrin (12,14).

Hormozgan Province is one of the most important malaria transmission areas in Southern Islamic Republic of Iran. Malaria eradication and control programmes have failed to sustain the area free of malaria (15). Malaria incidence has significantly reduced during the past 2 decades in Hormozgan. However, like other areas located in Southern Islamic Republic of Iran, the cross-border movement of populations from malaria-endemic Pakistan and Afghanistan is considered to be the main challenge for elimination of malaria in Hormozgan (16). Despite the risks of malaria transmission, mosquito bite protection and use of mosquito nets are not priorities among residents of the area (17). Hence, in the current study, we noted different behaviour of malaria vectors, in order to establish the key factors that have influenced disease transmission in a potential area. Based on the collected data, malaria elimination planning can be designed more efficiently.

Methods
Study design
This study was performed between September 2014 and August 2015 in Siaho District located about 90 km north of Bandar-Abbas County, Hormozgan Province (25°24–28°57 N and 52°41–59°15 E). The average Annual Parasite Index in the last 5 years was 0.18 in Hormozgan province. Siaho District has been malaria free for 5 years and vector control interventions are limited to larvicides and mosquito nets. Four malaria vectors exist in the area that allowed us to study their biting and resting behaviour. In addition, Siaho District is a potential area for malaria transmission but due to the strong healthcare system and early detection system, transmission of malaria has been hampered. The temperature reaches a maximum of 35°C in the highlands and 40°C in plain areas during the summer but it rarely declines to 5–10°C during winter.

Hormozgan comprises 3 regions of differing geography; the coastal region in the south, a mountainous region in the north, and a rural plateau or plain region located in the centre. Siaho District is a rural county located in the mountainous area with a total population of > 10 000. It is an agricultural region irrigated by rivers, deep wells and cement pools, which are the main breeding sites for mosquitoes. The annual rainfall ranges from 80 to 100 mm. The main factor that contributes to perennial transmission is population movement; especially from the western border province, Sistan-Baluchistan.

Entomological survey

The survey was carried out twice a month, from September 2014 to August 2015. The area had no interventions for mosquito control during the study period. Mosquito collections were performed monthly according to the WHO guidelines (18). The sampling methods were pyrethrum space-spray catches from the indoors of 8 houses, and pit shelter collections from 2 artificial shelters. Human and animal landing catches and larvae were also collected by dipper or pipette. All methods were carried out twice a month. All samples were identified according to the morphological features. The abdominal conditions of female mosquitoes were recorded and blood meals of freshly fed females were smeared on Whatman filter paper, which was left to dry and kept at −20°C until use.

Mosquito landing catch

Blood feeding activity of malaria vectors was estimated by human landing catches on 2 baits, as well as animal landing catches. Human landing catches were carried out continuously during a whole night period from sunset to sunrise by trained staff using mouth aspirators. Two human volunteers from the native inhabitants acted as baits, while wearing their normal clothing. The exposed body surfaces were searched and the mosquitoes that were attempting to bite were collected using mouth aspirators by insect collectors. During human landing collections, collectors changed shifts every 2 hours. Animal landing catches were carried out on cows, as the dominant domestic animals, for a whole night period as described above. The collected mosquitoes were kept and brought to the field laboratory alive to be identified. Finally, the
human biting rate was calculated directly from human landing catches, based on the average number of bites per person or animal per night.

**Blood meal identification**

In order to identify human blood index (HBI), the blood meals of collected mosquitoes on Whatman filter papers were used for enzyme-linked immunosorbent assay (ELISA) as described previously (19). Each mosquito abdomen was ground in 50 ml phosphate-buffered saline (PBS), and then 950 ml PBS was added after grinding. Blood meals were identified by direct ELISA using anti-human IgG conjugated to alkaline phosphatase (Sigma, St. Louis, MO, USA) and proteins in a single-step assay. The results were assessed by naked eye examination and absorbance was measured with an ELISA reader at 405 nm about 30 minutes after addition of the substrate solution. The test wells were considered positive if they gave a visible yellow colour.

**Results**

A total of 1742 adult female mosquitoes were captured (Table 1). Most of them (71.7%) were collected by landing catch methods on human (13.2%) and animal (58.5%) baits. The mosquitoes exhibited high exophagic behaviour and no indoor-biting mosquitoes were caught. A total of 590 larvae were collected. The adult mosquito species were A. stephensi (28.2%), A. culicifacies (18.7%), A. dthali (33.5%) and A. fluviatilis (19.6%). Regarding mosquitoes captured indoors, A. stephensi (50.5%) was the dominant species captured from the indoor places. An. fluviatilis (33.7%) and A. dthali (33.3%) were the dominant species collected in outdoor shelters. The landing catch method was the most convenient to collect mosquitoes within the study area. Overall, 71.7% anopheles vectors were captured on baits including 82% on animal and 18% on human baits. Among them, A. dthali showed the greatest propensity for animal baits, as from 422 adult females, 92.4% of this species was captured on animal baits, while only 7.6% was found on human baits. In contrast, 37.7% of A. fluviatilis was captured on human baits. This indicated that, compared with A. dthali, A. fluviatilis had greater propensity for humans. Furthermore, from 369 females of A. stephensi and 219 females of A. culicifacies, 21.4% and 13.2% were collected on human baits, respectively.

The seasonal biting activities of all collected vectors depended on the seasonal temperature and declined during the winter (Figure 1). The highest biting activities of mosquitoes on humans occurred in April and May. Generally, seasonal prevalence of all malaria vectors (both indoors and outdoors) consisted of 2 major peaks (Figure 2). The maximum activities of mosquito populations occurred in spring, while the temperature was mild enough, although during winter (between January and February), the populations decreased to minimum density in indoor and outdoor resting places. The population density of A. stephensi in indoor shelters was higher during the period of collection in comparison with
The monthly population density of A. fluviatilis in outdoors was higher when compared with that indoors. A. culicifacies and A. dthali used indoor and outdoor places alike (Figure 2).

The collected female mosquitoes were graded based on their abdominal condition (Table 2). The gravid and/or half-gravid appearance of the abdomen represented the resting stages. The ratio of A. stephensi captured in the indoor places was noticeably higher than other species. Among all females mosquitoes collected in indoors, 50.5% of them were A. stephensi and only 0.02% were A. fluviatilis. However, the high portion of A. stephensi females with gravid and half-gravid abdominal appearance was found in indoor places, indicating that these species prefer indoor resting places. In contrast, among the anopheles collected outdoors, almost 33.7% of them were A. fluviatilis, and 82.6% were blood fed or half gravid/gravid. HBI was 27.2%, 20.7%, 19.1%, and 23.0% for A. fluviatilis, A. stephensi, A. culicifacies and A. dthali, respectively. Blood feeding of anophele mosquitoes was mostly observed when the average monthly temperature was 23–27°C.

The results of the larvae surveys are presented in Table 3. A total of 590 larvae were collected from different habitats. The larvae of A. fluviatilis mostly were found in clear water streams with sandy beds. A. stephensi (100%) preferred non-vegetative stagnant water while A. dthali was mostly found in vegetative stagnant water. A. culicifacies also selected permanent stagnant water with/without vegetation.

Discussion

Overall, all malaria vectors exhibited exophagic behaviour in the study area. The exophagic behaviour of A. fluviatilis, A. dthali and A. stephensi has been previously reported in Hormozgan province, Southern Islamic Republic of Iran (20, 21). At that time, IRS implementation was performed by the Malaria Eradication Program, but during the present study, although IRS was not used, some vectors such as A. culicifacies showed propensities to rest both inside and outside places. This indicates that IRS intervention may cause this vector to change to outdoors for rest; thus, IRS should be used more cautiously.

Endophilic and exophilic behaviour varied among the 4 vector species. While A. fluviatilis exhibited a highly exophilic tendency, A. stephensi showed more propensity towards the indoor shelters. Abundance of A. stephensi in indoor shelters confirms the previous finding of endophilic behaviour of this species in Southern Islamic Republic of Iran (12, 22). Similar findings have been reported from the neighbouring country of Pakistan (23, 24). All these studies found that the mosquitoes were collected from sites that had no insecticide intervention.
The structure of shelters is important for A. stephensi. This species preferred thatched structures of cattle shelters due to the availability of eaves and crevices for resting and ageing (25). Furthermore, A. stephensi use household objects such as cupboards, furniture, hanging clothes, etc in the insecticide-sprayed villages (26). However, this species is mostly situated indoors, which is dependent on the seasonal temperature and structure of shelters and their availability for blood meal sources.

Seasonal blood-feeding behaviour of all anopheline mosquitoes partially depended on temperature and rainfall. Therefore, we found that the maximum human biting occurred in spring. As all 4 mosquito vectors showed outdoor-biting behaviour, it seems that the environment and weather of Siaho District provides conditions for vectors to exhibit this behaviour. Therefore, using mosquito nets ought to be a convenient method to protect inhabitants against malaria transmission.

We revealed the prevalence and predominance of A. fluviatilis in outdoor places. Slow running streams and stream channels around villages provide the favourite breeding places for A. fluviatilis to increase its population. Thus, identification of breeding places and high coverage of larvicidal operations is appropriate to keep the population of this mosquito low. Generally, these species have been reported as exophilic, with a high propensity for human blood in Southern Islamic Republic of Iran (5, 21, 22, 27). This species is widely distributed in the Indian Subcontinent, and exhibits a greater tendency to rest in human dwellings in Keonjhar and Chhattisgarh States (28, 29). In contrast, we found this mosquito mostly in outdoor shelters. It is noteworthy that the Indian species are mostly S and U of the Fluviatilis complex (30), while only the species T has been confirmed in Hormozgan Province (31). Therefore, the variation we observed regarding the resting behaviour of this species may have been due to the genetic difference in the population of A. fluviatilis complex, which requires more studies to be done. It is also possible that the environmental structure of the north of Bandar-Abbas (mostly at high temperature) caused the A. fluviatilis to display exophilic behaviour. The appropriate method to measure seasonal activity of this species is landing catch collection especially on animal bait. Previous studies have reported that A. fluviatilis has a high propensity for human blood (5, 20–22). In the current study, we also found it to be a highly anthropophagic species. The same behaviour has been reported among the A. fluviatilis complex in the Indian Subcontinent (32). Availability of human blood meal sources is dependent on house structure and resident behaviour but A. fluviatilis shows opportunistic feeding behaviour on human hosts, while resting outside for egg development (20). Thus, using mosquito nets, especially long-lasting insecticide-treated nets, is a convenient way to protect inhabitants and control this species in the study area.

A. dthali was reported for the first time as a malaria vector in Siaho in 1972 (13). Our study shows that this mosquito species is still predominant anopheles Siaho, north of Bandar-Abass
County. However, > 45 years ago, it was reported that this species was predominant in the area (20, 21). This species was found at high density in indoor and outdoor places during seasonal activities. Generally, this species prefers hilly and valley-based areas. The presence of A. dthali in indoor as well as outdoor places indicates that the species can shift its resting places under any adverse conditions such as IRS. In the present study, the larvae of A. dthali were found in natural and vegetative water sources within reach of filamentous green algae. Similar habitats were described by Maffi in 1964 (33).

A. culicifacies is distributed in the Indian Subcontinent and extends from southeast of the Islamic Republic of Iran to Thailand and Vietnam (34). Previous studies from the north of Bandar-Abbas showed low occurrence of this species (21, 22) while in the current study, we found high abundance of this vector in the study area. This occurrence was most likely due to climate change that has an influence on global distribution of many mosquito species (35).

The current study also shows that anopheline blood feeding behaviour depends on seasonal temperature. Accordingly, the human-biting rate increases from 23 to 27°C. The impact of environmental temperature is crucial for human–mosquito contact; thus, use of mosquito nets should be considered based on local temperature. Therefore, the average local temperature could be a helpful indicator for prediction of malaria transmission.

**Conclusion**

Biological variations in the vectors might complicate the control of malaria transmission, and vector control strategy depends on mosquito behaviour. Therefore, using appropriate sampling methods for mosquito behaviour must be considered as a critical factor for planning of malaria control. Exophilic/exophagic mosquito vectors lead to bite protection using mosquito nets as well as effective larval source management, which could provide an integrated vector management strategy in high-risk areas such as Hormozgan Province.

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