Scientific Note

Distribution and larval habitat characteristics of Anopheles Hyrcanus Group and related mosquito species (Diptera: Culicidae) in South Korea

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The Anopheles Hyrcanus Group consists of several species that are vectors of malaria and other mosquito-borne diseases in the Oriental and Palearctic Regions. The group has about three-quarters of the species that comprise the Myzorhynchus Series of genus Anopheles Meigen subgenus Anopheles in the two regions. It has about 30 species, including two newly described species, An. belenrae Rueda and An. kleilli Rueda (Rueda 2005). In South Korea (Republic of Korea), there are only six known species of the Hyrcanus Group, i.e., An. sinensis Wiedemann, An. sineroides S. Yamada, An. lesteri Baisas and Hu, An. pulius M. Yamada (Tanaka et al. 1979), and An. belenrae and An. kleilli (Rueda 2005). Other non-Hyrcanus Group species of Anopheles (Anopheles) in South Korea are An. koreicus Yamada and Watanabe and An. lindesayi japonicus S. Yamada (Tanaka et al. 1979). Because of the limited information about the distribution and larval habitat characteristics of the Hyrcanus Group and its associated species, we conducted this study from 1998-2004 in South Korea.

Anopheles sinensis is considered the most common Anopheles species in South Korea (Chai 1999), but its distribution within Korea is not well documented, except in Jeju Province (Kim et al. 2005a). In China, Rueda et al. (2005a) noted the occurrence of this species in eight provinces and one city (Beijing). Adults of An. sinensis have been incriminated as the natural and/or experimental malaria (Plasmodium vivax) vectors in South Korea (Lee et al. 2002), Japan (Otsuru and Ohmori 1960), China (Ho et al. 1962) and Indonesia (O’Connor 1980). Although it is found in Thailand, An. sinensis has minimal or no importance as a malaria vector in that country (Harrison and Scanlon 1975). In South Korea, it was found to be the major vector involved in the transmission of P. vivax along the border with North Korea since 1993 (Ree et al. 2001, Kim et al. 2005b).

Anopheles lesteri is a very important vector of malaria in many parts of China (Tang et al. 1991, Gu et al. 1996). In the Philippines, it is not known as a malaria vector (Rueda et al. 2005b). In South Korea, Shin et al. (2002) confirmed that An. lesteri was able to carry Korean malaria parasites and they noted its vector competence in that country. However, its status as a primary vector of malaria needs to be investigated because of its low population density compared with An. sinensis. Based on a combination of published and newly generated rDNA ITS2 sequences, Wilkerson et al. (2003) found that An. lesteri from the Philippines (type locality of lesteri) and South Korea, and An. anthropophagus Xu and Pen from China are indistinguishable, and placed An. anthropophagus in synonymy with An. lesteri. Gao et al. (2004) disagreed with Wilkerson et al. (2003) in their “lesteri” interpretation because the original type locality (Sta. Mesa, Manila, Philippines) conditions no longer exist and that it is possible that the specimens collected by the latter were not really “lesteri” but something else. However, Rueda et al. (2005b) designated and described the neotype of An. lesteri from the new type locality (Calauan, Philippines) to clarify and stabilize the taxon. This new type locality is the same place where the “cotypes” of the original lesteri were collected in 1936 by Baisas and Hu (1936). According to the International Code of Zoological Nomenclature (ICZN 1999), Article 76.3, page 87, the place of origin of the neotype becomes the type locality of the species-group taxon, despite any previously published statement of the type locality.

Anopheles pulius is a known malaria vector in South Korea (Shin et al. 2002). Hong4 initially confirmed the presence of sporozoites of P. vivax from wild adult females and oocysts from experimental infections of An. pulius in Korea. Anopheles belenrae and An. kleilli have been recently designated and described by Rueda et al. (2005a).

Keyword Index: Mosquitoes, Anopheles, Hyrcanus Group, malaria, Diptera, Culicidae, Korea.

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described from reared specimens whose original parents were collected from cowsheds (Rueda 2005). Their biting behavior, larval habitats, and medical importance are unknown. Anopheles sineroides, An. koreicus, and An. lindesayi japonicus are also non-malaria vectors in Korea and Japan (Tanaka et al. 1979).

We collected mosquitoes from 204 locations in South Korea from 1998-2004. This resulted in 2,804 individually reared pinned adults, 782 individually reared adults, and 155 larvae preserved in 100% ethyl alcohol for molecular tests, and 3,644 exuviae of larvae and pupae and whole larvae. Anopheles adults, particularly those fully engorged with blood, were collected from cattle sheds, allowed to lay eggs, and then reared for larvae, pupae, and adults. We initially targeted larval collections from habitats where Anopheles mosquitoes were likely to be found. Larvae and pupae from various habitats were collected using dippers and individually reared to the adult stage (Walter Reed Biosystematics Unit 2001). Larval and pupal skins were preserved in 80% ethyl alcohol and slide mounted using standard protocols. Emerged adults were pinned, labeled with appropriate collection data, and identified. Some adults and whole larvae were separately preserved in 100% ethyl alcohol for molecular analysis. Adult specimens and associated larval/pupal exuviae were identified using characters in Tanaka et al. (1979), and confirmed using rDNA ITS2-based method (Wilkerson et al. 2003, Li et al. 2005). Voucher specimens are deposited in the National Museum of Natural History, Smithsonian Institution, Washington, DC.

Figure 1 shows the collection sites of eight Anopheles species from South Korea. We collected specimens of An. sinensis from different provinces throughout South Korea, except Chungcheongbuk-do, and An. pullus from Gyeonggi-do and Gyeongsangbuk-do. Anopheles lesteri, An. belenrae, An. kleinii, An. koreicus, and An. lindesayi japonicus were found only in Gyeonggi-do. Based on both our collection data and published records (Table 1), all eight species were found in Gyeonggi-do, four in Jeju-do, three in Gyeongsangbuk-do and one each in Chungcheongnam-do, Gyeongsangnam-do, Gangwon-do, Jeollabuk-do, and Jeollanam-do. No Anopheles species have been reported in Chungcheongbuk-do.

Table 2 shows the summary of collection localities and larval habitats for eight Anopheles species in South Korea. Adults of Anopheles species that were collected resting in cow barns or attracted to Centers for Disease Control (CDC) light traps also were recorded. Larvae of An. sinensis were collected from various habitats either alone or in association with the following Aedes or Culex species: Cx. (Culex) tritaeneorhynchus Giles larva (in rice fields, irrigation and roadside ditches, marsh and drainage areas, ground pits, and ground and drain pools at Gyeonggi-do, Gangwon-do, and Jeju-do); Cx. (Lophoceraomyia) infantulus Edwards (roadside ditches at Gyeonggi-do); Cx. (Cux.) orientalis Edwards, Cx. (Cux.) mimeticus Noe, Cx. (Cux.) pipiens pallens Coquillett and Cx. (Eumelanomyia) hayashii hayashii Yamada (stream pools at Gyeonggi-do); Cs (Neoculex) rubens Sasa and Takahashi (roadside ditches at Gyeonggi-do), Aedes (Aedimorphus) vexans (Meigen) (marshy ground depressions, drain pools, roadside ditches at Gyeongsangbuk-do), and Ae. (Finlaya) koreicus (Edwards) (garden ponds, water drums at Gyeongsangbuk-do). Aside from An. sinensis,
Table 1. Larvae, pupae, and adults of Anopheles species previously recorded from seven provinces of South Korea.

<table>
<thead>
<tr>
<th>Species</th>
<th>CH</th>
<th>GA</th>
<th>GB</th>
<th>GE</th>
<th>GN</th>
<th>JE</th>
<th>JO</th>
<th>JU</th>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>An. kleini</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>An. koreicus</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>T</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>An. lesteri</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>C</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>An. lindesayi japonicus</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>An. pullus</td>
<td>-</td>
<td>-</td>
<td>T</td>
<td>X</td>
<td>C</td>
<td>H</td>
<td>T</td>
<td>X</td>
</tr>
<tr>
<td>An. sinensis</td>
<td>T</td>
<td>X</td>
<td>T</td>
<td>X</td>
<td>C</td>
<td>T</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
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<td>-</td>
<td>-</td>
<td>T</td>
<td>T</td>
<td>X</td>
<td>-</td>
<td>-</td>
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</tr>
</tbody>
</table>

*Provinces: CH (Chungcheongnam), GA (Gangwon), GE (Gyeonggi), GB (Gyeongsangbuk), GN Gyeongsangnam), JE (Jeollabuk), JO (Jeollanam), JU (Jeju).

**References: C (Claborn et al. 2002), H (Shin and Hong 2001), K (Kim et al. 2005b), L (Lee 1994), R (Rueda 2005); S (Shin et al. 2002), T (Tanaka et al. 1979), W (Whang et al. 2002), X (this survey).

no Anopheles species were collected from any larval habitats in association with Aedes or Culex species. The taxonomic classification used in this paper follows that of Knight and Stone (1977).

Table 3 shows the number and frequency of the environmental conditions for five Anopheles species (An. lesteri, An. pullus, An. sinensis, An. sineroides, and An. koreicus) from larval collections in four provinces in South Korea. Villages with rice fields and rural parks (43%) had the greatest number of positive larval habitats of Anopheles, followed by military camps (38%). Among habitats with vegetation, 31% had submerged plants and 29% had emergent and submerged plants. Habitats with clear, standing water having partial or no plant shade were more frequently positive for larvae (74%) as compared to other habitats. Irrigation and other ditches (29%), stream pools (20%), ponds (10%), rice fields and/or swamp drainage areas (8%), and ground and/or drain pools (8%) were common habitats of mosquito larvae during our survey.

Our findings on Anopheles distribution and larval habitat characteristics will be of interest to preventive medicine personnel, public health workers, and others tasked with malaria vector control in South Korea.

Acknowledgements

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REFERENCES CITED


Table 2. Summary of collection localities and larval habitats for eight *Anopheles* species in South Korea (1998-2004).

<table>
<thead>
<tr>
<th>Province</th>
<th>Locality</th>
<th>Grid Coordinates</th>
<th>Collection Date</th>
<th>Habitat type*</th>
<th>Collection No.</th>
<th>Stage</th>
<th><em>Anopheles</em> Species</th>
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<td>Chungcheongnam-do</td>
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<td>Collection Date</td>
<td>Habitat type*</td>
<td>Collection No.</td>
<td>Stage</td>
<td><em>Anopheles</em> Species</td>
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<td></td>
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<td>Latitude Longitude</td>
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<td>RC</td>
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<td>Adult</td>
<td>sinensis</td>
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<td>Sokcho-si</td>
<td>38° 08' 00&quot; N 128° 35' 34&quot; E</td>
<td>16, 21 Jun 2001</td>
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<td>sinensis</td>
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<td></td>
<td>Dongducheon-si, Kyungi, Korean Tng. Ctr.</td>
<td>37° 32' 59&quot; N 126° 55' 48&quot; E</td>
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<td>Larva</td>
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<td>Dongducheon-si, Camp Casey Gunnae-lycon, Paja-si, Camp</td>
<td>37° 54' 15&quot; N 127° 05' 23&quot; E</td>
<td>26 Jul 2002</td>
<td>RC</td>
<td>KS 02-5 (1-5)</td>
<td>Adult</td>
<td>koreicus</td>
</tr>
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<td></td>
<td>Greaves</td>
<td>37° 58' 12&quot; N 126° 47' 59&quot; E</td>
<td>21, 26 Jun 2001</td>
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<td>KS 5-1, 7(1)</td>
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<td>sinensis</td>
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<td>Gunnae-lycon, Paja-si, Camp Greaves</td>
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<td>KS 02-6(2)</td>
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<td>kleei</td>
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<td>20 Oct 1999</td>
<td>PS</td>
<td>KS 015</td>
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<td>KS 015</td>
<td>Larva</td>
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<td>Collection Date</td>
<td>Habitat type*</td>
<td>Collection No.</td>
<td>Stage</td>
<td><em>Anopheles</em> Species</td>
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<td>Habitat Type*</td>
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<td>Majeong-ri, Munsan-up, Paju-si Manwo-ri, Thanhyun-myeon, Paju-si</td>
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<td>RC</td>
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<td>RC</td>
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<td>Adult</td>
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<td>2 Jun 2003</td>
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<td>KS 03-1 (1, 8, 11, 12, 21, 10)</td>
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<td>Gyeonggi-do</td>
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<td>37° 59' 14&quot; N 126° 51' 22&quot; E</td>
<td>25 Jul 1998</td>
<td>ID</td>
<td>KS 1</td>
<td>Adult</td>
<td>sinerosides</td>
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<td>SP</td>
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<td>RC</td>
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<td>pullus</td>
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<td>Gyeonggi-do</td>
<td>Ogeum-ri, Thanhyun-myeon, Paju-si</td>
<td>37° 49' 00&quot; N 126° 43' 00&quot; E</td>
<td>29 Jul 2001</td>
<td>RC</td>
<td>KS 8 (1)</td>
<td>Adult</td>
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<td>Gyeonggi-do</td>
<td>Ogeum-ri, Thanhyun-myeon, Paju-si</td>
<td>37° 49' 00&quot; N 126° 43' 00&quot; E</td>
<td>29 Jul 2001</td>
<td>RC</td>
<td>KS 8 (5, 20, 27, 45, 67, 77), KS 8 (94, 140, 143, 145)</td>
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<td>sinensis</td>
</tr>
<tr>
<td>Gyeonggi-do</td>
<td>Ogeum-ri, Thanhyun-myeon, Paju-si</td>
<td>37° 49' 00&quot; N 126° 43' 00&quot; E</td>
<td>14 Apr 2002</td>
<td>RC</td>
<td>KS 02-2 (2)</td>
<td>Adult</td>
<td>sinensis</td>
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<tr>
<td>Gyeonggi-do</td>
<td>Tongilchon, Paju-si, Sokcho</td>
<td>37° 51' 00&quot; N 126° 42' 00&quot; E</td>
<td>12 Jul 2001</td>
<td>RC</td>
<td>KS 7 (27)</td>
<td>Adult</td>
<td>belenrae</td>
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<tr>
<td>Gyeonggi-do</td>
<td>Tongilchon, Paju-si, Tongilchon</td>
<td>37° 51' 00&quot; N 126° 47' 00&quot; E</td>
<td>26 Jun 2001</td>
<td>RC</td>
<td>KS 7 (6, 8)</td>
<td>Adult</td>
<td>pullus</td>
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<td>Gyeonggi-do</td>
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<td>37° 51' 00&quot; N 126° 47' 00&quot; E</td>
<td>26 Jun 2001</td>
<td>RC</td>
<td>KS 7 (5, 7, 9-14, 16, 17, 19)</td>
<td>Adult</td>
<td>pullus</td>
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Table 2. Continued.

<table>
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<th>Province</th>
<th>Locality</th>
<th>Grid Coordinates</th>
<th>Collection Date</th>
<th>Habitat type*</th>
<th>Collection No.</th>
<th>Stage</th>
<th>*Anopheles Species</th>
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<td>Province Locality</td>
<td>Latitude Longitude</td>
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<td>Gyeongsangbuk-do</td>
<td>Taegu, Cp Carrol</td>
<td>35° 49' 00&quot; N 128° 35' 00&quot; E</td>
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<td>GP, RD</td>
<td>KS 59</td>
<td>Larva</td>
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<td>Taegu, Apsan Park</td>
<td>30° 57' 00&quot; N 128° 49' 00&quot; E</td>
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<td>ID</td>
<td>KS 93</td>
<td>Larva</td>
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<td>KS 99</td>
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<td>Andeok-myeon, Namjeju-gun</td>
<td>33° 15' 04&quot; N 126° 18' 11&quot; E</td>
<td>22 Sep 2003</td>
<td>RC</td>
<td>KS 105</td>
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<td>Chochon-eup, Bukjeju-gun</td>
<td>33° 14' 49&quot; N 126° 16' 35&quot; E</td>
<td>22 Sep 2003</td>
<td>GD</td>
<td>KS 94</td>
<td>Larva</td>
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<td></td>
<td>Daejeong-eup, Namjeju-gun</td>
<td>33° 15' 13&quot; N 126° 12' 50&quot; E</td>
<td>22 Sep 2003</td>
<td>GD</td>
<td>KS 95</td>
<td>Larva</td>
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<td></td>
<td>Hangkyeong-myeon, Namjeju-gun</td>
<td>33° 19' 06&quot; N 126° 10' 40&quot; E</td>
<td>8 Jun 2004</td>
<td>ID</td>
<td>KS 96, 119</td>
<td>Larva</td>
<td>sinensis</td>
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<td>Hangkyeong-myeon, Namjeju-gun</td>
<td>33° 18' 46&quot; N 126° 10' 50&quot; E</td>
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<td>ID</td>
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<td>33° 17' 22&quot; N 126° 11' 10&quot; E</td>
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<td>ID</td>
<td>KS 136</td>
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<td>Hangkyeong-myeon, Namjeju-gun</td>
<td>33° 19' 17&quot; N 126° 11' 02&quot; E</td>
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<td>GD</td>
<td>KS 137</td>
<td>Larva</td>
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<td>Hangkyeong-myeon, Namjeju-gun</td>
<td>33° 19' 18&quot; N 126° 11' 02&quot; E</td>
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<td>KS 138</td>
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<td>ID</td>
<td>KS 139</td>
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<td>sinensis</td>
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<td>Namwon-eup, Namjeju-gun</td>
<td>33° 19' 45&quot; N 126° 33' 29&quot; E</td>
<td>22 Sep 2003</td>
<td>LT</td>
<td>KS 146</td>
<td>Adult</td>
<td>sinensis</td>
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<td>Seogwipo-si</td>
<td>33° 14' 37&quot; N 126° 32' 16&quot; E</td>
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<td>KS 80, 81, 135</td>
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<tr>
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<td>Seogwipo-si</td>
<td>33° 14' 30&quot; N 126° 25' 16&quot; E</td>
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<td>Seogwipo-si</td>
<td>33° 16' 05&quot; N 126° 33' 29&quot; E</td>
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<td>LT</td>
<td>KS 147</td>
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<td>Seogwipo-si</td>
<td>33° 14' 24&quot; N 126° 32' 44&quot; E</td>
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<td>GP</td>
<td>KS 83</td>
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<td>Haenam</td>
<td>34° 34' 27&quot; N 126° 35' 51&quot; E</td>
<td>4 Aug 2003</td>
<td>RC</td>
<td>KS 03-3(1-6)</td>
<td>Adult</td>
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<td>Jeonju</td>
<td>35° 49' 19&quot; N 127° 8' 56&quot; E</td>
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<td>35° 58' 43&quot; N 126° 47' 41&quot; E</td>
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<td>RC</td>
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<td>RC</td>
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</table>

*GD (garden and/or permanent pond, lake), GP (ground and/or drain pool), GT (ground pit), ID (irrigation, roadside and/or drainage ditch), LT (light trap at cowshed), MG (marshy ground depression), RC (resting collection), RF (rice field), RP (rock hole, pool), RR (road rut, track), SM (stream margin), SP (stream pool), SW (stream water drainage), WC (well/cistern), WD (water drum).

*Adults were collected while resting in cattle barns, usually engorged. They were used as parents for progeny rearing.
Table 3. Characterization of larval habitats positive for five *Anopheles* species from four provinces in South Korea (1998-2004).*

<table>
<thead>
<tr>
<th>Environment</th>
<th>Frequency</th>
<th>Provinces**</th>
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<tbody>
<tr>
<td>Military camp</td>
<td>21</td>
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<tr>
<td>Swamp</td>
<td>4</td>
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<tr>
<td>Urban park</td>
<td>7</td>
<td>CH, JU</td>
</tr>
<tr>
<td>Village (rice fields, rural park)</td>
<td>24</td>
<td>GE, JU</td>
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<tr>
<td><strong>Algae</strong></td>
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<tr>
<td>Absence</td>
<td>30</td>
<td>CH, GE, JU, GA</td>
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<tr>
<td>Presence</td>
<td>13</td>
<td>GE, JU, GA</td>
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<tr>
<td><strong>Vegetation</strong></td>
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<td>CH, GE, JU</td>
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<tr>
<td>Presence</td>
<td>42</td>
<td>CH, GE, JU, GA</td>
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<td><strong>Type of vegetation</strong></td>
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<td>Floating</td>
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<td>Submersed</td>
<td>13</td>
<td>JU</td>
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<tr>
<td>Emergent and floating</td>
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<td>CH, GE, JU</td>
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<tr>
<td>Emergent and submersed</td>
<td>3</td>
<td>GE, JU</td>
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<tr>
<td><strong>Condition of larval habitat</strong></td>
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<tr>
<td>Clear, standing water with partial or no plant shade</td>
<td>35</td>
<td>74</td>
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<tr>
<td>Clear, slow or moderate flowing water with no plant shade</td>
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<tr>
<td>Clear, fast flowing water, with partial plant shade</td>
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<tr>
<td>Turbid, standing water with partial or no plant shade</td>
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<td><strong>Type of larval habitat</strong></td>
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<tr>
<td>Garden and/or permanent pond</td>
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<td>CH, JU</td>
</tr>
<tr>
<td>Ground and/or drain pool</td>
<td>4</td>
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<tr>
<td>Ground pit</td>
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<td>Marshy ground depression</td>
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<td>Rock pool</td>
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<td>GE</td>
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<tr>
<td>Water drum</td>
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</table>


**Provinces: CH (Chungcheongnam), GE (Gyeonggi), JU (Jeju), GA (Gangwon).
Zoological Nomenclature.


