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5th Medical Detachment, 168th Medical Battalion (AS), 18th Medical Command, Unit# 15247, APO AP 96205-5247;
[1]Department of Entomology, Walter Reed Army Institute of Research, 503 Robert Grant Ave., Silver spring Maryland, 20910-7500, USA;
[2]Division of Medical Zoology, National Institute of Health, Korea Center for Disease Control and Prevention, Seoul, 122-701, Republic of Korea;
[3]Department of Virology, 1425, Porter Street, Bldg. 1425, U.S. Army Medical Research Institute of Infectious Diseases, Fort Detrick, MD 21702-5011;
[4]Force Health Protection, 18th Medical Command, U.S. Army, Unit# 15281, APO AP 96205-5281

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Research Paper

New Records and Reference Collection of Mosquitoes (Diptera: Culicidae) on Jeju Island, Republic of Korea

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[1]Department of Entomology, Walter Reed Army Institute of Research, 503 Robert Grant Ave., Silver spring Maryland, 20910-7500, USA;
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ABSTRACT Mosquito collections were carried out during 2003-2004 on Jeju Island, Republic of Korea. Eighteen species of mosquitoes in 7 genera were collected, including three new records, *Culex* (*Culex*) *mimeticus*, *Culex* (*Culiciomyia*) *sasai* and *Ochlerotatus* (*Finlaya*) *nipponicus*. Based on the available information, a total of 28 species representing 7 genera have been recorded from Jeju Island. Larval habitat characteristics, collection sites, bionomics, and vector potential for each of these species are described.

Key words : New record, Jeju Island, *Culex mimeticus*, *Culex sasai*, *Ochlerotatus nipponicus*, Korea

Jeju Island is 73 km wide and 41 km long with a total area of 1,847 km^2, is volcanic in origin, and is the largest island in the Republic of Korea. The highest point, Mt. Halla, rises in the center of the island to 1,950 m above sea level. The rest of the island slopes down from its summit and is covered with dark gray volcanic rocks and volcanic ash soil. Jeju Island is located between 126° 00′-126° 58′E Longitude and 33° 06′-34° 00′N Latitude. Its warm climate [average temperature 16.1°C (north)-17.4°C (south)] and moderate precipitation [average 1,388 mm (north)-1,782 mm (south)] provides good conditions for mosquito and other insect populations.

While human cases of Japanese encephalitis (JE) virus has been absent from Jeju Island for almost 20 years (1985-2004). However, as part of the K-NIH Japanese Encephalitis (JE) surveillance program, slaughtered swine were reported to be positive for JE virus (K-NIH, 2003). No malaria cases were reported from 1980 to 1996, but two cases were reported in 1997, 6 cases in 1998, 9 cases in 1999, 18 cases in 2000, 7 cases in 2001, 2 cases in 2002, 2 cases in 2003, and 1 case in 2004 (K-CDC and P, 2004a, b). If not all, most of these cases are believed to be imported from the mainland or other countries. Filariasis (*Brugia malayi*) has been endemic for several centuries on the island (Seo, 1978) and the presence of disease vectors, as well as other pest species of mosquitoes, are of great concern to the inhabitants and to military personnel stationed on the Island.

The mosquitoes of Jeju Island have been documented by various workers (Oh et al., 1961; Chun, 1968; Lien, 1969; Barrett, 1969; Wada et al., 1973; Tanaka et al., 1979; Lee, 1994; Ko, 1996). These studies recognized four *Anopheles* spp., four *Aedes* spp., five *Ochlerotatus* spp., eleven *Culex* spp., two *Lutzia* spp., *Tripteroides bambusa* (Yamada), and *Armigeres subalbatus* (Coquillett). To better under-

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*Corresponding author
E-mail: mosqkim@hanmail.net, Tel: 82-2-7915-1500

stand the mosquito fauna of Jeju Island in relation to the types of habits available, late and early season larval collections were conducted from 18 Sep to 3 Oct 2003 and 7 Jun to 18 Jun 2004. Additionally, adult light trap collections were conducted from Jun to Sep, 2004.

Materials and Methods

Adults and larvae were collected from various habitats and locations on the island (Fig. 1-A, B and Table 1). Adults were collected from resting sites using mouth aspirators or light traps (Nozawa black light trap) operated near cowsheds at 2 locations, South-Jeju and Seogwipo, respectively (Fig. 1-B). Larvae were collected from a variety of habitats with the primary intention of obtaining adults with associated larvae and pupal exuviae, with a subset of these retained for DNA analysis. Data from each collection site was recorded on a Walter Reed Biosystematics Adult and Larval Collection Standard Form (Pecor and Gaffigan, 1977). Fourth-stage larvae and pupae were individually reared to adult stage and the associated immature exuviae preserved in 80% ethanol (ETOH). Fourth-stage larvae were also preserved for morphological taxonomy by killing in near-boiling water, followed by storage in 80% ETOH until mounted on glass slides. Late instar larvae from several habitats were also placed in 100% ETOH for DNA analysis.

Approximately 24 hours after emergence, adults were transferred to a glass killing tube with a Plaster of Paris base saturated with ethyl acetate and sealed with a cork. Killed specimens were mounted on paper points on 3 insect pins and labeled. Exuviae of larvae and pupae were subsequently mounted in euparal on microscope slides for morphological characterization. Selected reared adults, particularly male specimens, were preserved in 100% ethanol for DNA extraction and characterization. Male genitalia were dissected when necessary to assist in identification. Specimens were identified to species by using keys and descriptions from the available literature (Tanaka et al., 1979; Lee, 1998, 1999) and DNA analysis (Wilkerson et al., 2003).

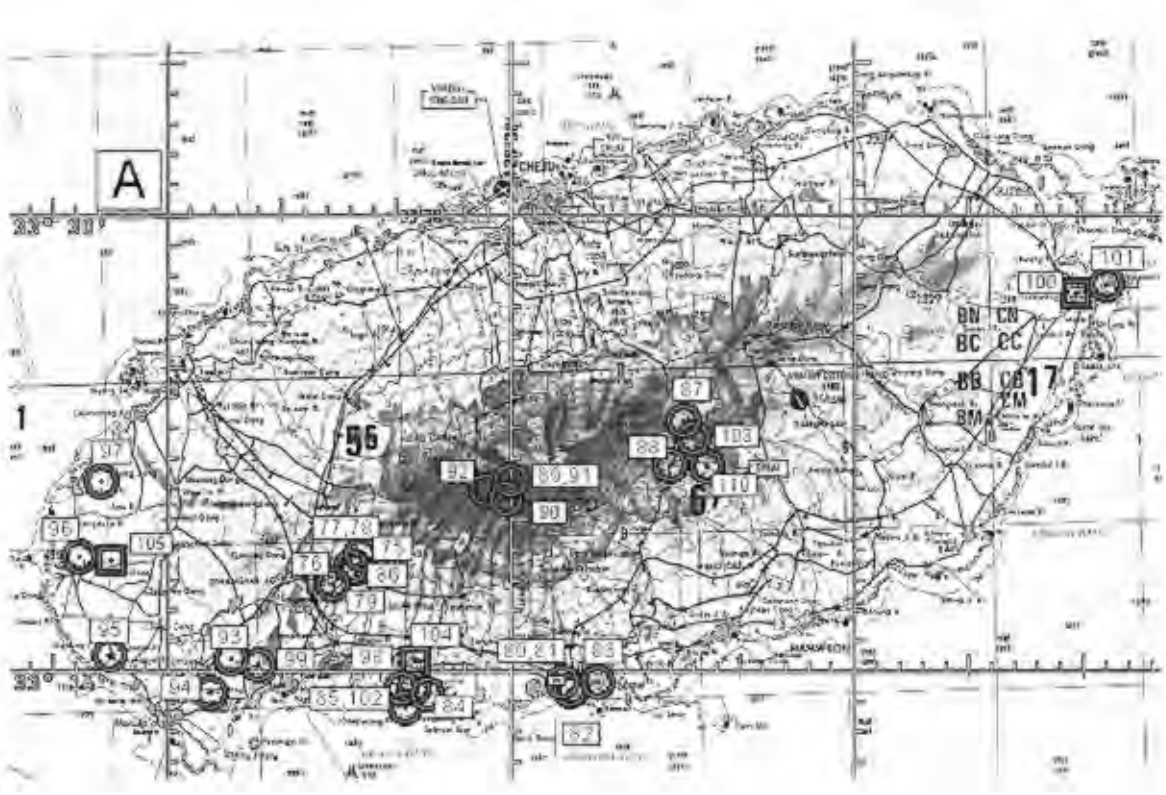
Results and Discussion

Sixty-four larval collections were made in Sep-Oct 2003 and Jun 2004, resulting in 3,201 study specimens as follows: 629 larval exuviae; 945 pupal exuviae; 951 reared-associated adults of which 886 were pinned for morphological study and 65 preserved as DNA vouchers; in addition, there were 333

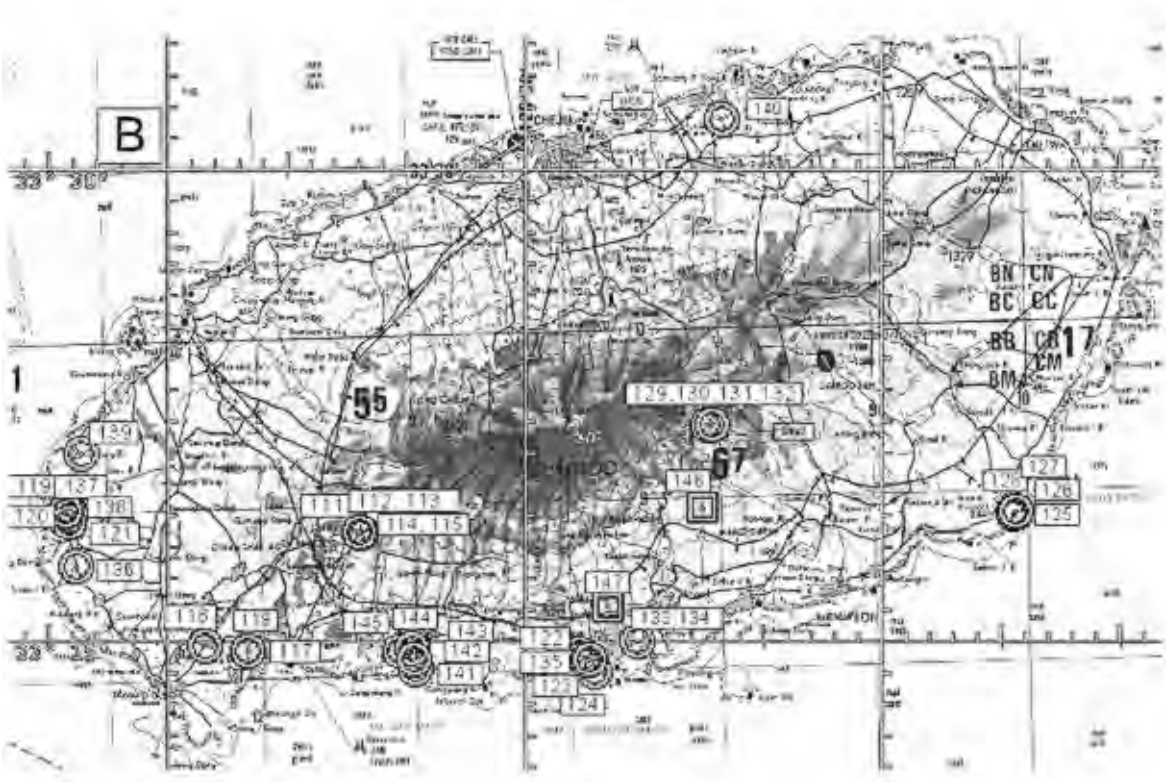
Table 1. Larvae and adult mosquito species collected from various habitats at Jeju Island during 2003 and 2004

Species	Habitats*															
	AC	BS	D	GP	T	P	M	PL	RF	RP	SM	SWD	TH	WC	LT	RC
Anopheles (Anopheles) sinensis			×	×		×	×	×	×		×				×	×
Aedes (Stegomyia) albopictus	×	×			×					×			×	×		
Ochlerotatus (Finlaya) hatorii										×				×		
Ochlerotatus (Finlaya) japonicus	×				×					×						
Ochlerotatus (Finlaya) koreicus					×					×						
Ochlerotatus (Finlaya) nipponicus													×			
Ochlerotatus (Finlaya) togoi	×									×			×	×		
Culex (Lophoceraomyia) infantulus			×													
Culex (Culiciomyia) kyotoensis					×					×						
Culex (Culiciomyia) sasai					×								×			
Culex (Culex) mimeticus										×						
Culex (Culex) pipiens			×	×	×		×	×		×		×	×	×	×	×
Culex (Culex) tritaeniorhynchus			×	×	×	×	×	×		×	×				×	×
Culex (Culex) vagans			×		×		×			×						
Lutzia (Metalutzia) fuscanus					×					×						
Lutzia (Metalutzia) halifaxii			×		×					×						
Tripteroides (Tripteroides) bambusa													×			
Armigeres (Armigeres) subalbatus	×									×					×	×

*AC (artificial container), BS (bamboo stump), D (ditch), GP (ground pool), T (tire), P (pit), M (marsh), PL (pond-lake), RF (rice field), RP (rock pool), SM (stream margin), SWD (storm water drainage), TH (tree hole), WC (well/cistern), LT (light trap), RC (resting collection).



○: Larval collection sites, □: Adult-resting collection sites



○: Larval collection sites, □: Adult-light trap collection sites

Fig. 1. Map of Jeju Island with Locations of Larval and Adult Mosquito Collection Sites (A, 2003; B, 2004).

Table 2. Larvae and adult mosquito species previously recorded from Jeju Island and surveys conducted during 2003 and 2004

Species recorded	Oh 1957	Chun 1968	Lien 1969	5th PMU 1966–69	Tanaka et al., 1979	Lee 1994	Ko 1996	Confirmed by author	Remarks
Anopheles sinensis	×	×	×	×		×	×	×	
Anopheles lesteri				×					
Anopheles lindesayi japonicus			×		×	×	×		
Anopheles sineroides		×		×	×	×	×		
Aedes albopictus	×	×	×	×	×	×	×	×	
Aedes flavopictus					×	×			
Aedes lineatopennis				×					
Aedes vexans nipponii	×	×	×	×		×	×		
Ochlerotatus hatorii	×	×	×	×	×	×	×	×	
Ochlerotatus japonicus			×	×	×	×		×	
Ochlerotatus koreicus					×			×	
Ochlerotatus nipponicus								×	New Record
Ochlerotatus togoi	×	×	×	×	×	×	×	×	
Culex bitaeniorhynchus		×		×		×	×		
Culex hayshii		×	×		×	×	×		
Culex infantulus					×		×	×	
Culex kyotoensis			×	×	×	×	×	×	
Culex mimeticus								×	New Record
Culex orientalis			×	×		×	×		
Culex pipiens	×	×	×	×	×	×	×	×	
Culex pseudovishnui					×				
Culex sasai								×	New Record
Culex tritaeniorhynchus	×	×	×	×	×	×	×	×	
Culex vagans		×		×		×		×	
Lutzia fuscanus			×			×	×	×	
Lutzia halifaxii		×		×				×	
Tripteroides bambusa			×			×		×	
Armigeres subalbatus	×	×	×			×		×	
Total (Species)	8	13	15	16	14	19	15	18	

whole larvae preserved as DNA vouchers. Adult resting and light trap collections were made in Sep 2003 and Jun–Sep 2004, resulting in 632 specimens as follows: 397 adults were from resting collections and 245 adults were from light trap collections near cowsheds. The collections represented 18 species from 7 genera and 9 subgenera (Table 1). Three species, *Culex* (*Culex*) *mimeticus* Noé, *Culex* (*Culiciomyia*) *sasai* Kano, Nitahara and Awaya, and *Ochlerotatus* (*Finlaya*) *nipponicus* LaCasse and Yamaguti, are new records for Jeju Island (Table 2). Ten species, not encountered during our surveys, were previously recorded from Jeju Island, bringing the total number of species reported to occur on Jeju Island to 28. However, some of these latter species may be the result of misidentifications due to unavailable information at the times of those earlier collections.

During our surveys, we collected larvae of 18 species from a variety of open and forested habitats, including natural water sources, artificial containers, temporary sites resulting from construction, and tree holes (Table 1).

New Records Collected During 2003/4 Surveys:

Culex (*Culex*) *mimeticus* Noé is widely distributed over the southern Palearctic and Oriental regions (Knight and Stone, 1977). Larvae were found in rock pools (Collection site, KS84) in association with *Ochlerotatus togoi* along the ocean margin on Jeju Island (Table 3). This species inhabits a broad range of habitats and on the Korean mainland, larvae were found in ponds, ditches, ground pools and rice paddies containing fresh water. We therefore believe that the brackish water rock pool habitat is highly atypical for this species. This species is not commonly collected and has not been incriminated in the transmission of human pathogens.

Culex (*Culiciomyia*) *sasai* Kano, Nitahara and Awaya was only previously reported from Japan and the

Table 3. Larvae and adult mosquito collection sites for various habitats and species collected at each site for 2003 (KS75–KS110) and 2004 (KS111–KS 147) surveys

Collection No.	Grid Coordinates	Locality	Habitat Type*	Species**																		
				SIN	ALB	HAT	JAP	KOR	NIP	TOG	INF	KYO	MIM	PIP	SAS	TRI	VAG	HAL	FUS	BAM	SUB	TOTAL
KS75	33°18′51″N, 126°23′30″E	Andeok-myeon, Namjeju-gun	D													1		1				2
KS76	33°17′51″N, 126°22′16″E	Andeok-myeon, Namjeju-gun	WC			1																1
KS77	33°18′27″N, 126°23′03″E	Andeok-myeon, Namjeju-gun	AC																		17	17
KS78	33°18′27″N, 126°23′03″E	Andeok-myeon, Namjeju-gun	T		19			2				4		1	5			4	1			36
KS79	33°18′26″N, 126°23′07″E	Andeok-myeon, Namjeju-gun	RP			20	2									2		2				26
KS80	33°14′37″N, 126°23′16″E	Seogwipo-si	M	31												5						36
KS81	33°14′37″N, 126°32′16″E	Seogwipo-si	P	2												1						3
KS82	33°14′21″N, 126°32′38″E	Seogwipo-si	RP		1	1										15						17
KS83	33°14′24″N, 126°32′44″E	Seogwipo-si	GP	6												1						7
KS84	33°14′24″N, 126°25′21″E	Seogwipo-si	RP							13			1									14
KS85	33°14′30″N, 126°25′13″E	Seogwipo-si	RP							49									22			71
KS86	33°18′24″N, 126°23′08″E	Andeok-myeon, Namjeju-gun	T											3								3
KS87	33°23′06″N, 126°37′10″E	Hallasan National park	RP		1		20	8		1		47									2	79
KS88	33°22′09″N, 126°37′29″E	Hallasan National park	RP				24															24
KS89, 91	33°21′10″N, 126°29′40″E	Hallasan National park	RP				12	1		1												14
KS90	33°20′48″N, 126°29′47″E	Hallasan National park	RP				5															5
KS92	33°20′46″N, 126°29′45″E	Hallasan National park	RP				11															11
KS93	33°15′04″N, 126°18′11″E	Andeok-myeon, Namjeju-gun	D	10										12		20						42
KS94	33°14′49″N, 126°16′35″E	Daejeong-eup, Namjeju-gun	PL	1												4						5
KS95	33°15′13″N, 126°12′50″E	Daejeong-eup, Namjeju-gun	PL	2												3						5
KS96	33°19′06″N, 126°10′40″E	Hankyeong-myeon, Namjeju-gun	D	8							1					14						23
KS97	33°21′30″N, 126°11′20″E	Hankyeong-myeon, Namjeju-gun	SM	6												15						21
KS98	33°14′52″N, 126°24′34″E	Seogwipo-si	TH		1					1				5	1							8
KS99	33°15′02″N, 126°19′03″E	Andeok-myeon, Namjeju-gun	PL	9												4						13
KS100	33°27′34″N, 126°55′47″E	Seongsan-eup, Namjeju-gun	RC																		3	3
KS101	33°27′42″N, 126°56′23″E	Seongsan-eup, Namjeju-gun	RP							1												1
KS102	33°14′30″N, 126°25′16″E	Seogwipo-si	GP	16												3						19
KS103	33°22′01″N, 126°37′38″E	Hallasan National park	RP			8	5															13
KS104	33°15′30″N, 126°25′21″E	Seogwipo-si	RC											13		13					1	27
KS105	33°18′37″N, 126°12′55″E	Hankyeong-myeon, Namjeju-gun	RC	86										13		256					5	360
KS110	33°22′53″N, 126°37′53″E	Hallasan National park	TH		9															4		13
KS111	33°18′27″N, 126°23′03″E	Namjeju-gun	T				2															2
KS112	33°18′26″N, 126°23′07″E	Andeok-myeon, Namjeju-gun	RP														21					21
KS113	33°18′26″N, 126°23′07″E	Andeok-myeon, Namjeju-gun	RP			22				1												23
KS114	33°18′26″N, 126°23′07″E	Andeok-myeon, Namjeju-gun	RP			12																12
KS115	33°18′26″N, 126°23′07″E	Andeok-myeon, Namjeju-gun	RC				3										9					12
KS116	33°14′49″N, 126°16′35″E	Daejeong-eup, Namjeju-gun	PL											2								2
KS117	33°14′40″N, 126°18′22″E	Andeok-myeon, Namjeju-gun	T											9			3					12
KS118	33°14′40″N, 126°18′22″E	Andeok-myeon, Namjeju-gun	T											15			9					24

Table 3. Continued.

Collection No.	Grid Coordinates	Locality	Habitat type*	Species**																		
				SIN	ALB	HAT	JAP	KOR	NIP	TOG	INF	KYO	MIM	PIP	SAS	TRI	VAG	HAL	FUS	BAM	SUB	TOTAL
KS119	33° 19′06″N, 126° 10′40″E	Hankyeong-myeon, Namjeju-gun	D	7																		7
KS120	33° 18′46″N, 126° 10′50″E	Hankyeong-myeon, Namjeju-gun	D	18																		18
KS121	33° 19′01″N, 126° 10′53″E	Hankyeong-myeon, Namjeju-gun	D	5																		5
KS122	33° 14′24″N, 126° 32′44″E	Seogwipo-si	GP											5								5
KS123	33° 14′21″N, 126° 32′38″E	Seogwipo-si	RP							4				3								7
KS124	33° 14′01″N, 126° 32′56″E	Seogwipo-si	RP							24												24
KS125	33° 19′08″N, 126° 50′38″E	Pyoseon-myeon, Namjeju-gun	AC		1					12												13
KS126	33° 19′05″N, 126° 50′34″E	Pyoseon-myeon, Namjeju-gun	WC		1					4				15								20
KS127	33° 19′05″N, 126° 50′34″E	Pyoseon-myeon, Namjeju-gun	AC		6		1															7
KS128	33° 19′02″N, 126° 50′34″E	Pyoseon-myeon, Namjeju-gun	AC							12												12
KS129	33° 21′53″N, 126° 37′53″E	Hallasan National park	TH		8				11											8		27
KS130	33° 21′53″N, 126° 37′53″E	Hallasan National park	RP				21			1												22
KS131	33° 21′53″N, 126° 37′53″E	Hallasan National park	RP				17															17
KS132	33° 21′53″N, 126° 37′41″E	Hallasan National park	TH		2				1											2		5
KS133	33° 14′59″N, 126° 34′45″E	Seogwipo-si	AC		16																	16
KS134	33° 14′59″N, 126° 34′45″E	Seogwipo-si	AC							8												8
KS135	33° 14′37″N, 126° 32′16″E	Seogwipo-si	M	6										8			4					18
KS136	33° 17′22″N, 126° 11′10″E	Hankyeong-myeon, Namjeju-gun	D	3																		3
KS137	33° 19′17″N, 126° 11′02″E	Hankyeong-myeon, Namjeju-gun	PL	12																		12
KS138	33° 19′18″N, 126° 11′02″E	Hankyeong-myeon, Namjeju-gun	RF	4																		4
KS139	33° 20′57″N, 126° 11′23″E	Hankyeong-myeon, Namjeju-gun	D											9			4					13
KS140	33° 31′37″N, 126° 38′19″E	Chocheon-eup, Bukjeju-gun	SWD	25																		25
KS141	33° 14′24″N, 126° 25′21″E	Seogwipo-si	RP							5												5
KS142	33° 14′46″N, 126° 25′16″E	Seogwipo-si	BS		20																	20
KS143	33° 14′40″N, 126° 24′44″E	Seogwipo-si	BS		3																	3
KS144	33° 14′06″N, 126° 25′25″E	Seogwipo-si	RP							22												22
KS145	33° 14′54″N, 126° 25′15″E	Seogwipo-si	RP											1			2					3
KS146	33° 19′45″N, 126° 36′52″E	Namwon-eup, Namjeju-gun	LT	5										124		35					1	165
KS147	33° 16′05″N, 126° 33′29″E	Seogwipo-si	LT	21										38		21						80
TOTAL				283	88	64	123	11	12	159		51	1	276	6	413	52	7	23	14	29	1613

*AC (artificial container), BS (bamboo stump), D (ditch), GP (ground pool), T (tire), P (pit), M (marsh), PL (pond–lake), RF (rice field), RP (rock pool), SM (stream margin), SWD (storm water drainage), TH (tree hole), WC (well/cistern), LT (light trap), RC (resting collecton).

**SIN, *Anopheles* (*Anopheles*) *sinensis;* ALB, *Aedes* (*Stegomyia*) *albopictus;* HAT, *Ochlerotatus* (*Finlaya*) *hatorii;* JAP, *Ochlerotatus* (*Finlaya*) *japonicus;* KOR, *Ochlerotatus* (*Finlaya*) *koreicus;* NIP, *Ochlerotatus* (*Finlaya*) *nipponicus;* TOG, *Ochlerotatus* (*Finlaya*) *togoi;* INF, *Culex* (*Lophoceraomyia*) *infantulus;* KYO, *Culex* (*Culiciomyia*) *kyotoensis;* MIM, *Culex* (*Culex*) *mimeticus;* PIP, *Culex* (*Culex*) *pipiens;* SAS, *Culex* (*Culiciomyia*) *sasai;* TRI, *Culex* (*Culex*) *tritaeniorhynchus;* VAG, *Culex* (*Culex*) *vagans;* HAL, *Lutzia* (*Metalutzia*) *halifaxii;* FUS, *Lutzia* (*Metalutzia*) *fuscanus;* BAM, *Tripteroides* (*Tripteroides*) *bambusa;* SUB, *Armigeres* (*Armigeres*) *subalbatus.*

Korean mainland. The adults of *Culex sasai* are quite similar to *Cx. kyotoensis* and *Cx. pipiens* which have been reported in the Mt. Songni of north Chungcheong Province and Hapcheon region of South Gyeongsang Province (Tanaka et al., 1979). Larvae were found in discarded tires (KS78) and tree holes (KS98) and in association with *Oc. togoi, Ae. albopictus, Lt. fuscanus, Lt. halifaxii, Cx. kyotoensis* and *Cx. pipiens.* This species is not commonly collected and has not been incriminated in the transmission of human pathogens.

Ochlerotatus (Finlaya) nipponicus LaCasse and Yamaguti had been previously reported only from Japan and mainland Korea (Knight and Stone, 1977). Larvae were usually found in tree holes (KS129 and KS132) and in association with *Ae. albopictus* and *Tr. bambusa* in forested areas surrounding Mt. Halla. This species was previously collected from tree holes from forested areas at Gyeonggi, Seoul and Gangwon Provinces (Tanaka et al., 1979); it has not been incriminated in the transmission of human pathogens.

Previously Recorded Species also Collected During the 2003/4 Surveys:

Aedes (Stegomyia) albopictus (Skuse) is a cosmopolitan mosquito and found throughout much of the world. It largely inhabits forested areas and is commonly found in tree holes and artificial containers. It has the potential to transmit a wide variety of arboviruses but has not been incriminated in the transmission of human pathogens in Korea. However, an unknown flavivirus has been isolated from this species collected near Munsan, ROK (J. S. Lee, personal communication).

Anopheles (Anopheles) sineneis Wiedemann is widely distributed throughout Southeast and East Asia (Knight and Stone, 1977). The primary habitat is rice paddies, ponds and margins of slow running streams and pools. In southern Korea and Jeju Island, it is considered the primary vector of Brugian filariasis and on the Korean mainland; it is considered the primary vector of malaria. However, newer evidence suggests that there is a complex of at least five species, *An. sinensis* sensu stricto, *An. pullus* Yamada, *An. lesteri* Baisas and Hu and two yet to be named species, that can not be separated by current morphological characters (Li et al., in press). Adults morphologically similar to *An. lesteri* were analyzed and determined to be *An. sinensis* by internal transcribed spacer-2 of ribosomal DNA sequence.

Ochlerotatus (Finlaya) hatorii Yamada has been recorded from Formosa, China, Korea and Japan. It was found in rock pools containing turbid organic water (often from leaf litter) on Jeju Island. It has not been incriminated as a vector of human pathogens in Korea.

Ochlerotatus (Finlaya) japonicus (Theobald) is widely distributed throughout much of East Asia and was recently introduced into the U.S. where it has become well established (Peyton et al., 1999). Its bionomics is similar to that of *Oc. koreicus* and *Oc. hatorii.* Adults are commonly found in forested habitats, often at high elevations. Larvae are typically found in natural and artificial containers and tree holes. While *Oc. japonicus* has the potential to transmit a variety of arboviruses, it has not been incriminated as a vector of human pathogens in Korea. In the U.S., it has been determined to be susceptible to and able to transmit West Nile virus in laboratory studies (Turell et al., 2001; Sardelis and Turell, 2001).

Ochlerotatus (Finlaya) koreicus (Edwards) is widely distributed throughout East Asia and the Former Soviet Union (FSU) and its Maritime Provinces (Knight and Stone, 1977). While experimental transmission of JE virus by this species has been reported in the FSU, JE virus has not been isolated from wild-caught mosquitoes in Korea (Gutsevich et al., 1970). *Ochlerotatus* spp. vector a wide variety of viral pathogens, however, *Oc. koreicus* has not been incriminated in the transmission of endemic human pathogens in Korea.

Ochlerotatus (Finlaya) togoi (Theobald) is commonly found throughout the ocean margins of Southeast and East Asia. Larvae are commonly found in large numbers in rock pools along the ocean margin where fresh and sea water mix. *Oc. togoi* is the primary vector of Brugian filariasis in Korea (Lee et al., 1964). The first survey in 1942-1944 for the prevalence of filariasis disclosed that of 5,000 people examined from 25 villages in the southern area of mainland Korea and on Jeju Island, 604 (12.1%) were shown to be infected with the microflaria *Brugia malayi.* The highest rate was found on Jeju Island, 30.3% (Senoo and Lincicome, 1951). Thereafter, many epidemiological studies were performed and Jeju Island was noted as the province showing the highest microfilaria positive rates (Lee et al., 1961; Seo et al., 1965, 1968). In the early 1970s, chemotherapeutic control programs were executed in the endemic areas of Jeju Island, with satisfactory results (Seo, 1978; Lee et al., 1985, 1986; Paik et al., 1988).

Culex (Lophoceraomyia) infantulus Edwards was

previously reported from Southeast and East Asia. Two male specimens (M-0852, M-0877) were first collected in Korea by Mizusawa in 1971 from Chungmun, Jeju Island (Tanaka et al., 1979). It was collected from irrigation ditch next to rice fields in western Jeju Island. Only one male (KS96-103) was collected and was associated with *An. sinensis* and *Cx. tritaeniorhynchus* (Table 3). More examples of this species are needed to preserve voucher specimens for future identification purposes. It has not been incrim-inated as a vector of human pathogens in Korea.

Culex (*Culiciomyia*) *kyotoensis* Yamagui and LaCasse has been reported from Japan, Korea and Taiwan. Larvae were commonly found in rock pools and discarded tires in the Halla mountain area. In Korea this species has only been reported from Jeju Island. The adults of *Cx. kyotoensis* are quite similar to *Cx. pipiens* and were found associated with species of *Oc. koreicus*, *Ae. albopictus*, *Cx. sasai*, *Cx. pipiens*, *Lt. halifaxii* and *Lt. fuscanus* in clear water and *Oc. japonicus*, *Oc. koreicus*, *Oc. togoi*, *Ae. albopictus*, *Ar. subalbatus* in turbid water. It has not been incriminated as a vector of human pathogens in Korea.

Culex (*Culex*) *pipiens* Linnaeus is a cosmopolitan species found throughout the world and often associated with human habitation. Two subspecies are reported from Korea. *Cx. pipiens molestus* does not require a bloodmeal during its first egg laying (Shim et al., 1989) and is found in close association with man (Sohn and Park, 1998). *Cx. pipiens pallens* (requiring a bloodmeal for all egg laying), is a domestic mosquito often associated with unsanitary conditions (breeding in stagnant water with high organic content). Both frequently enter houses and are probably the mosquito that most frequently bites humans in urban settings in Korea. *Culex pipiens* is a vector of filariasis in some regions of the world and one of the many vectors of West Nile in the U.S. However, it has not been incriminated in the transmission of human pathogens in Korea.

Culex (*Culex*) *tritaeniorhynchus* Giles is distributed throughout much of Asia and northern Africa. Near the Demilitarized Zone (DMZ) of South Korea, it is commonly a late season mosquito, but occurs much earlier in the year on Jeju Island and southern Korea. It is most commonly associated with wetland rice production, but may be found in ponds and pools. *Cx. tritaeniorhynchus* is the primary vector of JE virus in Korea. However, due to the mandatory JE vaccination policy in Korea, rates over the past two decades have decreased to 0-6 cases annually.

Culex (*Culex*) *vagans* Wiedemann has been reported from China, Japan, Korea, far eastern FSU, Manchuria, India and Iran. It is commonly an early season mosquito in Korea (Kim et al., 2003, 2004). It has not been incriminated as a vector of human pathogens in Korea.

Lutzia (*Metalutzia*) *fuscanus* (Wiedemann) is commonly reported throughout much of Asia (Knight and Stone, 1977). Larvae are predaceous and were found in association with *Oc. togoi* along the ocean margins where salt and fresh water mix on Jeju Island. The genus *Lutzia* was elevated from subgenus *Culex* (*Lutzia*), to generic level consisting of two subgenera, *Metalutzia* and *Insulalutzia* (Tanaka, 2003). It has not been incriminated as a vector of human pathogens in Korea.

Lutzia (*Metalutzia*) *halifaxii* Theobald is widely distributed throughout Asia and Australia (Knight and Stone, 1977). Larvae are predaceous and were found in association with *Oc. japonicus, Oc. koreicus, Oc. hatorii, Ae. albopictus, Cx. kyotoensis, Cx. sasai, Cx. pipiens, Cx. tritaeniorhynchus* and *Lt. fuscanus* in rock pools, drainage ditches and discarded tires containing water with a high organic content. It has not been incriminated as a vector of human pathogens in Korea.

Tripteroides (*Tripteroides*) *bambusa* (Yamada) is distributed throughout East Asia and Japan (Knight and Stone, 1977). It is a forest mosquito that is found primarily in tree holes. Larvae and eggs of *Tr. bambusa* were collected from tree holes in forested areas surrounding areas of Mt. Halla. Adults of this species are infrequently collected in light traps. However, several specimens were collected near Dongducheon, Gyeonggi Province, in a light trap baited with dry-ice (Strickman et al., 1999). Other workers have also infrequently collected this species in light traps. This species has a long immature period and has not been incriminated as a vector of human pathogens in Korea.

Armigeres (*Armigeres*) *subalbatus* (Coquillett) is a widely distributed mosquito throughout much of Southeast and East Asia. Larvae are found in pools and artificial containers containing nearly clear to turbid water. *Ar. subalbatus* has not been incriminated as a vector of human pathogens in Korea. However, a study in Taiwan indicated that it was a competent vector of JE virus in the absence of rice culture (Chen et al., 2000). *Ar. subalbatus* has not been found to be positive for JE virus when limited numbers of specimens were assayed in Korea (unpublished data).

Previously Reported Records, Not Collected During the 2003/4 Surveys:

Anopheles (*Anopheles*) *lesteri* Baisas and Hu is widely distributed throughout Southeast and East Asia (Knight and Stone, 1977). There has been much confusion about its identification since it cannot be reliably distinguished morphologically from *An. sinensis* (Wilkerson et al., 2003). Its distribution in Korea has not been determined and its distribution on Jeju Island has yet to be confirmed by DNA analysis. In China, *An. lesteri* (= *An. anthropophagus*) is one of the primary vectors of malaria, but is suspected to be a secondary vector of malaria in Korea (Shin et al., 2002). More studies are required to determine its impact on malaria transmission in Korea.

Anopheles (*Anopheles*) *lindesayi* Giles is widely distributed in Southeast Asia and more recently was described as a subspecies, *An. lindesayi japonicus*, from Japan (Knight and Stone, 1977; Yamada, 1918). *An. lindesayi japonicus* are encountered infrequently in Korea and can be considered relatively rare. This species was previously found in ground pools, rock pools and rock holes containing fresh water on Jeju Island (Lee, 1994). It has also been recorded from mainland Korea during a 2004 survey, but it has not been incriminated as a vector of human pathogens in Korea.

Anopheles (*Anopheles*) *sineroides* Yamada has been recorded from China, Korea and Japan, but is not commonly collected. This species was previously found in ground pools, rock pools and rock holes containing fresh water on Jeju Island (Lee, 1994). *An. sineroides* is not considered to be a vector of malaria, in part, due to its low numbers and zoophilic behavior.

Aedes (*Stegomyia*) *flavopictus* Yamada has been reported from Japan, Korea and the FSU. It is similar to *Ae. albopictus* and may have been misidentified in previous collections, but was not identified during this survey. This species was previously found in tree holes in forested area surrounding Halla Mountain, Jeju Island (Lee, 1994). It has not been incriminated as a vector of human pathogens in Korea.

Aedes (*Neomelaniconion*) *lineatopennis* (Ludlow) is a widely distributed mosquito found in East Asia, eastern and southern Africa and Australia (Knight and Stone, 1977). One male specimen (M-0105) was reported by Kimbell (1966) from Mosulpo on Jeju Island. In comparison, adults were previously collected in a light trap on a U.S. Army installation at Munsan, Gyeonggi Province, each year at a very low frequency (1-7 adults per year). Larvae were previously collected from ground pools near U.S. Army installations in Munsan. No specimens have been collected from Jeju Island since 1966. The original record may therefore have been misidentified or mislabeled during handling or transport of the specimens from Jeju Island to other U.S. Army installations in Korea. A more intensive investigation focusing on this species would be required to resolve the geographical range for JeJu Island. It has not been incriminated as a vector of human pathogens in Korea.

Aedes (*Aedimorphus*) *vexans* (Meigen) is a widely distributed mosquito throughout the world. A subspecies, *Ae. vexans nipponii* (Theobald), has only been reported from Japan, the eastern part of the FSU, Korea and China. This species was previously found in ground and stream pools containing fresh water and adults were collected by sweep netting and inside residences on Jeju Island (Lee, 1994). While a common mosquito, it was not collected from any of the larval habitats sampled during either of our 2003 or 2004 surveys. While it has been incriminated as the vector of various arboviruses, it has not been incriminated as a vector of human pathogens in Korea. An undescribed flavivirus was isolated from pooled specimens collected near the DMZ (J.S. Lee, personal communication).

Culex (*Culex*) *bitaeniorhynchus* Giles is a widely distributed mosquito found throughout East Asia, Australia, Africa and Southwest Asia. This species is very common in Korea and is often found in association with *Cx. tritaeniorhynchus* and *An. sinensis*, but no specimens were collected during our surveys. This species is found in ground pools and adults were collected in light traps on Jeju Island (Lee, 1994). It has not been incriminated as a vector of human pathogens in Korea.

Culex (*Eumelanomyia*) *hayashii* Yamada is found throughout East Asia, including Korea and Japan. This species was previously recorded from Halla Mountain on Jeju Island and mainland Korea, but was not collected during our surveys. It was previously found in ground and rock pools containing fresh water and adults were collected by sweep netting on Jeju Island (Lee, 1994). It has not been incriminated as a vector of human pathogens in Korea.

Culex (*Culex*) *orientalis* Edwards has been previously reported from Southeast and East Asia, including Korea and Japan (Knight and Stone, 1977). This species is very common in Korea, is usually found in association with *Cx. tritaeniorhynchus* and

Cx. mimeticus, but was not found during our surveys. Larvae were previously collected in stream pools often containing green filamentous algae in Pocheon, Gyeonggi Province. It has not been incriminated as a vector of human pathogens in Korea.

Culex (*Culex*) *pseudovishnui* Colless is widely distributed throughout East Asia (Knight and Stone, 1977). This species was originally recorded as *Cx. annulus* by Yamada in 1927 and then as *Cx. vishnui* by Chu in 1956 and Kimbell in 1966 in Korea. There were no voucher specimens of this species preserved during the early collection periods. Only one female specimen (M-0849) was collected by Mizusawa from Seogwipo by sweep netting collection (Tanaka et al., 1979). The appearance of adult and larvae are similar to that of *Cx. tritaeniorhynchus* which has been a point of confusion for some entomology groups. The creation of detailed taxonomic keys for the larvae and adults would facilitate proper identification of this species. It has not been incriminated as a vector of human pathogens in Korea.

Mosquito surveillance and descriptions of their bionomics and vector potential provides for the development of accurate ecological and medical threat assessments in Korea. Confirmation of specimens through available voucher specimens and DNA analysis of both larvae and adults is required to provide an accurate assessment of species distributions and habitat and species associations. Mosquito habitats are frequently transitory such that immature mosquitoes were collected from disturbed or agriculture areas during one survey (e.g., construction of highways and farming activities), but were not found during a later survey after the water was drained from these man-made habitats.

The identification and distribution of medically important vector species needs to be substantiated throughout Korea in order to estimate disease threats to animal and or human hosts and to plan and institute suppression or control measures. The Geographical Information System (GIS) is an important tool that provides for a better understanding of dispersal mechanisms and environmental perturbations for assemblages for mosquitoes and other insect taxa. Surveillance, using GIS, provides continued observations at sites that record environmental and mosquito fauna changes that can occur more readily among island communities.

A discussion of the species that were not collected during our recent survey is provided to identify possible problems with potential misidentification of species, especially where voucher specimens were unavailable and for areas for further consideration. These data further demonstrate the need for comprehensive mosquito fauna surveys of Jeju Island, in addition to the Korean mainland, especially in light of better taxonomic information that resulted in the identification of three previously unknown mosquito species (current distribution Korean mainland only) and is critical for developing and instituting health-risk assessments and vector suppression/control measures.

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