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Use of IKONOS and Landsat for malaria control in the Republic of Korea

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Abstract

Malaria reemerged in the Republic of Korea (ROK) in 1993. While limited numbers of U.S. soldiers in high-risk areas use chloroquine/primaquine chemoprophylaxis to prevent malaria, control of mosquito larvae through larviciding also can be used to reduce the risk of malaria transmission. In order to estimate the cost of larviciding, accurate estimates of the spatial extent of mosquito larval habitats are necessary. The purpose of this study was to determine whether an accurate estimate of the area covered by mosquito larval habitats can be obtained using Landsat 7 Enhanced Thematic Mapper+ (ETM+) and/or IKONOS data for the Korean test site.

To estimate the area covered by larval habitats near Camp Greaves [Paekyeon-Ri, near Tongil-Chon (village)] in the ROK, an IKONOS and a Landsat 7 ETM+ image were classified using a parallelepiped classification. In a comparison with rice paddy field sites, 24 (92%) of the sites were classified correctly on the IKONOS image and 17 (65%) were classified correctly on the Landsat image. Comparing the classifications on a pixel-by-pixel basis, the agreement between the two classifications was 79%. Part of the disagreement was due to the difference in resolution of the two images. In spite of local differences, the two classifications produced similar area estimates.

Although either Landsat or IKONOS could be used in Korea for a reasonable estimate of habitat area, only IKONOS can resolve small irrigation ponds. While ponds represent a small portion of the total larval habitat, they are an important source for mosquito breeding during the late rice-growing season in the ROK since they contain higher larval densities. High-resolution imagery, such as IKONOS, would be necessary for planning and implementing treatment of these smaller habitats.

Keywords: IKONOS; Landsat; Malaria control

1. Introduction

After being absent from the Republic of Korea (ROK) since the 1970s, *Plasmodium vivax* malaria reemerged in 1993 with the occurrence of two cases (Chai et al., 1994). The number of cases has grown almost every year since, resulting in 1642 cases in 1997 (Feighner, Pak, Novakoski, Kesley, & Strickman, 1998) and peaking in 2000 with 4142 cases (Korea National Institute of Health). The focus of malaria has been just south of the Demilitarized Zone (DMZ) in Kyonggi and Kangwon Provinces. The primary vectors of malaria in South Korea are *Anopheles sinensis* Wiedemann and perhaps *A. lesteri* Baisas and Hu, species that are associated with the rice paddy environment (Tanaka, Misusawa, & Saugstad, 1979). During 2001, the number of malaria cases declined to 2533, with 29 (1.1%) of the cases occurring in U.S. military personnel who had been stationed in the Republic of Korea (Preventive Services Directorate, 18th Medical Command, Seoul, ROK, personal communication).

Since 1999, U.S. Army personnel stationed near the DMZ have used chloroquine/primaquine chemoprophylaxis and other preventive measures such as permethrin-impregnated bednets and uniforms and topical deet mosquito repellents. The use of larvicides in rice paddies and ponds surrounding the military bases also has been suggested (Strickman et al., 1999). This study is part of a larger effort

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to determine the utility and cost of various methods to reduce the risk of malaria transmission to U.S. military personnel. The purpose of this study was to determine whether an accurate estimate of the area covered by mosquito larval habitats can be obtained using Landsat 7 Enhanced Thematic Mapper+ (ETM+) and/or IKONOS data for the Korean test site. The area estimates of mosquito habitats then can be used to estimate the cost of larviciding near U.S. military bases in Korea.

The use of remote sensing to detect mosquito breeding habitats has been shown to be possible by several authors, and a review of the techniques can be found in an article by Hay, Snow, and Rogers (1998). Remote sensing has been used to predict which California rice fields will have the highest production of *A. freeborni* larvae nearly 2 months before the peak larval density occurs (Roberts & Rodriguez, 1994; Wood et al., 1991). Beck et al. (1994) used images from Landsat Thematic Mapper (TM) to estimate the risk of malaria in 40 villages in Chiapas, Mexico, based on two environmental factors: transitional swamp and unimproved pasture. Rejmankova, Roberts, Pawley, Manguin, and Polanco, (1995) used classified multispectral SPOT data to identify marshes containing vegetation favorable for mosquito habitat in Belize. Thomas and Lindsay (2000) used SPOT imagery to estimate the risk of exposure to malaria in rural Gambian children. The current study utilized Landsat ETM+ and IKONOS images to quantify the size of larval habitats within the vector's flight range around two U.S. Army bases in the ROK.

IKONOS imagery is a commercial product acquired by the IKONOS satellite and sold by Space Imaging (http://www.spaceimaging.com). ETM+ is acquired by the Landsat 7 satellite and sold by the United States Geological Survey (http://earthexplorer.usgs.gov). Characteristics of IKONOS and Landsat are listed in Table 1. One important difference in the two sensors is that IKONOS lacks mid-infrared (IR) channels, which are very useful in vegetation studies. Scene size is different for the two sensors: 11 × 11 km for the IKONOS versus 185 × 185 km for Landsat. Generally, IKONOS acquisitions must be requested, whereas Landsat is automatically acquired every 16 days over the United States and approximately every 4 months elsewhere (Arvidson, Gasch, & Godward, 2001). Although costs have historically varied for both sensors, IKONOS imagery has always been more expensive per square kilometer than Landsat. The resolution of the two sensors is 15 and 30 m for the Landsat panchromatic and multispectral bands, respectively, versus 1 and 4 m for the IKONOS panchromatic and multispectral bands, respectively. Using IKONOS mosaics for large areas not only costs more than Landsat, the large image size can be very difficult to store and process. However, for certain projects, the increased resolution of IKONOS may be necessary. One of the questions that this study attempts to answer is whether the high-resolution imagery is more effective in delineating selected types of small larval mosquito habitats, and, if so, how this affects the overall estimate of total habitat as predicted by the low-resolution image.

Table 1
Characteristics of IKONOS and Landsat images

Image	Band	Wavelength (μm)	Resolution (m)
IKONOS	(1) Blue	0.45–0.52	4
	(2) Green	0.52–0.60	4
	(3) Red	0.63–0.69	4
	(4) Near-IR	0.76–0.90	4
	Panchromatic	0.45–0.90	1
Landsat ETM +	(1) Blue-green	0.45–0.52	30
	(2) Green	0.53–0.61	30
	(3) Red	0.63–0.69	30
	(4) Near-IR	0.75–0.90	30
	(5) Mid-IR	1.55–1.75	30
	(6) Thermal	10.4–12.5	60
	(7) Mid-IR	2.09–2.35	30
	(8) Panchromatic	0.52–0.90	15

Image	Scene size (km)
IKONOS	11 × 11
Landsat ETM +	185 × 185

The two sensors have significant differences in radiometric properties, and the gains are different. Furthermore, the conversion from measured analog signal to digital numbers results in 8-bit data for Landsat and 11-bit data for IKONOS (Goward, Davis, Fleming, Miller, & Townshend, this issue; Pagnutti et al., this issue).

2. Methods

2.1. Field work

Field work for this project was performed from June through September 2000, and concentrated on two military bases near the DMZ: Camp Greaves and Camp Casey. Camp Greaves [Paekyeon-Ri, near Tongil-Chon (village)] is located in a rural area just south of the DMZ. Camp Casey (Tongducheon) is approximately 35 miles east of Camp Greaves in a more populated area with less agriculture.

Standard larval survey techniques using a plastic dipper in all types of standing fresh water were conducted at both sites. Seven potential types of larval habitats were identified and sampled: (1) rice fields, (2) streamside pools, (3) irrigation ponds, (4) irrigation ditches, (5) drainage ditches, (6) swamps, and (7) rivers. Only two small swamps occurred in the study area and were not found to be important larval habitats. The Imjin River parallels the rear boundary of Camp Greaves and could not be sampled due to military security measures. However, a nearby upriver site was sampled and was negative for mosquito larvae.

During larval sampling, water quality testing was conducted to determine the potential effect of minerals on mosquito larvae populations. Samples were tested for nitrate and phosphate concentrations, total dissolved solids, and pH. Statistical analysis of these data showed that none of these factors was predictive for the presence or absence of *Anopheles* larvae (Claborn, Hshieh et al., 2002). These results suggest that most standing or slowly moving fresh water is suitable as a larval habitat for *A. sinensis* in this area.

Each field site was located by using a Garmin III Global Positioning System (GPS) unit (Garmin International, Olathe, KS, http://www.garmin.com/). Since GPS readings could not be taken in the center of the rice fields due to potential crop damage, four readings were taken at the corners of the field and then the points were averaged to get an accurate estimate of the center of the field. GPS points were plotted on topographic maps in the field using ArcView version 3.2 (Environmental Research Systems Institute, Redlands, CA, http://www.esri.com/). After the completion of the fieldwork, points also were displayed on the IKONOS image. Almost all of the 93 points collected were located within 5 m of the actual ground points. Four points had a greater locational error, possibly due to electromagnetic interference from nearby transmission lines (Earth Observation Magazine (EOM) Archives, 2002, http://www.eomonline.com/Common/Archives/Oct95/gps.htm, April 15, 2002) or from deliberate interference from local military forces (Ward & Johannessen, 1996). The four offset points were manually corrected using the topographic maps or IKONOS image as a reference.

Because of the interest in estimating the amount of larval habitat in areas that would affect the camps, buffer zones were created around the two camps using Arc/Info software (Environmental Research Systems Institute, Redlands, CA, http://www.esri.com/). The boundary of Camp Casey was digitized and a 1-km buffer zone was placed around the camp based on an approximate 1-km flight range of the *A. sinensis* mosquito. Due to the size and shape of Camp Greaves, a 2-km radius circle was created around a point marking the approximate center of Camp Greaves, resulting in an approximate 1-km buffer zone around the perimeter of the camp. Fig. 1 shows the larval sampling sites and the 1-km buffer zone around Camp Greaves.

2.2. Image analysis

Two images were used for this study: a Landsat 7 ETM+ image acquired on April 29, 2000, and an IKONOS image acquired on August 2, 2000. The Landsat image covers both

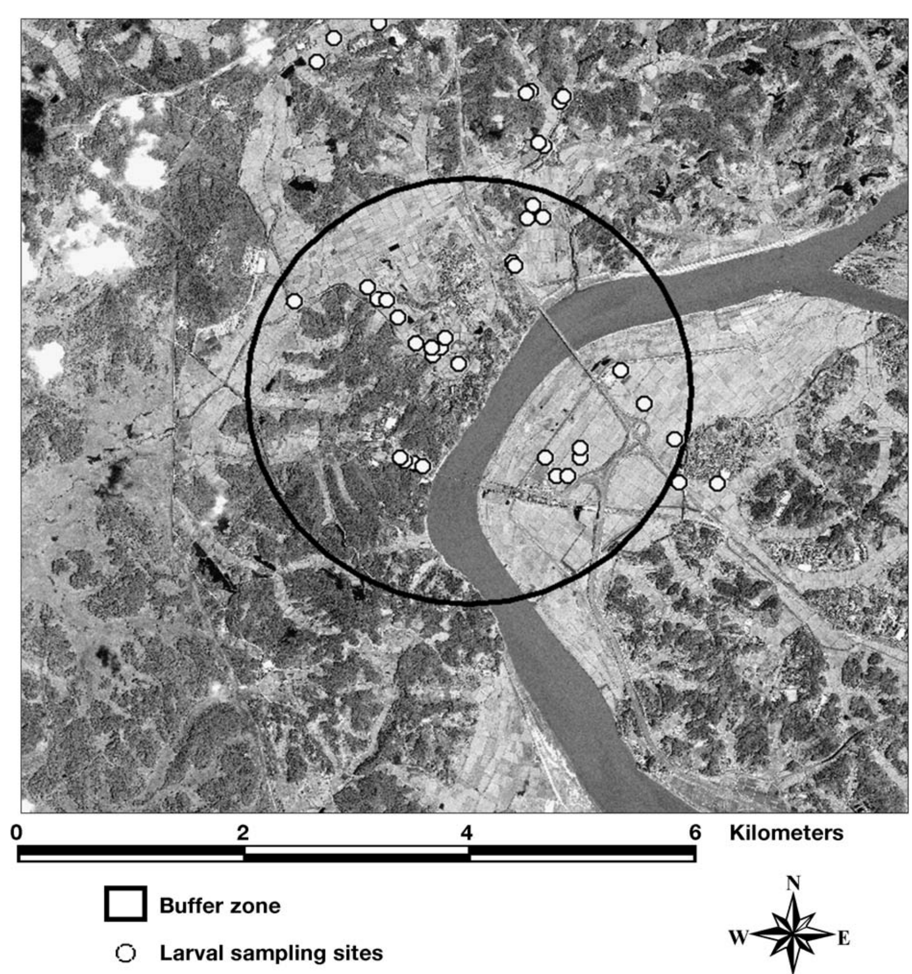

Fig. 1. IKONOS image with buffer zone around Camp Greaves and larval sampling sites. (Includes material from Space Imaging©.)

the Camp Greaves and the Camp Casey sites. The IKONOS image lies entirely within the Landsat image but only covers the Camp Greaves site. The images were georeferenced to a UTM projection with a WGS-84 datum. A visual comparison of the images with each other and with georeferenced topographic maps showed that the geometric correction of the images was good.

PCI remote sensing software (PCI Geomatics, Richmond Hill, Ontario, Canada, http://www.pcigeomatics.com) was used to perform supervised classifications on the IKONOS and Landsat images. Training sites for the classification were selected at locations where researchers had sampled standing water for anopheline larvae. Various classification algorithms were investigated including minimum distance, maximum likelihood, and parallelepiped programs. The parallelepiped algorithm with a maximum likelihood as a tiebreaker appeared to be the most accurate classification of the images based on a visual comparison with a plot of the sampling sites on the IKONOS image. For the IKONOS image, training sites were collected for the rivers, ponds, ditches, and rice fields. Because of the lower resolution, training sites on the Landsat image included only rice fields and the river; ponds and ditches were too small to be resolved. The river was considered to be nonhabitat based

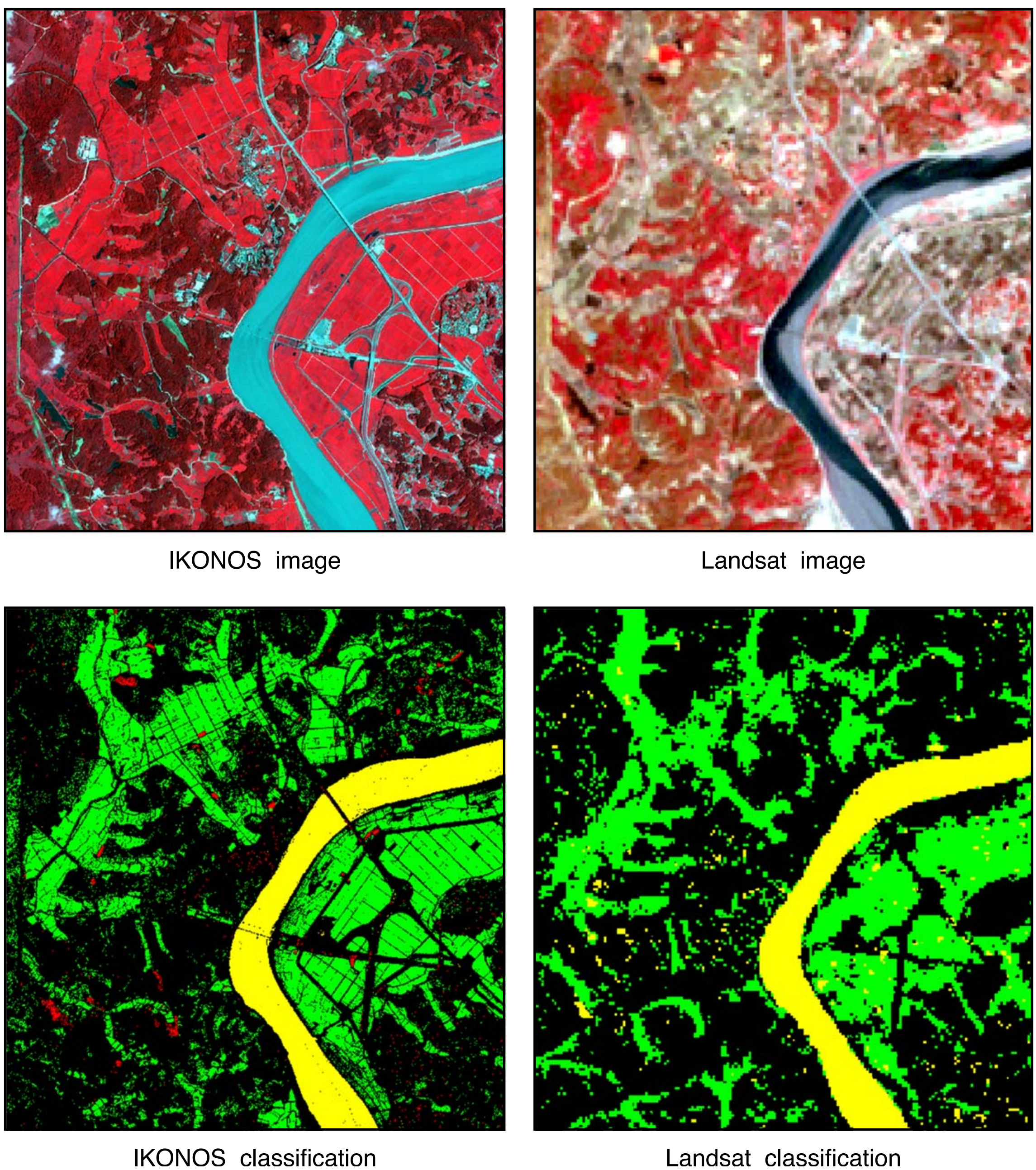

Fig. 2. Comparison of IKONOS false color composite and classification with Landsat. On classification images, the river class is shown in yellow, rice fields in green, and ponds in red. Each image is 5.5 km in width. (Includes material from Space Imaging©.)

on sampling at upriver sites. Other nonhabitat areas of the images were classified as urban and forest, but these were later grouped together as a single, nonhabitat class for the purpose of estimating area.

PCI's MODEL program was used to generate reports on the area covered by each class in the classified images. To compare the classification results between the two imagery types, a subset of the Landsat image was made to include only the area covered by the IKONOS image. A confusion matrix was generated to compare the classification accuracy of the Landsat and IKONOS with field sample sites common to both images. The MODEL program also was used to compare the Landsat and IKONOS classifications on a pixel-by-pixel basis and to create a new image that depicted matching and nonmatching pixels.

3. Results

3.1. Classification

Figs. 2 and 3 show the result of the classifications of the Landsat and IKONOS images. Based on a visual comparison between the classification and the original image, rivers, ponds, and rice fields were successfully classified on the IKONOS imagery. Ditches could not be successfully classified on the IKONOS imagery, possibly due to trees, shrubs, and other plants that grow along the ditches and make them spectrally similar to other land cover classes. On the Landsat imagery, rivers and rice fields could be classified, but ponds and ditches were too small and could not be used for collecting training sites. A visual comparison of the Landsat and IKONOS classifications shows that they are quite similar in the classification of the river (Figs. 2 and 3). Large areas of rice fields were classified fairly accurately on the Landsat classification (Fig. 3). However, small rice fields, as seen in the NW corner of the IKONOS image (Fig. 3), were not correctly classified by the Landsat classification.

A confusion matrix (or error matrix) was calculated for each of the classifications using the larval collection sites that fell within the IKONOS image as the reference data (Table 2). Twenty-six rice fields were sampled; 24 (92%) were classified correctly on the IKONOS image and 17 (65%) were classified correctly on the Landsat. Only one swamp was sampled, and since this was not a land cover type for which a training site was selected, it was accurately classified as unknown on the IKONOS image, but as rice on

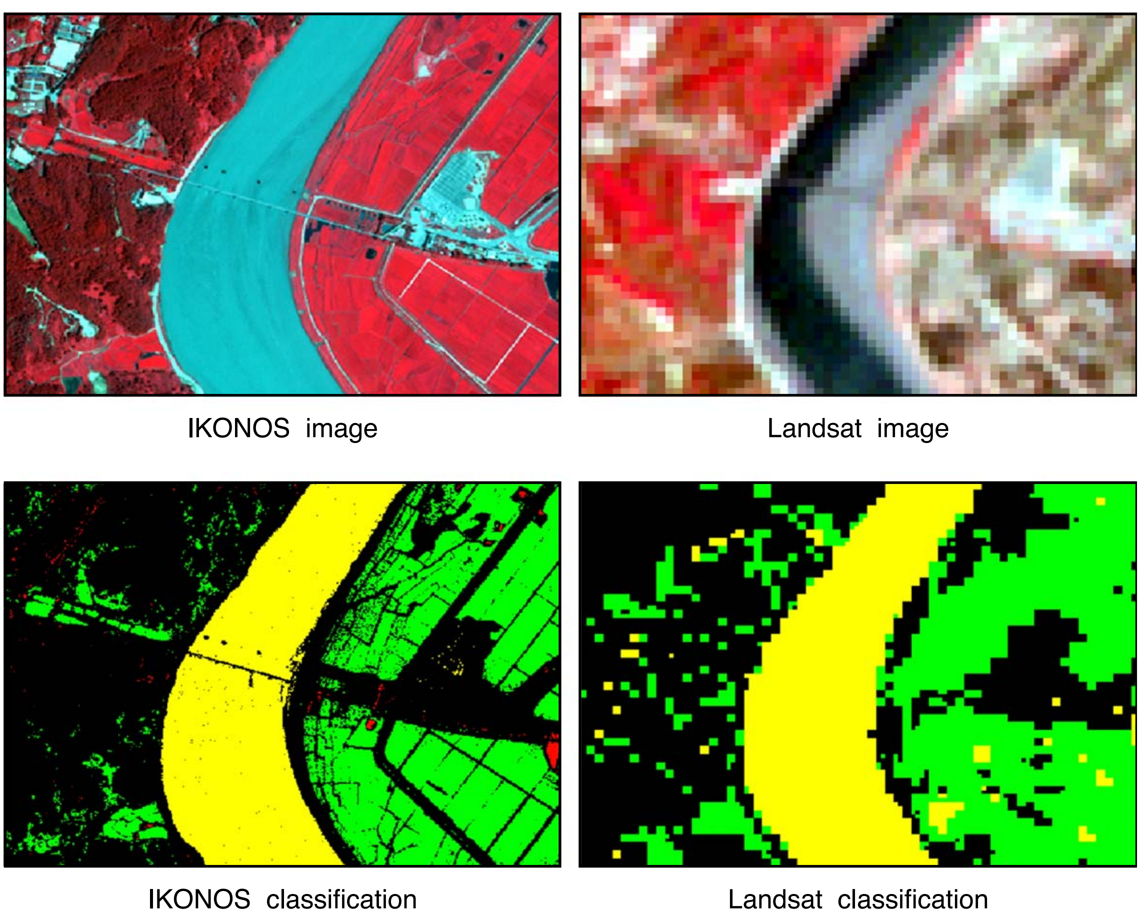

Fig. 3. An enlarged subset of the images from Fig. 2 comparing an IKONOS false color composite and classification with Landsat. On classification images, the river class is shown in yellow, rice fields in green, and ponds in red. Image width is 1.9 km. (Includes material from Space Imaging©.)

Table 2
Confusion matrices of land cover at larval sample sites compared to land cover determined by classification of the satellite imagery

Classified data	Field sample sites				
	Rice	Pond	Ditch	Swamp	Total
Confusion matrix—IKONOS					
Rice	24	0	4	0	28
Pond	0	0	0	0	0
Ditch	0	0	0	0	0
Swamp	0	0	0	0	0
Unknown	2	3	9	1	15
Total	26	3	13	1	43
Confusion Matrix—Landsat 7 ETM+					
Rice	17	2	8	1	28
Pond	0	0	0	0	0
Ditch	0	0	0	0	0
Swamp	0	0	0	0	0
Unknown	9	1	5	0	15
Total	26	3	13	1	43

The same sample site locations were used for both matrices.

the Landsat image. Ditches were classified as either rice or unknown on both the IKONOS and the Landsat images.

Only three ponds were sampled in the field in the area covered by the IKONOS image. Although a visual inspection of the classification with the IKONOS 1-m panchromatic image shows that many ponds were accurately classified, none of the three ponds sampled in the field was correctly identified in the classification. The misclassification of the ponds on the IKONOS image is probably due to the small size of these sampled ponds; the largest sampled pond was only 9 × 7 m.

A comparison of the Landsat and IKONOS classification was done using the PCI MODEL program to compare the classification on a pixel-by-pixel basis. White pixels in Fig. 4 represent the pixels that were classified the same on the two images; black pixels were classified differently. A report generated by PCI's MODEL program calculated a 79% agreement in pixel classification on the Landsat and IKONOS images. Differences in the classification may in part represent differences in resolution. Also, since the Landsat image was acquired early in the growing season (April 29) and the IKONOS was acquired late in the growing season (August 2), the differences in classifications may be partially due to the different stages of rice development.

More modeling was done to explore the differences in the two classifications. In Fig. 5, black pixels represent areas that were classified as habitat on Landsat but as nonhabitat on IKONOS. One reason for the difference is that Landsat classified the small roads and large dikes separating the rice fields as rice paddies because of lower resolution, whereas IKONOS classified them as nonhabitat. There also may be some mixed pixels on the Landsat that were classified as rice but were separated into rice and nonhabitat on the IKONOS image.

In Fig. 6, black pixels represent areas that were classified as habitat on IKONOS but as nonhabitat on Landsat. Larger patches of black on this image represent fields that were inaccurately classified as nonhabitat on the Landsat. A comparison with the Landsat image shows that some of these fields are obviously spectrally different from the other rice fields on the same image and may represent a different

Fig. 4. Image showing the agreement of pixels in the classification of Landsat and IKONOS images. Black pixels (21% of image) were classified differently in the two images. White pixels were assigned to the same class. Image covers the same area as Fig. 2 and is 5.5 km wide.

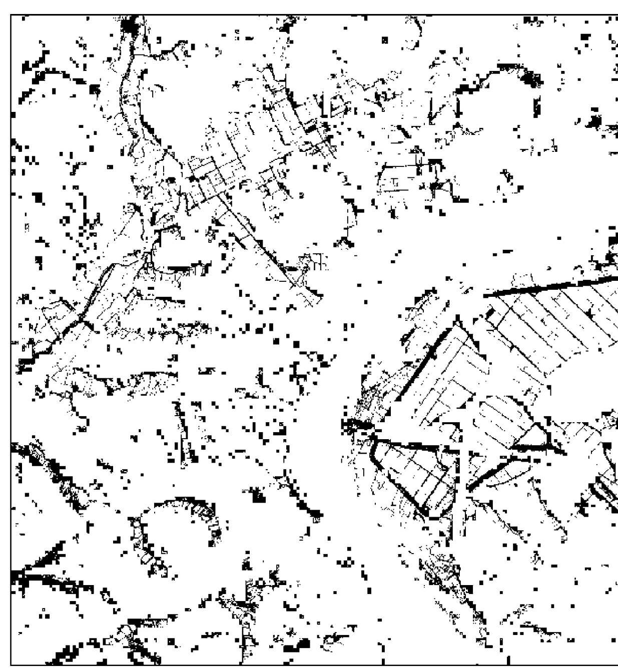

Fig. 5. Image showing pixels (in black) that were classified as habitat on Landsat but as nonhabitat on IKONOS. Image covers the same area as Fig. 2 and is 5.5 km wide.

Fig. 6. Image showing pixels (in black) that were classified as habitat on IKONOS but as nonhabitat on Landsat. Image covers the same area as Fig. 2 and is 5.5 km wide.

stage of rice planting (nonflooded versus flooded). In the IKONOS image that was acquired later in the growing season, rice crops were mature and no apparent differences existed between fields. Some of the small rice fields that were classified as nonhabitat on Landsat also are apparent on Fig. 6. A comparison of Fig. 6 with Fig. 2 shows that a scattering of pixels from forested areas was misclassified as rice on the IKONOS image.

Area estimates for the buffer zone around Camp Greaves are shown in Table 3. Although the difference in the classification of Landsat and IKONOS images was approximately 20%, the area estimates were very close. The Landsat 7 ETM+ estimate of rice paddies was only 2.4% less than the IKONOS estimate.

3.2. Larvicide treatment cost estimates

The habitat land cover estimates obtained in this paper have been used to estimate the cost of mosquito larviciding around the camps as a control method. The method of estimating cost for larvicidal treatments is described in detail in Claborn, Masuoka, Andre, Hooper, & Klein, 2002. Briefly, estimates were based on current costs of a growth-regulating insecticide, wages for workers who will apply the larvicide, fuel cost, and maintenance expense for ground-based dispersal equipment. These were compared to the cost of providing antimalarial medications based on the price of the drugs and required pretreatment testing.

Table 3
Comparison of land cover area estimates (m^2) for Camp Greaves and surrounding area, Republic of Korea

Class	Image	
	IKONOS	Landsat
Rice fields	4,198,151	4,304,250
Ponds	48,709	None
River	1,465,431	1,604,925
Nonhabitat	6,789,022	6,502,500

Nonhabitat includes all areas other than rivers, rice fields, and ponds.

Table 4
Cost comparison of chemoprophylaxis to larviciding for control of malaria within two military bases and a surrounding 1-km buffer zone

Camp Greaves	Camp Casey
430.4 ha of habitat	122.5 ha of habitat
Larvicide treatment = US$40,263.13	Larvicide treatment = US$11,450.37
Chemoprophylaxis cost for 760 persons = US$28,522.80	Chemoprophylaxis cost for 8000 people = US$330,264.00

Habitat estimates are based on the Landsat classification.

Larviciding cost estimates were compared to the cost of chemoprophylaxis for U.S. personnel stationed at Camp Greaves and Camp Casey. Results of the estimates are shown in Table 4. Because of the large habitat area and the low number of soldiers at Camp Greaves, malaria is most cost-effectively controlled with chemoprophylaxis. In Camp Casey, it is cheaper to use larviciding than chemoprophylaxis due to the large number of soldiers and the small mosquito habitat area.

4. Conclusions

We have found that similar land cover area estimates of mosquito larval habitat can be obtained from IKONOS and Landsat 7 ETM+ imagery. For estimating the costs of larviciding and other types of planning, which need only rough estimates of the major habitat areas defined, Landsat would be adequate. On a local level, the IKONOS image allowed a better classification of rice fields, accurately identifying 92% of the field sites versus 65% for the Landsat. Although we were unable to classify the three very small ponds sampled in the field, many larger ponds were visible on the IKONOS image. The use of IKONOS has the advantage of being able to portray and classify land cover features such as ponds and rice fields that are less than 30×30 m in size. Although ponds represent a relatively small portion of the total habitat area, they are an important breeding habitat for mosquitoes in Korea since they contain higher larval densities than the rice fields late in the growing season (Claborn, Hshieh et al., 2002). For areas where small features represent the majority of the habitat, high-resolution imagery would be necessary. In addition, high-resolution imagery would be much more useful in planning sampling collections and larviciding tasks than Landsat imagery.

The two imagery types could be used together in planning and implementing a malaria control program. Landsat, in conjunction with information on the location and number of cases in a geographic information system (GIS), could be used in the first stages of planning to estimate the costs and to plan the location of the spraying. The size of the area to be treated could be adjusted within the GIS depending on the budget available for the control program. Once local treatment areas are selected, IKONOS imagery could be used to locate habitats and track the local spraying efforts.

Worldwide, mosquitoes breed in a wide variety of habitats. Many mosquito habitats such as small marshes and streams can be mapped only on high-resolution imagery such as IKONOS. In many regions of the world, high-resolution imagery would be very useful for studying and controlling malaria and other mosquito-borne diseases.

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