Use of geographical information systems to analyze large area movement and dispersal of rice insects in South Korea

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The potential use of geographical information systems to analyze pest surveillance data was explored. The Spatial Analysis System (SPANS)[TM] was used to construct a spatial data base to study pest distributions based on pest surveillance data collected from 152 stations in South Korea. The annual spatial distributions of the striped rice borer (SRB), *Chilo suppressalis,* showed that areas with high densities started to expand in the early 1980s and reached a peak in 1988. The change in pattern appeared to be related to the cultivation of japonica and indica-japonica hybrid varieties of rice in South Korea. Japonica varieties have longer durations, which allows the SRB more time to mature and hibernate in winter. The locus of SRB spread was located in the midwest region near Iri in Chun-Buk. High brown planthopper (BPH) populations in South Korea are often related to immigration during the early rice season in June and to temperature. Simulated distribution of BPH densities in September using these two factors was compared with the actual 1990 distribution. The two density maps corresponded closely except for differences in the southeastern valley. When the simulated map was overlaid with elevation and rice area maps, more specific BPH risk zones could be identified. Several simulated world warming scenarios were also examined. If temperatures increase, BPH risk areas will probably expand both latitudinally and altitudinally.

Although temporal dynamics of insect populations takes place within a spatial context, population ecology tends to concentrate on dynamics at single locations (Johnson and Worobec 1988). Much of the recent attention given to large-scale spatial dynamics of insect populations has been related to migration as a factor in synoptic pest studies (Taylor 1986). However, insect distributions and abundances can be greatly affected by local conditions (Song et al 1982).

A recent technology for the analysis of geographic variables can be adopted to examine the spatial aspects of the dynamics of pest populations. Large-scale movement and dispersal of insect pests can be investigated. Geographic information system

(GIS) is an information system that works with data referenced by spatial or geographic coordinates (Star and Estes 1990). It is a data base system with specific capabilities for spatially referenced data. It can also be used to analyze data.

Geographical information, such as soil type and distribution of varieties, can be stored as a spatial map layer. When these map layers are overlaid, valuable information, such as pest zones or areas prone to pest attacks, can be extracted. This is similar to the process used to obtain new information from a classification of stored data in a conventional data base. Therefore, a GIS can help identify pest risk zones from a classification of spatial information. Subsequent investigations can discover the ecological basis for the distribution of certain pests in some areas.

This spatial analysis technology can be used to construct computer models that use the maps as variables. Maps of monthly rainfall, monthly hours of sunlight, and annual grasshopper counts were correlated, and forecast maps were constructed (Johnson and Worobec 1988).

This paper reports on a study to explore the potential of applying GIS to rice pest surveillance data. To illustrate this application, the spatial distribution of the brown planthopper (BPH) in South Korea was investigated. Maps of mean temperatures were used to construct estimates of the spatial distribution of the BPH for various global warming scenarios.

The pest surveillance system in Korea

The pest surveillance system in South Korea is organized by the Rural Development Administration (RDA). It consists of 152 stations that each use a 0.2-ha field. Three plots, each planted with three fixed rice varieties and with two major rice varieties grown in that region are maintained in each field. Density assessments of insect pests and diseases are carried out in two of the plots; the third is the control. In addition, a light trap (number of insects collected per night), a spore trap (number of rice blast spores per 2 h per day), an aerial net trap (number of insects collected per day), and a yellow pan trap (number of insects collected per day) are installed in each station.

Both field and trap records are obtained by the officer-in-charge. Data sets are entered into microcomputers at each office site using standard data entry screens. A computer network system (DACOMNET™) sends the data to the VAX-11/785 and 11/6420 machines at RDA in Suweon.

The data sets are processed and stored by the VAX mainframe. Data summaries are used in weekly pest surveillance meetings to prepare warning reports that are transmitted to the various regions. After they receive these reports, pest surveillance officers survey the farmers' fields in more detail. Based on this survey, the surveillance officers warn farmers by placing red flags with messages in the fields that require attention. Farm community leaders who receive the pest warnings often use public address systems to convey the warning messages to farmers (Heong 1989, Lee 1990).

Three categories of surveillance data were obtained from RDA from 1981 to 1991 (Table 1). CALMAIN consists of daily trap catches of 20 different pest species and meteorological information about temperatures (maximum, minimum, and average), humidity, wind speed, and wind direction. CALMAIN was used for the analyses.

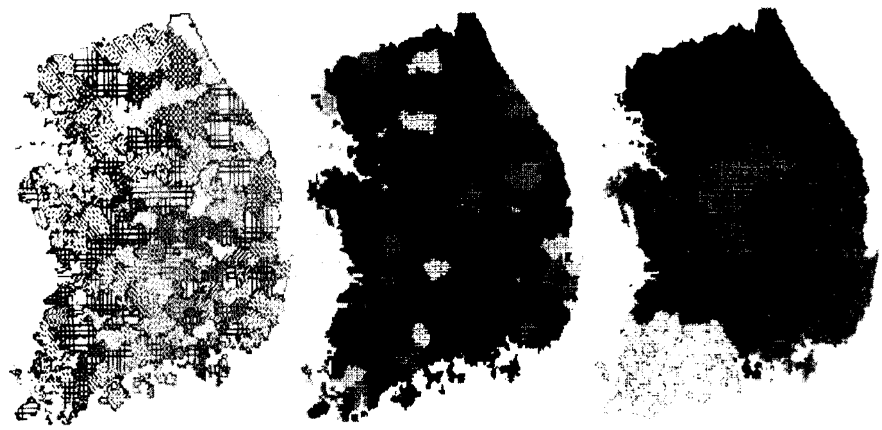
Table 1. The three categories of pest surveillance data in the computerized pest surveillance data acquisition and delivery system in Korea.

File name	File size	Collection frequency	Contents
CALMAIN.MAS	30MB	Daily	Light trap, spore collection, and weather data
FLDOBSD.MAS	10MB	Every 10 d	Pest density in farmers' fields
FLDDATA.MAS	10MB	Every 10 d	Pest density in pest surveillance fields

Preparation of basic thematic map layers

The SPatial ANalysis System (SPANS^{TM}, TYDAC Technologies Inc.), a GIS available on microcomputers, was used for the data analyses. SPANS is a raster-based GIS that can overlay several map layers to analyze information on each layer and to identify the structural relationships between the spatial variables. Several steps are needed to prepare the basic thematic map layers that are needed to build and classify the spatial data base. These steps include the construction of basic thematic ground-map layers, the construction of reclassified map layers, and the importation of topographical layers.

Figure 1 shows some basic maps prepared for South Korea. The county-border vector map was manually digitized, and the data were imported into SPANS. This map was translated into a map of quadtrees (a data structure for thematic information in a raster data base that minimizes data storage). Vector maps are widely used hierarchical data structures because they do not take long to run and they generate graphics quickly. Quadtrees construct regions by reclusive decomposition, that is, an area is repeatedly subdivided into quadtrees until areas of homogeneous value are attained (Johnson and



1. Some of the basic thematic maps prepared for SPANS analysis in South Korea: a vector map of county borders (left), a quadtree map (middle), and a provincial reclassification map (right).

Worsbec 1988). The quadtree county map can be reclassified based on the characteristics of each county quad.

A topographical map of ground elevation was prepared. Because elevation can influence pest abundances, the elevation data were read in quarter kilometer intervals, stored in raster form, and imported into SPANS. The data were obtained from B. W. Lee (Seoul National University, South Korea) and are currently only available for eastern Korea.

From the elevation map layer, a slope map of the ground was prepared to estimate rice areas. The slope was calculated from the raster elevation data. The elevation and slope map layers were overlaid to identify the rice areas (elevation < 400 m and slope < 15%). Because rice is the staple crop in Korea, farmers generally grow rice wherever land is suitable.

Interpolation of point data

To analyze the spatial patterns of pests, point data from surveillance were used to generate pest distribution map layers. The potential mapping routine (POTMAP) of SPANS produced a map based on interpolation from the weighted averages of the point data values. The weight applied to the values at distance d from the center was calculated by SPANS from the exponential function

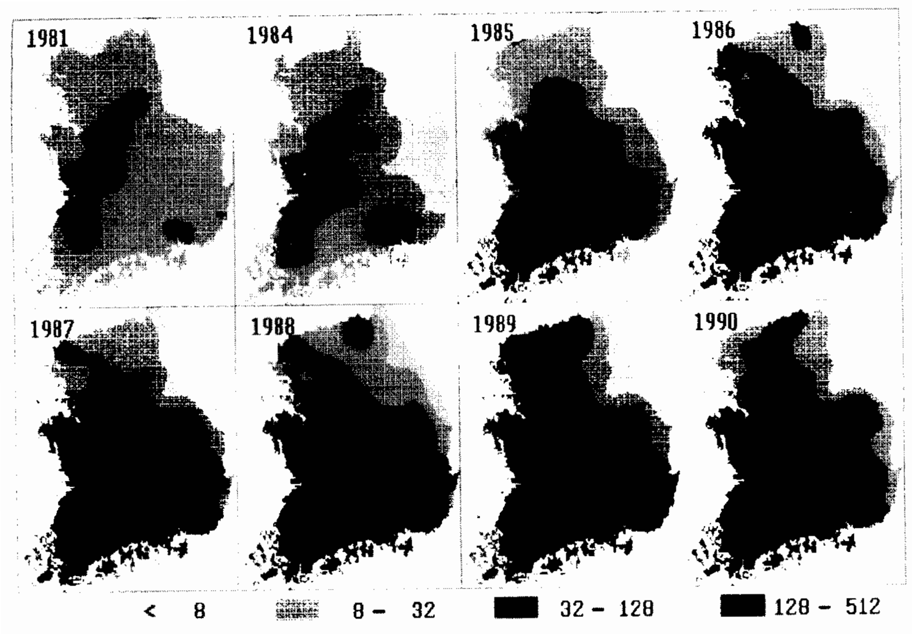
$$w(d)=n(r-d)/re^{-ad} \qquad [1]$$

where r is the sampling radius, d is the half-weight distance supplied by the user, a is a constant, n is the number of localities within the sampling circle, e is the exponent, and $w(d)$ is the weight value at that point.

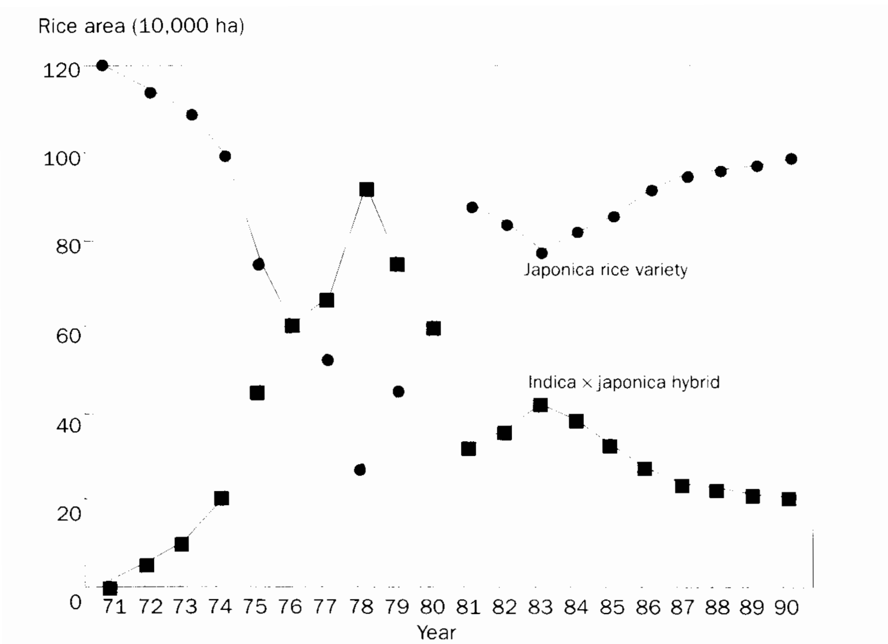
The thematic pest distribution maps were generated from this point data interpolation technique. The striped rice borer (SRB) (*Chilo suppressalis*) and BPH (*Nilaparvata lugens*) were studied.

Changes in *Chilo suppressalis* distribution in South Korea

The SRB *Chilo suppressalis* was a major insect pest of rice until the mid-1970s. In the early 197Os, SRB densities were high, but they declined in the mid-1970s and were extremely low in the late 1970s (Song et al 1982). Changes in SRB distribution during the last 10 yr (1981-90) were studied (Fig. 2). Two characteristics were apparent. SRB densities were high in the 1980s, reached a peak in 1988, and then declined. The locus of the SRB spread was located in the midwest region, near Iri, Chun-Buk. This pattern of change was related to changes in the cultivars that were grown (Fig. 3). The increase in use of indica-japonica hybrids in the 1970s shifted harvesting times by a month. Consequently, the SRB had only a short period to mature and prepare for winter hibernation (Song et a1 1982). In the 1980s, the proportion of japonica varieties increased from 20% in the early 1980s to 80% in the late 1980s. With the japonica varieties, harvest times were delayed and borers had sufficient time to mature and to hibernate for the winter.



2. Annual changes in the striped rice borer *Chilo suppressalis* density distribution from 1981 to 1990, based on annual total light trap catches.



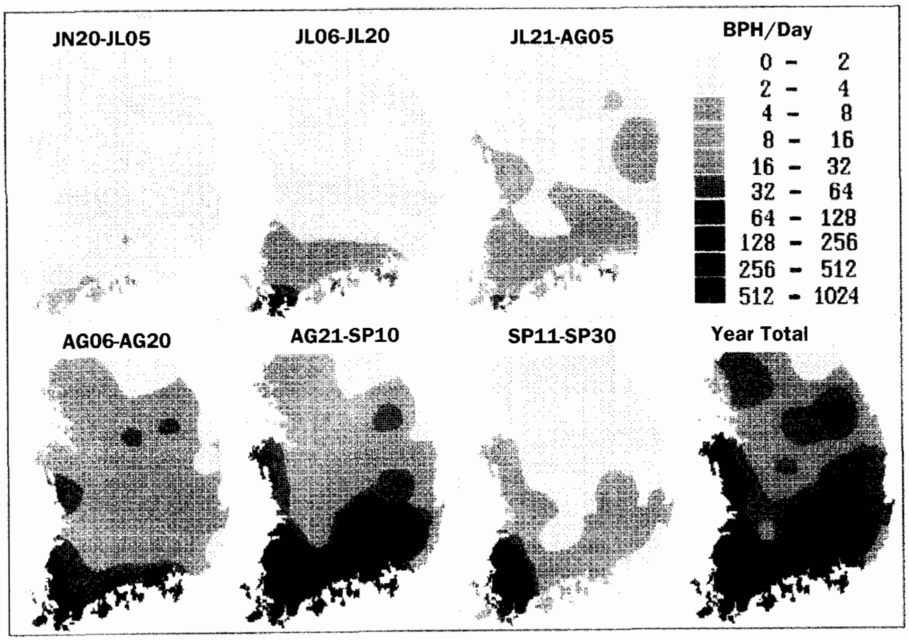
3. Changes in the composition of acreage of two major rice variety groups, japonica and indica-japonica hybrid, grown in Korea from 1970 to 1990.

Changes in BPH distribution

The BPH cannot hibernate in Korea; therefore, BPH populations are established from populations that immigrate into southwestern Korea (Uhm and Lee 1991). Similar migrations also occur in Japan, and this phenomenon is well described by Kisimito (1976, 1987). In temperate regions, the BPH population starts with low immigration at the beginning of the rice season and is characterized by a rapid increase late in the season (Song and Kim 1988). Thematic maps of BPH distribution (Fig. 4) show that immigration into the south and southwest coastal regions usually occurs in late June to July. High BPH densities were also found in late August and September.

The association between early immigration and BPH populations in September is closely related to temperature. The overlay/modeling utility in SPANS was used to simulate the distribution of BPH densities in September using immigration data from late June and the corresponding temperature data. The BPH densities in September were expressed as a function of early BPH immigration and temperature based on a temperature-dependent population dynamic model (Song 1988). The model translated in SPANS' overlay modeling language is given in Figure 5.

Figure 6 shows the comparison of actual BPH trap catches in September 1990 with the simulated and smoothed map. The two density maps corresponded closely, except for differences in the southeastern valley.

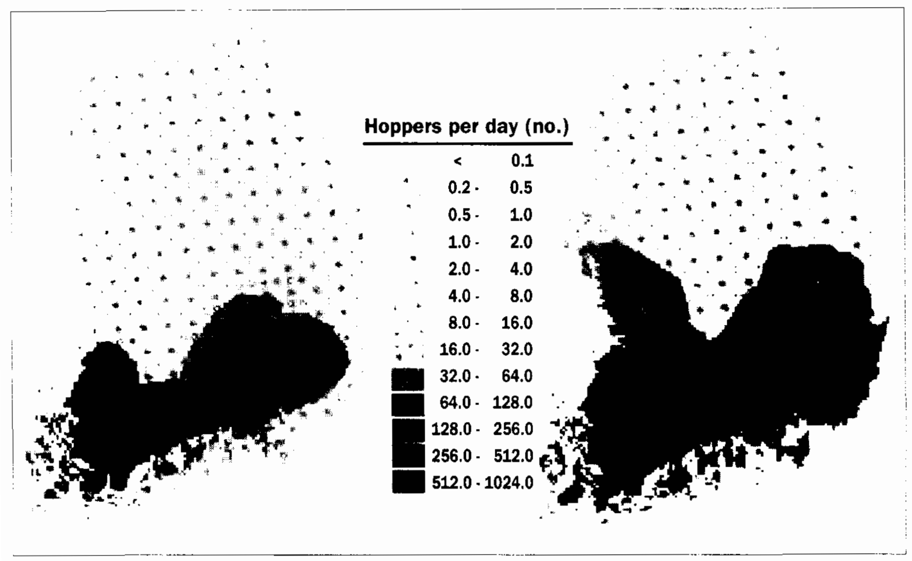


4. Temporal changes in the distribution of BPH density in different time periods, based on average light trap data for the period 1981-90.

```
E   bphmdl  BPHModel    =   Estimate the BPH occurrence in September
                             with immigration in period _1 (late June)
                             without adjustment of elevation effects

:   bpl   =  Immigrant Population in Period _1 (Jun 21 - Jul 10)
:   bpl   =  [bp90p1];
:   bp2   =  Immigrant Population in Period _2 (Jul 11 - Jul 31)
    bp2   =  [bp90p2];
:   bp3   =  Immigrant Population in Period _3 (Aug 01 - Aug 20)
    bp3   =  [bp90p3];
:   bp4   =  Immigrant Population in Period _4 (Aug 21 - Sep 10)
    bp4   =  [bp90p4];

:   tp1   =  Temperature Conditions in Period _1 (Jun 21 - Jul 10)
    tpl   =  [tm90p1];
:   tp2   =  Temperature Conditions in Period _2 (Jul 11 - Jul 31)
    tp2   =  [tm90p2];
:   tp3   =  Temperature Conditions in Period _3 (Aug 01 - Aug 20)
    tp3   =  [tm90p03];
:   tp4   =  Temperature Conditions in Period _4 (Aug 21 - Sep 10)
    tp4   =  [tm90p4];
:   tp5   =  Temperature Conditions in Period _5 (Sep 10 - Sep 30)
    tp5   =  [tm90p5];

:   Suppose the temperature decreases by 1 degree for every 100 meter elevation
:   el    =  Elevation
:   el    =  [elev];
:   el    =  0 for now (No elevation effect encountered)
    el    =  0;

:   r?    =  Rate of population increase per generation in the period-?
:   Suppose the rate of increase depends on rice stage (Uhm & Lee 1991)
    r1    =  90;
    r2    =  90;
    r3    =  50;
    r4    =  50;
    r5    =  50;

:   bt    =  Base (threshold) temperature
    bt    =  10;

:   ct    =  Degree-Days (above threshold) to finish one generation of BPH
    ct    =  400:
```

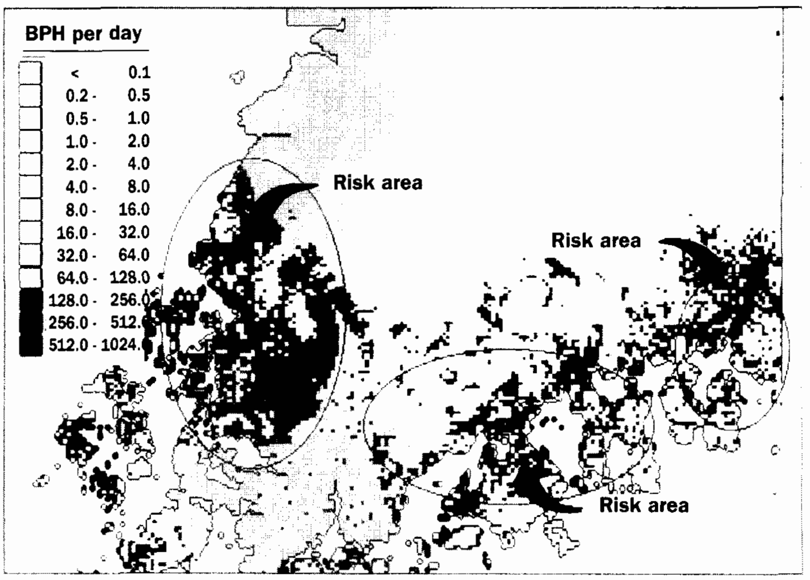
```
:    pd     =  The total number of days in one period
     pd     =  20;
:
:    cp?    =  Accumulated degree-days in period-'?
     cp1    =  (tp1-e1-bt+10)*pd;
     cp2    =  (tp2-e1-bt+10)*pd;
     cp3    =  (tp3-e1-bt+10)*pd;
     cp4    =  (tp4-e1-bt+10)*pd;
     cp5    =  (tp5-e1-bt+10)*pd;
:
:    ng?    =  Number of generations BPH could reproduce after immigration in period _?
:    tr?    =  Total rate of increase until period _5 after immigration in period _?
     tr1    =  pow (r1, cpl/2/ct) *pow (r2, cp2/ct) * pow (r3, cp3/ct)*
               pow (r4, cp4/ct) * pow (r5, cp5/2/ct);
     tr2    =  pow (r2, cp2/2/ct) * pow (r3, cp3/ct) * pow (r4, cp4/ct)*
               pow (r5, cp5/2/ct);
     tr3    =  pow (r3, cp3/2/ct) * pow (r4, cp4/ct)*
               pow (r5, cp5/2/ct);
     tr4    =  pow (r4, cp4/2/ct) * pow (r5, cp5/2/ct);
     tr5    =  1;
:
:    bph?  =  Estimated BPH density from immigration up to period?
     bph1  =           pow (2, bpl-5) * trl;
     bph2  =  bph1 +  pow (2, bp2-5) * tr2;
     bph3  =  bph2 +  pow (2, bp3-5) * tr3;
     bph4  =  bph3 +  pow (2, bp4-5) * tr4;
     bph5  =  bph4 +  pow (2, bp5-5) * trs;
:
:    fa     =  Flying activity as a function of temperature in Period_5. Assumed that 50%
              of the adults fly when the average temperature is 20 degrees
     fb     =  max ((tp5-5)/10, 0);
     fa     =  min (fb, 1);
:
:    The result of simulation
    (bph1)
```

5. Model used to simulate the distribution of BPH densities in September.

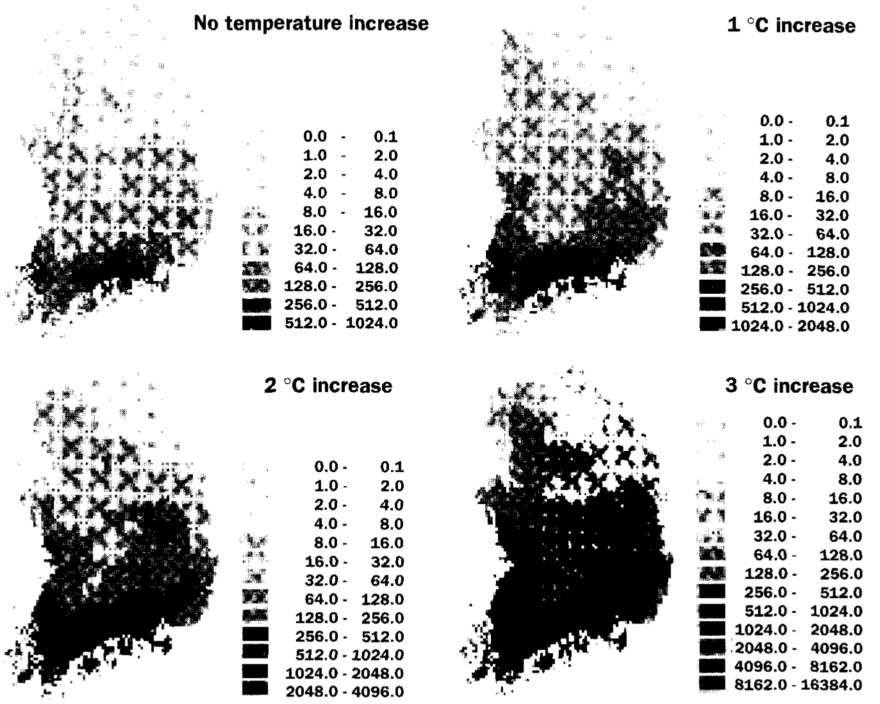


6. Comparison of the actual density of BPH in September 1990 (left) and the simulated density (right).

Changes were made on the temperature map layers to correct for elevation. The rice area map was overlaid on the density map to eliminate nonrice areas, which produced a more area-specific BPH distribution map. Figure 7 shows an enlarged map of the southwestern region where BPH is often the major problem. The simulation displayed



7. Identified risk zones of BPH in the southeastern coastal region of Korea.



8. Changes in BPH risk areas based on several world warming scenarios of temperature increase by 1, 2, and 3 degrees.

areas of BPH risk more precisely. Ground validation with actual field density records are needed to determine the accuracy of the simulation.

Global warming and possible changes in BPH distribution

There is evidence to suggest that rising concentrations of carbon dioxide and other gases will raise the earth's temperature by 3-6 °C. The manner in which rice pests respond to this change will depend on factors such as direct effects on fitness, physiological tolerance, and interspecific competition. The effects of temperature on fitness were used to construct several scenarios for BPH density distributions (Fig. 8). Global warming will tend to expand the BPH risk areas in South Korea both latitudinally and altitudinally.

Discussion

Spatial distribution data have traditionally been presented in map form. The availability of diverse categories of information on soil types, temperature ranges, varieties, elevation, and land use has made it cumbersome to handle the data and maps. Relationships between variables are also difficult to analyze. Recent advances in computer technology and the development of GIS have provided a powerful way to analyze spatial data.

Computer maps have been used to display the spatial dimension of insect populations. In England, mapping techniques were used to analyze aerial suction trap data for aphids and to indicate areas in which crops were at risk (Woiwood and Tayler 1984). A computer-mapping program, SURFACE-II, was used. A microcomputer-based mapping program for rice pest distributions was first developed in Korea (Song et al 1982). This program was further modified at IRRI for general use. However, these systems could only display pest distributions and could not analyze the data.

The GIS enables researchers to generate insect distribution maps from point data by using an interpolation algorithm. A time series of these maps can be used to indicate distribution changes. Furthermore, the modeling module in the GIS allows researchers to make predictions. These predictions can be used to indicate risk zones. In South Korea, where BPH populations are highly dependent on initial immigration and temperature, the identification of risk zones is a useful tool for pest management. Further research to reveal the factors that contribute to high pest densities in these areas can be designed. Johnson and Worsbec (1988) used this approach to reveal that geographic abundance was related more to soil type than to other factors.

Many rice-growing countries in Asia have pest surveillance programs (Heong 1988). Large volumes of data are collected annually. The data are often presented in summary tables. The GIS can be used to generate historical information on the temporal and spatial distribution of pests. Spatial modeling can also be used to develop forecasting models.

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Notes

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