Study on Land-use/Land-cover Change and Terrestrial Carbon Cycle in China

Japanese Oak Wilt Spread analyzed with GIS and Multi-spatial-scale Data

Ryotaro Komura[1], Andrew Libhold [2], Kojiro Esaki [3],
Ken-ichiro Muramoto[4] and Naoto Kamata[4]

[1] Ishikawa National College of Technology
Kitacyujo, Tsubata, Kahoku-gun, Ishikawa, 929-0392 Japan
[2]Northeastern Research Station, USDA Forest Service, 180 Canfield St, Morgantown, WV 26505 USA
[3]Ishikawa Forest Experiment Station, Tsurugi, Ishikawa, Japan
[4] Graduate School of Natural Science and Technology, Kanazawa University, Kakuma, Kanazawa, Ishikawa 920-1192, Japan

*corresponding author: +81-76-288-8130, email: komura@ishikawa-nct.ac.jp

Key words: Japanese oak wilt, Remote sensing, GIS

Abstract

In this study, statistical analysis of the spread of japanese oak wilt (JOW) was conducted using GIS tools and expansion behavior was quantified at different spatial scalew. There appear to be at least three different scales at which expansion of foci operate. These results suggest that adult beetles have capabilities of moving over various spatial scales.

1. Introduction

Recently, Japanese oak wilt (JOW) has been prevalent in Japan. The dieback oak was bored into by ambrosia beetle, *Platypus quercivorus* (MURAYAMA). The beetle has a symbiotic relationship with *Raffaelea. quercivorus* and carries the fungus to a new host trees. This fungus causes necrosis in sapwood of oak trees, stop water conductance, and kills oak trees [1][2]. The present case in Japan is widely noticed as the first example of an ambrosia fungus carried by an ambrosia beetle that kills vigorous trees [3]. Mass mortality of oaks has been recorded since 1935 in Miyazaki and Kagoshima prefectures. Then the mass mortality was observed at Hyogo prefecture in 1948, at Yamagata prefecture in 1959. Until 1970's, JOW was occurred separately at south part of Kyusyu Island, north part of Hyogo prefecture, Fukui, Niigata and Yamagata prefectures. Up to 1980 epidemics of JOW lasted for only a few years and were confined to a few areas on the west side of Japan. Since the late 1980, epidemics have lasted for more than ten years, and the area of dieback has been spreading to new localities where JOW has never been recorded in the past. Especially the area of dieback has expanded in the Japan Sea side of the main island of Japan. Ito and Yamada[1] summarized a map that showed the spreading of dieback by marking first year for each city. However, there is almost no report that analyzed spreading of JOW at individual tree level.

Invasive species usually spread concentrically from a source population [4]. As for organisms that can fly, stratified diffusion, a combination of diffusion with long-distance dispersals is often recognized [5].

To analyze spreading patterns of JOW in relation to behavioral ecology of vector insect is valuable to develop control strategy against JOW. In this study, patterns of spread of JOW were analyzed at two different scales using GIS tool and geostatistics technique. One is regional-level analysis, in which year of new infestation was recorded for each city (=county) based on the map made by Ito and Yamada [1]. The other is stand level analysis detecting crowns of dead trees using aerial photographs. From these results, the spreading process of JOW was discussed in relation to adult behavior of *P. quercivorus*.

2. Materials and Method

2.1 Study areas and data

2.1.1 Regional level analysis

Ito and Yamada published a map depicting the composite of all records of JOW discoveries in each city in Japan between 1979 and 1997 [1]. Geographical coordinates for each location of the city were determined by scanning the map and using a GIS to georeference the scanned image to a standard base map of Japan. Coordinates of the center point of each record location on the scanned map was then exported in meters using the universal transverse mercator projection. The point data from Ito and Yamada apparently represented four separate populations spreading from distinct foci; one foci was in Yamagata prefecture, and north area of Niigata prefecture, one was in south area of Niigata prefecture, and one was in Ishikawa, Fukui and Shiga prefectures, one was in Kyoto, Hyogo and Tottori prefectures.

2.1.2 Stand level analysis

The study site consisted of 1520m x 1380m region in Ishikawa and Fukui prefectures. The site was a mountainous region of Mt. Kariyasu and was nearly uniformly covered by a forest cover dominated by *Quercus crispula*. The study site was located in Ishikawa-Fukui-Shiga region. In this area, JOW was first discovered in 1997.

Around the study site, an attack of *P. quercivorus* starts at late in June. A part of attacked trees change leaf color to read from late in July and an outbreak of newly died trees is finished at August. The trees killed by *R. quercivora* wilt suddenly and can't make abscission layer. The leaves changing color keep on the tree. Then, in the aerial photographs taken until the middle of October, when the leaves hasn't started putting on autumn colors yet, the killed trees can be identified. The trees killed in past years drop its leaves and can be identified too with passable accuracy. Using above information about the process of JOW. From 1998 through 2000 aerial photography in October was collected at this site using an airborn camera (WILD RC-30) with a 23 x 23 cm full color print film (Kodak AEROCOLOR 2444). Negatives were printed on 26 x 24cm paper and scanned at 400pixel/inch resolution resulting in an image with ca. 3604 x 2820 pixels. Each pixel was classified for the presence / absence of JOW by manual interpretation and the distribution map of killed trees in 1997, 1998, 1999, 2000. The validity of this classification was checked by comparing classifications in a 54 x 63m sub area where the location of JOW killed trees was recorded by the investigation on the ground. In this sub area, the accuracy of classification is almost perfect.

2.2 Analysis methods

2.2.1 Data management

All information of killed trees was inputted to GIS (TNTmips) and managed. To know the positions of aerial photographs, DEM was inputted to GIS. In the regional level analysis the map of the JOW distribution made by Ito and Yamada was inputted to a computer using an image scanner. Then the positions of JOW were extracted inputted to the GIS and the map of JOW distribution was made from aerial photographs with visual inspection. Images of aerial photographs were registered to the DEM that was inputted in advance using affine transformation. By registration of DEM and aerial images, the positions of the killed trees were able to identified. After that, data were picked out from GIS as required and analyzed using statistics tools.

2.2.2 Regional level analysis

Distance from the city in that new JOW was observed after 1980 to the nearest city in that JOW was observed before 1980 was calculated. Then, a relationship between the distances and years when the JOW observed for each city was estimated by minimum square method. Spread rate was estimated as the slope, b, of the model distance = b*year, where distance is the distance to the nearest focal point and year is the number of years that transpired between discovery at the sample point and the focal point. This model was fitted using an ordinary linear regression procedure; no intercept was included in the model [6].

2.2.3 Stand level analysis

In stand level analysis, following three analysis methods were carried out. Method A is analysis of areas and polygon number of killed tree crowns, method B is calculation of spread rate of JOW, method C is analysis of distances from the nearest trees in bygone years. In method A, areas of killed trees were picked out form GIS with 2m x 2m resolution. Gropes of the killed trees were regarded as polygons, and areas and number of polygons were calculated and these changes as the years go on were analyzed. In method B, the distance from trees killed in each year to the nearest trees killed in 1997 like in regional level analysis. A tendency of relationship between the distances and years were estimated using minimum square method and spread rate of killed trees in stand level was computed. In that time, because the killed trees spread into outside of aerial photograph after 1998, spread rate calculated using the data for four years and using the data in 1997 and 1998 were compared. In calculation using 1997 and 1998 data, intercept of x-axis was fixed to 1997. In method C, distances between tree killed in each year and the nearest tree kill in past year were calculated and trends of spread rate in each year were analyzed using histogram of the distances.

3. Results

3.1 Regional level analysis

Results provide in table 1 represent spread in regional level analysis. In the beginning of JOW on all regions, the distribution was limited in close area. After that JOW was observed in the distance and the distribution of JOW became observed in wide area with passing time. The calculated spread rate were 3,818 m/yr in Kyoto-Hyogo-Tottori prefectures, 2,629 in Ishikawa-Fukui-Shiga prefectures, 2,787 in south part of Niigata prefecture and 1,805 in Yamagata prefectures and north part of Niigata.

Table1. Spread rate on regional level analysis.

Regions	Spread rate [m/year]
Kyoto-Hyogo-Tottori	3818
Ishikawa-Fukui-Shiga	2629
South part of Niigata	2787
North part of Niigata	1805

Table2. Number and mean size of polygon.

Year	Number of polygons	Mean size of polygon [m^2]
1997	48	41.3
1998	193	49.8
1999	351	73.3
2000	513	97.5

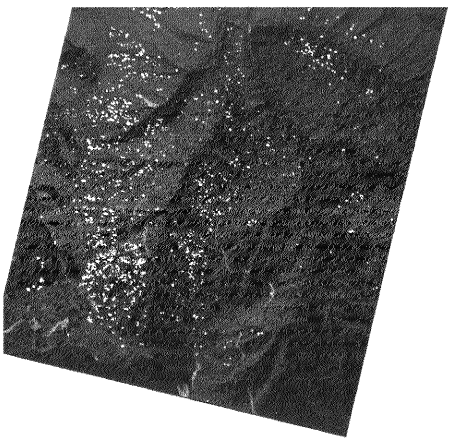

Fig.1 Location of classified as crowns killed by JOW. (White area shows killed tree crown)

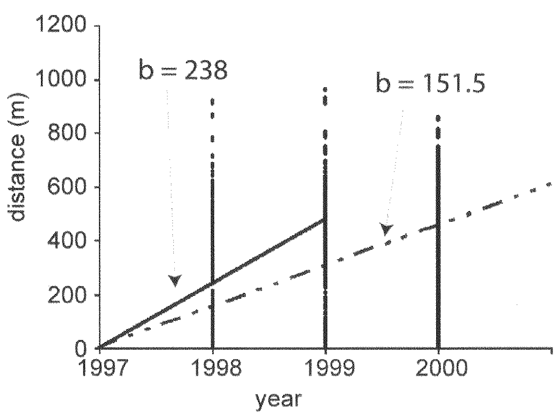

Fig.2 Scatterplot of year of first vs distance from nearest tree infested in 1997.

3.2 Stand level analysis

Figure 1 shows the location of all areas classified as crowns killed by JOW in 1997-2000. The initial distribution in 1997 appears mainly as a north-south band along a ridge area. In 1998 this area expanded in the same general area but expanded west to another ridge area. In 1999 and 2000 populations expanded further in these same areas.

3.2.1 Sizes and number of polygons

Table 2 shows time series changes of size and number of the polygons of killed tree crowns. Area and number were increase with passing time. These results show that the number of killed tree increased as the area increased. The number of the killed trees increased by linier. On the other hand, the size increased at an increasing tempo.

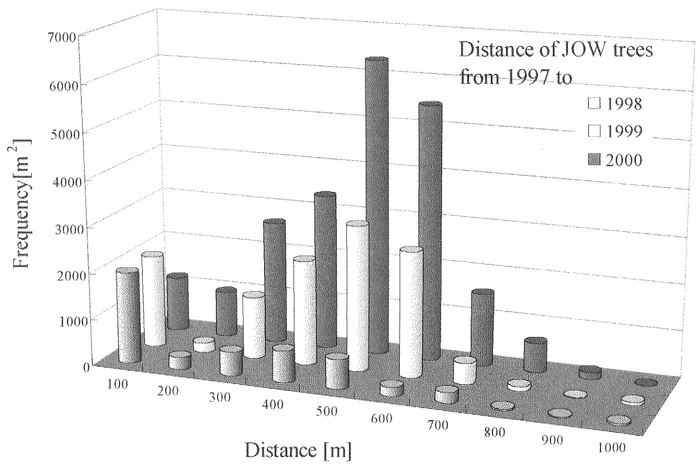

Fig. 3 the histograms of distances from killed tree to the nearest tree killed before year.

3.2.2 Spread rate

Figure 2 is a scatterplot of year of first detection vs distance from nearest tree infested in 1997. The lines represents the linear model distance = b*year, where distance is the distance to the nearest area infested in 1997 and year is the number of years after 1997. A spread rate calculated using the data from 1997 to 2000 was 151.5 m/yr. On the other hand, a rate calculated using data in 1997 and 1998 was 238 m/yr.

3.2.3 Analysis of distances between the nearest trees of different years

Figure 3 shows the histograms of distances from killed tree to the nearest tree killed before year. In every results of analysis for two years running, There were peaks around 50 - 100 m. The results mean that the locations of killed trees are near trees killed in just before year. There were two peaks in the histograms of distances of 1997-1998 and 1997-1999 trees. Second peak was around 300-700 m, and the frequency of killed tree around 300-700 m increased with passing year. But in the results using data after 1998, there isn't second peak.

4. Discussions

In regional level analysis, the spread rates are different depending on the areas and the rates became small as north. Some reports said that an activity of adult insects of *P. quercivorus* had relationship with air temperature and sunlight [7]. For example, when the air temperature is over 20 degrees the adult beetles fly and when temperature is lower than 19 degrees a number of flying beetles is small. A climate influences activities of the beetle flying.

In the analysis of the polygons of killed tree crowns, mean size of polygon area in 1997 was 41.3 m^2. This area probably corresponds to the area of a single crown. In subsequent years, the mean area of each contiguous damage area steadily increased. Two causes of this trend are suggested. One is that there is big killed tree and another one is that there area a group of killed trees. Ambrosia beetles usually attack large trees at first stage of JOW [8] and it is reject that the cause is big killed tree. The group of killed trees causes the increase of polygon size. These results suggest that damage in the 1997 scene was largely limited to individual trees but that over the subsequent 3 years there was an increasing number of groups of dead trees. By 2000 there were apparently relatively few isolated individual damaged trees; instead, most damage occurred in groups of adjacent trees. The number of polygons increased linearly year by year. This result suggests the JOW spread not only into adjacent trees but also to isolated areas. Accelerated increase of total JOW area is the results of the multiplier effect, the increase of each polygon size and the increase of polygon number.

The spread rate, that is different by the method of the calculation, in Mt. Kariyasu area are estimated 2629m/yr in regional level analysis and 151.5-238 m/year in stand level analysis. The rate is different 10 times by the analysis level. The different is significant (ANCOVA, value $p < 0.0001$.). Two causes of this different were suggested. One is a difference of the method of data collection, and the other is a difference of movement mode of the beetles. In regional level analysis, the first observation year data for each city was used. Even if JOW was continued, conditions after first observation year weren't reflected in the analysis. On the other hand, in stand level analysis if the trees adjacent to trees killed in the previous year were killed, a group of killed trees was collected as JOW polygon. In the latter analysis the spread rate is estimated smaller than that in the former analysis. But it is difficult that the 10 times different in the rate is occurred by difference of data collection. It seems that the main cause is difference of the beetle movement. In center of forest *P. quercivorus* fly low to find breeding trees. In an edge or open space of forest the beetles fly high to spread to wide area [8]. Thus, it is guessed that *P. quercivorus* has at least two movement modes. In stand level analysis, there were two peaks in the histogram of the distances from killed tree to the nearest tree killed in 1997. This result supports that this species has two movement modes, one is a shot distance movement to adjacent trees and another is a middle distance movement within the stand. It seems that the former movement made the first peak on less than 100 m and the latter movement made the second peak from 300 m to 500 m. In the histograms from 1998, two peaks weren't recognized. The reason is that the analyzed area using aerial photograph is too small to find the JOW area making second peak. It is assumed that in practice trees wilt outside of the photographs around the distances of second peak. The reason why the spread rate in the regional level analysis is larger 10 or more times than that in the stand level analysis is that the beetles moved long distance exceeding it ability with riding on the air currents.

In this way, it is recognized that there were at least three different mechanisms in *P. quercivorus* movements, one is short distance movement to adjacent trees, one is middle distance movement by itself flying and last one is the long distance movement by riding on the air currents. And it was suggested that the JOW was spreading with complex working of three different scale movements of the beetles. In some study [5], it is recognized that there was complex working of short distance movement and long distance movement in spreads of invaders. This study is the first example that the JOW spread with three layer movements, which are different in spatial scale.

References

[1] S. Ito, T. Yamada, "Distribution and spread of the mass mortality of oak trees," J. Jpn. For. Soc., 80(3): pp. 229-232, 1998.

[2] T. Kubono, S. Ito S, "*Raffaelea quercivora sp.* nov. associated with mass mortality of Japanese oak, and the ambrosia beetle (*Platypus quercivorus*)," Mycoscience, 43, pp. 255-260, 2002.

[3] N. Kamata, K. Esaki, K. Kato, Y. Igeta, K. Wada, "Potential impact of global warming on deciduous oak dieback caused by ambrosia fungus *Raffaelea sp.* carried by ambrosia beetle *Platypus quercivorus*", Bull. Entomol. Res., 92, pp. 119-126, 2002.

[4] C. S. Elton, The Ecology of Invasions by Animals and Plants, London: Methuen.

1958.
[5] N. Shigesada, K. Kawasaki, Biological invasions: theory and practice. New York: Oxford University Press, 1997.
[6] A. M. Liebhold, J. Halverson, G. Elmes, Quantitative Analysis of the Invasion of Gypsy Moth in North America. J. Biogeography, 19, pp. 513-520, 1992.
[7] A. Ueda, M. Kobayashi, "Relationship between flight of *Platypus quercivorus* (Coleoptera: Platypodidae), temperature and sunshine," Ap. For. Sci., 9-2. pp. 93-97, 2000.
[8] Forestry Agency, Report of measures to prevent harmful insects of natural broad-leaved forests. Forestry Agency, pp. 48, 1998.