

Satoyama landscape change in the periphery of a Japanese regional city from 1884 to 2002: a case study in Wakayama Prefecture

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Abstract

Satoyama, a traditional rural landscape of Japan, is considered to be a sustainable agricultural ecosystem managed by local farmers. However, the spread of urbanization and the increase in fossil fuel consumption have led the decline or the abandonment of the use of *Satoyama*, even though it has been highlighted recently for its ecological functions. General and site-specific information such as natural land conditions, long-term land-use changes, and their relationships are important in understanding *Satoyama*. The aim of this study was to examine relationships between topographic conditions and land-use changes in the periphery of Wakayama City, Japan. We produced three digital vector land-use maps for 1884, 1947, and 2002 by onscreen visual interpretation of scanned raster images of original paper topographic maps at a 1:25,000 scale. We used digital elevation data at a resolution of 5 m for landform modeling. We then conducted an overlay analysis among these four layers and quantified land-use changes as well as the relationship between land use and landform. In addition, we collected statistical data and historical documents on socioeconomic conditions in the study area, and conducted field interviews of local residents to verify driving forces of land-use change derived through above spatial analysis. Our results showed that orchards notably increased whereas rice fields had slightly decreased during the study period. Some conifer forests shifted to broadleaf forests between 1884 and 1947 and then back to the conifer forests between 1947 and 2002. The overlay analysis demonstrated that landforms performed as the basic environmental condition restricting possible land use throughout the period. However, our field survey results suggested that installation of new agricultural infrastructure, in this case a monorail for harvesting fruit products from orchards on steep slopes, also may have influenced landscape changes.

Key words: Land use, Landform, Agricultural facilities, Topographic maps, Geographic information system (GIS)

1. Introduction

Satoyama, a traditional rural landscape in Japan, is a system that coexists with the surrounding environment and includes residential and agricultural spaces. Farmers traditionally considered organic wastes as useful fertilizers and wood was utilized as fuel. Therefore, the system recirculated resources and did not create severe environmental pollution or greenhouse gas emissions¹⁾. After World War II, increased urbanization and fossil fuel use caused a decline and even the abandonment of *Satoyama* in many areas. Changes in the industrial structure of the Japanese economy yielded lower economic value to agricultural activities in *Satoyama* areas, so only a few farmers, especially few younger ones, had any interest in continuing *Satoyama* management²⁾.

Recently, there has been an increase the number of private-sector stakeholders managing *Satoyama*, including non-profit organizations (NPOs), enterprises, individuals, and administrations. Although these stakeholders are not landowners, they have interests in *Satoyama* itself and in related management activities, including face-to-face communication among members^{3, 4)}. They are also interested in the recreational and environmental education opportunities associated with *Satoyama*⁵⁾. The emerging management activities of these groups may help sustain *Satoyama*, which, in turn, will provide various ecological services⁶⁾.

Satoyama types differ regionally in Japan in terms of basic geological and ecological conditions^{7, 8)}. To elaborate efficient management schemes for local *Satoyama*, it is essential to understand general and site-specific information, such as land conditions, long-term land-use change and its driving forces, and their relationships^{9, 10)}. However, these conditions are not fully understood in many regions owing to limitations on the availability of geographic data. The purpose of this study was to examine relationships among topographic conditions, land-use changes, and technological development in agricultural equipment as a possible driving force for landscape change in the periphery of Wakayama City, Japan.

2. Study area

The study area is shown in Figure 1. It is located in the suburbs of Wakayama City and Kainan City. Wakayama City is a regional center in the middle of Japan with a population of 370,000. Geographic features include hills with steep slopes and numerous valley plains. The elevation ranges from 150 to 300 m above sea level. The Kishi River flows from south to north along the eastern edge of the study area, and the riverbed is at the lowest elevation in the area. The area, therefore, has traditionally been difficult to irrigate; hence, local farmers created numerous ponds at the end points of each valley for irrigating fields along the valley plains. Nevertheless, it was still difficult to use land on hill slopes as productive farmlands, and many of these areas historically remained as woodlands.

3. Materials and Methods

The digital data production flow is shown in Figure 2. The process consisted of collecting and digitizing topographic maps and producing land-use maps for the years 1884, 1947, and 2002.

3-1. Collecting topographic maps

As a data source for our analysis, we collected topographic maps published by the Geospatial Information Authority of Japan for the study area from 1884 (scale: 1:20,000), 1947 (scale: 1:25,000), and 2002 (scale: 1:25,000). In order to conduct spatial analysis using a Geographic Information System (GIS), these topographic maps were scanned at a 400 dpi resolution and georeferenced as digital raster images.

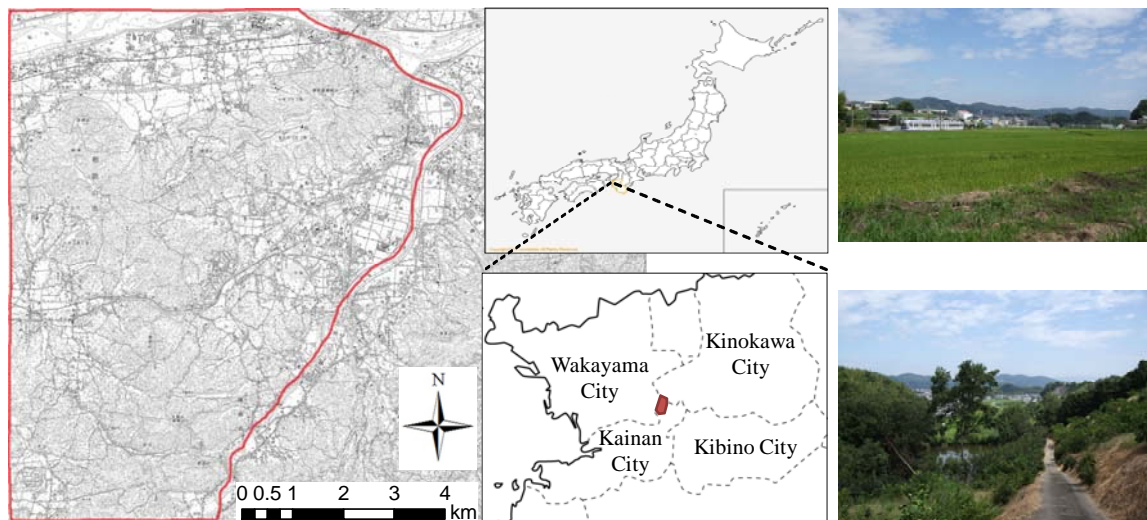


Fig. 1: Location and typical landscapes of the study area. The study area is outlined in the topographic map and shaded in the city map

3-2. Producing land-use maps in digital vector format

We downloaded a vector vegetation map for 1977 from the website of the Biodiversity Center of Japan and used it as source data for producing vector land-use maps. By overlaying the vegetation map with the raster image of the topographic map for 1947, we first modified it into a vector land-use map for 1947 through onscreen visual interpretation. We then rewrote the 1947 vector land-use map into the map for 1884 and 2002 by visual interpretation using the raster images of the topographic maps for these periods.

3-3. Using a digital elevation model (DEM) and overlay analysis

We used digital elevation data provided by the Geospatial Information Authority of Japan (5-m resolution) for landform modeling. Using these data, we calculated slopes to better understand the associations between geomorphic conditions and land uses. Slopes were classified at 5° intervals and were superimposed with the vector land-use maps for the three years.

3-4. Identifying the driving forces of land-use changes

To identify driving forces of land-use change in our study area, we conducted a field survey and interviews with local farmers. Beginning in 2009, we regularly attended local NPO¹¹⁾ activities for *Satoyama* management and gathered local oral accounts of landscape changes in this area. We also collected archives of documents on local history as well as

statistical data related to land-use changes. Because we found that the developmental process of agricultural technologies had a strong influence on land-use changes through the field survey, we intensively collected qualitative and quantitative data on this topic.

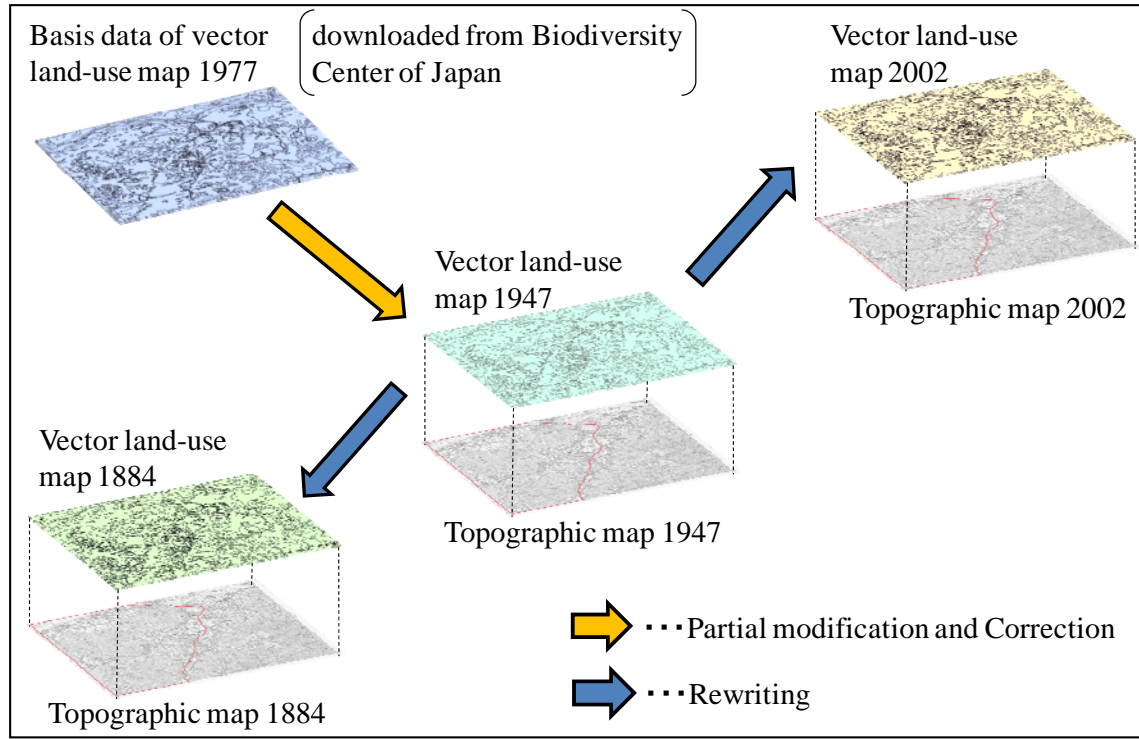


Fig.2: Digital data production flow

4. Results

4-1. Land-use changes

Land-use maps of the three years are shown in Figure 3. They are superimposed with the relief map created from the 5-m DEM. The land-use changes derived from the overlay analysis are shown in Figure 4. As can be seen from the figures, the built-up area continuously increased throughout the period. In terms of agricultural land uses, orchards increased remarkably, whereas rice fields slightly decreased from 1884 to 2002. Some conifer forests were replaced by broadleaf forests between 1884 and 1947. Some of these broadleaf forests reverted back to conifer forests between 1947 and 2002 even though the entire area of conifer forests still decreased during the same period.

4-2. Changes in the relationship between the topographic condition and land use

Table 1 shows the degree of specialization calculated by the overlay analysis among land-use categories and landform layers. A specialization degree of greater than 1 indicates considerable association between slope and land use. Rice fields were specialized in the 0–5° range in each year. Orchards were specialized at 5–10°, 10–15°, and 15–20° in each year and above 30° in 1947 and 2002. Conifer and broadleaf forests were specialized above 15° for each year, and had even higher values at slopes of greater than 30°.

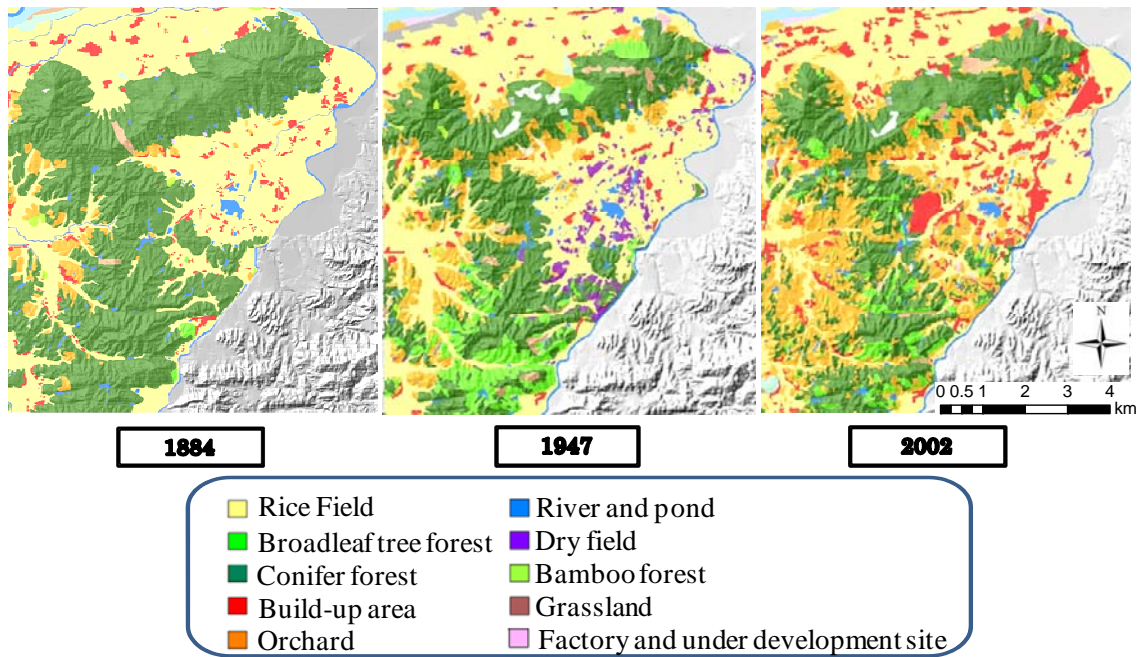


Fig. 3: Land use in 1884, 1947, and 2002

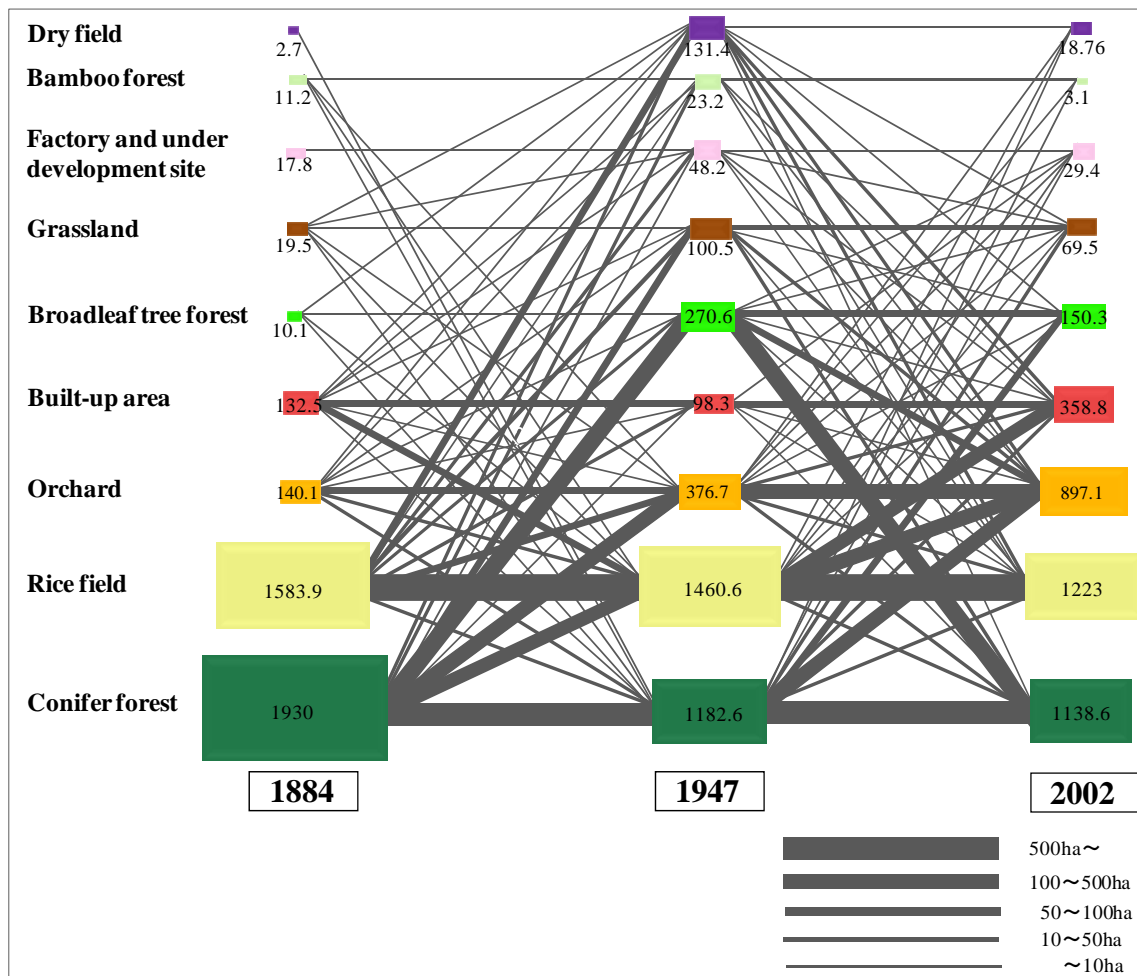


Fig. 4: Pattern of land-use changes between the three years (ha)

Table 1: The degree of specialization between slope and land use. Shaded numbers show a notably high degree of specialization.

Rice field	0~5°	5~10°	10~15°	15~20°	20~25°	25~30°	30° ~
1884	1.327	0.589	0.256	0.128	0.077	0.050	0.111
1947	1.251	0.587	0.272	0.149	0.086	0.061	0.111
2002	1.418	0.475	0.179	0.086	0.044	0.023	0.049
Orchard	0~5°	5~10°	10~15°	15~20°	20~25°	25~30°	30° ~
1884	0.413	1.358	1.318	1.012	0.710	0.505	0.631
1947	0.245	1.096	1.254	1.166	0.956	0.757	1.235
2002	0.380	1.057	1.120	1.013	0.890	0.763	1.550
Conifer forest	0~5°	5~10°	10~15°	15~20°	20~25°	25~30°	30° ~
1884	0.122	0.712	1.016	1.150	1.220	1.257	3.406
1947	0.099	0.601	0.931	1.102	1.216	1.296	3.562
2002	0.084	0.564	0.955	1.176	1.323	1.435	3.968
Broadleaf tree forest	0~5°	5~10°	10~15°	15~20°	20~25°	25~30°	30° ~
1884	0.248	0.647	0.612	1.200	1.091	1.231	2.245
1947	0.067	0.428	0.696	1.029	1.260	1.423	4.788
2002	0.065	0.402	0.727	1.033	1.238	1.454	5.683

Figure 5 shows the relationship between slope and the area of rice fields and orchards, respectively. Rice fields were concentrated on areas with the least slope in each year, and the ratio decreased exponentially as the slope increased. In contrast, orchards showed a different relationship between slope and area. In 1884, orchards were mainly located on slopes of less than 10°, and the area gradually decreased as slope increased. In 1947, the peak orchard area was in the 5–10° range, and the total area had increased. In 2002, the total orchard area almost doubled in every slope range as compared to 1947.

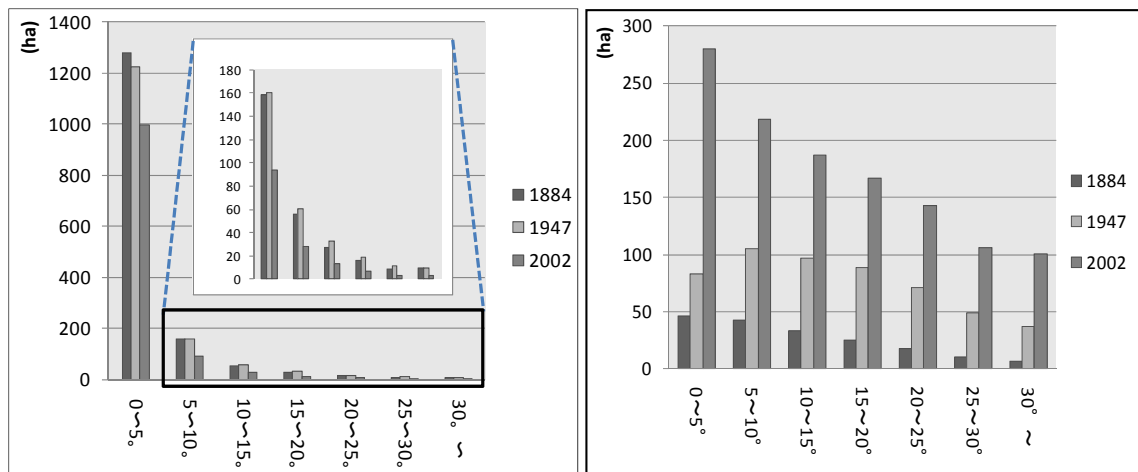


Fig. 5: Relationship between slope and area for rice fields (left) and orchards (right) in 1884, 1947, and 2002

4-3. Relationship between topographic condition and slope direction

In addition to inclination, we analyzed slope direction for orchards using DEM. The slope district was classified into eight categories: north, northeast, east, southeast, south, southwest, west, and northwest. We then defined the “north slope” to include the northwest, north, and northeast categories and the “south slope” to include the southwest, south, and southeast categories. The relationship between topographic condition and slope direction for the north and south slopes is shown Figures 6 and 7, respectively. The results indicate that, as the slope increased, land use decreased in the north slope, but there was little difference in land use above a slope range of 5–10° in the south slope.

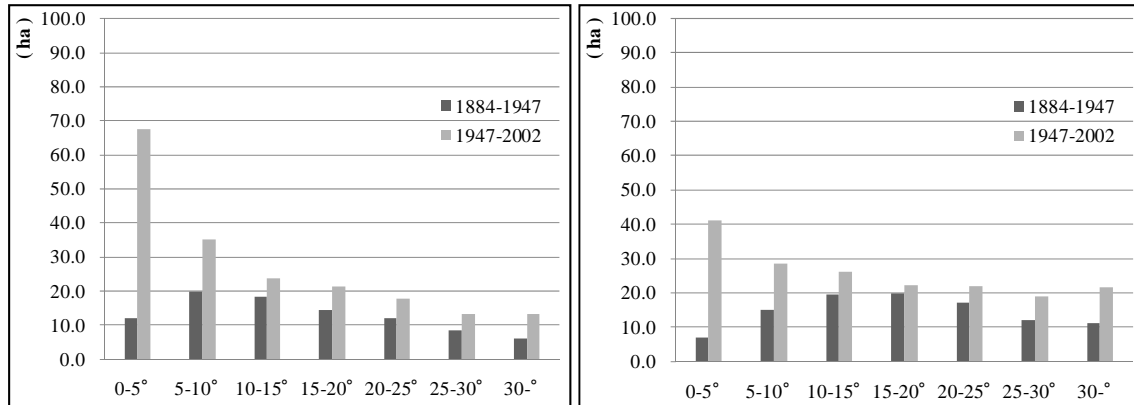


Fig.6,7 Relationships between slope and orchard area for the north and south slopes

4-4. Relationship between solar radiation and slope direction

We also calculated theoretical half-year (from January to June) cumulative solar radiation using DEM through an ArcGIS special analyst function. The relationship between solar radiation and slope direction is shown in Figure 8. The differences were relatively small—the average value was 3.63kwh/m² for the north slope and 4.08kwh/m² for the south slope, although the peaks differed.

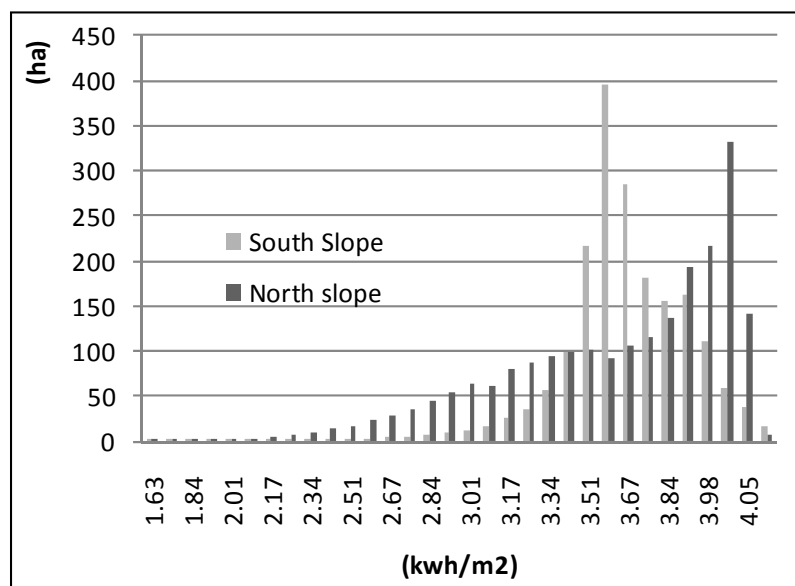


Fig. 8: Relationship between solar radiation and slope direction

4-5. Increases in orchard area and productivity

To gain a more detailed understanding of the notable increase in orchards from 1947 to 2002, we used statistical data from Kainan City, where our study area is located. Figure 9 shows trends in production for oranges and *Citrus hassaku* as well as the area planted, unit productivity from 1955 to 2000, and area with access to an agricultural monorail provided through governmental projects for all types of fruits in Kainan City. Both the production and the area planted dramatically increased after 1965, most likely as a result of agrarian reforms, in particular, the installation of agricultural monorails¹²⁾. The unit area productivity also increased throughout the period. These trends show the important role of the installation of new agricultural equipment in expanding particular types of agricultural land use. The results of field interviews and a search of historical documents¹²⁾ also support the strong influence of the monorail on the development of orchards in steeply sloped areas.

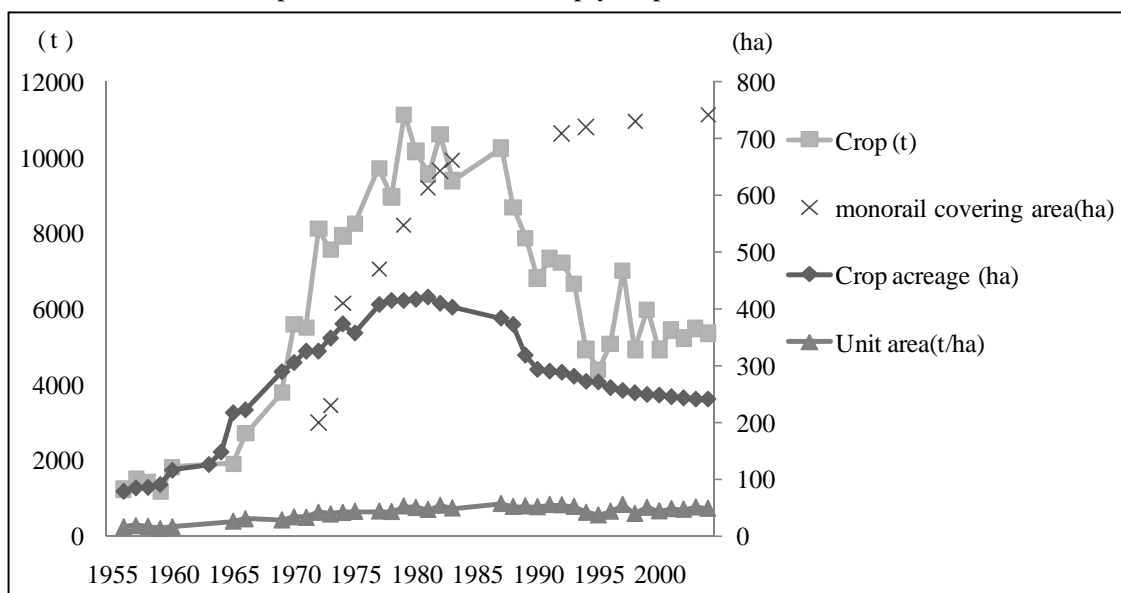


Fig. 9: Orchard production, planted area and unit area productivity (oranges and *Citrus hassaku*), and area with access to an agricultural monorail (provided through governmental projects only) in Kainan City

Through the GIS analysis, we found that the expansion of the orchards over the slope is one of the unique characteristics in land-use change in this area. Through field interviews and historical document¹²⁾, and statistic data (Fig.9), it was supposed that the installation of a monorail for agricultural uses (Fig.10) had significant influence on the development of steep orchards.



Fig. 10: The monorail system for orchards in steep areas

5. Discussion and concluding remarks

As compared with other areas near metropolitan fringes^{13, 14, 15)}, our study area was not greatly affected by urbanization. It is notable that in the study area an innovation in agricultural technology (use of a monorail) enabled steeply sloped areas that were originally disadvantageous for agricultural use to be transformed into sunny productive orchards. Although some of the areas in the study area are steeply sloped, the elevation is not high. Therefore areas in the north slope appear to get sufficient sun to allow for productive orchards, unlike similarly sloped but higher areas in other parts of Japan¹⁶⁾. Fruit products have become profitable as a result of increased demand since the 1970s. This has also been a factor in accelerating the use of land for orchards¹²⁾. Conifer and broadleaf forests on steep slopes, which function as one of the main *Satoyama* elements, were cut and replaced with orchards. This is different from the case in more metropolitan areas in which these forests are being abandoned.

We also found that conifer forests in the area were converted into broadleaf forests from 1884 to 1947 and then reconverted back to conifer forests from 1947 to 2002 (Fig. 4). A previous study¹⁷⁾ and the area monograph¹⁸⁾ indicated that the conifer forest around 1884 was mainly red pine (*Pinus densiflora*), which was used for fuel. This red pine forest was intensively utilized during the World War II period for fuel, particularly for military purposes¹⁸⁾. In addition to the red pine trees, cedar (*Cryptomeria japonica*) and cypress (*Chamaecyparis obtusa*) trees were planted for profitable timber uses after World War II¹⁸⁾, thereby shifting away from broadleaf forests to conifer forests from 1947 to 2002.

The study area showed an expansion of orchards supported both by agricultural technology and geomorphologic conditions. Further studies should be conducted in other areas to better understand the *Satoyama*. We need further case study in other area.

Acknowledgement

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