

Landscape ecological studies for the conservation and
restoration of the floristic diversity in *Yatsuda* agro-ecosystem

(谷津田地域における植物相保全・再生のための緑地生態学的研究)

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Acknowledgement

First of all, I would like to express my deepest gratitude to my advisor, Dr. Kazuhiko Takeuchi, Professor, Laboratory of Landscape Ecology and Planning, Department of Ecosystems Studies, The University of Tokyo, for his invaluable advice and continuous encouragement during the conduct of my study. I sincerely appreciate the chance he has given me to study in the laboratory again, where I had once graduated.

Likewise, I wish to express my sincere thanks and extend my heartfelt gratitude to the following:

Dr. Satoru Okubo, Research associate, Lab. of Landscape Ecology and Planning, The University of Tokyo, who was always willing to spare his time in giving me kind and precise suggestions for the thesis and journal articles.

Dr. Tomoo Okayasu, Research associate, Lab. of Landscape Ecology and Planning, The University of Tokyo, who kindly spare his time, giving me good advice from his experience in writing his doctor thesis.

Dr. Kazuhiro Kato, Associate Professor at The University of Tokyo, for advise in statistics and multivariate analyses, and who permitted me to attend the seminar of his laboratory, Experimental Station for Landscape Plants, through which I was given a lot of impressive knowledge.

Dr. Izumi Washitani, Dr. Hiroo Ohmori and Dr. Masahiko Ohsawa, Professors at The University of Tokyo, for sparing their precious time in intelligently examining and judging this piece of work.

Ms. Daphne Gondhalekar, a member of Lab. of Landscape Ecology and Planning, The University of Tokyo, for generously sharing her valuable time in going over the draft of my thesis.

I also especially thankful to the following:

Dr. Yoshihiro Higuchi, Prof. at The University of Tokyo, for permitting me to use his field station, from which I could easily access the research field in Motegi Town, Tochigi Prefecture, one of my research fields. Ms. Sumire Sakai at the University of Tokyo, who studied in the field station with whom I discussed.

Ms. Kaori Uchiyama, Ms. Akiko Mito and Mr. Katsuyoshi Saito, Tama Environment Office of the Bureau of Environment, Tokyo Metropolis, who understood well and permitted my researches in the conservation area of Tokyo Metropolis.

Further, I would like to express my appreciation to all local farmers in my areas of research, more particularly:

Mr. Koichi Tagoku, Head of the Machida Historic Environment Management

Organization, who continued to support the restoration experiments with his special techniques of traditional agricultural practices, and other kind members of the Machida Historic Environment Management Organization.

Mr. Mizuo Komori, and Norio Takatoku, both supporting my field research in Tochigi Prefecture.

Mr. Akira Akimoto, who kindly permitted me to investigate in his private agricultural land in Chiba City, also one of my research areas.

I wish to extend my wholehearted appreciation to all the members of the Lab. of Landscape Ecology and Planning and Experimental Station for Landscape Plants, who shared all times not only in enjoyable but also painful times.

More importantly, I would like to take this opportunity to express my deepest and sincerest gratefulness to Ms. Yoshiko Kitagawa, Secretary, Lab. of Landscape Ecology and Planning, The University of Tokyo, for her professional plant classification and all the suggestions not only regarding research but also in helping with the decision to re-enter the Lab. of Landscape Ecology and Planning. Without her advice, I could not have decided to re-enter the Lab. again, so early.

Abstract

One of the typical landscapes in paddy-field agricultural landscape in Japan is the Yatsuda landscape. The Yatsuda landscape locating in narrow valley floors in low-relief mountains, hills and uplands, gives the habitats for wetland and semi-natural grassland species. However, abandonment of agricultural practices resulted in the loss of biodiversity of such species.

Paddy fields, levees and semi-natural meadows (these meadows, locating in the lowermost slope between lowland rice fields and woodlands on slopes, are hereafter called “verge meadows”) were the main landscape elements in the Yatsuda landscape. Landscape elements in Yatsuda landscapes differ in different geomorphic conditions, for instance, uplands and hills. Such environmental conditions are assumed to affect floristic composition of these landscape elements through micro-scale habitat conditions such as light and soil moisture. This indicates that in order to maintain floristic diversity in various types of Yatsuda landscapes, it is essential to clarify the relationship between floristic diversity and habitat conditions with larger-scale environmental conditions taken into consideration.

Hence, the present study carried out classification of Yatsuda landscapes based on such environmental conditions. Next, in each detected classification unit, field surveys to clarify the relationship between floristic diversity and habitat conditions were carried out. We focused on three agricultural management units in the Yatsuda agro-ecosystem, the paddy field, levee and verge meadow, because they are the typical landscape elements enhancing grassland and wetland species. The floristic diversity and floristic composition of the three management units were compared intra- (i.e. inside a landscape element level) and inter-landscape level. The present study aimed at firstly clarifying the difference in floristic composition among classified Yatsuda landscapes, and second, detecting priority habitat(s) in these landscapes. A restoration project re-introducing agricultural practices in an abandoned Yatsuda agro-ecosystem were monitored, aiming at clarifying the degree to which formerly existing flora is restored in the three landscape elements of the restored site.

1. Classification of Yatsuda landscapes in Kanto region

The present chapter tried to clarify the relationship between geomorphic location and environmental conditions that are assumed to affect the floristic diversity in Yatsuda landscapes. Depth of valleys and the gradient of valley floors, both which are assumed to affect the slope length of verge meadows and levees, respectively, were used for the classification. This data was calculated in approximately 5 km × 5 km areas. Yatsuda paddy

fields were identified using two indices: the width of valley floors and the depth of valleys. In the present study, Yatsuda landscapes were identified by the presence of paddy fields, which are located in valley floors with less than an approximately 300 m width and also with 2 m to 60 m depth of valley floors.

As a result, Yatsuda landscapes were located in hills, uplands and mountains, whereas they are rarely observed in lowlands. Shallower valleys (on average 20 m) with almost flat valley bottoms (on average less than 1 %) were typical characteristics in uplands, whereas deeper valleys (on average 50 m) with steeper flat valleys (on average 5 %) were typical in high-relief hills and mountainous areas. Between these, low-relief hills are intermediate characteristics. This assumes that the lengths of both levees and verge meadows were the shortest in uplands, followed by in low-relief hills and then high-relief hills and low-relief mountains. High-relief hills and low-relief mountainous areas are similar in most measured indices. In consequence, landscape structures in the Yatsuda agro-ecosystem are classified into the following three types; upland, low-relief hills and high-relief hills and low-relief mountains.

2. Floristic composition in the Yatsuda agro-ecosystem in three different geomorphic conditions (inter- and intra-landscape scale analyses)

Corresponding to the analysis in the previous chapter, three study sites were selected to cover upland (Site A, located in Shimosa Upland), low-relief hills (Site B, located in Tama Hills), and high-relief hills and low-relief mountains (Site C, located in Yamizo Mountains). A small catchment of about 1 km around where geomorphic condition is typical in the given type of Yatsuda landscape and where rice culture is still carried out was selected to the study site. At each study site, the floristic composition of three landscape elements, i.e. paddy fields, levees and verge meadows were surveyed. To clarify the traits of appeared species, all recorded species were categorized into five potential habitat types; upland fields or roadside species (UR species), species favoured in wet conditions (W species), grassland species (G species), forest margin species (FM species) and forest floor species (FF species). The floristic data was compared according to two aspects, the intra-landscape scale and the inter-landscape scale. At the intra-landscape scale, three landscape elements were compared, while at the inter-landscape scale, each landscape element was compared at the three study sites.

In results, floristic diversity was subsequently higher at verge meadows both per quadrat and per total species number in each landscape element, followed by levees and paddy fields. Verge meadows had the most abundant unique species (the species not recorded in other

habitat types) in the three study sites, whereas in levees, both unique species number and its ratio were low.

Species recorded in paddy fields were mainly W species at the three study sites. In levees, the potential habitat of the occurring species was markedly different at the three sites. At Site A, potential habitat types of occurring species were mostly UR species. However, at Site B, G species were an added major component. Furthermore, at Site C, FM species were an added major component. These supposed to be corresponded to the differences of slope length in different geomorphic conditions. In verge meadows, G species and FM species were frequently observed compared with the other two landscape elements in each study site. UR species were most abundantly observed at Site A, followed by Site B and Site C. Conversely, G species were most abundantly seen at Site C, followed by Site B and Site A. At Site B, W species were more abundantly observed in verge meadows than in paddy fields and levees, whereas at other sites, paddy fields were the major habitat for W species.

3. Plant species composition of verge meadows in relation to habitat conditions (landscape-element scale analyses)

Verge meadows not only have the largest species number in the three landscape elements but also have the largest number of unique species. This indicates the importance of considering the floristic diversity in verge meadows for the conservation and restoration of Yatsuda agro-ecosystem. The present chapter, hence, focuses on verge meadows in detail.

In results, light and soil water contents commonly affects floristic compositions. A brighter condition tended to be linked to the abundant number of G species, indicating that brighter verge meadows were important for conserving G species. The number of UR species was markedly associated with anthropogenic disturbance. Especially adjacency to upland fields substantially enhanced UR species at Site A, while adjacency to footpaths and well-managed grassland more or less enhanced the occurrence of abundant UR species. Site B was observed to have especially wet conditions, which contributed to the occurrence of unique W species at the site. These quadrats were located in logged sandy deposits. The lower position of sandy deposits overlaid by mud deposits are reported to form an aquifer in the study site. Hence, the bedrock condition is assumed to greatly affect the appearance of W species.

4. Restoration of a Yatsuda landscape – a case study –

The restoration site is located in a hilly Yatsuda landscape, a valley adjacent to Site B of previous chapters. Restoration works started in the late spring of 1997. Restoration was

performed in 3 parcels where agricultural activities ceased in relatively recent years (approximately 10 years). Traditional rice culture was performed in paddy field, while levees and verge meadows were mown twice a year. Monitoring in the restoration site were carried out in 2005, in the 8th year after the start of the restoration.

The restart of agricultural practices in the abandoned Yatsuda agricultural landscape successfully led to the occurrence of paddy weed communities within fields. Similarly, the number of species typically observed in levees was not markedly different at the restored Yatsuda landscape compared to the reference site, although G species were not observed. These factors indicate that the reintroduction of agricultural practices in an abandoned Yatsuda landscape enhanced the occurrence of formerly observed floristic species in the two habitats. In terms of verge meadow, however, both characteristic species and the species number of herb species, especially the number of G species, was markedly different from the reference site.

In order to clarify the appropriate management interval within paddy fields, fallow condition up to three-year periods was set up subsequent to the restoration of rice cultivation. In results, 1-year fallow paddy fields were observed to be the most abundant species typically observed in paddy fields. In the subsequent years, they declined steadily. This evidence indicates that to maintain paddy weeds in the emergent flora, it is appropriate to create 1-year fallow condition: that is, to cultivate every other year.

5. General discussion

From the point of view of the conservation of floristic diversity in the Yatsuda agro-ecosystem, landscape classification was carried out based on geomorphic conditions (upland, low-relief hills, and high relief hills as well as low-relief mountains). This classification was well related to the differences in environmental conditions of landscape elements such as levees and verge meadows. Furthermore, this landscape classification also strongly affected floristic compositions and distributions through the environmental conditions of landscape elements. Therefore, the landscape classification in the present study give useful criteria to conserving floristic diversity in the Yatsuda agro-ecosystems.

Verge meadows deserved a higher priority because this landscape element has the most abundance of total species, grassland species and unique species. At a finer scale, the floristic composition of verge meadows was associated with the heterogeneity of the landscape element. Habitat conditions such as light, soil water contents were well corresponded to the species composition. Especially in the hilly Yatsuda agro-ecosystem, a logged water condition, which markedly corresponds to surface geological conditions, contributes to

species favouring wet conditions, indicating the special importance of the habitat.

The abandoned Yatsuda landscape was more or less restored, especially in paddy fields and levees. Although paddy fields were an important landscape element due to the high ratio of unique species, relatively extensive agricultural management like cultivation in every other year was assumed to be effective for maintaining floristic diversity. Since this restoration trial was only one case study, further restoration schemes should be carried out in other landscape classification types. In terms of the restoration of verge meadows, because of the bad performance of species observed in well-managed verge meadows, more effective restoration schemes will be developed.

Paddy fields were dominated by species favouring wet conditions (W species) due to similar anthropogenic disturbances linked to rice culture. In levees, corresponding to the increasing length of the levee slope, from Yatsuda landscapes in uplands via low-relief hills to low-relief mountains, an increasing number of grassland species (G species) and forest margin species (FM species) were observed. In verge meadows, the larger the valley depth, G species were observed to increase. In the Yatsuda landscape of low-relief hills, series of permeable and impermeable layers lead to logged habitat conditions, which enhance unique species favouring wet conditions. As a consequence, this classification unit was observed to be the most distinct floristic composition. Moreover, unique species were abundantly observed here compared to paddy fields and levees. Therefore, it is suggested that verge meadows deserve to be the most important habitat for conserving floristic diversity in the Yatsuda agro-ecosystem.

As a result of the restoration experiment, since paddy fields are similarly dominated by W species in any classification unit, it is likely that floristic composition in paddy fields is restored in all classification units by the reintroduction of agricultural practices. In levees and verge meadows, it is difficult to apply the results of the present study, because both habitat conditions and floristic composition were different among classification units. Especially in verge meadows, it is essential to perform restoration trials in other landscape classification types, but also to continue to monitor the restoration project in the present study.

Japanese abstract (要約)

我が国の代表的な里地の一つに、台地や丘陵地、低山地の開析谷に分布する水田とその周辺の里山林などから構成される谷津田地域が挙げられる。ここは草原生や湿地生の植物種の宝庫であったが、営農条件の悪い谷津田における水田の耕作放棄に伴って、こうした植物相の減少が問題となっている。

谷津田を構成する水田や畦畔、水田に接する斜面林の下端に位置する刈り取り草地（以下、裾刈り草地と呼ぶ）は、上記の植物相の主要な生育立地である。これら立地の規模や土壌水分・光条件などは、谷津田の位置する地形域、たとえば丘陵地と台地で大きく異なることが知られ、成立する植物相は、そうした環境条件の違いに応じて異なることが予想される。そのため、失われつつある谷津田地域の多様な植物相を維持するには、谷津田景観の構造をふまえ、草原生・湿地生種を中心とした保全・再生すべき植物相と生育条件を十分に理解しておかなければならない。

そこで本研究では、全国でも谷津田景観が広く分布する関東地方を対象に、畦畔や裾刈り草地の環境条件を考慮した谷津田景観の類型化を行い、抽出された景観類型ごとに選んだ対象地で、水田、畦畔、裾刈り草地に成立する植物相とその立地を精査した。各立地に成立する植物相を景観類型間および景観類型内で比較することで、谷津田景観の構造に応じた植物相と生育条件の関係について把握した。さらに、農業管理が放棄された谷津田景観の一つで、管理再開に伴って復元された植物相のモニタリング調査を行い、草原生・湿地生種を中心に、谷津田景観の典型的な植物相の再生可能性を検討した。

1. 関東地方における谷津田景観の類型化

谷津田の湿地生・草原生種の生育立地に影響する環境条件を規定する要因として、畦畔法面の長さを規定する谷底縦断面の傾斜と、谷津田周辺の環境傾度の大きさを決定する、台地の段丘面および丘陵地・山地の尾根と谷底との比高に注目し、谷津田景観の類型化を行った。およそ 5km 四方のグリッドを解析単位とし、標高データと植生図を用いて地理情報システムによる解析を行った。幅がおよそ 300m 以下で、縦断面比高が 2~60m の谷底面に水田が位置した場合を谷津田と定義し、それが解析単位に 5%以上確認できたものを谷津田景観として抽出した。

その結果、関東地方の谷津田景観は、比高および谷底面の縦断面傾斜が、小さいものから大きくなる順に、台地に分布するもの、小起伏丘陵地に分布するもの、大起伏丘陵地・小起伏山地に分布するものに分けられ、畦畔法面や裾刈り草地の規模はこの順に大きくなると予測された。大起伏丘陵地と低起伏山地は、比高および谷底面の縦断面傾斜の点で一つにまとめられると考え、谷津田景観を、台地、小起伏丘陵地、および大起伏丘陵地と小起伏山地を 1 つにまとめた 3 つに類型化して捉えることとした。

台地の谷津田（以下、台地型谷津田と呼ぶ）は、第四紀の隆起帯に位置する、開析が進んだ台地にみられ、小起伏丘陵地の谷津田（同、丘陵地型谷津田）は、第四紀前・中期更新世の堆積物

に覆われる地域にみられた。大起伏丘陵地、低起伏山地（同、低山地型谷津田）は第三紀の堆積物や基盤岩に覆われる地域にみられた。

2. 3つの谷津田景観に成立する植物相の把握

上記の3つの景観類型から、台地型谷津田の典型として下総台地の谷津田、丘陵地型谷津田として多摩丘陵の谷津田、低山地型谷津田として八溝山地の谷津田を選び、谷津田で営農が行われている小流域を各1カ所ずつ調査対象地とした。水田、畦畔、裾刈り草地において植生調査を行い、種組成の特徴を景観類型間と立地間で比較した。その際、植物社会学の分類体系におけるクラスレベルの標徴種群の出現状況に注目しながら、全出現種を最適生育立地タイプに分類し、タイプ間の比較も行った。

その結果、すべての景観類型で、水田、畦畔、裾刈り草地の順に出現種数は多くなった。景観類型ごとに各立地に出現した種を比較したところ、水田と裾刈り草地の場合、いずれの景観類型でも、他の立地にはみられない特異な種（以下、立地特異種と呼ぶ）が多かった。畦畔の立地特異種は、裾刈り草地と共通する種が多いことから、いずれの景観類型でも種数が限られた。

立地ごとに景観類型間で種組成の類似性を比較したところ、いずれの立地でも同様にばらついたが、最適生育立地タイプの出現割合は地域間で異なった。水田の場合、すべての景観類型で、出現種のほとんどがイネクラス標徴種をはじめとする湿地生種で構成された。畦畔では、台地型谷津田にはシロザクラスをはじめとする畑地生種が卓越した。丘陵地型谷津田には、台地型谷津田の種に加えてススキクラス標徴種をはじめとする草原生種がみられるようになり、さらに、低山地型谷津田には、上記の畑地、草原生種に加え、ノイバラクラス標徴種などの林縁生種が出現した。これは、畦畔法面のほとんど存在しない台地型谷津田から、長い畦畔法面を持つ低山地型谷津田への、谷津田をとりまく環境条件の違いに対応する変化であると考えられた。裾刈り草地は、いずれの景観類型でも草原生および林縁生種が卓越する立地であり、台地型谷津田、丘陵地型谷津田、低山地型谷津田の順に草原生種が増加した。また、台地型谷津田では畑地生種が多く確認され、さらに、丘陵地型谷津田では、水田とは異なる湿地生種が多く出現した。

3. 裾刈り草地における植物多様性とそれを規定する立地条件

裾刈り草地は、いずれの景観類型においても最も種多様性が高く、立地特異種も多いことが確認され、谷津田地域における植物相保全にとって重要な立地であることが示された。そこで、裾刈り草地における種多様性を規定する要因について、光や土壌水分条件、斜面上部に出現する植生と関連させながら、さらに詳細な調査を行った。

その結果、景観類型いずれも、裾刈り草地に設置した植生調査区ごとの種組成は、光、土壌水分条件、斜面上部の植物種組成に対応した。すなわち、主として南向き斜面で相対光量子密度が概ね40%以上の地点には、草原生種が卓越する群落が成立し、主に北向き斜面では、林縁生・樹林生種が草原生種を上回る群落が成立した。

一方、景観類型ごとの特徴もみられた。すなわち、台地型谷津田で畑地に接する裾刈り草地では、日射量の大小に関わらず、畑地生種が多く生育した。また、丘陵地型谷津田では、帯水層となる砂層最下部が丘陵地斜面下部に直接露出する過湿な裾刈り草地には、湿地生種が卓越した。

4. 放棄された谷津田における農業活動再開による植物相再生実験

丘陵地型谷津田を事例として、農業活動再開による谷津田の植物相再生可能性を評価した。前述の丘陵地型谷津田の調査地に隣接する約 10 年間放棄された地区において、水田や畦畔の復元を行った。その後、伝統的な手法による水田耕作と畦畔管理、裾刈り草地では年 2〜3 回の刈り取り管理実験を行った。前述の調査と同様に、3 つの立地それぞれで、再生実験開始後 8 年目にモニタリング調査を行った。得られたデータを前述の同景観類型のものを対照地として比較し、植物相再生可能性を評価した。

モニタリング調査の結果、水田では、耕作の再開によって、出現種数、水田雑草の種組成とともに、対照地の水田と同様の植物相が再生された。畦畔も、畦畔を特徴づけるオオジシバリ・ミゾカクシ群落の構成種が確認されたことから、再生可能性が高いことがわかった。一方裾刈り草地では、優占種や光・土壌水分条件の類似した対照地と種組成の特徴を比較した結果、その類似性は低く、同様の立地条件にある裾刈り草地に出現する種の過半を占める半地中植物の割合が、再生地では明らかに低く、とくに、林縁生種に比べ、草原生種の欠落傾向が認められた。

また、水田雑草を保全する際の、適切な水田耕作の頻度を明らかにするために、耕作を再開した後、再び 3 年間耕作を停止した区画を設け、継続的に調査を行った。その結果、耕作を停止した実験区では、休耕 1 年目には周辺の耕作水田以上の水田雑草がみられたが、2 年目以降は急激に減少した。したがって、水田耕作は 2 年間に一度以上行う必要があることが明らかになった。

5. 総合考察：谷津田地域における保全すべき立地とその再生可能性

本研究では、谷津田景観を地形特性に応じて、台地型谷津田、丘陵地型谷津田、低山地型谷津田に類型化した。これらの景観類型は、畦畔や裾刈り草地が成立する立地特性の違いを反映し、植物相も大きな差異を呈することが明らかとなった。したがって、この景観類型は、谷津田地域における植物相保全の検討に際して、有用な分類基準であると考えられる。水田の植物相は、人による管理の影響を強く受けた結果、谷津田景観の構造に関係なく同様な種組成の特徴を示した。一方、畦畔の植物相は、台地型から低山地型谷津田に向かって谷底面の縦断面勾配が大きくなり、草原生種数や林縁生種数が顕著に増加した。裾刈り草地の植物相は、台地型谷津田から低山地型谷津田に向かって、谷底面から段丘面・尾根までの比高が大きくなり、草原生植物種数が増加する。また、表層地質の影響を受け、とくに、帯水層と難透水層の互層によって形成される丘陵地型谷津田では過湿な立地に特異な湿地生種が生育しており、景観類型ごとの植物相の特性が、最も顕著に表れた。さらに、水田や畦畔と比較すると立地特異種も多かったことから、裾刈り草地は、谷津田地域全体の植物相を保全する際に、高い優先度が与えられるべき立地と判断さ

れた。

谷津田の植物相再生に関する本研究の成果から、すべての景観類型で水田に出現した種組成の特徴は類似したため、水田の植物相は丘陵地型谷津田以外の景観類型でも同様に再生できると考えられる。畦畔と裾刈り草地については、景観類型ごとに立地特性と植物相が大きく異なることから、丘陵地型谷津田における事例を他の景観類型へ適用することは難しいと判断される。とくに、裾刈り草地に関しては、再生実験による植物相の再生が不十分であったことから、他の景観類型においても実験を行うと同時に、現在の実験と植物相再生モニタリング調査を長期継続する必要がある。

1. Introduction

1.1. Background of the present study

Agricultural practices are wide spread around the world, covering almost 40% of the world's land area in some form. This factor alone means that the involvement of ecology in agriculture is crucial (Ormerod *et al.*, 2003). Agriculture has for centuries had a major influence on biodiversity (Alard & Poudevigne, 1999). Although many native plant species have been affected negatively by agricultural land use, primarily through loss and modifications of forested and wetland habitats (Jobin *et al.*, 1997), some native plant species have benefited from agricultural activities concomitant with forest removal, especially those growing in more open types of landscapes or those taking advantage of anthropogenic circumstances such as trampling by livestock in pastures (Sutherland, 2002; Svenning, 2002). In most of Europe, for example, people have made the landscape (Krebs *et al.*, 1999) and as agricultural landscape is the most common landscape, many species have been associated with such landscapes (Duelli & Obrist, 2003).

Japan also has a long history of agriculture, which has resulted in the wide distribution of human-influenced land. Traditional, rural landscapes are social and ecological networks of a village and its surroundings, which include agricultural lands, open forestlands and forests (Fukamachi *et al.*, 2001). The most common production farmlands are rice paddies, which is covering about 55% of the total agricultural land in 2000 (MAFF, 2003).

One such typical landscape is the Yatsuda landscape. The Yatsuda landscape is a paddy-field agricultural landscape, which is located in narrow valley floors (Takeuchi *et al.*, 2002) in low-relief mountains, hills, and uplands. Since only 35% of the total land area of Japan is composed of lowland areas (Yonekura *et al.*, 2001) and two-thirds of either uplands or hills, the Yatsuda landscape is a major agricultural landscape including paddy fields in Japan.

The nature of agro-ecosystems is the mosaic of habitats. Abundance of the number of habitats substantially contributes to abundant floristic diversity (Duelli, 1997). Yatsuda landscape is composed of many small habitats due to the narrow valley floors, which assumes abundant floristic species in the ecosystem. For instance, the Yatsuda landscape was composed of landscape elements associated with agricultural management regimes. Paddy fields, levees and semi-natural meadows were the main landscape elements in the Yatsuda landscape. These landscape elements were the habitats for wetland and semi-natural grassland species, and have been reported to be the habitats of threatened plant species (Environmental Agency of Japan, 2000; Shoji, 2003).

However, abandonment of agricultural practices resulted in the loss of biodiversity of such species. Since paddy fields located in mountainous and hilly areas had higher ratio of abandonment than in wide alluvial lowlands (MAFF, 2001), decline of floristic diversity due to the abandonment is more serious.

Despite of the wide distribution of the Yatsuda agro-ecosystem in Japan, floristic species observed in such agro-ecosystem is not generalized. In European countries, on the other hand, generality of valued habitats like at grasslands have been tried to introduce at a regional, country to Europe-wide scale (Hodgson *et al.*, 2005; Tallowin *et al.*, 2005; Rosenthal, 2003; Carey *et al.*, 2002), which enables separate studies to be integrated and to clarify the importance of local habitat values. Considering wide-spread abandonment of agricultural practices in the Yatsuda agro-ecosystem, it is essential to perform restoration trials in the abandoned Yatsuda agro-ecosystem. This is also important as basic information in order to restore degraded Yatsuda landscapes.

This chapter first defines terms especially in relation to different scales (Chapter 1.2). Then, review work was carried out on two aspects. One, ecological studies in paddy-field agro-ecosystems including Yatsuda agro-ecosystems (Chapter 1.3). By this review, I tried to hypothesize the criteria of the classification of Yatsuda landscapes. The other aspect reviewed involves the ecological restoration of agro-ecosystems (Chapter 1.4). Since there have been only few restoration trials of agro-ecosystems in Japan, trials in European countries, where agri-environmental schemes to protect biodiversity were widely performed and many conservation and restoration projects were carried out (Kleijn *et al.*, 2001; Hansson & Fogelfors, 1998; Ovenden *et al.*, 1998), were also reviewed. Based on these reviews, objectives of the research were set up in Chapter 1.5.

1.2. Definition of terms with regard to ranging scales

In agricultural landscapes, the most basic units affecting floristic diversity are farmland habitats (Duelli, 1997), which include farmlands, woodlots, fencerows and roads (Freemark *et al.*, 2002), or in wet grasslands include wetland features such as drainage channels or ditches, and floodplain pools (Joyce and Wade, 1998).

According to Duelli (1997), the factors most pertinent to predicting and evaluating biodiversity in an agricultural mosaic landscape are (1) *habitat variability*, i.e. the number of biotope types per unit area; (2) *habitat heterogeneity*, i.e. the number of patches and the length of ecotones per unit area; and (3) the surface proportions of natural, semi-natural and intensively cultivated areas. Duelli (1992, 1997) proposed the use of the mosaic concept as an alternative approach to explaining patch species richness in cultural landscapes (Wagner, *et al.*, 2000).

The composition of the plant assemblages depends upon complex interactions between local structure and landscape structure (Le Coeur *et al.*, 2002; Weibull *et al.*, 2000; de Blois *et al.*, 2002). Different vegetation patterns are resolved by examining biotic responses to environmental forcing functions on different scales in space and time (Delcourt & Deocourt, 1992). At a habitat scale (or landscape-element scale), biodiversity is generally assessed and monitored at the patch scale (plots or land use units). At this level, many studies have shown the impact of a cultivation regime (i.e. preparation for crop and pasture seeding, crop management, harvesting method and grazing management; Aude *et al.*, 2003; Bengtsson *et al.*, 2005; Froud-Williams *et al.*, 1983), fertilizer application (Kleijn & Voort, 1997), herbicide (Kleijn & Snoeijs, 1997) as well as colonization process (Blomqvist *et al.*, 2003).


Developments in landscape ecology have shown that agricultural dynamics are also related to changes in the structure of habitats. Spatial (habitat heterogeneity, distance from seed sources and structure) (Benton *et al.*, 2003; Boutin & Jobin, 1998; Baudry *et al.*, 2000; Burel & Baudry, 1990) was important in determining plant communities (Schmuckl *et al.*, 2002) as well as temporal (land-use history) (Eriksson *et al.*, 2002). An agricultural habitat obtains its characteristics also from environmental factors such as climate, soil or topography (Luoto, 2000). For example, site history or colonization along hedges from woodlands were important in determining plant communities of field margins (Marshall & Arnold, 1995; Marshall, 1989).

The present study distinguishes terms in relation to ranging scales. Table 1.2-1 illustrates the concept. The present study deals with a regional scale, landscape scale and landscape-element scale. The regional scale corresponds to, for example, the scale of the

Kanto district, i.e. a hundred kilometers. This scale corresponds to the Yatsuda agro-ecosystem, which includes various types of Yatsuda landscapes. At this scale environmental conditions such as geomorphology and geologic condition are the key features affecting the types of Yatsuda landscapes.

The landscape scale corresponds to one kilometer. The Yatsuda landscape contains various types of landscape elements, i.e. paddy fields, levees and semi-natural grassland, which correspond to agricultural treatments. At an even finer scale, each habitat is influenced by light, water, anthropogenic disturbance and soil condition, which lead to heterogeneity even within these habitats.

Table 1.2-1 Terminology of different scales in the present study.

Scale	Place units corresponding to the scale	Physical condition corresponding to the scale
Regional scale (i.e. Kanto region)	Yatsuda agro-ecosystem	Environmental condition (i.e. geomorphic condition, geologic condition, etc.)
Landscape scale	Yatsuda landscape	<div>  </div>
Landscape-element scale	Habitat (agricultural management units) Paddy field (Yatsuda paddy field), levee, semi-natural grassland	

1.3. Nature of paddy-field agro-ecosystem

1.3.1. Floristic diversity in the paddy-field ecosystem and Yatsuda agro-ecosystem

Rice is mainly cultivated in paddy fields. According to Karube *et al.* (1995) eighty-seven percent of the land used for rice cultivation in the world is in a submerged condition. Because they are submerged, paddy fields usually need a certain structure, namely a) irrigation systems to guarantee the water source and drainage, b) the soil surface to be leveled as precisely as possible to keep a uniformly submerged water condition, and c) surrounding bunds (levees) to keep the water depth. Variations in flooded fields and levees are reported to enhance aquatic and terrestrial habitats (Bambaradeniya *et al.*, 2004; National Institute of Agro-Environmental Science, MAFF, 1998).

Moreover, the Yatsuda agro-ecosystem has diverse habitats due to a complicated geomorphologic condition. In the lowermost slope between lowland rice fields and woodlands on slopes, there is a unique semi-natural meadow (these meadows are hereafter called “verge meadows”). Especially in narrow valley floors, because of the shortage of sunlight for rice cultivation, local farmers periodically mow lowermost slopes adjacent to paddy fields. Kitazawa & Ohsawa (2002) carried out floristic diversity studies in Yatsuda landscapes including paddy fields, levees and verge meadows and showed the importance of the verge meadows for maintaining the unique floristic diversity in Yatsuda landscapes. Similarly Ohtsuka *et al.* (2004) mentioned the importance of the mosaic of habitats in Yatsuda landscapes.

1.3.2. Ecological studies dealt with each landscape element in paddy-field ecosystem

Despite the two above-mentioned studies dealing with the Yatsuda agro-ecosystem at the landscape scale, landscape-scale studies in paddy-field ecosystems are quite scarce. Most ecological studies are associated with a particular landscape element (such as paddy fields, levees and verge meadows). However, they can provide information on the ecological properties in each landscape element.

Paddy fields

Due to the importance of rice agriculture, a substantial number of ecological studies on weedy species in paddy fields has been conducted, most of which concentrated on the eradication of weedy species.

Although paddy fields are similar to upland fields in terms of performing periodic soil disturbance, their floristic compositions are quite differed. According to Kasahara (1951), 191

species were defined as “paddy weed species”, of which only 76 species were seen in upland fields, though almost 60% of the occurring species in paddy fields and upland fields were annual species (Itoh, 1993).

In paddy fields, agricultural practices are the biggest determinant of floristic composition (Itoh, 1993). Correspondingly, most paddy weed species are distributed all around Japan (Kasahara, 1951). Seriously problematic paddy weeds around Japan were 53 species, whereas those occurring only in either northern or southern Japan were 3 and 5 species, respectively (Kasahara, 1951). This is quite different from upland weed species. Major changes in weed species composition in upland fields were associated with a complex gradient of increasing altitude and precipitation and decreasing temperature and base status of the soils (Losová *et al.*, 2004).

The management practice affecting species composition the most is the water regime; submerged in the rice-growing season and drained in the other season. For terrestrial plant species, the onset of flooding imposes metabolic stress which, if sufficiently prolonged, can result in death (Jackson & Drew, 1984). Since rice plants tolerate water flooding, artificial water control can be used to control non-tolerant weed species. Most species have a limited tolerance (McIntyre *et al.*, 1989; Arai & Miyahara, 1955), and factors such as their developmental stage at the time of flooding and water depth are critical to their survival. Relationships of the water depth and the persistence of each weed species are also a major topic (Morita & Kobaki, 2002; Nishida & Kasahara, 1978). In some cases this tolerance may be extremely well developed, e.g. *Monochoria vaginalis* (Kataoka *et al.*, 1978) and *Echinochloa crus-galli* (Kennedy *et al.*, 1980).

Paddy weeds also adapt to frequent soil disturbances in terms of both period and frequency (Kasahara, 1960a, b). Minimum tillage leads to an increase in perennial species (Nakagawa, 1965), whereas frequent tillage is attributed to the eradication of weedy species (Kasahara, 1960a, b).

In fact, many studies indicate that some weedy species (segetals) are highly adapted to agricultural management regimes. For instance, seeds of *E. crus-galli* break dormancy under submerged and cold conditions, which corresponds to the soils of wet-paddy fields and induced dormancy in deoxyic conditions (Miyahara, 1961).

Levees

Levees are mostly the habitats of ruderals and harbor terrestrial habitats in paddy-fields agro-ecosystems (Bambaradeniya *et al.*, 2004). There are severe disturbances, such as mowing (3 to 5 times per year) and yearly soil addition for maintenance as well as the input

of herbicides. Hence, low stature species or stolon species are commonly observed in these habitats (Miyawaki *et al.*, 1994).

Levees are structurally divided into three components; a flat part where farmers often walk in conducting agricultural practices; a slope adjoining a paddy field at the top, where surface soil was artificially added for yearly water control; and a slope adjoining a paddy field at the bottom (Yamaguchi & Umemoto, 1996). Biomass of the floristic community is not substantially affected by eight times of mowing (Umemoto & Yamaguchi, 1997).

In mountainous areas paddy fields are distributed on relatively steep slopes. There, levees with longer slopes are reported to be the habitat of semi-natural meadows, which are the habitat of rare species in Japan (Okubo, 2002; Baba *et al.*, 1991; Iiyama *et al.*, 2002). This is mainly due to less possibility of herbicide application and soil input on the slope.

Verge meadows

As mentioned above, verge meadows, which are observed in Yatsuda landscapes, are reported to contain different types of species. Kitazawa & Ohsawa (2002) mentioned this habitat as being abundant in meadow species. However, another floristic composition was observed in verge meadows. Kitagawa *et al.* (2004) targeted the floristic diversity in verge meadows and suggested that this habitat has abundant species composed of not only grassland species but also forest margin species and species in wet conditions. Okubo *et al.* (2005; 2003) compared the floristic composition of verge meadows and forest floors in different micro-scale landforms in a hilly area and implied the importance of variety of topographic conditions and bedrock conditions. In fact, in hilly areas, micro-scale landform conditions were reported to be the major determinant of floristic composition (Nagamatsu & Miura, 1997; Ishizaka *et al.*, 1986; Matsubayashi, 1997).

Influence of changing agricultural practices in paddy-field ecosystem

Despite of many contributions to the biodiversity of agricultural activities, farmland activity also deeply associated with the decline of biodiversity. Floristic diversity is declining with intensification and cessation of agricultural activities by changes in socio-economic aspects.

Influence of intensification

To enhance rice productivity and farmers' work efficiency, many paddy fields were consolidated to form larger plot sizes. Today, 50% of plots are more than 1 ha in size, while especially those located in wide alluvial lowlands have been equipped with modern drainage

systems and made drier during the non-cultivation season (Hasegawa & Tabuchi, 1995). In levees, consolidation of paddy fields leads to the destruction of existing levees instead of newly created ones.

This change in water condition has decreased the value of the paddy fields' ecological function as a wetland habitat, encouraging less hydrophilic vegetation and reducing floristic species richness (Arita and Kobayashi, 2000). These levees are mentioned to host markedly different plant communities than traditional levees (Ito *et al.*, 1999; Yamato *et al.*, 1999). In both habitats, exotic species were more frequently observed, whereas the total species number tends to decline. *Miscanthetia sinensis*, a typical species, substantially declined in mountainous areas (Yamato *et al.*, 1999).

Influence of abandonment

Meanwhile, as a result of shifting economics and the decline of the rural population since the 1970's, a substantial percentage of paddy fields, today more than 30%, especially in mountainous and hilly areas, are no longer being cultivated (MAFF, 2001).

Many studies report the establishment of wet grasslands characterized by *Phragmites australis* and *Isachne globosa* (Hakoyama *et al.*, 1977; Matsumura *et al.*, 1988; Ohkuro *et al.*, 1996; Comín *et al.*, 2001) or wet woodlands characterized by *Salix koriyanagi* and *Alnus japonica* (Hayakawa & Takahata, 1975; Shimoda, 1996; Lee *et al.*, 2002) in the process of secondary succession when land management was applied whilst fields remained wet. Of course, secondary succession is a complex multi-factorial process. The process depends on light condition (Kang *et al.*, 2004), seed sources from surrounding vegetation (Shimoda, 1996), climate (Lee *et al.*, 2002), soil moisture (Hakoyama *et al.*, 1977), and corresponding other dominant species. In the succession sere, some nationally endangered wetland species were not rarely observed. These floristic changes are accompanied by a shift of chemical and physical conditions of the soil. The soil surface was nutrient (nitrogen and carbon) -rich due to the remaining biomass of emergent flora (Anzai, 1992). This trend was remarkable in wet succession sere. Soil porosity, on the other hand, increased markedly in dry conditions (Ohta *et al.*, 1996).

Nevertheless, species representative of cultivated paddy fields tended to decrease in most of these processes, even if the fields remained wet (Matsumura *et al.*, 1988; Shimoda, 1996). Of 191 species, 110 were especially problematic. Yet now, 10 of these 'problematic' weeds are listed in the Japanese *Red Data Book* (Environment Agency of Japan, 2000) as threatened, and even more species are listed at a regional level. Therefore, immediate actions should be launched to preserve paddy fields in a wet condition and to restore the specific conditions in

which paddy weeds grow.

Levees were reported to collapse and hence distinct species in this habitat have disappeared (Ohtsuka *et al.*, 2004).

Influence of intensification and abandonment in the Yatsuda agro-ecosystem

In the case of rice cultivation in the Yatsuda agro-ecosystem, land consolidation has not been frequently performed in these areas because of the small size of the valley floors, hence traditional low-intensity agricultural practices still tend to remain. However, this also suggests a tendency towards a higher risk of abandonment of agricultural practices.

1.4. Ecological restoration in agro-ecosystems

As in agricultural landscapes in Japan, biodiversity in European countries is facing a serious decline (Robinson & Sutherland, 2002; Hyvönen & Salonen, 2002). In terms of nature conservation, there is no substitute for preserving good quality habitats, of which the maintenance and management is a number one priority. However, in many parts of the world, this is either no longer an option because few areas of unaltered habitat remain, or it is no longer sufficient since the remaining habitat on its own cannot sustain the biota, and hence needs to be improved or expanded (Hobbs & Harris, 2001). This section demonstrates the decline of flora in Europe and then clarifies the concept and methods of ecological restoration in the countries.

1.4.1. Decline of diversity caused by changing agriculture in Europe

In Europe, both agricultural intensification and the cessation of agriculture have been deeply associated with the decline of floristic diversity (Burel & Baudry, 2003).

Agricultural intensification

According to Matson *et al.* (1997), the total area of cultivated land worldwide increased by 466% from 1700 to 1980. Whereas the rate of expansion has slowed in the last three decades, yields (food produced per area of land) have increased dramatically and have outpaced global human population growth. This remarkable scientific and technological achievement is based largely on intensification of management of land already under cultivation. These intensifications affecting the loss of biodiversity are well described in Benton *et al.* (2003). The loss of ecological heterogeneity at multiple spatial and temporal scales is a universal consequence of multivariate agricultural intensification. At the landscape scale (between farms to across regions), larger contiguous areas (regions) dominated by either tilled land or grassland replaced landscapes formerly characterized by mixed farming systems with spatially intimate mixes of tillage and grassland. At the between-field scale, larger fields, and hence larger contiguous areas under identical management, as a consequence of maximizing the efficiency of operation of agricultural machinery and reducing management costs in arable systems, hedgerows and other field boundary structures no longer serve stock-proofing functions. At the within-field scale, species diversity declined by killing weeds, re-seeding with palatable, competitive grass species and favoring those species through drainage and fertilizer use.

Intensive agriculture has resulted in the loss of biodiversity and the specialist flora and

fauna associated with the semi-natural grasslands of low-intensity pastoral systems throughout northwest Europe (Walker *et al.*, 2004), though grasslands of the highest botanical value are present on soils with a low nutrient status (Vermeer & Berendse, 1983; Fuller, 1987). Up to 97% of unimproved grasslands have been lost in England and Wales since the 1930's (Fuller, 1987). Between 1950 and 1990 the area of wet meadows in Hungary declined from 600 000 to 200 000 ha as a result of drainage and agricultural intensification to increase production (Joice and Wade, 1998). Besides, according to the review of Le Coeur *et al.* (2002), 5000 km of field boundaries were removed annually in the UK in the 1960's (Hooper, 1970), 14% of the hedgerow network disappeared from the landscape of Northern Ireland between 1976 and 1982 (McAdam *et al.*, 1994), 500 000 km of uncultivated linear features vanished from Finnish agricultural landscapes during the last three decades (Helenius, 1994), and 740 000 km of hedgerows were lost in France during the same period (Pointereau & Bazile, 1995).

Abandonment

Another problem is abandonment. An example are heath-land communities, which are plagio-climax communities, created and maintained by man. Unless succession is prevented by man's influence, changes in the species composition occur from open heath to either bracken-dominated communities or woodland (Thompson *et al.*, 1995; Webb, 1990). Around 20% of upland heather moorland present in England and Wales in the mid 1940's has changed due to afforestation, agricultural reclamation, high grazing pressures and bracken *Pteridium aquilinum* invasion (Thompson *et al.*, 1995).

Consequent loss of floristic diversity

As a consequence, various types of loss in agricultural landscapes were reported. Many weeds have become very rare or totally extinct, for instance in Holland (Andreasen *et al.*, 1996) and in the UK (Robinson and Sutherland, 2002). In Britain trait changes in frequencies of each species were largely consistent with the impact of increased nutrient availability across vegetation types associated with inherently low fertility. Linear habitats in lowland Britain saw trait changes consistently with secondary succession. Grassland field boundaries can function as refugia. However, the lower relative amount of species in boundaries next to the least productive fields indicated that some plant species will, on average, be increasingly uncommon or absent in boundaries as field productivity increases. Field boundaries next to highly productive grasslands appear to function as partial refugia for grassland plants (Smart *et al.*, 2002), (cited from Walker *et al.*, 2004).

In arable land, the application of inorganic and organic fertilizer can result in the addition of plant nutrients in non-target areas such as field margins (Tsiouris & Marshall, 1998). The number and percentage of species present did not differ greatly in different farming regimes whereas the species composition varied considerably (Boutin & Jobin, 1998).

1.4.2. Restoration programs in agro-ecosystems in Europe

Since changing agricultural features greatly affect the decline of floristic diversity as mentioned above, ecological restoration of agricultural landscapes is a substantial priority.

Moreover, in agro-ecosystems, biodiversity performs a variety of ecological services beyond the production of food, including recycling of nutrients, regulation of microclimate and local hydrological processes, suppression of undesirable organisms and detoxification of noxious chemicals (Altieri, 1999). The net result of biodiversity simplification for agricultural purposes is an artificial ecosystem that requires constant human intervention, whereas in natural ecosystems the internal regulation of function is a product of plant biodiversity through flows of energy and nutrients, and this form of control is progressively lost under agricultural intensification. For instance floristic diversity of uncropped edges managed for biodiversity do not increase weed occurrence in adjacent crops (Marshall *et al.*, 2003; Marshall & Moonen, 2002; Smith *et al.*, 1999).

Now, a large number of restoration trials, extending to many habitats such as grasslands, heath-lands, hedgerows, wetlands, ditches and fields, has been conducted in cultivated ecosystems. Table 1.4-1 showed restoration procedure on agro-ecosystem.

Ecological restoration trials in agricultural landscapes

According to the Society for Ecological Restoration International Science & Policy Working Group (2004), ecological restoration is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability. Concerning attributes of restored ecosystems, this society first describes that “the restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure”, which indicates the importance of the comparison with a proper reference ecosystem.

Restoration can be ‘passive,’ in which the degrading agent(s) is identified and removed, or ‘active,’ in which management techniques such as planting, weeding, burning, and thinning are undertaken with a particular image of the desired structure, composition, or pattern in mind (McIver & Starr, 2001). Restoration of agricultural ecosystems has to be attained by more or less active methods because reciprocity exists in these cultural

ecosystems between cultural activities and ecological processes, such that human actions reinforce ecosystem health and sustainability.

Passive restoration

In the simplest circumstances, restoration consists of removing or modifying a specific disturbance, thereby allowing ecological processes to bring about an independent recovery. For example, removing a dam allows the return of an historical flooding regime (Society for Ecological Restoration International Science & Policy Working Group, 2004). Traditionally, restoration efforts have focused on re-establishing historical disturbance regimes or abiotic conditions, relying on successional process (i.e. removing a dam; Kauffman *et al.*, 1997). In the US, the two most common examples of successful passive ecological restoration are the rewatering of streams after years of withdrawal for agricultural or municipal purposes and the cessation of livestock grazing in riparian areas (Kauffman *et al.*, 1997).

In agricultural landscapes, passive restoration was used only for the recovery of natural habitats. Cessation of intensive agricultural activities also represented a passive restoration. For instance, natural wetland ecosystems can be restored by passive restoration (Klötzli & Grootjans, 2001; Pfadenhauer & Klötzli, 1996; Middleton, 2003). Cessation of intensive rice cultivation enhances the occurrence of wetland floristic communities (Mesléard *et al.*, 1999; Comín *et al.*, 2001).

Active restoration

The restoration of agricultural ecosystems normally includes the concomitant recovery of indigenous ecological management practices, including support for the cultural survival of indigenous peoples and their languages as living libraries of traditional ecological knowledge.

One efficient and the simplest restoration method might be the restart of former low-intensity agricultural practices. An example is the fact that the introduction of grazing or higher stocking rates generally increases plant species richness in heath-lands (Bullock & Pakeman, 1997; Hulme *et al.*, 2002; Degn, 2001) or hedgerows (Croxtton *et al.*, 2004). This restoration method is applicable in recently abandoned low-intensity agricultural sites where intensive agriculture (fertilizer and herbicide use) had never been performed (Grootjans *et al.*, 2002; Pykälä *et al.*, 2005). The sites adjacent to surrounding valued vegetation were also restored by the method (McDonald *et al.*, 1996).

However, the re-introduction of low-intensity agricultural practices does not always correspond to the restoration of former plant communities (Kleijn, 2003; Marrs *et al.*, 1998) including semi-natural wetlands (Klötzli & Grootjans, 2001) and wet Heathland ecosystem

(Jansen *et al.*, 1996), or rates of re-assembly of plant communities with affinity to existing semi-natural grasslands which have generally been slow (Walker *et al.*, 2004). Recent reports suggest that some degraded systems shift to a new state (persistent, resilient, alternative state) that cannot be restored to the previous condition or disturbance regime (Kleijn, 2003; Suding *et al.*, 2004). Strong feedback between biotic factors and the physical environment can alter the efficiency of management efforts because of constraints such as eutrophication and acidification (Pywell *et al.*, 1995; Willems, 2001; Walker *et al.*, 2004), landscape connectivity (Hutchings and Booth, 1996a, b; Bischoff, 2005), loss of species pool (Bakker and Berendse, 1999), and shifts in species dominance (Anderson *et al.*, 2000).

For instance, semi-natural grassland is the most important habitat in European agro-ecosystems. Yet, the recolonization of the final biodiversity is likely to be slow and unreliable, because so many of the desired species are no longer available in the vicinity and migration over long distances can be limited (Dobson *et al.*, 1997; Bischoff, 2002). Species that arrive first by chance may persist and dominate the ecosystem for many decades, especially if they become established in large numbers (Dobson *et al.*, 1997).

Hence, active restorations often involve fairly intensive work. The reinstatement of extensive cutting and grazing regimes, following the cessation of fertilizer inputs, can cause measurable changes in the composition, productivity and diversity of formerly improved swards (Bakker, 1989). Direct over-sowing of improved swards with seed mixtures offers a simple and cost-effective method for diversifying grassland provided that “gaps” for establishment are created by grazing or mechanical disturbance (Jones & Hayes, 1999). One of the simplest ways to diversify species-poor grasslands is to introduce seeds (Jones & Hayes, 1999; Lawson *et al.*, 2004) or to insert container-grown plants (plug-plants) into an established sward (Bruehlheide & Flintrop, 2000). This method has a number of advantages over seeding methods, particularly when seed is scarce (e.g., when collected from plants of a particular genetic provenance), or when restoration involves the introduction of mid- to late-successional species that are vulnerable to competition or have seed dormancy mechanisms (Hopkins *et al.*, 1999). At heathland restoration, tranlocating turves, application of heathland topsoil or application of harvested heather shoots were used (Pywell *et al.*, 1995).

On agricultural land, high soil fertility is also an important constraint to restoration (Janssens *et al.*, 1998). On sites that have received minimal inputs of fertilizer, extensive management has been sufficient to overcome these constraints and restore calcareous and mesotrophic grasslands of conservation value in less than 20 years (Moutford *et al.*, 1996). In these studies, hay-cutting and aftermath grazing have been shown to reduce the cover of

competitive grass species, overall biomass yield and in some cases soil fertility, with cutting and grazing being more successful than either cutting or grazing alone. In contrast, where soils have received repeated fertilizer inputs, natural reversion to species-rich grassland has been shown to take several decades, even on sites adjacent to natural seed sources. In contrast, nutrient-stripping (e.g. deep cultivation, deturfing) and seed addition on ex-arable soils has led to the re-creation of species-rich grasslands in less than 10 years (Walker *et al.*, 2004). Heath-land communities were reported to also have constraints for restoration (Bakker & Berendse, 1999).

A further example is the restoration of arable weed communities. Recognition of the role of weeds in supporting sustainable agriculture (Marshall *et al.*, 2003; Büchs, 2003), and matching production and conservation were tested (Paoletti *et al.*, 1992). On arable land, effects of organic agriculture on biodiversity including arable weeds are a major focus (Bengtsson *et al.*, 2005; Hyvönen *et al.*, 2003). As a consequence, few studies have been carried out on the ecological restoration of arable weed communities because farmers still consider these species as competitors to the cultivated species. Some studies tried to restore arable weed communities on abandoned arable land (Dutoit *et al.*, 2003) or cultivated arable land (Albrecht & Mattheis, 1998). Albrecht & Mattheis (1998) demonstrated that organic agriculture, adopted widely throughout Europe, is associated with the decline of rare weedy species mainly due to the shortage of tillage. Dutoit *et al.* (2003) suggested the risks of a long fallow condition because of loss of seed bank in targeted segetal species.

Table 1.4-1 Restoration procedure on agro-ecosystem.

Which is the target species habitat, natural habitat or semi-natural habitat?

Natural habitat (→a)/ Semi-natural habitat (→b)

a. Natural habitat

Restoration method: Passive restoration (Cessation of agricultural activities)

b. Semi-natural habitat

Restoration method: Active restoration

Is a degraded site recently abandoned low-intensity agricultural one where intensive agriculture (fertilizer and herbicide use) had never been performed, or adjacent to surrounding valued vegetation?

Yes (→b-1)/ No (→b-2)

b-1. Reintroduction of former extensive agricultural practices (simpler and lower-cost method) [First priority]

b-2. Newly intensive methods which did not carried out at former agricultrue (more difficult and higher-cost method)

1.4.3. Ecological restoration of paddy-field ecosystems in Japan

In Japan, several restoration programs in paddy-field ecosystems have been carried out for conserving rare arable weeds and other wetland species. These projects either re-start cultural practices in abandoned paddy fields (Shimoda and Nakamoto, 2003; Nakamoto *et al.*, 2002; Yamada *et al.*, 2002; 2000; Asami *et al.*, 2001; Mitsutaka *et al.*, 1999) or use other managements (i.e. mowing; Osawa & Katsuno, 2003; Morimoto *et al.*, 2005; Ohkuro *et al.*, 2004), demonstrating the success of either rare paddy weed species or natural wetland species.

However, they failed to make clear statements concerning target species or reference sites. For instance, restored paddy weed communities are rarely compared to other paddy fields' floristic compositions. Worse, in some cases, paddy weeds and natural wetland species are not distinguished according to the restoration programs in restored sites although these two floristic groups are considered to be different traits from management regimes.

Moreover, all the restoration studies mentioned above related to within paddy fields. No studies were conducted on other management units, much less on holistic restoration programs in paddy-field agro-ecosystems.

1.5. Objectives and flow of the study

According to the review work of this chapter, several problems for the present status of research on agro-ecosystems were identified.

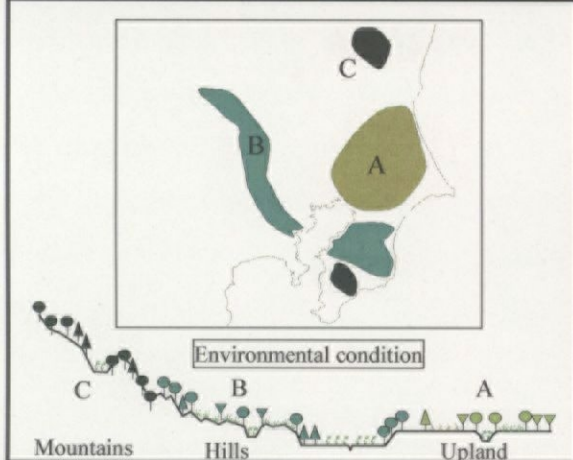
Review work of paddy-field ecosystems implied that floristic composition of levees and verge meadows might be affected by the difference in geomorphic conditions through the slope-length of levees, and the shapes of slopes adjacent to verge meadows. Hence, the present study carried out classification of Yatsuda landscapes based on such environmental conditions. Subsequently, in each detected classification unit, field surveys to clarify the relationship between floristic diversity and habitat conditions were carried out. We focused on three agricultural management units in the Yatsuda agro-ecosystem, the paddy field, levee and verge meadow, because they are the typical landscape elements enhancing grassland and wetland species. The floristic diversity and floristic composition of the three management units were compared intra- (i.e. inside a landscape element level) and inter-landscape level. The present study aimed at firstly clarifying the difference in floristic composition among classified Yatsuda landscapes, and second, detecting priority habitat(s) in these landscapes.

In terms of the review of ecological restoration in agricultural landscapes, since the mosaic of habitats is the key feature of the landscape, it is important to carry out restoration programs not only in paddy fields but also in other landscape elements. Reintroduction of former agricultural practices in formerly managed extensively and abandoned sites for shorter periods is the first step to active restorations. Based on this information, a restoration project re-introducing agricultural practices in an abandoned Yatsuda agro-ecosystem was monitored. The objective is to clarify the degree to which formerly existing flora is restored in the three landscape elements of the restored site.

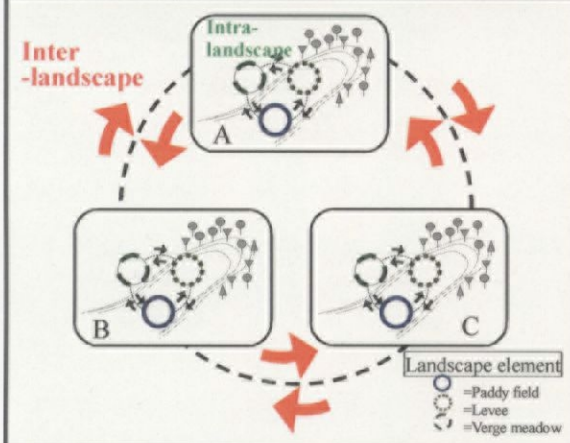
Chapter 1 Introduction

- Present status of paddy-field ecosystem (especially Yatsuda agro-ecosystem) in Japan
⇒ Why is a landscape- and regional-scale survey needed?
- Review work of ecological conservation and restoration trials in European countries
⇒ Obtain methodologies and concepts of ecological conservation and restoration.

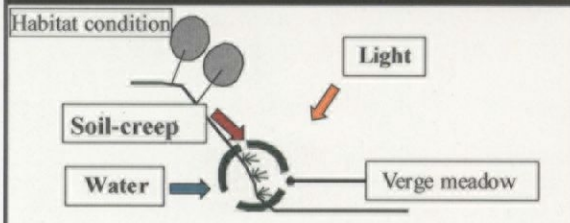
Chapter 2 Landscape classification analysis (Regional-scale analysis)



Chapter 3 Inter- and intra-landscape scale analysis



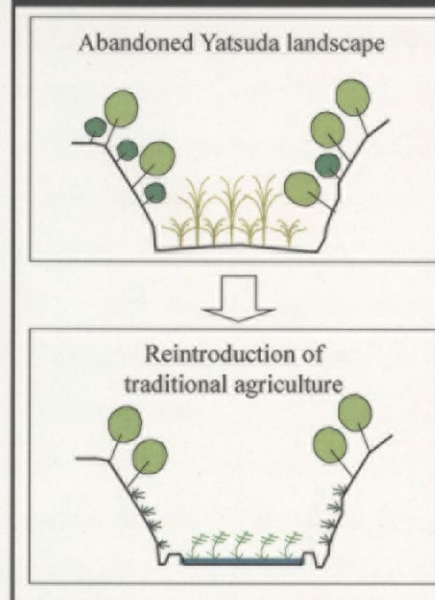
Chapter 4 Landscape-element scale analysis



General discussion

- Adequacy of the landscape classification of Yatsuda agro-ecosystem
- Clarify habitat(s), which deserve to be conserved
- Possibility of vegetation restoration

Chapter 5 Restoration Experiment



Summarize the relationships between environmental condition, habitat condition and floristic diversity

Figure 1.5-1 Research flow of this thesis.

2. Classification of Yatsuda landscapes by environmental conditions which are assumed to affect floristic diversity

2.1. Introduction

‘Yatsuda’ is a quite general term, indicating paddy fields and the surrounding agricultural area located in alluvial lowlands in narrow and shallow valley floors. When we look at 1:25,000 topographic maps in Kanto region, Japan, there are many place-names including the term “yatsu” or its dialect “yato”, many of which are distributed in less than 500 m wide valleys in uplands, hills and low-relief mountains. However, there is no definition in terms of shape.

As a result of the review work in the previous chapter, the present chapter tries to clarify the relationship between geomorphic location and environmental conditions that are assumed to affect the floristic diversity in Yatsuda landscapes.

2.2. Materials and methods

2.2.1. Definition of Yatsuda landscape in this study

Previous studies mention the ecological importance of verge meadows. The presence of the meadows was related to the width of valley floors because the improvement of light condition is more important in narrower valleys. Moreover, parcels of paddy fields remain small, and farm roads were frequently unpaved and used only by local farmers, which signifies less intensive anthropogenic disturbances to Yatsuda landscapes. In the present study, Yatsuda landscapes were identified by the presence of paddy fields, which are located in valley floors with less than an approximately 300 m width, which mostly corresponds to the first- and second-order valley floors in the 1:25,000 topographic maps. The defined valley width is markedly small compared to the geomorphic definition (Suzuki, 2000).

From an ecological point of view, Yatsuda paddy fields located in narrower valleys were reported to be more important. Azuma *et al.* (1998) demonstrated that Yatsuda paddy fields located in valleys less than 200 m wide are especially important for the habitat of the gray-faced buzzard. One of the reasons is likely to be the influences due to the absence of land consolidation in such small valley floors. These characteristics correspondingly are assumed to affect the distribution of vegetation composition. Hence detection of such smaller Yatsuda paddy fields can be a good indicator for remaining traditional agro-ecosystems.

In mountainous areas, many paddy fields were located in valley floors. However, most of them are distributed in deep valley floors and along higher ordered rivers and paved public roads. In the present study these valley floors are not regarded as Yatsuda paddy fields. By

looking at 1:25,000 topographic maps, Yatsuda landscapes were identified by the presence of paddy fields which are located in valley floors with less than an approximately 60 m depth.

In consequence, Yatsuda paddy fields were identified using two indices: the width of valley floors and the depth of valleys.

2.2.2. Study area

The Kanto region was selected as a study area. This is because it includes higher ratios of both uplands and hills than other plains of Japan (Yonekura, *et al.*, 2001), hence the Kanto Plain area is known as a major location of Yatsuda paddy fields.

2.2.3. Identification of Yatsuda landscapes using GIS

To understand the original distribution of Yatsuda landscapes in the Kanto region, cultivated rice paddies and abandoned rice paddies are both regarded as rice paddy fields. Other vegetation types are summarized as woodlands, upland fields, residential areas or artificially modified areas. In terms of valley depth, a 2 m to 60 m depth was defined as the location of Yatsuda paddy fields.

Data sources of the analysis were a 50 m-grid digital elevation model (DEM) and a digital vegetation data surveyed. The DEM data was interpolated from contours in 1: 25,000 topographical maps, acquired from the Geographical Survey Institute Japan as a digital map with a 50 m-grid (elevation), of Japan. Digitized vegetation data was used for land use classification. This data was provided by the Environment Agency Japan as a digitized actual vegetation map 1: 50,000 in the period of 1979 to 1984. To prepare land use data, polygon vector data of vegetation was converted from a polygon data set into the same 50 m-grid cell data set as the 50 m-DEM.

The depth of the valleys was identified using a program to create a summit plane using the GIS software TNT Mips version 7.0 (MicroImage Inc., Lincoln, NE, USA) was obtained by repeated calculation in each cell in 5×5 moving windows. The following analyses were performed using Arc GIS version 9.0 (ESRI, New York, USA). The depth of the valleys was calculated by the differences between the summit levels and actual elevation. In this procedure, paddy fields in wide alluvial lowlands adjacent to terrace scarps were misclassified as Yatsuda paddy fields. These paddy fields were in quite flat locations except for the adjacent terrace scarp, hence grids with less than 1 % gradient in 3×3 moving windows were eliminated from the extracted paddy fields.

The gradient of valley-floors was calculated by the difference in elevation of a given paddy field and an adjacent paddy field with the nearest lower elevation.

This data was calculated in approximately 5 km × 5 km areas (calculation unit), which corresponds to half the size of each 1: 25,000 topographical map. If the number of grids in paddy fields in a calculation unit exceeded 5 % of the total number of grids, the given calculation unit was regarded typically as Yatsuda landscapes, in which characteristics of environmental condition could be comparable with each other.

In each calculation unit, medians of relief energy of Yatsuda landscapes, gradients of valley-floors of Yatsuda landscapes and ratios of land use adjacent to Yatsuda landscapes were calculated.

Table 2.2-1 Items evaluating the difference of Yatsuda landscapes in geomorphic conditions.

Item	Explanation	Aggregate calculation in 5 km × 5 km calculation unit
Relief energy	Difference of elevation between summit level and actual elevation in Yatsuda landscapes	Median
Gradient of valley-floor	Minimum difference of elevation to adjacent paddy fields in lower elevation	Median
Land use	Ratios of woodlands, upland fields and residential areas adjacent to Yatsuda landscapes	Ratio

2.2.4. Classification of geomorphic conditions

Geomorphic conditions identified by 1:200,000 landform classification maps were divided into major 6 categories; lowlands, uplands, low-relief hills, high-relief hills, mountains and others. In the above-mentioned calculation units, only those units in which a single geomorphic condition was predominant were extracted to use comparison among geomorphic units.

2.3. Results

2.3.1. Distribution of Yatsuda paddy fields in Kanto region

Among a total of approximately 1,000 calculation units in the Kanto region, 280 units were identified as those including more than 5 % of Yatsuda paddy fields. The location of calculation units identified as Yatsuda landscapes is shown in Figure 2.3-1. Yatsuda landscapes were located in hills, uplands and mountains, whereas they are rarely observed in lowlands.

Figure 2.3-2 shows the numbers and ratios of Yatsuda paddy fields in each geomorphic condition. The ratios show the number of calculation units identified as Yatsuda landscapes in each geomorphic condition to all calculation units in given geomorphic conditions. Although numbers of Yatsuda landscapes were the largest in uplands, ratios of Yatsuda landscapes were larger in low-relief and high-relief hills.

In uplands, Shimosa Upland, Tsukuba-Inashiki Upland, Namekata Upland, Kashima Upland and Higashiibaraki Upland were locations of Yatsuda landscapes, whereas in other uplands an abundant distribution of Yatsuda landscapes was not observed.

Yatsuda landscapes in low-relief mountains are located in the fringe of the Yamizo Mountains and southern part of the Boso Peninsula. Usually, mountains were formed out of bedrock in the Mesozoic and Paleozoic era (Suzuki, 2000), whereas these low-relief mountains were formed out of bedrock in the Neocene.

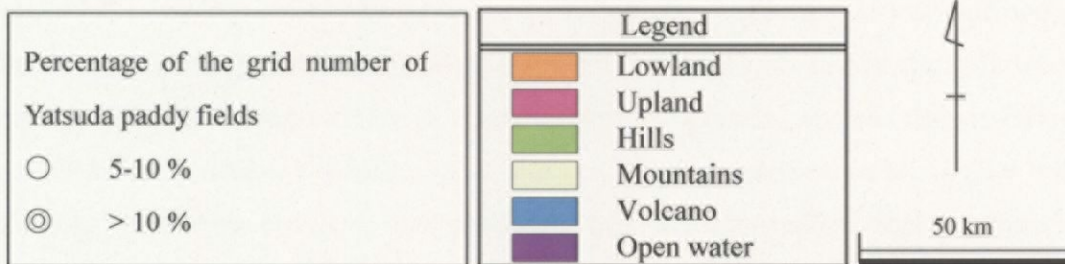
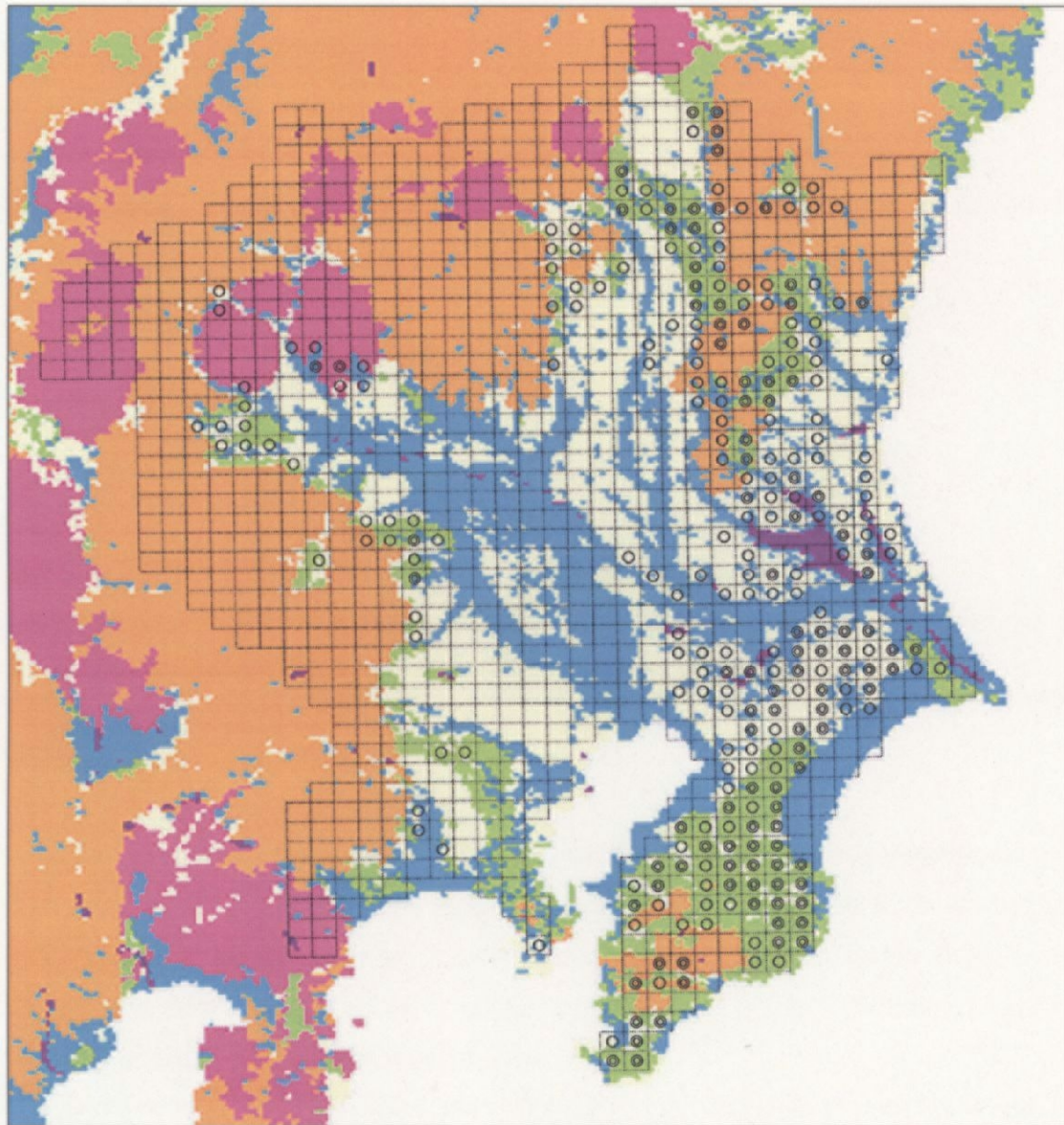


Figure 2.3-1 Locations of Yatsuda landscapes in the Kanto region.

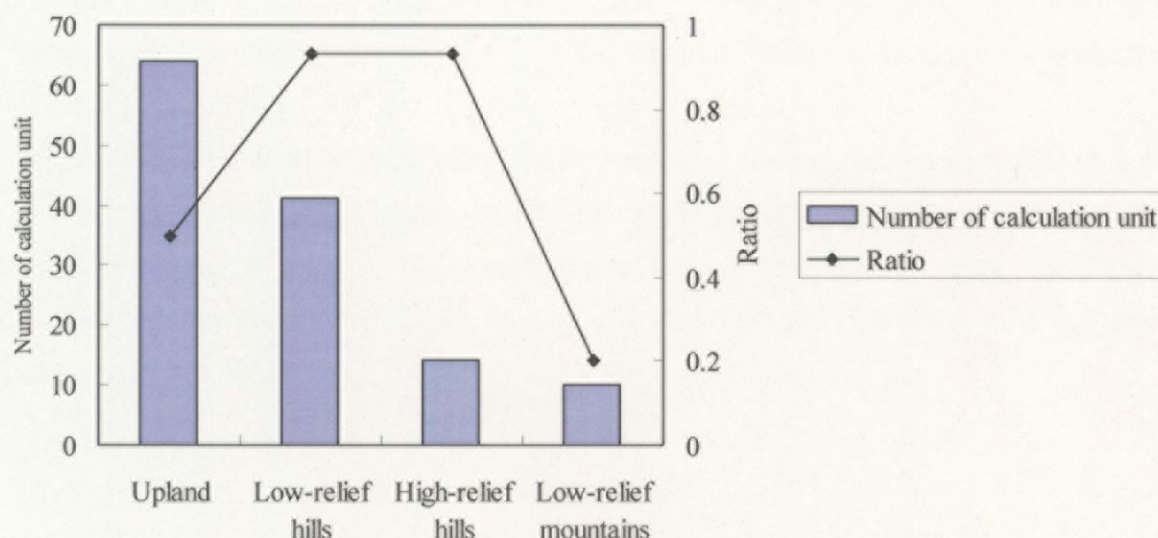


Figure 2.3-2 Numbers and ratios of Yatsuda landscapes in each geomorphic condition.

Ratios = the number of calculation units of Yatsuda landscapes in each geomorphic condition / all calculation units in given geomorphic conditions.

2.3.2. Characteristics of Yatsuda paddy fields in different geomorphic conditions

The location of calculation units with abundant Yatsuda landscapes is shown in Figure 2.3-3. Low-relief hills showed significantly higher ratios of Yatsuda paddy fields in each calculation unit than other geomorphic conditions ($p < 0.01$, Mann – Whitney U -test with sequential Bonferroni's correction, Table 2.3-1).

The average slope of valley floors and valley depths are shown in Figures 2.3-4 and 2.3-5, respectively. These differed significantly in different geomorphic conditions except in high-relief hills and low-relief mountains ($p < 0.01$, Mann – Whitney U -test with sequential Bonferroni's correction). Shallower valleys (on average 20 m) with almost flat valley bottoms (on average less than 1 %) were typical characteristics in uplands, whereas deeper valleys (on average 50 m) with steeper flat valleys (on average 5 %) were typical in high-relief hills and mountainous areas. Between these, low-relief hills have are intermediate characteristics.

The land use composition verging on Yatsuda paddy fields is shown in Figure 2.3-6. Table 2.3-1 showed the significances. Although woodland was predominant regardless of geomorphic conditions, ratios of upland fields decreased from uplands, via low-relief hills, to high-relief hills. Ratios of woodland in Yatsuda landscapes located in uplands were significantly smaller than in other geomorphic locations ($p < 0.05$, Mann – Whitney U -test with sequential Bonferroni's correction). Conversely, ratios of upland fields were

significantly larger in Yatsuda landscapes in uplands than those in low-relief hills, and larger in uplands than in high-relief hills ($p < 0.01$, Mann – Whitney *U*-test with sequential Bonferroni's correction).

High-relief hills and low-relief mountainous areas are similar in most measured indices. In low-relief mountains, both paddy fields and upland fields are found in relatively wide valley floors, which leads to a significantly higher ratio of upland fields bordering Yatsuda landscapes. In narrower valley floors, low-relief mountains and high-relief hills are rarely adjacent to upland fields.

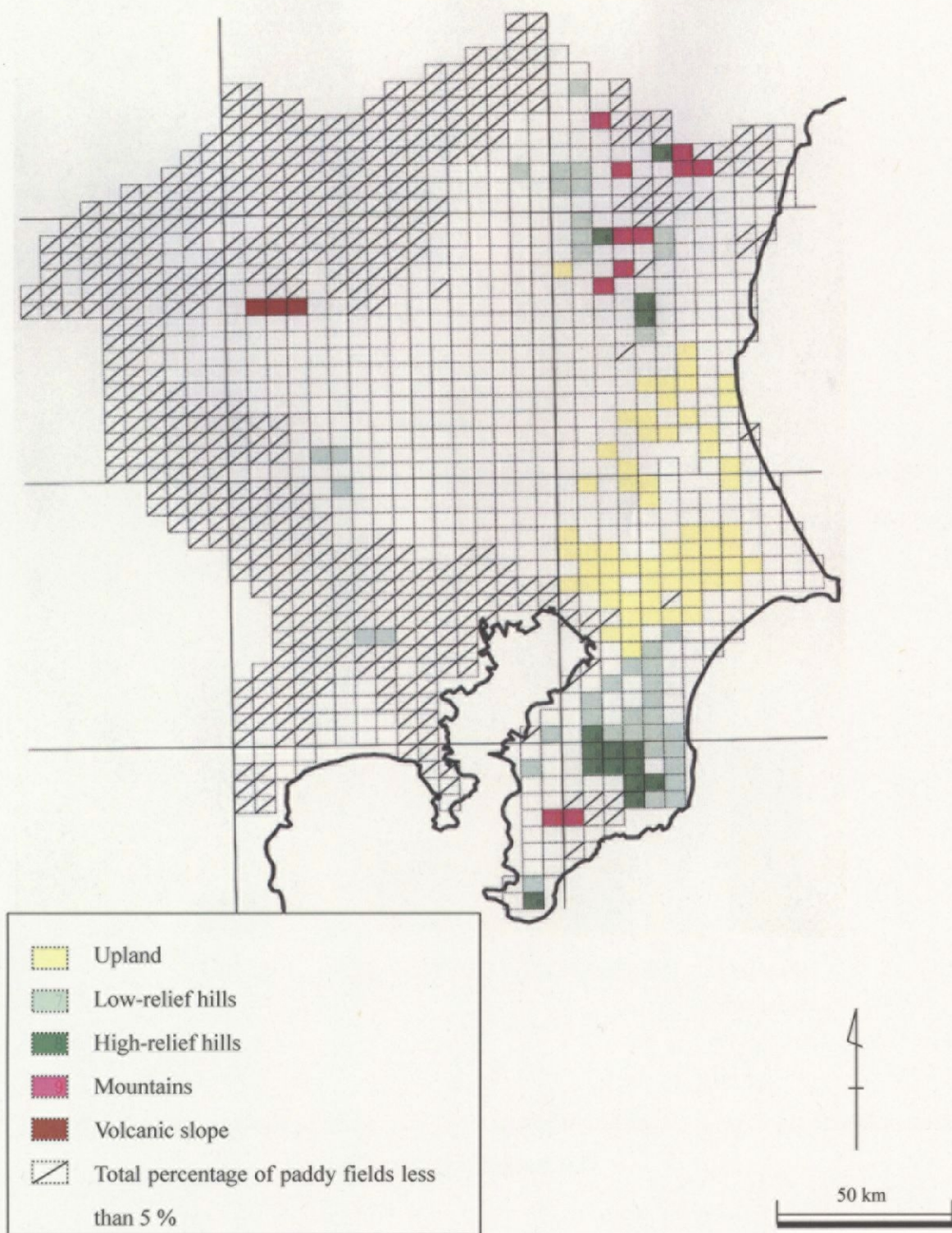


Figure 2.3-3 Locations of calculation units of Yatsuda landscapes were frequently observed in relation to a major geomorphic condition.

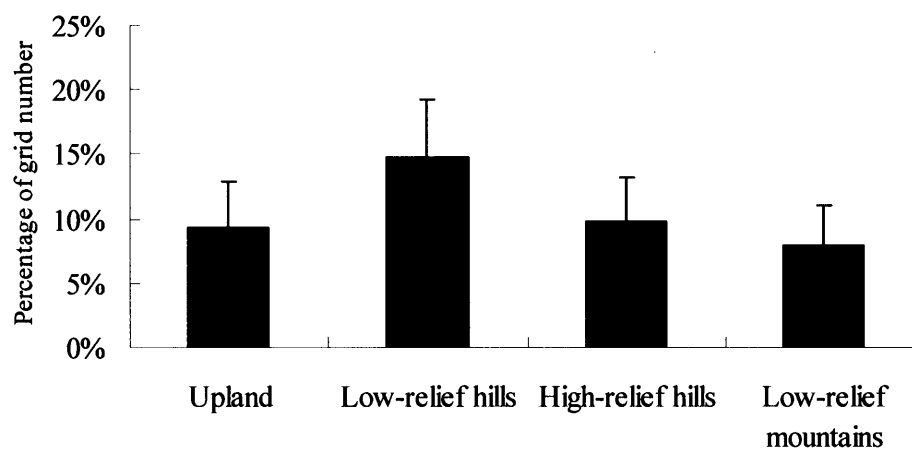


Figure 2.3-4 Average ratio of Yatsuda paddy fields in each geomorphic unit. Error bar indicates S.D.

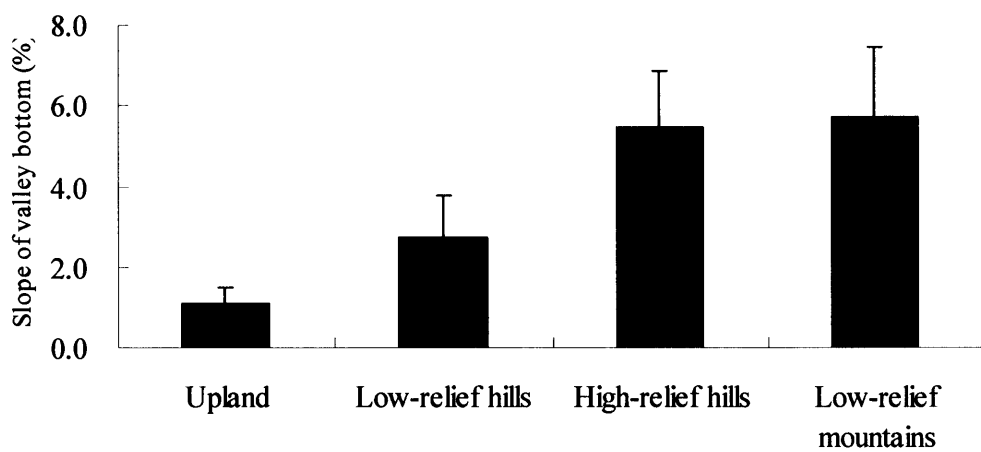


Figure 2.3-5 Average slope of valley floors in Yatsuda landscapes in each geomorphic unit. Error bar indicates S.D.

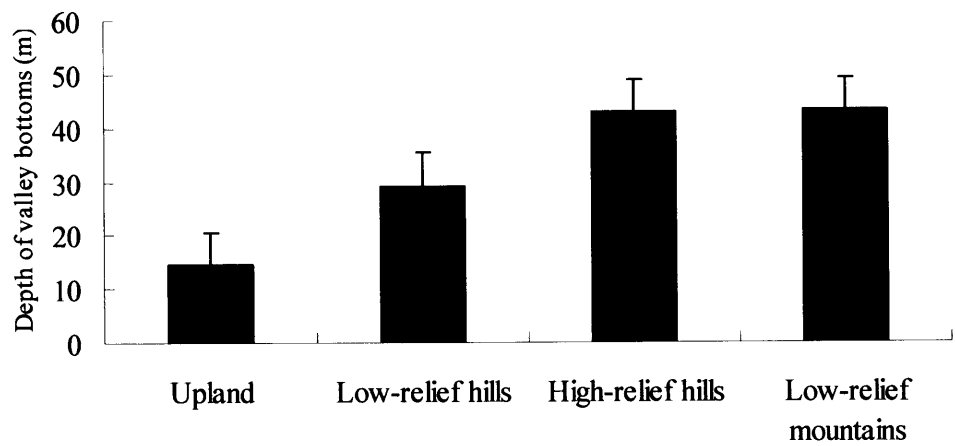


Figure 2.3-6 Average depth of valley floors in Yatsuda landscapes in each geomorphic condition. Error bar indicates S.D.

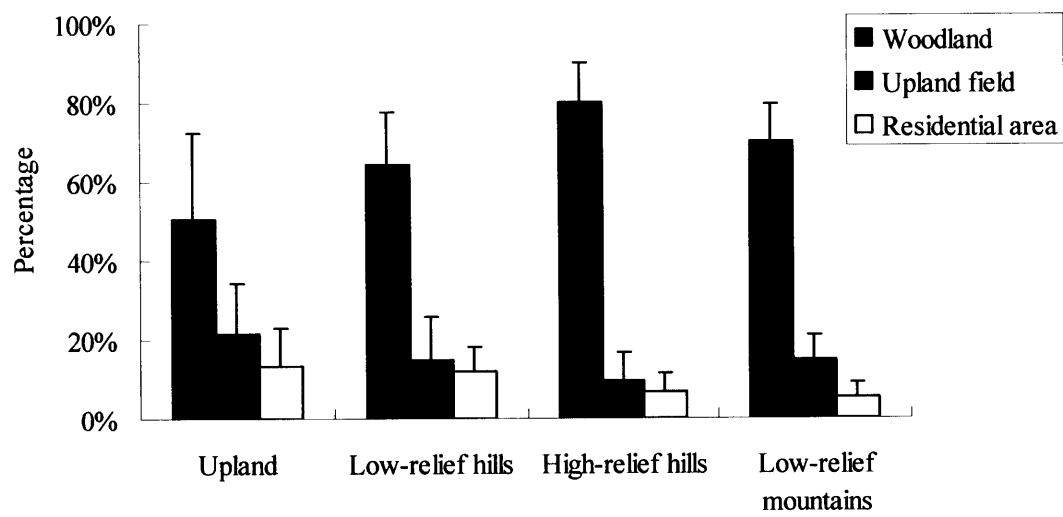


Figure 2.3-7 Land-use type adjacent to Yatsuda paddy fields. Error bar indicates S.D.

Table 2.3-1 Differences of characteristics of Yatsuda landscapes in each geomorphic condition.

Ratio of Yatsuda landscape			
	Low-relief hills	High-relief hills	Low-relief mountains
Upland	< 0.001 **	0.867	0.118
Low-relief hills		0.001 **	< 0.001 **
High-relief hills			0.192
Gradient of valley bottom			
	Low-relief hills	High-relief hills	Low-relief mountains
Upland	< 0.001 **	< 0.001 **	< 0.001 **
Low-relief hills		< 0.001 **	< 0.001 **
High-relief hills			0.625
Relief energy			
	Low-relief hills	High-relief hills	Low-relief mountains
Upland	< 0.001 **	< 0.001 **	< 0.001 **
Low-relief hills		< 0.001 **	< 0.001 **
High-relief hills			0.886
Adjacent land use: woodland			
	Low-relief hills	High-relief hills	Low-relief mountains
Upland	0.003 *	< 0.001 **	0.004 *
Low-relief hills		< 0.001 **	0.286
High-relief hills			0.016 *
Adjacent land use: upland field			
	Low-relief hills	High-relief hills	Low-relief mountains
Upland	< 0.001 **	< 0.001 **	0.040
Low-relief hills		0.058	0.602
High-relief hills			0.036
Adjacent land use: residential area			
	Low-relief hills	High-relief hills	Low-relief mountains
Upland	0.484	0.001 **	0.001 **
Low-relief hills		0.004 *	< 0.001 **
High-relief hills			0.508

P values of Mann – Whitney U-test were shown. The significance values were corrected using the sequential Bonferroni techniques.

2.4. Discussion

Yatsuda landscapes in the Kanto region were most abundantly observed in uplands, whereas not all uplands have abundant Yatsuda landscapes. According to the valley density map (1: 200,000), a higher density of valley floors was recorded in these uplands. These areas have unconsolidated deposits from the late Pleistocene, mainly composed of sandy deposits. The density of valley was reported to vary (Suzuki, 2000) though there are many complicated factors such as periods after emergence of depositions (Tokunaga, *et al.*, 1980), permeability of rocks (Yoshinaga & Takeuchi, 1981; Koide, 1973) and distance from the sea (Yonekura, *et al.*, 2001). These factors might affect the location of Yatsuda landscapes.

Although there are significant differences of the land use types adjacent to Yatsuda landscapes in different geomorphic conditions, woodlands were predominantly observed as adjacent land use, indicating that Yatsuda landscapes were surrounded predominantly by woodland. The gradient of the geomorphic condition from upland via hills to mountains showed that the ratio of woodland was getting larger, whereas that of upland fields and residential areas were getting smaller. However, the ratio of upland fields in low-relief mountains was not significantly lower than in uplands. One reason is that the misclassification of Yatsuda landscapes in mountainous areas is likely. In the present study, paddy fields were located in mountainous areas in valleys with a deeper relative height to the ridge. These paddy fields were likely to be adjacent to upland fields.

According to soil maps in these areas, most soil types in paddy fields in such Yatsuda landscapes belonged to either lowland soil or gleyic soil types, indicating poor drainage of water. On the other hand, several calculation units of Yatsuda paddy fields were observed in other geomorphic conditions. They were mostly located on the volcanic slopes of Akagi Mountain. Here, soils were characterized by good drainage (Gunma prefecture, 1978), implying that the areas were not suitable to be Yatsuda landscapes.

2.5. Conclusion

Yatsuda landscapes were markedly different according to geomorphic condition. The geomorphic condition was a good indicator not only of the factors investigated in this chapter (i.e. relief energy and slope of valley floors) but also of other environmental conditions. For instance, the age of bedrocks differed according to geomorphic condition. Uplands are composed mainly of Late Paleocene deposits, whereas low-relief hills are composed mainly of Middle Paleocene semi-consolidated rocks, and high-relief hills and low-relief mountains are composed of Miocene consolidated rocks. Land use also differed in different geomorphic conditions. Yatsuda landscapes located in uplands had higher ratios of upland fields.

Consequently, landscape structures in the Yatsuda agro-ecosystem are classified into the following three types; upland (Type A), low-relief hills (Type B) and high-relief hills and low-relief mountains (Type C). The characteristics of the three classified types of Yatsuda landscapes are shown in Table 2.5-1.

Table 2.5-1 Characteristics of the three classified types of Yatsuda landscapes.

	Type A	Type B	Type C
Location	Upland	Low-relief hills	High-relief hills Low-relief mountains
Gradient of valley floor	Low	←————→	High
Relief energy	Low	←————→	High
Land use			
Woodland	Low	←————→	High
Upland field	High	←————→	Low
Residential area	High	←————→	Low