Research note

The First National Vegetation Inventory in Taiwan

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【Summary】

This article describes the successful implementation and preliminary results of the first national vegetation inventory in Taiwan. This project which aimed to establish national criteria for vegetation classification, map island-wide forest vegetation at a scale of 1: 5000 and establish a vegetation data management system was launched in 2003. More than 3000 permanent plots (20 m ×20 m) were set up throughout Taiwan, and 792 articles on vegetation of Taiwan were located to acquire vegetation data. Vegetation types were identified according to the physiognomic appearances in aerial photographs. The national vegetation classification system was constructed by referring to field observations, vegetation data, and currently available vegetation classification schemes.

This project was finalized in 2008. Up to 67% of native vascular plant species in Taiwan were recorded, and 59% of the total area of Taiwan was mapped in this project. Preliminary vegetation analyses identified 9 major vegetation types and their diagnostic species, constant species and dominant species. The Taiwan Vegetation Information was established and has performed the functions of data management for the current project since 2003. The latest version of the Taiwan Vegetation Classification System was released in 2007. The achievement and experiences of the current

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project have paved the way for the successful implementation of subsequent large-scale surveys in Taiwan.

Key words: data management, phytosociology, Taiwan, vegetation mapping, vegetation survey.

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研究簡報

台灣第一次全國植被調查計畫

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摘 要

這篇文章簡述已成功執行的第一次台灣全國植被調查計畫及其初步成果。這個以建立國家植被分類標準、畫出1: 5000比例森林植被圖及建立植被資料管理系統為目的的計畫開始於2003年。為了取得植被資料，本計畫在全台灣共設置了3,000多個永久樣區，並收集到792篇關於台灣植被的文章。植被圖上的植被型是依空照圖上的形相來辨識。國家植被分類系統是以參考野外觀察結果、植被資料及現有植被分類法來建構的。

這個計畫已在2008年結束。在這計畫執行期間，記錄了高達67%的台灣原生維管束植物，且植被圖的繪製涵蓋了59%的台灣面積。初步資料分析確認出台灣的九大植被型，以及各植被型的特徵種、恆存種及優勢種。台灣植被資訊系統早在2003年就已建妥，並自此一直發揮資料管理的功能。最新的台灣植被分類系統已在2007年出版。這個計畫的成果及經驗已為之後大型調查計畫鋪出一條成功之路。

關鍵詞：資料管理、植物社會學、台灣、植被圖繪製、植被調查。

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Vegetation studies in Taiwan date back to the late 19th century (e.g., Honda 1899). More than 300 vegetation studies had been conducted in Taiwan before World War II. However, because plant species nomenclature was inconsistent and criteria for sampling and vegetation classification differed, understanding of vegetation became more complicated as more studies were conducted. Therefore, national standards for vegetation surveys and classification became an urgent issue to put an end to the increasing chaos.

Detailed vegetation maps are needed for natural resource management due to the pressure of overexploitation associated with the growing human population. Nevertheless, previous studies either were too small in geographical extent or could not provide precise information for the needs of natural resource management (e.g., Liu 1972). Thus, a phyto-

sociological database which is designed for vegetation classification and provides information on the distribution of species and patterns of species diversity had to be set up.

Under these circumstances, the first National Vegetation Diversity Inventory and Mapping Project in Taiwan was launched in 2003 and finalized in 2008. Due to time constraints, this project mainly focused on the dominant vegetation type, forests. The main objectives of the project were: 1) to establish the Taiwan Vegetation Classification System (TVCS) consisting of national classification criteria for forest vegetation, 2) to pursue nation-wide mapping of forest vegetation at a scale of 1: 5000, and 3) to establish the Taiwan Vegetation Information System (TVIS) for data management and information dissemination.

The National Vegetation Diversity Inventory and Mapping Project was funded by the Bureau of Forestry in Taiwan and was led by Dr. C.F. Hsieh. Three working groups were formed for various tasks, including an administration team, 8 field survey teams, and an information team. The administration team was composed of staff members of the Taiwan Vegetation Center and the Bureau of Forestry. This team was in charge of administration-related tasks, communication among teams, and quality control for field-collected data and vegetation maps. Field surveys and vegetation mapping were carried out by field survey teams led by 8 professors: Drs. C.F. Hsieh, J.C. Wang, M.Y. Chen, H.Y. Liu, C.L. Yeh, S.Z. Yang, T.Y. Chen, and Y.J. Hsia. The main tasks for the information team (led by Dr. C.R. Chiou) were to maintain the databases, set up an official website, and provide technical aids for vegetation mapping.

To assure that data were collected and processed with the same methods, 22 training courses were held for personnel of this project. These courses covered fieldwork safety, methods for field surveys, procedures of vegetation mapping, analysis of vegetation data, modeling of vegetation distribution, and software training. Experiences with vegetation surveys in other countries were also acquired. Twenty vegetation scientists from 8 countries, including the USA, South Africa, Czech Republic, Austria, Germany, the Netherlands, Russia, and Japan, were invited to Taiwan to share their experiences. International symposia, attended by 1500 participants in total, were held in Taiwan annually from 2003 to 2008 to facilitate exchange and dissemination of vegetation mapping expertise.

Permanent plots (20 m × 20 m) were laid out all over Taiwan to acquire data on species composition and community structure of forest vegetation. General environmental factors were also evaluated for each plot, including GPS coordinates, elevation, slope, aspect, topography, understory cover, soil stone content, percentage area of rock outcrops on the ground surface, canopy height, and canopy cover.

Vegetation literature was collected and transformed into electronic documents. Three types of information were extracted from the vegetation literature, including general information (title, publisher, and author), investigation information (investigation time, sample method, sample plot size, vegetation type, and number of species), and spatial information (GPS coordinates and the location in terms of administration districts and watersheds). The revision of scientific names was conducted by Dr. C.F. Hsieh following the nomenclature of the latest edition of the *Flora of Taiwan* (Editorial Committee of Flora of Taiwan 2003).

Broad vegetation types on aerial photographs were identified according to the physiognomic appearances. Follow-up ground truthings were conducted to eliminate

misidentification, after the vegetation types were mapped.

To assure the compatibility of the database with those in other regions, the TURBOVEG program (Hennekens and Schaminée 2001), a database management software developed originally for the Dutch National Vegetation Survey and later used on other projects in Europe, America, Asia, and Africa, was used to compile and pre-process vegetation data. JUICE (Tichý 2002) and PC-ORD (MjM Software Design, Gleneden Beach, OR, USA) program packages are prime software pieces used in data exploration.

Construction of the TVCS was carried out after field vegetation surveys and a literature review for vegetation classification schemes in other regions. The 2 main outcomes of the field surveys (results of preliminary vegetation analyses and field observations) and currently available vegetation classification schemes provided fundamental elements for construction of the TVCS (Fig. 1). In order to meet the tight schedule of the project, many vegetation polygons on aerial photographs were mapped before construction of the TVCS (Fig. 1). As soon as the first draft of the TVCS was released, the feasibility of the system was evaluated by applying it to vegetation mapping and verifying the results of test runs (preliminary vegetation maps) in the field (Fig. 1). Drafts of the TVCS were revised whenever necessary. Newer versions of the TVCS were revised with the same procedures used to revise the first draft until a satisfactory one was obtained. Vegetation maps of Taiwan were acquired by revising preliminary vegetation maps with the latest version of the TVCS.

During implementation of the project, 3564 permanent plots were sampled in the field. Up to 792 articles on the vegetation of Taiwan were located and collected from journals or unpublished sources, and saved into the literature database in the format of electronic image files. Vegetation data from 9678 historical plots documented in those vegetation articles were geo-referenced and included in the database. There were 2837 vascular plant species (including 899 woody species and 1938 herbaceous species) recorded in the permanent and historical plots, accounting for 67% of the native vascular plant species recorded in the latest edition of the *Flora of Taiwan* (Editorial Committee of Flora of Taiwan 2003). Vegetation on 3016 aerial photographs at a scale of 1: 5000 was mapped; these account for 59% of the total area of Taiwan and 95% of the area covered by naturally regenerated forest vegetation or plantations.

Preliminary vegetation analyses conducted by Lin et al. (2007) showed that elevation was the most important environmental factor controlling vegetation patterns. They identified 9 broad vegetation types, including 7 primary and 2 secondary vegetation types (Table 1). The primary vegetation types form vegetation belts spanning an elevational gradient, whereas secondary types are scattered across several belts. These types were named following Su's (1984) system which was established using similar methods as those of the current project but on a much smaller scale. In ascending order of elevational zonation, the primary vegetation types are the *Ficus-Machilus* forest, *Machilus-Castanopsis* forest, lower *Quercus* forest, upper *Quercus* forest, *Tsuga* forest, *Abies* forest, and *Juniperus* forest (Table 1). The secondary types are azonal along elevational gradients and include *Alnus* forest and *Pinus* forest. The diagnostic, constant, and dominant species of each vegetation type were identified (Table 1).

The web-based TVIS (http://140.112.183.207/for93-2/) was established and began

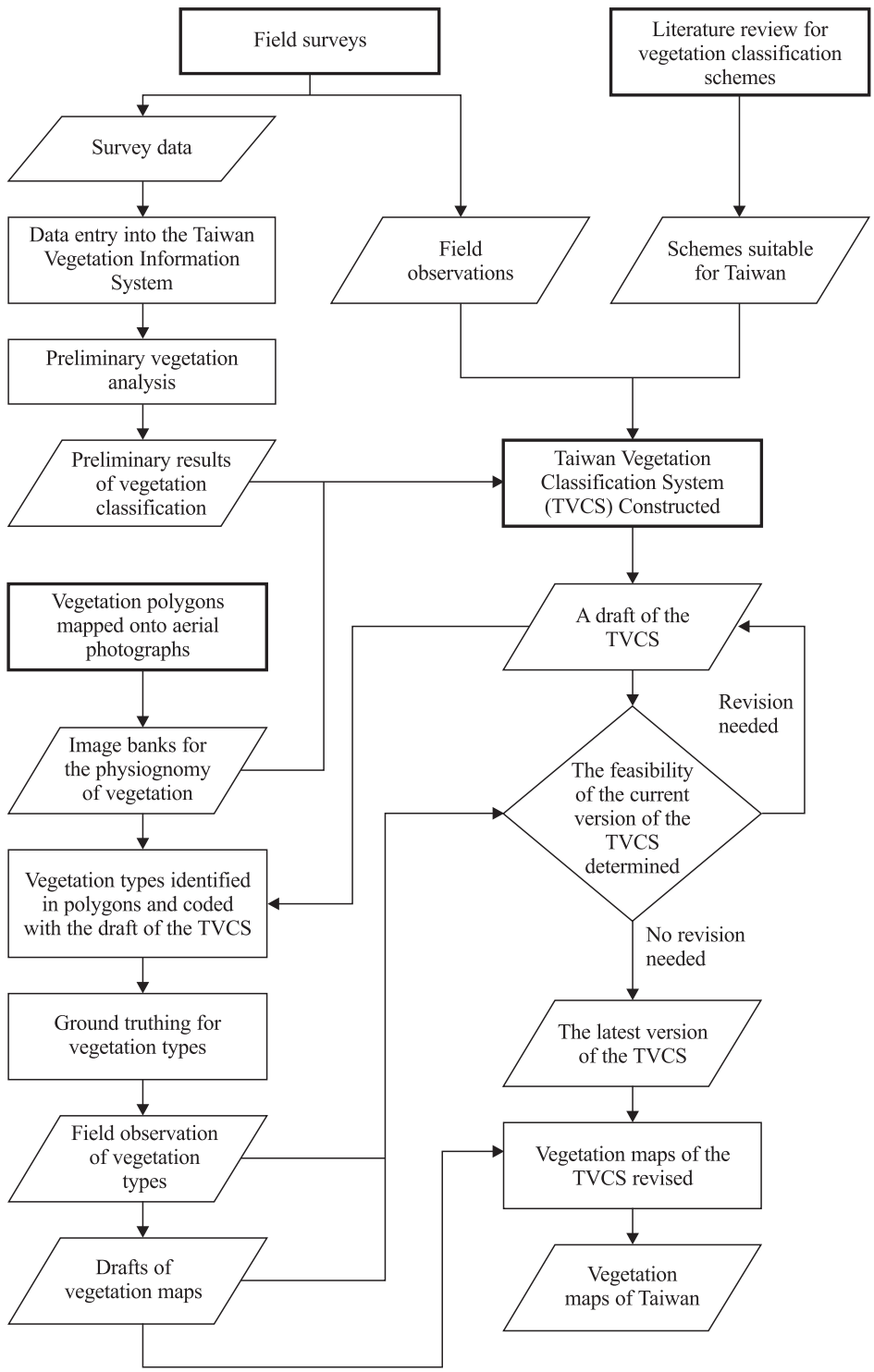

Fig. 1. Flowchart showing the construction of the Taiwan Vegetation Classification System (TVCS) and the acquisition of vegetation maps of Taiwan.

Table 1. General information of the 9 vegetation types in Taiwan (Lin et al. 2007)

Status of succession	Vegetation type	No. of plots	Elevational range (m)	Diagnostic species	Constant species	Dominant species
Primary vegetation	*Juniperus* forest	11	> 3300	*Juniperus squamata*	*Juniperus squamata*	*Juniperus squamata*
	Abies forest	96	> 2750	*Abies kawakamii*	*Abies kawakamii*	*Abies kawakamii*
	Tsuga forest	124	2200~3300	*Tsuga chinensis* var. *formosana*	*Tsuga chinensis* var. *formosana*	*Tsuga chinensis* var. *formosana*
	Upper *Quercus* forest	474	1500~2800	*Neolitsea acuminatissima*	*Neolitsea acuminatissima*	*Fagus hayatae* *Castanopsis cuspidata* var. *carlesii* *Chamaecyparis formosensis* *Chamaecyparis obtusa* var. *formosana* *Picea morrisonicola*
	Lower *Quercus* forest	851	750~2300	*Litsea acuminata* *Osmanthus matsumuranus*	*Litsea acuminata* *Machilus thunbergii* *Prunus phaeosticta* *Michelia compressa*	*Machilus japonica* *Castanopsis cuspidata* var. *carlesii* *Schima superba* *Rhododendron formosanum* *Pasania kawakamii*
	Machilus-Castanopsis forest	724	< 1500	*Schefflera octophylla*	*Schefflera octophylla* *Ardisia sieboldii*	*Machilus zuihoensis* *Machilus japonica* var. *kusanoi* *Cyclobalanopsis glauca* *Zelkova serrata* *Trema orientalis*
	Ficus-Machilus forest	91	< 400	*Dendrocnide meyeniana* *Champereia manillana* *Bischofia javanica* *Ficus irisana*	*Dendrocnide meyeniana* *Ardisia sieboldii*	*Ficus irisana* *Ficus benjamina* *Bischofia javanica*
Secondary vegetation	*Alnus* forest	32	100~3000	*Alnus formosana* *Deutzia pulchra*	*Alnus formosana* *Deutzia pulchra*	*Alnus formosana* *Quercus variabilis*
	Pinus forest	131	300~3500	*Pinus taiwanensis*	*Pinus taiwanensis*	*Pinus taiwanensis* *Pinus armandii* var. *masteriana* *Pinus morrisonicola*

functioning in 2003. The functions of the system include data entry, database management, data extraction and preprocessing, basic analysis, and display of results.

The latest version of the TVCS was released in 2007 (Hsieh 2007). The TVCS was developed down to the formation level (Table 2). High levels (class, subclass, and formation) of the system were constructed based on a widely accepted older scheme of vegetation classification in Taiwan (Su 1984) and a newly released one (Song and Xu 2003). Low levels (e.g., alliance) of the TVCS were developed by referring to the schemes used in other countries (e.g., Anon. 2006), field observations of the field survey teams, and results of preliminary analyses. Currently, 4 classes, 8 subclasses, and 43 formations are recognized in this system (Table 2). At the class level, vegetation types are identified based on

Table 2. High-level classification units for the mapping of the vegetation of Taiwan (Hsieh 2007)

Class	Subclass	Formation
Forest	Needle-leaved forest	Subalpine needle-leaved forest
		Upper montane-montane-lower montane secondary needle-leaved forest
		Upper montane needle-leaved forest
		Montane needle-leaved forest
		Lower montane needle-leaved forest
		Lowland needle-leaved forest
	Mixed needle-broad-leaved forest	Upper montane-montane-lower montane secondary mixed needle-broad-leaved forest
		Upper montane mixed needle-broad-leaved forest
		Montane mixed needle-broad-leaved forest
		Lower montane mixed needle-broad-leaved forest
		Lowland mixed needle-broad-leaved forest
	Sclerophyllous broad-leaved forest	Upper montane sclerophyllous broad-leaved forest
	Evergreen broad-leaved forest	Montane evergreen broad-leaved forest
		Montane evergreen broad-leaved dwarf forest
		Lower montane-lowland secondary evergreen broad-leaved forest
		Lower montane evergreen broad-leaved forest
		Lowland windswept dwarf forest
		Lowland evergreen broad-leaved forest
		Subtropical coastal forest
		Coral reef coastal forest
		Mangrove forest
	Semi-deciduous broad-leaved forest	Subalpine-upper montane secondary semi-deciduous broad-leaved forest
		Subalpine-upper montane secondary semi-deciduous broad-leaved forest
		Montane-lower montane-lowland semi-deciduous broad-leaved forest
	Deciduous broad-leaved forest	Subalpine-upper montane secondary deciduous broad-leaved forest
		Upper montane-montane-lower montane landslide deciduous broad-leaved forest
		Montane-lower montane-lowland secondary deciduous broad-leaved forest
		Montane deciduous broad-leaved forest
Thicket	Mixed needle-broad-leaved thickets	Alpine mixed needle-broad-leaved thicket
		Subalpine-upper montane-montane mixed needle-broad-leaved thicket
	Broad-leaved thicket	Lower montane-lowland broad-leaved thicket
		Coral reef broad-leaved thicket
		Coastal broad-leaved thicket
Herbaceous vegetation		Alpine herbaceous vegetation
		Subalpine-upper montane-montane herbaceous vegetation
		Lower montane-lowland herbaceous vegetation
		Sand dune vegetation
		Coastal herbaceous vegetation
Sparse vegetation		Subalpine-upper montane chasmophytic and scree vegetation
		Montane chasmophytic and scree vegetation
		Lower montane-lowland chasmophytic and scree vegetation
		Mudstone vegetation
		Coastal chasmophytic vegetation
		Swamp and aquatic vegetation
Artificial vegetation		Plantation forest
		Bamboo forest
		Cultivated land
Others		Man-made bare land
		Garden or cemetery
		Natural bare land
		Water area
		Urban or built-up land

their growth forms (trees, scrubs, and herbs; Table 2). At the subclass level, vegetation is classified according to leaf morphology (needle-leaved and broad-leaved) and phenology (evergreen and deciduous) (Table 2). The formation level represents a grouping system for vegetation types in similar habitats in terms of elevation, topography, and substrate (Table 2).

After finalization of the current project at the end of 2008, a few follow-up tasks were carried out, including further modifications of the TVCS, describing associations and alliances of the vegetation of Taiwan, and conducting biodiversity-related analyses. In order to evaluate the increasing environmental impacts associated with invasive alien species and obtain a more-complete picture for the vegetation of Taiwan, the following national project focuses on alien species and herbaceous vegetation which was omitted from the current project. The experiences gained in the current project will be a stepping stone to the successful implementation of subsequent large-scale natural resource surveys.

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