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Content

News Brief

Technical Paper

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Chief editor	Shaw-Lei Yu, UVa, USA
Editorial consultants	Jen-Yang Lin, NTUT, ROC.
	Kuang-Chih Chang, WRA, ROC.
Executive	Chi-Chang Liu
Telephone No.	+886-2-2771-2171 ext 2647
FAX	+886-2-87719190
Website	http://www.ntut.edu.tw/~wwwwec

2008 AWRA Summer Specialty Conference —

Riparian Ecosystems & Buffers: Working at the Water's Edge

The American Water Resources Association (AWRA) offers superior technical programs presented with a balanced and friendly approach to problem solving on a national and local level. During June 30 – July 2, 2008, AWRA held a specialty conference in Virginia Beach, Virginia -- at the mouth of the Chesapeake Bay and in the heart of central Atlantic Coast. The Conference is the 3rd quadrennial Riparian Ecosystems and Buffers Conference organized by AWRA.. The Summer Specialty Conference offered opportunities for guests to learn, network, and be entertained.

The main goal of the conference is to provide the attendees with new insights into the function and management of the critical riparian landscape and an enjoyable environment for networking with scientists, and the managers who are implementing riparian programs and practices on the ground. Participants of the conference included scientists, engineers and water resources managers and professionals in the field of riparian ecosystem research from around the world. From Taiwan, papers accepted for presentation at the conference included one by WERC Director Jen-Yang Lin and one by Water Resources Agency Deputy Director Kuang-Chih Chang.

Reference:

1. http://www.awra.org/meetings/Virginia_Beach2008/

International Forum — Green Infrastructure

Date：June 24. 2008（Tuesday）13:30~17:00
Location：Conference Room, 8FDepartment of Architecture Building, National Taipei University of Technology（NTUT）

Agenda

Time	Subject	Speaker	Moderator
13:30~14:00	Check in		
14:00~14:15	Opening Remarks	Dir. Kuang-Chih Chang (Conservation Division, WRA) Dir. Siang-Peng Rui (R & D Center, NTUT)	Prof. Jen-Yang Lin WERC, NTUT
14:15~14:45	校園於都市介面空間之探討以台北科大校園為例 The intermediary between Urban and campus interface in NTUT	Prof. Jen-Hui Tsai Department of Architecture, NTUT	Prof. Kuang-Hui Peng Collage of Design, NTUT
14:45~15:15	Source Control: The Solution to Stormwater Pollution	Michael A. Ports American Academy of Water Resources Engineers	
15:15~15:30	Tea Time		
15:30~16:00	Waller Creek Restoration & Rehabilitation Project- An Environmentally Responsive / Green Project	William H. Espey, Jr. Espey Consultants, Inc.	Prof. Yeou-Fong Li Department of Civil Engineering, NTUT
16:00~16:30	Advanced Drainage Concepts Using Green Solutions for CSO Control	Richard Field Leader of Wet-Weather Flow Research Program, U.S. EPA	
16:30~17:00	Discussion	Prof. Shaw L. Yu (Civil Engineering, UVa)	

Description：

In the past, ecology and environment protection might be thought of as only a slogan. However, nowadays the notion has changed to mean actions. The Water Environment Research Center (WERC) organized the International Forum on Green Infrastructures with the main objective of providing a discussion by international and domestic experts on how to incorporate “green infrastructure into water environment practices.

WERC invited scholars and experts, who are professionals in the water resource and management, from U.S. and Taiwan, to report on their experiences and to have a Q/A session with the audience.

The audience asked many interesting questions and had a good discussion with the speakers. Some highlights are presenting below.

Question 1:

How do we apply green solutions in Taiwan? In the urban areas, where we have high percentage impervious areas and densed population, which green infrastructures would be suitable for us?

Answer 1 by Richard Field:

We need to first gather detailed water/environment information for the urban areas in Taiwan in order to select the appropriate green infrastructures.

Answer 1 by Michael Ports:

We have to collect detailed local information before doing the planning and implementation of green solutions in Taiwan. For example, with Taiwan’s small size ans strong rainfall intensities, we may need to use smaller scaled BMPs in large numbers in order to achieve the desired level of reduction in stormwater runoff and improvement in runoff quality.

Question 2:

Recently some builders in Taiwan suggested to the Government that, if they implement the green building specifications and receive a recognized certification, they should be given volumetric rewards. Do you have such experiences in the U.S.?

Answer 2 by Michael A.Ports:

The answer to this question is twofold: One, if the builder considers the relevant characteristics of the site and decides to use porous pavement, he might save lower his construction cost and then sells the property for a higher price because of the “green construction” recognition. Two, many U.S. citizens need to pay stormwater utility taxes, if they adopt the green infrastructure concept and for example build stormwater storage facilities, they can reduce the runoff volume from their sites and therefore lower their utility taxes. This is a good incentive.

Question3:

Regarding Prof. Tsai’s idea about building farms on the roofs. How does it actually work in Taiwan?

Answer3:

First, we could establish a company to promote pilot roof farms. If the idea gains popularity and success, we can then charge those who rented the farm roofs fees. The generated income than can be returned to the university and donated for charity.

Figure. 1 Kuang-Chih Chang, Director Conservation Division of WRA giving the opening remark.

Figure. 2 AAWRE’s President Michael A.Ports

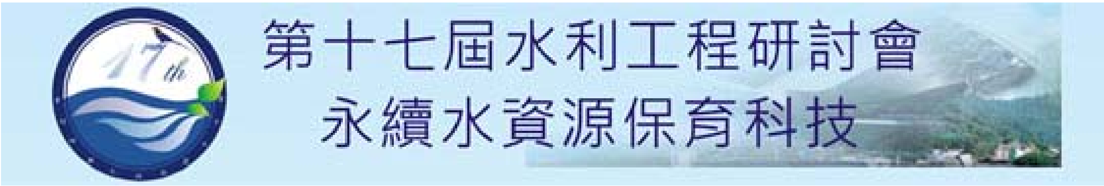
Figure. 3　Dr. William Espey

Figure. 4　Interaction between audience and speaker.

Figure. 5　Picture-taken after Forum with guests

The 17th Hydraulic Engineering Conference —

Conservation Technologies for Sustainable Water Resource



Feng-Chia University will hold the 17th Hydraulic Engineering Conference at Taichung, from August 5th to 6th, 2008. The main subject of this conference is conservation technologies for a sustainable water resource.. Water resources and nature disasters are the two main issues for this meeting. There will be thirteen sub-topics including water resource planning and management, flooding management, water resource policy, wetland, etc.

Reference:

1. http://hec2008.wre.fcu.edu.tw/

WERC

Technical Paper

J. of Ecotechnology, 2008 (1) : pp.7-19

Theories of Ecological Conservation for Engineers

Shyh-Chyang Lin[1]

[1] Department of Construction Engineering, National Kinmen Institute of Technology, #1, University Road, Jinning, Kinmen

Abstract

Great number of species in the world had gone extinct due to human development. The impacts of human activities have also affected global biodiversity. Facing the deteriorating ecosystem in each continent and island, people have realized the importance of ecological conservation and started to consider and implement ecologically friendly engineering practices. The objective of this article is to present the evolution of conservation theories and concepts by introducing Island Biogeography and Landscape Ecology. It also depicts the evolution of ecological conservation theories for civil engineers who are the most influential in keeping our ecosystem intact. First discussed in the theory of island biogeography, and then applied to habitat islands, is the effect of island size, isolation, and location on species abundance and biodiversity. The framework of landscape ecology covers most factors that interfere with various habitat characteristics and affect species population and evolution. Configuration, structure, allocation, and connectivity of landscape elements may change the methods for the conservation of different species. The concepts of two scientific areas provide conservation principles such as avoidance, mitigation and compensation for engineering practices. From initiation of the theory of island biogeography to landscape ecology and conservation biology, a systematic cascade development of conservation has been summarized in this research. The ultimate goal of this article is to provide an opportunity for civil engineers to comprehend the basic conservation theories, apply them to engineering, and implement genuine ecological engineering.

Keywords: Ecological Conservation、Island Biogeography、Species-Area relationship、Landscape Ecology、Habitat Shape

生態工程保育理論

世界上因為人類的開發行為大量的物種而滅絕，人類的活動亦衝擊了全球生物多樣性。面對大陸或海島生態系統的惡化問題，人類意識到生態保育之重要性，並且開始思考應用友善生態系之工程。本文的宗旨期客觀的呈現出保育理論之演變及簡介海島型生物地理學及景觀學之理念。並且描繪出生態保育之演變理論，使土木工程師於工程中能維持生態系統的完整。首先討論海島生物地理學理論，有關海島大小、隔離和地點的應用在種類豐富且生物多樣性之海島棲地上。景觀生態學的架構干涉了各式各樣的棲地特徵及人口演變的影響因素。改變配置、建造、風格元素及連通性等景觀設計因子係為不同的保護方法。科學上的兩個領域為工程施工提供了保育的原則概念，如退避、緩和和報償。從海島型生物地理學理論開始到景觀生態學和生物保育，串聯一個有系統性的保育開發是本研究的結論。本文的最終目標期以提供一個機會給土木工程師去了解基礎的保育理論，並實地的將此理論應用於生態工程之中。

關鍵詞：生態保育、海島生物地理學、物種與地域關係、景觀生態、棲地形狀

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Introduction

The newly emerged field of ecological engineering has been recognized by the vast majority of Taiwan's civil engineers and has become one of government’s most important policies. However, most engineers are unaware of the theoretical frame works of ecological conservation which may cause misinterpreted or miscalculated engineering practices. Without adequate knowledge of ecological conservation, one would be unable to assess or predict the long term ecological effects of engineering planning or design on the ecosystem and environment. Numerous ecological engineering designs in Taiwan were limited and concentrated on revegetation or the use of natural materials. Broader conservation was either overlooked or was not feasible to implement. Therefore, the contributions of the ecological technologies on engineering practices become limited in terms of conservation. It is a challenge for civil engineers to effectively conserve the integrity of the local ecosystem and increase the biodiversity, achieving the goal of the development in the meantime. Ideal ecological engineering planning and design should maintain or improve the ecological integrity, health, and biodiversity in the scale of the "region". With solid ecological surveying data and conservation theories, a civil engineer can establish a system of ecological assessment methods during planning of engineering life circles.

Persistent land development has greatly reduced, fragmented, isolated, and degraded natural habitats. The decline of animal habitat is not only causing decrease of some species population or local extinction but also causing decreased biodiversity around the globe. In the tropical areas, 1% of forest disappears annually due to development (Dobson, 1996). The extinction rate of avian species is 1,000 times the normal rate due to human activities (MacDonald, 2003). From the estimation by Wilson (1989) estimated that 10,000~15,000 species go extinct each year, the lost of species is directly or indirectly caused by the destruction of habitat. Maintaining integrity and size of natural habitats is the major objective of mitigating the loss of species, since small habitats can not provide enough area to support the evolution of the regional ecosystem due to the invasion of dominate exotic species (Gehlhausen, 2000). It is important to predict the effects on the regional ecosystem by remnant habitat caused by construction or bisected by roads.

Evolution of ecological conservation was pioneered by Wallace and Darwin in 1858 who stated that geological isolation may alter the attributes of organisms and create new species. The oceanic islands turned out to be ideal experiment sites for testing the evolution of species and became one of the most important fields of ecology, Island Biogeography. Before 1960, most biologists could only describe the phenomena of ecosystem without applying mathematics or statistical methods, hence, the evolution of species and ecosystem couldn’t be predicted or assessed. This situation changed in 1967 when MacArthur and Wilson published a celebrated monograph, The Theory of Island Biogeography.

Island Biogeography

Islands play an important role in the development of ecology because, surrounded by ocean, an island forms an independent and unique ecosystem compared to continent areas. Islands can be divided into two categories: oceanic islands, formed by the eruption of underwater volcanoes or tectonic activity, and continent islands, formed by separation from continent due to the raise of see level at the end of the glacier maxima. Organisms that arrived the newly formed oceanic islands were isolated from their origins and started to evolve into different species because of the islands' unique environment, climate, and food chain. The new organisms would therefore become endemic species of this island such that the biological diversity and abundance of the world were increased as more islands were formed in the ocean or separated from continents. In the 1960's MacArthur and Wilson pieced together investigation data about island species and generated mathematical formula to explain the ecological implication of island organisms. Two important theories were obtained from their research.

Equilibrium Theory

For oceanic islands, no organisms existed in the early days of a newly emerged island. Pollens landed on the island and established the pioneer vegetation. Avian species followed and terrestrial animals taking floating logs landed on the island, and the biological abundance and biodiversity of the island increased rapidly. But some species may go extinct due to competition or inadaptability to the island environments. In the early age of the island history, the rate of organism colonization (immigration) is always greater than extinction, but the mechanism of colonization, competition, and extinction of island organisms continues on the island and may reach a status of biological equilibrium. With no external disturbances or human colonization of the island, this dynamic equilibrium can be sustained. The Equilibrium Theory of island biogeography can be depicted as shown in Figure 1.

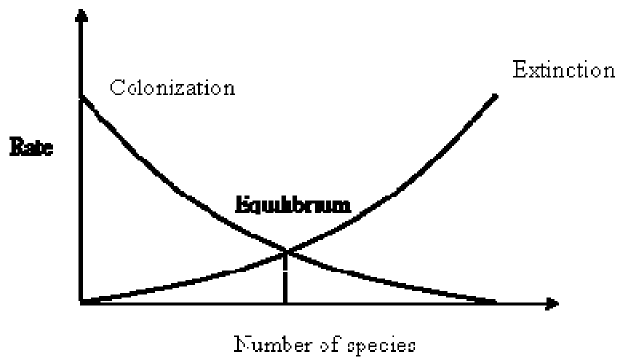

Figure 1. Equilibrium of island ecosystem

To test the theory, Wilson and Simberloff (Wilson and Simberloff, 1969; Simberloff and Wilson, 1969; Simberloff and Wilson, 1970) conducted a series of experiments on colonization and extinction phenomena of Arthropoda mangroves in the Key West, Florida. The results of the well designed experiments confirmed accuracy of the Equilibrium Theory for this species and the paper became a proof of the validity of the theory. The confirmation of the theory led to fast development of conservation biology and broadened the applications of island biogeography. The Equilibrium Theory illustrates that the rate of species colonization is low and the rate of extinction is high for the island isolated far away from the sources of species which are normally either continents or large islands. Conversely, islands near continents or large islands would have higher rate of species colonization and lower rate of extinction. Another important phenomenon was also identified by the two scientists: smaller islands have a higher rate of species extinction because of limited resources and high competition. A number of researchers had found such relationship between number of species and area of an island, however, MacArthur and Wilson have included the relationship into the Equilibrium Theory. The factors which influence the rate of species colonization are depicted in Figure 2.

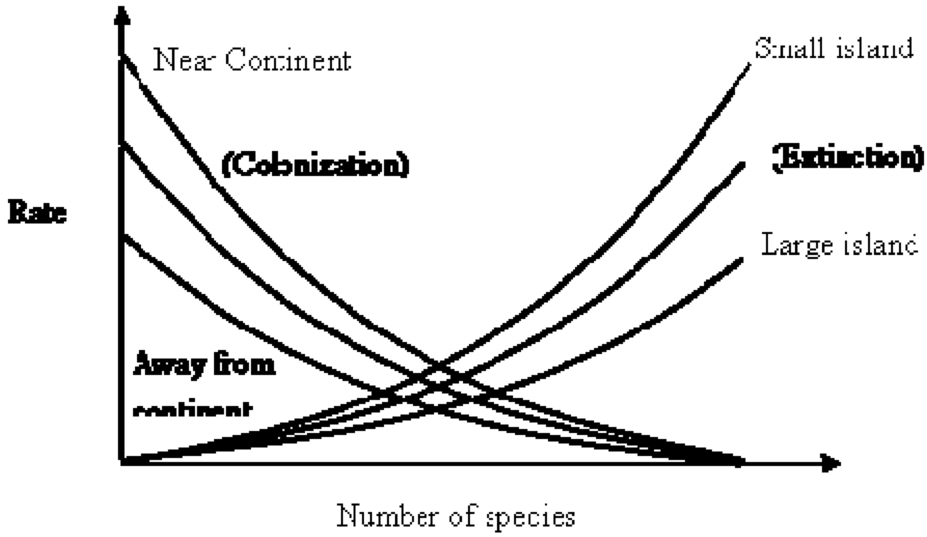

Figure 2. The influences of island geological conditions on the equilibrium of island ecosystem.

1. The higher degree of isolation of islands the lower bio-abundance and lower rate of species colonization.
2. The islands in the areas of lower latitude have higher rate of species colonization.
3. The existence of stepping stones (islands between continent and the island discussed) may increase the rate of species colonization.

It can be summarized that the distance between continent and island, the relative location of islands, and latitude of an island are major elements in influencing the number and immigration rate of species on the island.

Species-Area relationship

Numerous biologists have perceived that there is a certain relation between the area of an island and its number of species under a similar ecological and geological situation. They found that the larger the island, the higher the number of species. MacArthur and Wilson formulated this relation mathematically as the following equation.

$$S=CAz,$$

where S: number of species; A: area of the island; C: a constant associates with the geological location; and Z: constant depending on the species which is normally between 0.24~0.34. If we take a logarithm for both sides of the equation, we have a linear form for the relation as

$$\log S=Z(\log C+\log A),$$

To test the validity of the equation, MacArthur and Wilson collected the data of amphibians on Caribbean islands and compared it to the prediction by the equation. The correlation was excellent as shown in Figure 3.

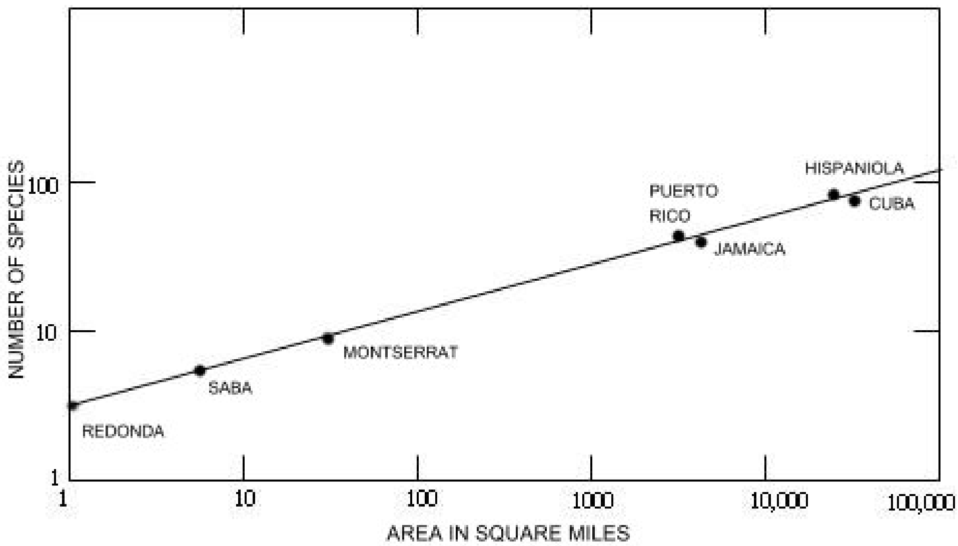

Figure 3. Relationship of number of species and areas of Caribbean islands.(Duplicated from The Theory of Island Biogeography, p8)

To test the equation in Asia, applying the equation with the number of resident birds of Taiwan and Kinmen, we are able to calculate the constants of C and Z. With constants known, the number of resident birds on Okinawa islands, Japan, can also be predicted as S=53 (Lin, 2006). The observation found that S=54 on Okinawa islands (McWhirte et al., 1996).

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These two cases show a good agreement between the equation and observations. The nonlinear equation also implies that by assuming Z=0, an island loses 50% of its area, as the equilibrium of the island ecosystem is reached, 20% of its species will be lost. If 10% of an island's area remains, 50% of the species will be lost (Figure 4). The species-area relationship became a very important theoretical foundation for conservation biologists to design wild life reserves and to assess the impacts of habitat fragmentation. Even though the Equilibrium Theory and species-area equation have been challenged for their over-simplicity, their basic idea is still guiding the development of ecological conservation.

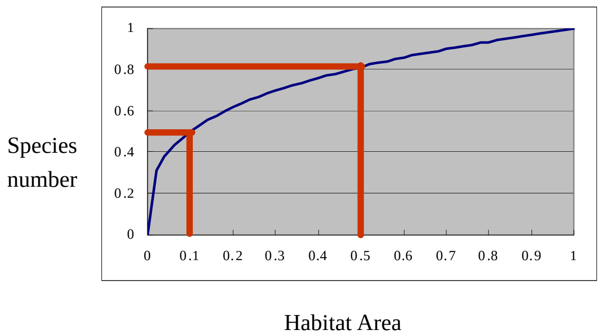

Figure 4. Relationship between species number and habitat area

Implications of the Theory of Island Biogeography

An island is an isolated ecosystem surrounded by ocean, and a similar situation can be found for various terrestrial ecosystems. A woodland surrounded by farmland; an oasis surrounded by desert; a wetland; a lake; a river; a cave; an urban park; large national parks; natural reserves; mountainous areas; prairies etc. are also isolated and unique ecosystems. They are called continental habitat islands (Gorman, 1979). These ecosystems, independent from the surroundings, are similar to the island ecosystem where colonization, competition, extinction, and equilibrium are constantly happening. Therefore, the theory of island biogeography can be applied to continental habitat islands. The implications of the theory on conservation ecology can be summarized and listed as following principles.

1. Habitat islands close to a large habitat have higher rate of species colonization and higher degree of biological abundance.
2. Two habitat islands with stepping stones located between them would have higher rate of species colonization.
3. Habitat islands located in lower latitude areas have higher degree of biological abundance.
4. With similar ecological characteristics, large habitat islands have higher number of species.

Concepts of the theory can be applied to the design of natural reserves and preservation of remnant habitats due to construction or development. Diamond (1975) suggests some simple rules for conservation planning based on island biogeography as shown in Figure 5.

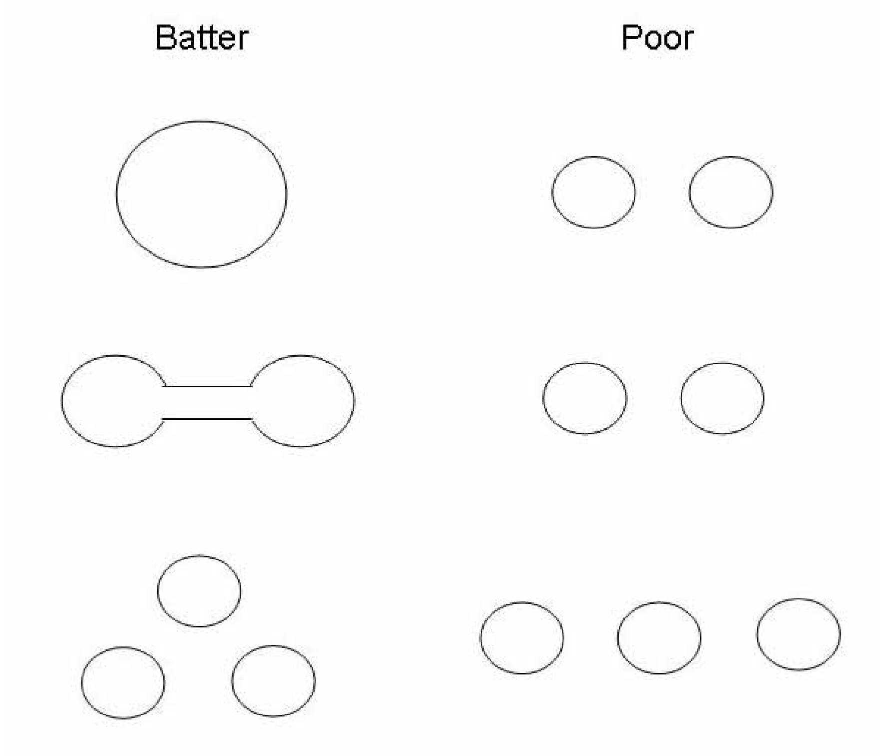

Figure 5. Different configurations of conservation areas or remnant habitat compared

The theory of island biogeography provides fundamental principles for conservation to increase the rate of species colonization, number of species, biodiversity, and bio-abundance. However, the theory simply sees the ecosystem as a habitat (island) or non-habitat (ocean). This is over simplified in categorizing the characteristics of ecosystems and can not explain various situations. On the other hand, with similar area, latitude, and degree of isolation, one habitat island is round and the other is elliptic. Which habitat has higher degree of biodiversity? It is obvious that the theory of island biogeography can not explain the implications of some ecological factors such as shape, texture, and distribution patterns of habitats. After years of research, a new field of ecology, Landscape Ecology, has started to emerge.

Landscape Ecology

The domain of landscape ecology is broad. Forman (1995) considered a landscape as a form of land mosaics and has classified landscapes into 3 elements which are patch, corridor, and matrix. Based on the pattern, distribution, and evolution of land mosaics, the effects of driving forces by nature, human, and organisms on the ecosystem of a landscape can be obtained. Land use planning can then be used to increase landscape biodiversity. The basic ideas and principles of landscape ecology applied to conservation can be summarized by the following.

Patch (Habitat)

1. Area: Large patches have higher bio-abundance and biodiversity. However, small patches still can be ideal habitats for species which can not survive in large patches.
2. Number: To preserve diversified species, 2 large patches along with a few small patches are needed.
3. Metapopulation: Organisms can migrate or interchange gene among dispersed patches and their movement routes should always be preserved to maintain the metapopulation mechanism.
4. Shape: A round habitat is ideal for major habitats due to less edge and larger inner core area.

Edge

1. Disturbances: Habitat edges are disturbed by human development or microclimates. The disturbances along habitat edges may include air pollution, soil erosion, noise, road kill, high human accessibility, introduction of invasive species, increase of evapo-transpiration rate, raise of local temperature, decrease of humidity, and a higher rate of sun light.
2. Structure: The structure of edge affects the permeability of organisms. High diversity, broader width, high penetration rate, and lower landscape gradient can increase colonization rate for most species.
3. Shape: Animals prefer curved edges over straight ones to penetrate into a patch.
4. Softness: Soft landscape gradient can provide more ecological benefits than hard ones. That means that sudden landscape change may lower the rate of usage by most organisms.

Corridor

1. Function: Habitat corridors such as hedgerows, windbreaks, linear woodlands, and rivers can function as animal migration conduits, habitats for various organisms, buffer zones for water resource, recreational areas, agricultural landscape elements, or agents for cultural and community identity.
2. Similarity: To enhance the usage by animals, the structure and texture of a corridor should be arranged to match the characteristics of adjacent vegetation and habitats.
3. Stepping stone: In an area where corridors are not connected, a series of stepping stones can provide substitute migration routes for animals.
4. Artificial corridor: Artificial corridors such as roads, railroads, and electric transmission cables may disturb or form ecological barriers to local organisms or migratory animals. They may also provide assess for exotic or disturbance tolerant species into the ecosystem.
5. Stream: The width of riparian vegetation

must be sufficient to absorb the nutrients and chemicals, and to facilitate migration corridors for amphibians.

Habitat Configuration

1. Network: Habitat or green networks can furnish organisms with dwelling, interaction, or migration conduits. The well connected networks may lower the possibility of local extinction and improve regional gene diversity.
2. Node: Nodes, intersections of habitat networks, can effectively facilitate organisms with brief habitat or breeding places.
3. Fragmentation: Habitat fragmentation leads to habitat loss, reduction of core area, increase of edge areas, increase of degree of isolation, adverseness of habitat quality, and ultimately breakdown of interior species population.
4. Grain size: Various organisms have distinct concepts of landscape grain size. However, fragmented landscape with coarse grains is adverse for most organisms. It is necessary to maintain a continuous landscape with various grain sizes.

Habitat Shape and Distribution

The effects of shape are not noticeable in large habitats but they may be decisive factors to small or fragmented habitats. In landscapes where natural habitats are constantly reducing, it is important and feasible to develop ideal shapes for habitat. The edge located between the patch and matrix plays a decisive role in designing the shape for habitat. The microclimate, local environment and resources of the edge form a unique ecosystem and create driving forces to alter the adjacent vegetations. The effects of edge on vegetation cover may include (1) introduction of exotic species, (2) increased seedlings, (3) increased bush coverage, (4) increased species abundance, and ultimately change the whole landscape vegetation and affect the survival of animals within the landscape. Animals may also be ecologically or geometrically affected by the edge, but most importantly the impacts are two fold. (1) Increase of edge species: Most disturbance-tolerant or generalist species such as squirrels, raccoons, sparrows, cuckoos, and rodents concentrate along the edges of woodland due to the resources within the area. Most parasitism happens along the edge and cause great reduction of interior or vulnerable species and finally may lead to the breakdown of the whole ecosystem. It can be found that human developments (such as road construction) create edges that become ideal habitats for edge species, and a high degree of development would cause an explosion in the number of edge and generalist species. (2) Decrease of interior habitat: generally, edge species are neither endangered nor rare species but interior species whose habitats are mostly located in the core area of natural lands are. Because of their low tolerance to disturbances, interior species would be expelled into the remnant core area once new edges are created. More development or high road density will greatly reduce the size of the core area of woodlands and may eventually lead to local extinction of interior species.

Considering the abundance of both interior and edge species, a so called star-ship shaped habitat is effective (Forman, 1995). A large spherical habitat provides sufficient core area (the shade area in Figure 6) for interior species and the arms as shown in Figure 6 act as conduits for animal to enter the habitat. On the other hand, there is still abundant area for edge species such that a balance between edge and interior species can be accomplished.

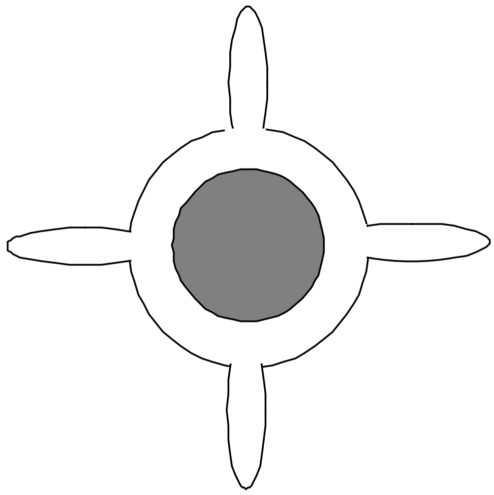

Figure 6. Star-Ship Shaped Habitat

The distribution pattern, degree of isolation, connectivity, and configuration of a habitat produce various effects on the integrity of a regional ecosystem. Before the commencement of a construction or development, proper management or arrangement of landscape elements may maintain the sustainability of local species populations. The following principles can be considered in landscape design.

1. Maintaining a large and integrated habitat to reduce the degree of fragmentation.
2. If large habitats can not be achieved, habitat clusters may reduce habitat isolation and promote species interaction among the habitats.
3. To lower the number of edge species, regular or near round shaped habitats are preferred.
4. Green corridors connecting habitats would provide animals with conduits for interaction or migration.
5. Considering designing series vegetation stepping stones to facilitate substituted routes for un-linked green corridors.
6. An ideal habitat is textured with diverse landscape elements and avoids abrupt vegetation gradients.
7. Reduce landscape change frequency and sustain natural evolution within the ecosystem.

These are only general principles for habitat management. The design details have to be local and based upon geological environment, climate conditions, ecosystem characteristics, organisms, and landscape functions. However, the principles can be a blueprint for ecologically friendly engineering planning.

Framework of the theories of ecological conservation for engineers

Most engineering developments of eco-technology conducted in Taiwan are focused on vegetation arrangement, reduction of cement usage, or utilization of natural construction materials. It is much more important for regional conservation to implement mitigation of edge disturbances, create ecological corridors, decrease the degree of habitat fragmentation, maintain habitat size, build green networks, create stepping stones, design proper habitat shapes, and soften the landscape gradient. The gap between engineering practice and ecological conservation was formed because most engineers are unfamiliar with the concepts of biological conservation and few biologists get involved in engineering design. Hence, the results of current eco-technology practices are only effective locally and the contribution to conservation of regional ecosystems is limited and, sometimes, the outcomes of eco-technology are misunderstood by the public. To enhance regional biodiversity, it is more effective to transform ecological engineering into a catalyst for ecological conservation by planning large scale ecosystem connection and stimulating metapopulation mechanisms within the framework of engineering design. Such that a civil engineer with basic knowledge of island biogeography and landscape ecology will be able to carry out some ecologically friendly practices and fulfill the requirements of conservation.

As discussed above, the basic theoretical framework of ecological engineering should be extended on the foundation of Island Biogeography to Landscape Ecology blended with the concept of Biology and Ecology and fit in Land Planning and Civil Engineering Technologies to shape the Eco-Technology for Conserving Regional Ecosystem (as shown in Figure 7). It is the objective of Eco-Technology to implement an ecologically tranquil engineering design.

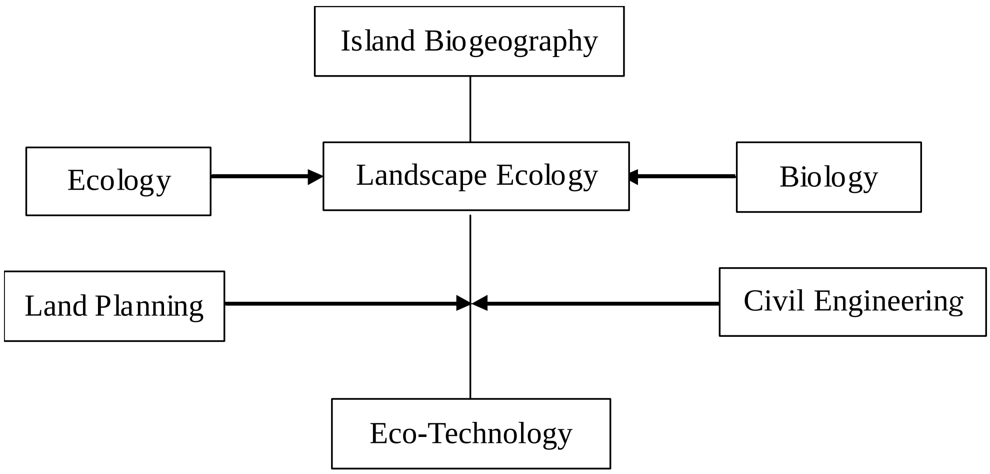

Figure 7. Theoretical framework for Eco-Technology

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Assessing Wooden Material Application in Ecological Engineering Methods in Taiwan

Chiang Wei[1], Far-Ching Lin[2], Chin-Ling Lee[3], Yu-San Tseng[3], Yi-Jru Chien[4]

[1] Assistant Researcher, Experimental Forest, National Taiwan University

[2] Assistant Professor, School of Forestry and Resource Conservation, National Taiwan University (corresponding author) E-mail: farching@ntu.edu.tw

[3] Research Assistant, Experimental Forest, National Taiwan University

[4] Graduate Student, School of Forestry and Resource Conservation, National Taiwan University

Abstract

The Central Taiwan region suffered severe damage caused by debris flow during the disastrous Chi-Chi Earthquake in 1999, Typhoon Toraji and Nali in 2001. Rehabilitation work was undergoing by the authorities who invested a great deal of money and resources. Part of the work adopted the ecological engineering techniques to reconstruct the facilities such as the articulated blocks bank, gabion and geogrid walls by the “local material was utilized first” principle to reduce the usage of concrete. Some of these facilities based on the design of ecological techniques, which was made of wooden material, had passed the test of Typhoon Mindulle in July of 2004. However, few studies were focused on the design, monitoring and assessment of the wooden material applied on ecological works in Taiwan. This study analyzes some ecological works made of wooden material by the Forest Bureau, the Soil and Water Conservation Bureau and National Taiwan University Experimental Forest where these works are located in Yilan and Nantou County respectively. The displacement, strength, rottenness and water content of wooden structure, along with the recovery benefits were monitored and assessed in this study. The preliminary results show that the displacement and rottenness of wooden material works is minor and the safety is quite well subject to the subsequent typhoons and large rainfall events between 2006 and 2007. Besides, the vegetation spreads well over the works and merges with the environment after the wooden material works are finished and the abundance is also investigated to stand for the recovery effect of these works. Further, by comparing wooden ecological works with concrete ones, the former can obviously decrease the amount of carbon dioxide emission and increase sequestration of carbon in the material. The result provides a key reference to set the design regulations and rules in the future.

Keywords: wooden material, ecological engineering techniques, assessment and monitoring, carbon sequestration

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木質材料應用於臺灣地區生態工法之監測與效益評估

臺灣中部近年分別於 1999 年遭受九二一集集大地震、2001 年桃芝颱風及納莉颱風引發之土石流侵襲，有關單位耗費相當之資源進行復建工程。部份復建工程採用『因地制宜、就地取材』如砌石護岸、蛇籠、格柵式擋土牆等生態工法進行，其中部份以木質生態材料進行之復建工程，亦已經通過 2004 年敏督利颱風之考驗。然而在臺灣有關利用木質材料進行之生態工法案例，仍少有研究針對其工法之設計、後續監測與評估進行較深入之探討。本研究針對行政院農委會年林務局、水土保持局及臺大實驗林管理處於災後於宜蘭與南投縣所興建之生態工法木質結構物進行分析。其中包括木質結構物後續之變位、腐朽程度及結構強度及其完成後植生覆蓋之效益進行分析。經過 2006 年三月至 2007 年六月為期一年多之監測，初步結果顯示木質結構物歷經後續之颱風豪雨侵襲，其結構監測點之變位仍屬輕微；木質之腐朽強度及結構強度仍維持良好之狀態。而取代傳統硬式混凝土工法之木質材料之生態工法，於完工之後更利於植生之被覆與復育。除讓工程結構物更融入週遭環境，研究中亦針對被覆之植生進行定量之現地調查分析，其結果亦顯示對植生復育具有正面之效益，同時相較於混凝土材質，使用木質材料之結構物亦可有效降低二氧化碳之排放。本研究結果可提供未來利用木質材料進行生態工法設計時之重要參考。

關鍵詞：木質材料、生態工法、監測與評估、碳吸存

Introduction

Since Odum first defined the ecological engineering at the Conference of the Suburban Forest and Ecology in 1962 (Odum, 1962), it had become a new field with its roots in the science of ecology. It can be viewed as the design, restoration, and protection of ecosystems according to ecological principles that we have learned over the past century (Mitch and Jorgensen, 2004). After natural disturbances such as earthquakes and typhoons in recent years, areas in Central Taiwan were severely damaged by typhoon Herb in 1996, the 921 Chi-Chi earthquake in 1999, typhoon Toraji and Nalie in 2001, and typhoon Mindulle in 2004. Unlike the traditional engineering work that uses concrete material, part of remediation works following these disasters used wooden materials. Considering the strength of the structure, there are few engineering works made of wooden material, which is commonly used as the material of staking and wattling for stabilizing the slope land and back filling of rock revetment along the streams in Taiwan (Lin et al., 2004). Since the Kyoto Protocol on global climate change had taken effect on February 16, 2005, the reduction of carbon dioxide and the application of ecological engineering have received close attention both in the general public as well as the academia. However, few studies were focused on the monitoring and assessment of wooden materials. Most experts and scholars still hold the conservative viewpoint for the safety of wooden structure. In fact, the detailed characteristics of wooden material are yet to be verified and it provides good opportunities for interested researchers. Wang et al. (2005) analyzed the thinned logs of Japanese cedar for the construction of retaining wall. They concluded that if concrete material is substituted by thinned D-log, the total carbon dioxide is significantly reduced while the construction cost is also low. Hung et al. (2006) also found the retaining wall and check dam made of wooden structure instead of reinforced concrete can significantly reduce the emission of carbon dioxide and increase the carbon sequestration. Wang (2006) first completed the “handbook of design, construction, and maintenance of wooden-based material applied to ecological engineering methods” which provide the public and engineers the rules and reference to follow. This study analyzes some ecological works made of wooden material by the Forest Bureau (FB), thw Soil and Water Conservation Bureau (SWCB) and National Taiwan University Experimental Forest (NTUEF) where these works are located in Yilan and Nantou County respectively. The displacement, strength, rottenness and water content of wooden structure, along with the recovery effect are monitored and assessed in this study.

Methods and Materials

This study monitored the variation of wooden material applied on check dam, revetment and retaining wall built after Typhoon Toraji in 2001 from February 2006 to July 2007. As the word “monitor” stated that it is essential to make measurements at regular intervals over a substantial length of time (Wiersma, 2004). However, due to the different characteristics of parameters, such as strength of the structure, displacement of the structure, abundance of vegetation, the measuring interval in this study vary each other according the degree of variation previously investigated (Lee, 2006). Except the displacement of wooden structure measured at every season, other measurements are made annually. Monitoring items in this study included detecting the rottenness, the estimation of strength of logs and displacement of structure. The positive benefits if these wooden structures were assessed by the vegetation restoration, reduction of carbon dioxide and carbon sequestration by using wooden material.

Study sites

The wooden structure located in Yilan and Nantou County were designed and built by different units. The detailed characteristics of these structures are shown at Table 1 and their locations shown at Figure 1. No.1 site was located at University Gully in Sitou Tract of NTUEF which is regarded as an experimental design. The University Gully area suffered severe damage of debris flow induced by Typhoon Toraji and Nalie in 2001. According to the investigation by NTUEF after the disaster, two hectares forestland of *Taiwania cryptomerioides* and *Cryptomeria japonica* were damaged and over 200,000 cubic meter debris still lied above the gully. The first stage for reconstruction work including staking and wattling on the slope, stone masonry for revetment, sabo dam, comb dam, submerged dam, warning facilities for debris were completed in 2003. However, few applications of ecological engineering were implemented at this site surrounding beautiful scenery of forest. In 2005, several projects based on ecological technique were accomplished at University Gully area (See Figure 2). Two distinguished check dams made of Japanese cedar and moso bamboo were first utilized to test the feasibility of wooden material applied on ecological engineering; revetment also made of Japanese cedar was selected in replace of stone masonry. In particular, the Japanese cedar and moso bamboo were the domestic wooden material by annually thinning and cutting which fulfilled the basic principle of ecological engineering, i. e., “utilizing local materials first”. No.2 and No.3 sites were located in Shan-An Village, which is in the watershed of a tributary of the Chenyoulan River (See Figure 3 and Figure 4). This river was one major upstream of Jhuoshuei River, which is the longest river in Taiwan, also very famous for the disasters of landslide and debris flow since Typhoon Herb in 1996. Shan-An village suffered large lives casualties during Typhoon Toraji and reconstructed as an important demonstration site for ecological engineering by SWCB. We select one site for revetment of little creek and one retaining wall beside the road by using wooden material. No.4 site (See Figure 5) was located at Ren-Lun village where there was a huge landslide after Typhoon Toraji. No.5 site (See Figure 6) was beside the Provincial 16th Road at Ming-He village which lies on the north embankment of Jhuosheui River. There are eight wooden retaining walls along the Provincial 16th Road and we only selected representative one. No.6 site (See Figure 7) was located at Road Yichuan No.1 1.72K in Datong Township Yilan County. There were also several wooden structures built by Loudong Forest District Office of Forest Bureau and selected as sample site for analyzing the construction of retaining wall (Wang et al., 2005). All these six wooden structures were finished after 2003 and survived the typhoon and rainfall events before this study began in 2006. The corresponding time diagram for monitoring and rainfall event, for example, No.1 site illustrated in Figure 8 is clear to shown the influence between the events.

Table 1 Characteristics of monitored wooden structure

		No. 1 Site	No.2 Site	No. 3 Site	No. 4 Site	No. 5 Site	No. 6 Site
location	County	Nantou	Nantou	Nantou	Nantou	Nantou	Yilan
	Township	Sinyi	Shueili	Sinyi	Sinyi	Shueili	Datong
	Village	Lugu	Shan-An	Shan-An	Ren-Lun	Ming-He	
	Site	University Gully	Road near the Anshan No.4 Bridge	Creek beside the Anshan No.4 Bridge	1K Landslide to RoGeGe Bridge	Beside the Provincial Road No.16 23K	Road Yichuan No.1 1.72K
Type		Check dam revetment	Retaining wall	Revetment	Retaining wall	Retaining wall	Check dam
Material		Japanese cedar Moso bamboo	China Fir	China Fir	China Fir	China Fir	Japanese cedar
Monitored/Estimated items		RoS SoS DoS	RoS SoS V	RoS SoS V	RoS SoS V	RoS SoS V	RoS SoS V
Coordinates (m)	TM2 X	227494	235649	235776	239240	238532	299897
	TM2 Y	2618229	2625290	2625218	2630911	2632186	2717440
Elevation (m)		1230	633	653	382	346	483
Watershed		Bei-Shi river	Chenyoulan River	Chenyoulan River	Jhuoshuei River	Jhuoshuei River	Lanyang River
Establish year		2006	2005	2004	2003	2003	2005
Establish unit		NTUEF	SWCB	SWCB	SWCB	SWCB	FB

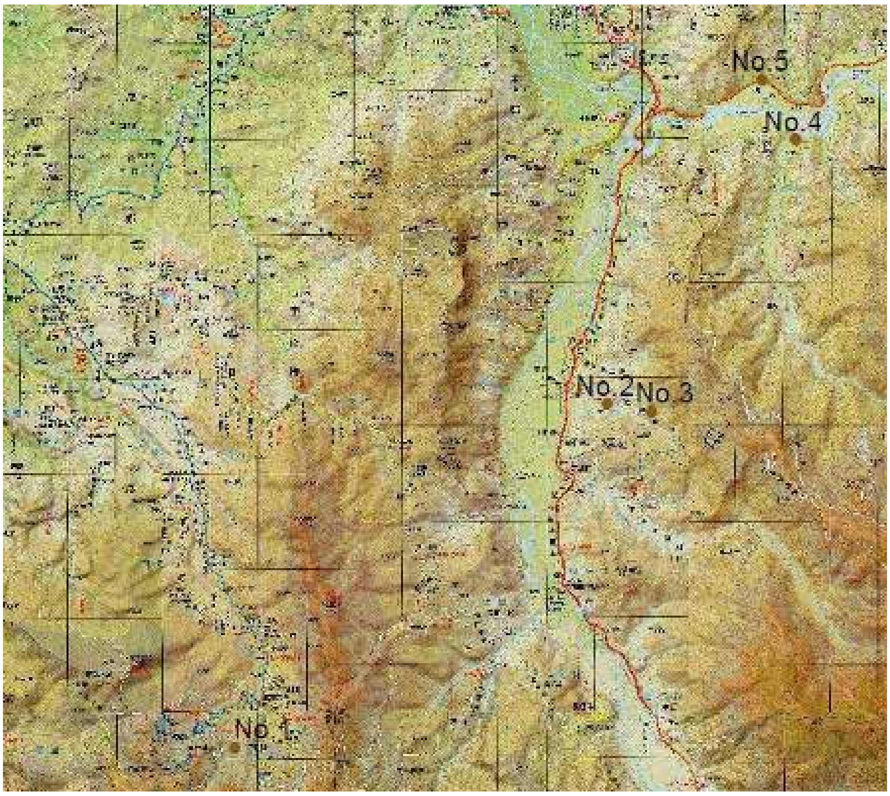

Figure 1. (a) Locations of No.1-5 site in Nantou County

Figure 1. (b) Location of No.6 site in Yilan County

(all photos taken by Dr. Chiang Wei)

Figure 2. Ecological works at No.1 site, University Gully, Sitou

Figure 3. Retaining wall at No.2 site, Shan-An, Shueili.

Figure 4. Revetment along the creek at No.3 site, Shan-An, Shueili.

Figure 5. Retaining wall at No.4 site, Ren-Lun, Sinyi.

Figure 6. Retaining wall at No.5 site, Ming-He, Shueili.

Figure 7. Check dam at No.6 site, Datong, Yilan.

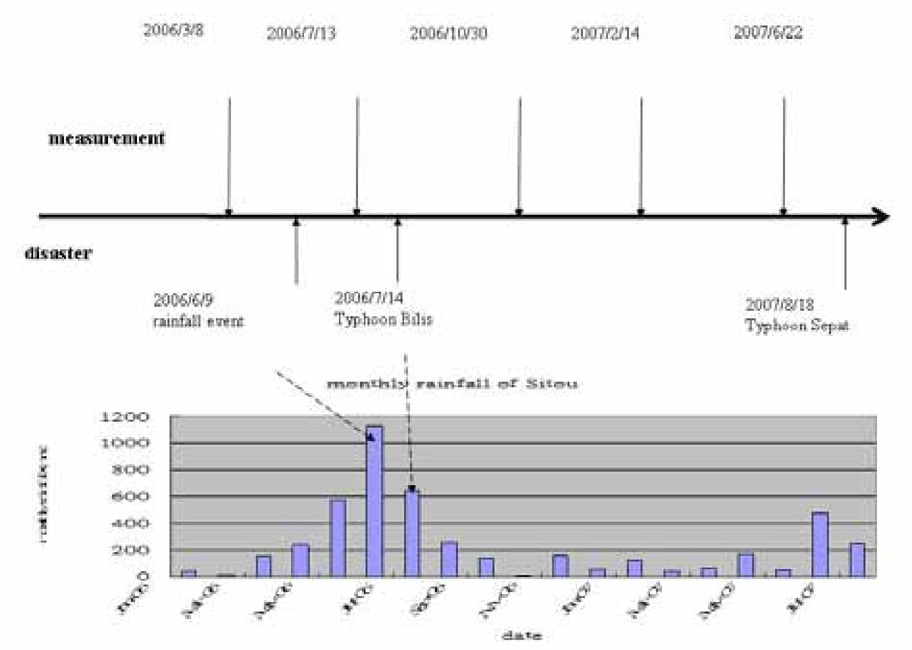

Figure 8. The corresponding time frame for monitoring displacement with disasters and monthly rainfall diagram at No.1 site

Detecting the rottenness of wooden material

Outdoor wooden facilities are exposed to sunshine and precipitation, and vulnerable to bio-degradation both cause wood decay. Hence, preservative treatment on wood is recommended when it was used outdoors. The surface rottenness of these wooden members was measured by a wood tester, PILODYN-6J, made by PROCEQ SA, Swiss. The tester is driven by a spring with constant energy, 6 joules, and impacts on wood surface by a 2.5mm pin in diameter. The impact depth was recorded in order to calculate the surface rottenness.

Estimating the strength of wooden material

Once the rotten depth was measured, the residual strength of wooden member could be estimated since rotten part of member could not carry load. The estimation is based on the bending strength of member. Hence, the section of modulus is considered because the extreme fiber stress is equal to bending moment divided by section of modulus. Section of modulus could be calculated as follows:

$$Bending\quad Strength\quad \mathrm{Re}taining(\%) = S_1 / S \times 100\%$$

where S1 is residual section of modulus due to rotten and S is section of modulus.

$S_1 = (d - 2r)^3 \pi / 32$, while d is original diameter and r is depth of surface rottenness.

$$S = \pi d^3 / 32 \quad (1)$$

For circular cross section member, while d is the diameter of the member

$$S = wt^2 / 6$$

For square section member, while w and t are width and depth of the member, respectively.

Monitoring the displacement of structure

The strength of wooden structure is not as rigid as concrete or even reinforced concrete structure. However, it still can be applied on small watersheds or hills of mild slope without instant danger. We monitored the displacement of No.1 site where check dams and revetment existed. For the monitoring process, first we selected several reference control points, and set monitored points with marked nails on the main joints of wooden structure (See Figure 9). Originally monitored points on check dams were located at the joints on the downstream side, considering the influence of the backfilled material inside the check dam several monitored points on the upstream side were added at the second measurement. The accurate position and elevation were measured by laser theodolite (See Figure 10). All displacement of each measurement was estimated by comparing with the reference control points which is regarded as fixed points while there is no actual big earthquake during the period of this study. The locations of all monitored points at site 1 are shown in Figure 11.

Figure 9. Monitored points with marked nails on the joints of wooden structure at No.1 site

Figure 10. Monitor the displacement of wooden structure with laser theodolite at No.1 site

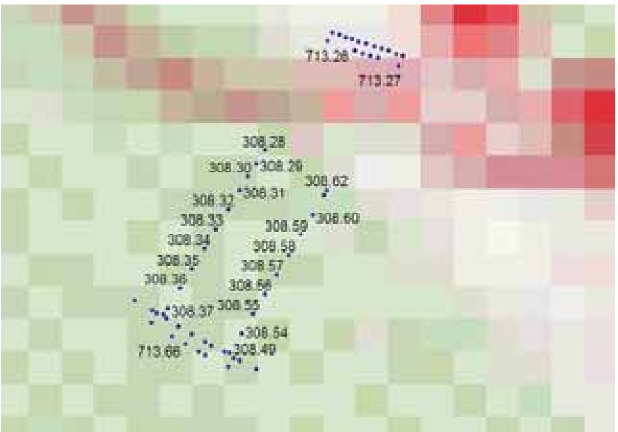

Figure 11. Locations of monitored points at No.1 site

Assessment of vegetation restoration

The restoration of vegetation implies positive benefits for ecological works. The abundance and coverage of deep-rooting plants over ecological works shows the coincidence and reconciliation with environment, stabilize the bank, infiltrate the pollutant and reduce the surface runoff and also provide the habitat for wildlife and resort area for the public (Lin and Chang, 2005). Each sample site is divided into several sub-areas of 1 meter by 1 meter for investigating according to the actual size and length of the wooden structure. Three factors, including relative dominance, relative frequency and relative density are investigated. The Important Value Index (IVI) will be the average percentage of these three factors for representing the composition of society of flora. If the vegetation inside the sub-region were herbaceous plants, the IVI will be the average percentage of relative coverage and relative frequency. The computational form for IVI is shown as Equation (2). Investigation of vegetation will be done at all sites except No.1 site. The wooden structure here is backfilled with cobbles and little masonry eroded from upstream which is not suitable for growth for vegetation and surrounding area is artificially rooted with different kind of tree and plants (Wei, 2006). In order to assess the natural restoration of vegetation, we neglect the No.1 site. The time interval for investigating the vegetation will be once a year, considering there is no significant seasonal change (Wei et al., 2007).

For wooden plants

$$IVI = (relative \quad density + relative \quad dominace + relative \quad frequency)/3$$

while $\quad relative \quad density = density \quad of \quad certain \quad kind / total \quad density \times 100$

$$relative \quad dominance = bottom \quad area \quad of \quad certain \quad kind / total \quad bottom \quad area \times 100$$

bottom area is computed by DBH (Diameter at Breast Height) curve

$$relative \quad frequency = numbers \quad of \quad sample \quad area \quad for \quad certain \quad kind / numbers \quad of \quad total \quad area \times 100 \qquad (2)$$

for herbaceous plants

$$IVI = (relative \quad coverage + relative \quad frequency)/2$$

while

$$relative \quad coverage = coverage \quad of \quad certain \quad kind / total \quad coverage \quad of \quad all \quad kinds \times 100$$

$$relative\ frequency = numbers\ of\ sample\ area\ for\ certain\ kind / numbers\ of\ total\ area \times 100$$

Reduction of the carbon dioxide and carbon sequestration

Wood is composed of about 50% of carbon by weight, that is, the carbon exists as organic status and is sequestrated in tree. For Japanese cedar, its specific gravity is 350kg/m3, that is, 175kg/m3 of carbon is sequestrated. It will consume about 980MJ/m3 during processing while about 20kg/m3 of carbon is emitted. The net amount of carbon sequestration is equal to the amount of carbon emission minus the amount of carbon sequestration. In other words, the -155kg/m3 (-155kg/m3 = 20kg/m3 -175kg/m3, the “-“ means sequestration）of carbon is sequestrated in lumber products of Japanese cedar. Generally, all kinds of wood are attributed to carbon sequestrating materials while mental, plastics, and cement are attributed to carbon emitting materials.

To calculate the reduction of the carbon dioxide emission from the engineering cases constructed with wood and concrete, the volume of the facilities body should be calculated first. The following calculation was based on the information from Wood Promotion Section, Department of Fisheries and Forestry, Hokkaido. About 66kg/m3 of carbon dioxide was emitted in the wood construction. In the study, a 20m2 area of retaining wall was investigated; 3.4m3 of wood was used in Azekura retaining wall (O&D method while 8.9m3 of concrete was used in RC one. Then, considering their carbon dioxide emitting and the carbon sequestration, the wood was 66kg×3.4m3 = 224kg and 642kg×3.4m3= 2,183kg, respectively; while concrete are 440kg×8.9m3=3.916kg and 0kg, respectively. In the case, if Japanese cedar was not treated with ACQ(Alkaline Copper Quaternary), the preservative the carbon will be emitted to atmosphere within 2-3 year due to decay, that is, about 175×3.67 kg/m3= 642 kg/m3 of carbon dioxide will be generated, however, these amount of carbon will be sequestrated in wood for at least 30 years. Therefore, if concrete can be substituted by logs in construction of retaining wall, the total carbon dioxide of 5,875kg = 3,916kg + 2,183kg - 224kg, is reduced. More realistically, carbon dioxide expiration of each people is about 320kg per year, the reduced carbon dioxide amount of 5,875kg substituted by logs is equivalent to the expiration of 18 persons per year.

Results

The rottenness of wooden material

Endurance of wooden structure at all sites measured is shown at Table 2. At No.1 site, the revetment of Japanese cedar showed different result over the right and left bank. On the right bank we observed larger rottenness depth of PYLODIN both in the longitudinal and the latitudinal directions. The average rottenness of two directions on the right bank is 23.13mm

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and 21.33mm, compared to 14.35mm and 15.53mm on the left bank, respectively. The possible reason is that the right revetment on No.1 site was located beside the forestland of Taiwania cryptomerioides and Cryptomeria japonica which exists more soil pressure acting on the revetment. On the other hand, the moisture in the latitudinal direction (21.33%) is comparatively much higher than right bank (15.33%) and may cause by the same reason: the forestland preserves more water storage and it seeps from the holes and gaps underground and infiltrate into the wooden structure due to the water pressure. On the other hand, the moisture condition on both banks of check dam is quite different. The moisture content on the left bank in the latitudinal direction (27.8%) appears to be higher than that of right bank (20.97%) due to the eco-detention pond just beside the road and left bank. The moisture content at upstream and downstream of cedar check dam shows no significant difference while the value on the right bank is higher than that of left bank. The reason is possibly that the measured points both on the upstream and downstream are above the riverbed in low water level and the pathway of water may result in the moisture difference between left and right bank.

Table 2 Endurance of wooden material at all sites

No. 1 Site			No.2 Site		No. 3 Site		No. 4 Site		No. 5 Site		No. 6 Site	
Monitored Items Rottenness (R) Moisture Content (MC)	R(mm)	M C (%)	R(mm)	M C (%)	R(mm)	M C (%)	R(mm)	M C (%)	R(mm)	M C (%)	R(mm)	M C (%)
Revetment left bank (Retaining wall, check dam for Site 3-6)			14	>40		>40		>40		>40		
Longitudinal	14.35	15.34			37.1		26		11		23.7	23.5
Latitudinal	15.53	27.80			29.9		26.3		12.8		19.5	25.4
Revetment right bank			23.8									
Longitudinal	23.13	21.67										
Latitudinal	21.33	20.97										
Japanese cedar dam left bank												
Upstream	23.67	19.07										
downstream	25.20	18.15										

Japanese cedar dam left bank								
Upstream	19.25	23.15						
Downstream	18.25	23.73						
Average at site	20.09	21.23	18.9	33.5	26.2	11.9	21.6	24.5

At No.2 site, the average rottenness of revetment on the left and right bank is 14 and 23.8mm, respectively. Although the material of No.2 site (China fir) is different from that of No.1 site (Japanese cedar), the rottenness of No.2 site is very close to that of No.1 site. Two wooden structures were built in 2005 and 2006 with not much time lag. As for No.3 site, the longitudinal rottenness 37.1mm is significantly higher than 29.9mm of latitudinal direction. It may be referred that the hillside behind the retaining wall of No.2 site is heading northwards. Due to the less sunshine and more moisture, the longitudinal logs deep into the soil may be easily decayed than other sites. From the measurements shown in Table 2, it actually exhibits the highest rottenness of all sites. Moisture content of both No.2 and No.3 site were over 40%.

The No.4 and No.5 site were selected alone the Jhuoshuei River, both are retaining walls with similar length, height, material, and structure, which were also constructed in 2003 by SWCB. The major difference is the slope direction; the No.4 is toward to south while No.5 is toward to west. According the endurance of wood material shown in Table 2, the average rottenness of members at the No.4 site is 26.2mm while 11.9mm at the No.5 site. The rottenness difference could be attributed to the moisture content of soil which caused members wet and decay. It seems that vegetation at the No.4 site is much prosperous than that at the No. 5 site, which also imply there was higher moisture content of soil at the No.4 site.

The No.6 site was the only one which used ACQ treated wood as material and constructed with concrete foundation. The site is totally different from the previous five because of its climate, location, and construction method. The average rottenness shown in Table was 21.6mm and 24.5mm in both directional members, respectively. Rottenness variation was very small at the site because the preservative provided good protection on wooden member surface from decay.

The estimation of strength of wooden material

The estimation of strength of wooden material from the rottenness is shown at Table 3. The bending strength retaining ranges from 11% to 64%. Among them, the No.4 site shows the lowest value. The retaining wall was located at the foot of steep landslide area with over 100% slope which may cause larger soil stress than other sites. The bending strength retaining of the other sites is around 60%. From the rottenness and moisture content measured at No.1 to No.5 site, we found that the bark of the log was not removed and it may cause the log contain more moisture inside and easy to decay. In addition, the environmental conditions may be another reason to influence the strength of wooden structure. For example, the rainfall, relative humidity and aspect for sunlight may cause different moisture content in the soil; the level of underground water will also influence the soil moisture. At No.6 site, the log was processed by the O&D wood method, the bark had been removed and preserved by ACQ and the bending strength retaining remains very good.

Table 3 estimation of strength of wooden structure

item	No. 1 Site	No.2 Site	No. 3 Site	No. 4 Site	No. 5 Site	No. 6 Site
Average rotten depth d (mm)	20	14	33.5	26	12	21.6
Average log diameter D (cm)	15	18.3	18.3	10	16	12
Estimation of Log Bending Strength Retaining S (%)	39	50	25	11	61	26

The displacement of structure

Test site for monitoring the displacement of wooden structure are No.1 site. We made five measurements on March 8, July 13, October 30 in 2006 and February 14 and June 22 in 2007. In order to analyze the influence of backfilled rocks inside the check dam, we added five extra monitored points both on the upstream side of Japanese cedar and moso bamboo check dams. The result of displacement at site 1 is shown on Table 4, Figure 12 and Figure 13, respectively. From Table 4 we can find that major displacements happened at the right bank of revetment and the downstream of Japanese cedar check dam. The former displacements begin from 0.071 and increase to 0.097 meters and the latter range from 0.062 to 0.081 meters. The right bank shows larger displacement than left one may be caused by the soil pressure of forestland on the right bank mentioned above. The other possible reason is that the live load of passing cars and tourists may carry the inverse effect of displacement for left bank of revetment. Compared with the downstream side of check dam, the monitored points on the upstream side for moso bamboo and Japanese cedar check dams had little displacements with 0.011 and 0.075 meters at the fourth horizontal direction, respectively.

Table 4 displacements (m) of wooden structure at No.1 site

	1st Horizontal	2nd Horizontal	3rd Horizontal	4th Horizontal	1st vertical	2nd vertical	3rd vertical	4th vertical
Revetment Left bank	0.023	0.034	0.024	0.031	0.014	-0.006	0.011	0.036
Revetment Right bank	0.071	0.083	0.085	0.097	0.013	-0.005	-0.009	0.037
Upstream of moso bamboo dam	-	0.047	0.034	0.039	-	0.018	0.010	0.032
downstream of moso bamboo dam	0.043	0.107	0.040	0.050	0.043	0.004	0.027	0.053
Upstream of Japanese cedar dam	-	0.025	0.010	0.016	-	0.010	0.013	0.035
downstream of Japanese cedar dam	0.062	0.080	0.072	0.081	0.003	-0.016	0.003	0.027
Overall	0.050	0.068	0.049	0.058	0.018	-0.002	0.009	0.037

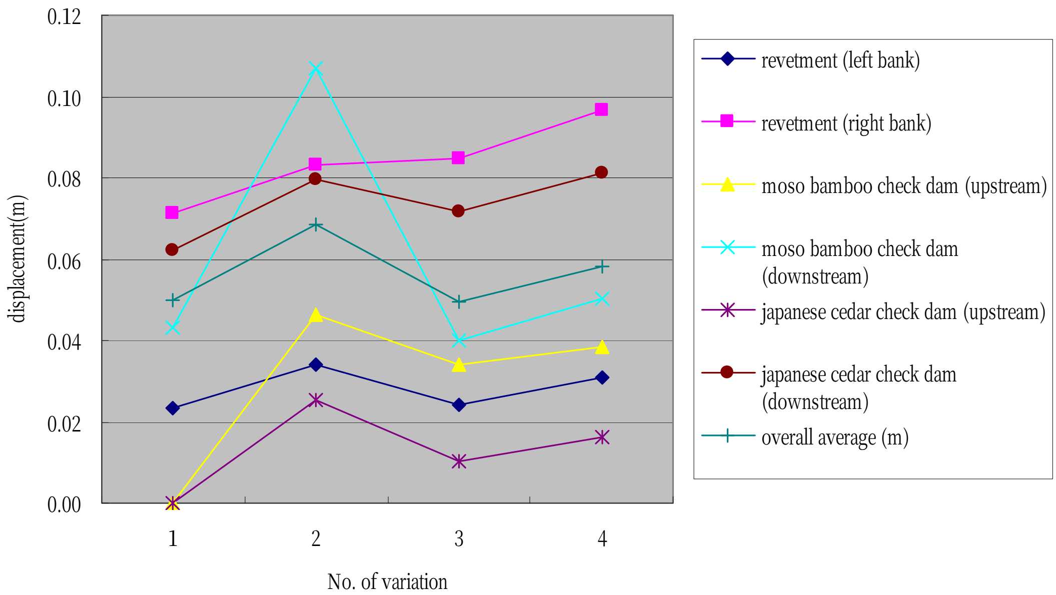

Figure 12. Horizontal variation of average displacement on joints of wooden structure at No.1 site

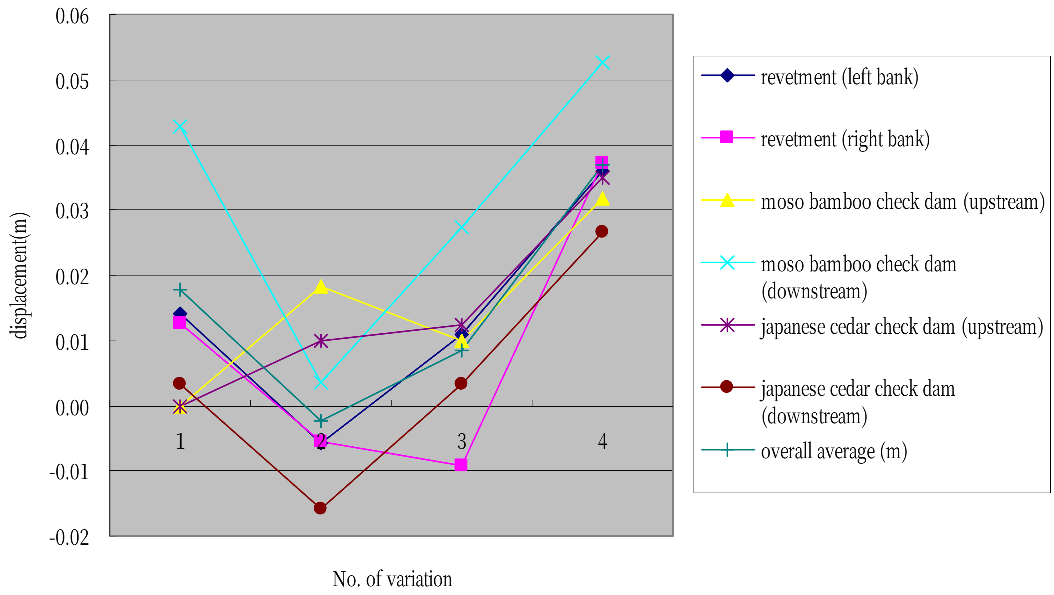

Figure 13. Vertical variation of average displacement on joints of wooden structure at No.1 site

Assessment of vegetation restoration

The investigation of vegetation covered on the top of wooden structure is shown at Table 5. Due to the restrictions of the context, we only list the first ten vegetation species with largest IVI value at all sites except No.1 site. 25,25,13,14 and 24 species were found from No.2 to No.6 site. The most dominant specie is Bidens alba, Pueraria, Miscanthu, Bidens pilosa and Lolium with IVI value of 30.45, 55.33, 56.33, 56.19 and 22.43, respectively. From Table 5 we can compare the first ten species with largest IVI value, vegetation of No.2, No.3 and No.4 are much alike owing to the similar environmental conditions such as landslide beside the road, elevation and nearby locations.

Reduction of the carbon dioxide and carbon sequestration

The estimated amount of reduction of the carbon dioxide and carbon sequestration is shown at Table 6. These quantities were based on the new constructed facilities and the rottenness was ignored after long term service. However, the preservative treated wood consumed more energy that emitted more carbon dioxide than untreated wood did during process, the carbon sequestrating ability should be better than that of untreated in a certain period. Further analysis could be conducted in order to understand the even point of time in carbon dioxide emission due to untreated rottenness.

Table 5 First ten largest IVI vegetation species at all sites except No.1 site

No.2 site		No.3 site		No.4 site		No.5 site		No.6 site	
No. of species	25	No. of species	25	No. of species	13	No. of species	14	No. of species	24
Chinese and Scientific Name	IVI	Chinese and Scientific Name	IVI	Chinese and Scientific Name	IVI	Chinese and Scientific Name	IVI	Chinese and Scientific Name	IVI
大花咸豐草 *Bidens alba*	30.45	葛藤 *Pueraria montanus*	55.33	五節芒 *Miscanthus floridulus*	56.23	小白花鬼針草 *Bidens pilosa* var. *minor*	59.19	多花黑麥草 *Lolium multiflorum*	22.43
紫花霍香薊 *Ageratum houstonianum*	21.19	大花咸豐草 *Bidens alba*	21.08	葛藤 *Pueraria montanus*	31.00	小花蔓澤蘭 *Mikania micrantha*	36.77	芒 *Miscanthus sinensis*	13.66
駁骨丹 *Buddleja asiatica*	17.63	小白花鬼針 *Bidens pilosa* var. *minor*	18.96	九芎 *Lagerstroemia subcostata*	29.50	大黍 *Panicum maximum*	15.85	白花柳葉箬 *Isachne albens*	10.04
小花蔓澤蘭 *Mikania micrantha*	17.18	木賊 *Equisetum ramosissimum*	13.58	小白花鬼針草 *Bidens pilosa* var. *minor*	21.80	樹薯 *Manihot esculenta*	13.56	棕葉狗尾草 *Setaria palmifolia*	6.29
腺萼懸鉤子 *Rubus sumatranus*	13.2	非洲鳳仙花 *Impatiens walleriana*	12.49	淡竹葉 *Lophatherum gracile*	17.93	構樹 *Broussonetia papyrifera*	11.36	竹葉草 *Oplismenus compositus*	5.60
毛蕨 *Thelypteris interrupta (Willd.) K. Iwats*	11.84	昭和草 *Crassocephalum crepidioides*	9.34	紫花霍香薊 *Ageratum houstonianum*	16.10	馬纓丹 *Lantana camara*	10.98	細尾冷水麻 *Pilea matsudai*	5.54
五節芒 *Miscanthus floridulus*	10.29	紫花霍香薊 *Ageratum houstonianum*	7.00	山月桃 *Alpinia macrocephala*	4.87	南美蟛蜞菊 *Wedelia trilobata*	10.19	闊葉樓梯草 *Elatostema platyphylloides*	5.09
颱風草 *Setaria palmifolia*	9.36	檳榔 *Areca catechu*	6.53	臭辣樹 *Tetradium ruticarpum*	4.39	淡竹葉 *Lophatherum gracile*	8.68	火炭母草 *Polygonum chinense*	4.23
葛藤 *Pueraria montanus*	7.54	心葉藤 *Philodendron scanaens*	5.71	禾本 *Poaceae*	3.92	鷗蔓 *Tylophora ovata*	8.19	長葉木薑子 *Litsea acuminata*	3.61
苦苣菜 *Sonchus arvensis*	7.46	火炭母草 *Polygonum chinense*	4.33	加拿大蓬 *Conyza canadensis*	3.74	狗尾草 *Setaria viridis*	7.02	大葛藤 *Pueraria lobata*	3.06

Table 6 estimation of reduction of carbon dioxide and carbon sequestration

	No. 1 Site	No.2 Site	No. 3 Site	No. 4 Site	No. 5 Site	No. 6 Site
Average log diameter D (cm)	16	18.3	18.3	10	16	12
Total log volume(m^3)	8.44	38.11	10.52	17.89	40.32	12.53
carbon sequestration (kg)	1519	6860	1894	3220	7258	8044
Reduction of carbon dioxide (kg)	5570	25153	6943	11807	26613	29495
Equivalent No. of persons for emission of carbon dioxide per year	18	81	22	38	86	92

Discussion

1. The construction site selection for wooden material also derives the problem- Where the engineering works should be built and what is the proper size of watershed for construction? Studies indicate that the proper area size of watershed suitable for ecological engineering works is among 300 to 2000 hectare which is the typical medium size of watersheds in Taiwan (Lin et al., 2004). In this study we only select six sample sites to test the performance of wooden structure, the proper size needs to be further analyzed by more sample sites with different watershed size, geological, soil and climatic conditions which will severely restrict and influence the usage of wooden structures.
2. From the result of rottenness depth measured from No.1 to No.5 site, we suggested that the bark of log should be removed before construction in order to sustain to life of wooden material. The log could also be preserved in the pressure process by using ACQ. But considering the pollutants voided from the wooden material, whether the construction site is located within the watershed for water resources or not should be taken into account carefully.
3. The overall average of displacement at No.1 site is around 0.05 to 0.06 meters, which is within the acceptable range despite several tests of heavy rainfall and typhoon events. The check dams of No.6 site suffered only very slight influence by the events though the watershed is smaller than No.1 site. However, the displacement of retaining wall and revetment should also be monitored by the subsequent measurements to get more proofs of the practicability of wooden material.

Conclusion and future work

We conclude that the wooden material for ecological works is feasible in small watersheds. The results of monitoring show that the wooden structure can pass the tests of heavy rainfall and typhoon events. Some logs with bark and without the preservation from decay remain little strength than others. Nevertheless, most wooden structures stand still without instantaneous danger of corruption. The positive effectiveness of vegetation restoration and carbon sequestration also indicate the potential and superiority of wooden material than other materials. However, the principles of site selection, detailed characteristics and parameters for wooden structure are yet to be developed and proved by the subsequent studies.

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