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新竹香山濕地生態系統演進模擬分析之研究
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新竹香山濕地生態系統演進模擬分析之研究

Prediction of Ecological System Change for Hsiang Shan Wetland in Hsin Chu

計畫類別：☑ 個別型計畫　□ 整合型計畫
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中英文摘要

一、中文摘要

台灣四面為海，一直以來與海的互動相當密切。台灣本島雖擁有長達 1,250 公里的海岸線，過去卻因地理位置及天然因素等限制，海岸地區的土地大多為低密度且開放的利用。然而近年隨著經濟與社會的轉變，海岸地區的土地已相繼開發以容納多元性的使用方式，但大量開發海岸地區及使用強度上的增加，是否會導致土地過度的使用與破壞生態體系的平衡，卻也成為各界相當關心之議題。有鑑於生態環境的重要性，在海岸地區的土地開發與使用上，須要更加嚴謹的評估與審核，尤其是在土地使用上區位及使用類型的選擇，皆須嚴加考量是否會對周邊的生態環境造成不可彌補的傷害。以往在海岸地區土地的使用及開發區位決策上，土地使用適宜性分析方法扮演相當重要的角色，其中自然環境因素更是分析當中不可或缺的決策因子。但傳統上以使用為導向的適宜性分析方法過於單一且主觀，且缺乏模擬與預測的特性，故本研究將先經由生態經濟的理論與觀點，收集相關文獻與資料進行分析，以建立新竹市香山濕地的生態能量系統模型，在能值與一般系統理論的概念下，透過建立其系統方程式及電腦程式輔助運算，藉由動態的模擬預測未來的生態演替趨勢。最後將預測結果應用地理資訊系統讓龐大且多樣的運算數據轉換成圖面化的整體呈現，在結合適宜性分析的概念之後，將可提供相關環境研究更落實的參考與依據。

關鍵字：生態經濟、生態能量模型、濕地、土地使用適宜性分析、地理資訊系統

二、英文摘要

Taiwan has long been influenced by ocean that surrounds it. While it has a coastline stretching 1,250 kilometers long, its geographic location and natural factors, however, have kept most of the coastal land from being used and developed. With the social and economic developments in recent years, coastal land has been developed for various purposes. Whether massive development and intense use of coastal land will result in excessive exploitation of the land and consequently ruin the balance of ecological system has become a great concern for many in different communities. As such, land use and development in coastal areas, particularly the site and purposes, should be evaluated and reviewed with more scrutiny, while the consideration should be given to whether it might cause irreversible damage to the ecosystem. The land use suitability analysis has been highly regarded in the site of land use and development, but the methods for determining the burden of development have been too one-sided and subjective, lacking the features of fussiness and prediction. Hence, this study intends to establish an ecological energetic model for Hsiang Shan Wetland in Hsin Chu, from the perspective of ecological economic theories, while adapting concepts of energetic value and general theories on common systems. By means of the formula of the system and computer calculation, the system is able to predict future trends of ecological succession through dynamic simulation. Moreover, with the aid of GIS analysis, the system can convert massive sophisticated data into graphic display, and further generate an analytical model showing urban index and energetic value index, so as to serve as references for studies in the related fields. By matching the images and the overlapping areas, the findings of this study will help with the decision on the site, and planning for the purpose and intensity of land use, and thus allow the findings of this study to be more useful for reference.

Key words: ecological economics, ecological energetic model, wetland, land use suitability analysis, Geographic Information System (GIS)

報告內容

一、緒論

隨著時代的轉變與都市的發展，都市經濟活動與種類日益頻繁及多樣化，創造出許多的工作機會與貿易行為，並且吸引區外人口至都市定居。大量的土地用來建設人們的居所與工商發展所需要的建設，並且以舊有的市區為發展核心向外擴展，在台灣都市發展過程中是相當常見的一種型態。然而在都市擴張的過程中，衍生出周邊自然環境的過度開發及環境課題，則大多是以社會需求及經濟利益來加以衡量，忽視甚至可說漠視自然環境對維繫生態系統(ecosystem)的平衡和對都市發展所扮演的角色與價值。

海岸地區一直是人類獲取海洋資源的重要媒介，也可能是促使一個都市形成所依靠的重要經濟來源。然而新竹市近數十年來因科學園區的快速發展，且因新竹市中心區的腹地狹小，讓過去一向以近海養殖業與農業為主的海岸周邊地區，逐漸轉變成都市郊區與鄰避設施(NIMBY(Not In My Backyard) facilities)的集中地。再加上西濱快速道路的開設與近年旅遊風氣的興盛，具有觀光資源的海岸景點相繼開發後所引入大量的旅遊人潮與商機，讓海岸周邊地區土地的開發逐漸成了各界關注的焦點，也成了環保團體、利益團體與政府三者之間角力的舞台。

先姑且不論開發海岸地區的目的為何，抑或不論在土地使用強度上是否需要限制，每一寸土地的開發，人類都是去改變自然環境來迎合人類的需求，且其行為往往都是不可逆的結果。從這個觀點來看，過去我們在形容繁華的商業土地時是叫作寸土寸金，現在似乎更適合用來形容我們所要開發自然環境中的每一塊土地，尤其是在新竹海岸濕地擁有豐富的生態環境條件下，更是需要縝密的評估制度來規劃每一塊土地，去避免觸碰到極為敏感的生態體系，來繼續維持新竹海岸濕地物種的多樣性及保持自然環境對周邊都市地區所提供的維生服務。

過去在開發土地時,常藉由土地使用適宜性分析(land use suitability analysis)來做為決策上的參考或依據，而自然環境保護等相關因素在近年因環境意識的抬頭，已成為土地使用適宜性分析進行時相當重要的判斷指標。不過其分析判別的方法仍過於單一且缺乏模擬預測的特性，無法掌握及了解後續對生態環境所造成的影響與傷害，並且忽略了整體生態系統平衡的重要性，僅以數個較具有指標性的生物種類及數量加以評估，有失系統評估的客觀性與整體性。

鑑於上述的研究背景與動機，本研究將由生態經濟的觀點了解研究區內生態系統各元素之能量(energy)組成與相互的關係，進而建立生態能量系統(ecological energetic system)，用以模擬及預測新竹香山濕地生態系統之改變，並利用地理資訊系統(Geographic Information System, GIS)去呈現其結果，最後將重新檢視新竹市海岸周邊地區自然環境系統之發展。歸納研究目的為下述兩點；

(一)應用生態經濟學(ecological economics)基礎，建立新竹香山濕地的生態系統模型，透過能量流動(energy flow)之模擬及預測，分析香山濕地各組成變數間的互動關係。

(二)利用地理資訊系統(GIS)，將透過動態模擬所運算出的數據加以圖面化，以利往後相關研究的比對及利用，並可做為海岸地區土地使用適宜性分析之參考。

二、理論應用分析

自然環境系統一直被經濟系統視為外部性的一個考量，但事實上自然環境與經濟體系的關係卻是密不可分的，因此生態經濟學乃將兩者涵括於一體。本研究將對生態經濟學的涵義與相關文獻進行回顧，進而了解生態經濟學的理論基礎與其應用的方式。

生態經濟學是一門新的跨領域學科，旨在由廣義的角度，探討生態系統與經濟系統之間的關係，此關係為當前人類所面臨許多問題之中心議題，且為目前許多學科所無法涵蓋，是未來探討永續性議題之關鍵所在。

傳統經濟學之世界觀是以人為本，人類的偏好主宰經濟行為的行動力，由於對科技的進步抱存極為樂觀的態度，因此傳統經濟學視資源為無限量的供應，且不同因素兼具可替代性。而生態經濟學的世界觀較為廣義，人類的偏好、科技與組織，皆應與自然環境所提供之機會與限制共同演化，且以演化作為探討內部結構變化之根源。所謂的演化(evolution)是指一複雜系統再調適改變之變化、選擇的過程，為動態的、非均衡的，在考量的時間、空間與生物種方面，生態經濟學所涵蓋的範圍較傳統經濟學與生態學更廣(黃書禮，2004)。

生態系統模型的建立將可提供決策者做為推論預估的根據及有利於決策上的判斷，在透過一般系統理論(general system theory)所建立的生態能量系統(ecological energetic system)時，不但可以用來了解人類行為對生態系統潛在的影響，更可得知生態系統與經濟系統相互依賴的程度與共生共利的特性。(Costanza et al, 1991)

表 1 生態經濟學與傳統經濟學及生態學之比較表

比較項目	傳統經濟學	傳統生態學	生態經濟學
基本的世界觀	機械式的、靜態的	進化的，原子論的	動態的、系統的
時間考量	短期 1~50 年	日~代	日~代
空間考量	地方~國際	地方~區域	地方~全球
生物種	人	非人之生物	包含人的整體生態系統
主要的總體目標	國家經濟成長	物種生存	生態經濟系統之永續性
研究重點	偏重數學	偏重技術與器具	偏重問題探索

資料來源：Costanza et. al,(1991)

近代的系統理論，其重要的概念乃是系統具有交互作用、整體性、組織性、複雜性及演化性，而系統是由數個相關的個體所組成，各個體相互之間有直接及間接的聯繫，彼此之間有互動的關係，在真實環境中大多為開放系統具有能量輸入及輸出的關係，能與週遭的系統產生互動，並且具有回饋的機制(feedback mechanism)，將輸出的能量透過反省機制再轉回輸入的條件。

系統亦可為真實環境的縮影，具有複雜性(complexity)與階層性(hierarchy)的特性，進而再進一步細分為次系統，並組織其階層的關係，聯繫各次系統間的互動，整體來看小至細胞、大至宇宙皆可視為一個系統（高偉傑，2001）。

生態學家 Howard T.Odum 藉由生態經濟之觀點，引進熱力學定律與能值分析(emergy analysis)，探討生物與非生物之間，甚至人與自然環境間之關係，以圖形方式來表示一生態系統中所包含之組成成分以及組成成分間之相關性。由生態經濟學所建立的能值評估觀念，有別於個體經濟學之觀點，其乃是由整體經濟的角度，結合生態與經濟系統，以能量為衡量單位另建立一價值體系。但此方法並非用來取代市場貨幣之衡量，

而是用來評估自然作用對經濟系統的貢獻，適用於作為政策分析的工具 (黃書禮，2004) 。

經由一般系統理論了解，在真實的環境中可透過此理論將複雜的環境組成的成分簡化並分析各系統之間的關係，且將真實世界中的生態系統經由簡化而成模型(models)(參見圖 1）。運用模型的建立將可幫助決策者在預測及分析上得到更正確的結果 (Odum, 1988) 。

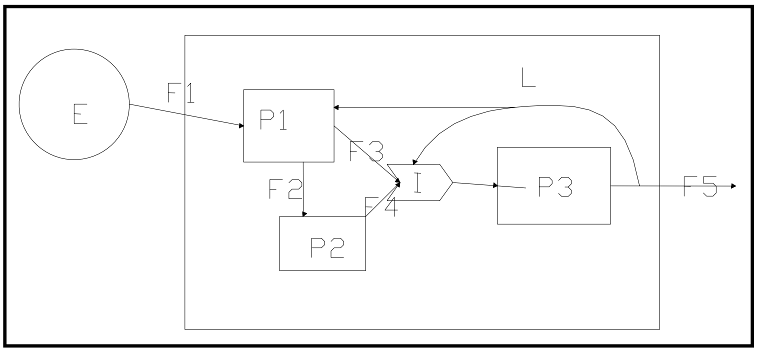

圖 1 簡易生態系統模型圖 資料來源：黃書禮 (2004)

三、新竹香山濕地生態能量系統模型之建立

本研究依照香山濕地整體環境的生態食物鏈以及外來因素之影響，架構合理的生態能量系統(ecological energetic system)，並依此建構生態系統能量模型的參數與函數，以利相關軟體之模擬與分析。

(一)生態能量系統之分析

香山濕地整體的環境構成相當的複雜，生物的種類也相當的豐富，已經形成完整的生態體系。在此區域的能量流動，可以透過外界能量陽光、潮汐、河流、土地的輸入，以及生態體系之食物鏈階層關係一探究竟。

香山濕地的海岸潮間帶擁有豐富的底棲性生物，為鳥類食物的來源，為維繫棲地生態重要關鍵。客雅溪出海口孕育大量的沼澤植物，其透過光合作用產生養分進而生長，並提供生物所需的營養。植物掉落的樹葉經由腐爛發酵成為大量的有機質，為底棲生物重要的能量來源，而底棲生物並進而成為鳥類和蟹類食物的主要來源，形成濕地生態食物鏈。此區物種相當豐富，在採樣調查中有 106 種大型的底棲性生物，包括甲殼類、軟體類、多毛類與其他的底棲性物種，大部份屬於稀有的種類。而在蟹類中，和尚蟹與萬歲大眼蟹更是以億做為單位，台灣特有的招潮蟹及雙扇股蟹亦達千萬隻，為北台灣最重要的潮間帶蟹類棲息地區。在鳥類方面，曾記錄者達 201 種，其中遷徙性的鳥類約佔 66.6%，且多屬於保育性的鳥類，顯示此區物種的多樣性與完整性，也造就了豐富且複雜的生態體系，進而形成在新竹香山濕地中特殊的碎屑食物鏈(detritus food chain)。

(二)生態能量系統模型之建立

在了解香山濕地中環境的要素以及食物鏈的架構後，本研究將透過建立生態系統模型來探討整個香山濕地能量流動的關係。構成一個生態系統模型架構，需要完整且合理的能量流動的脈絡，故本研究在探討整個香山濕地的環境構成後，依照真實世界的物理性、化學性及其生物的特性，並考量之間的層級性與互動關聯性，進而架構出一個合適與合理的生態系統模型架構（參見圖 2）。

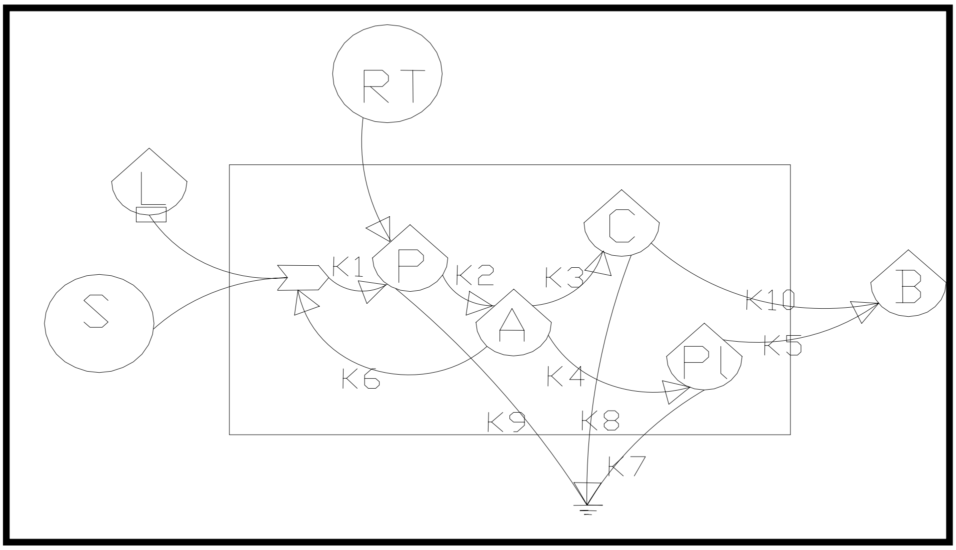

圖 2 新竹香山濕地生態系統模型圖

1.系統內部主要因素

根據研究區環境的特色與本研究的重點與目的，將系統內部所考量的主要因素分為：土地（L）、植物量（P）、沉積物的儲存量（A）、底棲生物量（pl）、蟹類（C）五種。其中土地為整個生態作用之基礎環境，也直接反應出能量的接受大小；而植物為香山濕地中能量的轉換與製造者，在植物的代謝中所產生的沉積物為底棲性生物主要的能量來源。而在整個濕地中最具特色的蟹類則是以底棲性生物為食物的來源。

2.系統外部主要因素

系統外部所考慮的因素為：太陽（S）、潮汐（T）、河流（R）、土地使用的變遷（Lc）、鳥類（B）。在自營性的環境系統中太陽為主要的能量來源；潮汐的作用與河流搬運、侵蝕、堆積作用影響了整個濕地的面積與地貌；人為的開發和土地使用上的轉變也直接影響到濕地的面積。而濕地生態食物鏈中最高階的消費者：鳥類，則為獲取濕地能量的重要族群，但因其並非棲息於濕地內，故將其視為系統外部所考慮的主要因素。

(三)生態系統模型方程式

在 Odum 的系統模型建構的過程中，將以能量循環圖例建立系統模型架構，並運用一般系統理論的時間微分數學方法，根據系統內部各組成變數間能量流動的關係，建立其相關的數學函數意義。直接轉換成的微分方程式，代表各組成變數存量之間的時間改變率，可做為電腦模擬程式的依據。本研究在系統內所考量的變數存量方程式如下所示：

植物量(P)的變動量為其生成量減去其自然的消耗量與轉變成有機質沉積物的能量

$$dP/dt = K1*S*L*P*A - K2*A*P - K9*P \qquad (1)$$

有機質沉積量為植物代謝所轉變成的一個能量儲存系統，並加上河流與潮汐所帶來的有機質沉積物，來提供底棲性生物所需的能量

$$dA/dt = K2*P*A - k3*A*C - K4*A*Pl - k6*A*S*L*P \qquad (2)$$

底棲性的生物量將可提供鳥類(B)所需的能量來源，故將本身的生成量再減去所提供出的能量以及本身自然的耗損

$$dpl/dt = K4*A*pl - K5*pl - K7*pl \qquad (3)$$

蟹類主要的能量來源為底棲性的生物，再扣除本身自然汰換的減損，其數學方程式為

$$dC/dt = K3*pl*C - K8*C - K10*C \tag{4}$$

在這邊所探討的系統模型與一般系統理論，模型的架構會依照問題的尺度與目的的不同，而有不同建構方式。本研究所建立的生態系統模型，主要是以生態能量觀點的角度切入，其系統內部所考量的因素：植物量（P）、沉積物的儲存量（A），底棲生物量（pl）、蟹類（C），皆為香山濕地中最主要的生態因子，並符合該地區的食物鏈架構。

(四)生態能量系統模型校估

由前面所建立的系統方程式，在考量各變數的儲存量與變化量之間關係時，先須檢討存在於各變數儲存量與變化量間的係數關係。本研究中能量的流動與組成間具有自我回饋的機制，故校估後的參數乃是在系統穩定的狀況下所推估的結果。一般係數估算可以運用統計資料的分析來校估，或透過研究實證的運算來檢測。

在本研究中將以新竹香山濕地來做為生態能量系統模擬的對象，並以西元 2005 年的資料為基年資料，在系統穩定的狀態下來調整各變數儲存量與變化量之間的參數值。

1.主要能量輸入之校估

由相關文獻資料求得陽光、潮汐、河流等能量輸入值，如下表所示。

表 2　新竹香山濕地主要能量輸入之校估表

能源輸入項	代號	數值	單位
太陽	SL	1.96E+15	卡/年
潮汐、河流	RT	1.06E+09	卡/年

2.主要儲存量之校估

本研究所建立之系統模型包含的儲存項目為(P)植物量、(A)有機沉積物、(Pl)底棲性生物、(C)螃蟹四項儲存量，在建立資料的基礎上土地與蟹類族群的資料來自相關統計資料，其中在螃蟹族群的統計資料與分佈數據是以新竹市政府委託新竹市野鳥協會，針對新竹市濱海野生動物保護區進行調查的成果報告為依據。

有關於底棲性生物的儲存量在過去的統計資料上並無相關的正式調查報告，本研究乃由王勝民(2002)年針對香山濕地所進行的底棲生物研究報告，做為建立生物能量資料的依據，並根據其調查的結果與結論來推估底棲性生物在本研究區內的分佈與數量。

有機沉積物目前在研究區內並無相關具有量化的統計資料，故本研究在有機沉積物方面將以國外針對岸緣的紅樹林族群所產生的落葉腐化量研究數據，以及客雅溪河口所提供的有機質沉積物量，來進行假設與推估，並選取與國內較近似的紅樹林之樹種與相似的地理環境以降低推估數據上的誤差（參見表 3）。

表 3 系統儲存與變量項表

主要儲存項	代號	數值	單位
植物量	P	1.00E+10	卡
螃蟹量	C	1.31E+09	g
底棲性生物量	Pl	3.80E+07	g
有機沉積物	A	3.87E+09	卡

3.流動量與參數值之校估

研究區內具有四項儲存量，在各儲存量間的變動能值為系統內能量流出與流入量，整體的流動量為在系統穩定的狀態與遵守能量守恆的原則下求得，再經由本研究針對香山濕地所建立的生態系統模型方程式進而推估出各流動量中的參數值，

在本研究中植物儲存量流入與流出的情形，乃根據岸緣紅樹林能值需求量來推算，以每平方公尺需要 108 卡的日需求量以及每日每平方公尺產生 51 卡的枯枝落葉生成量來求得植物生成量與輸出量，且透過植物的輸出量進而成為有機物生成量。

有機物的輸出量乃是經由底棲性生物生成量、螃蟹族群生成量與回饋(feedback loop)於植物的能量所分配，故在底棲性生物的需求量是以根據生物基礎生產效率中，底棲性生物呼吸量所求出，其是以每日每平方公分所需 29 卡的能量為計算值。而螃蟹族群的需求量則假設其與底棲性生物總質量為等比關係，再經由案例比較估算為底棲性生物所需生成量的 47.4 倍加以推估，而回饋於植物生成量則為有機物輸出量分別減去底棲性生物與螃蟹族群的生成量而得。

在穩定的狀態下分別求得各流動量的數值後，再分別去校估各流動量的參數值，並依照先前所求得的各流動量數值除以該估算式之儲存量求得（如參數(k2)為其流動值(6.04E+08)除以植物儲存量(P)與有機物儲存量(A)）。有關各能量流動之數值、估算式與參數值如表 4 所示。

表 4 參數校估表

能量流動項	方程式	數值	單位	參數值	
植物生成量	K1*P*A*S*L	1.27E+09	卡/年	K1	2.34398E-20
有機物之生成量	K2*P*A	6.04E+08	卡/年	K2	1.56068E-11
蟹類之生成量	K3*A*C	4.67E+08	卡/年	K3	9.21135E-11
底棲性生物之生成量	K4*A*Pl	9.80E+06	卡/年	K4	6.66377E-11
底棲性生物輸出值	K5*Pl	7.43E+06	卡/年	K5	0.195526316
有機質回饋能量	K6*A*P*S*L	6.66E+08	卡/年	K6	1.2292E-20
底棲性生物能量流失	K7*Pl	1.57E+06	卡/年	K7	0.041315789
蟹類能量流失	K8*C	1.13E+08	卡/年	K8	8.63E-02
植物能量流失	K9*P	6.60E+07	卡/年	K9	0.0066
蟹類能量輸出值	K10*C	3.54E+08	卡/年	K10	2.70E-01

四、新竹香山濕地生態系統演進模擬分析

本研究將運用前節所建立的模型方程式以及各項變數儲存量與變動量，透過模擬軟體(STELLA)與地理資訊系統(GIS)來進行模擬，並分別以兩個部份來分析之。一為視本研究區為一整體發展空間，將模擬分析區內各儲存量的發展趨勢與演替程度；其二將研究區劃分為 30 公尺乘以 30 公尺網狀方格，進而模擬網格空間內的發展變遷與物種分佈的規模與區位。

(一)生態能量系統模型模擬分析(STELLA)

以西元 1994 年為模擬的起始年，參考新竹香山地區海埔地造地開發計畫環境影響評估報告書(1995)所調查的相關資料作為統計資料之依據，輸入各儲存變數量之起始值（參見表 5）。

表 5　1994 年主要的儲存項起始值

儲存項	數值	單位
紅樹林面積	0.1	公頃
螃蟹族群	140000000	隻
有機物儲存量	9000000	公斤
底棲性生物量	1200000000	隻

資料來源：台灣省水利局(1995)

經由模型模擬可由圖 3 得知，研究區內位於客雅溪出海口潮間帶以人工種植的紅樹林，在客雅溪注入大量有機質與本身自我交互的作用下，發展的相當迅速且蓬勃，並持續耗損有機質之儲存量。但因客雅溪穩定的逕流量與日照面積並無可增加之空間，在受到有限的再生能源之限制後，發展將逐漸趨於平緩。

由圖 4、圖 5 可見，有機物儲存量在持續被耗損的情況下，賴以維生的物種--螃蟹與底棲性生物皆受到牽連，導致螃蟹族群與底棲性生物儲存量逐漸的減少。直至紅樹林發展受限後，進而使得有機質儲存量趨於穩定，螃蟹族群與底棲性生物的儲存量才獲得改善並趨於穩定。

依照整體模擬的結果來看，在處於自營性的環境體系下，即使各個變數儲存量互有消長，皆受限於有限的再生資源而漸趨於穩定的狀態，此點符合 Odum 所提出的能量成長模式。而在本研究所建立的模型中，紅樹林為人工種植的物種，因為環境相當合適其物種之發展，該物種所需的能量生成量可藉由河流之供給與本身自我交互的作用所提供，在土地與該物種之條件容許下能持續增長，一直至所消耗的能量僅能維持本身所需耗能的呼吸量為止。而在紅樹林增長後所增加的耗能壓縮了底棲性生物以及蟹類獲得能量的多寡，故在模擬的狀態下蟹類族群與底棲性生物的數量乃持續減少，由圖 6 可知蟹類族群與底棲性生物數量發展的趨勢大致上是與有機質的儲存量發展趨勢相吻合。

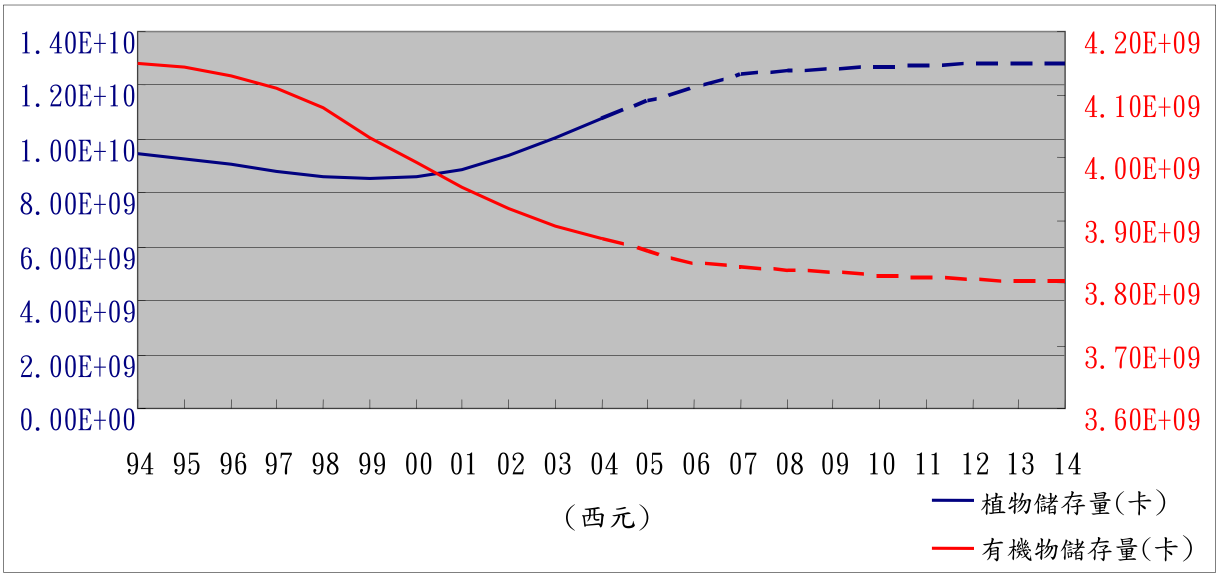

圖 3　植物儲存量與有機物儲存量之關係圖

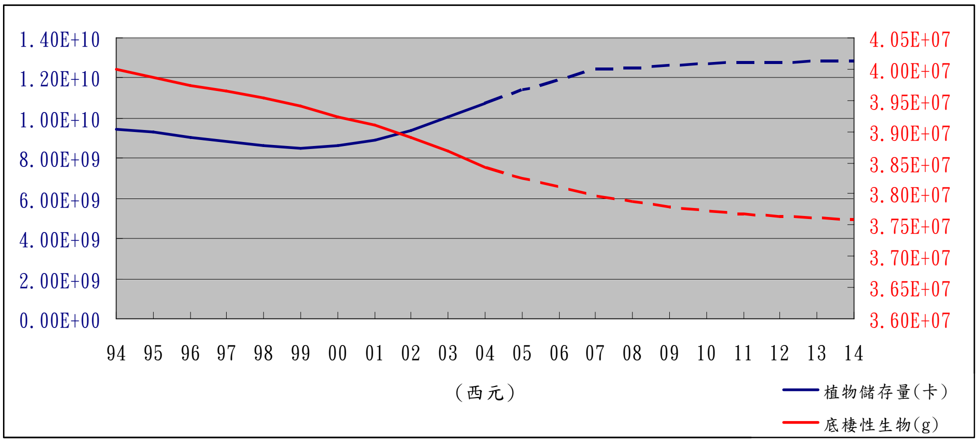

圖 4 植物儲存量與底棲性生物之關係圖

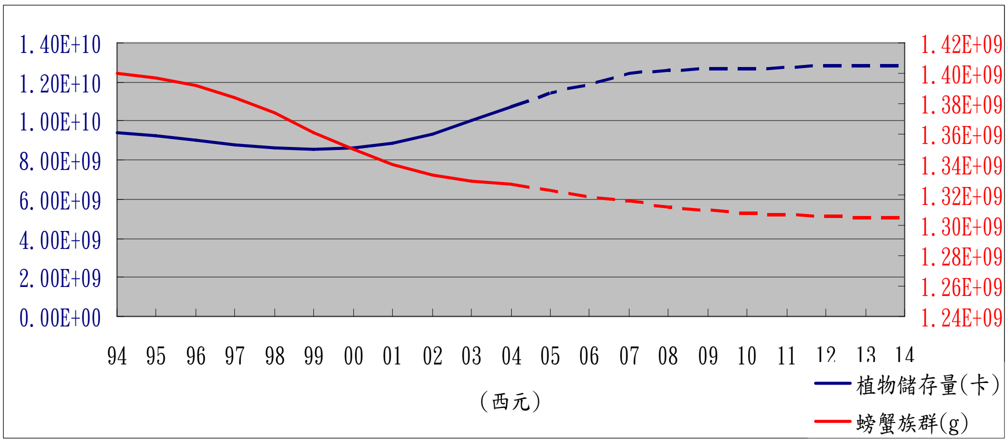

圖 5 植物儲存量與螃蟹族群之關係圖

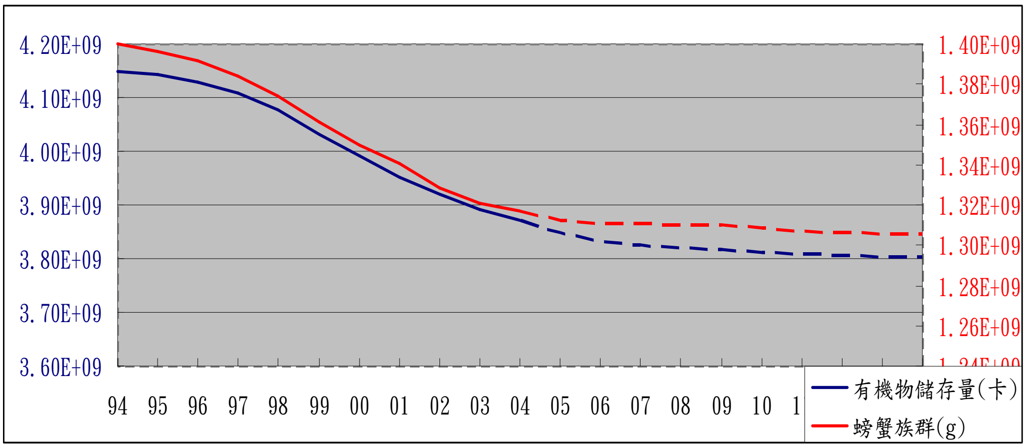

圖 6 有機物儲存量與螃蟹族群之關係圖

(二)生態能量空間模型變遷分析(GIS)

本節將著重於探討經由模擬運算後儲存量的分佈與區位變化，根據上述的動態模擬結果，將其模擬的數據經由地理資訊系統(GIS)呈現其空間模擬的狀態，並比照現況的分佈作一比對。本研究將研究區畫分為 30 公尺*30 公尺之方格狀，根據 STELLA 軟體運算的方式，分別模擬各個網格內之發展與變遷之情形。

經由疊圖運算後的數據(單位能量)將反推各物種原始的族群數量，再經由地理資訊系統的分級色階來表現物種的分佈與區位。空間模擬不以能量單位為劃分等級的依據，主要是考量物種的生物特性與其習性，因生物群聚活動是具有選擇性的，其分佈的密度、數量與

區位主要取決於物種習性，且具有族群數量上的限制，並非像人類可以有相當大的密度彈性與適應能力。故本研究將以現有的資料為依據，將假設經由模擬後的能值數據反算回原始單位時，仍需遵守實際物種分佈的密度與數量資料的限制，並設定單位面積內的現有密度為上限，如超過此上限須將能量平均分配於周邊的九宮格內，以期能更貼近真實世界中的生態發展與演替的情形。

綜觀模擬出的結果（如圖 7、8），檢視紅樹林與蟹類兩個儲存變動量的模擬成果，其整體數量大致符合前節的估算結果，並與動態模擬出的發展趨勢相同。從 T5 的圖面上可發現，在紅樹林的擴張範圍下，蟹類族群將漸漸失去發展的空間，進而轉向靠海岸與河岸出口處發展；而紅樹林族群則以客雅溪、三姓公溪與海岸高潮線三者之交匯處依著河岸的兩旁發展。經由地理資訊系統(GIS)模擬後所呈現出的分佈狀況反應出一個特點，即能量在空間上具有收斂的效果，可由蟹類儲存變數量之模擬圖上明顯的發現，即使蟹類族群在模擬後成長的狀況為負成長且發展空間受到擠壓，高密度的空間單位仍比鄰而生，亦即在空間上分佈的低密度能量會向高密度的空間單位靠攏，逐漸形成類似同心圓狀的能量分佈態勢，此應為同心圓中心具有較優勢的發展條件所致。

的低密度能量會像高密度的單位面積靠攏，逐漸形成類似同心圓狀能量分佈。

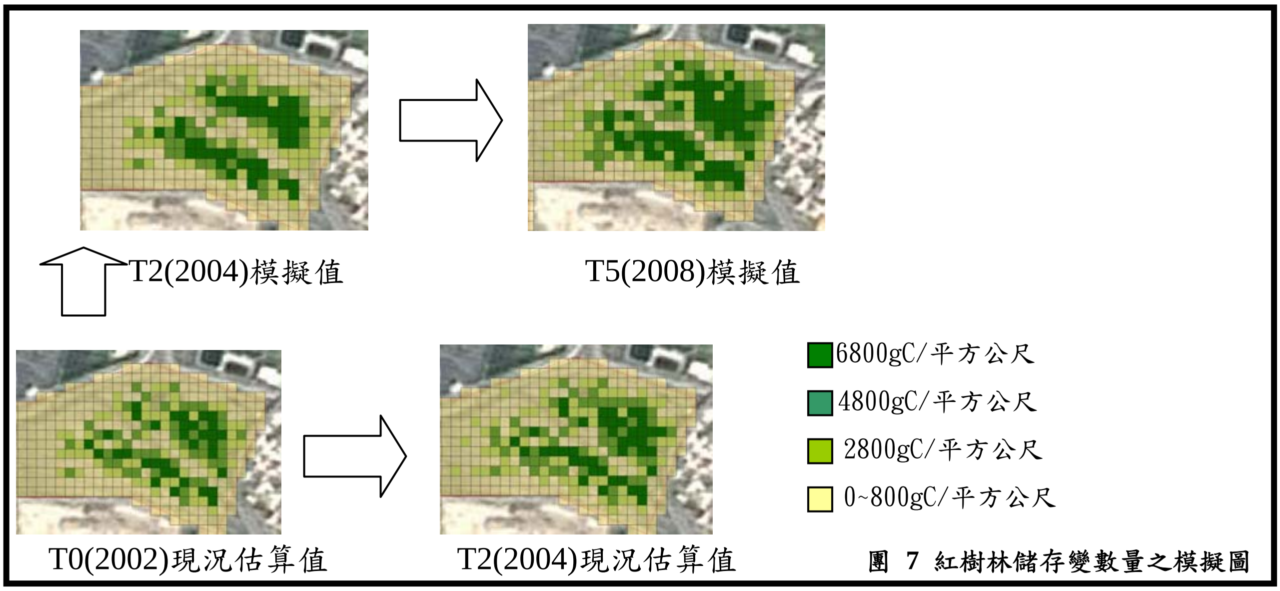

圖 7 紅樹林儲存變數量之模擬圖

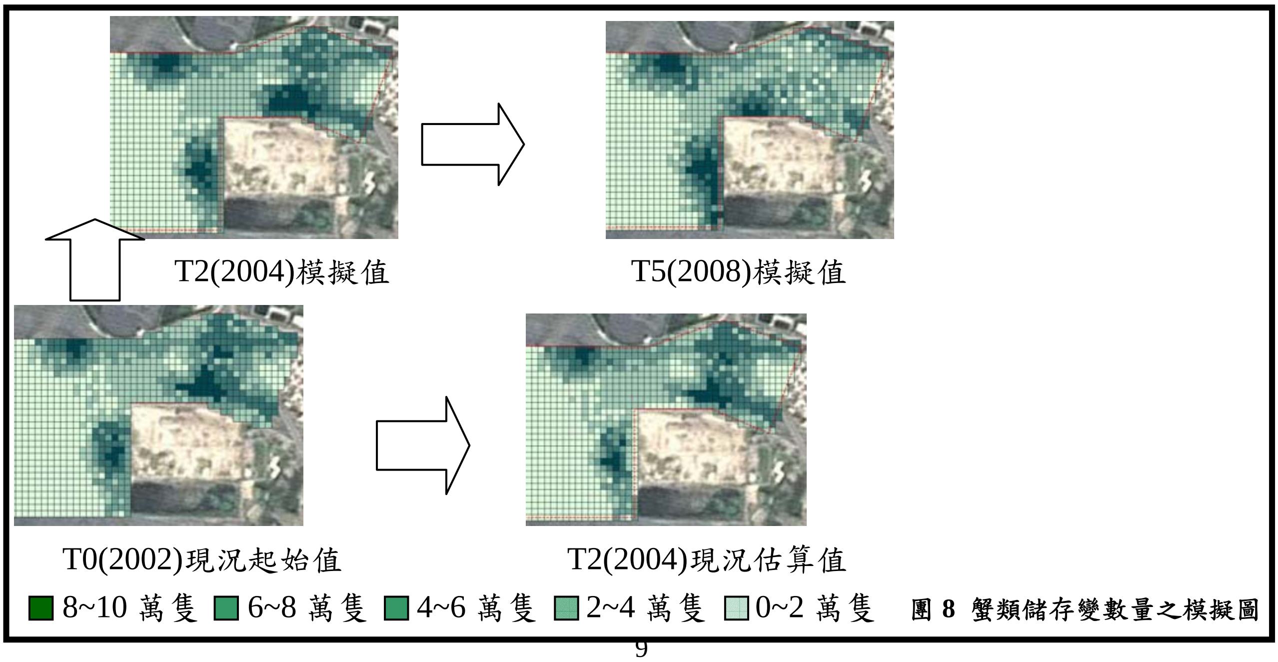

圖 8 蟹類儲存變數量之模擬圖

五、結論與建議

(一)結論

本研究在經由回顧生態經濟學、一般系統理論，並引用 Odum 系統生態學的能值概念後，根據研究區內環境系統的組成去建立新竹香山濕地的生態能量系統模型，並透過軟體的計算分析，來模擬新竹香山濕地演替的過程與未來的發展。所獲得的成果如下所示：

1.本研究區在處於自營性的環境體系下，即使各個變數儲存量互有消長，皆受限於有限的再生資源而趨於穩定的狀態。在模型中紅樹林為人工種植的物種，該物種所需的能量可藉由河流之供給與自我交互作用所提供，在土地與該物種之特性容許下能持續增長，一直成長至所消耗的能量僅能維持本身所需耗能的呼吸量後進而逐漸趨緩。

2.模擬後的結果得知，紅樹林在擴張的範圍內蟹類族群漸漸失去發展的空間，進而轉向靠海岸與河岸出口處發展，而紅樹林族群就依著河岸的兩旁發展，在紅樹林增長所增加的耗能下壓縮了底棲性生物以及蟹類獲得能量的多寡，並約於西元 2010 年取得平衡且趨於穩定的狀態。

3.透過地理資訊系統(GIS)模擬後所呈現出的分佈，反應出能量在空間上具有收斂的效果，以蟹類族群為例在模擬後成長的狀況為負成長且發展空間受到擠壓，高密度的空間單位仍比鄰而生，在空間上所分佈的低密度能量會向高密度的地區靠攏，逐漸形成類似同心圓狀的能量分佈。

(二)建議

本研究操作過程中，受限於外在因素的限制，因此提出在研究時所遭遇的瓶頸與困難的相關建議：

1.在資料取得方面，進行模擬分析須要長期的基礎資料支持，才能建立更完整的環境模擬模型。但礙於生態資料取得相當不易或完整性不夠，以至於無法針對模擬出的數據做更進一步的比對，且在各個參數的校估中所引用推估的依據有些是國外學者的研究數據，在不同的環境背景與地理條件下，是否會產生較大的誤差尚有待檢討與修正。若相關政府單位或民間團體能擴大及持續建立香山濕地的生態資料庫，將有助於提升研究的效益與模擬預測的準確性。

2.本研究所建立的生態系統模型所探討的各變數儲存量中，因受限於精確的蟹類資料，乃將數種蟹類視為一個族群並整體的分析之，但不同蟹類的族群仍有彼此競合的關係與各具其物種的特色。故建議往後的研究，若能取得足夠的基礎資料，可分別去探討與分析不同種類的蟹類之間，其能量流動的狀況與分佈範圍，以期獲得更客觀與完整的研究成果。

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計畫成果自評

在一個完整平衡的生態環境體系中，各個物種皆會以最有利的發展行為與模式在此環境內生存，以利確保本身在一個有限資源的空間內佔有一席之地，人類也不例外。但人類在擴張同時，往往受到過於主觀判斷的影響，會基於人類的活動需求與目的，以及本身所建立的價值標準，來決定土地開發的依據或劃分的準則。而現今的土地使用適宜性分析方法在評估自然環境的項目上，是否會與自然環境系統互利共生的演替性原則相違背或偏離，此點是為日後可深思之處。

新竹香山濕地是一個極其複雜的生態系統，本研究運用一般系統理論檢視其環境生態的組成，並根據系統內各組成間之能量流動的方式與關係，建構本研究區的生態系統模型及其數學方程式。建立之模型架構與數學方程式，經由參數的校估及 STELLA 模擬軟體模擬出各個變數量，並透過 GIS 呈現模擬分佈之變化情形。針對本計畫之計畫成果提出下列說明：

1.本計畫依照原定目標完成，在資料的分析與模擬上都有成果產生，與原訂計畫目的相符。計畫中應用生態經濟學為基礎建立出新竹市海岸周邊地區的生態系統模型，並透過能量流動之模擬及預測去分析香山濕地各組成變數之間的互動關係。最後藉由地理資訊系統透過動態模擬所運算出的數據加以圖面化，建立一生態環境模擬分析資訊系統。
2.本計畫以地理資訊系統為基礎，發展一套生態環境即時調查資訊系統，有助於日後濕地環境進行事前預測、事後監控的環境管理機制的建立。在計畫中生態環境動態模擬資訊可應用在土地使用適宜性分析上，使海岸開發對於生態環境、人文經濟之衝擊減至最低，並可藉此研擬最適宜之土地利用型態的合理空間分佈規劃，套繪出發展潛力與限制疊圖結果之最適空間量與區位分配圖，真正達成環境與土地使用資源整合的目標。
3.運用地理資訊系統的研究成果，可作為往後相關學術研究的比對及應用參考，有助於解決海岸環境生態資料缺乏之問題。然而海岸地區的環境現況，很容易隨著時間的變化而有所改變，也因此其資料庫必須要有長時間的調查及建置，才能在環境狀況改變的時候，能夠對模型函數及參數加以變更及修正，達到濕地生態資源最有效發展的結果。因此，未來還是有必要繼續對本區進行相關研究與調查。
4.未來可依照不同地區的環境特性及生態資料，對本計畫中之生態系統模型中的各個參數進行適當的修正，將其應用在台灣其他的海岸地區，以進行更有效的海岸資源管理。
5.本計畫為一具獨創性的研究，相關研究成果已經發表在國際研討會中，未來將進一步投稿國內外的學術期刊。

DETERMINE ECOLOGICAL CHANGE IN HSIANGSHAN WETLAND, HSINCHU BY AN ECOLOGICAL ENERGETIC MODEL

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ABSTRACT

Taiwan has long been influenced by its surrounding ocean. While Taiwan has 1,400 kilometers of coastline, its geographic location and natural factors remoteness and inaccessibility have prevented limited the utilization for development of this coastline. However, recent social and economic development has lead to this coastal land being developed for various purposes. Whether intensive development and use of coastal land result in excessive exploitation of that land and thus disrupt the ecological balance has become a major concern for various communities. Consequently, land use and development in coastal areas, particularly development locations and objectives, should be evaluated and reviewed more carefully, and consideration should be given to whether such development might cause irreversible ecological damage. Analysis of land use suitability has been highly regarded in the site of land use and development, but methods for identifying negative consequences of development have been too one-sided and subjective, and have lacked the characteristics of fussiness and prediction on change of coastal wetlands environment. Consequently, this investigation attempts to develop a system model of wetland ecosystem for the Hsiang Shan Wetland in Hsin Chu, from the perspective of the methodology of systems ecology, while adapting concepts of emergy analysis and General System Theory. Via the programs of the ecological energetic system together with computer calculation, the system can predict future trends in ecological change via dynamic simulation. Furthermore, based on GIS analysis, the system can convert large quantities of sophisticated data into graphic displays, and can further generate an analytical model exhibiting wetlands and emergy analysis indexes, which can then serve as a reference for studies focused on related fields. By matching the images and the overlapping areas, the findings of this investigation help in deciding locations for development, and planning for land use purpose and intensity, and thus enable the study findings to provide a useful reference.

Keyword: Systems ecology, emergy analysis, wetland, land use suitability analysis, Geographic Information System (GIS)

INTRODUCTION

With the city development and transition of the times, city economic activities and types became more frequent and diversified day by day. It created a lot of working opportunities and trade behaviors, and also attracted the people outside the district to settle down in the cities. A large number of lands were developed for residential, industrial and commercial buildings that expanded outwards from the core of the old cities. It was a quite common type of the city development process in Taiwan. However, the process of city expansion derived out issues of the overexploitation of the peripheral natural environment and other environmental issues. Those were mostly considered from social demand and economic benefits point of views, even ignoring their balancing function to maintain the ecosystem of natural environment and the role and value for city development.

The coast area has been an important media for obtaining marine resources, and an important economic source impelling urbanization. However, with the fast development of Hsinchu Science Park, the hinterland Hsinchu downtown became narrow and small. The surrounding coastal area used to rely mainly on coastal aquaculture and agriculture now became suburbs and NIMBY (Not in My Backyard) facilities gradually. In addition, the development of West Coast Speed Way and the prosperity of travel in recent years attracted a large number of tourists and businesses to the coast spots with tourism resources. Thus, the development of the lands surrounding coast became the focus of all parties. It also became the stage of wrestling among environmental protection group, beneficial groups and the government.

Disregard of the purpose of coastal land development and the limitation of land utilization intensity, every inch of land development changed natural environment to cater to the human demand with irreversible results. According to this view, we described the flourishing commercial land as “an inch land, an inch gold” in the past seem to be suitable to describe every land in the natural more environment under development now. Especially the ecological environment conditions of coast wetland of Hsinchu is abundant, a careful appraisal system is needed to plan land usage to avoid affecting the extremely sensitive ecosystem. Therefore, the variety of the coast wetland species in Hsinchu will be maintained and keeps the natural environment offers service to the peripheral city area.

While developing the land in the past, land use suitability analysis was often used for land utilization policies as reference or basis. Factors such as natural environmental protection, etc. had become an important index for land use suitability analysis in recent years since environmental awareness rose. However, the analysis method was too focused on single factor and lacked the characters of prediction and simulation to find out about the follow-up influence and damage toward ecological environment. It also neglected the importance of whole ecosystem balance by assessing only several index species with limited quantity. It lost the objectivity and integration of a systematical assessment.

In view of above-mentioned research backgrounds and motives, this research studied the relation of energy among each element within the ecosystem by the view of ecological economy. Furthermore, an ecological energetic system was set up to simulate and predict the change of ecosystem in Hsiangshan wetland, Hsinchu. The results were presented by the Geographic Information System and reviewed the development of the natural environment system of surrounding Hsinchu coast area finally. The purposes of this study are summarized as two subjects in the following:

(1) Use ecological economics as the basis to set up an ecosystem model for the wetland of Hsiangshan, Hsinchu. Analyze the interrelation of the variables in Hsiangshan wetland by simulating and predicting the energy flow.

(2) Utilize GIS to present the results of dynamic simulation as figures for better comparison and usage in the future studies. Those can be used for land use suitability analysis for the coast areas well.

RESEARCH STRUCTURE AND LITERATURE REVIEW

1. Research structure

Of whole ecological economic system, the mutual composition of each system and their relations are extremely complicated. This study concentrated on the natural environment system of the west coast in Hsinchu to discuss the inside energy composition and the energy flow in between, and simulating and predicting the ecological change of the study area.

(1) Information collection and analysis

This study was based on ecological economics to discuss the energy flow and characters of the coast wetland in Hsinchu. The literature review was focused on the change mechanism and energy hierarchy character, etc. of the systems ecology, and also collected geographical space and relevant ecological statistical data.

(2) Build a wetland ecosystem model

Build a wetland ecosystem model by relevant theories and information. Through calibration and estimation of the parameters, the simulation and prediction results were more close to the actual development trend and the error was reduced. The software STELLA was used to build systematic equations to carry on dynamic simulation analysis. After build value data and equations, repeated tests were performed to correct the logic errors of the equations to strengthen the explanation and rationality of the system model.

(3) Wetland ecosystem simulation and prediction analysis

Through the dynamic simulation, the change and development of the wetland regional ecosystem can be predicted, and the energy growth, decline and flow among each system can be understood. The wetland space and energy indices were built through the data analysis.

(4) Build geographical information system (GIS) data

The signal data obtained by dynamic simulation were transferred into information presented in space through the GIS. They were presented as figures in spaces to show the concept of space distribution and simulation results of ecological environment changes for better planning.

2. Literature review

Natural environment has been regarded as the outside concern of the economic system all the time. However, the relation between the natural environment and economic system is integral in fact, so ecological economics includes both of them as a whole subject. This study reviewed the meaning and relevant literatures of ecological economics, and then understood the theoretical foundation of ecological economics and its application.

(1) Ecological economics

Ecological economics is a new science that crosses different disciplines, which aims at discuss the relation between the ecosystem and economic system from a broadly defined angle. This relation is the central topic of a lot of problems faced by mankind today and unable to be contained by many science disciplines. It is also the key point of the sustainability issue in the future.

The world vision of traditional economics took human as the first. Since human preferred dominating the action of the economic behavior and were extremely optimistic to the progress of science and technology, traditional economics regarded resource as the endless supply and can be replaced by different elements. However, the world vision of ecological economics is comparatively broader, human preference, science, technology and organization all evolved with the opportunities and restrictions provided by natural environment. Evolve was also the origin to discuss interior structure changes. The so-called evolution referred to the process for one complicated system to adjust, change and choice. It was dynamic and uniformed. Regarding time, space and species, the ecological economics contained boarder scope than the traditional economics and ecology (Huang, 1998).

The ecosystem model can offer the decision-maker estimates for helping make judgments for the decision. Through the general system theory built by the ecological energetic system, not only can obtain the potential influence of human behavior to the ecosystem, but also can access the interdepend degree between the ecosystem and economic system and characters of growth altogether (Table 1) (Costanza et al, 1991).

Table 1 The comparison among ecological economics and traditional economics and ecology

Comparison Item	Traditional economics	Traditional ecology	Ecological economics
Basic world vision	Machinery type, static	Evolve, atomic theory	Dynamic, systematic
Time consideration	Short-term 1~50 years	Day~generation	Day~generation
Space consideration	Local~worldwide	Local ~ area	Local~worldwide
Species	Human	Species except human	Whole ecosystem including human

Main overall goal	National economical growth	Species survival	Sustainability of the ecological economics
Study focus	Emphasis on mathematics	Emphasis on technology and tools	Emphasis on issues discussion

Source: Costanza et. al, 1991

(2)General system theory

The important concepts of modern systematic theory were the systems have characters of interactions, integration, organization, complexity and evolution. The system consists of several relevant individuals that were connected to each other directly or indirectly. There were interdynamic relations with each other and mostly were open systems with energy inputs and outputs in the actual environment. They interact with the systems at the surrounding area, and the feedback mechanism can make the output energy become the input condition again.

The system was also the epitome of the actual environment with the characters of complexity and hierarchy. The system was subdivided into sub-systems and organized the relation of hierarchy, and then connected the interactions among sub-systems. Generally, a system can be small as a cell to large as a universe (Figure 1) (Odum, 1996).

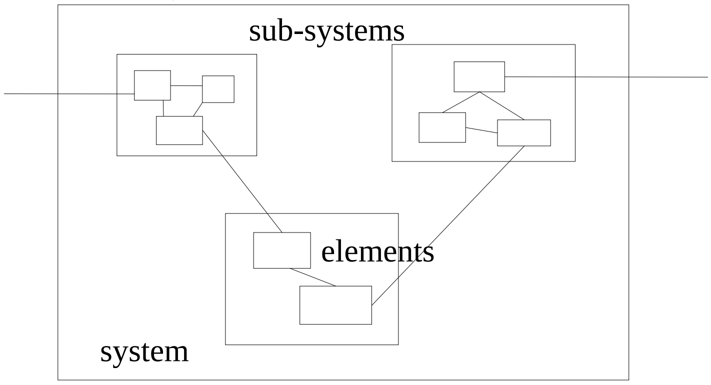

Figure 1 The diagram of complexity and hierarchy of system Source: Odum, 1996

(3)Emergy analysis

Ecologist Howard T.Odum introduced the thermodynamics and emergy analysis from the view of ecological economy to discuss the relation between biology and non-biology, even the relation among human and natural environment. The compositions and their relations within an ecological system were showed by figures. The concepts of emergy analysis built by ecological economics view were different from those of individual economics. It set from total economics' angle and included ecology and economics to establish a value system measured by energy. This method was not used for replacing measurement of market currency, but used for assessing the contribution to the economic system of the natural. It was suitable tool for policy analysis (Huang and Odum, 1991).

With the general system theory, the complicated composition of actual environment can be simplified by this theory and the relations among the systems were also analyzed. Furthermore, the ecosystem in the true world can be simplified into models (see Figure 2). Apply the established model can help the decision-maker to obtain more accurate prediction and analysis results (Odum, 1988).

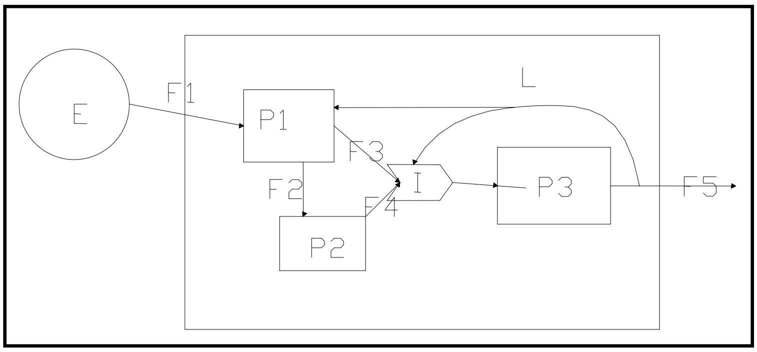

Figure 2 The diagram of energy system model Source: Odum, 1988

BUILD ECOLOGICAL ENERGETIC SYSTEM MODEL OF WETLAND

This study built a reasonable ecological energetic system for the wetland in Hsiangshan, Hsinchu according to the ecological food chain and outside influence of the environment. The system was then used to build parameters and functions of the ecosystem energy model for relevant software to perform simulation and analysis.

1. Ecological energetic system analysis

The environmental composition of wetland in Hsiangshan, Hsinchu was quite complicated and the number of species was abundant that already formed an intact ecosystem. The energy flow in this area can be obtained through external energy inputs and food chain hierarchy relation of the ecosystem. The relation and interaction of the hierarchy in the wetland in Hsiangshan are discussed from the views of energy inputs and outputs in the following.

(1) Energy input

A. Sunlight

The wetland of Hsiangshan was a self-operation environmental system that drove by the solar energy. The energy was absorbed by the photosynthesis of the green plants. Sunlight became the most basic and major energy source in the wetland in Hsiangshan, no matter to the animals or the plants.

B. Tide, river

Tide was one of the major elements to form a wetland. The cyclic tides offer enormous nutrients, and wash out most water and solid pollution during ebbs. Tides also make the wetland ecology different from the ecology in other areas. Tide is also the main reason to form biodiversity. The main hydrology system of the wetland in Hsiangshan is Kerya Stream. The sands and nutrients of the rivers and creeks were brought to the wetland ecological environment through eroding, carrying and piling that make the wetland in Hsiangshan special.

(2) Land formation

The wetland was formed by the eroding at tidal zone and by the piling sand at the river-to-sea. The area of wetland determined the amount of energy inputs in the natural environment and determined the area of inhibit for the species. The coast of Hsinchu was massively developed in recent years. The construction of the port influenced the sand-drifting route, which caused the coast to be corroded. In addition, the expansion of city made wetland used as city land such as the soaked trash buried plant and West Coast Speed Way. The influence to the wetland ecology was quite serious when there was no protective buffer space.

(3) Food chain Structure

The coastal tidal zone of the wetland in Hsiangshan has abundant benthos that was the birds' food and the key to maintain the ecology of benthos. There was a large number of swamp plants appeared at Kerya Stream to sea and the plants produced nutrients and grow through photosynthesis and offer the nutrition to other species. Dropped leaves were transferred into a large amount of organic substances by fermenting and became an important energy source for benthos. The benthos then became the main source of food of birds and crabs and formed the ecological food chain of wetland. This species are quite abundant in this area including 106 types of marcrobenthos of crustacean, mollusks, polychaete and other benthos, and the majority belonged to the scarce species. Among the crabs, the numbers of Mictyridae and Macrophthalmus were counted in 100 millions, and the numbers of Taiwan Ucaformosensis and Scopimera bitympana were counted in 10 millions. It was the major tidal zone inhibit for crabs in northern Taiwan. As the birds were concerned, recorded types reached 201 and the migration birds were accounted for 66.6%. Most of the birds were protective species. The types of species in this area were diversity and complete to form the abundant and complicated ecosystem. As a result, a special detritus food chain in the wetland in Hsiangshan, Hsinchu was created (see Figure 3).

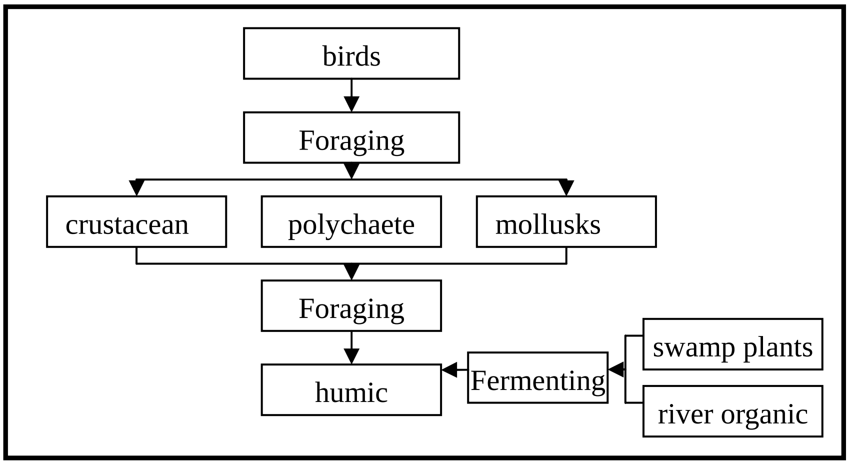

Figure 3 The diagram of detritus food chain in the Hsiangshan wetland

2. Build an ecological energetic system model

After finding out the key environment elements and the food chain structure about the wetland in Hsiangshan, this study discussed the energy flows of the wetland in Hsiangshan through establishing an ecosystem model. Construct an ecosystem model structure needed complete and reasonable routes of energy flows. After discussing the environmental composition of the wetland in Hsiangshan, this study proposed a suitable and reasonable ecosystem model structure according to the physics, chemistry and biological characters of actual world with considering their relations of hierarchy and interaction (see Figure 4).

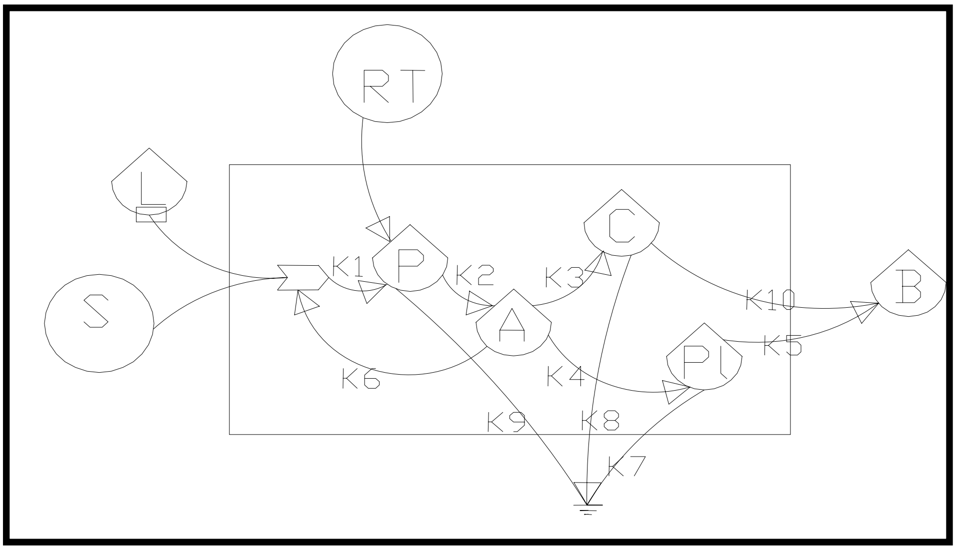

Figure 4 The **diagram of ecosystem model of Hsiangshan wetland**

(1) Main factors inside the system

According to the environmental characters of the study zone and the key points and purposes of this study, the main factors inside the system were: Plants (*P*), amount of sediment storied (*A*), amount of benthos (*pl*) and crab (*C*). Among them, land is the basic environment of the whole ecological activities and also represents the size of energy inputs directly. And the plants converse and produce energy of the wetland in Hsiangshan, and the sediments produced by the metabolism process of the plants become the major energy resource of the benthos. The specialist crab in the whole wetland takes benthos as food.

(2) Main factors outside the system

The main factors considered outside the system are: Sun (S), tide (T), river (R), land usage change (L) and birds (B). The sun is the main energy source in the self-operation environmental system. The influence of tide and carrying, corroding, and pilling effects of the river has influenced the area and landscape of the whole wetland. Development and the land usage change also affected the area of wetland directly. The consumer of the highest stage of the ecological food chain in wetland, birds, is the major specie consumes the wetland energy. Since birds does not inhibit in the wetland, they are considered as the main factor outside the system.

3. Ecosystem model equations

In the processes of building the Odum model, the energy cycle legend was used for the system model structure. The time differential method of the general system theory and the relations of the energy flow of the parameters within the system were also used to develop the mathematical functions. The directly transferred differential equation representatives the time change rate among the stock variables and can be used as the basis for computer simulation. The stock variables equations considered in this study are shown as follows.

The change of plant amount (P) equals production amount subtracts natural consumption amount and the amount transferred into organic sediments.

$$dP/dt = K1*S*L*P*A - K2*A*P - K9*P \qquad (1)$$

The organic sediment is an energy storage system generated by the metabolism of the plant. With the organic sediments brought by rivers and tides, they offer benthos-required energy.

$$dA/dt = K2*P*A - k3*A*C - K4*A*Pl - k6*A*S*L*P \qquad (2)$$

The amount of benthos offers birds (B) necessary energy, which equals the production amount by itself subtract the offered energy and natural self-consumption.

$$dpl/dt = K4*A*pl - K5*pl - K7*pl \qquad (3)$$

The main energy source for crab is benthos, which subtract the natural weeding out can be showed as the equation:

$$dC/dt = K3*pl*C - K8*C - K10*C \qquad (4)$$

The model structure constructing methods of the system model and general system theory discussed in this study are different by their sizes and purposes. This ecosystem model proposed in this study set off from the ecological energy view and the factors considered within the system are: plant amount (P), amount of sediment storied (A), amount of benthos (pl) and crab (C). Those are all main ecological factors in the wetland in Hsiangshan and match with the food chain structure in this area. The relations among each composition are adjusted through the feedback function and perform interactions to adjust the succession process to adapt environmental changes. The mathematical equations transferred from the constructing system model can carry on dynamic simulation through computer languages in order to be closer to the complicated relations of the simulated natural environment.

4. Ecological energetic system model calibration

As the system equations mentioned above are considered, the relation of constant between each stock variable and change amount need to be discussed when considering the relation between stock variable and change amount. There was a feedback mechanism between the energy flows among the compositions in this study. Thus the calibrated variables were estimated under the stable condition of the system. Analysis of the statistical data was used to calibrate the estimation of general constants. They can also be tested by research-validated calculations.

This study took the wetland in Hsiangshan, Hsinchu as the target for ecological energetic system simulation. The baseline data was the data collected in year 2004. The values of stock variables and change amount were adjusted under stable conditions.

(1) Main energy inputs calibration

The energy input values for sunlight, tide, river, etc. were obtained from relevant information.

Table 2 Main energy inputs calibration

Item	Variable	Amount	Units
Sun	*S*	1.96E+15	cal /year
Tide and River	*RT*	1.06E+09	cal /year

(2) Main stock variables calibration

The system model built in this study contained 4 stock items as plant amount (*P*), organic sediment (*A*), benthos (*pl*), and crabs (*C*). The information of land and crab ethnicity was obtained from relevant statistical data when setting up the information data. The statistical data in crab's ethnicity and their distribution were obtained from the investigation reports for coastal wildlife reserve area in Hsinchu City prepared by the Wild Bird's Association of Hsinchu City, which was entrusted by Hsinchu City Government.

Since there was no relevant formal survey report on the statistical data about the benthos amount, this study adopted the research paper for the benthos of wetland in Hsiangshan (Wang, 2003) as the basis to build biological energy. The investigation results and conclusions were also used to estimate the amount and distribution of the benthos in this study area.

Since there was no relevant quantitative statistical data on organic sediments in the study area, this study used the data of the amount of fallen leaf produced of mangrove ethnicity at bank reason in foreign countries and the organic sediment amount at Kerya Stream to sea to estimate the amount of organic sediments. Similar domestic species of mangrove and geographical environment in Taiwan were chosen to reduce the estimation error (see Table 3).

Table 3 Main stock variables calibration

Item	Variable	Amount	Units
Plant	*P*	1.00E+10	cal
Crab	*C*	1.31E+09	g
Benthos	*Pl*	3.80E+07	g
Sediment storied	*A*	3.87E+09	cal

(3) Energy flow and parameter calibration

There were 4 stock items in the study area and the energy changes among them were inflow and outflow energy of the system. The total flow amount was obtained under stable conditions and in accordance with the principle of energy conservation. Then the parameter values of each flow amount were estimated by ecosystem model equations built for wetland in Hsiangshan in this study.

The inflow and outflow stocks of plant in this study were estimated by the energy required of the mangrove on the bank. The amounts of energy production and output were calculated by daily demand amount of 108 cal/m^2 and daily withered fallen leaves production amount of 51 cal/m^2, which then became organic substance production amount through the output amount of the plant.

The output amount of the organic substance consisted of the production amounts of benthos, the production amount of crab ethnicity, and the assigned energy from feedback loop to the plant. The daily demand amount of benthos was 29 cal/cm^2, which was calculated by their amount of breath according to the basic production efficiency. Suppose that the demand amount of crab ethnicity was proportional to the total mass of the benthos, it was estimated to be 47.4 times of the total mass of the benthos by comparing with other example cases. The production amount of feedback to plant equaled the amount of organic substance output deducted the production amount of benthos and crab ethnicity.

After the value of each flow was obtained under a steady state, calibrate the parameter of each flow separately. The parameter was calculated by dividing the calculated amount of flow by the stock of the equation (ex. parameter *K2* equaled the amount of flow 6.04E +08 divided by the stock of plant (*P*) and the stock of organic substance (*A*)). The values, estimation equations, and parameters of flows are showed in Table 4.

Table 4 The parameter calibration

Item	Equation	Amount	Units	Parameter calibration	
Plant products	*K1*P*A*S*L*	1.27E+09	cal /year	*K1*	2.34398E-20
Organic sediment products	*K2*P*A*	6.04E+08	cal /year	*K2*	1.56068E-11
Crab products	*K3*A*C*	4.67E+08	cal /year	*K3*	9.21135E-11
Benthos products	*K4*A*Pl*	9.80E+06	cal /year	*K4*	6.66377E-11
Benthos output	*K5*Pl*	7.43E+06	cal /year	*K5*	0.195526316
Organic matter feedback	*K6*A*P*S*L*	6.66E+08	cal /year	*K6*	1.2292E-20
Benthos entropy	*K7*Pl*	1.57E+06	cal /year	*K7*	0.041315789
Crab entropy	*K8*C*	1.13E+08	cal /year	*K8*	8.63E-02
Plant entropy	*K9*P*	6.60E+07	cal /year	*K9*	0.0066
Crab output	*K10*C*	3.54E+08	cal /year	*K10*	2.70E-01

SIMULATION ANALYSIS OF ECOSYSTEM CHANGE OF WETLAND

This study used model equations mentioned above with stock variables and amount of change to perform simulation through the software STELLA and the GIS. The analysis was separated into with two parts: One part took the area of study as a whole development space to simulate the development trend and degree of succession of each stock variable; The other part divided the area into 30 x 30 m grids to simulate the development changes and the scale and location distribution of species within the grids.

1. Ecological energetic system model simulation analysis (STELLA)

A.D. 1994 was taken as the Initial year for simulation, and used the relevant information of the environmental impact assessment report of land reclamation plan in Hsiangshan, Hsinchu (1995) as the basis of statistical data to input and the initial value of each stock variable (see Table 5).

The simulation results by the model are shown in Figure 5. The planted mangrove at the tidal zone of Kerya Stream to sea in this study area grew flourishingly and rapidly with the large amount of organic substance brought by Kerya Stream and their self-interaction, and consumed organic substance continuously. Because of the steady run-off of Kerya Stream and not expansible sunlight area, the recycling energy was limited and the development became slow.

Table 5 The initial value of each stock variable(1994)

Item	Amount	Units
Mangrove	0.1	hectare
Crab	140000000	number
Organic matter	9000000	Kg
Benthos	1200000000	number

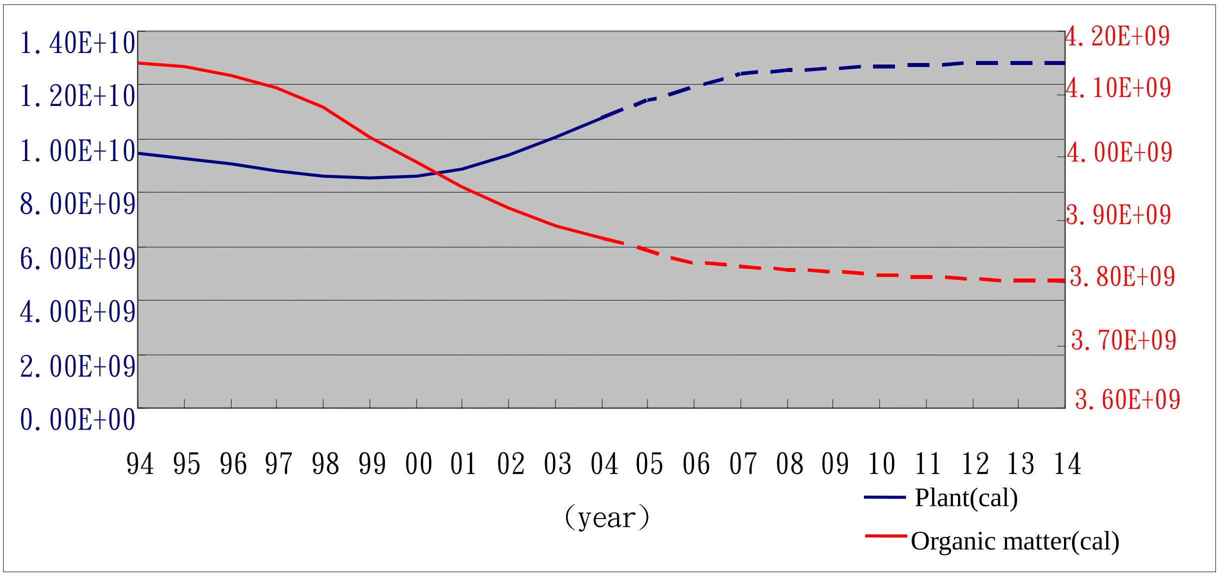

Figure 5 Results of simulating ecosystem model with organic matter and plant in 1994-2014

As showed in Figure 6 and 7, the stock of organic substances was continuously consumed and the species that relied on them, crab and benthos, were affected and resulted in gradual reduction of amount of stock. Until the development of mangrove was restricted, the stock of organic substance tended towards stability. Consequently, the stocks of crab ethnicity and benthos were improved and tended towards stability.

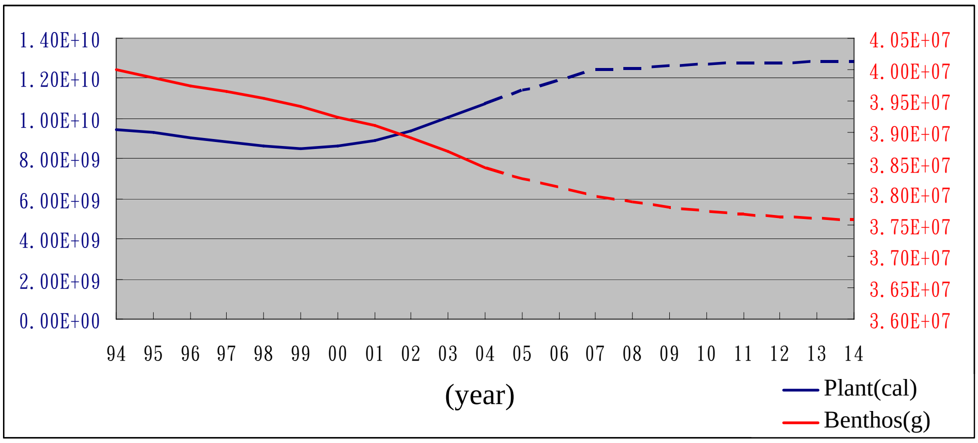

Figure 6 Results of simulating ecosystem model with benthos and plant in 1994-2014

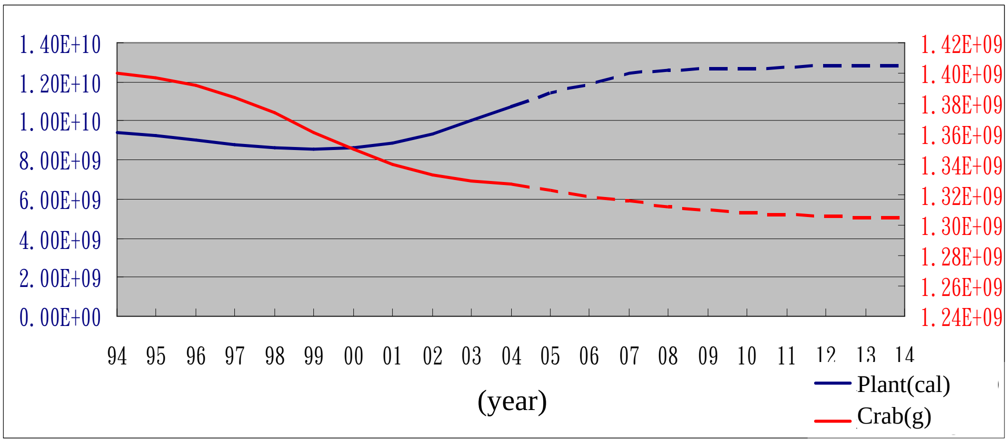

Figure 7 Results of simulating ecosystem model with crab and plant in 1994-2014

The simulation results showed that each stock variable tended towards stability gradually with limited recycling resources under a self-operative environmental system, even the stock of variable had growth and decline. It also matched with the energy growth model proposed by Odum. The mangrove in this research was a manually planted species that was suitable in the environment. The demand energy production for this species was offered by the river and through self-supplements. As long as the condition of land and the species allowed, they can grow continuously until the energy consumption can only maintain their demand amount for breath. The increased energy consumption of the increased mangrove compressed the energy for benthos and crabs. Thus the amount of crab ethnicity and benthos reduced continuously in the simulation. The Figure 8 showed that the development trend of the amount of crab ethnicity and benthos was roughly identical with the development trend of organic substance.

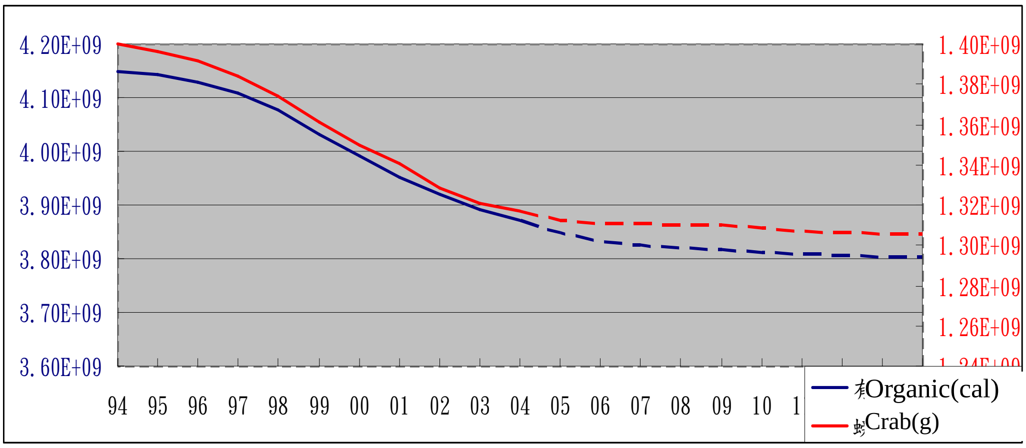

Figure 8 Results of simulating ecosystem model with crab and organic matter in 1994-2014

2. Ecological energy space model change analysis (GIS)

The section focuses on the simulation results of stock distributions and location changes. The dynamic simulation results mentioned above were presented in space via GIS and then compared with the present situation. The study area was divided into 30 x 30 m girds to simulate the development and change within the grids using software STELLA.

The original quantity of each ethnicity was estimated by the data (per unit energy) after stacking the figures, and then displayed the distribution and location of the species by color scales via GIS. Space simulation cannot use per unit energy as the basis of classification. The main considerations were the characters and behaviors of the species because of the selective character of the clustering activity of the species. The density, quantity and location distributed depend on the behavior of the species. There was a quantitative restriction for an ethnicity, not as mankind have elasticity in density and adaptive capacity. Therefore, this study based on the existing data and supposed that the calculated original unit from the simulated emergy data still meet the restriction of density distribution and quantity of actual species. Also, set the existing density within the unit area as the upper limit. The energy exceeded upper limit must average allocated on the peripheral nine grids to be closer to the ecological development and succession in the true world.

Take a view of the simulation results (Figure 9 and 10), the simulation results of the stock variables for mangrove and crab generally matched with the calculation results in previous section and the development trend obtain from dynamic simulation. From the figure of T5, the crab ethnicity lost their space of development gradually under the expansion of mangrove and then turned to the coast and bank for development. The mangrove ethnicity developed along the riverbank at the intersection point of Kerya Stream, Sanshinkung Stream and the high water level line. The distributions simulated by GIS showed a character that the energy converged in space. As shown obviously in the simulation figures of the stock change of the crabs, the unit space with high density neighbored still even the crabs ethnicity growth was negative after simulation and their space was compressed. The energy in the area of low density will move closer to the area of high space density to forming the energy distribution similar to the concentric circles gradually. It may be caused by the relatively better development condition in the center of the concentric circles.

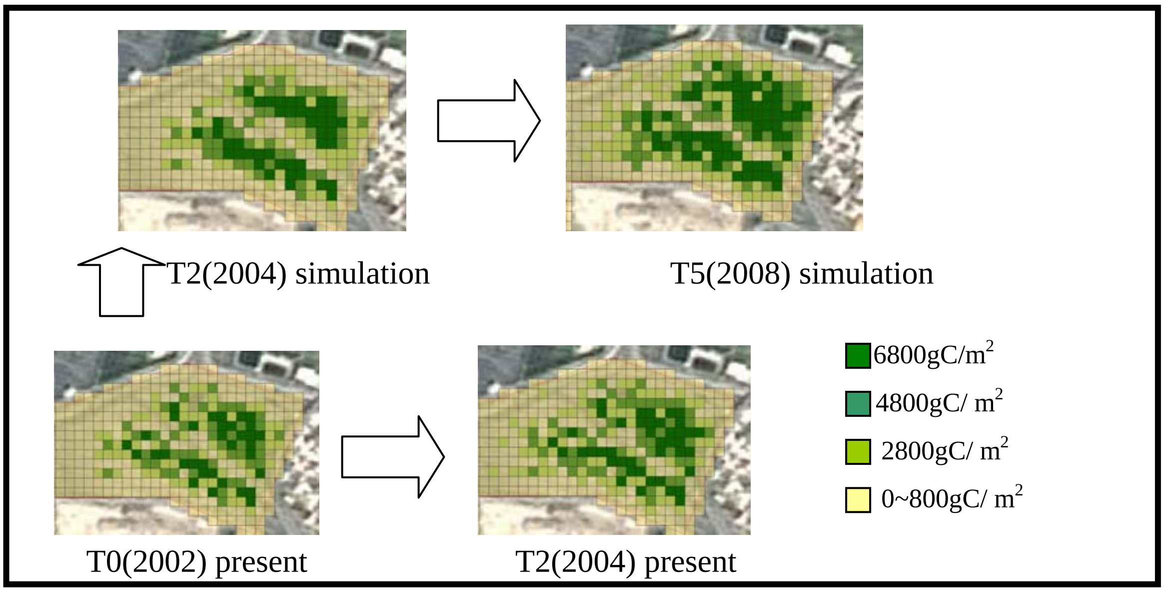

Figure 9 Results of simulating ecological change of mangrove by GIS in 2002-2008

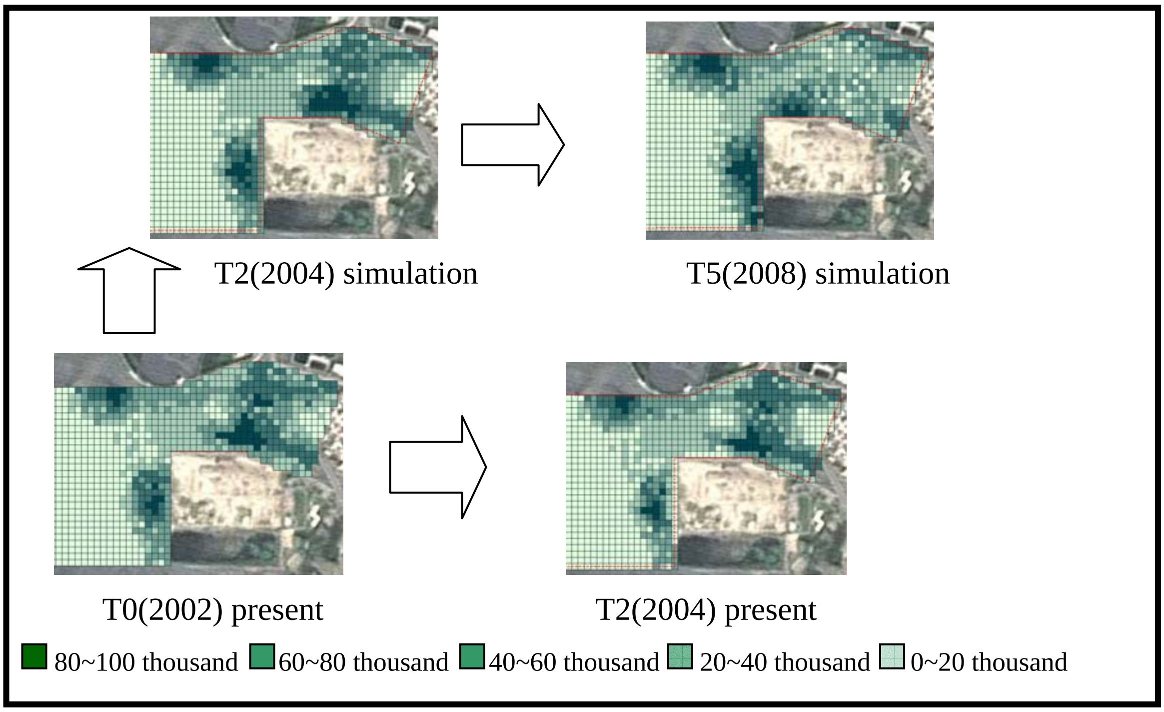

Figure 10 Results of simulating ecological change of crab by GIS in 2002-2008

CONCLUSION

1. Conclusions

In a complete and balanced ecological environmental system, each species will survive with the most favorable development behavior in order to guarantee itself occupy a space in the limited space and resource. There is no exception for human beings. With the expansion of mankind, the criteria for land development and classification was often influenced by the subjective judgment and human demanded activity and purpose. However, the land suitability analysis on the project of assessing natural environment needed to considered in the future that whether it violates the sex principle of mutual beneficial intergrowth of the natural environment system.

This study reviewed ecological economics, general system theory and adopted the concept of emergy of ecosystem proposed by Odum, then built a ecological energetic system model of wetland in Hsiangshan, Hsinchu according to the composition of the environmental system in the study area. Through the computational analysis by the software, the succession processes and development in the future of the wetland in Hsiangshan, Hsinchu were simulated. The achievements obtained are showed as follows:

(1) The wetland of Hsiangshan in Hsinchu is an extremely complicated ecosystem. This study used general system theory to inspect the composition of the ecological environment. Then the ecosystem model and mathematical equations were built in this study area according to the energy flow and relations among the compositions of the system.

(2) The model structure and mathematical equations built in this study were performed parameter calibration and variable simulation by software STELLA. The simulated change of distribution through GIS was presented in the following.

A. The study area was a self-operative environmental system. Even some of the stock variables had growth and decline, they were all restricted by the limited recycling resources and tended towards stability. The mangrove in the model was a manually planted species that obtained energy from the river and by self-reciprocation. It can grow continuously as long as the characters of land and species allowed until the consumed energy can only maintain its breath thus the growth will slow down gradually.

B. The results of the simulation showed that the development space for crab ethnicity had lost gradually with the expanding mangrove and turned to develop by the coast and river to sea. Then the mangrove ethnicity grew along the bank. With the increasing energy consumption caused by increased mangrove, the energy for benthos and crabs was compressed and gradually became balance and tended towards stability in A.D. 2010.

C. The distributions demonstrated through the GIS showed that energy had converged in space. For example, the simulation growth for crab ethnicity was negative and their space was compressed. The space unit of high density neighbored still and the portion with low energy density distributed tended to move toward the area of high density in space and formed the energy distribution similar to the concentric circles gradually.

2. Suggestions

The research processed was restricted to some external limitations. Thus, the encountered difficulties and bottlenecks and related suggestions are proposed:

(1) As the availability of information is concerned, a simulation analysis requires the support of long-term basic data to build a more intact environmental simulation model. Due to the difficultly of collecting ecological data or incomplete data, it was unable to compare the simulation data further. Some estimation bases for parameter calibration quoted the data of foreign scholars under different environmental backgrounds and geographical conditions may produce greater error that need to be discussed and corrected. If relevant governmental or other private organizations support building the ecological database of the wetland in Hsiangshan continuously, the simulation accuracy will be improved and the research efficiency will also be enhanced.

(2) The stock variable discussed in the ecosystem model of this study was limited to the accuracy of crab data, the regarded the crab as a whole ethnicity. But there are different characters of different crab species and there are competitions among them. So suggest the researches later on can analyze the conditions and distribution range of energy flow of different crab species separately when enough basic data is available to get more objective and more intact research results.

ACKNOWLEDGMENTS

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A CONSTRUCTS FOR PERFORMANCE MANAGEMENT OF COASTAL WETLANDS IN TAIWAN

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ABSTRACT

Wetlands are natural buffer areas crucial to coastal environments, especially for island countries such as Taiwan in which land resources depend on wetlands for protection. However, the current regional management system for land use cannot effectively prevent damage to coastal wetlands. The significance of wetlands outweighs the consequences from restricting or controlling their utilization and development. A management system utilizing performance standard criteria based on sustainable managerial concepts will likely prove useful for sustaining conservation of wetland. The goal of this study is to establish criteria for performance standards for Taiwan's coastal wetlands, and, by using the Grey Relation Analysis Model, develop a performance index for independence and availability that can serve as reference for future study. Of the 22 index features of wetland environmental functionality that are determined based on the definition and functionality of wetlands, this study identified 7 index items for applicability and representative for coastal wetland performance management. Following screening, these indices employed in managing coastal wetland environments in which exist a high degree of uncertainty, extreme difficulty gathering data, ambiguous correlations among functionality indices, and vulnerable to the effects of subjective definitions.

Keyword: Coastal wetland, performance management, grey relational analysis model

INTRODUCTION

As an island, Taiwan has approximately 11,846 hectares of wetlands. Therefore most coastal development is directly or indirectly related to wetlands. Wetland preservation is typically in conflict with development. Wetlands are natural buffer areas and their importance has been well recognized by many countries. Advanced countries, such as the US, Japan and the most European countries, have adopted sustainable management systems to protect their wetlands (Broll et al. 2002; Yamashita 1994), implementing different levels of wetland in accordance with wetland functions. However, in many years of development of west coastal wetland, it is mostly for external use of land, but seldom for management on inherent characteristics of land. The results in some environmental issues and creates many land ecological problems being overlooked.

Agenda 21, was adopted by the United Nations Conference on Environment and Development, its contents emphasized ecological land use and environmental planning and management (Chiau 1998). Taiwan's current land management system is still based on traditional land classifications and zoning and cannot exert precise control over land use and fails to protect the environment. The conventionally adopted system is particularly not applicable to resource management and preservation for sensitive areas such as waterfront and wetlands. Performance standards, which are substantial and flexible criteria for land resource utilization, accommodate public interests while prioritizing the carrying capacity of the land. The feature of performance standards is that land use plans and resource management measures are combined. To respect carrying capacity of environment and resources, performance standards are developed to control the negative effect of zoning and achieve the goal of coexistence of humans and their surrounding environment.

This study, which adopts the concept of sustainable management, attempts to establish the performance standard criteria for sustainable management of coastal wetlands. After examining issues related to wetland resources, indicators that can investigate performance management for different development activities were identified. Since wetland environments are complex and dynamic environmental systems, there are numerous obstacles to data collection. Thus, this study considers wetland performance management system as a grey system. Under the condition of small sample with uncertainty, grey relational analysis from grey system theory is used to select performance standard criteria for management of coastal wetlands. The method will increase the feasibility of the proposed research and reduce subjectivity in manual operation of information. After the characteristics of the performance indicators are selected by independence, data accessibility and simple operation, these performance standard criteria are used as references to develop land use zoning for coast and help establish the method of research for wetland classification, assessment and quantification.

SELECTION MODEL —GREY RELATIONAL ANALYSIS

The grey system is a real-world system that can accommodate incomplete or uncertain information. A small sample with uncertainty can be described in the grey system (Deng 1989). Correlation grade is typically a relationship between two variables, functions, etc. Grey relational analysis assesses the relationship between factors (grey relational grade) to evaluate correlations among factors. Through such a correlation grade differentiation, the independence of factors can be identified.

The grey relational analysis model is an influence measurement model based on grey system theory which, in turn, is based on the following principles (Tzeng and Tsaur 1994): (1) the established model is a non-functional sequence model; (2) the calculation method is simple and easy; (3) there is no strict requirement for sample quantity; (4) sequence data for section characteristics do not require normal distribution with probability compliance; and, (5) the correlation grade among sample data can be analyzed and conclusions made without any conflict with qualitative analysis.

If $X = \{x_j \mid j \in N\}$ is a grey relational factor set, $x_0 \in X$ is a reference sequence, $x_i \in X(i \neq 0)$ is a comparative sequence, *k* is the number of samples (*k* =1,2,...,*n*), *i* is the number of indicators (*i* =1,2,...,*m*), then $x_i(k)$ represents the number for *ith* indicator and *kth* point and $x_0(k)$ is the number of *kth* point for the reference indicator. Thus, the grey relational grade definition for x_i, with respect to x_0, is $\gamma(x_0, x_i)$ and the grey relational coefficient is $\gamma(x_0(k), x_i(k))$. The more similar x_i and x_0 are, the larger $\gamma(x_0, x_i)$ is. From each of the above assumptions, the equation for grey relational grade $\gamma(x_0, x_i)$ can be derived as

$$\gamma(x_0, x_i) = \frac{1}{n}\sum_{k=1}^{n}\gamma(x_0(k), x_i(k)), \quad \gamma(x_0(k), x_i(k)) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \varsigma \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \varsigma \max_i \max_k |x_0(k) - x_i(k)|}$$

This study, therefore, adopts the grey relational analysis model as its indicator selection method for coastal wetland performance indicators. For wetlands with complex environments, uncertainty of information and difficulty in data collection, this methodology can identify simply representative wetland indicators.

SELECTION OF COASTAL WETLAND PERFORMANCE MANAGEMENT INDICATOR

3-1 Initial Indicators

According to the elements comprising wetlands and their non-use functions, this study uses hydroperiod, soil structure and aquatic plants as the three natural wetland components to develop the wetland environmental function indicators (Mitsch and Gosselink l993).

1.Hydrology: Groundwater recharge(*W*1); Surface water inflow(*W*2); Assimilative capacity(*W*3); Tidal effect(*W*4); Water level(*W*5); Water flow velocity(*W*6); Self- purification(*W*7); Influent and effluent(*W*8); Flood frequency(*W*9)

2.Soil structure: Salinity(*W*10); Water quality(*W*11); Water saturation period(*W*12); Soil porosity(*W*13); Nutrient effectiveness(*W*14); Soil erosion(*W*15); Contaminant sediment(*W*16); Organic content(*W*17)

3.Plant ecology: Vascular plant type(*W*18); Aquatic plant density(*W*19); Plant energy flow(*W*20); Plant community structure(*W*21); Animal community structure(*W*22)

3-2 Grey Relational Grade Calculation and Sequencing

1.Calculation of grey relational grade $\gamma(W_1, W_i)$

2.Grey relational grade $\gamma(W_1, W_i)$ Sequencing

3.Clustering of performance indicator: repeating steps 1 and 2 for grey relational grade calculations and sequencing obtains the indicator of comparative sequence result for each reference sequence. The comparative sequence indicators with similar sequencing are clustered as are those with high correlations. Fig. 1 shows each reference sequence indicator in the same cluster as *W*1 and the comparative sequence indicator sequencing results. The six corresponding values in the normalized matrix to the reference sequence are plotted as a broken line. From Fig.1, the similarity among *W*1, *W*5, *W*8, *W*12, *W*16, and *W*20 is identified.

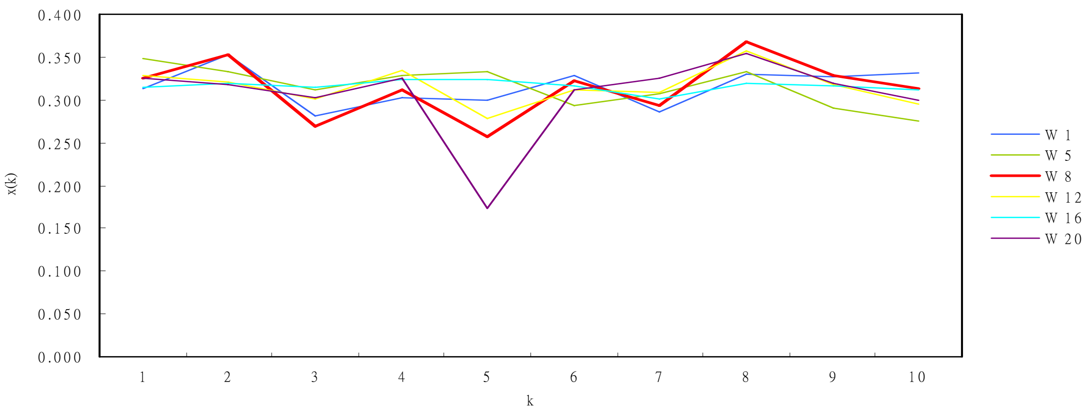

Figure 1 Broken Line for Indicators of *W*1, *W*5, *W*8, *W*12, *W*16, *W*20 in the Same Cluster

3-3 Selection of Representative Indicator

Following the calculation in Section 3-2 the 22 wetland environmental functional indicators are clustered into 7 categories. Then one indicator in each category is selected as the representative indicator by applying the principles of selection for a representative indicator with consideration of data availability, indicator controllability, minimization of indicator and repeating relationships among indicators. The 7 clusters is: 1.Water level(*W*1; *W*5; *W*8; *W*12; *W*16; *W*20); 2.Surface water inflow(*W*2; *W*4; *W*15); 3.Water quality(*W*7; *W*11); 4.Water flow velocity(*W*6; *W*10; *W*18); 5.Organic content(*W*9; *W*14; *W*17); 6.Soil porosity(*W*3; *W*13; *W*21; *W*22); 7.Aquatic plant density(*W*19).

CONCLUSION

Increasing urbanization is gradually destroying Taiwan's western coastal wetlands. Most advanced countries recognize the importance of wetland preservation. If effective wetland management measures are not instituted, the roughly 20 remaining wetlands in Taiwan will likely disappear. This attempted to develop an effective wetland environmental management standard despite the lack of wetland environmental data and related research activities. Grey system theory was applied to identify a coastal wetland performance management indicator. Such representative indicators should provide a reference for further management system planning.

ACKNOWLEDGMENTS

The authors would like to thank the National Science Council of the Republic of China, Taiwan for financially supporting this research under Contract No. NSC 96-2415-H-216-007.

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出席國際學術會議心得報告

計畫編號	NSC 96-2415-H-216-007
計畫名稱	新竹香山濕地生態系統演進模擬分析之研究
出國人員姓名 服務機關及職稱	閻克勤 中華大學建築與都市計畫學系　副教授
會議時間地點	97 年 7 月 6 日至 7 月 10 日 South Korea, Seoul
會議名稱	International Conference on Business and Information, BAI 2008
發表論文題目	1.Determining ecological change in the Hsiang Shan wetland in Hsin- Chu via an ecological energetic model; 2. A constructs for performance management of coastal wetlands in Taiwan

一、參加會議經過

7/6 搭機前往韓國首爾，抵達仁川機場後轉搭巴士前往飯店住宿。7/7 下午前往會場 JW Marriott Hotel 報到。7/8 早上九點開始進行論文發表的專題報告行程，此次共計有 295 篇論文在七個會議室分成兩天以 53 個場次進行發表，另有 170 篇的張貼論文文章，參與國家達到 39 國，規模可謂非常盛大。每日在論文發表告一段落之後，傍晚還安排有相關的討論會，提供參與人員進行交流。7/8 共進行 165 篇的論文發表，相關子題含括經濟學、市場學、商業管理、科技管理、社會議題等範疇。

7/9 上午開始有休閒及社會環境研究議題的論文發表，本人發表之論文排在 7/9 早上 E5 會場的第三場及第五場，Sesion Chair 是 Islamic Azad 大學的 Shafiezadehgarousi 教授，報告之後由 Shafiezadehgarousi 教授提問有關方法論使用上的相關問題。當天發表的論文尚有關於文化創意產業設施、非營利組織管理、休閒旅館管理及多目標規劃方法學的應用等多篇論文共同進行討論。研討會會議在 7/9 傍晚圓滿閉幕，7/10 搭機回國。

二、與會心得

此次會議為本人第二次參加國際研討會，會議中與世界各國大學教授面對面接觸，除能拓展視野、增加見聞之外，對於專業領域中的新思潮、新觀念並有耳濡目染之效。尤其議程中針對經濟學與管理學方面的專題報告及論文發表，對於日後進行環境規劃相關研究具有啟發式的正面意義，並可在接受新知、激發創意上，達到加分的效果。此外，會議中認識了相當多此一領域的朋友，接觸來自世界各地的不同文化，對於國外的做事方法與態度亦有深刻印象。

南韓的經濟發展過程與台灣相似，且與台灣的關係深厚，原先對南韓的印象並不好，但此次研討會之旅卻讓人對南韓的都市建設與環境管理留下深刻的印象，其接收新觀念與新技術的積極態度，以及求新求變的企圖心實應為國人之借鏡。此次研討會經驗讓人感受到主辦單位在場地安排與時程設計上的用心，但因規模過於龐大，有些場次稍嫌流於形式之感，未來若要舉辦類似國際研討會應可引以為戒。

三天的研討會並無安排參訪行程，不過利用 7/7 當天報到之前自行前往首爾著名的

清溪川親水區參觀。個人認為清溪川建設的成果並不能算是真正的河川整治，僅能說是觀光遊憩親水設施上的建設而已，因為其在生態環境規劃上的投入可說是微乎其微。尤其是河床竟然是水泥鋪設而成，這種作法會使河川喪失原本的自淨與循環功能，河川已然被宣判死刑。因此對於其被渲染的整治成果，個人深感不以為然。

三、攜回資料名稱及內容

1.會議資料：包括議程、作者個人基本資料

2.研討會論文全集 CD 一片

3. International Journal of Business and Information 期刊論文一本

4. International Journal of Cyber Society and Education 期刊論文一本

5.Contemporary Management Research 期刊論文二本

四、發表論文摘要

DETERMINE ECOLOGICAL CHANGE IN HSIANGSHAN WETLAND, HSINCHU BY AN ECOLOGICAL ENERGETIC MODEL

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ABSTRACT

Taiwan has long been influenced by its surrounding ocean. While Taiwan has 1,400 kilometers of coastline, its geographic location and natural factors remoteness and inaccessibility have prevented limited the utilization for development of this coastline. However, recent social and economic development has lead to this coastal land being developed for various purposes. Whether intensive development and use of coastal land result in excessive exploitation of that land and thus disrupt the ecological balance has become a major concern for various communities. Consequently, land use and development in coastal areas, particularly development locations and objectives, should be evaluated and reviewed more carefully, and consideration should be given to whether such development might cause irreversible ecological damage. Analysis of land use suitability has been highly regarded in the site of land use and development, but methods for identifying negative consequences of development have been too one-sided and subjective, and have lacked the characteristics of fussiness and prediction on change of coastal wetlands environment. Consequently, this investigation attempts to develop a system model of wetland ecosystem for the Hsiang Shan Wetland in Hsin Chu, from the perspective of the methodology of systems ecology, while adapting concepts of emergy analysis and General System Theory. Via the programs of the ecological energetic system together with computer calculation, the system can predict future trends in ecological change via dynamic simulation. Furthermore, based on GIS analysis, the system can convert large quantities of sophisticated data into graphic displays, and can further generate an analytical model exhibiting wetlands and emergy analysis indexes, which can then serve as a reference for studies focused on related fields. By matching the images and the overlapping areas, the findings of this investigation help in deciding locations for development, and planning for land use purpose and intensity, and thus enable the study findings to provide a useful reference.

Keyword: Systems ecology, emergy analysis, wetland, land use suitability analysis, Geographic Information System (GIS)

A CONSTRUCTS FOR PERFORMANCE MANAGEMENT OF COASTAL WETLANDS IN TAIWAN

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ABSTRACT

Wetlands are natural buffer areas crucial to coastal environments, especially for island countries such as Taiwan in which land resources depend on wetlands for protection. However, the current regional management system for land use cannot effectively prevent damage to coastal wetlands. The significance of wetlands outweighs the consequences from restricting or controlling their utilization and development. A management system utilizing performance standard criteria based on sustainable managerial concepts will likely prove useful for sustaining conservation of wetland. The goal of this study is to establish criteria for performance standards for Taiwan's coastal wetlands, and, by using the Grey Relation Analysis Model, develop a performance index for independence and availability that can serve as reference for future study. Of the 22 index features of wetland environmental functionality that are determined based on the definition and functionality of wetlands, this study identified 7 index items for applicability and representative for coastal wetland performance management. Following screening, these indices employed in managing coastal wetland environments in which exist a high degree of uncertainty, extreme difficulty gathering data, ambiguous correlations among functionality indices, and vulnerable to the effects of subjective definitions.

Keyword: Coastal wetland, performance management, grey relational analysis model