應用 SWAT+於森林集水區之碳增匯評估

Assessment of Carbon Sequestration within Forest Watershed via SWAT+ Modeling

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摘　要

當前全球面臨氣候變遷帶來的嚴峻挑戰，溫室氣體的大量排放造成全球暖化、極端氣候事件頻繁發生與降水分布變化等現象，均威脅自然生態系統與人類生活。聯合國於2001 發布了《千禧年生態系統評估》報告書，旨在評估生態系統變化對人類福祉的影響，之後於 2013 年綜合了千禧年生態系統評估和生態系統暨生物多樣性經濟學倡議(TEEB)，提出了國際通用生態系服務(CICES)三大分類，共分為供給、調節與維持以及文化服務。為因應氣候變遷之影響，聯合國在 2015 年「2030 永續發展目標」(Sustainable Development Goals,SDGs)，當中提出了減緩及調適行動。因人類活動所造成之氣候變遷對生態系統之生物以及環境多樣性的嚴重衝擊，導致地球環境恢復力和生物承載量都明顯減少，其中大氣中二氧化碳濃度不斷因人為活動而持續升高，因此碳儲存可歸類於生態系服務中調節和維持服務中之「調節氣候與化學物質能力」與「水循環和流動調節」這兩項服務。

SWAT+(Soil and Water Assessment Tool+)模式具有空間分布參數、可長時間連續模擬之特性，能夠模擬集水區內的水文、泥沙、作物生長、營養鹽循環等多種生態系統過程。本研究將應用 SWAT+模式評估翡翠水庫集水區之森林碳儲存服務，分析森林集水區之碳增匯效益狀況。研究藉由模式模擬集水區陸域生態系統之水文與營養鹽循環、土壤沖蝕傳輸過程與作物生物質量，再更近一步轉推估碳儲存量。最後，不同管理措施與林種，如樟科、柳杉、闊葉林等在增匯上的表現將作深入分析，以期具體化森林碳增匯之成果。

透過 SWAT+模式模擬翡翠水庫集水區的森林成長，即森林從栽種、樹苗發芽，經歷光合作用代謝枯萎而逐漸成長，最終發展成穩定成熟的森林的過程，大約需 12 年時間，此亦相當符合當地原生樹種之生長週期，並反應出森林處於不同成長階段，可儲存生物碳量之效益。模擬結果顯示年輕森林長速度較快，碳儲存量也增加較多；成熟森林則呈現穩定狀態，碳儲存也維持動態穩定。該期間內年平均碳增匯量約為 7.6 噸/公頃，相當於每年約可吸收27.9噸/公頃的二氧化碳，顯示此森林集水區碳儲存之貢獻相當可觀。

關鍵詞：SWAT+模式，碳儲存，碳增匯，生態系統服務

Abstract

Global climate change presents a serious challenge, as the large-scale emission of greenhouse gases leads to global warming, more extreme weather events, and variance in rainfall distribution. These changes threaten both natural ecosystems and human societies. To address this, the United Nations released the Millennium Ecosystem Assessment in 2001 to evaluate how ecosystem changes affect human well-being. Building on this, the Common International Classification of Ecosystem Services (CICES) was introduced in 2013, which integrated the Millennium Ecosystem Assessment with The Economics of Ecosystems and Biodiversity (TEEB). The CICES framework categorizes ecosystem services into three main groups: provisioning, regulating and maintenance, and cultural services. In 2015, the UN launched the 2030 Agenda for Sustainable Development (SDGs), which includes strategies for both climate change mitigation and adaptation. Human activities have severely impacted the diversity of life and environments within ecosystems, significantly reducing Earth's resilience and biological carrying capacity. The continuous increase in atmospheric carbon dioxide concentrations due to human activity highlights the importance of carbon storage. This is classified under the CICES regulating and maintenance services, specifically as "regulation of climate and chemical composition" and "regulation of water flows and cycles."

The SWAT+ (Soil and Water Assessment Tool+) model, which incorporates spatially distributed parameters and enables long-term continuous simulation, is capable of modeling various ecosystem processes such as hydrology, sediment transport, crop growth, and nutrient cycling within a watershed. This study applies the SWAT+ model to evaluate the forest carbon storage services in the Feitsui Reservoir watershed, aiming to analyze the carbon sequestration potential of forested areas. Through simulation of hydrological and nutrient cycling processes, soil erosion and sediment transport, and crop biomass production within the terrestrial ecosystem of the watershed, the model can be used to estimate carbon storage. Finally, the performance of various forest management practices and tree species—such as Lauraceae, Japanese cedar, and broadleaf forests—will be analyzed in detail to concretely assess their contributions to enhanced carbon sequestration.

The SWAT+ model was used to simulate forest growth within the Feitsui Reservoir watershed. The simulation, which encompasses the entire growth process from planting and germination to a mature, stable forest, spans approximately 12 years. This duration aligns with the natural growth cycle of the region's native tree species. The model’s results effectively illustrate the biocarbon storage benefits at different stages of forest development. The simulations reveal that younger forests exhibit a faster growth rate, leading to a greater increase in carbon storage. In contrast, mature forests maintain a stable state, with carbon storage remaining in a dynamic equilibrium. During the simulated period, the average annual carbon sequestration was approximately 7.6 tons per hectare, which is equivalent to absorbing

roughly 27.9 tons of carbon dioxide per hectare per year. This demonstrates the significant contribution of this forest watershed to carbon storage.

Keywords: SWAT+ Model，Carbon Storage，Carbon Sequestration，Ecosytem Services