

Environmental and Anthropogenic Influences on Stream Nitrate Concentrations in Forested Watersheds of Kyushu Main Island, Japan

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Abstract

Forested watersheds play a crucial role in regulating nitrogen (N) cycling and protecting downstream water quality, yet they are increasingly vulnerable to atmospheric depositions, land-use changes, and climate variability. This thesis investigates the spatial patterns, environmental drivers, and anthropogenic influences on stream nitrate (NO_3^-) dynamics across forested watersheds of Kyushu Main Island, Japan, a warm temperate region strongly influenced by the East Asian monsoon.

A total of 869 water samples were collected from undisturbed forest watersheds, supplemented by isotopic analysis ($\delta^{15}\text{N}$, $\delta^{18}\text{O}$), machine learning (Random Forest regression), cluster analysis, and paired watershed approaches. Results revealed a regional distribution pattern, while northern prefectures (Fukuoka, Oita) exhibited higher NO_3^- linked to fossil fuel and agricultural deposition, while southern prefectures (Miyazaki, Kagoshima) showed lower concentrations due to high precipitation and frequent hydrological flushing but were influenced by temperature and livestock-derived N inputs. Isotopic evidence demonstrated that microbial nitrification was the dominant pathway supplying NO_3^- in the southern part of Kyushu, while evidence for denitrification was limited or spatially restricted.

Random Forest models identified annual precipitation as the strongest negative regulator of stream NO_3^- , whereas atmospheric total annual N deposition acted as a positive driver, with concentrations increasing markedly above a threshold of $\sim 12 \text{ kg N ha}^{-1} \text{ yr}^{-1}$. Cluster analysis delineated three environmentally distinct regions, each with unique anthropogenic and climatic drivers, underscoring the importance of region-specific management. A paired watershed study in Miyazaki prefecture revealed that even partial clear-cutting significantly elevated stream NO_3^- , particularly in spring, demonstrating that even moderate forest disturbance alters N dynamics under monsoon-driven conditions.

Collectively, this thesis provides a comprehensive assessment of the environmental and anthropogenic controls on stream N cycling in warm temperate forests. The findings highlight the resilience of undisturbed forests as N sinks, but also their vulnerability to atmospheric inputs, land-use disturbances, and climatic extremes. Given the shared features between Kyushu and other monsoon-influenced forested landscapes in East and Southeast Asia, these results offer a transferable framework for developing regionally tailored strategies to mitigate N pollution and support sustainable forest and watershed management.