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The use of a geographic information system to analyze long-term landscape alteration by beaver

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Abstract

A Geographic Information System (GIS) was used to analyze how beaver (*Castor canadensis*) have altered the hydrology and vegetation of Voyageurs National Park, Minnesota over a 46-year period. Maps of beaver ponds prepared from 1940, 1948, 1961, 1972, 1981, and 1986 aerial photographs were analyzed with a raster-based GIS to determine impoundment hydrology and vegetation distributions for each map date. Overlay and classification techniques were used to quantify hydrologic and vegetation changes between map dates. The GIS was superior to manual methods for some analyses (*e.g.*, area measurement), and indispensible for others (*e.g.*, transition analysis). Total area impounded increased from 1% to 13% of the landscape between 1940 and 1986, as the beaver population increased from near extirpation to a density of 1 colony/km^2. Most of the impoundment area increase occurred during the first two decades, when 77% of cumulative impoundment area was flooded. Once impounded $\geq$ 60% of the area maintained the same water depth or vegetation during any decade. GIS procedures were combined with field data to show that available nitrogen stocks nearly tripled between 1940 and 1986 as a result of beaver impoundment.

Introduction

Temporal change is an integral part of community, ecosystem, and landscape functioning: pioneer plant communities are succeeded by secondary plant communities, nutrient availability is affected by litter accumulation, landscape patchiness is altered by disturbance, and ecotone locations are affected by climatic change. While conventional research methods are suitable for quantifying such changes in small areas (*i.e.*, 0.1 to 10 ha) over short periods of time (*i.e.*, <3 yr), they are inadequate for studying longer-term ecological change over large heterogeneous areas.

Geographic Information System (GIS), coupled with field studies and historical aerial photography, provide a means of researching the magnitude and consequences of temporal change for large areas over the half-century record of available air photo coverage. We have used this technique to study long-term landscape alteration by beaver (*Castor canadensis*). By changing the flow of water in the landscape, beaver impoundments convert terrestrial to aquatic ecosystems, alter plant communities, and effect pathways and rates of nutrient cycling (Johnston and Naiman 1987; Naiman *et al.* 1986, 1988a). Beaver ponds increase landscape heterogeneity by creating a spatial mosaic of aquatic and

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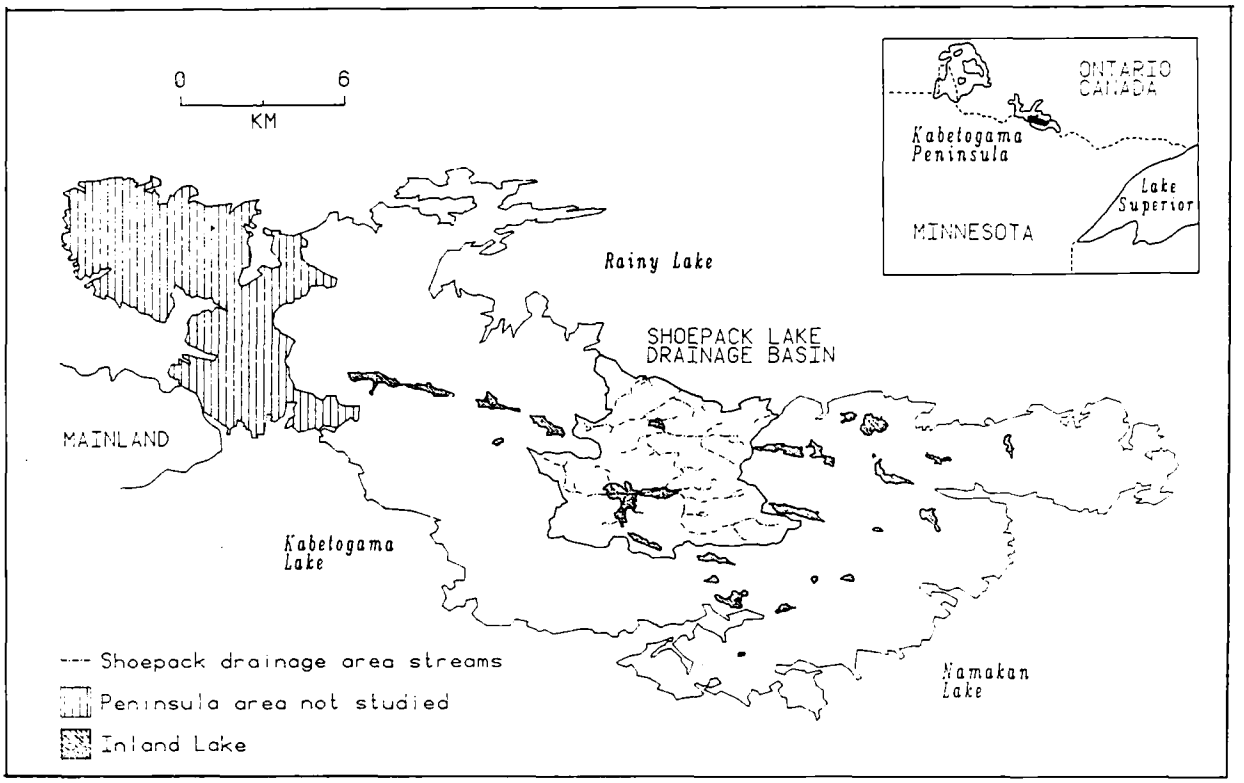

Fig. 1. Study site. The Shoepack Lake drainage basin was used to develop the empirical relationship between measured and GIS-estimated stream lengths (Table 4).

semi-aquatic patches in an otherwise forested matrix. This mosaic has been an integral part of the landscape for thousands of years, and only in the last 200–300 yrs has it been reduced in extent due to trapping pressure by man.

Because they are created and maintained by living organisms, beaver ponds are themselves dynamic, changing as they are colonized, flooded, and abandoned by beaver. Beaver act as agents of disturbance, setting back terrestrial vegetation succession by flooding forested areas. The ponding of water creates anaerobic conditions in beaver impoundment sediments, altering the form and abundance of compounds affected by redox reactions. When beaver leave and the pond drains, vegetation succession resumes and the sediments revert to aerobic conditions. In this way, beaver ponds constitute a rapidly shifting mosaic of hydrological and vegetatively diverse landscape patches.

The relatively large size (>0.5 ha) of most beaver ponds, and their sharp contrast with the surrounding forest, makes it possible to accurately map the ponds using current and historical aerial photography. The GIS makes it possible to analyze the aerial extent, distribution, and characteristics of beaver ponds from these maps. Not only can GIS be used to determine spatial relationships at a given point in time, it can also be used to rapidly analyze temporal changes in the spatial mosaic.

All data presented here, with the exception of nutrient and precipitation data, were derived from GIS analysis of air photo-derived maps, and illustrate how GIS techniques can be used for ecological research. By combining GIS capabilities with air photo interpretation and field studies, we have: (1) measured the length of streams impounded by beaver, (2) determined the location, areal extent hydrology, and vegetation distributions of areas altered by beaver impoundment, (3) analyzed how the hydrology and vegetation of those areas have changed over time as a result of beaver disturbance and vegetation succession, and (4) related the spa-