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Research papers

Groundwater discharge and phosphorus dynamics in a flood-pulse system: Tonle Sap Lake, Cambodia

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ABSTRACT

Tonle Sap Lake (Cambodia), a classic example of a "flood pulse" system, is the largest freshwater lake in SE Asia, and is reported to have one of the highest freshwater fish productions anywhere. During the dry season (November–April) the lake drains through a tributary to the Mekong River. The flow in the connecting tributary completely reverses during the wet monsoon (May–October), adding huge volumes of water back to the lake, increasing its area about six fold. The lake is likely phosphorus limited and we hypothesized that groundwater discharge, including recirculated lake water, may represent an important source of P and other nutrients. To address this question, we surveyed hundreds of kilometers of the lake for natural ^{222}Rn (radon), temperature, conductivity, GPS coordinates and water depth. All major inorganic nutrients and phosphorus species were evaluated by systematic sampling throughout the lake. Results showed that there were radon hotspots, all at the boundaries between the permanent lake and the floodplain, indicating likely groundwater inputs. A radon mass balance model indicates that the groundwater flow to Tonle Sap Lake is approximately 10 km^3/yr, about 25% as large as the floodwaters entering from the Mekong River during the wet monsoon. Our results suggest that the groundwater-derived dissolved inorganic phosphorus (DIP) contribution to Tonle Sap is more than 30% of the average inflows from all natural sources. Since the productivity of the lake appears to be phosphorus limited, this finding suggests that the role of groundwater is significant for Tonle Sap Lake and perhaps for other flood pulse systems worldwide.

1. Introduction

The "Flood Pulse Concept" states that regularity is central to the importance of flooding in tropical systems, allowing biota to evolve adaptations that enable exploitation of newly accessible habitat and the 'pulse' in nutrient availability and primary productivity associated with floodplain inundation (Junk et al., 1989). The pulse is thus seen to stimulate a chain-reaction of increased productivity, which is transferred up the food chain. Junk (1999) observed that periodic floodplain inundation increases the availability of nutrients and rates of organic matter recycling, increasing the potential for primary and hence secondary production.

While evidence accumulated from a number of controlled laboratory experiments suggests that re-flooding of dried wetland sediments can result in a significant release of both nitrogen and phosphorus (Briggs et al., 1985; Fabre, 1988; Qiu and McComb, 1994, 1996; Turner and Haygarth, 2001), other laboratory studies showed no significant nutrient release following re-flooding (Qiu and McComb, 1994; Mitchell and Baldwin, 1998, 1999; Baldwin et al., 2000).

It is thus not entirely clear what the controlling mechanisms are for nutrient delivery within flood pulse systems. In addition, not much consideration has been given to groundwater as a nutrient source in such environments. Rivers and streams have traditionally been thought to be the major conduits of nutrient transfer to receiving water bodies, including lakes and the ocean (see Ruttenberg, 2003 and citations therein). However, groundwater may also be an important transport medium (Slomp and Van

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Cappellen, 2004; Spiteri et al., 2008; Moore, 2010), and may be particularly important in flood pulse systems.

Tonle Sap Lake (TSL), the largest freshwater lake in SE Asia (Fig. 1), floods every year during the wet monsoon, from about May to October. Floodwaters from the Mekong River enter TSL via a connecting tributary (Tonle Sap River, TSR). By the end of the wet season TSL is ~7 m deep and has a volume of ~60 km^3. When the rains end in late October or so, the flow in TSR reverses, draining much of the lake and providing a source of fresh water to the Mekong Delta. By the end of the dry season in May or June, the lake is now <1 m deep, and has experienced a 6-fold reduction in surface area and a volume of only about 1.6 km^3 (Table 1). While

Table 1
Average characteristics of Tonle Sap Lake at low water level and flood stage (Kummu et al., 2008).

Parameter	Low Water Level (Apr/May)	Flood Stage (Oct/Nov)
Area (km^2)	2240	13,220
Length (km)	120	250
Width (km)	35	100
Volume (m^3)	1.6 x 10^9	59.6 x 10^9
Depth (m)*	0.5	7

* Average depths measured at low (June 2014) and high (November 2014) water level during our expeditions were 0.9 m and 6.0 m, respectively.

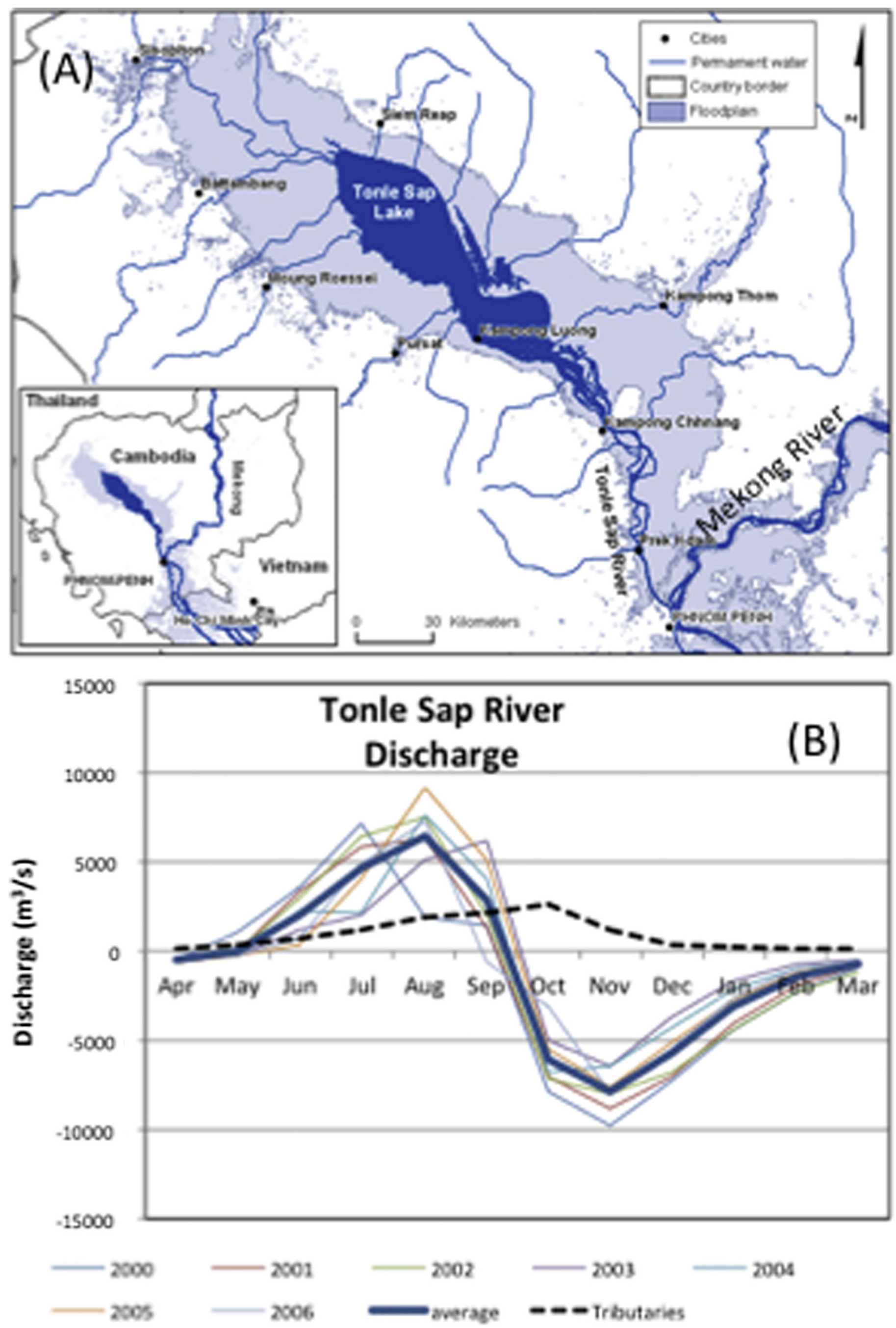

Fig. 1. (A) Map of Tonle Sap Lake (TSL), showing the Mekong River, and their connection via the Tonle Sap River (TSR). Dark color represents the permanent lake; lighter color shows extent of the floodplain. (B) Variations of discharge of the TSR from 2000 through 2006 and average flow as well as the average monthly total discharge of all tributaries into TSL. Positive values represent flow into TSL while negative values are for flows exiting the lake through the TSR. Discharge data compiled by M. Kummu (pers. comm.).