Warfare rather than agriculture as a critical influence on fires in the late Holocene, inferred from northern Vietnam

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Fire has played an essential role in the development of human civilization. Most previous research suggests that frequent-fire regimes in the late Holocene were associated with intensification of human activities, especially agriculture development. Here, we analyze fire regimes recorded in the Song Hong delta area of Vietnam over the past 5,000 years. In the prehistoric period, 2 long-term, low-charcoal abundance periods have been linked to periods of low humidity and cool climate, and 5 short-term fire regimes of 100–150 years in duration occurred at regular intervals of ≈ 700 years. However, over the last 1,500 years, the number, frequency, and intensity of fire regimes clearly increased. Six intensified-fire regime periods in northern Vietnam during this time coincided with changes of Vietnamese dynasties and associated warfare and unrest. In contrast, agricultural development supported by rulers of stable societies at this time does not show a positive correlation with intensified-fire regime periods. Thus, warfare rather than agriculture appears to have been a critical factor contributing to fire regimes in northern Vietnam during the late Holocene.

fire regime | Song Hong (Red River) | charcoal | human activities

Fire regimes play an important role in nutrient cycling, the development of vegetation ecosystems (1–3), and global concentrations of CO₂ in the atmosphere (4). To understand the factors that influence them, fire regimes have been studied at various time scales. Wildfire and climate are intimately linked (5–7). Many previous studies have shown that fire regimes at decadal, centennial, and millennial time-scales are influenced by climatic change at the similar pacing (8–12). Fire regimes have been presumed to occur under hot and dry climatic conditions (13–16). However, high fire frequencies have also been identified during relatively cool and moist periods, which suggests fuel-determined rather than directly climate-determined influences on fire regimes (17, 18). Climate controls fire directly by providing opportunities for ignition and spread of fire, but also indirectly through regulation of the accumulation and structure of fuel at longer time scales (19). In addition to natural fire triggers, human activities can also play an important role in the occurrence of fire. In the advancement of human civilization, fire has played an essential role; for example, fire has been used for heat and light, for cooking, to fend off wild animals, and to clear land in preparation for planting (20–22).

Because human activities intensified in the late Holocene, fire regimes became decoupled from climate, especially during the last 2 millennia (4, 21). Campbell and Campbell (23) suggested that a sharp increase of fire regimes in the last 2 millennia can be ascribed in large part to an increase in human population compared with prehistoric times. Human activity is believed to induce more fire regimes as a result of adaptation of the landscape for human use, large-scale deforestation, burning, agriculture, and warfare, even as a result of forest-conservation

measures in areas of open forest in present-day monsoonal environments (4, 21, 22). However, determining how these activities have affected fire regimes is complicated, and there are still insufficient reliable data to do so.

The Song Hong delta is densely populated and most of the land has been cultivated for rice fields; fire has certainly been used for deforestation and domestic purposes. This research was carried out to address the question of how often fire regimes occurred and what were the critical factors influencing the fire regimes in northern Vietnam during the late Holocene.

Results and Discussion

Charcoal records in sediments provide the only way to reconstruct fire records spanning more than a few hundred years. We carried out charcoal analysis on samples with a resolution of several decades from 2 sediment cores, VN (20°24'37"N, 106°22'39"E) and GA (20°15'26"N, 106°30'57"E), drilled in the Song Hong (Red River) delta in northern Vietnam during a cooperative project between Japan and Vietnam (Fig. 1). In previous studies, we reconstructed the palaeoclimate and depositional environments from these 2 cores (24, 25). Depositional environments in core sections we analyzed were submarine delta from delta front platform to prodelta on the basis of results from sediment facies analysis including molluscan fossils (25) (Fig. 2) (see *Materials and Methods*). All of the charcoals in the submarine delta were transported by river from the Song Hong (Red River) drainage area and surroundings together with sediment materials, not in situ. Our age model was based on 14 AMS (accelerator mass spectrometry) ¹⁴C dates from core VN, and 13 ¹⁴C dates from core GA, and was calibrated using CALIB5.01 (24–26) (see *Materials and Methods*).

According to archaeological records, from ≈ 3000 BC most of the population of Vietnam migrated from mountainous areas to areas of low hills surrounding the midlands and fertile plains of large rivers valleys and coastal areas, shown by cultures of the Phung Nguyen, Ha Long, and Mai Pha in the Song Hong delta (27). Stone hoes, harvesting knives, stone spades, and stone ploughs found at archaeological sites at Hoa Binh suggest that rice was cultivated in these areas. Rice grains related to the Phung Nguyen culture have also been found at the Dong Dao

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Fig. 2. Curves of charcoal and palynological records from 3550 BC to 1950 AD (mud content and the sedimentary environment modified from ref. 25).

and 20–50 μm , and that $<5\%$ of particles are larger than 50 μm (Fig. 3). All of the samples for our study were from submarine delta sediments, which are generally subjected to much stronger hydrodynamic action than lake sediments. Thus, the relationship between charcoal size and transport distance determined from lake samples is not appropriate for use in this study. Charcoal analysis of surface samples from the whole Song Hong drainage basin including mountains, floodplain, and submarine delta shows that charcoals in submarine delta are dominated by subround-subangle grains, and both round and angular charcoal grains are rare (See *SI*). The charcoals in our cores are mostly subround-subangle and rarely display round and angular shapes, suggesting these charcoals, are not local, but were transported from the Song Hong drainage basin through rivers.

Two long-term, low-charcoal periods (periods I and II of Fig. 2) during 2550–2050 BC and 400 BC–200 AD correspond to periods of low humidity and cool climate, as demonstrated by low abundances of aquatic herb pollen and the low ratio of tropical arboreal pollen to temperate arboreal pollen. In the cool humid climate period III (1350–1750 AD, Fig. 2), charcoal concentrations show considerable variation, but generally increase toward 1750 AD. A total of 10 short-term charcoal peaks were clearly identified over the last 5,000 years (Fig. 3A). In prehistoric times, each of the periods of high charcoal concentration lasted for ≈ 100 –150 years and occurred at regular intervals of ≈ 700 years (peaks 1–5 of Fig. 3A). Most of the regional fires likely took place in upstream forest areas, as suggested by the rarity of charcoal particles larger than 100 μm (Fig. 3A). The regular cycles of these charcoal records are perhaps indicative of natural fire regimes induced by systematic effects associated with climate and fuel accumulation. However, in the late Holocene, intensified human activity likely upset the natural balance of fire regimes.

The frequency of fire regimes intensified after 450 AD, occurring periodically at intervals of 100–200 years, as indicated by charcoal peaks 6–10 (Fig. 3A). The record of charcoal concentrations since 950 AD shows several intensified-fire regime periods (A–F of Fig. 3B), when dynasties changed frequently and society were unstable in northern Vietnam. Periods A–C correlate with charcoal peaks 7, 8, 9, and periods D–F with charcoal peak 10 (Fig. 3). Charcoal peak 6 spans the period from 450 to 610 AD, when Ly Bon successfully revolted against Chinese rule, occupied Long Bien (modern-day Hanoi), and founded the Empire of Van Xuan (Anterior Ly Dynasty) that remained in power until Chinese domination of the region returned in 602 AD (39). There were several episodes of warfare along the Song Hong drainage area during the period 450–610 AD. These included the Ly Bon rebellion, which mobilized the imperial troops and naval fleet of Giao Chau (in the area roughly corresponding to modern Hanoi) in 542, 544, and 545 AD; retaliation by the Chinese Liang Dynasty against Emperor Van Xuan in the areas of Hanoi, Vinh Phuc, and Viet Tri in 545–548 AD; and Trieu Quang Phuc's resistance and defeat of Liang Dynasty troops in 548–550 AD (35, 39).

Fire was used during warfare as a tactic in ancient times; for example, the firing of Chibi, the firing of the Shangfang Valley, and the firing of the 800-mile Military Barracks in battles in Three Kingdoms in China (40). Sun Tzu specially summarized 5 ways of attacking with fire on military strategy: to burn soldiers in their camp, to burn stores, to burn baggage trains, to burn arsenals and magazines, and to hurl dropping fire among the enemy, having a significant impact on ancient warfare in Asian (41). Fire was also used in ancient warfare to destroy fortifications, to create confusion among opposing troops, to provide communication signals between groups of allied troops, and as a signal of rebellion (35).

The frequent dynastic changes from the end of the third period of Chinese rule to Vietnamese autonomy, followed by the Ngo, Dinh, and Prior Le Dynasties, correspond to the intensified-fire regime of period A (Fig. 3B), indicated by charcoal peak 7 (Fig. 3A). During this period, warfare recorded in Vietnam history includes rebellions led by Mai Thuc Loan in 722 AD, by Phung Hung in 767–791 AD, by Duong Thanh in 819–820 AD, and other rebellions in 828, 841, 858, 860, and 880 AD; battles with the Nam Chieu in China in 816, 832, 846, 853, 858, 861, 862, 863, and 865 AD; the Rebellion of A Dozen Local Military Chiefs from 944 AD to 948; and battles driving out Chinese troops in 931, 938, and 981 AD. During this period, guns and gunpowder were used in battle (35, 41, 42).

Intensified-fire-regime period B corresponds to charcoal peak 8 and is perhaps associated with the rebellions of 1140, 1144, 1154, 1192, 1198, 1208, 1205, 1212, and 1218 AD in Thai Nguyen, Ninh Binh, Hai Duong, and Bac Giang during the later Ly dynasty, and battles against the Yuan Dynasty troops in the areas of Hai Duong, Hanoi, Hung Yen, and Bac Ninh in 1257, 1284–1285, and 1287–1288 AD during the Tran Dynasty.

Intensified-fire-regime period C corresponds to a period when there were frequent changes of dynasty: from the Tran Dynasty to the Ho Dynasty, followed by the fourth period of Chinese domination, the Early Posterior Le Dynasty, the Mac Dynasty, and the Restored Le Dynasty. During the Southern and Northern Dynasties period, there was an ongoing civil war between the Northern Court (Mac Dynasty) and the Southern Court (Restored Le Dynasty) until 1592 AD, when the army of Trinh Tung conquered Hanoi and executed king Mac Mau Hop (26, 38). Two charcoal peaks at ≈ 1550 and 1600 AD are perhaps associated with 2 main periods of conflict in northern Vietnam, in 1546–1561 and 1583–1592 AD. In addition to annual battles at this time, frequent flood and other disasters created an unstable society for 200 years (Fig. 3B) (35). The high relative abundance of aquatic herb pollen substantiates the occurrence of frequent floods during this period (Fig. 2).

Intensified-fire-regime period D spans from 1640 to 1670 AD, concomitant with the Trinh-Nguyen War (1627–1672 AD). It is not likely that this war contributed to the fires at this time because the war occurred mainly in present-day Central Vietnam. Other battles in the surrounding mountains, in which the Mac army attacked Trinh in the Thai Nguyen area in ≈ 1638 AD and Trinh eliminated Mac's army in the Cao Bang area in 1667–1669 AD, should be the dominant events contributing to this high-charcoal-value interval.

Historical records show that Vietnamese farmers in the 18th century suffered starvation, flood disasters, and oppression from their dynastic masters, such as a severe famine in 1741 AD, devastating floods in 1735 and 1746 AD, and the largest gap between the rich and the poor because of oppressive government (35). Many rebellions occurred, spreading widely in northern Vietnam, such as the rebellion led by Nguyen Tuyen, Nguyen Cu, and Vu Trac Oanh in the Hai Duong area from 1739 to 1741 AD; the Ngan Gia rebellion in the Son Nam area in 1740 AD; the rebellion led by Nguyen Danh Phuong from Tam Dao in 1740 AD, which spread to Viet Tri and Bach Hac in 1744 AD, and conquered Thai Nguyen, Tuyen Quang, Viet Tri, and Vinh Yen from 1740 to 1750 AD; and the rebellion led by Hoang Cong Chat in Hung Yen and Hai Duong, which spread to Nam Dinh and Thai Binh (Khoai Chau) in 1740–1768 AD. The Tay Son revolution was successful in 1771 AD, and moved northwards from present-day Central Vietnam to oppose the Trinh Lord in 1786 AD, and then to the Hanoi area, Ha Tay, Hai Duong, and Ninh Binh on the Song Hong delta plain, where several fierce battles broke out between Chinese Qing troops and Vietnam Tay Son between 1788 and 1789 AD (35). Fire-regime period E in our data reflects this period well. There is a published description of the use of fire in battle at this time: “They

made fire torch with rice straw pouring oil, and lighted forming a fire net surrounding the enemy” (35).

Besides the 2 clear intensified-fire regime periods E and F, the high charcoal concentrations of our data show intensified fire regimes throughout the period since 1740 AD (Fig. 3B). Advanced weaponry and gunpowder introduced from western countries might have contributed to this. Period F should correspond to the period of the rebellions in the mountain areas of Thai Nguyen (1917), Yen Bai (1930), and Nghe An/Ha Tinh (1930–1931).

Conclusion

In summary, our data show 2 long-term low-charcoal periods (periods I and II of Fig. 2) that are probably linked to millennial-scale periods of low humidity and cool climate, as inferred from comparison of charcoal concentrations and palynological records. Short-term fire regimes in prehistoric times burned at regular intervals of ≈ 700 years and had durations of ≈ 100 –150 years. These fire regimes can be reasonably explained as being controlled by balance systems in nature, with little or no input from humans. Within the last 2 millennia, high charcoal concentrations show 6 clear periods of intensified-fire regime. All of these periods of intensified-fire regime correspond to frequent dynastic changes in northern Vietnam and the human conflict and civil unrest that accompanied them. In contrast, periods of agricultural development supported by rulers in stable societies do not appear to show a positive correlation with periods of intensified-fire regime periods. Thus, we conclude that human conflict, rather than agriculture, was likely the critical influence on fire regimes in the Song Hong delta in the late Holocene.

Materials and Methods

Age Model. 14 AMS (^{14}C) dates from core VN and 13 from core GA were used for the age model after calibration using CALIB 5.01 (24–26). The relationship between age and depth was expressed by change-point model with linear interpolations between the adjacent points. Other nondirectly measured ages were calculated by inserting points. Based on the age model, 58 samples from core GA that were younger than 1720 cal. BP and 45 samples from core VN spanning from 5270 to 1720 cal. BP were analyzed for pollen and charcoal contents at a sample interval of ≈ 30 –80 years. Each sample is ≈ 45 –50 mm thick and represents a time span of approximately several years to a decade (24).

The Sedimentary Environment. Based on sedimentary facies analysis characterized by sediment color, grain size variations, sedimentary structure, sediment composition, and molluscan fossils, more than 10 sedimentary environments from river to coastal/shelfal systems were identified (25). According to the sedimentary facies and (^{14}C) dating (Fig. 3), pollen and charcoal samples were analyzed only taken from submarine delta facies from prodelta to delta front platform through delta front slope, as shown above (Fig. 2).

Palynological Analysis. HCl (15%), KOH (15%), and HF (30%) were used to dissolve calcareous minerals, humic components and siliceous materials, respectively. The pollen and spores were then concentrated by heavy liquid flotation with ZnCl_2 (specific gravity 2.2) (24).

Charcoal Analysis. We counted charcoal particles by using the slides prepared for pollen analysis. *Lycopodium* spores were added to each sample for calculating charcoal concentration. We counted only particles whose length is between 250 and 5 μm . Four size groups were defined: 5–20 μm , 20–50 μm , 50–100 μm , and >100 μm to allow discrimination between local fires and regional fires. Charcoal concentration diagrams were created with Tilia and Tilia-Graph software, as were pollen concentration diagrams.

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