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Formation of sand path and ecosystem functions of riverbeds with pale and dark colors in Kizu River, Kyoto

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Introduction

Bars and pool-riffle structures are basic bedform patterns developed by erosion and deposition of sediment (sand, stones) during floods. Many habitats are defined and correspond to the bars and pool-riffle structures. However, few studies have focused on sediment dynamics during non-flood periods, spatial pattern of mobility and its effect on riverine biota.

Color patterns can be an effective indicator for assessing water and habitat quality, as variations in color can result from physical, chemical, or biological processes. In rivers, algal growth and organic matter accumulation contribute to the beds having dark green or brown colors. A distinct pale and dark pattern have been observed in the Kizu River, Kyoto (Fig 1), with clear pale and dark belts extend underwater along the entire sandy bar. Our previous study inferred that the pale and dark beds reflect the sand path and organic matter accumulation and also offer different habitats sustaining biodiversity of benthic animals (Hu,2023).

To understand the spatial pattern and ecological effects of sand mobility during non-flood periods on riverine ecosystem, we 1) explored the definition and quantification of the pale and dark beds, and 2) examined the formation processes of the pale and dark beds. We finally discussed how to enhance future river rehabilitation based on findings of the patterns and processes of the pale and dark beds.

Figure 1　Drone picture taken in 27th Feb 2022 shows

Study area and methods

Definition and quantification of pale and dark

Bed color varies according to water depth, color sources, water transparency, weather condition, and others. Brightness was used to define pale and dark because it is simple and resultantly fit to our study. Relative brightness as indicator was developed using orthoimages taken in Kizu River. We also developed dark width proportion to quantify the amount of dark according to cross-sectional pale and dark patterns. Historical changes in dark width portion in Kizu River were evaluated using past aerial photos every 10 years since 1940s to present.

Controlling factors determining pale or dark

Field surveys were conducted to understand flow and bed characteristics that determine bed color (i.e., pale or dark). The surveys were conducted at 15.2-15.6 km in the lower reaches of the Kizu River on July 29th, 2023, Dec 17th, 2023, and Aug 10th, 2024. On each date, 4-10 cross-sections were set up including both riffle and pool section beside a large bar. Aerial photos were taken by a drone (Mavic3, DJI) to obtain orthoimages and bed color patterns. Each cross-section had 2 to 8 sampling points including both middle and near-shore parts. At each point, water depth and flow velocity were measured, images and videos of bed were taken to analyze grain size and bed mobility, and benthic organic matter (BPOM) was collected.

Results

Definition and quantification of pale and dark

The range of brightness for pale and dark beds varied among survey dates, which makes it difficult for defining pale and dark in different orthoimages. Relative brightness was calculated by using the brightness of bar (dry area) as the higher standard and the brightness of the darkest underwater as the lower standard. The relative brightness at 0.5 succeeded to separate pale and dark beds in different orthoimages.

Dark width proportion increased with time since the last flood, which was more evident when the water level of 0.5 m was considered as floods than using 1.0 m and 2.0 m. Soon after the flood, the range of relative brightness was small with small difference between pale and dark, while long after flood, there was a distinct difference in the relative brightness between pale and dark beds.

Dark width proportion has increased gradually since 1940's to present, especially the increasing rate appears to have accelerated in recent years (Fig 2). The result suggests that the riverbed of Kizu River was originally pale, while dark continues to increase.

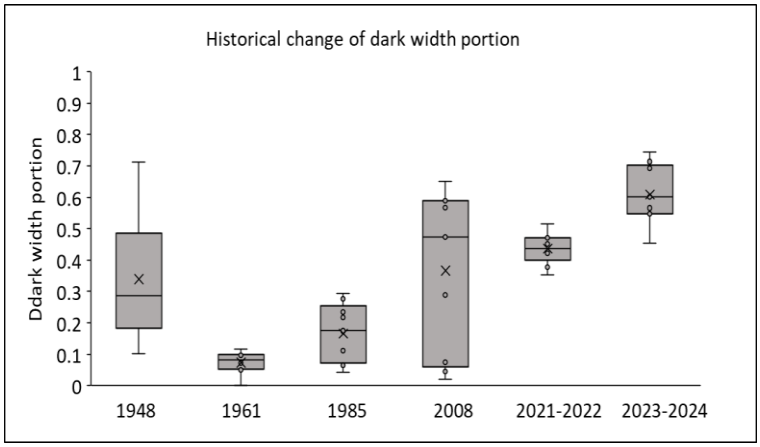

Fig 2 Historical changes of dark width portion

Controlling factors determining pale and dark

According to discriminant analysis and ANOVA analysis, none of the flow and bed parameters (depth, flow velocity, shear stress, grain size, Shield's parameter) succeeded to separate the pale and dark beds. Pale and dark are linked most strongly to Shield's parameter among all parameters. Thus, none of the flow characteristics can explain the reason for the difference between the pale and dark beds.

In contrast, sand mobility and organic matter accumulation succeeded in separating between the pale and dark beds. Thus, although it is difficult to explain why such difference occurs, the pale part in the middle of flow is a sand path and the dark part near shore is a bottom accumulated organic matter or algae.

Discussions and Future work

This study contributed to understanding the spatial and temporal patterns of the pale and dark. It is likely that the pale beds increase by floods and the dark beds increase during stable period after the floods. The historical steady increase of dark beds probably reflects the sediment transport conditions in Kizu River. Kizu River was originally a sandy river, and the bed was only pale under high sediment transport. Dark beds have gradually increased associating with sediment reduction, bed armoring, and increasing bed stability due to upstream dams.

Considering both pale and dark beds are important habitats in river ecosystem, it is better to keep the balance of the two habitats. Because too much dark beds in recent years, pale beds should increase in future. Based on these, two ways for river rehabilitation can be proposed. The first way is to add more fine sediment to the river which would help restore and maintain the balance between pale and dark parts. The second way involves modifying the river morphology by the river work installation to increase width variations, thereby promoting the increasing of pale parts within the river channel.