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Relation of Hydrogeomorphology of Gravel Bar to Particulate Organic Matter Dynamics in Braided Alpine River

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Synopsis

Channel geomorphology has ecologically important functions to remove organic particles from flowing water providing availability of organic matter to benthic organisms. The present study focuses on the roles of braided gravel-bar for riverine organic matter retention, aiming to elucidating the retention processes corresponding to the diverse hydrogeomorphological conditions in the Tagliamento River in north east Italy. Results of longitudinal changes in concentration, stable isotope analyses and C:N ratio of suspended particulate organic matter (POM) as well as in chlorophyll a of epilithon, which were collected at canal, narrow channel and braded bars, showed a distinct retention pattern and algal production of braided-bar. In addition, we found that secondary flow velocity and direction occurred near bar shoreline can be critical factors to affecting suspended POM retention. On the other hand, in an island bar unit, barhead riffle and bartail shore showed a selective retention capacity according to particle size. Overall the spatial diversity of POM quantity and quality along gravel-bar can lead to high heterogeneous habitats in braided channel.

Keywords: braided channel, island bar, POM retention, Tagliamento River

1. Introduction

Reservoir dams are known to degrade ecological functions of riverbed in dam downstream reaches by alteration of channel geomorphology (e.g., riverbed degradation and channel incision) caused by reduced bed load transport. Recent river management particularly in dam tailwaters has a growing concern on riverbed management, i.e., through sediment replenishment, bypass tunnel, dry dam without impoundment (Sumi, 2005), for recovering functions of habitat conditioning and of material cycling acceleration. From a perspective of riverbed management considering sediment and flow regime controls, therefore, development of ecological evaluation methodology for desirable geomorphology is required as a reference river (Takemon, 2010).

Riverine bar, one of the most dynamic patch responding to flow and sediment regimes in fluvial landscape, have ecologically important roles to remove organic particles from flowing water and to provide availability of organic matter to benthic organisms. Thus the POM retention can be used as an indicator for evaluating river ecosystem in terms of material cycling, field transport distance and self purification of contaminants.

In our previous studies, we emphasized on the significance of river channel geomorphology as a key factor controlling the fate and budget of riverine POM retention. For instance, comparative study of 4 types of different channels in rivers and canals showed that the braided river channel with lower hydraulic radius due to well developed bar systems had a higher retention efficiency than channelization channels (Ock and Takemon, 2010). In addition, using stable isotope mixing model, we traced the relative contributions of the trophic sources of POM in downstream reaches of Uji River, and found that riffle and pool geomorphology has a specific retention process according to the trophic sources (Ock *et al.*, 2010), and the benthic invertebrates communities were also adapted to the downstream POM distribution patterns (Ock and Takemon, 2009). Also through physical hydraulic model using fine pollens as FPOM traces, we found that the head and mid range of alternate bar had much higher retention density than tail of bars, and suggested that aspects of alternate bar slopes is also critical to POM retention (Ock *et al.*, 2009). However the retention processes and mechanism in natural fluvial rivers are still obscure due to complex interaction among hydro-geomorphological conditions in river-floodplain ecosystems. Nevertheless, such knowledge in braided channel is increasingly required as a reference model for expecting the geomorphology-ecology relations in river habitat restoration research.

The present study focuses on the roles of island gravel-bar for riverine organic matter retention in the braided channels of the Tagliamento River in north east Italy. We aim (1) to evaluate POM retention function of braided-bar system, (2) to identify POM retention processes corresponding to diverse hydrogeomorphological conditions within a gravel-bar unit and (3) to quantify the retention capacity.

2. Materials and Methods

The Tagliamento River is regarded as the last morphologically intact river in the Alps (Tockner *et al.*, 2003), because of highly dynamic channel geomorphology created by natural flooding events and massive amounts of sediment supply from upstream Alpine region. The 7^{th} order river with 172 km length and 2,580 km^2 catchment area flows headwater-braided channel and downstream to bar-braded, island-braded and meandering channels till reaching the Adriatic Sea.

In field study conducted in mid Tagliamento River basin (Fig.1) in March and July 2010. In the Palar River, the tributary of Tagliamento River, a total of 8 sites are longitudinally selected for field survey according to channel form types; Lake Cavazzo, canal sites (C1 to C2), narrow channel sites (C2-R2-R3), braided bar channel sites (R3-R4-R5) as shown in Fig.2. At each site, suspended POM (SPOM) samples were collected. And then, the concentration, stable isotope values ($\delta^{13}C$-$\delta^{15}N$), C:N ratio and Chlorophyll a of epilithon were analyzed. River stage was relatively low and showed a diel fluctuation by hydropeaking by the hydropower discharge upstream.

In order to identify and quantify detailed processes, intensive survey was done at an island-bar unit located at Flagogna Reach of the Tagliamento River. The reach has been monitored by fixed camera at 1hr interval. A total of 14 sampling points were established along shore of the bar, including barhead shore, bartail shore, main-channel transition shore and sub-channel transition shore (Fig.3). Benthic POM (BPOM) were collected at each point by both quantitative and qualitative samplings for estimation of standing stock, stable isotope composition and C:N ratio. Terrestrial plant leaves, epilithic algae were also collected as SPOM source origins.

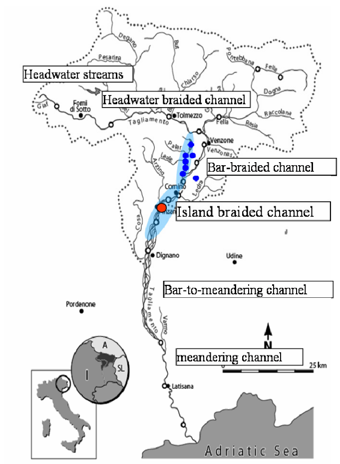


Fig.1 Location of study sites in Tagliamento River basin in NE, Italy.

In addition, we conducted filed experiment at two sites within the bar to investigate the shallow area retention capacity association with the island-bar morphology. Riverbed area of bartail shore (100 m^2=25m L x 4m W) and barhead riffle (40 m^2=10m L x 4m W) were covered up using vinyl sheets and measured SPOM concentration along the experiment area.

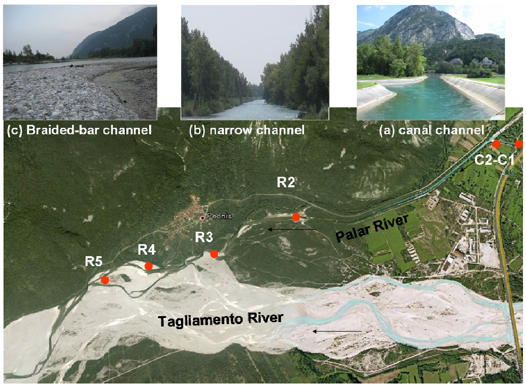


Fig.2 Study reaches in Palar River with longitudinal changes of channel forms. Canal from C1 to C2 (a), Narrow channel from C2-R2 to R3 (b), and Braided-bar channel from R3-R4 to R5 (c).

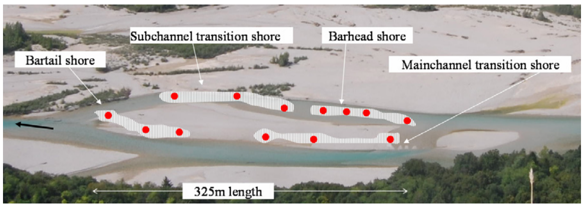


Fig.3 BPOM sampling sites within an island-bar unit located on Flagogna Reach.

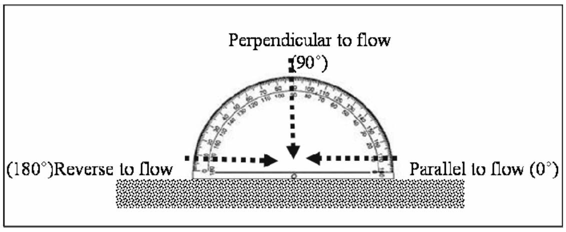


Fig. 4 Relation of secondary flow direction to bar shore

SPOM samples were collected using a POM net sampler with 100 ㎛ in mesh size and 30cm in diameter of flame size. For sampling of stable isotope analysis, the POM net was kept in the water for one to three minutes. Three replicates were collected at each site. Each S-FPOM samples was filtered in situ using the sieve of 1.0 ㎜ mesh size to separate it from S-CPOM. For quantifying S-FPOM concentration (the weight of S-FPOM per unit water volume), additional three replicates of samples were collected at each site. The current velocity in front of the net opening and elapsed sampling time were measured using a current-meter (CR-11, Cosmoriken) to estimate the volume of water filtered through the net sampler. S-FPOM concentration (CS-FPOM) was calculated by Eq.1:

$$C_{S\text{-}FPOM}\ (\mu g/m^3) = \frac{\textit{Ash free dry weight of S-FPOM}}{\textit{Volume of water filtered through the sampler}} \quad (1)$$

where the Ash free dry weight (AFDW), which is calculated as the weight of the dry weight (oven dried in 60℃ for 24 hours) minus the residual ash (combusted in 600℃ for 2 hours). As the same method, S-CPOM was also measured.

On the other hand, benthic POM (BPOM) samples were collected using BPOM sampler, and divided into B-CPOM and B-FPOM. Secondary flow direction was calculated as the degree to shoreline. As shown in Fig.4, 0°, 90° and 180° means that secondary flow is parallel and perpendicular and reverse to shore, respectively. All isotopic samples were dried at 60℃ for 24 hours and then ground to homogenized bulk samples with a mortar and pestle in the laboratory. Stable isotope ratios of carbon and nitrogen were measured by a continuous-flow isotope ratio mass spectrometry system with an elemental analyzer The concentration of organic carbon and nitrogen were measured simultaneously. Stable isotope ratios are expressed by the standard δ notation as the following equation (Eq.2):

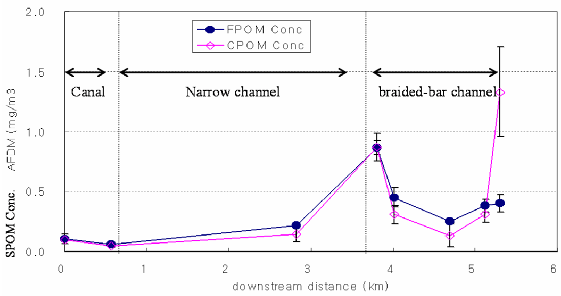
$$\delta^{13}C \text{ or } \delta^{15}N\ (‰) = (R_{sample}/R_{standard} - 1) \times 1000 \quad (2)$$

where R is $^{13}C/^{12}C$ for $\delta^{13}C$ or $^{15}N/^{14}N$ for $\delta^{15}N$. The standards were PeeDee Belemnite for $\delta^{13}C$ and atmospheric nitrogen for $\delta^{15}N$. DL-alanine was used as working standard and the analytical precision was ±0.2 ‰ for the $\delta^{13}C$ and the $\delta^{15}N$.

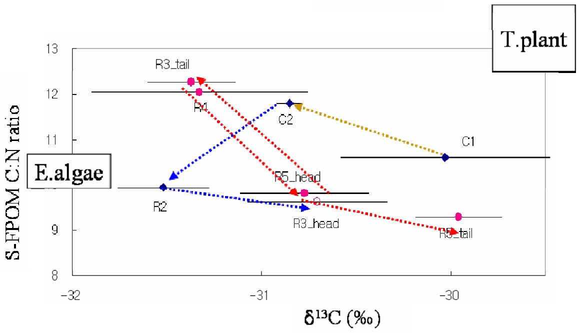
3. Results and Discussion

3.1 Longitudinal changes of SPOM dynamics

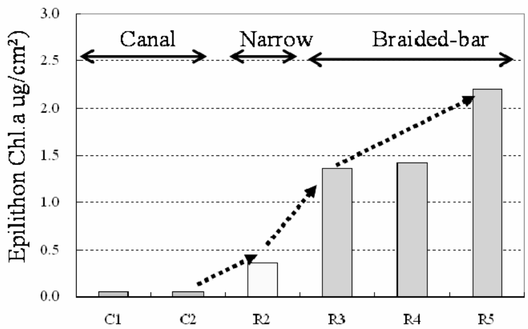
Downstream changes in SPOM concentration varied according to channel forms. Little significant change appeared in the canal channel, whereas the concentration started to increase during the narrow channel particularly passing R2 to R3, and then reduced to approximately 70% sharply passing through R3 to R4 (Fig.5a). The result clearly indicates the SPOM dynamics is strongly dependent on the channel form; the canal mainly tends to transport SPOM, and the single cross-sectional narrow channel supplies SPOM from near terrestrial forest, whereas the braided gravel-bar has retention capacity. In order to identify the source composition of SPOM at the channels, stable isotope values were analyzed. The result shows that contribution of autochthonous production and allochthonous input were repeated depending on local reach conditions (Fig. 5b). In particular, we found that algal production was activated in braided bar channel comparing other channels (Fig. 5c).



(a) SPOM Concentration



(b) SPOM composition

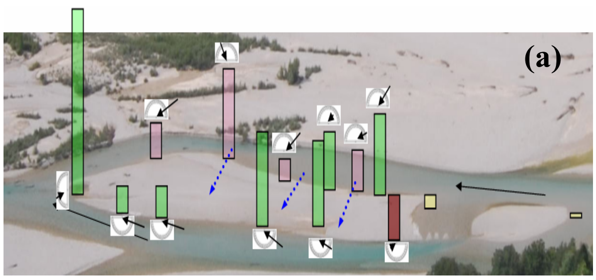


(c) Chlorophyll a of epilithon

Fig.5 Downstream changes in SPOM concentration (a), trophic source composition (b) and algal production (c) passing through different channel forms in the Palar River.

3.2 BPOM density distribution along island bar unit

Amount of standing stock of fine BPOM spatially varied along shoreline (Fig. 6a), and was found to be negatively correlated with secondary flow velocity whereas positively with secondary flow direction, but no significantly related with surface elevation and water depth in shore (Fig. 7). The result indicates that a reduced secondary velocity and recirculation formation along shore lead to higher retention of POM within the gravel-bar. Results of stable isotope and C/N ratio analyses showed that the spatial distribution of BPOM composition was classified into three groups by source origin and decomposition process (Fig.6b), indicating a higher retention of SPOM in barhead and sub-channel transition shores with downwelling inflows, whereas higher retention of terrestrial plant in bartail and main-channel transition shores. In particular the barhead backwater deposited more fresh terrestrial fragments. Based on the findings in island gravel bar scale, our discussion will extend to the effects of water level fluctuation on contribution changes of hydrodynamic retention processes.



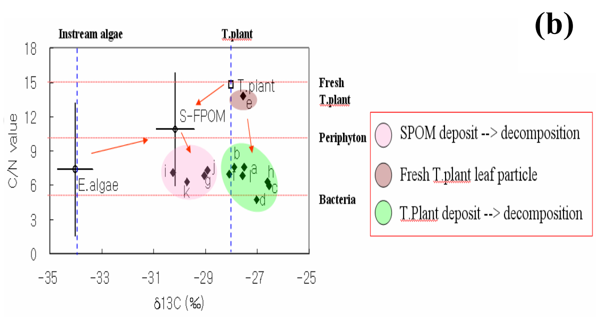


Fig.6 Spatial distribution of standing of fine BPOM stock and secondary flow velocity/ direction (a), the arrow length and angle represent velocity and direction, respectively; Stable carbon isotope to C:N ratio value (b)

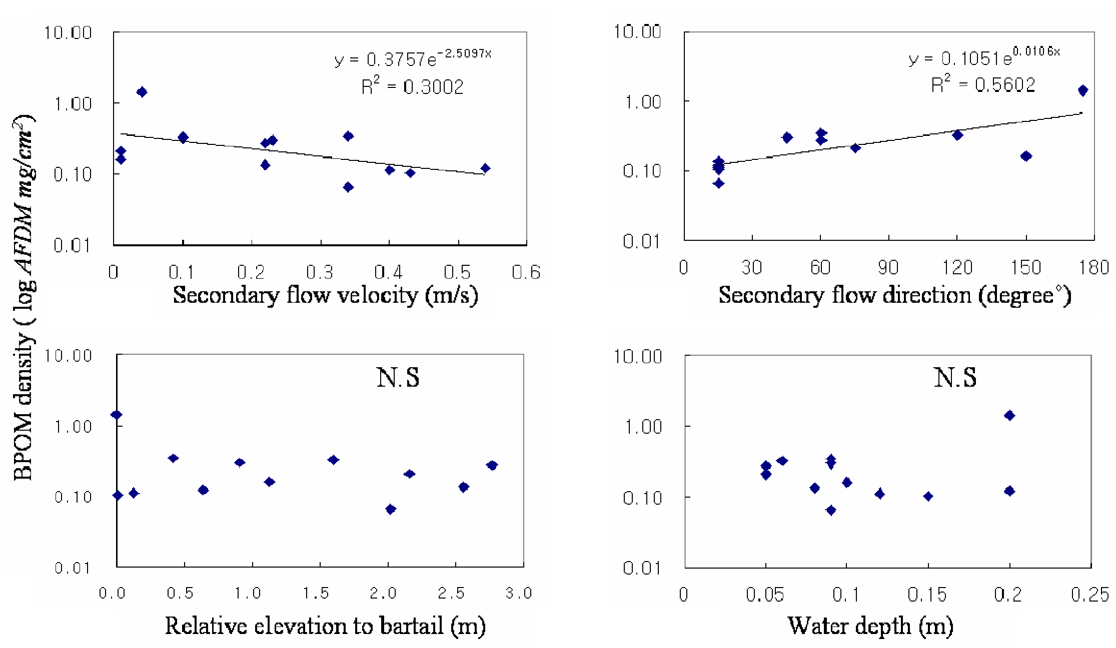


Fig 7. Relation of BPOM density to secondary flow velocity/direction, relative elevation and water depth of shallow area in an island bar unit.

3.3 Quantification of barhead trapping and bartail shore filtering within a bar unit.

As a result of field experiment, retention of the bartail shore showed significant reduction of fine POM (1.4 mg AFDM/m^2) but not coarse POM, whereas the barhead riffle retention lead to significant reduction of coarse POM (3.9 mg AFDM/m^2) but not fine POM (Fig. 8). The results revealed that bartail shore had strong capacity for FPOM filtering and barhead riffle for CPOM trapping, indicating that difference of hydrogeomorphology in shore and riffle within an island bar result in a size specific retention capacity.

Overall, the results suggests the significance of secondary flow (velocity and direction) for POM retention along the island-bar shore, and asymmetry of island geomorphology causing variation of

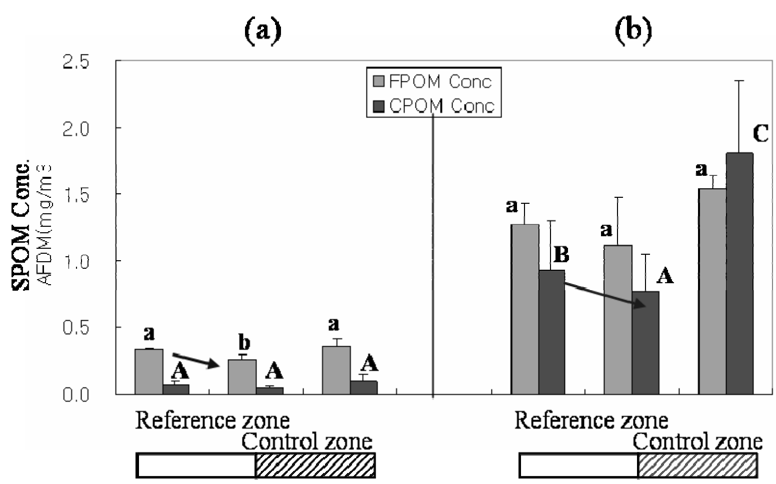


Fig.8 Shallow area filtering experiments at bartail shore and barhead riffle in gravel island bar. Control zone means the area covered by vinyl sheets, and reference zone is upper area without covering.

BPOM source composition. The spatial diversity of POM quantity and quality along shore will lead to high heterogeneous habitats in braided island-bar.

4. Conclusion

Retention is the process of which removes matters from transport within the reaches so that it can make available for reduction the suspended materials and for utilization by stream biota. In dam tailwater ecosystem, the retention of lentic plankton is important for recovering from trophically reservoir dependant state to a normal state of lotic ecosystem. The present study focusing on elucidating the retention processes in relation to channel geomorphology, particularly in braided gravel bar system showed the following major findings; (1)braided bar channel showed high SPOM retention capacity and increased algal production, (2)secondary flows occurred near shoreline of bar is critical to SPOM retention; reduced velocity and circulation flow accelerate BPOM retention, thus asymmetry of island geomorphology causes variation of BPOM source composition. (3) in shallow area retention, barhead riffle had strong capacity for CPOM trapping, whereas bartail shore for FPOM filtering. Therefore, such spatial diversity of POM quantity and quality along shore will lead to high heterogeneous habitats in braided island-bar. The present study contributes to provide a reference model for sediment management for sustaining and enhancing the ecosystem functions.

Acknowledgement

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タリアメント川 網状河道における粒状有機物の捕捉過程に関する研究

玉　基英・竹門康弘

要　旨

タリアメント川における原生的洪水氾濫源の豊かな生物多様性を維持する一つの原因である，網状河道砂州の粒状有機物の捕捉機能を定性的，定量的に研究した。 運河，単断面河道， 網状河道などの調査地点で流下粒状有機物の濃度，炭素-窒素の安定同位体比，CN比及び付着藻類のクロロフィルa値を分析した結果，運河では粒状有機物の移動機能，単断面河道では隣の陸地域からの供給機能，そして網状河道の砂州では捕捉機能が支配的であることが明確に示された。また，二次流の流速と流向が砂州地形の捕捉過程において重要であることが示された。

キーワード：粒状有機物，捕捉，安定同位体， 河床地形