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Ecosystem Function of Sand Bar Segment in Sandy River with Particular Reference to Denitrification Potential

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Abstract

River is an artery and simultaneously a vein of human activity of river basin, and we have to conserve river ecosystem to expect its ecological function for sustainable human life there. However, we have degraded river environment through rapid development in floodplain. In order to make our efforts vital, it is important to understand the structure and function of river ecosystem. In this paper, we focused on denitrification as one of the ecosystem function in the sand bar landscape possesses and its temporal change with landscape transition and change of human activity along a river. The objective of this study was to develop a model that could be used to examine how the nitrogen is trapped and retained by several elements of a sandbar in an alternate bar reach. We also developed a framework to analyze the temporal change in the denitrification by using a numerical simulation, aerial photos, and a water quality information system. The main results of this study are that the temporal change in the denitrification ecosystem function in a sandbar reach can be quantified using the proposed model and the denitrification activity has increased over the past 34 years.

Keywords: River landscape; sand bars; ecosystem; denitrification; vegetation; land use along a river

1. Introduction

River is an artery and simultaneously a vein of human activity of river basin, and we have to conserve river ecosystem to expect its ecological function for sustainable human life. Japan is a narrow island with mountain area as its backbone, and thus respective rivers are short with narrow basin. Most of human activity is concentrated in the floodplains of those rivers, and we have received many blessings as well as flood disasters from them. In this half century we have developed flood control, water resources management and human activity along rivers advanced economically. However, we have degraded river

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environment through rapid development in floodplain. The effort for improve environment has not yet sufficient in spite of our awareness of the importance of ecosystem conservation. Moreover they are threatening our sustainability. As mentioned above, now we are facing a problem of water quality attendant on releasing much environmental load into rivers. Though point sources have been improved by waste water treatment in these decades, non-point environmental load from floodplain to river has been insufficiently treated. Rivers have been channelized and robed habitat of organisms. On the other hand, flood control and water resources development have caused the change of flow discharge and sediment transport and successively degraded habitat condition and energy-material flow to support the ecosystem. In this paper, we discuss the transition of river landscape focusing on a segment characterized by sand bed with alternate bars, human activity in floodplain adjacent to which is popular in Japan: rice paddy fields, tea patches, and residential areas. The middle reach of the Yahagi River in Central Japan is as a study field. The water quality of river is affected by land-use change. Dam construction changed the flow discharge and sediment transport and sand bar landscape has been appreciably changed. River landscape is represented by alternate sand bars, and vegetated area has been appreciably increased on sand bars during these decades. In particular we have focused on denitrification potential the river ecosystem possesses in particular reference on the temporal changes in vegetation invasion in sand bars and still increasing environmental load by non-point sources in floodplain.

2. Landscape analysis focused on river ecosystem

We recognized the structure and functions of ecosystem as follows: There are several mosaics in a river and they are connected each other by flux network of water and materials. Particularly biophilic elements are keys for ecosystem because they change forms in inorganic and organic and even biomass. In this sense, the ecosystem can be recognized landscape units connected by water/material flux networks. From headwater to river mouth, there are many types of landscapes, and the hierarchy structure exists. Focusing on a landscape unit, we recognize it is constituted by three subsystems interacted one another [1, 2]. For example, a sand bar has a function to provide habitats for peculiar organisms, and water/material flux network supports biophilic elements cycle because of various landscape units in a sand bar.

The investigation was conducted on the downstream of the Yahagi River, which has the sandy river segment with alternate bars. The length is around 6km, the average bed slope is 1/1200 and the bed is composed of mainly coarse sand but mixed with fine sand and gravels. The channel width is around 250m and around 6 alternate bars with around 1km of length are continued. Some of them are appreciably vegetated and some are less vegetated. Fig.1.(a) shows a typical landscape of sand bar with vegetation and it also depicts how to recognize some mosaics linked by water/material flux networks. Because of construction of dams in upstream region, this segment is exposed to appreciable bed degradation and the invasion of riparian vegetation. We combined the data of aerial photos and ground survey data, and recognized the quantitative vegetation invasion to these sand bars as shown in Fig.1.(b) and (c).

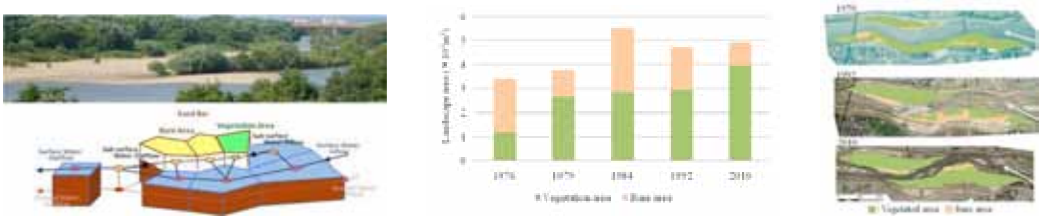


Fig. 1. (a) Various landscapes connected by flux networks; (b) Invasion of vegetation to sand bar; (c) Temporal change of portion of vegetated area in bar

3. Numerical simulation method

A numerical computation was conducted to quantify of denitrification rate driven by sub-surface water flow regarding to sub-surface flow and nutrient transport in sandbar. It is composed of two parts which is to calculate sub-surface flow and nutrient transport of sandbar. A two dimensional sub-surface flow analysis was conducted by regarding sub-surface flow in sandbar as unconfined aquifer flow. In our study site, there is the impermeable layer lied one meter below from sub-surface water level. Hence, we assumed the sub-surface flow to be plane and to consider the Depuit-Forchheimer hypothesis by using following equation:

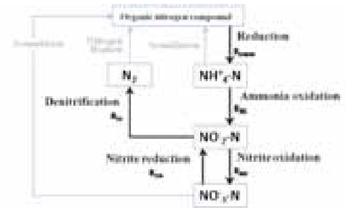
$$\lambda\frac{\partial h}{\partial t}=\frac{\partial}{\partial x}\left(kh\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(kh\frac{\partial h}{\partial y}\right) \quad (1)$$

in which h is the hight of ground water, λ is the porosity rate and k is the hydraulic conductivity. The boundary condition of Eq.(1) is determined that the boundary between surface flow and sandbar is given the surface water level, the transverse direction of boundary on the side of levee in sandbar is given as zero for the surface slope. The hydraulic conductivities used with each sub-bar scale landscape (vegetated and bare area) in our calculation are $k=5.0\times 10^{-3},\ 2.0\times 10^{-5}$ *(m/s)* based on the field observation, respectively. A schematic view of the process of nitrogen cycle as shown in Fig.2.(a), in which the nitrogen form considered in our analysis is three kinds of inorganic nitrogen, such as ammonium, nitrate and nitrite ion. Each concentration of them were represented as $C_{NH4\text{-}N}$, $C_{NO3\text{-}N}$, $C_{NO2\text{-}N}$. The amount of concentration of each inorganic nitrogen is estimated by the advection-dispersion equation considered microbial process as follows;

$$\frac{\partial C_i}{\partial t}+u\frac{\partial C_i}{\partial x}+v\frac{\partial C_i}{\partial y}=\frac{\partial}{\partial x}\left(D\frac{\partial C_i}{\partial x}\right)+\frac{\partial}{\partial y}\left(D\frac{\partial C_i}{\partial y}\right)+R_i \quad (2)$$

in which u is the velocity of ground water, D is the variation coefficient and R_i is the biochemical reaction term. the boundary condition of Eq. (2) is determined that the boundary part of sub-surface inflow to sandbar is given as the stream water quality value ($C_{NH4\text{-}N}$, $C_{NO3\text{-}N}$, $C_{NO2\text{-}N}$), the boundary part of sub-surface outflow to surface flow is given as zero for concentration gradient, and the transverse direction of boundary on the side of levee in sandbar is given as zero for the surface slope (see [3]).

As for the biochemical reaction term, we considered their formularization by combining with the each reaction of nitrogen cycle as shown in Fig.2.(a). Especially we focused on formulating denitrification process considering the effect of organic matter and dissolved oxygen which change according to characteristics of landscapes, and their parameters were given each concentration refer to observation result [3], and others were given refer to literatures because it is not enough for each landscape to obtain their information.



Parameters for organic matter and dissolved oxygen

	C_{DON} (mg/l)	C_{DOC} (mg/l)	C_{DO} (mg/l)
Bare area	0.04	0.75	4.0
Vegetated area	0.08	1.5	2.0

Parameters for the biochemical reaction term

	R_{DNH4}	R_{NS}	R_{NB}	R_{DA}	R_{DI}
X (mg/l)	0.50	0.30	0.10	1.0	3.0
Y (mg.cell/mg)		0.13	0.05	0.60	0.72
μ (s^{-1})		5.3×10^{-6}	8.3×10^{-6}	1.1×10^{-5}	2.0×10^{-4}
K_S (mg/l)		5.0	5.0×10^{-4}	1.0×10^{-3}	5.0×10^{-4}
$K_{S\cdot DO}$ (mg/l)		0.20	0.20	0.20	0.20
$K_{S\cdot DOC}$ (mg/l)				0.70	9.0
k (l/mg/s)	2.2×10^{-7}				

Fig. 2.(a) Elementary processes in nitrogen cycle; (b) Parameters of biochemical reaction term

4. Transition of denitrification activity

In this study, it is most important to quantify the ecosystem service change in target area during 40 year-period by using GIS technique mentioned in Chap. 2 and numerical simulation explained in Chap. 3.

The sandbar landscape transition was simplified as the change of plane shape of sandbar and the distribution of vegetated area. With these assumptions, the numerical computation was carried out under the condition of 5 cases represented in Chap. 2 based on the characteristics of landscapes in each year. Regarding the stream water quality during 34-year period, several observations have been reported about long term transition of water quality [4], [5]. The numerical calculation was conducted under the stream water quality based on field observation result as shown in table.1.

Table 1. Condition of stream water quality in each year

year	1976	1979	1984	1992	2010
$C_{NO3\text{-}N}$ (mg/l)	0.32	0.38	0.48	0.52	0.60
$C_{NO2\text{-}N}$ (mg/l)	0.001	0.001	0.001	0.001	0.001
$C_{NH4\text{-}N}$ (mg/l)	0.022	0.022	0.015	0.031	0.010

The calculation result is shown as temporal and spatial distribution of denitrification activity in Fig.3. It shows that denitrification activity tends to increase for 34 years by affected the expansion of vegetation area. This is corresponding to the fact that the vegetation area has higher potential of denitrification activity than bare area because of fine sediment trap and deposition which covers the sub-surface flow and provision of litters which consume oxygen for their decomposition. As the reason that the maximum value appears in 1984, it is considered that the effect of sandbar landscape area appeared sensitively. Moreover the upstream part of vegetated area of sandbar has denitrification activity higher than downstream part by using with the results of spatial distribution of each sandbar. In addition, denitrification activity is different according to the length from the waterside. The results mentioned above significantly showed that denitrification activity rate is affected by the difference of sandbar area, especially vegetated area.

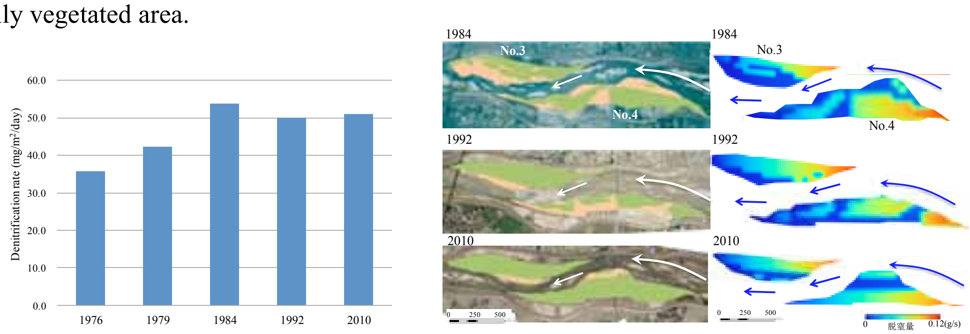


Fig.3. (a) Calculated result for temporal change in denitrification activity, (b) Spatial distribution of denitrification activity

5. Conclusion

In this paper, we showed our recognition and understanding of river ecosystem, and we demonstrated the importance of ecosystem conservation. Among various ecosystem functions, we focused on denitrification as true water purification. In sand bar segment, we have recognized that increase of vegetated area in sand bar is recent noticeable characteristics in landscape transition and which has been caused by discontinuity of water and sediment by artificial constructions such as dams. On the other hand, floodplain land use has changed the environmental load to the river. Particularly, the land-use change from rice-pads to tea patches has the causes of higher environmental non-point source load. We presented a method of numerical simulation of subsurface flow and subsequent change in nitrogen cycle, and made it possible to analyze the change of denitrification activity. According to the analysis, the vegetated landscape unit has a power for denitrification and its distribution near the upstream water edge is effective because it can meet higher concentration of nitrate ion. Denitirification has a role to change the nitrate ion to nitrogen gas and thus higher supply of nitrate brings effective removal of it (to nitrogen gas). Although it is speculated that the original landscape (Sandy River) of the target river was turned by the expansion of vegetation, it may be caused the degradation of river ecosystem. Hence, it is needless to say that more work is necessary from the general overview.

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