Stream Diversity and Hydrodynamic Characteristics of Riverine Habitats

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Abstract

The conditions and spatial diversity of the river flow are the formative elements of a diverse riparian habitat. The arrangements of covers over water-surface and bed sediments that harbor the microenvironments are especially important for fish species (Inoue and Nakano, 1994). However, there have been very few instances in which the microenvironmental flow conditions in relation to the river configuration have been measured. Measurement techniques that can measure such complicated flow conditions are being sought.

In this study, the spatial structure of the flow which determines the benthic and fish habitats was measured. In order to elucidate the function of these characteristics in the riverine habitats, a survey of fish and benthos as well as flow regime was conducted on 13 rivers in Hokkaido, and on the Toyohira River, a survey of the fish habitat in conjunction with measurements of the turbulent pressure fluctuations was performed so that the relationship between flow diversity and fish and other habitats could be analyzed.

The density of chub was found to be high when there was a broad range of both water depth and flow velocity. Similarly comparing the benthos, the density of benthos was higher when the range of flow velocity and depth was limited.

Dynamic pressure and 3-dimensional velocity were measured in areas inhabited by fish. The spatial variability of the velocity vector and the spatial distribution of the dynamic pressure are conjectured to be related to the behavior of fish. Fish hover in areas where the flow is directed upstream, and the dynamic pore pressure and velocity vector of these areas where fish hover are smaller than surrounding areas. Moreover, the power spectral density in the range of 1～20Hz of the dynamic pressure is smaller than in the circumferential areas. The slope of the power spectrum is about -1 in the fish hovering zones and -1.5 ～ -2.0 in the more turbulent surrounding areas.

Introduction

In order to more quantitatively assess stream diversity and its function in the ecosystem of aquatic habitat of various microenvironmental scales, we need to use indexes which specify different types of stream conditions such as flow velocity, water depth, hydro pressure, bed materials, covers for fish and/or wildlife and their spatial arrangement.

Terms such as riffle, pool and eddy are often used to quantitatively explain relationships between flow structures and wildlife conditions, but these terms are not sufficiently quantitative to objectively index the difference of spatial hydrodynamic characteristics (Baba, 1996).

The objective of the study is to develop quantifiable indexes of flow structures and to make their relationship with aquatic wildlife clear in order for environmental habitat assessment and for design of river restoration works.

The study reviews results of field measurements conducted in a wide range of different

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flow conditions in rivers in Hokkaido. Detailed micro-scale stream measurements were also conducted in a specific flow space where a tangled flow was created by in stream log groyne structures.

Study area and method

The first part of this study concerns a survey of 52 reaches of 13 rivers in 9 major drainage systems in Hokkaido, carried out in July 1996. In each reach, fish and benthos capturing and floating object trapping were conducted at around 10am and 8pm. Thus, differences in day and night behavior could be ascertained. The spatial distribution of velocity and water depth was measured in the same day. Figure 1 shows a typical distribution of water depth in the Ishikari River.

The second part embodies a detailed survey of the fish habitat in conjunction with measurements of the dynamic pressure and 3-dimensional velocity. The study was conducted in 1996 on the Toyohira River, a tributary of the Ishikari River. The surveyed reach contains riverbank groins which have been constructed with logs and boulders in 1995 to enhance stream diversity and improve the fish habitat.

Results and Discussion

1. Hydrodynamic characteristics of fish and benthos habitat

There are several methods of analyzing stream diversity such as that using the spectral distribution of turbulent velocity fluctuations (Hino, 1975), classification of pools, riffles and other morphological characteristics (Tamai, et al. 1993), and graphical analysis of the stream channel (Fujita, 1992). These methods could have been adopted in this study, but, in order to quantify many different stream reaches in comparable way, a simplified spatial information of both velocity and water depth is needed.

Using a map of velocity and water depth contours, the simple calculation of maximum, minimum and range within a 5m radius of each survey point was conducted to index hydraulic characteristics. Figure 1 shows an example from the Ishikari river for the case of water depth.

The calculated indexes represent hydraulic characteristics can then be compared with habitat densities of fish and benthos species. Chub fish, the most commonly seen in all rivers surveyed, for example could be densely inhabited in spaces where shallow water flows have a minimum depth of 0 to 0.5m. However, in spaces where the range of water depth is small, Chub could scarcely populated (Figure 2). This could indicate that, for Chub fish, shallow flows combined with deep spaces are preferable water depth conditions.

In contrast, for velocity, densely inhabited spaces by Chub are seen at

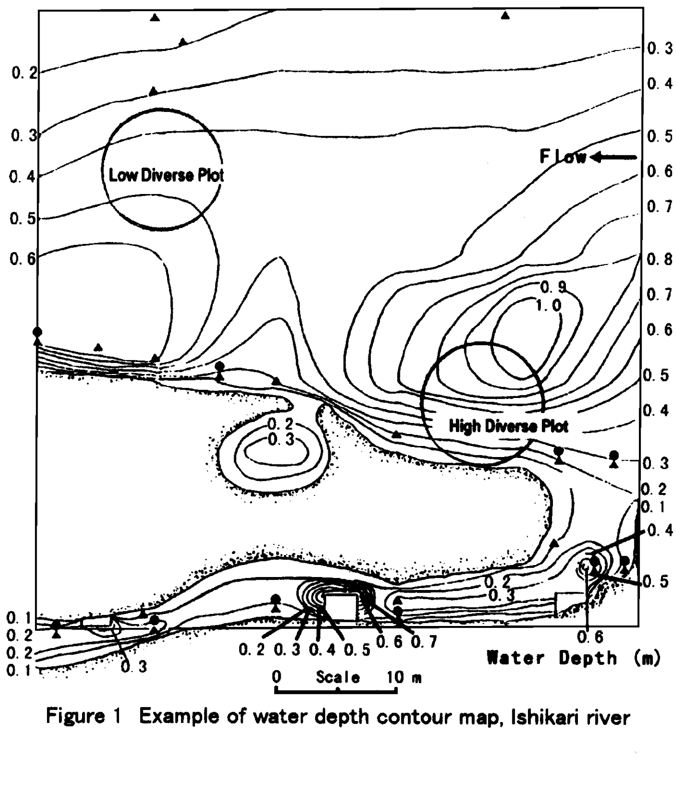


Figure 1 Example of water depth contour map, Ishikari river

points where the maximum velocity is comparatively high (almost 2m/s) and the range is large. This again indicates that the combination of rapid and slow hydraulic conditions are needed where Chub fish are densely populated.

The diversity of water depth and flow velocity does not correspond perfectly with inhabitation density but could explain certain important hydraulic characteristics that have relation to biological functions. Bait trapping of fish, which can be observed, is an example that requires divergent hydraulic condition in which the fish draft and wait for bait flowing from upstream.

In contrast to the result of Chub fish, benthos has a completely different relationship between hydraulic characteristics and inhabitation density (Figure 3). The most significant difference is seen in the distribution of inhabitation density versus flow velocity. Highly populated plots are observed in streams where the range of velocity is comparatively small.

The 5m-radius scale of benthos habitat may be greater than their individual radius of action, but as a group the benthos needs flow velocities that are small and uniformly distributed in the space.

These indexes using flow depth and velocity can also distinguish areas where Chub fish swarms at daytime or night (Figure 4). In the daytime Chub tend to swarm in areas where even high minimum velocities occur, and at night they swarm in areas where there is a lower minimum velocity but a wide velocity range. It could be said that even at night, Chub prefer flows with a wide range of velocity. This may be because a relationship between biological functions and hydrodynamics, such as water

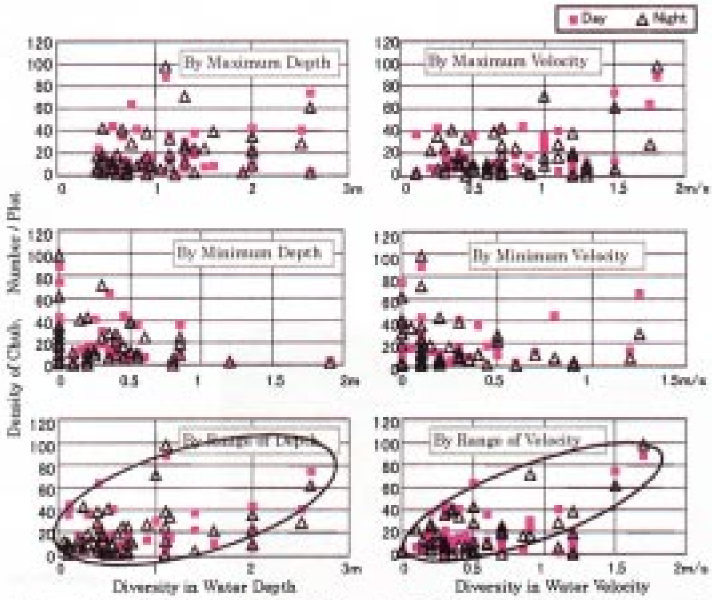


Figure 2 Relationship between Diversity of Water Depth, Velocity and Inhabitation Density of Chub Fish

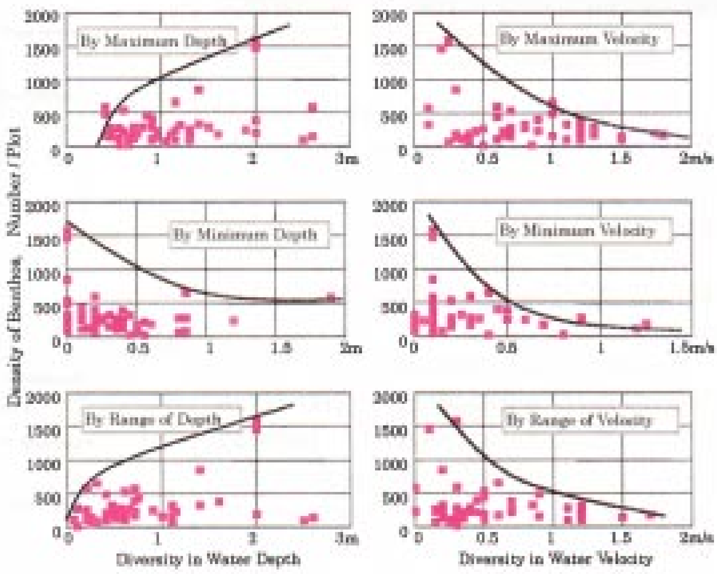


Figure 3 Relationship between Diversity of Water Depth, Velocity and Inhabitation Density of Benthos

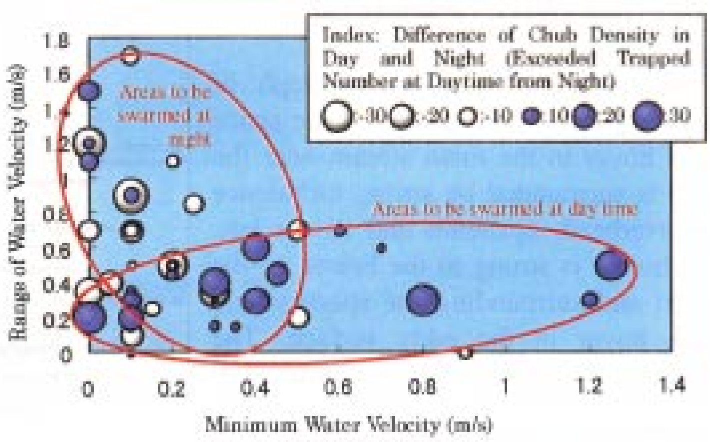


Figure 4 Characteristics of Chub fish habitat in water velocity and its diversity focusing inhabitation densities at daytime and night

purification, aeration or positioning (rheotaxis) of their body.

2. Velocity fluctuation in fish habitat

The spatial variability of the velocity vector was measured in a stream where a complex flow pattern is created by restoration works (Photo 1).

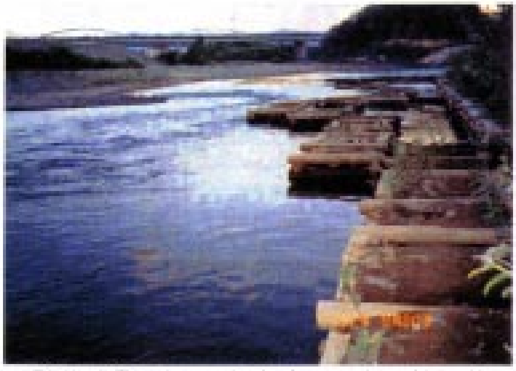


Photo 1 Training works by logs and boulders for improving microhabitat, Toyohira River

Five species of fish* were surveyed. They hover in areas where the flow is relatively slow near the bed of the thalweg or where the flow is directed upstream by eddy current. Fish also densely inhabits spaces covered by log structures (Figure 5).

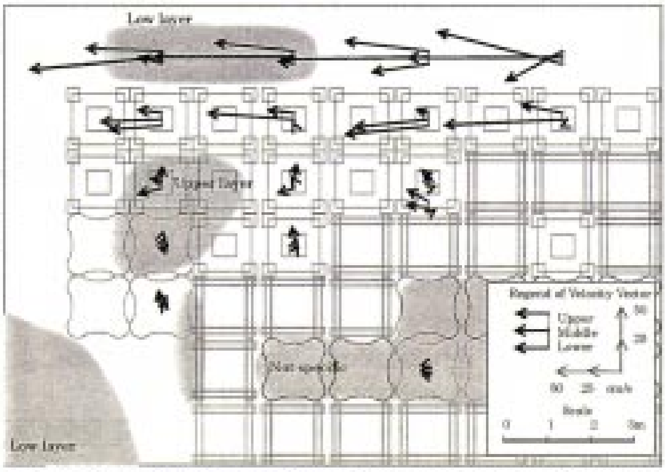


Figure 5 Fish Habitat colored gray, Stream vectors and Structures

Velocity was measured in three dimensions at a frequency of 1Hz 10cm below the water surface, halfway between the bed and water surface and 10cm above the bed. Three minute averages indicate the general flow condition of the areas where spiral flow is generated at the front of log groin and eddy and created downstream of the groin (Figure 5).

According to the vector graph of velocity fluctuation (Figure 6), the space fish hover in the main stream near the bed is surrounded by strong turbulence in overhead, upstream and to the left. Turbulent is strong to the below, to the right and surrounding the space where fish hover in the eddy surface. The velocity fluctuations in spaces with high

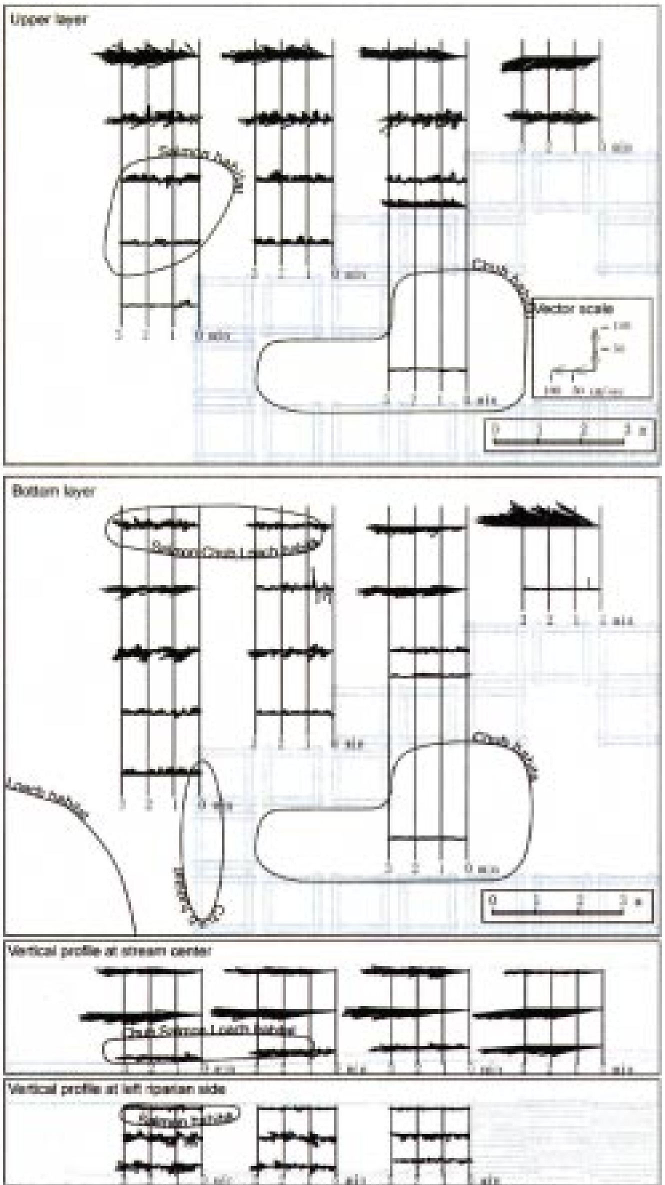


Figure 6 Fluctuation of velocity vector

* chub: *Tribolodon hakonensis*, salmon: *Oncorhynchus keta*, loach: *Noemacheilus toni*, goby: *Chasmichthys gulosus*, lampley: *Lethenteron reissneri*

fish density have an intermittent changing of direction every 20~30 seconds a result which can also be estimated by observation of the water surface. This is in agreement with Jackson's equation (=15~30sec) which estimates the boiling cycle of large eddies ($T \times U_{max} = 7.6h$).

Salmon especially tend to hover in the wavering eddy flow having a small mean velocity and points upstream of the eddy fence. They also prefer the wavering flow in main stream near the bed where the flow scours sand and small gravel creating a scoured bed.

3. Hydrodynamic pressure and fish behavior

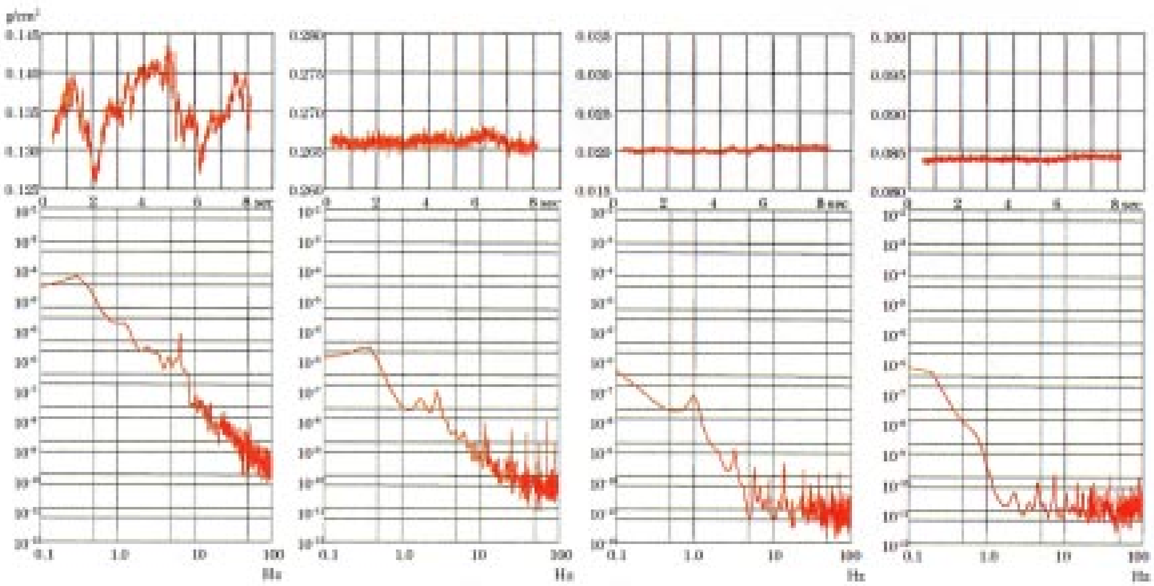
Photo – 2 Device for measuring dynamic hydropressure

The spatial distribution of dynamic hydropressure is measured in relation to the behavior of fish.

A gauging device was specially developed for measuring the dynamic hydropressure at frequencies of 0.1~1000Hz. However it is not known what range of frequency is sensible by fish.

A time series of measured hydropressure and its power spectrum at different points are assorted by the extent of fluctuation and some examples are shown (Figure 7). The space where dynamic pressure fluctuates with high amplitude especially at low frequencies below 20Hz, is found in the middle depth at the center of flow. At this space the fish density is scarce. Near the bed and in the eddy surface area where salmon and chub fish hover, the turbulence is lower than in center flow. In fish hovering zones, the power spectral density in the range of 1～20Hz of the dynamic pressure is smaller than in circumferential areas.

It is commonly known that the energy spectrum of dynamic velocity of turbulent flow is in proportion to -5/3 power of frequency (Tatsumi, 1986). The measured result of dynamic pressure in most areas is in proportion to about -2 power of frequency. The difference means that the turbulent energy created by log groins or complicated riverbed shapes is higher than that of uniform channel flow. The exaggerated energy is propelled over surrounding flows, decreasing the slope of the spectrum.



(1)Middle at Line1/Right1 (2)Bed at Line1/Right1 (3)Surface at Line1/Left3 (4)Control at still water

Figure 7 Power spectrum of hydrodynamic pressure. Fish hover in (2) and (3) but rarely seen in (1).

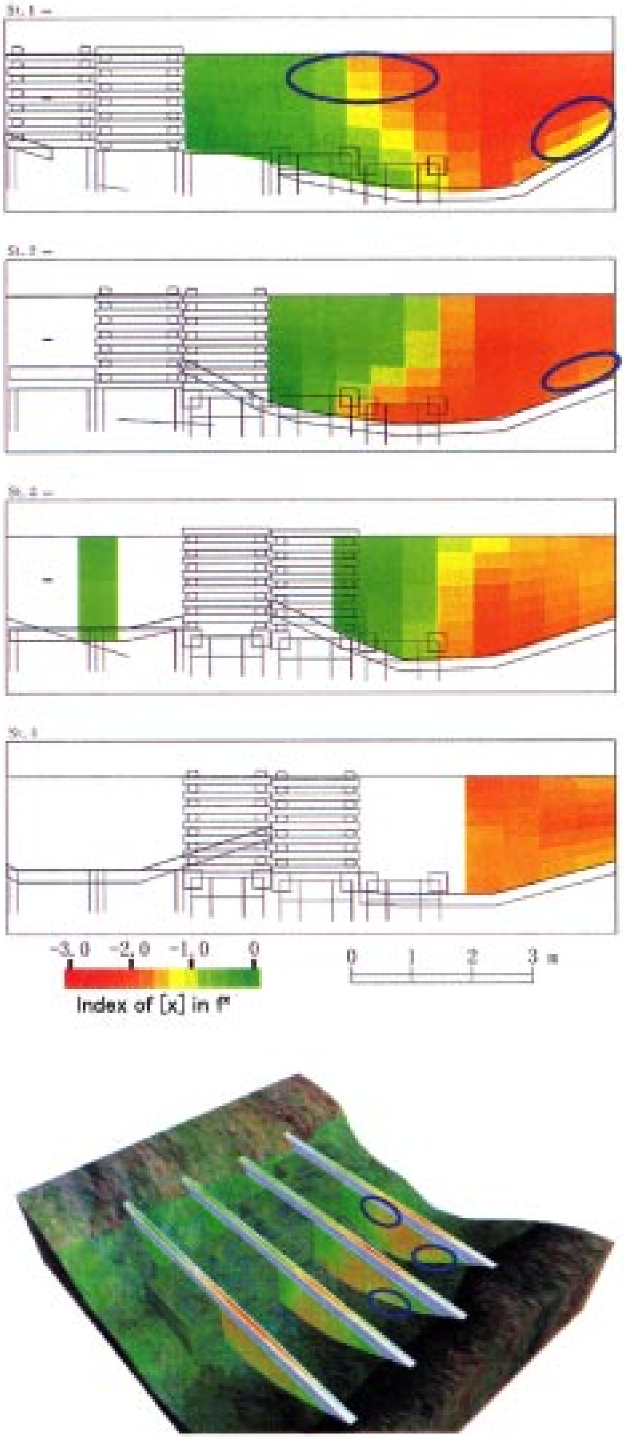


Figure 8 Distribution of slope index calculated from hydrodynamic pressure spectrum.
Circles point spaces where Salmon inhabit.
The bottom picture is a three-dimensional rendering of the same index in the stream.

Fish tend to inhabit areas between high turbulence and still water. The slope of the power spectrum is approximately between -1.5 and -0.5 in fish hovering zones and between -2.0 and -1.5 in the more turbulent surrounding areas. Most zones where fish hover are surrounded nearby by high turbulence flow, which has a steep spectrum (Figure 8).

It is commonly believed that the biological sense of animals is affected by fractal condition of natural phenomenon, in which comfortable disturbance normally indexes around -1.0 in slope of the power spectrum. Similarly, the results of this study show that spatial preference of fish has relation to the fractal condition of disturbance, which can be calculated from hydrodynamic pressure.

Conclusion

The density of chub was found to be high when there was a broad range of both water depth and flow velocity. The density of benthos was higher when the range of flow velocity and depth was limited.

The spatial variability of the velocity vector and the spatial distribution of the dynamic pressure are related to the behavior of fish. The dynamic pressure and velocity of areas where fish hover is smaller than surrounding areas. The slope of the power spectrum is about -1.0 in the fish hovering zones and -2.0 ~ -1.5 in the more turbulent surrounding areas.

The hydrodynamic conditions of areas in which fish and benthos inhabit can be elucidated with the proposed indexes of from flow velocity, water depth and hydrodynamic pressure. More details of the ecosystem, however, must be examined in comparison with bed materials, riparian systems, water temperature, water quality and other factors.

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