2-1.Flushing clayey dam sediments influence on downstream benthic life

SEDIMENTS

Flushing clayey dam sediments influence on downstream benthic life

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Abstract

In 1985, Dashidaira Dam equipped with a flushing gate was built for the first time in Japan at Kurobe River, Toyama, Japan. Since the dam sediments were first flushed out in December 1991, benthic fishes decreased year by year due to repeatedly flushing clayey dam sediments. In June 2001, the flushing dam water contained a low oxygen (1 ~ 2 mg/l) and high concentrations of smectite and vermiculite. To detect the reason of the death of benthic fishes, the living flatfishes were collected from Toyama Bay to observe the gills, showing tissue damages and chemical changes with adherent expandable clays, derived from flushing dam sediments. For comparison, exposure experiments of rainbow trout were carried out using smectite suspensions. SEM-EDX observation revealed that the gills were shrunk because of the concentrations of expandable clays. Low oxygen and high expandable clays are a great influence on downstream benthic life.

Key Words: Flushing dam sediments, Expandable clays, Smectite, Vermiculite, Flatfish, Low oxygen, Rainbow trout.

INTRODUCTION

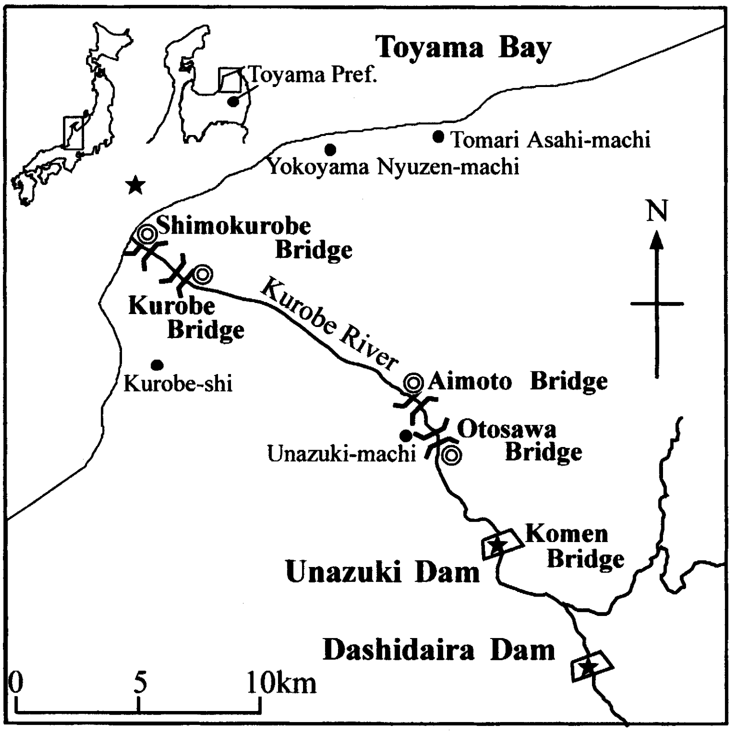
In Japan, large dams have been built since 1965 as hydroelectric power plants, for flood control and water utilization. Most of dams are located in high mountain areas. Dashidaira Dam was the first dam equipped with flushing gates in Japan: it was built in 1985 about 26 km upstream from the estuary of the Kurobe River, Toyama, Japan. Normally river water transports the sediments to a lake or a sea. If a dam interrupts a river, then water velocity drops locally to zero. As a result, sediment particles settle. To prevent filling up the dam reservoir by sediments, which will influence energy production and flood control, the sediments of a reservoir are discharged by flushing. Flushing activity transports sediments and suspended materials downstream in enormous amounts. Obviously, there could be very serious ecological impact in the river. The conditions of flushing operations (duration, time, frequency etc.) at some 70 hydropower installations have been defined in view of principal effects that may result, in the short term, from the increased discharge and the deterioration in water quality (Merle 2000). However, in longer term, alterations in the life cycle of aquatic organisms are not known.

In general, flushing and emptying of reservoirs behind dams usually have a severe impact on the aquatic communities living downstream of those dams. In Switzerland, such aquatic systems are especially sensitive to flushing for at least two reasons: first, most Swiss dams are located in alpine and pre-alpine regions; even under natural conditions, fish and macro-invertebrates are here exposed to a harsh environment. And secondly, there is the effect of anthropogenic impact: dam construction for hydroelectric power causes alterations in aquatic environment (Staub 2000).

In this study, we have observed the flushing dam sediments, characteristic river water, and flatfish in Toyama Bay, to show influence on downstream benthic life. Furthermore, exposure experiments with rainbow trout were carried out using smectite suspensions to identify the effect of expanding clays on the gills of fishes.

ENVIRONMENTAL SITUATION OF THE DASHIDAIRA DAM AND UNAZUKI DAM

Dashidaira Dam is a typical concrete gravity dam with a height of 76.7 m providing 124 MW/year hydroelectric power. Kurobe River is about 85 km long and has a discharge area of 682 km^2. It originates in the mountains, 3000 m above sea level, and flows steeply into Toyama Bay with inclinations of 1/5 - 1/80 (Kokubo 2000). The coastal area of Toyama has typical west-coast weather with a high precipitation (3800 mm/year). The dam is located 26 km upstream from the estuary of the Kurobe River (Fig. 1). The geological setting around Kurobe River valley is mainly granite and gneiss rocks, which are in part deeply weathered. They produce clay minerals, such as smectite, chlorite, vermiculite, mica, and kaolinite (Tazaki et al. 2001). Abundant landslips and landslides have occurred. As a consequence large volumes of gravel and sand have flowed into Kurobe River. For this reason, the river is the worst situation in Japan.



★ ; Sediments were collected from Dashidaira Dam, Unazuki Dam and Toyama Bay.
◎ ; Flushing water was collected from each bridge.

Figure 1 Locality map of Dashidaira Dam and Unazuki Dam at Kurobe River, Toyama, Japan.

Dashidaira Dam was the first dam equipped with flushing gates in Japan. Flushing of Dashidaira Dam was carried out for the first time in December 1991. At that time an awful strong smell, like sludge, originating from the sediments and brought into suspension by flushing, could be noticed along the entire downstream area. Until 1999, flushing events were carried out 8 times into Kurobe River.

Unazuki Dam was built in 2000, downstream of Dashidaira Dam. It was also equipped with a flushing gate. In June 2001, the sediments of both Dashidaira and Unazuki Dams were flushed (Fig. 2). During this period, river water and sediments were collected from each of 4 bridges, shown in Fig. 1, to verify the influence on downstream. The flushing dam sediments contained large amounts of dark grey clayey particles with

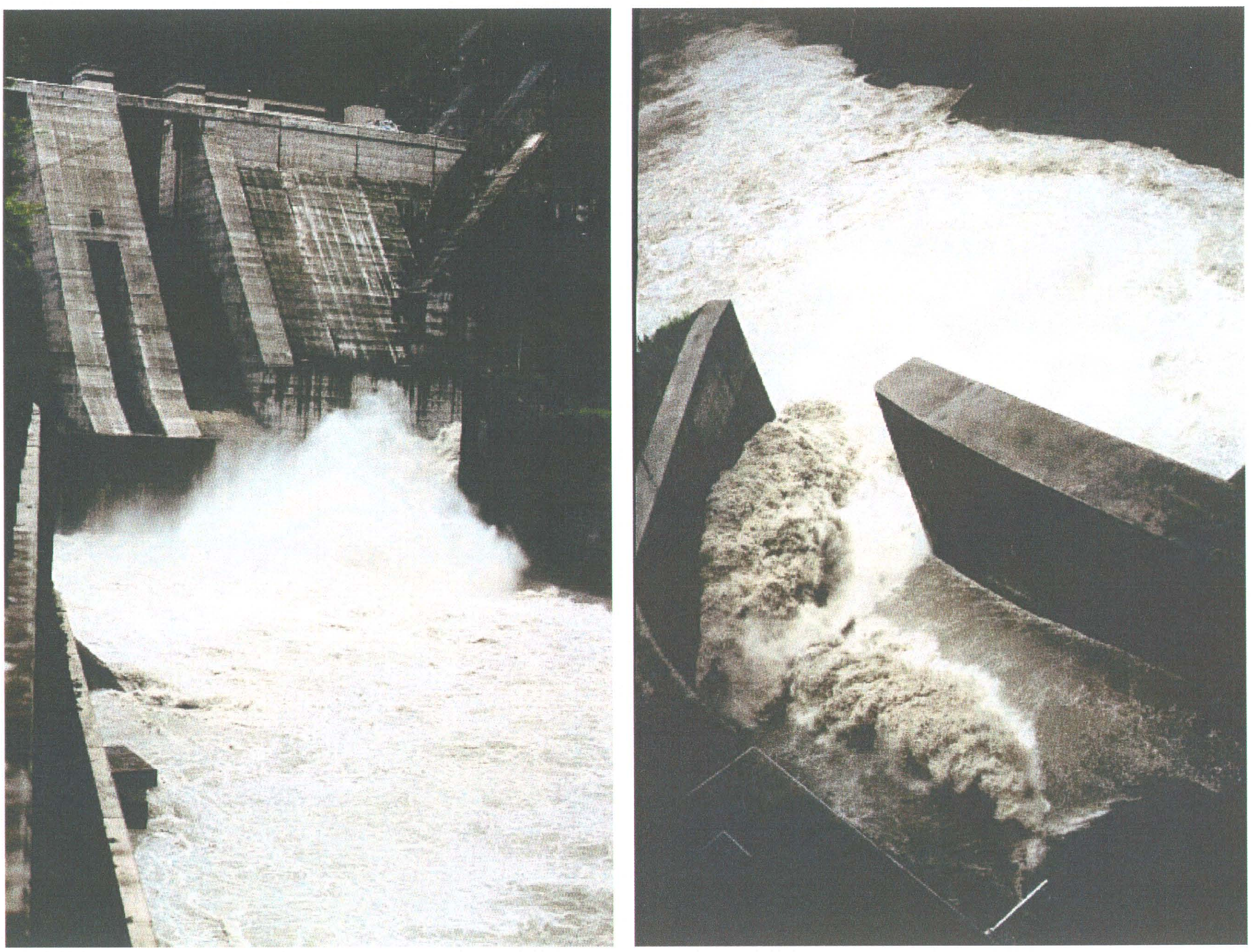


Figure 2 Flushing events of Unazuki Dam, in June 2001, showing ordinarily drainage (left) and flushing dam sediments (right). The latter oxygen-depleted water contains large amounts of organic matter and dark grey clayey sediments during flushing (right).

a stinky smell (Tazaki et al. 2001, 2002). Moreover, numerous split trees and dark brownish organics marked a trail on the water surface. In some places, split trees stacked themselves, making small "hills". Expanding clays, such as smectite and vermiculite, were found in Kurobe River and Toyama Bay sediments (Tazaki et al. 2002).

The objectives of this paper were to characterize the expanding clays from flushing dam sediments and to evaluate the influence on downstream fishes.

MATERIALS AND METHODS

For the 3 days of dam flushing in June 2001 (the 19^{th} to the 22^{nd}), more than 300 bottles of river water samples were collected every 30 minutes to 1 hour at the 4 bridges over the Kurobe River. The water parameters, pH (hydrogen-ion concentration), Eh (reduction-oxidation potential), EC (electrical conductivity), and DO (dissolved oxygen), were measured for all water samples using a portable inspection meter made by HORIBA. Dam, river and bay sediments were also collected at the points in Fig. 1, making a comparative study.

The mineralogical composition of the sediment samples was measured by X-ray powder diffraction (XRD), using Rigaku RINTO 2000 equipment with CuKα radiation. Specimens of the < 2 μm size fractions were analyzed; a) not treated (N.T.) and b) treated with ethylene glycol (E.G.). The sediment samples were analyzed on a home built XRD apparatus applying CuKα radiation: they were kept at different levels of relative humidity (RH) during measurement. The < 2 μm size fractions from the samples were Ca-exchanged and measured at 100 % RH (wet), 50 % RH, and 0 % RH. Clay minerals that transform upon drying, such as freshly formed vermiculite, can then been found. Patterns were corrected for the Lorentz and polarization factor and for the irradiated volume.

To identify damage to the gill tissue of fishes, optical microscopical observation was carried out. A wet scanning electron microscope equipped with an energy dispersive X-ray spectroscopy (wet-SEM-EDX) (JEOL JSM-5200 LV and PHILLIPS EDAX PV 9800EX) was used in order to observe the micro-morphological surface of gills and its chemical composition. Gill samples from the smectite-exposure experiments were mounted on Mylar film and measured by an energy dispersive X-ray fluorescence spectrometer (ED-XRF) (JEOL JSX 3201) applying Rh radiation at 30 kV.

Damaged fish observations were carried out on flatfish collected from Toyama Bay. The 10 flatfishes were collected from Toyama Bay in March 2001 at the same positions as that for the sediments. The gills of living flatfish were studied by wet-SEM-EDX to measure the chemical composition of adsorbed clay particles.

Exposure studies on rainbow trout (*Salmo trutta Linnacus*) were carried out using smectite suspension. In the 4 different experiments, 7 ~ 9 rainbow trout were kept in a volume of 10 litres of river water for 24 hours: a control group with no smectite, and other groups at smectite concentrations of 0.5 g/l, at 5.0 g/l, and at 10.0 g/l. The oxygen concentration was monitored during the experiment. The pH, Eh, EC, and temperature of the water were measured at the beginning and at the end of the experiments. Na-bentonite (Kunigel-VI) that contains large amounts of smectite was used as a representative for expanding clay minerals in this experiment.

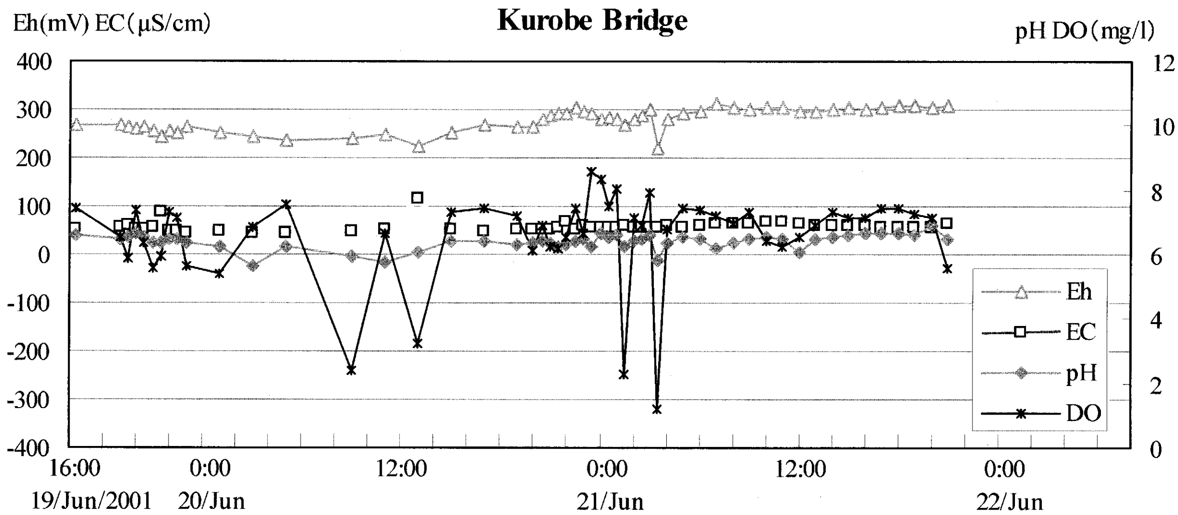
RESULTS

Characteristics of the flushing water

The oxygen-depleted water and dark grey bottom sediments from both Dashidaira and Unazuki Dam reservoir were discharged to the downstream of Kurobe River between June 19th - 22nd, 2001. The suspended solids (SS) levels of the river water during flushing were 500 - 1000 mg/l. The pH, Eh, and EC parameter of river water at Kurobe Bridge and Shimokurobe Bridge are shown in Fig. 3: they indicate rather stable values during ordinary drainage; such as pH 6, Eh 200 ~ 300 mV, and EC 50 ~ 100 μS/cm, respectively. But, during flushing, the DO displayed low values at 4 times (in 2 sets of 2 minima) (Fig. 3 upper). At the times the water was almost oxygen-depleted.

At the Shimokurobe Bridge, the DO values were mostly stable with values ranging from 6 to 8 mg/l (Fig. 3 bottom). However, 2 periods with low oxygen content of the water can be seen, as was the case at Kurobe Bridge, through they were split into group of three minima. The low periods were from 20:00 on June 20 to 0:00 on June 21 and from 12:00 to 16:00 hours on June 21 with values ranging from about 1 to somewhat more than 4 mg/l. In the last period the water was twice close to being oxygen-depleted.

Normally, the pH was somewhat more than 6. During the low DO periods, the pH values dropped to around 4 in the first period. In the second period, pH ranged from 5 to 6. Most of the time, Eh values were slightly higher than at Kurobe Bridge. However, there was a significant drop during the 2 periods (to Eh -100 ~ -200 mV in the first period and Eh 150 ~ 200 mV in the second period). Note that the DO shows only 1 ~ 2 mg/l lower values in each of the 2 periods. The EC shows only a few slight increases during the 2 periods.



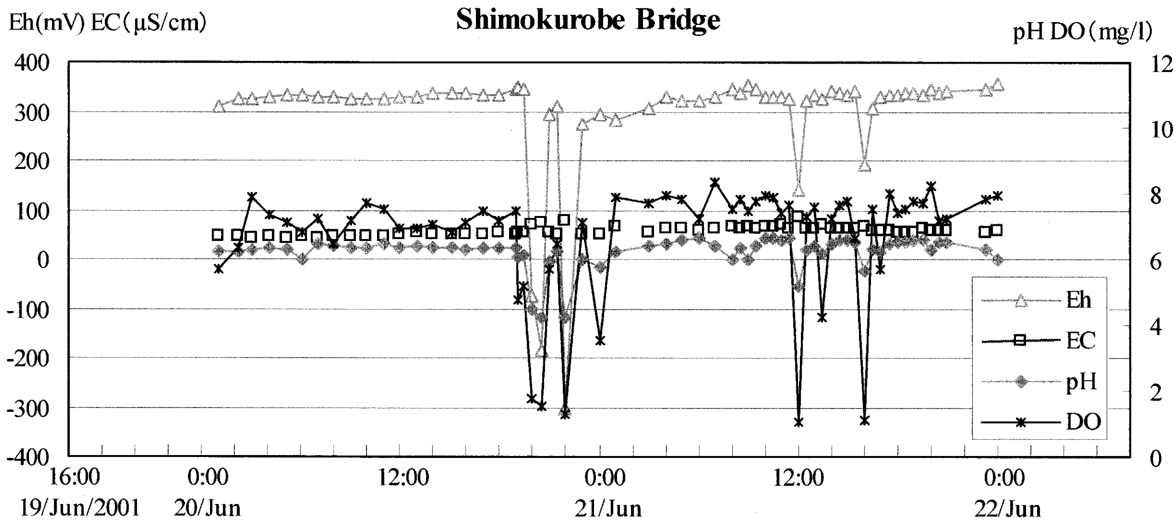


Figure 3 The Eh, EC, pH, and DO values of river water at Kurobe Bridge and Shimokurobe Bridge during flushing of Dashidaira Dam in June 19th - 22nd, 2001. At the both bridges the DO data indicates twice much lower oxygen at few times of 2 periods. Note that lower DO values are associated with lower Eh and pH.

From visual inspection, we noticed that during flushing the suspended load of the bottom water of the river came to the surface due to collision with the legs of the bridge. This explains why, at Shimokurobe Bridge, which is downstream of Kurobe Bridge, the low DO periods are split up further. Plotting of the results (Fig. 3) clearly showed that a block of dead water was flowing downstream. It divided into smaller masses without mixing with the normal river water.

The results suggest that 1) the periods with low DO, and in the case of Shimokurobe Bridge also the Eh and the pH, clearly show the flushed water masses split up in different segments; the river water and the flushed water apparently do not mix well, 2) a time lag of about 24 hours can be seen between the 2 bridges. The water speed of the current must be low because these sampling points are just a few kilometres apart, 3) the flushing dam sediments are transported slowly as a thick suspension along the bottom of the river. When it meets obstacles such as legs of bridges it comes to the surface, visually without mixing with the surface water.

Sedimental characteristics

Kurobe River sediments contain weathered granite particles with clay sized fractions. XRD data indicated similar clay components between Unazuki Dam sediments and suspended solids on the seabed at the Kurobe River mouth (Fig. 4). They are closely related to patterns of river products and estuarine clay minerals. Both sediments of the < 2 μm fractions and that of the suspended solids contain relatively high contents of smectite (17.1 - 17.4 Å) with vermiculite and chlorite (14.2 Å), mica (10.1 - 10.0 Å), and kaolinite (7.1 Å) with small amount of talc (9.4 Å). At controlled RH, XRD patterns show that vermiculite is present in both Toyama Bay sediments (sample No. 22) and Dashidaira Dam sediments (sample No. 4) with showing of 15.0 - 15.1 Å at 100 % RH. The smectite expands to 18.8 Å at 100 % RH (Fig. 5). Since vermiculite has a high charge, it is likely to have at least a similar effect on the fish to smectite. Rather large amounts of vermiculite are observed in the fractions 10 - 16 μm. This size of particles could easily pass through the gills of the fish and thus cover large areas of gills. Staub (2000) has reported that the < 75 μm size of particles also can easily pass through the gills. We believe that smectite and vermiculite play a similar role in the experiments and observations.

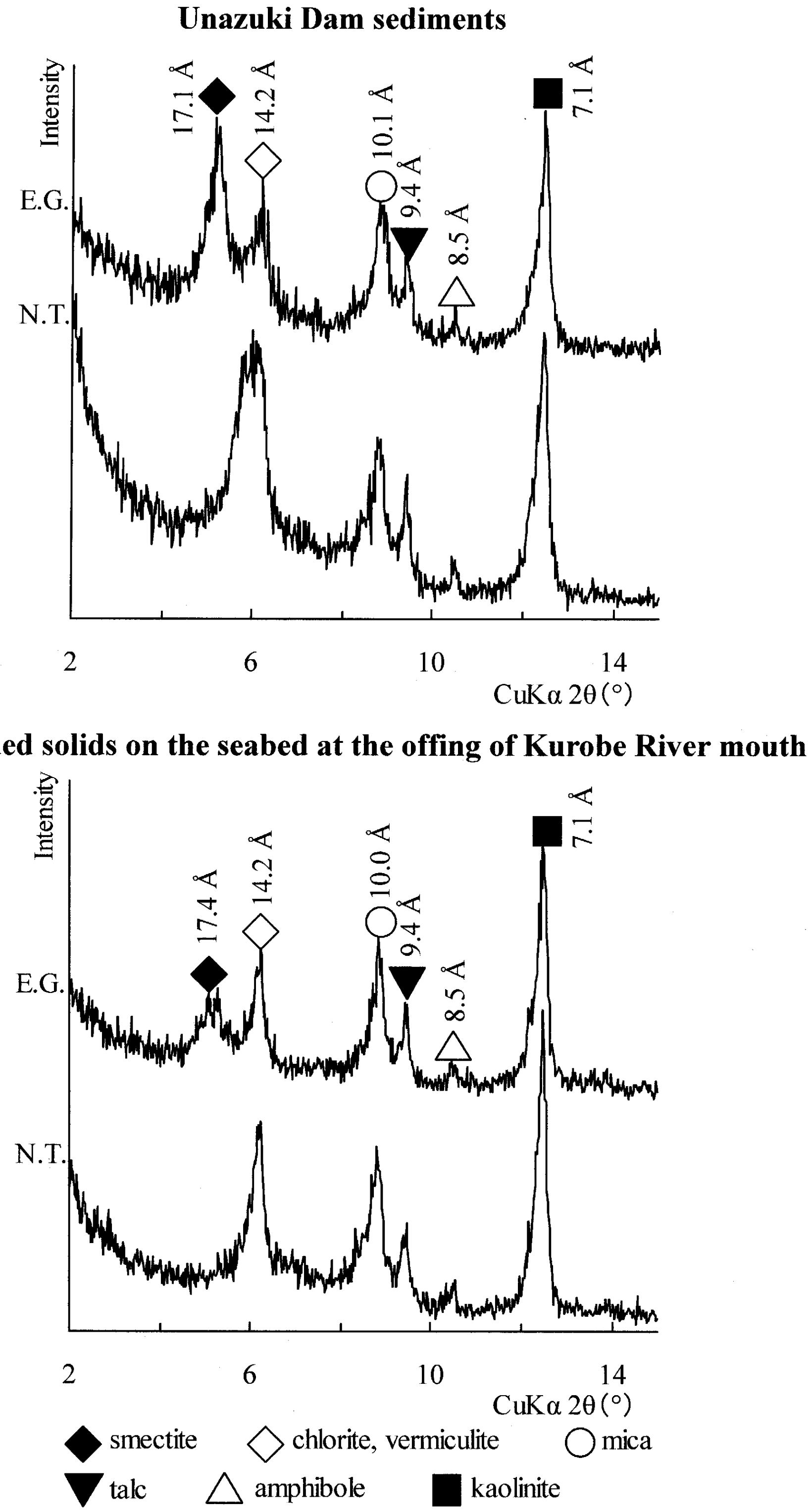


Figure 4 XRD patterns of the < 2 μm size fractions from Unazuki Dam sediments (upper), and suspended solids on the seabed at the offing of Kurobe River mouth (bottom), showing a strong similarity of clay minerals. Both clays are rich in smectite, chlorite, vermiculite, mica and kaolinite. (N.T.; not treated, E.G.; ethylene glycol treatment).

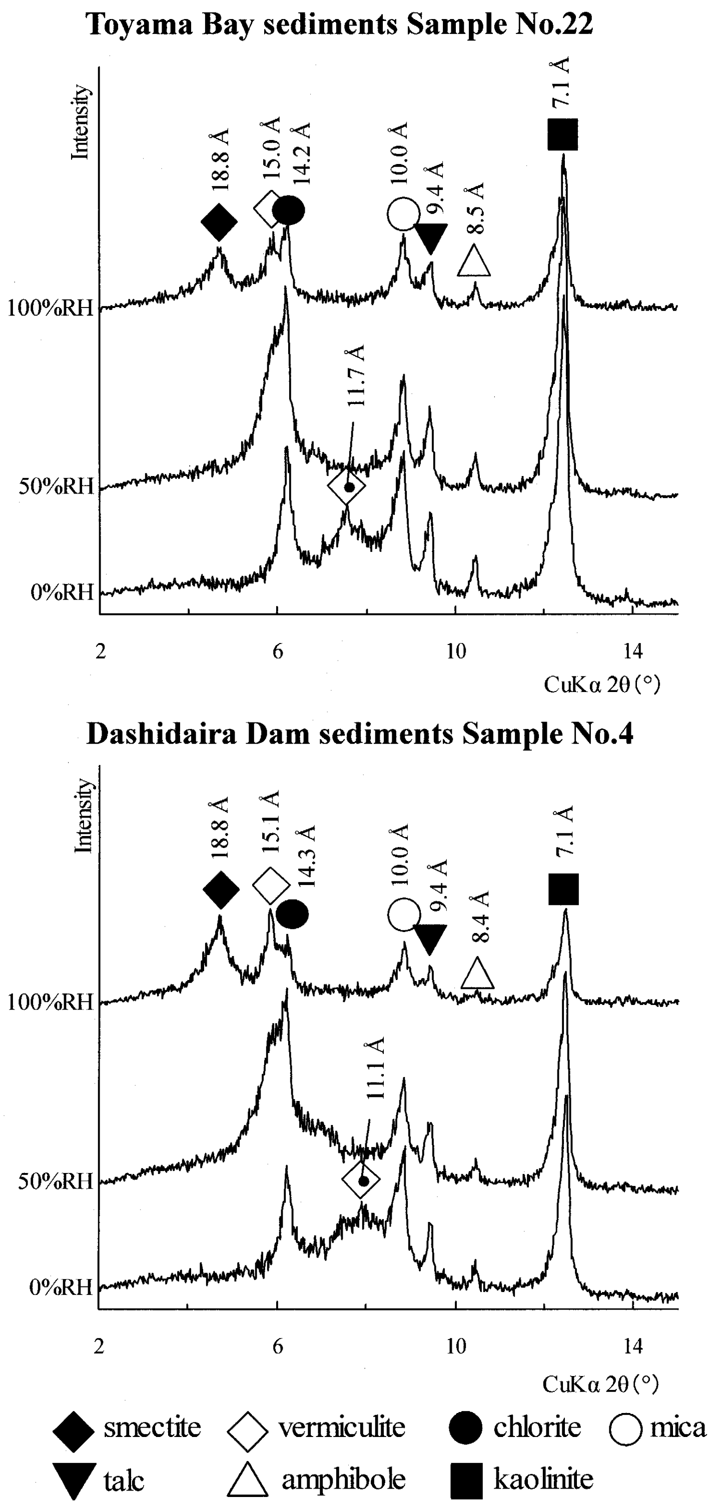


Figure 5 XRD patterns of the < 2 μm size fractions from Toyama Bay sediments and Dashidaira Dam sediments, applying the RH method. Both sediments show a similar clay composition. Here the 15.0 - 15.1 Å peaks in the 100 % RH patterns represent vermiculite, as well as a 0 % RH the vermiculite peak is shifted to 11.1 - 11.7 Å.

Fish damage observation

The flatfishes were collected from Toyama Bay after the dam flushing. On the wet-SEM micrographs of Fig. 6 A and B, thin films adhered to the gill can be seen. The Al and Si elements from the EDX pattern (Fig. 6 C) and their intensity reveals that these thin films are identified as clay minerals, probably of the 2:1 type, comprising the expanding clay minerals such as smectite and vermiculite. The P and S signals are due to fish body tissue components and probably to the mucus. The other elements originate from both clay minerals and the organic matter of the fish tissue and the mucus. The combination of mucus and clay minerals probably adheres easily to the surface of the gill. Fig. 7 A shows thick clay films that cover a large part of a gill. At larger magnification (Fig. 7 B and C) the network films show a strong deformation and/or dehydration. The chemical composition (Fig. 7 D) shows a strong similarity to that of the material shown in Fig. 6. From this observation we conclude that the clay minerals are highly likely to be from the flushing dam sediments.

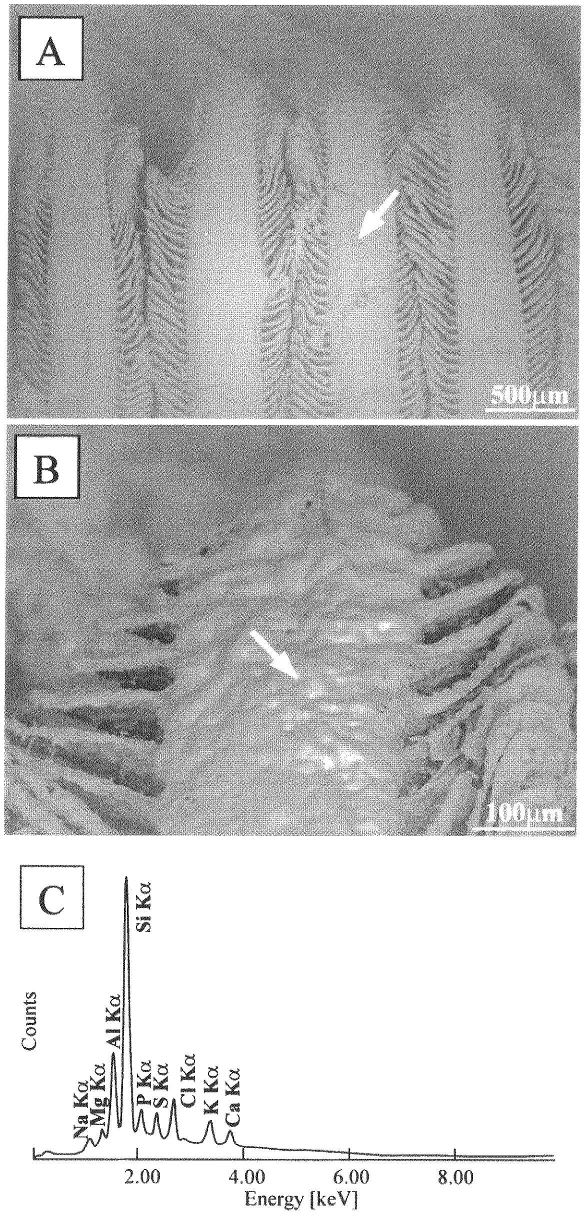


Figure 6 SEM micrographs of the gill of flatfish collected from Toyama Bay (A and B). Thin films with mucus are adhered on the surface of the gill (arrows). EDX analysis of the clayey films on the gill (arrow in B: analytical point) indicates Al and Si composition due to clay minerals (C). The P and S elements are due to tissue and mucus of fish.

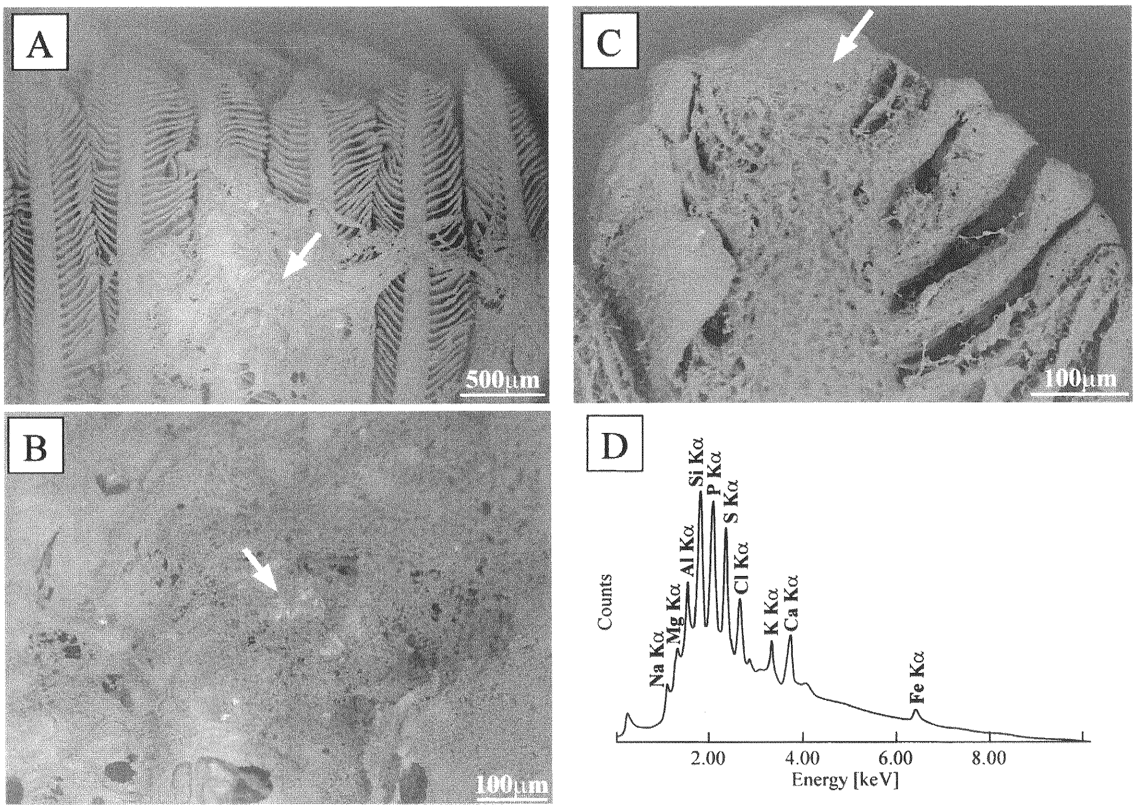


Figure 7 SEM micrographs and the EDX analysis of the gill of flatfish. Large aggregates and network structures of clay minerals (A, B and C, arrows). Mucus with clays are present on the surface of the gill. The arrow in B indicates the analytical point of EDX (D).

Fish damage experiments with smectite

The results of exposure experiments of rainbow trout in smectite suspensions are shown in Table 1 and Fig. 8. From the control group, no trout died during the experiment. From the group of 9 trout that were exposed to 0.5 g/l smectite, 2 trout died after 18 hours. For the group that was exposed to 5.0 g/l, 3 trout died after 14 hours and 3 more after 24 hours. At the highest concentration of 10.0 g/l, 2 trout died after only 2 hours. After 6 hours all trout were dead.

In the 10.0 mg/l smectite suspension, the DO was somewhat lower. However, in all cases the DO during the experiment was sufficient to keep the rainbow trout alive (Table 1). The Eh decreased probably as a result of the metabolism activity of the rainbow trout. At the end of the experiments, the pH and the EC increased in all cases, and temperature increased by 3 ~ 4 °C.

The experimental results suggest that the suspended smectite has a great impact on the mortality of rainbow trout. Optical microscopical observation revealed that the gill area was reduced because of the concentration of smectite (Fig. 8). The points of the gills were sharpened and separated in smectite suspension. The ED-XRF patterns from the gills of the exposed rainbow trout indicate that P, S, K, Ca, and Fe contents are reduced. The gills with smectite suspension show both damage of body tissue and chemical changes. Note that the gills from the control group did not show the Si peak.

Table 1 Results of the exposure experiments of rainbow trout using smectite suspensions. The number of existent rainbow trout is closely related with concentration of smectite.

Number of existent rainbow trout

aging time (hour)	Conc. of smectite			
	Control	0.5 g/l	5.0 g/l	10.0 g/l
0.0	7	9	7	7
0.5	7	9	7	7
1.0	7	9	7	7
1.5	7	9	7	7
2.0	7	9	7	5
6.0	7	9	7	0
14.0	7	9	4	0
18.0	7	7	4	0
24.0	7	7	1	0

Dissolved Oxygen (mg/l)

aging time (hour)	Conc. of smectite			
	Control	0.5 g/l	5.0 g/l	10.0 g/l
0.0	8.9	9.5	8.8	7.9
0.5	10.1	9.6	9.6	8.5
1.0	8.4	9.2	9.4	8.2
1.5	6.8	8.2	8.4	7.3
2.0	6.2	8.0	8.0	6.5
6.0	8.4	8.1	8.5	7.1
14.0	8.6	8.4	8.3	8.0
18.0	8.8	8.5	8.8	7.5
24.0	8.6	8.0	7.6	6.1

Characteristic water at the starting point

Conc. of smectite	pH	Eh [mV]	DO [mg/l]	EC [μS/cm]	WT [℃]
control	7.2	280	8.9	91	13
0.5 g/l	8.2	230	9.5	117	12
5.0 g/l	9.4	110	8.8	311	13
10.0 g/l	9.9	110	7.9	674	13

Characteristic water after completed examination (after 24 hours)

Conc. of smectite	pH	Eh [mV]	DO [mg/l]	EC [μS/cm]	WT [℃]
control	7.7	230	8.6	125	16
0.5 g/l	7.6	170	8.0	216	16
5.0 g/l	8.4	160	7.8	528	16
10.0 g/l	8.9	160	6.1	743	16

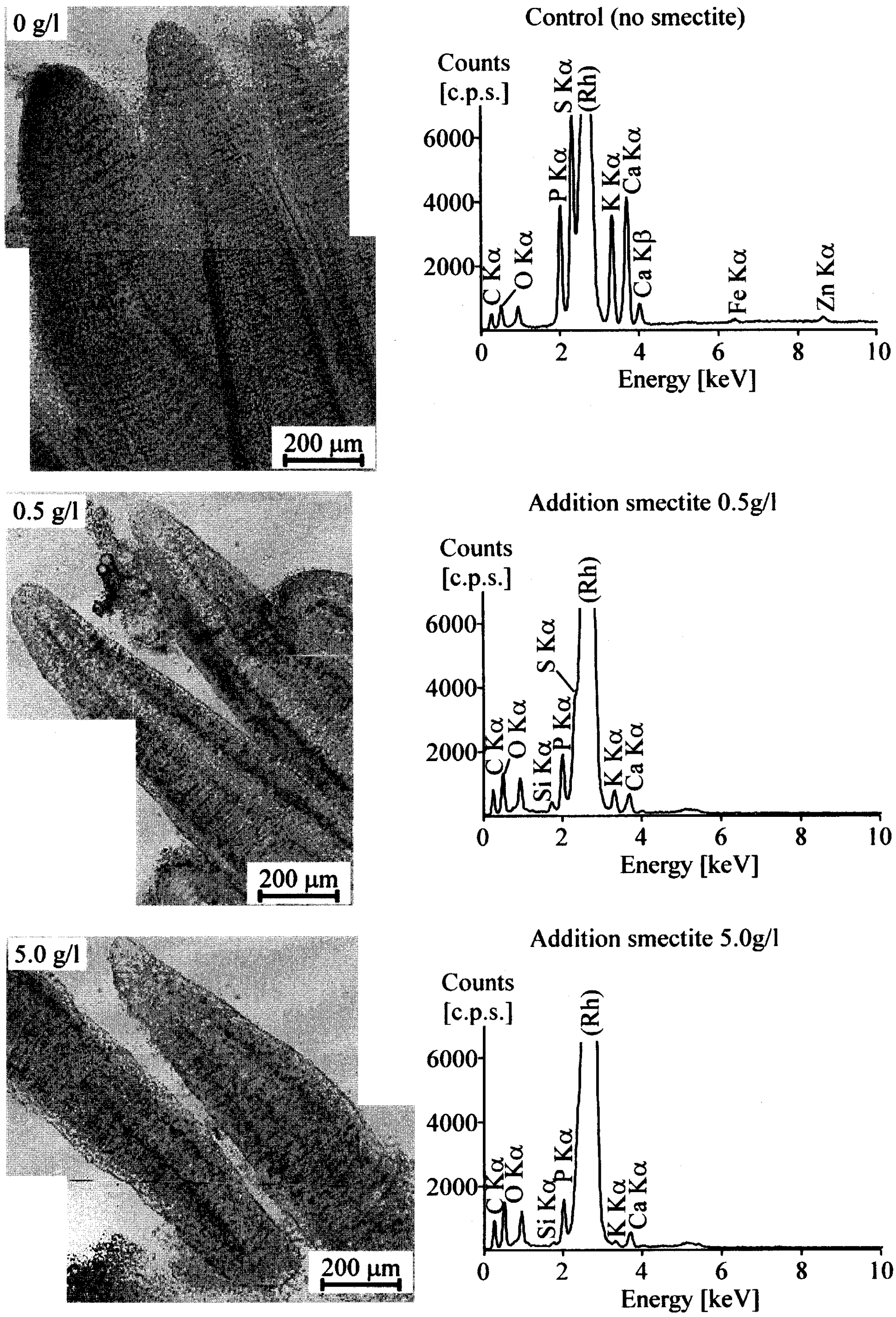


Figure 8 Optical micrographs of gills of rainbow trout from the exposure experiments under control (no smectite), 0.5 and 5.0 g/l of smectite suspensions. The gill with smectite suspension shows the damage of body tissue and changes in chemical composition. ED-XRF (Energy dispersive X-ray fluorescence spectrometer) analysis of gill indicated effective chemical change of reduced P, S, K and Ca components in smectite suspension. The Rh peak is due to the mechanical X-ray tube.

DISCUSSION

Influence of clayey particles on fishes

The particle size of the suspended clays is relevant for gill damage. Particles smaller than 75 μm are fine enough to pass through the gill membranes and cover the interlamellar spaces of the gill tissue. This can induce mucus production, which reduces the velocity of oxygen diffusion between the surrounding water and the fish blood. Coarse particles (75 - 250 μm) are large enough to cause mechanical abrasion of the gill (Staub 2000), which is probably also the case in Kurobe River and in Toyama Bay.

Since 1991, dam sediments have been flushed in short periods: the maximum was 174×10^4 m^3 in 1995. These events correspond to the drastic decline of the yearly catch of flatfishes and wakame seaweed production in Toyama Bay (Fig. 9). Wakame seaweed is very important to give the place for fish spawning. Therefore, if flashing dam sediments affect seaweed, yearly catch of fish is also influenced.

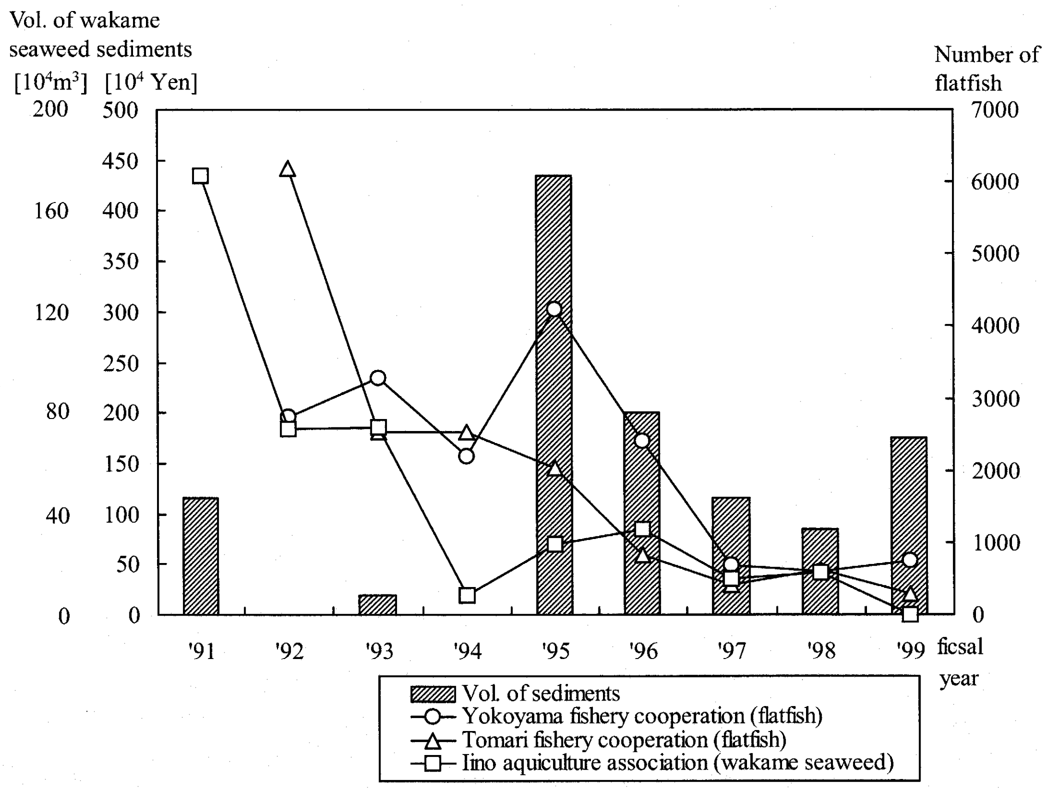


Figure 9 The drastic decline of the yearly catch of flatfish and wakame seaweed since the first flushing of dam sediments in 1991. The hauls of flatfish and wakame seaweed dramatically have been dropped year by year. The volume of flushing dam sediments is closely connected with the ratio of dropping hauls.

From the XRD patterns of Dashidaira Dam sediments and Toyama Bay sediments, expanding clay minerals (smectite and vermiculite) were identified as important constituents. These clay mineral particles are sufficiently fine to pass through the gill membranes. From the SEM micrographs we conclude that the gills of the flatfish, that were collected after flushing of dam sediments from Dashidaira Dam, were covered with thin films (Fig. 6 and 7) containing clay minerals from these dam sediments. EDX analyses sustain this view, indicating Al and Si peaks from 2:1 clay minerals, which are probably smectite and vermiculite. Thin films consisting of clay minerals in combination with mucus, that is developed after adsorption of these clay mineral particles onto the gills, were found to be relevant for gill damage. Rainbow trout exposed to smectite suspensions gave similar evidence as with that obtained from the flatfish.

The clayey films, which are shown in Fig. 6 and 7, reduced the velocity of oxygen diffusion. Therefore most gills exhibited deformation and/or dehydration damage. Smectite and vermiculite, which are derived from dam sediments, could easily adsorb organic materials on the outer surfaces and in the lattice interlayer. Kennedy et al. (2002) have reported that smectite allows fixation of organic matter in the interlayer, facilitating its preservation. Our data also provide evidence for organic matter reacted with smectite.

The effect of expanding clays is remarkable condensation and precipitation in seawater of pH 8, which is well known. Therefore expanding clays harm especially flatfish living in sea bottom, because of mechanical abrasion of the gill and reducing oxygen transfer from the water towards the blood. Fish gills are very sensitive for physical and chemical attack with the clay minerals.

Economic problems

After reduction of benthic life by flushing operations (Gartman 1990; Waters 1995; Mann and Plummer 2000; Collie et al. 2000; Kareiva et al. 2000; Jackson et al. 2001) public awareness of the environmental impact increased in the early 80’s. This situation lasted until 1991, when regulations on the flushing and emptying of reservoirs were introduced in the Swiss water protection legislation (Council 1991).

In this study the ecological and environmental effects of flushing dam sediments of Dashidaira Dam indicates that such events have a strong impact on aquatic life. The study understands that flushing dams will result in a continuing decline of the yearly catch of fish and seaweed (Fig. 9), and the death of huge numbers of marine animals. In general, all life is dependent on clean water. In our case poor water management of the dams of Kurobe River almost eradicated flatfish and seaweed, thus having a strong negative economical impact is on the fishery community of this region (Fig. 9).

In a related study, the effects of suspended or accumulated kaolinite particles on the adhesion and the germination of *Porphyra yezoensis* conchospores were investigated (Suzuki et al. 1997, 1998). These authors conclude that the damage to seaweed communities with suspended matter has generated by human activities in the coastal region. Flushing clayey sediments with expandable clay minerals carry the important factor to effect on fishes and seaweed in downstream ecosystem.

CONCLUSIONS

Flushing dam sediments from Dashidaira Dam at Kurobe River in Toyama Bay, Japan, contain large amounts of smectite and vermiculite. In combination with low oxygen water the clayey films result in tissue damage to fish gills. This effect was demonstrated by exposure experiments of rainbow trout in smectite suspension: within 24 hours a high percentage of the rainbow trout died. Such a combination also resulted in serious damage to flatfish in the bay. The catch of benthic fish in Toyama Bay has decreased to one seventh since the first dam flushing in 1991. This resulted in a strong negative economic impact on the fishery community around Toyama Bay.

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REFERENCES

Collie, J., Saila, S., Walters, C., Carpenter, S., Mann, C. C. and Plummer, M. L. (2000) Of salmon and dams. *Science*, **290**, 933-934.

Council (1991) Federal Law on the protection of waters. *Swiss Federal Department of the Interior*, SR, **814**, 20-27.

Gartman, R. (1990) Splungen und entleerungen von stauseen und Ausgleichsbecken umweltbezogene anforderungen. *Wasser, Energie, Luft*, **82**, 33-36.

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., Cooke, R., Erlandson, J., Estes, J. A., Hughes, T. P., Kidwell, S., Lange, C. B., Lenihan, H. S., Pandolfi, J. M., Peterson, C. H., Steneck, R. S., Tegner, M. J. and Warner, R. R. (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science*, **293**, 629-637.

Kareiva, P., Marvier, M. and McClure, M. (2000) Recovery and management options for Spring/Summer Chinook salmon in the Columbia River Basin. *Science*, **290**, 977-979.

Kennedy, M. J., Pevear, D. R. and Hill, R. J. (2002) Mineral surface control of organic carbon in black shale. *Science*, **295**, 657-660.

Kokubo, T. (2000) Effects of Dashidaira Dam sediment flushing on Kurobe River. *Proceeding of International Workshop and Symposium on Reservoir Sedimentation Management*, 99-116 (in Japanese).

Mann, C. C. and Plummer, M. L. (2000) Can science rescue salmon ? *Science*, **289**, 716-719.

Merle, G. (2000) Some environmental aspects of flushing. *Proceeding of International Workshop and Symposium on Reservoir Sedimentation Management*, 195-202.

Staub, E. (2000) Effects of sediment flushing on fish and invertebrates in Swiss Alpine Rivers. *Proceeding of International Workshop and Symposium on Reservoir Sedimentation Management*, 185-194.

Suzuki, Y., Maruyama, T., Miura, A. and Shin, J. (1997) Effects of suspended or accumulated kaolinite particles on adhesion and germination of *Porphyra yezoensis* conchospores. *Journal of the Society of Civil Engineers of Japan*, **559**, 73-79 (in Japanese with English abstract).

Suzuki, Y., Maruyama, T., Takami, T. and Miura, A (1998) In habition effects of suspended and accumulated particles on adhesion and development of *Undaria pinnatifida* zoospores. *Journal of the Society on Water Environment of Japan*, **21**, 670-675 (in Japanese with English abstract).

Tazaki, K., Kunimine, Y. and Morikawa, T. (2001) Dam sediments on downstream of Kurobe River - The variation of water quality and suspension chemistry during discharge of dam sediments. *Journal of the Clay Science Society of Japan*, **41**, 64-74 (in Japanese with English abstract).

Tazaki, K., Nawatani, N., Kunimine, Y., Morikawa, T., Nagura, T., Wakimoto, R., Asada, R., Watanabe, H., Nagai, K., Ikeda, Y., Sato, K., Segawa, H. and Miyata, K. (2002) Sediment characteristics of Dashidaira Dam reservoir at Kurobe River and Toyama Bay, and flushed suspension impacts on fishes. *Journal of the Geological Society of Japan*, **108**, 435-452 (in Japanese with English abstract).

Waters, T. F. (1995) Sediment in Stream. *American Fisheries Society Monograph*, **7**, 251.