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PREDICTIONS OF ENVIRONMENTAL EFFECT DUE TO SEDIMENT SLUICING AT A SERIES OF THREE DAMS*

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SUMMARY

With the flood disaster experienced in the Mimikawa River system due to Typhoon Nabi in 2005, various problems caused by sediment in the river basin became clear, including increased risk of flooding with rising riverbed levels in dam-regulating reservoirs, grain coarsening in the downstream river channel with the entrapment of sediment in dams, and the destabilization of bridge piers in the downstream river channel. As part of an effort to resolve all these problems simultaneously, from 2017 sediment sluicing at a series of dams was implemented. Sluicing is an operation carried out when there is river flooding due to typhoons. Dam-regulating reservoir drawdown is carried out, and sediment flowing into these reservoirs from the upstream is allowed to flow downstream of dams.

** Prévisions du l'influence de la vidange des sédiments sur l'environnement dans un groupe de trois barrages*

This paper principally covers 1) an overview of sediment sluicing at dams in the Mimikawa River system, 2) understanding and analysis of the river environment prior to sluicing, 3) predictions of the effect on the river environment due to sluicing, and 4) testing of these predictions.

Keywords: Sedimentation, Effect of Dams on Environment, Alteration, Monitoring, Numerical Model.

RÉSUMÉ

Avec la crue catastropohique dans le bassin de la rivière Mimikawa à cause du Typhon Nabi en 2005, plusieurs problèmes causés par l'afflux de sédiments dans le bassin de cette rivière sont apparus : le risque croissant d'inondations à cause de la hausse du niveau du lit de la rivière dans les barrages-réservoirs, augmentation de granulométrie dans le cours de la rivière en aval à cause de la capture des sédiments dans les barrages et déstabilisation des piles de pont dans le cours de la rivière en aval ; pour résoudre l'ensemble decces problèmes, on exécute une vidange des sédiments dans un groupe des barrages depuis 2017. La vidange des sédiments est une opération exécutée à la suite d'une crue provoquée par un typhon ; cela abaisse le niveau de l'eau dans les barrages-réservoirs, et transfère en aval les sédiments arrivés de l'amont dans les barrages-réservoirs.

Cet article traite principalement 1) un aperçu de la vidange des sédiments exécutée dans le bassin de la rivière Mimikawa, 2) la compréhension et l'analyse de l'environnement fluvial avant la vidange des sédiments, 3) les prévisions de l'influence sur l'environnement fluvial à la suite de la vidange des sédiments et 4) la vérification de ces prévisions.

Mots-clés: Yamasubaru Dam, Saigou Dam, Oouchibaru Dam.

1. INTRODUCTION

In the Mimikawa River system, located in Miyazaki Prefecture in the southeast of the island of Kyushu, Japan, unprecedented intense rainfall accompanying Typhoon Nabi in 2005 caused a large number of mountain slope failures, a huge quantity of sediment to flow into the river and dam-regulating reservoirs, and extensive flood damage to occur in cities, towns and villages in the river basin. Following this large-scale disaster, in 2009 Miyazaki Prefecture, the river administrator, re-examined the Mimikawa River System River Development Plan and in 2011 formulated the Integrated Sediment Flow Management Plan [1].

With the Integrated Sediment Flow Management Plan as a core project, Kyushu Electric Power Co., Inc., the owner of 8 dams and 7 power stations in the Mimikawa River system (Fig.1), is planning for sediment sluicing at a series of 3 dams: Yamasubaru, Saigou and Oouchibaru Dams. Since 2011 retrofitting and other work involving the partial cut-down of overflow sections, and installation of large spillway gates in existing dams has been carried out. From 2017, with preparation for sluicing at Saigou and Oouchibaru Dams (a series of 2 dams) completed, sluicing commenced.

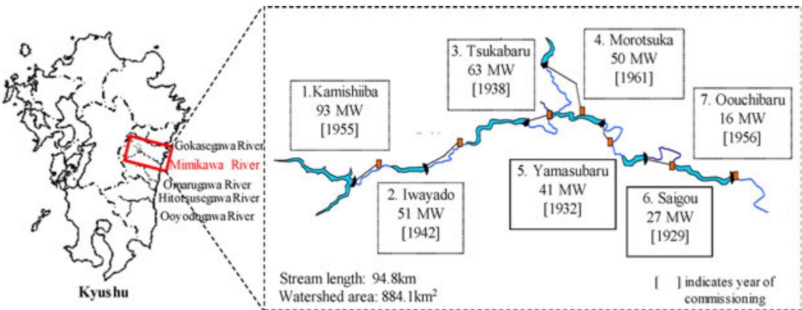


Fig. 1
Mimikawa river basin – overview
Bassin de la rivière Mimikawa – aperçu

Sediment sluicing at dams (hereafter referred to simply as “sluicing”) is carried out when there is large-scale river flooding due to typhoons, and involves dam-regulating reservoir drawdown so that these reservoirs come close to the state of the original natural river. This then allows sediment from the upstream that has flowed into reservoirs to flow downstream of these dams [2]. Up until now, large quantities of sediment have flowed into and became deposited in dam-regulating reservoirs at times of river flooding. Through sluicing operation, this sediment will pass to the downstream of these reservoirs, thereby mitigating the risk of flooding in areas around the reservoirs due to rising water levels that accompany aggregation. In addition, sediment entrapped up until now at dams will be fed to the downstream river channel, which has been subject to progressive grain coarsening and armoring. This is expected to lead to effects such as the restoration of the downstream river channel to a form close to its original form, and habitat regeneration.

This paper focuses on the effects of sluicing that affect the river environment, and covers principally 1) an overview of sluicing being implemented at dams in the Mimikawa River system, 2) understanding and analysis of the river environment prior to sluicing, 3) predictions of the effect on the river environment due to sluicing, and 4) testing of these predictions by survey and analysis of the river channel downstream of dams through which sediment has passed.

2. OVERVIEW OF SEDIMENT SLUICING AT DAMS IN MIMIKAWA RIVER

2.1. OVERVIEW OF DAMS WHERE SEDIMENT SLUICING IS TO BE IMPLEMENTED

The 3 dams at which sluicing is to be implemented are located in the midstream of the Mimikawa River, where riverbed gradient varies between 1/600 and 1/400. As shown in Table 1, which gives dam and dam-regulating reservoir dimensions, dam height ranges from 20 to 30m. Amongst these are low-water-head dams with concrete sections of 10 to 20m high and spillway gates that make up 1/3 to 1/2 of dam height. As shown in Fig. 2, because these dams have no facilities to discharge flood water other than spillway gates, these dams are operated to always maintain a water level within the range of these gates, even

Table 1
Main dimensions for 3 dams and regulating reservoirs

		Yamasubaru	Saigou	Oouchibaru
Dam	Height (m)	29.40	19.96	25.50
	Crest height (m)	19.71	10.01	11.00
Reservoir	Capacity ('000m^3)	4,194	2,452	7,488
	Length (km)	5.80	6.44	7.32
	Riverbed gradient	1/400	1/500	1/600

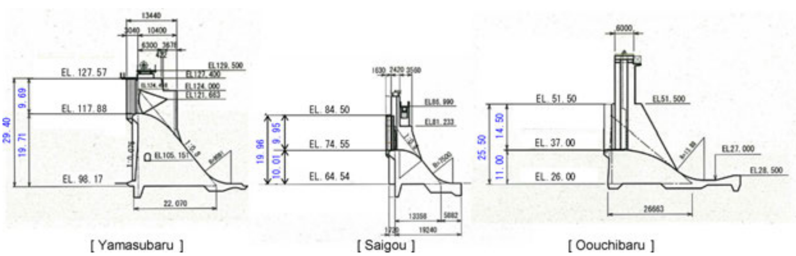


Fig. 2
Cross sections of 3 dams
Vues en coupe longitudinales des 3 barrages

in times of river flooding. The available depths shown in Fig. 2 are the ranges of normal water level fluctuations.

To reduce dam water levels at times of river flooding below the levels up to now, for these dams which have no discharge facilities in their lower sections, it was necessary to cut-down the dam bodies. For Yamasubaru Dam, the furthest upstream of the 3 dams, retrofitting work began in 2011 to cut down the overflow section in the center of the dam by approximately 9.3m, and install a single large spillway gate. Similarly, for Saigou Dam, retrofitting work to cut down the central section of the dam body by approximately 4.3m, and install 2 spillway gates was completed in 2017(Fig. 3).

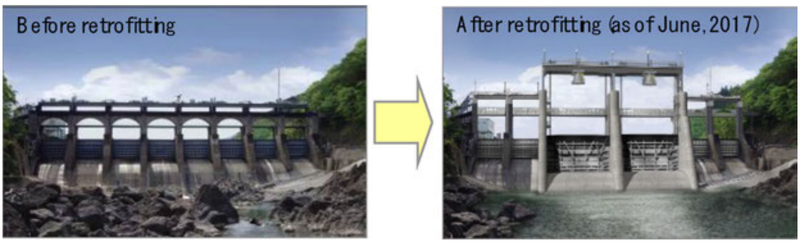


Fig. 3
Existing dam retrofitting (Saigou dam)
Remise à neuf du barrage existant (barrage Saigou)

However, for Oouchibaru Dam, the furthest downstream, the available depth is the top section (EL. 48.5m – EL. 50.0m) of, and equivalent to 12% of the water level that can be ensured by spillway gates (EL. 37.5m – EL. 50.0m). By very significantly lowering water level beyond this 1.5m, including in times of river flooding, an effect similar to cutting down the dam body can be obtained. Therefore, unlike the 2 dams further upstream, no retrofitting work is to be carried out for Oouchibaru Dam, and sluicing is done by changing only dam operation water level.

2.2. Overview of sediment sluicing at dams

In general, at the point where water flows into a dam-regulating reservoir from the upstream river channel, current speed slows, and therefore there is a tendency for the sediment that flows in with the water to settle and accumulate in the upstream area of the reservoir. The central part of Morotsuka Village, which suffered very serious damage as a result of the 2005 typhoon disaster, is located in the upstream area of the Yamasubaru dam-regulating reservoir. A very large quantity sediment from the many mountain slope failures in the upstream area that flowed into and was then deposited in the reservoir during the typhoon, raised the water level during river flooding, and this is thought to have increased the scale of damage. After river flooding had subsided, despite emergency work done to remove accumulated sediment, there was concern that inflow of sediment from failed mountain slopes would continue. For this reason, it was decided to take radical measures against accumulated sediment by allowing sediment that has entered dam-regulating reservoirs to flow downstream of dams (i.e. sluicing).

In sluicing, sediment that has flowed into dam-regulating reservoirs is allowed to flow in a downstream direction. This is done by drawing down water level in reservoirs at times of heavy inflows of sediment, which accompany river flooding caused by large-scale typhoons, thereby changing the form of reservoirs so that they come close to the state of the original natural river (Fig. 4). Through sluicing, sediment that had in the past accumulated in the area close to the upstream end of dam-regulating reservoirs will be carried toward the dam end, and then flow downstream of the dam. This has the possibility of mitigating riverbed aggregation, and thereby reducing the risk of flooding. For the Mimikawa River system, it was decided to carry out sluicing operation at the 3 dams in the midstream where great damage was caused as a result of the 2005 typhoon disaster.

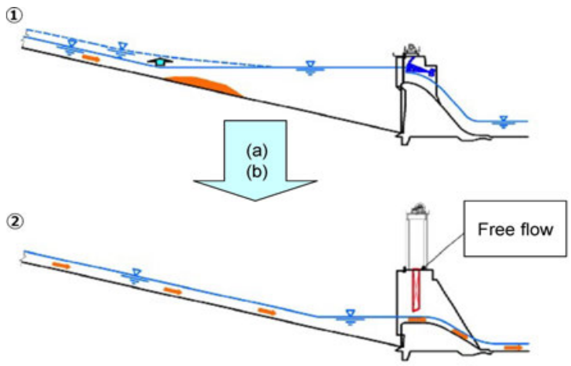


Fig. 4
Sediment sluicing– image [2]
Vidange de sédiments – image[2]

(a)	Dam modification (reservoir level reduction)	*(a)*	*Modification de barrage (niveau de réservoir abaissé)*
(b)	Sluicing of sediment (early realization of flood control + environmental measures)	*(b)*	*Vidange de sédiments (réalisation rapide des effets de nettoyage + mesures environnementales)*
①	Process of dam sediment accumulation under current operation (image)	①	*Processus d'accumulation de sédiments au barrage dans son fonctionnement actuel (image)*
②	Dam sediment sluicing management (ideal image)	②	*Gestion des vidanges de sédiments au barrage (image idéale)*

The 2005 typhoon disaster was also used as an opportunity to elucidate sediment-related problems in the river basin. In addition to the aspect of river safety, problems related to river environment and water use, such as armoring of the downstream river channel due to entrapment of sediment at dams, and difficulties in drawing water for the water supply due to lowering of the riverbed, had also become apparent. For these reasons, the river administrator Miyazaki Prefecture, had repeated discussions with stakeholders including river basin residents to resolve these problems and find methods to evaluate the results through stakeholder coordination. And as a result, compiled the Mimikawa River System Integrated Sediment Flow Management Plan. As one of the core action plans of the sediment flow management plan, the necessity of implementing sluicing at the 3 dams was acknowledged by stakeholders including river basin residents.

2.3. CHANGES IN SEDIMENT DYNAMICS WITH SEDIMENT SLUICING AT DAMS

To understand riverbed variation over the entire river channel on the premise of the above-mentioned effects of sluicing, a one-dimensional simulation of riverbed variation was carried out for the approximately 58km stretch of the main river between the upstream extremity of the Yamasubaru dam-regulating reservoir and the river mouth, covering the 3 dams where sluicing was to be implemented. Table 2 shows study conditions for one-dimensional analysis of riverbed variation over 33 years from 2009 in the approximately 58km stretch of river from the Yamasubaru Dam upstream to the river mouth. Fig. 5 shows a comparison of riverbed height between the case of conventional dam operation and the case of sluicing for Yamasubaru Dam for the 33-year period. Fig. 6 shows the results of calculation of average annual sediment inflow and outflow over the 58km stretch of river for the sluicing case.

Table 2
Investigation conditions

Investigation conditions			Yamasubaru Dam upstream	Saigou Dam upstream	Oouchibaru Dam upstream	Oouchibaru Dam downstream river
Initial riverbed conditions			Riverbed survey after Typhoon 0514			
River flow rate conditions			Actual flow rates at each dam 1994-2004			
Post-calculation conditions			Calculation until dam-regulating reservoir riverbed stabilization confirmed			
Sediment inflow conditions	First 10 years ($m^3/km^2/year$)		1,092	1,056	791	791
	From year 11 ($m^3/km^2/year$)		606	742	521	521
Water level conditions	Case1	Existing operation case	Reflects dam operation results			
	Case2	Sluicing of sediment case	Using actual flow rates, while flow rate at each dam exceeds $200m^3/s$, calculate water level during sluicing of sediment (all gates free flow)			

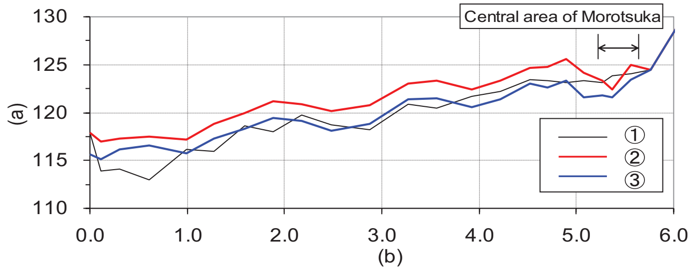


Fig. 5
Results of riverbed fluctuation analysis (Yamasubaru dam)
Résultats des analyses au niveau du lit de fleuve

(a) Elevation (EL.m)
(b) Distance from dam (km)
① Initial elevation of riverbed
② Case1 : Riverbed under continued existing operation
③ Case2 : Riverbed under sluicing of sediment

(a) Hauteur (EL.m)
(b) Distance du barrage (km)
① *Hauteur initiale du lit du fleuve*
② *Cas1 : Lit du fleuve dans son fonctionnement actuel*
③ *Cas 2 : Lit du fleuve si vidange de sédiments*

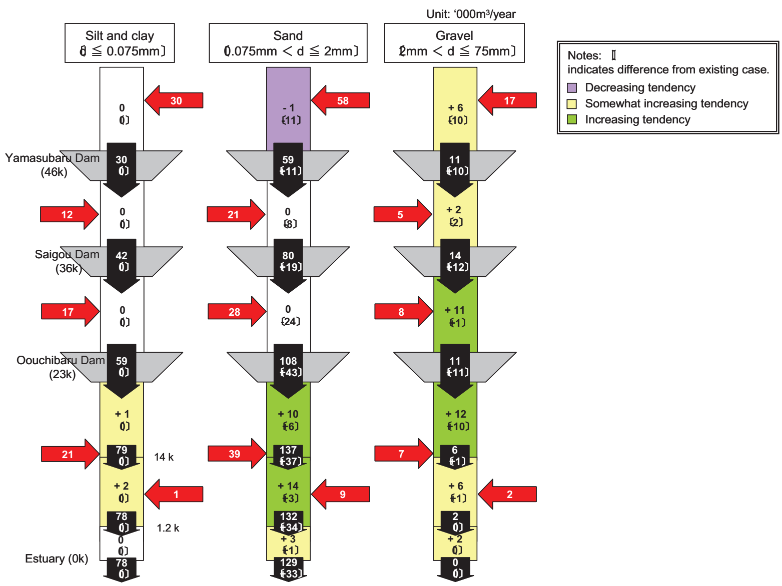


Fig. 6
Results of calculation for incoming and outgoing sediment in case 2
Résultats des calculs des sédiments entrant et sortant dans le cas 2

From the results of analysis for Oouchibaru Dam, the furthest downstream, it was understood that with sluicing gravel would pass through the dam, something that did not previously happen, and the amount of sand passing through the dam would increase by a factor of 1.7.

3. UNDERSTANDING AND ANALYSIS OF RIVER ENVIRONMENT BEFORE SEDIMENT SLUICING AT DAMS

3.1. River environment surveys Title of paper

In assessing the effect on the river environment associated with sluicing, under the basic concept of carrying out comparisons and assessments before and after the operation of sluicing, since 2007 river environment surveys have been carried out [3].

3.1.1. Basic concepts of surveys

To understand the change in the river environment resulting from sluicing, it is necessary to set impact-response for sluicing, and to establish survey methods that will make accurate assessment possible. Table 3 shows assumed responses of the physical environment and habitat with the impact of increased amounts of sand and gravel passing through dams in the river. Impact was set based on computed change in sediment dynamics resulting from calculated sluicing derived from one-dimensional riverbed variation calculations. Response was set based on results of sluicing confirmed at other sites in Japan and opinions of people in the fishery industry.

As shown in Fig. 7, assessment of environmental effect will be carried out through a combination of the viewpoint of before and after sluicing, and the viewpoint of presence or absence of effect due to sluicing. The differences in data between before and after sluicing in the zone impacted will be a mix of changes associated with sluicing and changes in nature itself. Therefore, if changes in nature are not understood, it will not be possible to understand changes associated with sluicing. For this reason, after understanding changes in nature in control zones not affected by sluicing, the effect due to sluicing will be understood by assessing the difference between the control and impact zones.

3.1.2. Survey points

Fig.8 shows an overview of survey points. Survey points were set “upstream and downstream of dams where sluicing was to be carried out” and “before and

Table 3
Assumed impact-response

Impact: Sluicing (increased passage of sand and gravel through dams)

Assumed response to sluicing

Physical environment	Water quality	Normal times	No change
		Times of river flooding	Increase in quantity of sand in SS concentration, no change in fine grain sediment for silt and finer particles
	Riverbed materials		Increased proportion of sand and gravel downstream of dams No change in chemical properties
	River channel form		Development of sand bars downstream of dams, change in distribution of shallows and pools
Habitat	Fauna	Fish	Increase in species that prefer sand and gravel environments
		Plecoglossus altivelis spawning beds	Increase of shallows preferred by *Plecoglossus altivelis* (gentle shallows with mainly fine to medium gravel)
		Benthos	Increase in species that prefer sand and gravel environments Decrease in species that prefer stable environments (snarers, etc.)
	Flora	Attached algae	Accelerated detachment, thick new growth
		River bank vegetation	Changes in distribution of plant communities associated with changes in river channel form

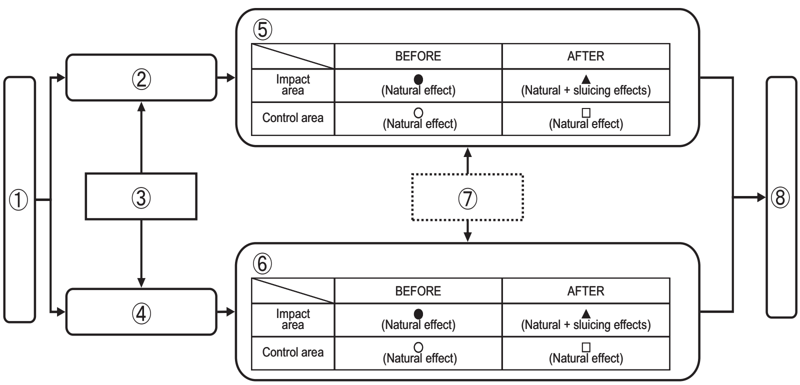


Fig. 7
Image of environmental impact survey
Image de sondage de l’impact environnemental

① Implementation of sluicing of sediment at dams
② Check changes in physical environment
③ Environmental monitoring data (2016—)
④ Check changes in wild-life habitat environment

① *Mise en oeuvre de vidange de sédiments aux barrages*
② *Vérifier les changements dans l’environnement physique*
③ *Données de suivi environnemental (2016 -)*
④ *Vérifier les changements d’habitat des espèces sauvages*

⑤ Assess changes in physical environment before and after sluicing (understand natural and sluicing effects)	⑤ *Évaluer les changements dans l'environnement physique avant et après la vidange (identifier des effets naturels et ceux dus à la vidange)*
⑥ Assess changes in wildlife habitat environ. before and after sluicing (understand natural and sluicing effects)	⑥ *Évaluer les changements d'habitat des espèces sauvages avant et après la vidange (identifier des effets naturels et ceux dus à la vidange)*
⑦ Environmental Monitoring (2007—2015)	⑦ *Surveillance environnementale (2007-2015)*
⑧ Assessment of effect and impact of sluicing	⑧ *Évaluation des effets et de l'impact de la vidange*

after convergences with tributaries" For the control zones which would not be affected by sluicing, the following were chosen: (1) Ego-no-saki survey point, located in the river channel upstream of the extremity of the Yamasubaru dam-regulating reservoir, together with (14) Nanatsu-yama River survey point, and (15) Tsuboya River survey point, which even though located in tributaries have similar river basin and channel characteristics to the main river.

3.1.3. Survey details

Table 4 shows river environment survey items and details. The items in this table are items needed to understand the impact-response determined in Table 3. For each item, frequency, survey point and survey particulars were set.

Over the course of surveys conducted between 2007 and 2011, the relationship between physical environment and bioenvironment of the Mimikawa River under normal conditions slowly became clear. However, there was insufficient data to understand the environmental state at times of river flooding, when sluicing would be carried out. For this reason, from 2012 survey content for times of river flooding was increased and enhanced.

3.2. Assessment of environmental state

3.2.1. Physical environment

In predicting the effect on the river environment due to sluicing, based on the results of monitoring surveys in the period 2007– 2014, information on the state of the physical environment in the Mimikawa River was organized. Because the area that will be affected by sluicing is large, when organizing information, the area was divided into 11 sections (Fig. 9). Points at which for example riverbed

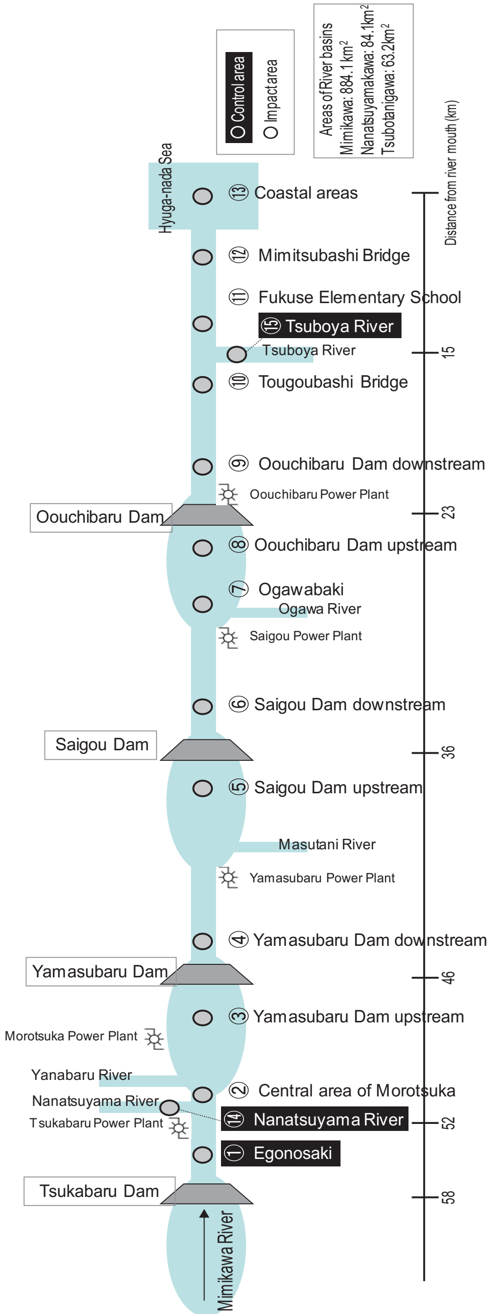


Fig. 8
Survey points for environmental assessment
Points de sondage pour estimation de l'environnement

Table 4
Examples of survey items (river areas)

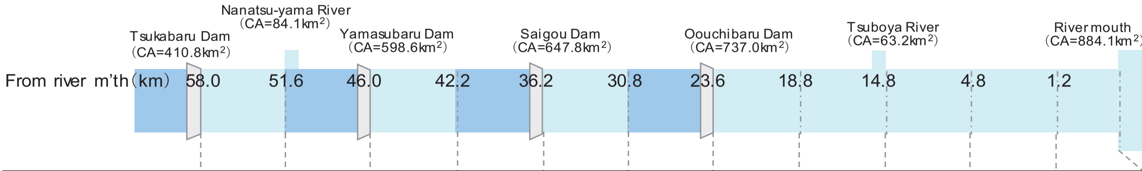
Item			Timing		Survey details (2012—2016)		
			Periodical	River flooding	Frequency	Survey area	Survey item
Physical environment	Water quality		○	—	1 time / 2 months	All areas	·Site measurement ·Analysis
			—	○	1 time / river flooding	All areas	·Site measurement ·Analysis
	Riverbed materials		○	—	1 time / year (Feb)	All areas	·Particle size distribution ·Riverbed material survey
			—	○	1 time / after river flooding	All areas	·Particle size distribution ·Riverbed material survey ·Chemical analysis
	River channel form		○	—	1 time / year (Nov)	Recession areas	·Segment classification ·Riffle-pool distribution
Wildlife habitat environment	Animal	Fish	○	—	2 times / 2 years (Jul, Oct) 2013, 2015	All areas	·Species composition ·Biomass ·Distribution
		Plecoglossus altivelis spawning beds	○	—	1 time / year (Nov)	Tsuboya river confluence down-stream	·Spawning bed distribution ·Spawning (yes/no) ·Physical environ. of shallows
		Benthos	○	—	2 times / 2 years 2013, 2015 1 time / 2 years 2012, 2014	All areas	·Species composition ·Biomass ·Distribution
	Plant	Attached algae	○	—	(FY2009—2011 survey details)		
			—	○	2 times / after river flooding	All areas	·Species composition ·Biomass ·Chlorophyll a
		Bank vegetation	○	—	1 time / 5 years 2013	Oouchibaru Dam down-stream	·Distribution

slope changes and tributaries merge with the main river were used as boundaries for these sections. In addition, the characteristics of sediment dynamics, riverbed form and riverbed grain size were ascertained for each section.

For sediment dynamics, the results of riverbed variation calculations were analyzed based on the results of yearly depth sounding carried out to ascertain the amount of sedimentation at dams. For riverbed form, by extracting sandbar area from past aerial photographs, change over time was analyzed. For riverbed grain size, the results of planar riverbed composition material surveys and other data were analyzed for all sections. Table 5 shows the physical characteristics of sections except for dam-regulating reservoir sections.

3.2.2. Habitat

As a result of surveys, 60 species of fish and 509 species of benthos were identified in the area of the Mimikawa River that will be affected by sluicing. These species can be broadly classified into those identified as inhabiting all parts of the river basin, and those identified as inhabiting limited parts, depending on river channel environment. In particular, in parts of the river channel downstream of dams, where coarsening and armoring have progressed, habitation by *Pseudogobio esocinus* (fish) and *Glossosoma* sp. (benthos) which prefer a sand and gravel environment, could not be confirmed. From this it was understood that river channel biodiversity has been undermined.



Section			No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11
Section length (km)			6.4	5.6	3.8	6.0	5.4	7.2	4.8	4.0	10.0	3.6	1.2
River/reservoir			River	Reserv.	River	Reserv.	River	Reserv.	River				
Riverbed gradient			1/130	1/400	1/200	1/500	1/330	1/600	1/540	1/380	1/330	1/670	1/260
Characteristics	Sediment dynamics (entrap't of sand/gravel)		~	Sand 12% Gravel 100%	~	Sand 8% Gravel 86%	~	Sand 23% Gravel 100%	~	~	~ Feed of sediment from tributary Tsuboya River	~	~
	River channel form	Sand bar area	—	—	Main-tenance	—	De-crease	—	De-crease	De-crease →Main-tenance	De-crease →Main-tenance	—	—
		No. of sh'ws	38	—	24	—	22	—	11	11	29	3	—
		No. of pools	25	—	10	—	5	—	2	2	13	1	—
	River bed grain size		Mainly stone	Immed. upstr'm of dam med. sand	Mainly stone	Immed. upstr'm of dam med. sand–cse grvl.	Sand and gravel	Immed. upstr'm of dam silt–fine sand	Mainly stone	Gravel and stone	Gravel and sand	Gravel and sand	Gravel and sand

Fig. 9
State of Mimikawa river physical environment
État de l'environnement physique de la rivière Mimikawa

Table 5
Characteristics of physical environment of river channel sections

Section 3 Yamasubaru Dam downstream	• Riverbed gradient is steep (1/200), with no change in sand bar area over time, therefore river has ample power to feed sediment downstream
Section 5 Saigou Dam downstream	• Sand bar area has reduced over time, but in recent years there has been deposition of sand and gravel • Proportion of inflowing sand passes through dam
Sections 7-11 Oouchibaru Dam downstream	• Decrease of sand bar area over time; riverbed material is mainly stone • In sections after confluence with tributary (Tsuboya River) , sand and gravel is distributed

3.2.3. Relationship between physical environment and habitat

To make predictions about the effect on life forms using predicted changes in the physical environment, a model that quantitively connects the physical environment and life forms (fish) was created [4].

Using results of monitoring surveys up to 2014, fish with a high dependence on riverbed materials were extracted using statistical analysis methods such as cluster analysis and seriation. As a sandy environment dependent species, *Pseudogobio esocinus*, and as a stony environment dependent species, *Sicyopterus japonicus* were extracted. Therefore, as a prediction of the effect on life forms, the effect of feeding of sand and gravel through sluicing on these two species was assessed.

Fig.10 shows models for the predicted appearance of *Pseudogobio esocinus* and *Sicyopterus japonicus*. These apply generalized linear models. For *Pseudogobio esocinus*, a model that can be explained by only the percentage of sand was employed, and for *Sicyopterus japonicus*, a model that can be explained by average speed of current and percentage of stone was employed.

4. PREDICTIONS OF ENVIRONMENTAL CHANGES DUE TO SLUICING

4.1. Predictions of changes in physical environment

For each of the 11 sections, the change due to sluicing was predicted from one-dimensional riverbed variation calculations (Fig. 11). Concerning calculation

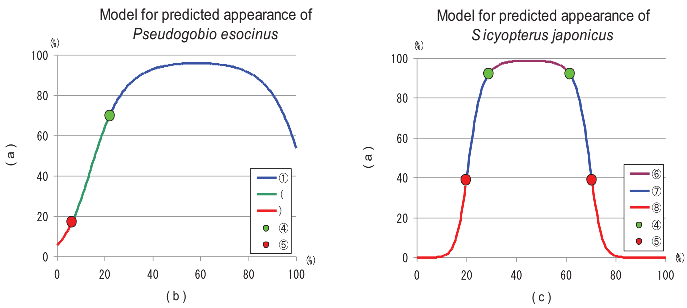


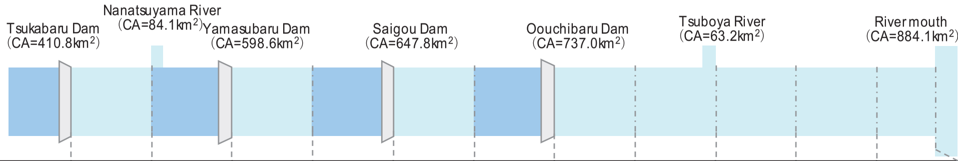
Fig. 10
Habitat preference curve
Courbe de préférence d'habitat

①	Present with high probability	①	*Présent avec forte probabilité*
②	Possibility of presence	②	*Présent possible*
③	Absent with high probability	③	*Absent avec forte probabilité*
④	Upper threshold	④	*Seuil supérieur*
⑤	Lower threshold	⑤	*Seuil inférieur*
⑥	Present with high extremely probability	⑥	*Présent avec probabilité extrêmement forte*
⑦	Present with high probability	⑦	*Présent avec forte probabilité*
⑧	Absent with high probability	⑧	*Absent avec forte probabilité*
(a)	Predictive probability	*(a)*	*Probabilité prédictive*
(b)	Sand content (%)	*(b)*	*Teneur en sable (%)*
(c)	Gravel content (%)	*(c)*	*Teneur en gravier (%)*

conditions, for both operation of dams without sluicing and with sluicing, assessment was carried out from the points of view of sediment dynamics, riverbed form and riverbed grain size over a medium- to long-term time frame. Specifically, it was assumed that the historical pattern of river flooding for the 11 years from 1994 to 2004, known from flood records, would be repeated 3 times in the 33 years from 2009, and predictions were made in terms of what changes would occur in which section. Table 6 shows the characteristics of predictions of medium- to long-term changes due to sluicing.

From the results of predictions of riverbed variation, the river channel downstream of Saigou Dam and the section immediately below Oouchibaru Dam were set as sections for priority assessment, where the effect of sluicing would be very significant.

With the objective of making a detailed prediction of physical environmental changes, such as for the distribution of shallows and pools in curved sections of the riverbed, a planar two-dimensional riverbed variation calculation



Section		No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11
Prediction of sediment dynamics		—	Passage of sand and gravel will increase	Almost total amount will pass	Passage of sand and gravel will increase	Sand and gravel will be deposited (moderate change)	Passage of sand and gravel will increase	Sand and gravel will be deposited (very significant change)	Sand and gravel will be deposited (moderate change)	Deposition of sand will increase slightly		
Cumulative 33-year sediment quantity totals for inflow and outflow ('000m³)	Silt and finer – Inflow	5	833	23	353	4	501	14	21	699	4	0
	Silt and finer – Deposit.	1 (0)	3 (▲4)	3 (+1)	2 (▲4)	3 (0)	8 (▲25)	6 (+3)	10 (+1)	32 (+2)	14 (+1)	10 (0)
	Silt and finer – Passage	4 (0)	835 (+4)	854 (+3)	1205 (+7)	1206 (+7)	1700 (+33)	1708 (+30)	1719 (+29)	2386 (+26)	2376 (+25)	2366 (+25)
Inflow / Deposit. / Passage	Sand – Inflow	34	1613	75	551	50	775	103	73	1347	52	0
	Sand – Deposit.	0 (0)	▲24 (▲195)	▲3 (0)	4 (▲166)	▲1 (+8)	75 (▲386)	64 (+65)	112 (+54)	339 (+104)	100 (+32)	75 (+17)
	Sand – Passage	34 (0)	1672 (+195)	1750 (+195)	2297 (+362)	2347 (+354)	3047 (+740)	3086 (+675)	3047 (+621)	4056 (+517)	4008 (+485)	3933 (+468)
( ) difference between operation with and w/o sluicing	Gravel – Inflow	77	398	57	89	46	182	59	14	196	36	0
▲ negative quantities	Gravel – Deposit.	9 (0)	202 (▲232)	0 (0)	33 (▲120)	23 (+46)	329 (+89)	239 (+200)	29 (+22)	238 (▲6)	▲25 (▲1)	75 (+1)
	Gravel – Passage	68 (0)	265 (+232)	321 (+232)	377 (+352)	399 (+305)	249 (+217)	72 (+16)	56 (▲6)	15 (0)	76 (+1)	2 (0)
	All grain sizes – Inflow	116	2844	154	992	100	1458	176	109	2242	92	0
	All grain sizes – Deposit.	10 (0)	180 (▲431)	0 (0)	39 (▲290)	26 (+53)	413 (▲322)	309 (+268)	150 (+77)	608 (+100)	89 (+32)	159 (+19)
	All grain sizes – Passage	107 (0)	2771 (+430)	2925 (+430)	3879 (+720)	3952 (+666)	4998 (+989)	4865 (+720)	4824 (+644)	6457 (+544)	6461 (+512)	6301 (+493)

Fig. 11
Prediction of sediment dynamics due to sluicing
Prédiction de la dynamique sédimentaire en raison de la vidange

Table 6
Predictions of changes to river channel sections

Section 3 Yamasubaru Dam downstream	• Inflow quantities of sand and gravel will increase, but almost all of it will pass through this section; changes in river channel form and riverbed materials will be very small
Section 5 Saigou Dam downstream	• Quantities of sand and gravel deposition will increase; sand bars will recover and the number of shallows will increase • Change in riverbed grain size will be small
Sections 7-11 Oouchibaru Dam downstream	• Quantities of sand and gravel deposition will increase immediately downstream of dam; sand bars will recover and the number of shallows will increase; grain coarsening will be resolved • In sections after confluence with tributary (Tsyboya River), changes due to sluicing will be small

model that could recreate sediment dynamics transverse to the riverbed, was created. In assessing the result of this calculation to predict riverbed variation due to one typhoon, attention was given to "sanding of river channel," "filling in of pools," and "increased silt deposition in pools." Amongst the results obtained, the effects on river channel form and riverbed grain size were the greatest in the case shown in Figs. 12 and 13 (scale of river flooding: 2,100m^3/s, recurrence interval: 5 years).

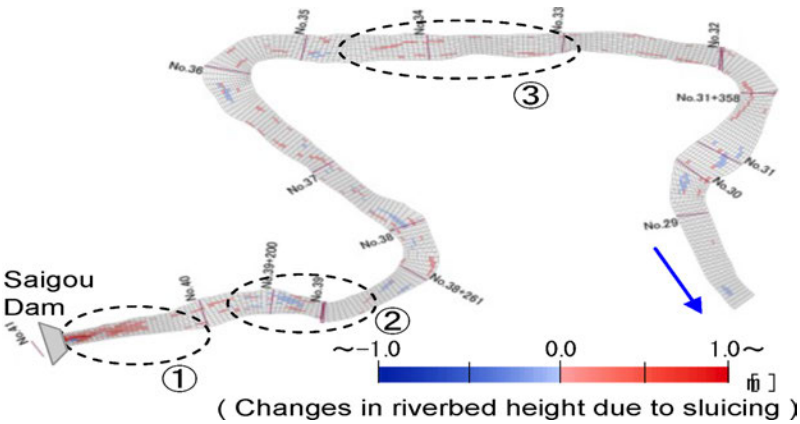
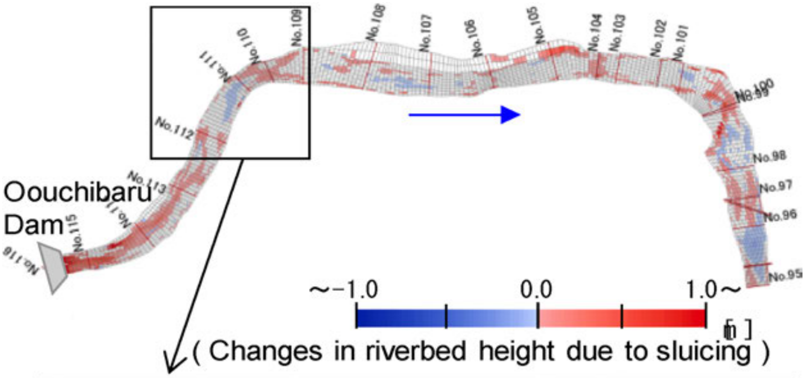


Fig. 12
Predicted changes in physical environment (Saigou Dam downstream)
Changements prévus dans l'environnement physique (aval du barrage Saigou)

① Rising of riverbed due to gravel deposition
② Filling in of pools and increased silt deposition in pools not evident
③ Sand deposited by river bank

① *Élévation du lit de fleuve en raison du dépôt de gravier*
② *Remplissage des mouilles et dépôt de limon croissant dans les mouilles ne sont pas évidents*
③ *Amoncellement de sable dans le bord de rivière*



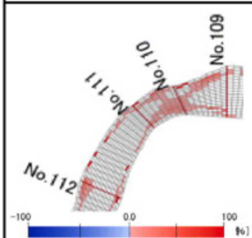
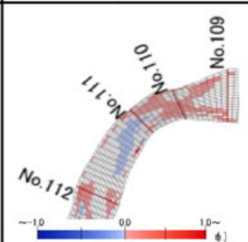
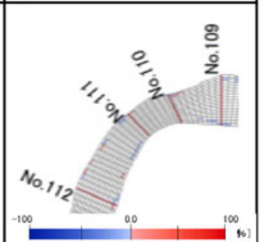
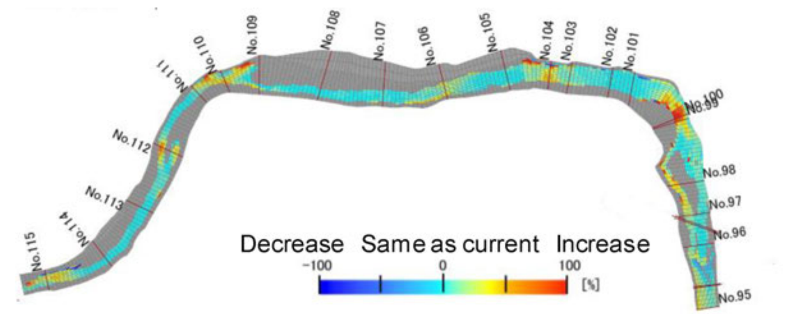
Sanding of river channel	Filling in of pools	Increased silt deposition in pools
 Variation in riverbed grain size due to sluicing	 Changes in amounts of sand due to sluicing	 Variation in riverbed grain size due to sluicing
Sand deposited by river bank, but it is considered that possibility of sand deposition over entire river channel is low.	Pools shows tendency to deposition, but it is considered that possibility of filling in is low.	It is considered that silt deposition in pools is not evident.

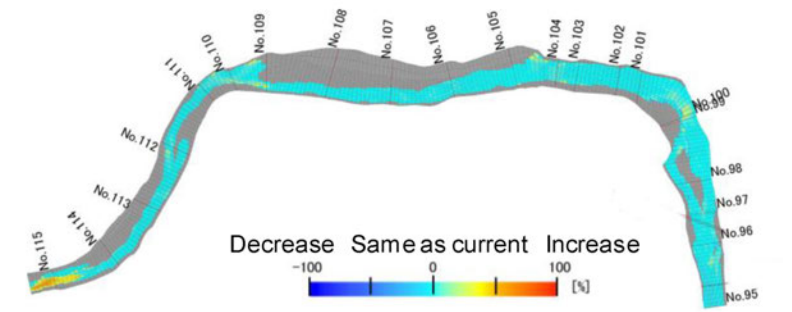
Fig. 13
Predicted changes in physical environment (Oouchibaru Dam downstream)
Changements prévus dans l'environnement physique (aval du barrage Oouchibaru)

4.2. PREDICTIONS OF CHANGES TO HABITAT

By applying the model used to predict the appearance of life forms in 3.2, and superimposing predictions of changes in the physical environment, the effect on life forms was predicted. Fig. 14 shows differences in the predictive probability of the appearance life forms between the case of sluicing and the case of no sluicing at dams. The result of prediction showed spot increases for predictive probability of the appearance of *Pseudogobio esocinus* through increases in sand



(Changes in predictive probability for appearance of *Pseudogobio esocinus*)



(Changes in predictive probability for appearance of *Sicyopterus japonicus*)

Fig. 14
Predictions of changes to habitat (Oouchibaru Dam downstream)
Prédictions des changements d'habitat (aval du barrage Oouchibaru)

as a result of sluicing. On the other hand, predictive probability for the appearance of *Sicyopterus japonicus*, principally immediately downstream of dams, increased only slightly, and overall, the effect of sluicing was not negative. From these results, through sluicing, it is predicted that river environment will change to one in which the many life forms that prefer sand and stone can coexist.

4.3. TESTING OF PREDICTION

In preparation for sluicing, retrofitting work on Saigou Dam involving cutting down part of the existing dam body was carried out. During the period of this work, a temporary gate was installed, and low water level operation of the gate was carried out until the end of periods of river flooding. Because of this operation, in the river channel downstream of the dam, a tendency similar to predictions for the impact of sluicing was apparent. Operations using the temporary gate commenced in 2013 (Fig. 15).

Through operation in 2013, approximately 63,000m^3 of sediment from Saigou dam-regulating reservoir passed through the dam. This was understood from the results of sounding in the reservoir, and of calculated riverbed variation. Comparing with 2012 when there was a similar scale of river flooding, in 2013 there was a very significant increase in the passage of sediment, especially for gravel (Table 7).

Fig. 15
Overview of operation using temporary gate
Aperçu de l'opération avec la barrière provisoire

Table 7
Passage of sediment through Saigou Dam

		2012 (w/o sluicig)	2013 (with temp. gate)
All Grain Size		40.6	62.6
	Silt/Clay	20.8	20.0
	Sand	19.1	19.7
	Gravel	0.7	22.9

(estimates based on sounding and calculated riverbed variation)

4.3.1. Changes in physical environment

Immediately downstream of Saigou Dam, he presence of gravel that had passed through the dam was confirmed, and at the downstream monitoring point, the area of sand bar had increased (Fig. 16). Furthermore, it was confirmed that the number of shallows had increased, and that sand had been deposited at the edge of the river by the river bank at the downstream monitoring point.

4.3.2. Changes in habitat

Changes to attached algae, benthos and fish were also confirmed at the same monitoring point (Table 8). For attached algae, detachment and renewal due

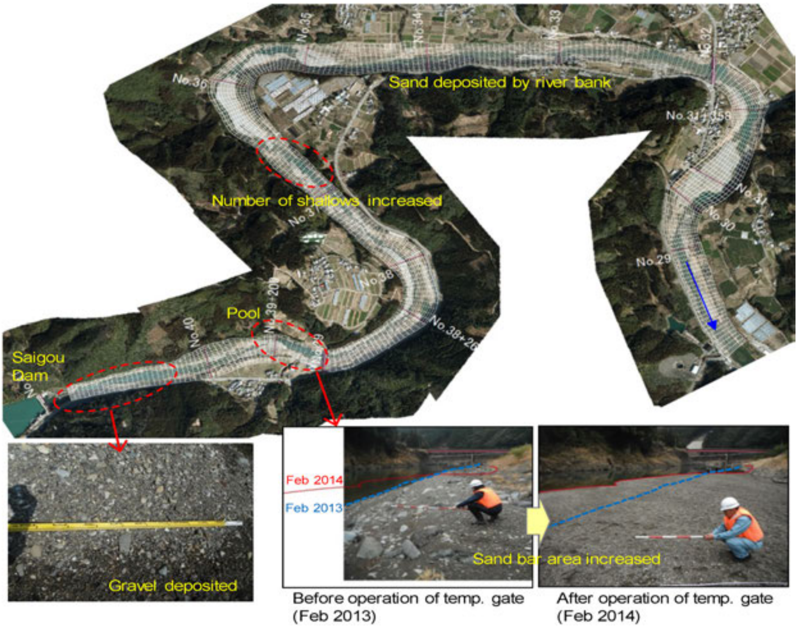


Fig. 16
Changes in physical environment (Saigou Dam downstream)
Changements dans l'environnement physique (aval du barrage Saigou)

Table 8
Changes in habitat (Saigou Dam downstream)

[legend: smallest – average – largest value]

Item		Period		Data
Attached algae	No. of cells appearing ('0,000 cells/cm^2)	2007-2011 (regular surveys)		0.6-263-987
		2013	9 days after riv. flood	18
			23 days after riv. flood	385
Benthos	*Glossosoma sp.* habitat density (organisms/m^3)	2007-2012 winter		16-213-413
		2013 winter		651
	Diversity index (Shannon-Wiener H')	2007-2012		2.74-3.78-4.84
		2013		3.29
Fish	*Pseudogobio esocinus* caught (no. of organisms)	2007-2011		37-49-79
		2013		89
	Diversity index (Shannon-Wiener H')	2007-2011		1.93-2.39-2.81
		2013		2.35

to flooding was confirmed. For benthos, the number of *Glossosoma* sp., which prefers a sand and gravel environment, was larger than for any previous survey. For fish, the number of *Pseudogobio esocinus*, which prefers a sand environment, was also larger than for any previous survey. However, while life forms preferring sand as well as sand and gravel environments responded, on calculating a diversity index for life forms, it was found to be within the range of fluctuation of previous results, and it was considered that for life forms overall the impact of the passage of sediment was not large.

4.3.3. Results of testing

In the section where passage of sediment occurred in a way similar to actual sluicing, it was confirmed that for the physical environment such as river channel and riverbed materials as well as habitat, there was environmental change similar to that predicted to occur after sluicing.

5. CONCLUSION

Based on the results of calculations of riverbed variation and the results of extensive surveys, this paper provides quantitative predictions of environmental impact of sediment sluicing at dams in the Mimikawa River from the viewpoints of the physical environment (impact) and associated habitat (response). The main conclusions are as follows.

1) As a result of one-dimensional riverbed variation calculations, the effect of sluicing will be to feed sand and especially gravel, which until now have been trapped at dams, widely downstream of dams.

2) For life forms for which the physical environment is a dominant condition for feeding and egg-laying, a model that incorporates a significant connection between physical environment and such life forms was able to account for their appearance.

3) Quantitative prediction of the appearance of life forms through prediction of physical environment, while difficult, is possible. Furthermore, even in cases where due to weather and other conditions appearance of life forms cannot be confirmed, it is possible to make an assessment as to whether a physical environment is habitable.

4) Environmental change due to sediment sluicing at dams is expected to show tendencies similar to predictions of results made in this research.

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