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Advantages of the Open Levee (Kasumi-Tei), a Traditional Japanese River Technology on the Matsuura River, from an Ecosystem-Based Disaster Risk Reduction Perspective

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Abstract: Large-scale disasters, such as hurricanes, cyclones, tsunamis, and forest fires, have caused considerable damage in recent years. This study investigated two case studies of discontinuous open levees (kasumi-tei), which are a traditional Japanese river technology, on the Matsuura River at the sites of Okawano and Azame-no-se, and evaluated the advantages of these levees from the perspective of ecosystem-based disaster risk reduction (Eco-DRR). These case studies were conducted through literature surveys, flood observations, and oral interviews. The systems in both the cases were flood control systems utilizing ecosystem services. The traditional river technology (the flood plain open levee) served as an effective Eco-DRR in both cases. Additionally, the flood plain levee technology enhanced the ecosystem services at both sites, including not only flood control capabilities, but also other ecosystem services. Furthermore, the open levees offered substantial cost advantages over their alternatives. These results suggest that other traditional Japanese river technologies may also be effective in strengthening Eco-DRR.

Keywords: open levee; kasumi-tei; ecosystem-based disaster risk reduction; disaster risk reduction; flood control; traditional river technology; disaster resilience; Matsuura River

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1. Introduction

In recent years, numerous disasters, such as hurricanes, cyclones, tsunamis, and forest fires, have caused tremendous amounts of damage, the scale of which is usually witnessed once in several hundred years [1–3]. In this context, there have been active discussions on global frameworks for disaster prevention and mitigation, with particular attention being paid to comprehensive approaches based on novel concepts. The idea of managing ecosystems to reduce risks and vulnerabilities gained prominence as part of the Hyogo Framework for Action (HFA) at the second UN Conference on Disaster Reduction held in Kobe, Japan in 2005 and with the launch of the Partnership for Environment and Disaster Risk Reduction (PEDRR) in 2008. Subsequently, the concept and methodology known as "ecosystem-based disaster risk reduction" (hereinafter "Eco-DRR") has steadily gained popularity as a global disaster prevention framework, most recently as the focus of the Sendai Framework at the fifth UN Conference on Disaster Risk Reduction in 2015 [4]. Eco-DRR involves mitigating disasters, which are a barrier to sustainable development, through ecosystem management.

Furuta et al. suggested that some of Japan's traditional river technologies function as Eco-DRRs [5]. In addition, Japan's Ministry of the Environment has identified traditional Japanese river technologies as examples of Eco-DRR [6]. Studies on traditional knowledge and techniques against disasters can be found in countries around the world, based on the type of disaster and regional characteristics [7–11]. In Japan, the historical literature features a wide range of case studies on traditional river technologies [12–17]. However, except for the aforementioned paper by Furuta et al., no studies have addressed Eco-DRR and traditional knowledge and technologies [18–22]. In particular, no studies have evaluated specific examples of traditional Japanese river technology from the viewpoint of Eco-DRR.

Despite having reached an advanced stage of development, Japan has a wealth of traditional knowledge and technologies that continue to function effectively and play a role even in the modern world. Japan's traditional knowledge and technologies, including its traditional river technologies, are sustainable, diverse, and flexible. Considering the advantages and functionality of traditional river technologies from the perspective of Eco-DRR, we hope to contribute to the global development of Eco-DRR and social sustainability.

This study examines the discontinuous open levees (kasumi-tei) constructed along the Matsuura River, which are a traditional Japanese river technology. Specifically, we aim to:

1. Elucidate the mechanism of the open levees on the Matsuura River;
2. Elucidate the flood control effects of the open levees;
3. Elucidate the ecosystem services of the open levees other than flood control.

2. Scope and Method

2.1. Research Sites

This study covers two locations on the Matsuura River: Okawano and Azame-no-se.

The Matsuura River is located in the northern part of Kyushu, the southernmost of the four main islands of Japan. Karatsu, the largest city in the river's basin, lies in the estuary where the river meets the sea. However, the upstream areas are mostly farmlands and mountains. Here, there has been little development, and traditional flood control methods remain in use (Table 1).

The first research site, Okawano, located 25 km from the estuary, has an ancient open levee that is still functional. The second research site, Azame-no-se, located 15.6 km from the estuary, uses an open levee to maintain its wetlands, which were excavated in 2005 (Figure 1, Tables 2 and 3).

The Matsuura River flows through the cities of Karatsu, Imari, and Takeo in the Saga prefecture in the northern part of Kyushu. It is designated as a class 1 river and is managed by the national government. The drainage area is 446 km^2 and the length of the main river channel is 47 km. Most of the basin is occupied by mountainous areas close to gentle hills. There are a few open fields but the slope of the river is nevertheless relatively gentle, with much of the river flowing slowly through valley bottom plains among the mountains [23].

The Matsuura River basin features numerous ancient burial mounds and settlements dating back more than 2000 years. At present, urbanization has not progressed outside the estuary, and modernization has not significantly altered the terrain or the forms of rural settlement. Azame-no-se is a wetland created in recent years as part of a nature restoration project. We selected it as a research site because it serves the purpose of this study, namely elucidating the flood control and ecosystem services of the river's open levees.

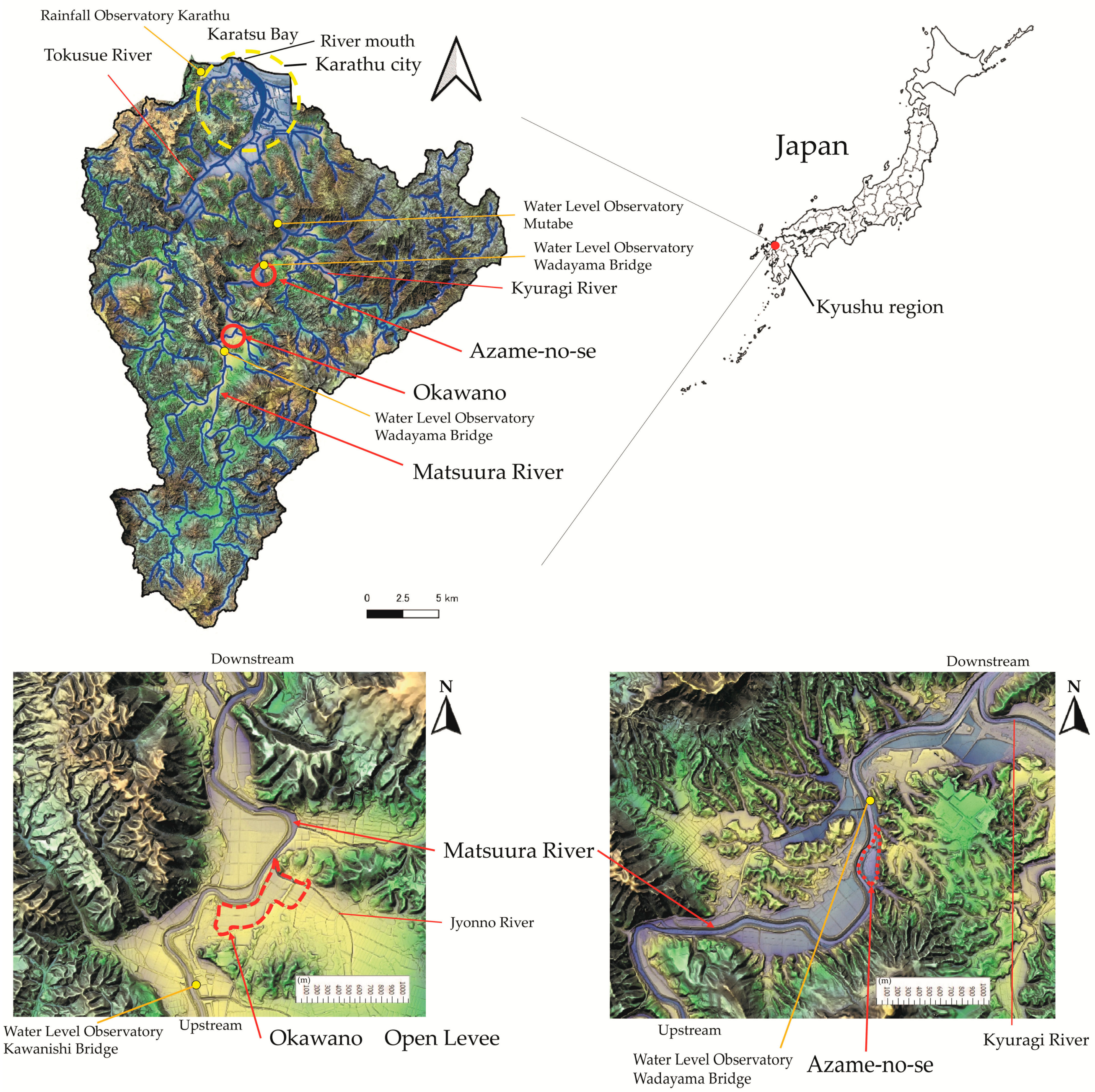

Figure 1. Matsuura River basin and research sites (Okawano and Azame-no-se) [24].

Table 1. Matsuura River's elements and flow regime [23,25,26].

Matsuura River			**Flow Regime**		
Length of mainstream	47	km	Name of station	Mutabe	
Drainage area	446	km^2	Max flow	1791.66	m^3/sec
Yearly averaged rainfall	2100	mm	185 days (50%) flow	5.53	m^3/sec
Population in the watershed	About 100,000	people	355 days (97%) flow	2.08	m^3/sec
Land use			Yearly averaged discharge	12.46	m^3/sec

Table 1. *Cont.*

Matsuura River			Flow Regime		
Mountain and Forest	84	%	Basic flood discharge	3800	m^3/sec
Farmland	15	%	Average river bed slope		
Urban area	1	%	Downstream area	1/3100	
			Midstream area	1/1100	
			Upstream area	1/350	

Table 2. Research sites elements [23,25].

Name of Station	Mutabe		Wadayama Bridge		Kawanishi Bridge	
Site	Downstream of the Matsuura River		Downstream of Azame-no-se		Upstream of Okawano area	
Start (year)	1961		1958		1958	
Distance from estuary	11.85	km	15.05	km	25.2	km
Catchment area	275	km^2	150	km^2	120	km^2
Design water level (T.P.)	8.59	m	11.4	m	21.86	m
Design flood discharge	2400	m^3/s	1500	m^3/s	1300	m^3/s

Table 3. Water Level Observatory [27].

	Open Levees in Okawano		Azame-no-se	
Distance from estuary	25	km	15.6	km
Catchment area	127	km^2	146	km^2
Bed slope	1/600		1/2700	
Slope in the open levee	1/536			
Area	0.16	km^2	0.06	km^2
Water storage capacity	378,203.0	m^3	341,584.7	m^3
Name of the branch river	Jyonno River			
Catchment area	4.3	km^2		

2.2. Method

2.2.1. Literature Survey

We gathered local materials, public administrative materials, old topographic maps, and aerial photographs to survey ecosystem services, flood control functions, the background and history of the traditional river technology. A list of the materials is shown in the Table 4.

The historical materials in 1–4 were used to understand the history of the region and open levees. The aerial photographs and maps in 10–12 were used to identify the old topography of the Okawano area and the Azame-no-se. Administrative documents No. 8 was used to confirm the scale of the heavy rainfall. Reports and papers No. 5, 9, 13–20 were used to corroborate the natural environment of the Azame-no-se. Reports and papers No. 6, 7 were used to evaluate the flood control function.

2.2.2. Flood Observations

We installed a water level gauge (HOBO CO-U20L-01) each at Okawano and Azame-no-se to observe the water level from July to November 2019, and we installed a camera at Azame-no-se for the purpose of time-lapse photography.

We also conducted a flood line survey of the flood disaster that occurred on 27 and 28 August 2019. In the Okawano district, we measured the location and height of the flood lines on 29 August and 5 September using the Real Time Kinematic Global Navigation Satellite System (RTK-GNSS: Trimble R4 GPS VRS Bundle (N9LC)).

Table 4. A list of the materials.

No	Title	Class	Source/Publisher	Issue Date	References No
1	Okawa Town History	Local history documents	Okawa-cho onko-chisin-kai	1978	[28]
2	Karatsu City History	Local history documents	Karatsu City	1964	[29]
3	Imari City History Early Modern and Modern Edition	Local history documents	Imari City	2007	[30]
4	Saga history middle volume	Local history documents	Saga Prefecture	1968	[31]
5	A record of Azame-no-se	Reports	Kyushu Regional Development Bureau, MLIT	2011	[32]
6	Matsuura River maintenance plan	Administrative documents	Kyushu Regional Development Bureau, MLIT	2009	[23]
7	Rokkaku River Water System "Mutanabe" retarding basin construction Project Ex-post evaluation, Explanatory material	Administrative documents	Kyushu Regional Development Bureau, MLIT	2006	[33]
8	Damage Caused by Heavy Rainfall Accompanying the Front in August 2019-15th Report	Administrative documents	Cabinet Office	2019	[34]
9	CIVIL ENGINEERING DESIGN PRIZE, JSCE, Selected Works 2017	Reports	Japan Society of Civil Engineers (JSCE)	2017	[35]
10	GSI Maps Imari (1/50000) (1945)	Maps	Geographical Survey Institute	1945	[36]
11	Aerial photograph (USA-M663-11)	Aerial photograph	Geographical Survey Institute	1947	[37]
12	Aerial photograph (CKU773-C20C-17)	Aerial photograph	Geographical Survey Institute	1977	[38]
13	A study of seed dispersal by flood flow in an artificially restored floodplain.	Full Paper	Landscape and ecological engineering 8.2	2012	[39]
14	A Study about hydraulic characteristics of unionoida under flowing water.	Full Paper	Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering) 67	2011	[40]
15	A CASE STUDY OF FLOOD DISTURBANCE IMPACT ON HABITAT OF FRESH WATER MUSSELS	Full Paper	Journal of Environmental Systems Research, Vol.43	2015	[41]
16	A case study of water quality fluctuations in an artificially restored floodplain	Full Paper	Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering) 68.4	2012	[42]
17	A Comprehensive Report of Activities and Monitoring Conducted in the Azame-no-se Floodplain Restoration Project.	Review	Wetland research 2	2012	[43]
18	Settling characteristics and the limiting factor of habitat distribution of unionoida mussels in the Matsuura River	Full Paper	Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering) 69	2013	[44]
19	EFFECTS OF FLOOD PLAIN ON MAIN CHANNEL WITH FLOOD FLOW OF THE MATSUURA RIVER	Full Paper	PROCEEDINGS OF HYDRAULIC ENGINEERING 51	2007	[45]
20	The Possibilities of 'Temporary Consent' in Collaboration toward Environmental Conservation: A Case Study of the Nature Restoration Project at Azame-no-Se	Full Paper	Journal of Environmental Sociology. Volume 16	2010	[46]
21	FUNCTIONAL EVALUATION OF OPEN LEVEES IN THE OKAWANO AREA OF THE MATSUURA RIVER	Full Paper	Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering) 76.2	2020	[47]

In Azame-no-se, we captured aerial photographs using an unmanned aerial vehicle to observe the flood status on 28 August. We also installed a stationary camera on high ground and captured time-lapse photographs.

We measured the volume of the water during the flood using an ArcGIS plug-in (surface deposition measurement), setting the range and height based on our flood line measurements.

2.2.3. Oral Interviews

On 14 June 2019, we interviewed a local archivist in the Okawano district about the region's history and experience with flood disasters. We also interviewed a farmer in the Okawano district on 28 November 2019 about his rice crop yields from the paddy fields within the range of the open levee and his experiences of flood disasters (Table 5).

Table 5. Details of the oral interview.

Subject	Local Archivist	Farmers
Method of selection	Introduction from Imari City	Introduction from a local historian
Reasons for selection	Knowledgeable about the history and local community of the Okawano area	Owner of the paddy field in the open levee
Date	21 July 2019	28 November 2019
Place	Subject's home	Subject's garden
Method	Oral Interviews	Oral Interviews
Contents	Local history, flood experience, expansion of residential areas, height of ring levees, flood control activities, function of open levees, frequency of flooding, impact on agricultural revenue, behavior at the time of flooding, fish catching, and species of living things	About the current disaster, frequency of flooding in paddy fields, amount of damage caused by flooding, impact on rice, inflow of garbage, inflow of sediment, rice disease, thoughts as a farmer, catching fish, and behavior at the time of flooding

3. Results

3.1. Open Levees in Okawano

3.1.1. Overview

In the Okawano district, which is located in the heart of the Matsuura River basin, there is a traditional flood control structure called a kasumi-tei, usually translated as "open levee". Kasumi-tei is a generic term for the traditional Japanese technology of discontinuous open levees, which fall into two categories [13].

The first category is the "alluvial fan open levee." These are mainly constructed along torrential rivers at alluvial fans or similar sites. This type of levee is constructed by densely arranging several short-length levees and its main purpose is to fix the flow channel to prevent turbulence at the alluvial fan and return the floodwaters to the river when the levees break.

The second category is "flood plain open levee" (Figure 2). This type is used for gentle rivers in plains. Under this system, the levees surround the flood plain, but are discontinuous at the downstream end to flood the flood plain deliberately during a flooding event. The main role of this kind of open levee is to accumulate organic matter on farmland during floods and gradually store the floodwaters. In this study, we focus on this second category of open levee.

The flood plain open levee at the Okawano site is situated at the confluence of the tributary (a) where the levee becomes discontinuous and opening (A) (Figure 3). The opening is located at the downstream end of the flood plain on the south side of the Matsuura River. When the water level of the Matsuura River rises because of the flood, the river water flows backward from this opening (b), flooding the paddy fields (D). As the opening is at the most downstream part of the flood plain, backflow from the downstream side slows down the flow rate. The paddy fields in the flooded area of Okawano are surrounded by a river terrace (E) and levees (B, C). The flood plain that serves as a retarding basin consists of approximately 0.16 km^2 of paddy fields. In addition, inundation due to interior runoff from the tributary (a) can be stored in this retarding basin. When the water level in the Matsuura River drops, the water drains naturally and the floodwaters recede. No pumps or special structures are required. In Japanese rivers, the flood duration is often short and the water level drops in a short period of time. Consequently, the part of the plain that serves as a retarding basin is immersed in water for a very short duration. The retarding basin is normally used as a rice paddy field. Area A has a bamboo forest, which dissipates energy and captures debris during the influx of floodwater. This is commonly referred to as a flood-restraining forest belt. There is another open levee (F) on the opposite bank.

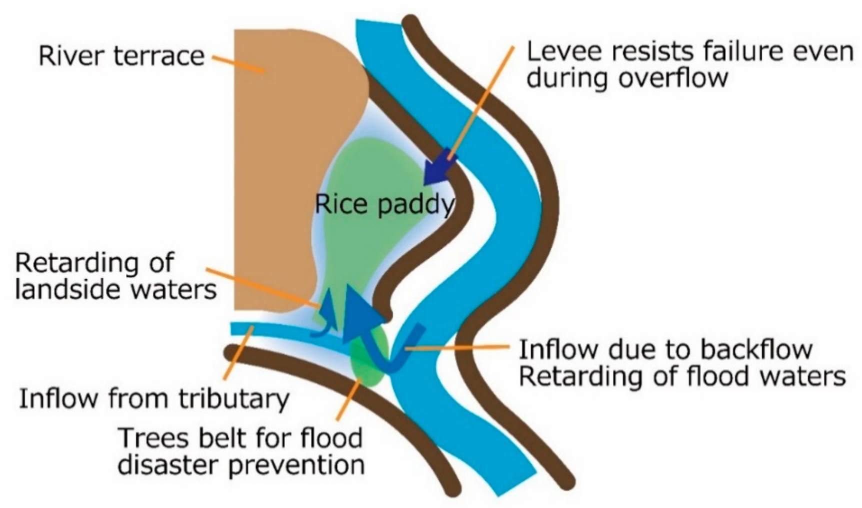

Figure 2. Open levee on flood plain.

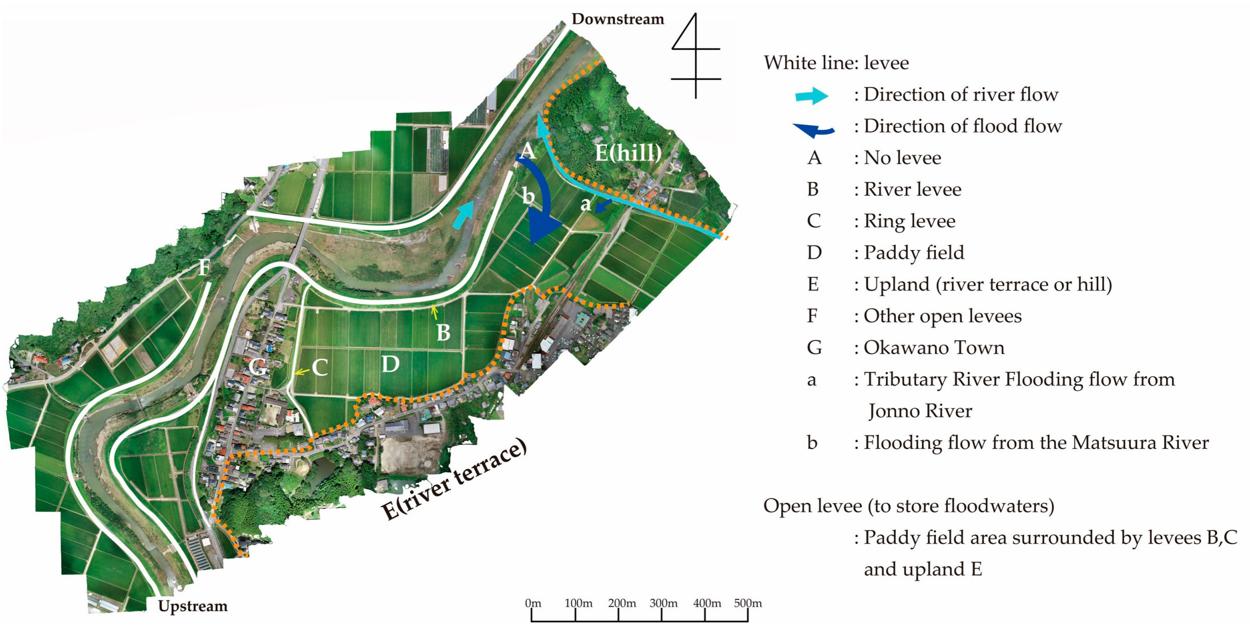

Figure 3. Okawano ortho image and explanation.

The construction period of the Okawano open levee system is unknown. The town of Okawano (G), which is surrounded by the ring levee (C) at the upstream end of the Okawano open levee, is a former lodging and post-station town on one of the old Edo-period highways [28]. The old highway through the town of Okawano, called Tsukasaki Road, was established in 1705, and was one of the old Nagasaki Highway routes. The ring levee surrounding the town is believed to date to this time approximately. According to interviews with local residents, the ring levee was just over 1 m high until the 1950s, but is now 2 m high. As the locations of the lodging town, paddy fields, and river channel have hardly changed, it is likely that Okawano's open levee has existed in its original form since the 1700s.

3.1.2. Flood on 28 August 2019

From 27 to 28 August 2019, heavy rainfall struck the northern area of Kyushu Island, where the Matsuura River is located, causing flood damage [34]. The damage was particularly severe in the Rokkaku River basin next to the Matsuura River basin, where extensive inundation occurred.

There was also widespread damage due to inundation in the Matsuura River basin. During this flood, the open levee on the flood plain in Okawano caused the floodwaters to flow backward and accumulate in the retarding basin. According to interviews with a local farmer, it was the first time since 1990, 29 years earlier, that water had been stored in the retarding basin through Okawano's open levee (Table 6). Prior to that, water had entered the retarding basin more frequently, but the frequency of flooding had decreased in recent years due to improvement projects on the Matsuura River.

Table 6. Observation status at the time of flood event [27,34].

Flood Event			
Date	26–29 August 2019		
Flood damage to houses:	29		
Inundation area	1.82 km^2		
Rainfall Observatory			
Name of station	Karathu		
Site	Near the mouth of Matsuura River		
Amount of rainfall (During the period)	533	mm	2nd largest in recorded history
Amount of rainfall (48 h)	422	mm	Largest in recorded history
Water Level Observatory			
Name of station	Kawanishi Bridge		
Site	Upstream of Okawano area		
Design water level (T.P.)	21.86	m	
Design flood discharge	1300	m^3/s	
Max water level for the event (T.P.)	21.88	m	3rd largest in recorded history
Max flood discharge for the event	1110.64	m^3/s	
Name of station	Wadayama Bridge		
Site	Downstream of Azame-no-se		
Design water level (T.P.)	11.4	m	
Design flood discharge	1500	m^3/s	
Max water level for the event (T.P.)	11.18	m	4th largest in recorded history

It is concluded by examining the water level gauge records at the time of the flood that the flood lasted approximately 40 h, with the water level rising approximately 6 m, and the water flooding the paddy fields to a depth of approximately 3.2 m (Figure 4).

It is concluded by examining the flood lines in Figure 5 that the lines are concentrated near an elevation of 19 m at each location within the retarding basin of the Okawano open levee system. In other words, within the retarding basin, the height of the water surface was almost constant, regardless of the distance from the inlet. The water depth varied depending on the topographic slope, reaching 3.2 m at point 1, compared with 0.78 m at point 5, i.e., the innermost point.

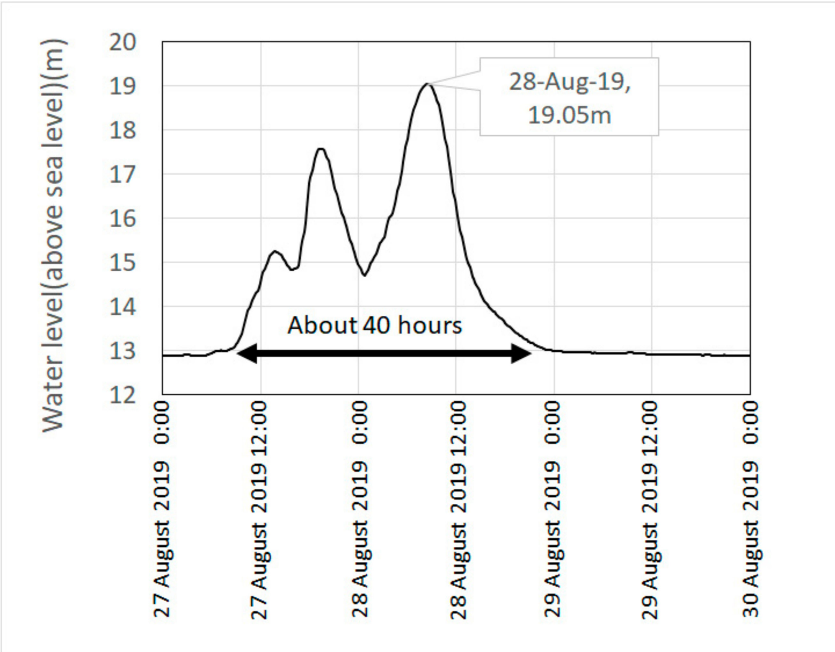

Figure 4. Changes in water level over time at point Y.

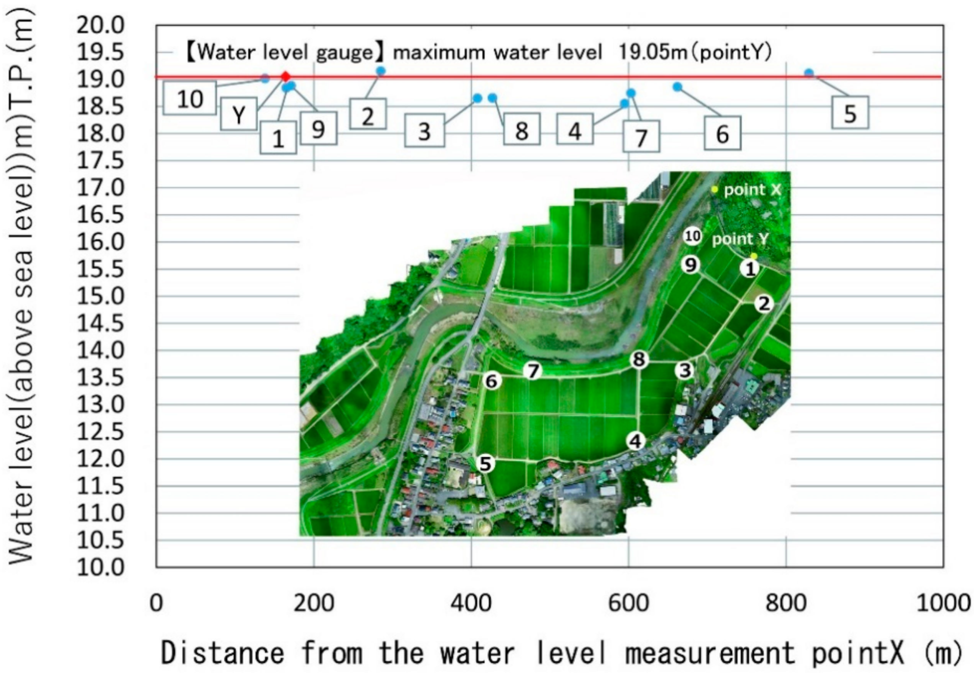

Figure 5. Water level and height of flood line. The points where the flood line is lower than the other points may underestimate the actual high-water levels because the values were determined based on evidence from plants, such as damage to the grass.

Using ArcGIS, we calculated based on the topography, water depth, and area of the retarding basin that 378,203.0 m^3 of floodwater was stored on the flood plain in Okawano at the time of the maximum water level of 19.05 m, demonstrating that the open levee reduced the downstream flood volume.

Rice had been planted in the paddy fields in the retarding basin, but except for a very small area near the inlet, the plants survived. There was little debris influx, driftwood, or mud deposition, and there was no significant damage to the paddy fields (Figure 6).

Figure 6. Damage of the Okawano open levee after the flood.

The inside of the open levee is used only as a rice paddy field. All the houses and major transportation facilities were located inside the ring levee or on the river terrace and did not suffer inundation damage.

Our findings suggest that the open levee on the flood plain in Okawano allowed up to 378,203.0 m^3 of floodwater to be stored by allowing the floodwater to flow in reverse through the opening provided on the downstream side into the space enclosed by the levees and river terraces. During this process, the inundation inflow and outflow behaviors occurred naturally, depending on the water level of the Matsuura River. Furthermore, owing to the extremely slow flow velocity, no significant damage occurred to the paddy fields. The nearby houses and facilities were also undamaged. Therefore, it appears that the open levee on the flood plain in Okawano could handle the inundation with only minor losses.

Simulations in existing studies have shown similar results [47]. The simulation results show that the velocity of the floodwaters flowing into the paddy fields is very slow.

3.1.3. Interviews

We interviewed the local archivist and a farmer in the Okawano district. We interviewed the local archivist before the flood disaster in August 2019 and the farmer after the flood disaster.

- Results of interview with local archivist:
  - Okawano is an old lodging and post-station town dating back to 1705.
  - Levees have surrounded the town since ancient times.
  - The height of the river levees was approximately 1 m.
  - There has been no major flood disaster recently. In the 1990 flood, the houses (G) inside the ring levee (C) flooded above the floor level.
  - After the 1990 flood, the Ministry of Land, Infrastructure, Transport and Tourism raised the ring levee.
  - I am not sure about damage to farmland as I am not a farmer, but I do not recall any major damage.
  - The houses on the river terrace were built after the railroad was built. Before that, the entire town was inside the ring levee.
  - During the flood, the archivist went to the retarding basin to catch fish.

- Interview with farmer:
  - The 2019 rice harvest suffered almost no damage from the influx of floodwater. Other types of bad weather had a greater impact.
  - After the 1990 flood, the paddy fields did not flood again until 2019.
  - There was only minor damage to the paddy fields due to the bending of rice plants and the influx of debris and driftwood. Afterward, I had to go into the fields to remove the debris.
  - The soil becomes more fertile when the fields are submerged. Next year's yields will be better.
  - The paddy fields on the downstream side are often submerged, but the upstream side is rarely submerged.
  - The rice plants need to be disinfected after being submerged because they become more susceptible to blight.
  - The water does not have much mud, and hence, adherence of mud to the rice plants after submergence is not a problem.
  - The fields are flooded for approximately a day.
  - When I was a boy, when water flowed into the open levee, I would go fishing there.
  - I would catch carp, catfish, and so on. I caught a big carp.

3.2. Azame-no-se

3.2.1. Overview

Azame-no-se is a wetland created in 2008 as a nature restoration project on the Matsuura River, 15.6 km from the estuary. Because of the increased risk of flooding in the area around Azame-no-se, a river improvement project was undertaken upstream of the affected areas. The national government bought paddy fields that were originally habitually flooded and excavated them approximately 5 m deep to create a wetland environment 0.06 km^2 in size [35].

Azame-no-se is a restored artificial wetland with six different environmental features, including ponds, paddy fields, and creeks (Figures 7 and 8). The flood plain environment utilizes the open levee mechanism, by which floodwater flows in as backflow from the most downstream part of the flood plain. The height of the opening is designed to allow water to flow in from the Matsuura River during small floods at least 20 times per year. Because of the different elevations of the ponds, the frequency of flooding varies by pond. The wetland's creeks have been restored. Under normal circumstances, their water comes from the ponds, which are located upstream, and continues to the Matsuura River. The paddy fields are used for environmental education by local organizations [32].

In the course of the planning, construction, and maintenance of Azame-no-se, workshops and other forms of consultation with local businesses and residents were held repeatedly for consensus building. By 2019, more than 130 consultations had been held. In the process, a citizens' association of Azame-no-se was established in 2002 and incorporated as an official non-profit organization in 2005. Through this process of repeated consultation, utilization of the experience of local residents and application of traditional flood control techniques were incorporated into the design.

To manage disturbances to the wetlands, Azame-no-se created a prototype of the flood plain open levee to establish a mechanism for floodwater to flow in as backflow from the most downstream part of the wetlands. The flood plain open levee is a traditional flood control technique, but it is applied here to protect the natural environment. Although it also has a flood control function, its essential function is to restore and preserve the natural environment, and the flood control function is a secondary function.

There is a levee on the river side of Azame-no-se, but it is designed to be 5 m lower than the levee on the west side. During large-scale flooding, the levee on the Azame-no-se side is designed to overflow before the levee on the west side.

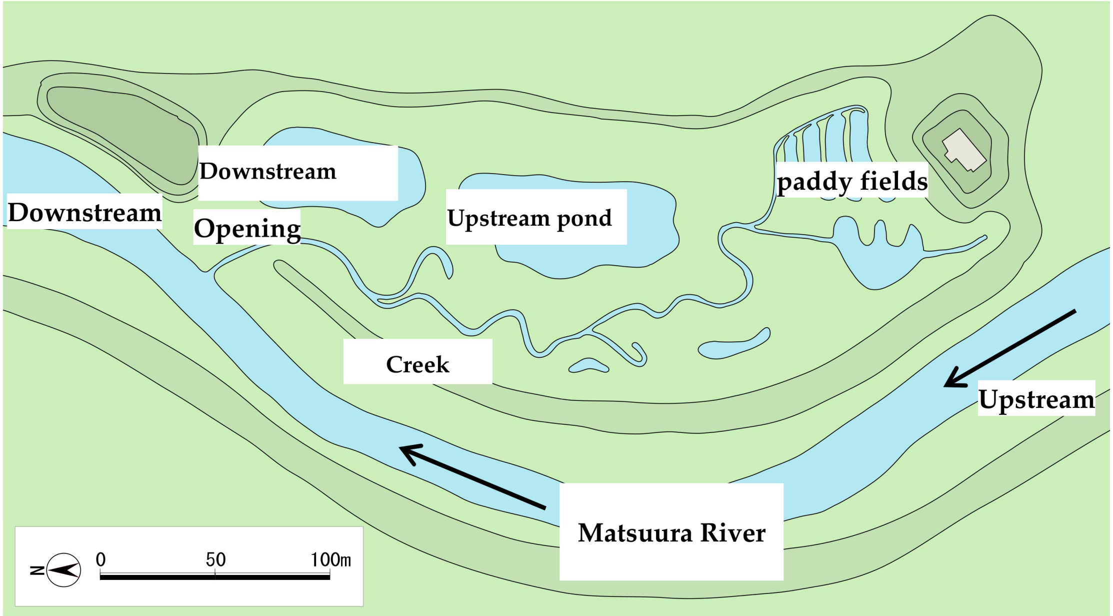

Figure 7. Plan view of Azame-no-se (Drawing by Hironori HAYASHI) [43].

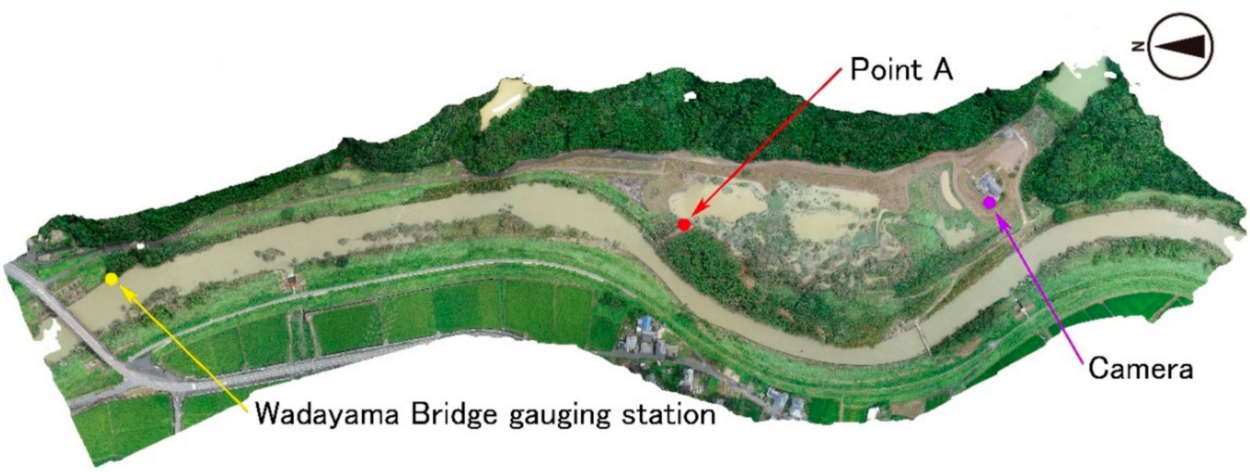

Figure 8. Ortho image of Azame-no-se.

A detailed survey report on the changes in the ecosystem before and after the construction of the wetland at Azame-no-se exists [32]. Many species maintained or increased their numbers after wetland development. Shortly after the wetlands were developed in 2009, 28 species of fish, 193 species of plants, 35 species of dragonflies, 54 species of birds, 3 species of mammals, 4 species of reptiles, and 4 species of amphibians were observed. Particularly notable were fish and dragonflies, which exploited the wetlands as breeding grounds.

Studies on the nature restoration at Azame-no-se are abundant and wide-ranging, ranging from the relationship between flooding and biodiversity to social consensus building [39–46].

3.2.2. Flood on 28 August 2019

The flooding on August 2019 was the largest flood since the completion of Azame-no-se in 2008. The floodwater overflowed the levee between Azame-no-se and the Matsuura River, and at the peak of the flood, the levees were submerged. At the insistence of local residents, bamboo was planted on the upstream side of the levee to prevent the destruction of the wetlands. Planting bamboo on levees has long been practiced in Japan as a traditional flood control method.

It is observed from the time-lapse imaging that, in the early stages of the flood, the floodwater slowly flows in from the downstream side, flooding the wetland (Figure 9). During the inflow of water from downstream, the flow velocity in the wetland is sufficiently low to be unrecognizable on the image. However, once the flood passes over the levee, the floodwater can be observed flowing within Azame-no-se. This can also be observed from the fact that trees were knocked down near the levee that overflowed, as shown in Figure 10.

Figure 9. Azame-no-se in different stages, from immediately before the flood to the maximum water level.

Figure 10. Azame-no-se immediately after flooding.

It can be observed from the water level gauge records of the water level at the time of the flood that the flood lasted approximately 48 h, and the water flooded Azame-no-se (Figure 11). However, the water level gauge installed inside Azame-no-se could not measure the maximum water level because the water level exceeded the measurement threshold. Hence, we instead used the flood line around Azame-no-se provided by the Ministry of Land, Infrastructure, Transport and Tourism, and the water level at the Wadayama Bridge gauging station directly downstream. The water level at the Wadayamabashi gauging station is located about 550 m downstream from the water level gauge (Point A) at Azame-no-se. The water level between point A and Wadayamabashi always has a difference of about 0.8 m. For this reason, it is estimated that the maximum water level in Azame-no-se was about 12 m.

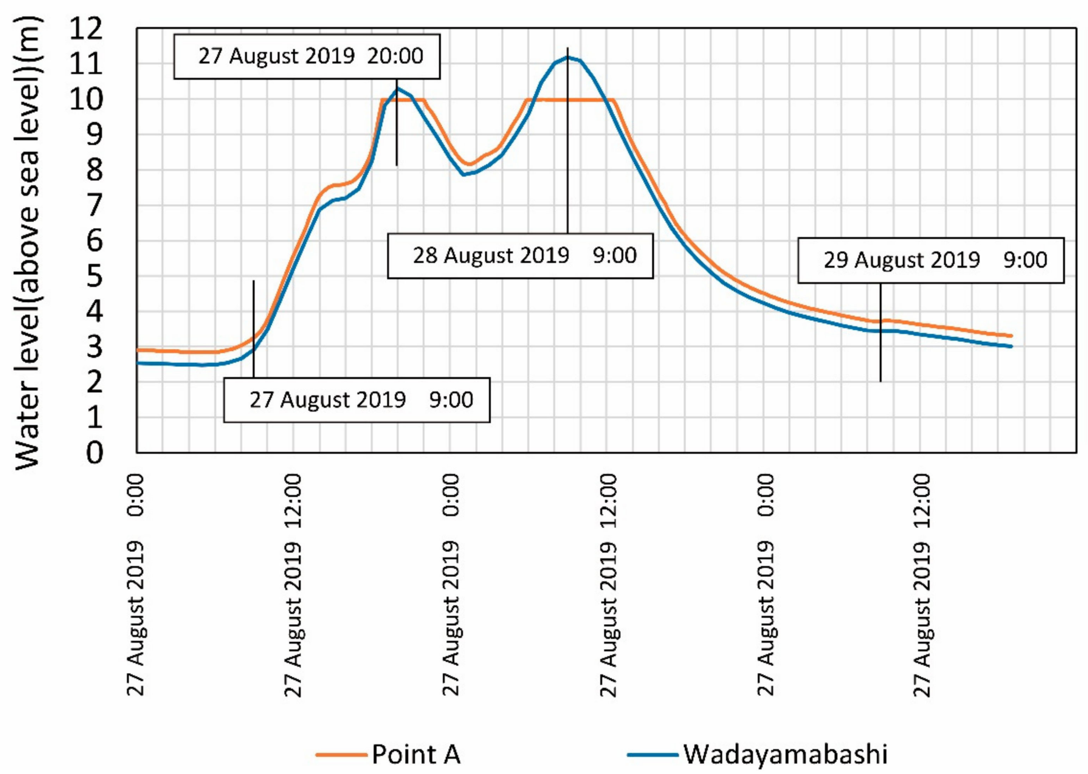

Figure 11. Changes in water level over time at Azame-no-se (Point A) and Wadayamabasi [48].

Similar to the Okawano flood plain, we used ArcGIS to calculate that, based on the topography, water depth, and area, 341,584.7 m^3 of floodwater may have been stored at the time of the maximum water level of 12 m. However, unlike in Okawano, where the maximum water level was almost constant across the entire surface, the floodwater was stored at the location of the overflow where the influx of floodwater occurred in Azame-no-se.

Azame-no-se is a wetland that was excavated in a nature restoration project, and it is also the site of a traditional flood plain open levee, which provides flood control capability by taking advantage of the wetland ecosystem itself.

4. Discussion

So far, this paper has focused on the functions of flood control and ecosystem services using the two research sites as case studies. Each research site displays elements of Eco-DRR in the way it harnesses the traditional river technology.

4.1. Eco-DRR Functions of Okawano Open Levee

Okawano is not only a farmland for rice production but also a natural ecosystem that serves as a habitat for a wide variety of species.

During a flood, the flow rate through the flood plain open levee is very slow, which not only prevents damage to the rice plants but also supplies nutrients to the paddy fields. The Okawano open levee has a resilient function in the use of agricultural land. It is believed that the flood plain open levee played a major role in improving agricultural production in an era without chemical fertilizers.

As the flood plain open levee is continuous with the river, it creates an environment in which water, sediment, nutrients, and organisms can be transported from the river, especially in the event of a flood. In Japan, open levees play a major role in maintaining the flood plain environment for fish such as catfish, loach, and carp, which migrate from rivers to rice fields in the rainy season to lay their eggs [49,50].

Okawano's open levee is also effective at flood control. It can store approximately 378,203.0 m^3 of floodwater in the paddy fields, and has a capacity of up to 421,000 m^3. In the Matsuura River basin, there are 14 open levee sites including Okawano, which comprise a combined area of 1,919,301.9 m^2, providing a significantly large flood control capability. In the future, floods are expected to increase in frequency and volume owing to climate change, and hence, it is necessary to make efforts to ensure that these open levees do not disappear.

4.2. Eco-DRR Functions of Azame-no-se

Azame-no-se is a wetland that was only reclaimed recently, but owing to its open levee structure, it operates well as a flood plain and has a significant effect on the conservation of biodiversity. The low height of the open levee creates an environment where the river overflows the top of the levee during a flood, generating disturbances that greatly contribute to the maintenance of biodiversity in the wetlands.

Azame-no-se continues to be managed with the ongoing involvement of the local community, and is used as a forum for networking within and outside the community and for environmental education and study tours. Recreational uses such as walking and biological observation are also available [32].

The restoration of the wetlands at Azame-no-se has enabled the provision of ecosystem services in general and supporting services in particular. A particularly distinctive characteristic of Azame-no-se, which originates from the way it was constructed with widespread community involvement, is the abundance of the cultural services that it offers that are centered around its practical uses.

With respect to flood control effectiveness, approximately 342,000 m^3 was stored in the wetlands, which unlike the case in Okawano, is the maximum possible water storage at the design high water level of just under 12 m.

4.3. Value in Terms of Construction Costs

Table 7 compares the construction costs and effectiveness of the two case study sites. Azame-no-se has better water storage efficiency per unit area than Okawano. This originates from the fact that the soil in Azame-no-se was excavated when the wetlands were created. In contrast, as Okawano has formed over a long duration, it could be argued that the costs are essentially zero in modern times.

Table 7. Comparison of effectiveness and costs [33].

Location		Okawano	Azame-no-se	Mutabe Retarding Basin
Water level (elevation)	m	19.1	12.0	
Area	m^2	209,135.5	60,745.0	534,000.0
Volume	m^3	378,203.0	341,584.7	900,000.0
Water storage per unit area	m^3	1.81	5.62	1.69
Construction cost	billion yen	free	0.8	
Percentage of water storage compared with the Mutabe retarding basin	%	42.0	38.0	100.0
Estimated cost based on the construction cost of the Mutabe retarding basin	billion yen	4.7	4.2	

The Mutabe retarding basin, which is on the Ushizu river in the neighboring Rokkaku river basin, was built in 2001 for 11.1 billion yen, and is similar in function and form to Okawano and Azame-no-se. The Rokkaku River basin is located next to the Matsuura River basin. It can be concluded using this cost as the comparison baseline that Okawano provides flood control services worth 4.7 billion yen and Azame-no-se provides flood control services worth 4.2 billion yen. The cost of construction of Azame-no-se was

800 million yen, which indicates that its flood control effectiveness is 5.2 times the cost of construction.

4.4. Relationship between Ecosystem Services, Eco-DRR and Traditional River Technologies

Originally, Eco-DRR involved the concept of ecosystem services, especially with respect to disaster prevention capabilities. Within the four elements of ecosystem services (provisioning services, regulating services, cultural services, and supporting services), Eco-DRR fell under "regulating services." Regulating services include weather regulation and disaster abatement and mitigation [51]. The International Union for Conservation of Nature (IUCN) states that "ecosystem-based disaster risk reduction refers to decision-making activities that take into consideration current and future human livelihood needs and biophysical requirements of ecosystems, and recognize the role of ecosystems in supporting communities to prepare for, cope with, and recover from disaster situations" [52]. In other words, Eco-DRR refers to not only a framework for ecosystem-based disaster prevention capabilities, but also ecosystem-based mechanisms for confronting disasters (focused on disaster prevention capabilities) by means of the multifaceted functions of the associated ecosystem services.

Figure 12 illustrates this idea of the relationship between Eco-DRR and ecosystem services. Ecosystem services are provided by the underlying ecosystem. While Eco-DRR focuses on disaster prevention within ecosystem services, it also comprehensively encompasses various other accompanying ecosystem services.

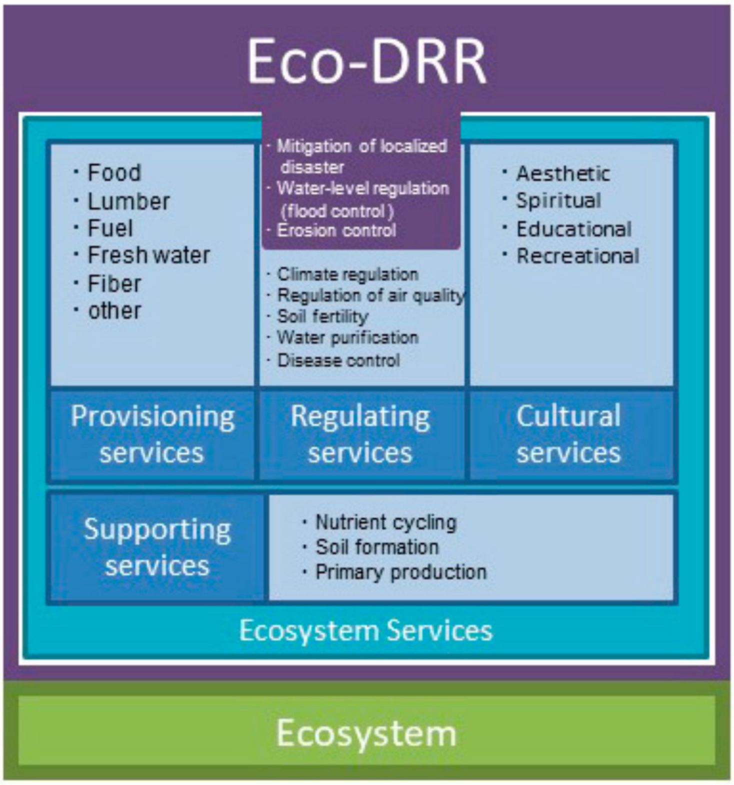

Figure 12. Position of ecosystem-based disaster risk reduction (Eco-DRR) in ecosystem services.

In the two case studies along the Matsuura River discussed in this paper, the flood control capabilities qualify as services obtained from nature or the ecosystem according to the basic model for Eco-DRR shown in Figure 12. The Okawano flood plain obtains ecosystem services from the paddy fields, and Azame-no-se from wetlands. Applying the model in Figure 12 to the Okawano flood plain and Azame-no-se, we obtain the diagrams shown in Figures 13 and 14, respectively.

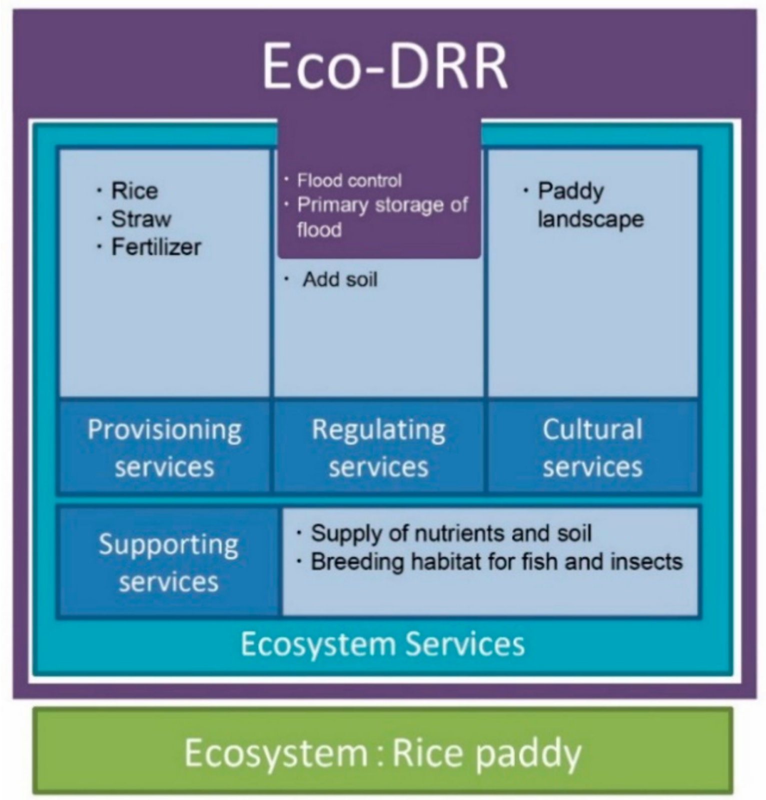

Figure 13. Eco-DRR and ecosystem services at Okawano flood plain.

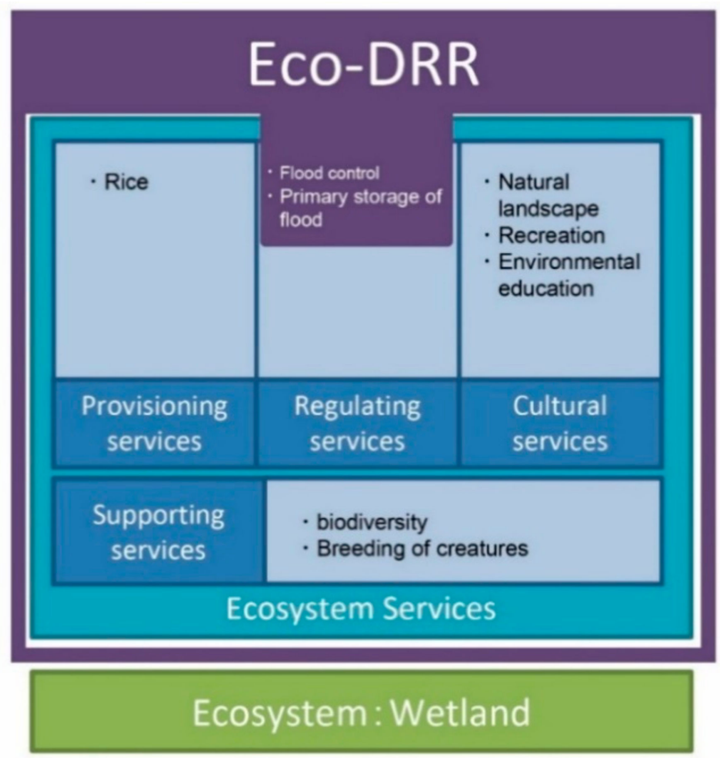

Figure 14. Eco-DRR and ecosystem services at Azame-no-se.

The Okawano site relies on the paddy ecosystem to regulate the flood plain and perform primary storage. The ecosystem also supplies ecosystem services such as the supply of nutrients and soil, breeding habitat for fish and insects, the production of rice, and the landscape scenery of the paddy fields.

The wetland ecosystem provides flood control and primary storage functions to Azame-no-se. In addition, the creation of the wetlands provided biodiversity and a breeding environment for living things. The natural environment of the wetlands is also used for environmental education and recreational activities such as walking and birdwatching.

While it is evident that both case studies exhibit ecosystem-based disaster prevention functions and multifaceted associated functions, traditional river technologies are not incorporated into either model.

Figures 15 and 16 illustrate the incorporation of traditional river technologies into Figures 13 and 14, respectively.

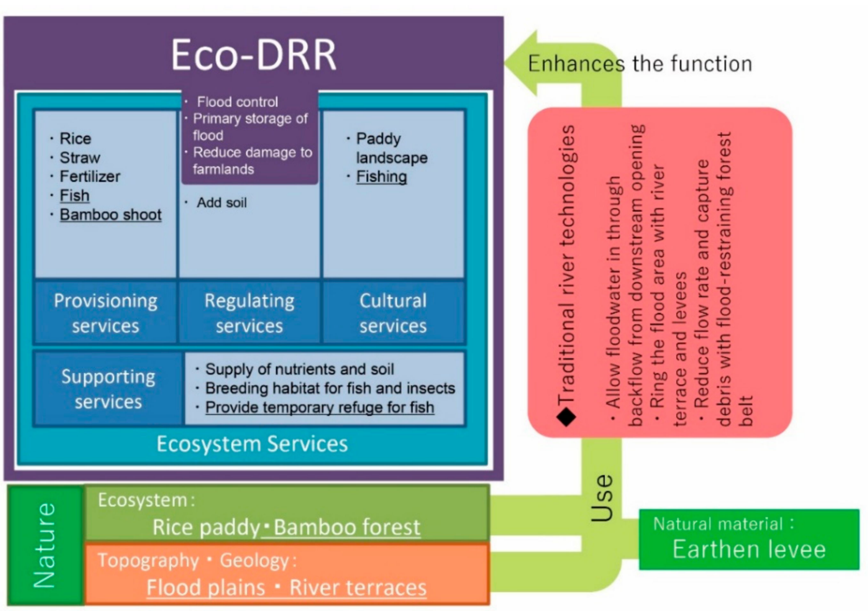

Figure 15. Eco-DRR and traditional river technology at Okawano flood plain.

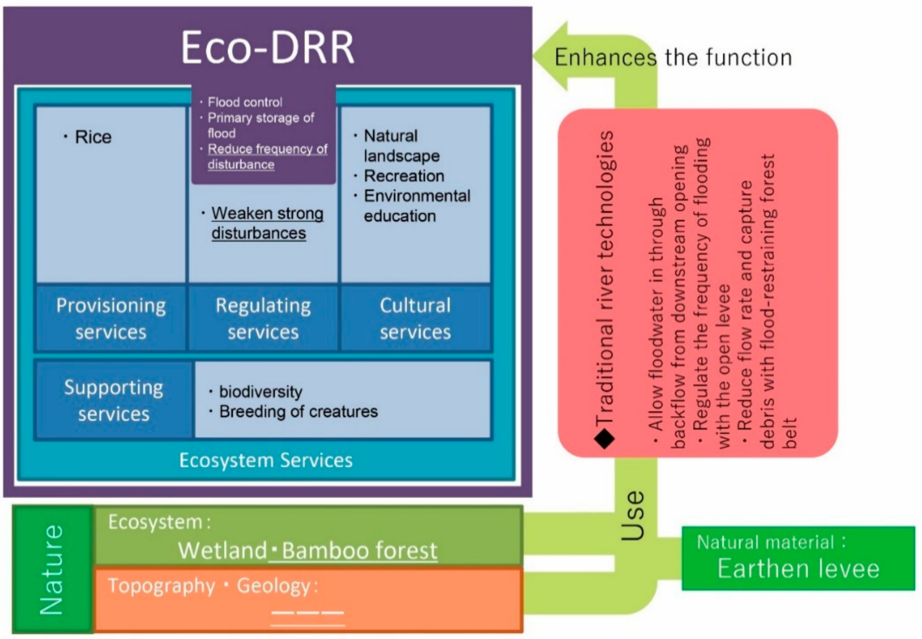

Figure 16. Eco-DRR and traditional river technology at Azame-no-se.

In Okawano, the traditional river technology includes the use of embankments, a flood-restraining forest belt, and microtopography to enhance flood control capabilities. Consequently, in addition to the normal ecosystem services provided by paddy fields, it was possible to not only reduce damage to the farmlands but also create a culture of providing temporary refuge for fish and harvesting the displaced fish.

In Azame-no-se, the frequency of the influx of floodwater into the wetlands was regulated by planting a flood-restraining forest belt and setting up embankments that apply the traditional technology of the flood plain open levee. Consequently, the frequency of disturbance of the wetlands was maintained under control and intense disturbances were reduced.

Thus, the traditional river technology has an ecosystem-based disaster prevention function, and also enhances the function of ecosystem services by utilizing aspects from nature such as topography and natural materials. Ecosystem services that may be enhanced by the addition of traditional flood control technology include not only disaster prevention functions but also provisioning services and cultural services. These comprehensively enhance the disaster resilience of the region.

4.5. Open Levees as an Eco-DRR System

By studying Okawano and Azame-no-se, we have elucidated the mechanism of the open levees, which is as follows.

The flood plain open levee is created by making a portion of the levee discontinuous (2) (Figure 17). In the event of a flood, this allows floodwater to flow slowly into wetlands and paddy fields through an opening (3) downstream of the flood area. This has the effect of storing the flood flow, thereby reducing the amount of flooding downstream. Inside the opening, a forest belt serves to trap debris, as the floodwater flows in. The floodwater flows slowly into the wetland (5), transporting organisms and depositing nutrients and fine soil and sand. If the height of (2) is lower than that of (1), the floodwater overflows (2) and disturbs the wetland.

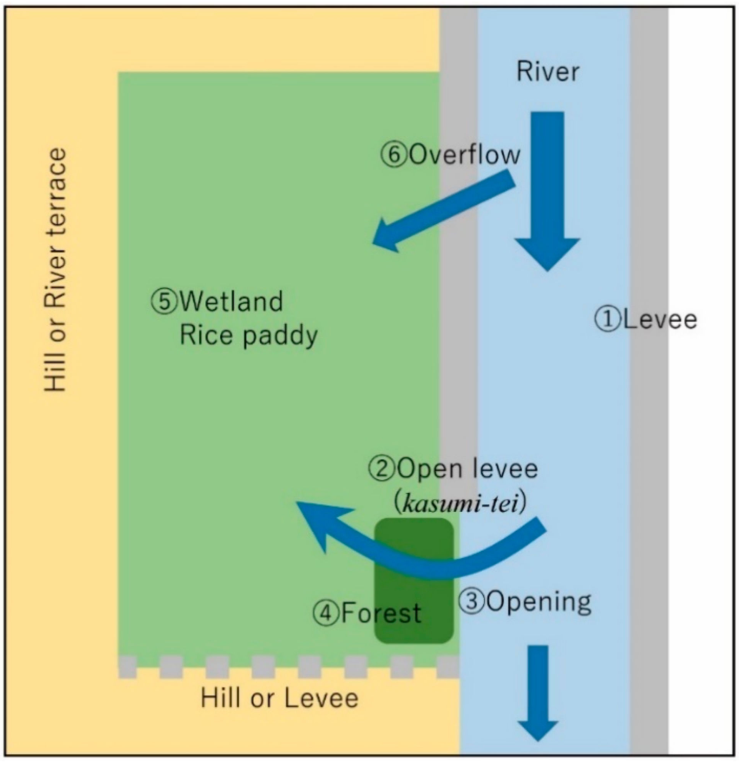

Figure 17. Open levee system.

The open levee is a traditional river technology that demonstrates, through the above mechanism, effective flood control and environmental capabilities, and can therefore be described as an effective Eco-DRR in the face of future climate change.

5. Conclusions

In this study, we examined two case studies of discontinuous open levees (kasumi-tei) on the Matsuura River, and evaluated the advantages of this traditional Japanese river technology from the perspective of Eco-DRR. It would be premature to conclude from our findings that all traditional Japanese river technologies are related to Eco-DRR similarly. In addition to the two case studies on the Matsuura River, there are numerous traditional river technologies in Japan, several of which are relevant to Eco-DRR.

In the two cases discussed in this paper, it is evident that both systems are flood control systems utilizing ecosystem services. In both cases, the traditional river technology (the flood plain open levee) serves as an effective Eco-DRR. In addition, the flood plain levee technology enhances the ecosystem services at both sites, including not only the flood control capabilities, but also other ecosystem services. Furthermore, the open levees offer substantial cost advantages over the alternatives.

Our results suggest the possibility that other traditional Japanese river technologies may be effective in strengthening Eco-DRR, as in our case studies on the Matsuura River. In the future, we intend to examine more case studies comparing the relationship between traditional Japanese river technologies and Eco-DRR.

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