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Original research article

Assessment of the historical environmental changes from a survey of local residents in an urban–rural catchment

Goro Mouri [a,*], Seirou Shinoda [b], Taikan Oki [c]

[a] Institute of Industrial Science (IIS), The University of Tokyo, Be505, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
[b] Information and Multimedia Center, Gifu University, 1-1 Yanagido, Gifu City 501-1193, Japan
[c] Institute of Industrial Science (IIS), The University of Tokyo, Be607, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan

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ABSTRACT

When attempting to address the environmental problems of a catchment, it is important to consider changes in a long-term environmental context. However, the long-term data on the state of the environment that are required for such an examination are rarely documented. Such data collection typically requires several years of investigation and observation. In addition, as there may be a significant time lag between the occurrence of a phenomenon and its cause, subsequent environmental investigations of changing animal and plant states scaling up to 5 years may be inadequate. We conducted a long-term analysis of the environmental changes in five sub-catchments of the Nagara River, Japan, assessing a period of 30 years, using a questionnaire survey approach involving local communities. Four sub-catchments of the Yoshida River were also analyzed for comparison. In addition, we attempted to clarify the relationship between various environmental factors and the space–time response of animals and plants. The survey included eight topics: assumed information, hydrological characteristics, habitat conditions for living things, forest state, land cover conditions, river awareness, free-entry information, and respondent information. Our method also has academic significance in that it validates the environmental agent extraction technique using a questionnaire survey. Our results identify management strategies for minimizing biodiversity loss due to climate change. Forest management and human activities should be undertaken with care, and the environmental context going forward into the next century should be considered for integrated catchment management. Elsewhere, reduced greenhouse gas emissions, a much expanded network of protected areas, and/or efforts to provide corridors to ease species movements may be necessary at the global level.

1. Introduction

Many living things from around the world are on the verge of extinction. According to the International Union for Conservation of Nature (IUCN) Red List (Rodrigues et al., 2006; Currey et al., 2009; Szabo et al., 2012;), 8782 species of animals and 8509 species of plants are in danger of extinction. In Japan alone, 3155 species are in danger of extinction (Szabo et al., 2012; Miller, 2013).

Long-term observations and model projections indicate that freshwater ecosystems are highly vulnerable to and directly affected by climate change (Meyer et al., 1999; Oki and Kanae, 2006; Scholze et al., 2006; Fischlin et al., 2007; Bates et al., 2008; Susan and Lawrence, 2008; Moss et al., 2009; Mouri and Oki, 2010; Mouri et al., 2010a, 2012a, 2013a,b,c,d). Even with restrictive policies on greenhouse gas emissions, there is a strong possibility that the global mean temperature could rise by more than 2 °C (Allen et al., 2009). Furthermore, the impact on freshwater ecosystems may be exacerbated by other human pressures including habitat loss, pollution, and invasive species (Angold et al., 2006; Millennium Ecosystem Assessment, 2005). This has led some to conclude that policies aimed at preventing such changes are urgently required (Falloon and Betts, 2009; Parry et al., 2009). Despite growing calls for action, the scientific community still has relatively little to say about how to prepare freshwater ecosystems for climate change (Ormerod, 2009). To date, most efforts have been piecemeal and have focussed on gathering evidence of trends in physical drivers and biological impacts. Anticipated changes in thermal and hydrological regimes include higher water temperatures, longer ice-free seasons, increased water body stratification, earlier snowmelt, more extreme floods and droughts, increased

* Corresponding author. Tel.: +81 3 5452 6382.
E-mail address: mouri@rainbow.iis.u-tokyo.ac.jp (G. Mouri).

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sediment and nutrient transport, lower dissolved oxygen, and increased salinity (Andersen et al., 2006; Kundzewicz et al., 2007; Whitehead et al., 2009a,b; Mouri et al., 2010b, 2011a,b,c). Biological effects include changes in species physiology, phenology, dispersal, predation, and ultimately changes in ecosystem structure, productivity, and nutrient cycling (Markus, 2010; Pekka et al., 2009; Wilby, 2008; Mouri and Oki, 2010; Mobaied et al., 2012; Baral et al., 2013; Mouri et al., 2013d). Potential outcomes have been reviewed for groups of organisms such as phytoplankton (Thackeray et al., 2008), invertebrates (Durance and Ormerod, 2007), amphibians (Araújo et al., 2006), macrophytes (Franklin et al., 2008), fish (Attila et al., 2010; Graham and Harrod, 2009), and aquatic birds (Poiani, 2006). Others have provided useful syntheses of climate impacts for landscape units such as the coastal zone (Richards et al., 2008), wetlands (Harrison et al., 2008), uplands (Orr et al., 2008), glacier-fed rivers (Milner et al., 2009), lowland rivers (Johnson et al., 2009), lakes (Mooij et al., 2005), and for aquatic ecosystems more generally (Heino et al., 2009; Palmer et al., 2009; Wade, 2006).

Thorough appraisals of climate drivers and ecological responses are traditionally seen as important first steps towards developing adaptive management strategies for freshwater and pollution load, and concerns about the sustainability of some environmental policies have provided further impetus for research (Birch and McCready, 2009; Georgios et al., 2003; Hans, 2010; Ingram, 2008; Whitalla et al., 2004; Mouri et al., 2012a). Across Europe, there is growing recognition that the objectives and programmes of the European Union (EU) Water Framework Directive (WFD) and EU Habitats Directive are potentially climate-sensitive (Wilby et al., 2006). Although it is generally accepted that adapting to climate change involves rejecting basic assumptions about static conditions (which until recently have underpinned flood, water, and conservation management efforts), opinion is divided on how best to move forward (Milly et al., 2008; Mouri et al., 2011c). Others are asking more generally how biodiversity policies and management practices might be modified and implemented to address the impacts of climate change (Beiera et al., 2006; Hovardas and Poirazidis, 2007; Sutherland et al., 2006, 2009; Collins, 2009; Wamelink et al., 2009).

2. Objective

Although home to approximately 1 million people, the Nagara River catchment has robust biodiversity, pure and rich water resources, and is a major limpid river in Japan. However, while the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) water-quality values of the Nagara River and its tributaries are good, other aspects of the catchment environment seem to be worsening, based on observations including a sharp decrease in freshwater fish such as *Plecoglossus altivelis altivelis* (Mouri et al., 2010a). Local residents have voiced their increasing concern about the degradation of the Nagara River valley environment in the past 10 years. The establishment of a scientific technique that can evaluate the health of the catchment has become a pressing need. When attempting to address the environmental problems of a catchment, it is important to consider changes in a long-term environmental context. However, the long-term data on the state of the environment that are required for such an examination are rarely documented. Such data collection typically requires several years of investigation and observation. In addition, as there may be a significant time lag between the occurrence of a phenomenon and its cause, subsequent environmental investigations of changing animal and plant states scaling up to 5 years may be inadequate. We conducted a long-term analysis of the environmental changes in five sub-catchments of the Nagara River, Japan, assessing a period of 30 years, using a questionnaire survey approach involving local communities (Fig. 1). In addition, we attempted to clarify the relationship between various environmental factors and the space–time response of animals and plants.

The purpose of the questionnaire was to clarify the relationship between changing habitat characteristics and environmental factors. In survey-based studies, questionnaires are typically mailed to candidate participants selected at random using resident cards or other similar forms of information and then the investigator(s) await a reply. However, this requires time and significant cost. Furthermore, the recovery rate averages about 50%, which is usually not adequate. Therefore, we sent our questionnaire to children (elementary school, grades 4–6), students (junior high school, grades 1–3), and their guardians in

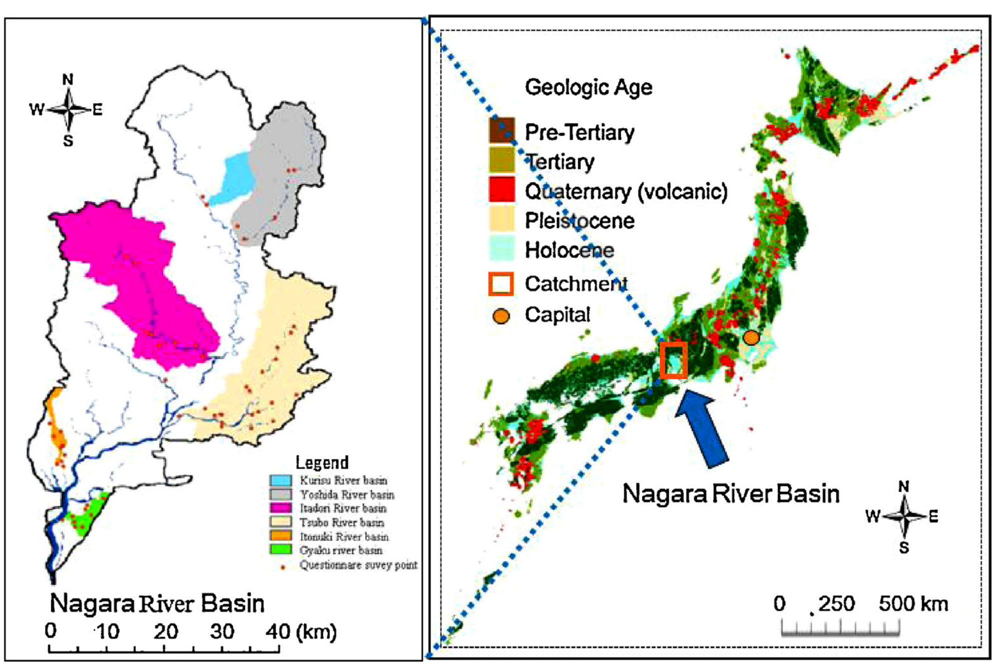

Fig. 1. The distribution of the sub-catchment in the Nagara River Basin, and questionnaire survey of cooperating elementary and junior high schools.

the target catchment area. A total of 48 schools were included. This proved to be less time-consuming and more economical, and resulted in an improved response rate (70%). In addition, the questionnaire served as an educational tool, as respondents (child, student, or guardian) learned about current environmental conditions in the catchment. That is, the process of completing the questionnaire improved awareness of local environmental problems. Moreover, considering that the survey included students, our results have the potential to become environmental education teaching materials in the participating schools.

3. Methods

3.1. Question plan

When seeking answers regarding a given place, its location was made very clear and easy to find on a map. A question was prepared for every feature of the catchment and for all five representative tributaries. For questions regarding habitat conditions for living things, the following two choices were included: "it was a long time ago, although I do not know if it is now," and "it was not long ago, although I do not know if it is now." To prevent variation in replies due to ambiguity about which type of fish a question referred to, a different question was prepared for each fish species. Because we received a very large number of replies, it was necessary to efficiently sum the survey results. To this end, many of the results were considered in an alternative form and were summarized in the free-entry column at the end.

3.2. Question content

The survey included eight topics: assumed information, hydrological characteristics, habitat conditions for living things, forest state, land cover conditions, river awareness, free-entry information, and respondent information, all consisting of various items. The content of the survey is shown and summarized in Table 1.

3.3. Database construction, analysis, and statistical procedures

(a) Code numbers were assigned to the following categories: collected data, tributary stream, school, guardian, and student. In addition, each respondent was given a unique code number. The replies of each participant were entered into a database under that participant's code number. For free-entry replies, the reply was inputted as text.

(b) The simple total of replies was calculated for tributary stream, guardian, and student. The simple total results for child, student, and guardian are shown in Figs. 2 and 3. The ratio of individual replies to the total number of replies is shown in Fig. 3.

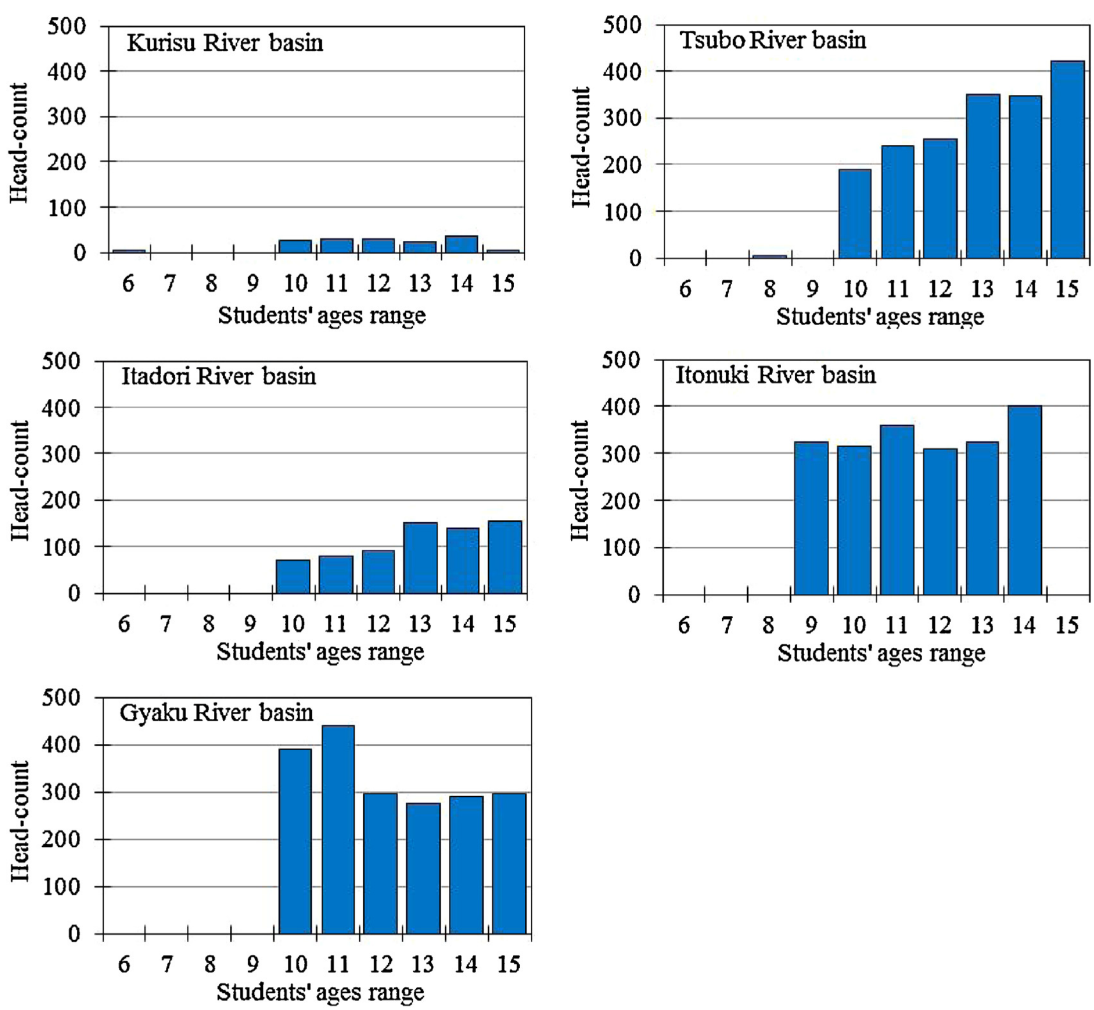

Fig. 2. The questionnaire survey age distribution of cooperating elementary and junior high school students in five selected sub-catchments.

Table 1
Questionnaire survey items for the five selected sub-catchments.

Survey item		Sub-catchment					The question for students and guardians	Option
		Kurisu River basin (upper stream)	Itadori River basin (middle stream)	Tsubo River basin (middle stream)	Itonuki River basin (down stream)	Gyaku River basin (down stream)		
1	Water level, water quantity	○	○	○	○	○	Did the depth and the depth of water of the river at the time of fine weather change as compared with ancient times?	Increased Remain the same Decreased
2	Water level, water quantity	○	○	○	○	○	Did the depth of water of the river at the time of rain change as compared with ancient times?	Increased Remain the same Decreased
3	Transparency			○	○	○	Did the transparency of the water of a river and murky change as compared with ancient times?	Became transparent Remain the same Became murky
4	Recovery of turbidity	○	○	○	○	○	After the river became muddy by rain as compared with ancient times, did returning to the original river become early? Did it become late?	Became early Remain the same Became late
5	Sediment	○	○	○	○	○	Did the quantity of sediment and sludge change as compared with ancient times?	Increased Remain the same Decreased
6	Ground water				○	○	Did the taste of groundwater (well water) change as compared with ancient times?	Became delicious Remain the same Became less delicious
7	Suspended solids	○	○	○	○	○	Did the branches and leaves which flow from the upper stream at the time of rain increase in number as compared with ancient times?	Became delicious Remain the same Became less delicious
8	Fish species distribution (upper stream)	○	○	○			Did the number of fish change as compared with ancient times?: In the case of the fish which lives in beautiful rivers, such as a *Plecoglossus altivelis altivelis and Salvelinus pluvius*	Increased Remain the same Decreased
9	Fish species distribution (upper stream)	○	○	○			Did the number of fish change as compared with ancient times? In the case of the fish which lives in dirty rivers, such as a crucian carp and a carp	Increased Remain the same Decreased
10	Fish species distribution (upper stream)	○	○	○			Did the number of fish change as compared with ancient times? In the case of the fish which lives in the bottom of beautiful rivers, such as fat hen and *Misgurnus anguillicaudatus*	Increased Remain the same Decreased
11	Fish species distribution (upper stream)	○	○	○			Did the number of fish change as compared with ancient times? In the case of the fish which lives in the bottom of dirty rivers, such as a Silurus asotus.	Increased Remain the same Decreased

Table 1 (*Continued*)

Survey item		Sub-catchment					The question for students and guardians	Option
		Kurisu River basin (upper stream)	Itadori River basin (middle stream)	Tsubo River basin (middle stream)	Itonuki River basin (down stream)	Gyaku River basin (down stream)		
12	Fish species distribution (middle and down stream)				○	○	Did the number of fish change as compared with ancient times?: In the case of the fish which lives in beautiful rivers, such as a *Plecoglossus altivelis altivelis and Salvelinus pluvius*	Increased Remain the same Decreased
13	Fish species distribution (middle and down stream)				○	○	Did the number of fish change as compared with ancient times? In the case of the fish which lives in dirty rivers, such as a crucian carp and a carp	Increased Remain the same Decreased
14	Fish species distribution (middle and down stream				○	○	Did the number of fish change as compared with ancient times? In the case of the fish which lives in the bottom of beautiful rivers, such as fat hen and *Misgurnus anguillicaudatus*	Increased Remain the same Decreased
15	Fish species distribution (middle and down stream)				○	○	Did the number of fish change as compared with ancient times? In the case of the fish which lives in the bottom of dirty rivers, such as a Silurus asotus.	Increased Remain the same Decreased
16	Benthic insect	○	○	○			Did the number of bottom student insects change as compared with ancient times?	Increased Remain the same Decreased
17	Agriculture	○	○	○	○	○	Did the number of shrimps (prawn, a crayfish, etc.) change as compared with ancient times?	Increased Remain the same Decreased
18	Liverwort			○	○	○	Did the moss of river bottom and the quantity of the alga change as compared with ancient times?	Increased Remain the same Decreased
19	Forest	○	○	○			Did the beauty and the fresh green vividness of autumnal leaves change as compared with ancient times?	Became various and beautiful Remain the same Decreased
20	Forest	○	○	○			Did the state of forestry management, such as pruning, thinning, and bottom grass cutting, change as compared with ancient times?	Increased Remain the same Decreased
21	Land use			○	○	○	Did paved roads and buildings increase in number as compared with ancient times?	Increased Remain the same Decreased
22	River structure	○	○	○	○	○	Did the rivers and waterways of Concrete revetment increase in number as compared with ancient times?	Increased Remain the same Decreased
23	Riverside environment	○	○	○	○	○	Did the places where a child can play at the water's edge increase in number as compared with ancient times?	Increased Remain the same Decreased

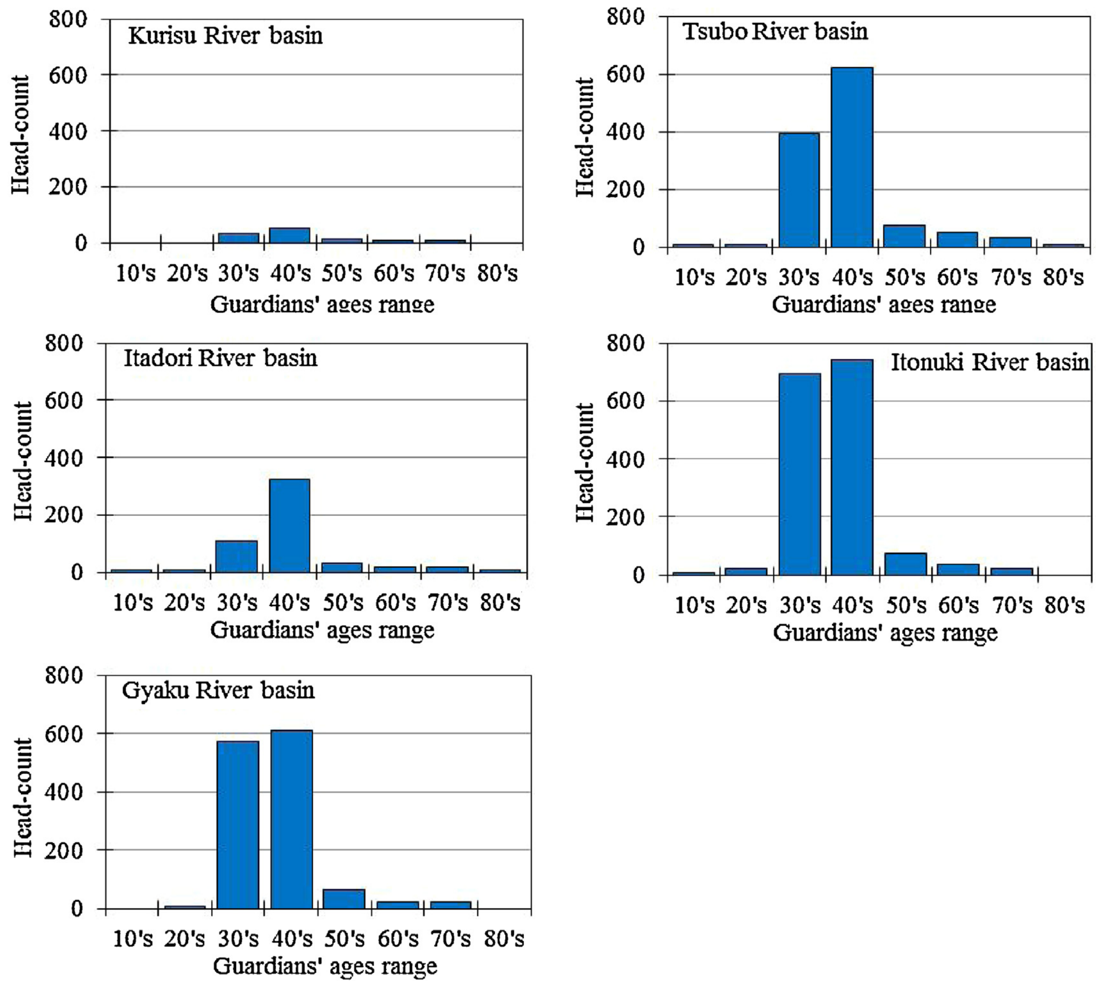

Fig. 3. The questionnaire survey age distribution of cooperating elementary and junior high school guardians in five selected sub-catchments.

(c) The questionnaire allowed for time-series response analysis to understand environmental changes over time in the catchment. For each question, "Increased", "Remained the same", and "Decreased" choices were presented. To analyze the results, the absolute value X of each environmental state was calculated using weighted averages, as follows:

$$X = 100 - \frac{100a}{a+b+c} + \frac{100c}{a+b+c} \quad (1)$$

where a, b, and c represent the number of replies for increased, remained the same, and decreased, respectively. In Eq. (1), when the number of replies for decreased and increased is the same ($a = c$), then state X does not change. That is, it will be a value of 100. On the other hand, if $a > c$, then X becomes smaller than 100. In this way, state X can be transformed into a value that represents its relative increase or decrease over time. Then it becomes possible to quantify this change over time for the entire catchment.

We were concerned about the potential effect of guardian age group on the results. For example, there were many 40-year-olds surveyed (Fig. 3), and relatively few other age groups. To overcome this problem, in the above-mentioned calculation, the range was set as the age applicable to the analysis, and the number of replies from participants within that age range was used, suppressing statistical variation in weighted averages. The reply result according to age of a guardian and the presumed result of serial change of catchment environmental quantity were within an age range of five. The results broken down by year are shown in Fig. 4. These data were used to conduct a time series analysis with adjusted age range, i.e., a cross-correlation analysis of relationships and how they changed in time in each sub-catchment. This analysis made it possible to presume the relationships among environmental factors.

Additionally, the questions regarding the aquatic habitat not only included the terms "Increased", "Remained the same" and "Decreased", but also "No recollection". The number of no recollection responses was defined using the following formula to evaluate the catchment's environmental context "X":

$$X = 100 - \frac{100a}{a+b+c+d+e} + \frac{100c}{a+b+c} - \frac{50d}{a+b+c+d+e} + \frac{50e}{a+b+c+d+e} \quad (2)$$

In formula (2), as in formula (1), when the number of replies for decreased and increased is the same ($a = c$), and the state X does not change ($X = 100$). If $a > c$, then X becomes smaller than 100, and thus the results indicate a tendency of the environmental context to increase over time. The value of the environmental context X displays variation relative to the present value of 100. Thus, as this value changes year by year, the value of the environmental context can be estimated.

The question regarding aquatic habitat included the above choices (increased, remained the same, and decreased) as well as "Remained the same but previously was not habitat" and "Remained the same but previously was habitat". The numbers of responses

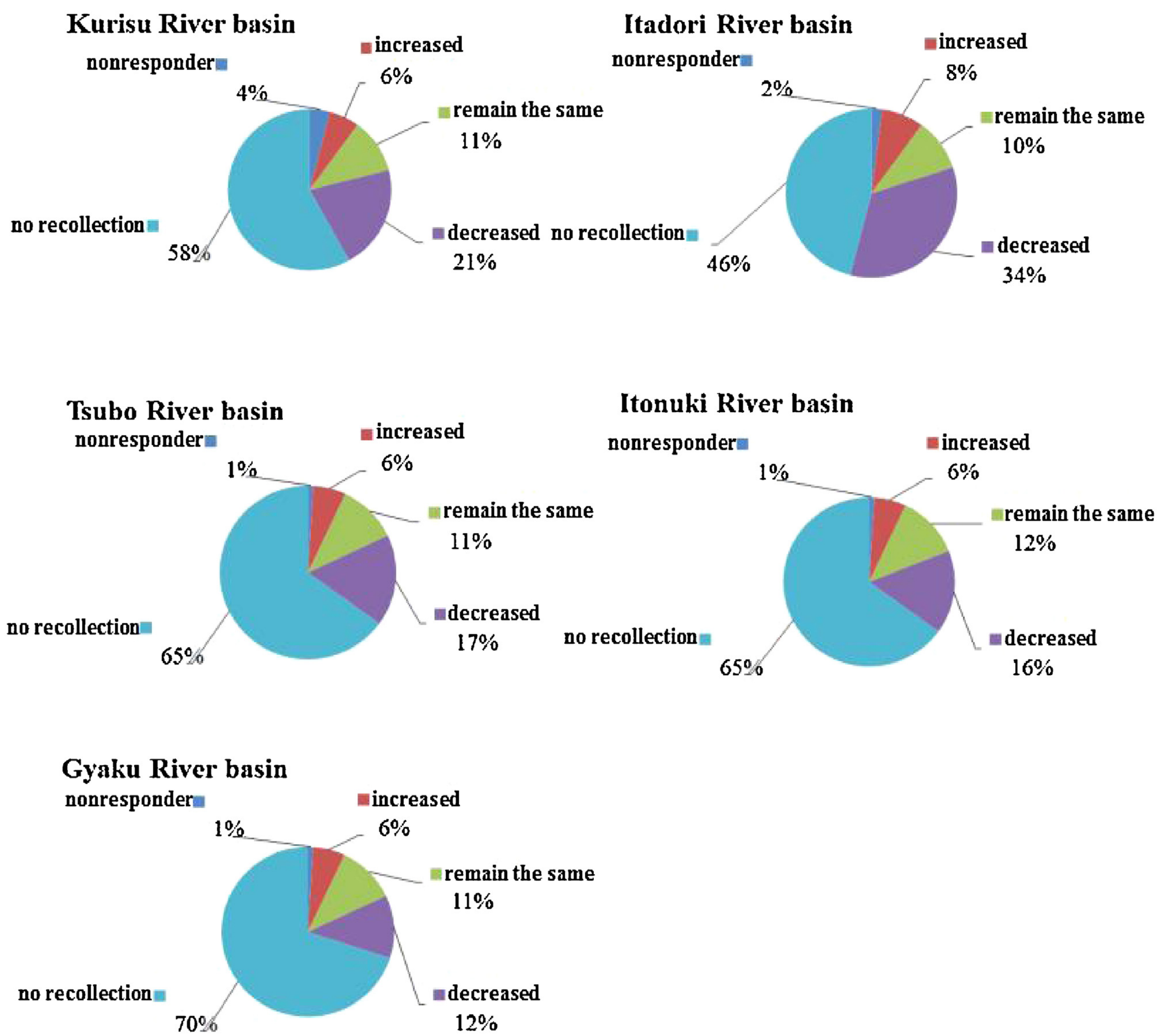

Fig. 4. Replies to change in water depth on the questionnaire survey in five selected sub-catchments.

giving the former and latter choices were defined as "d" and "e". The "d" and "e" choices are considered to be vaguer responses than "a", "b", and "c", and thus the weighting factors used for these terms were half of those used for the other terms. The environmental context variables considered in the survey were "water level", "turbidity", "fish diversity", and "forest management". The relationships between these environmental context variables were estimated using a cross-correlational analysis and the time variation and time lag of these factors were measured.

4. Results

The results of the survey are shown in Table 2. Approximately 17,000 surveys were distributed at 48 schools in the entire catchment (including five sub-catchments), and the response rate was very high (70%).

4.1. Reliability of survey results

The serial change in environmental state was presumed based on respondents' subjective impressions or memories. Therefore, accuracy could be a problem. It would be desirable to scientifically acquire data on each corresponding environmental state and compare it to the questionnaire items to ensure accuracy. However, such data do not exist for every factor analyzed, and thus it is impossible to verify the accuracy of all of the questionnaire results. However, such data do exist for changes in river water levels, and these data were used to analyze the corresponding questionnaire results; this analysis validated their reliability. Fig. 5 compares river water depth as reported by the Ministry of Land Infrastructure and Transport (MLIT) to the results of the survey. There is a 67% correlation between the two sources of data.

However, only approximately 0.1% correlation was found between the survey results for flow quantity and the water depth from the MLIT. The survey asked "Is the depth of water in the river during periods of fine weather different from that in ancient times?". Thus, the respondents may have considered the water level rather than the actual depth of the water. The scientific data, although limited, could confirm the actual phenomenon, following an examination of responses to questions from different perspectives.

Table 2
Questionnaire survey results for the five selected sub-catchments.

Sub-catchment		Municipality	School	Student numbers	Distribution numbers			Quantity of responses			Response rate		
					Student	Parent	Total	Student	Parent	Total	Student	Parent	Total
1	Kurisu River basin (upper stream)	Yamato-cho	Minami junior school	148	75	75	150	62	55	117	82.67	73.33	78.00
			Yamato junior high school	272	100	100	200	45	40	85	45.00	40.00	42.50
		Subtotal		420	175	175	350	107	95	202	61.14	54.29	57.71
2	Itadori River basin (middle stream)	City of Mino	Shinomaki junior school	143	65	65	130	70	62	132	107.69	95.38	101.54
			Kamimaki junior school	124	68	68	136	58	51	109	85.29	75.00	80.15
			Monikita junior high school	169	166	166	332	149	87	236	89.76	52.41	71.08
		Seto village	Seto junior school	111	60	60	120	55	51	106	91.67	85.00	88.33
			Seto junior high school	74	68	68	136	67	57	124	98.53	83.82	91.18
		Itadori village	Itadori junior school	78	35	35	70	27	28	55	77.14	80.00	78.57
			Itadori junior high school	62	57	57	114	56	52	108	98.25	91.23	94.74
		Mugi village	Terao junior school	51	27	27	54	26	9	35	96.30	33.33	64.81
			Mugigawa junior high school	247	227	227	454	169	150	319	74.45	66.08	70.26
		Subtotal		1059	773	773	1546	677	547	1224	87.58	70.76	79.17
3	Tsubo River basin (middle stream)	City of seki	Asakura junior school	513	125	125	250	91	75	166	72.80	60.00	66.40
			Sakuragaoka junior school	417	150	150	300	134	87	221	89.33	58.00	73.67
			Tomino junior school	125	65	65	130	35	34	69	53.85	52.31	53.08
			Midorigaoka junior high school	655	631	631	1262	563	266	829	89.22	42.16	65.69
			Asahigaoka junior high school	489	120	120	240	101	75	176	84.17	62.50	73.33
			Sakuragaoka junior high school	675	250	250	500	0	0	0	0.00	0.00	0.00
			Tomino junior high school	82	84	84	168	69	52	121	82.14	61.90	72.02
			Koganeda junior high school	394	101	101	202	99	70	169	98.02	69.31	83.66
		City of Mugi	Muginishi junior school	88	40	40	80	40	33	73	100.00	82.50	91.25
			Mugihigashi junior school	139	78	78	156	73	54	127	93.59	69.23	81.41
			Mugihi junior high school	164	143	143	286	137	78	215	95.80	54.55	75.17
		Kaminoho village	Kaminoho junior school	100	49	49	98	49	45	94	100.00	91.84	95.92
			Kaminoho junior high school	90	82	82	164	84	68	152	102.44	82.93	92.68
		City of Minokomo	Hachiya junior school	309	145	145	290	103	88	191	71.03	60.69	65.86
			Ibuka junior school	101	13	13	26	13	13	26	100.00	100.00	100.00
			Miwa junior school	40	30	50	80	14	31	45	46.67	62.00	56.25
		Tomika-cho	Tomika junior school	346	180	180	360	158	155	313	87.78	86.11	86.94
			Hutaba junior high school	313	106	106	212	72	39	111	67.92	36.79	52.36
		Subtotal		5040	2392	2412	4804	1835	1263	3098	76.71	52.36	64.49
4	Itonuki River basin (down stream)	City of kitakata	Kitakata junior school	463	253	253	506	211	212	423	83.40	83.79	83.60
			Kitakanishi junior school	225	75	75	150	71	68	139	94.67	90.67	92.67
			Kitakataminami junior school	504	268	268	536	246	122	368	91.79	45.52	68.66
			Kitakata junior high school	568	571	571	1142	428	381	809	74.96	66.73	70.84
		City of Mizuho	Honda junior school	462	231	231	462	228	169	397	98.70	73.16	85.93
			Namazu junior school	334	167	167	334	153	146	299	91.62	87.43	89.52
			Hozumikita junior high school	399	373	373	746	356	188	544	95.44	50.40	72.92
		City of Itonuki	Musiroda junior school	364	189	189	378	185	134	319	97.88	70.90	84.39
			Ishiki junior school	221	107	107	214	105	103	208	98.13	96.26	97.20
			Itonuki junior high school	414	357	357	714	259	257	516	72.55	71.99	72.27
		Subtotal		3954	2591	2591	5182	2242	1780	4022	86.53	68.70	77.61

5	Gyaku River basin (down stream)	City of Hashima	Ajika junior school	271	150	150	300	90	99	189	60.00	66.00	63.00
			Masaki junior school	943	120	120	240	91	26	117	75.83	21.67	48.75
			Takehana junior school	766	378	378	756	283	210	493	74.87	55.56	65.21
			Chuo junior school	790	383	383	766	321	217	538	83.81	56.66	70.23
			Fukujyu junior school	343	172	172	344	162	99	261	94.19	57.56	75.87
			Hashima junior high school	709	35	35	70	7	8	15	20.00	22.86	21.43
			Takehana junior high school	592	600	600	1200	500	336	836	83.33	56.00	69.67
			Chuo junior high school	417	389	389	778	261	209	470	67.10	53.73	60.41
		Kasamatsu-cho	Matsueda junior school	502	233	233	466	189	194	383	81.12	83.26	82.19
		Subtotal		5333	2460	2460	4920	1904	1398	3302	77.40	56.83	67.11
		Total		15,806	8391	8411	16,802	6765	5083	11,848	80.62	60.43	70.52

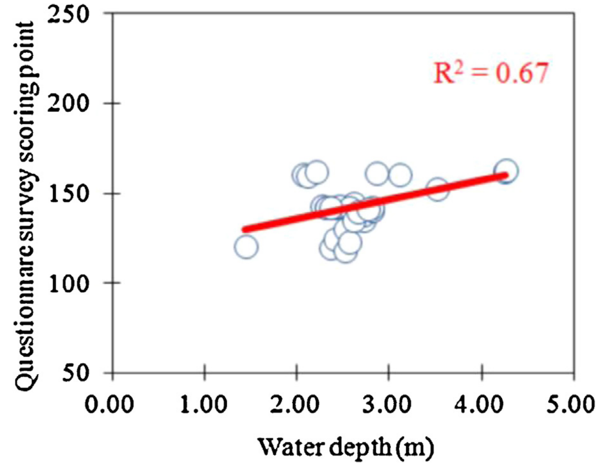

Fig. 5. Annual average water depth levels and comparison of questionnaire results by the Ministry of Land, Infrastructure and Transport (MLIT). Data are from the MLIT.

4.2. Serial changes in the catchment

The serial changes in the dominant environmental factors of the upper and middle areas of three selected sub-catchments are shown in Fig. 6. While diversity and forest management tended to decrease in time, conifer plantation increased, indicating insufficient management. The analysis of sedimentation conditions, including changes in outflow and river turbidity after rainfall, as well as the input of branches and leaves during rains, revealed that sediment levels have increased gradually in time. Habitats also changed in time, and the number of fishes and aquatic insects tended to decrease each year. These changes tended to occur more rapidly during the first half of the 20th century, due to a high number of river-development construction projects.

4.3. Cross-correlation analysis of environmental factors

Cross-correlation analysis was conducted to analyze the relationships among environmental factors and how they changed in time. The results are shown in Fig. 6. Fig. 7 shows how forest management changed in time compared to other select factors, illustrated as a crossing correlogram.

4.3.1. Response relationship between a forest management state and turbidity time of recovery

As shown in Fig. 7 several years after starting a forest management programme, turbidity had dropped/water clarity for upper and middle stream had improved. After 7 years, turbidity time of recovery was lengthy and turbidity recovery speed became slow. After 14 years, turbidity time of recovery became lengthy and turbidity recovery speed became slow. After two decades, turbidity time of recovery was lengthy and turbidity recovery speed became slow; the cross-correlation coefficient was low and factors other than the forest management state were considered to have affected turbidity time of recovery. That is, about 90% of each of the Kurisu and Itadori catchments was forested while only 70% of the Tsubo catchment was forested, the remaining area being arable land (20%) and human developments (10%). This difference in land use may have further delayed turbidity recovery. It is presumed that the difference in the response time of these three sub-catchments was related to forest area because Kurisu, Itadori, and Tsubo had 26, 292, and 195 km^2 of forested area, respectively, and response times of 7 years, 14 years, and 20 years, respectively. Fig. 8 also shows several years after starting a forest management programme, turbidity had dropped/water clarity for down stream

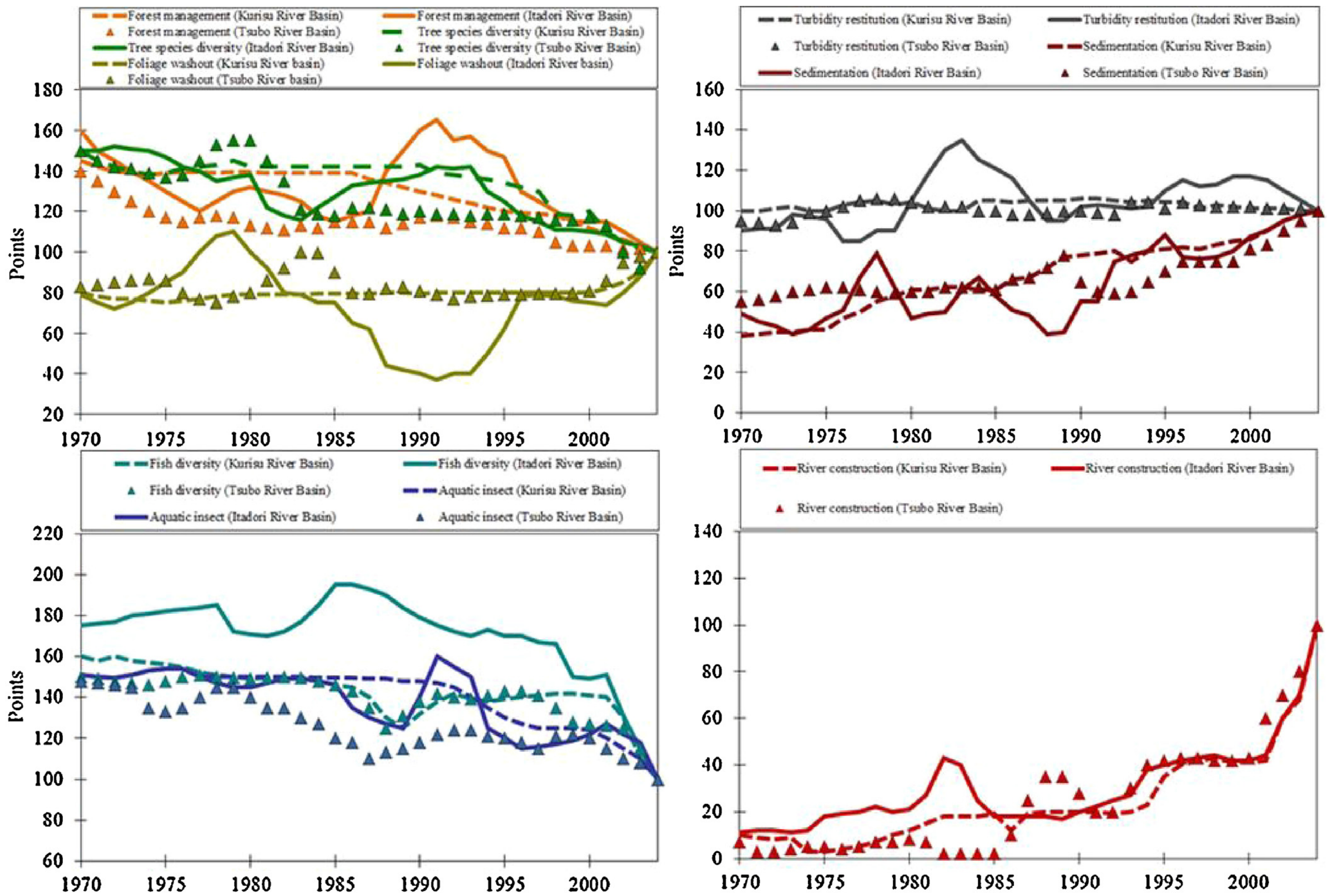

Fig. 6. Serial change of various catchment environmental agents in three selected sub-catchments of the upper and the middle stream of the Nagara River presumed from questionnaire survey results.

had improved, which is specifically shown. After fifteen year, turbidity time of recovery was lengthy and turbidity recovery speed became slow. After twenty-five, although turbidity time of recovery became lengthy and turbidity recovery speed became slow. After a decade, turbidity time of recovery was lengthy and turbidity recovery speed became slow, the cross correlation coefficient was low and factors other than a forest management state were considered to have affected turbidity time of recovery.

4.3.2. Relationship between forest management and sedimentation

Bed load deposition was negatively correlated with forest management after 5 years (refer to Fig. 7). In the Nagara River Basin, forest management decreased after 5 years, and there was a corresponding increase in the amount of sedimentation. It was 21 years until the forest management state fell, and there was a corresponding increase in sedimentation. These results suggest that, like turbidity, sedimentation loads may be affected by other factors in addition to forest management.

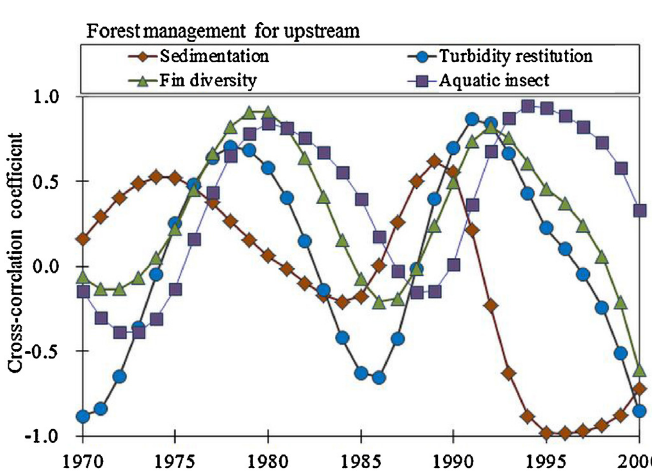

Fig. 7. Response relation of the various catchment environmental agents in a forestry management context in Nagara River upper and middle streams.

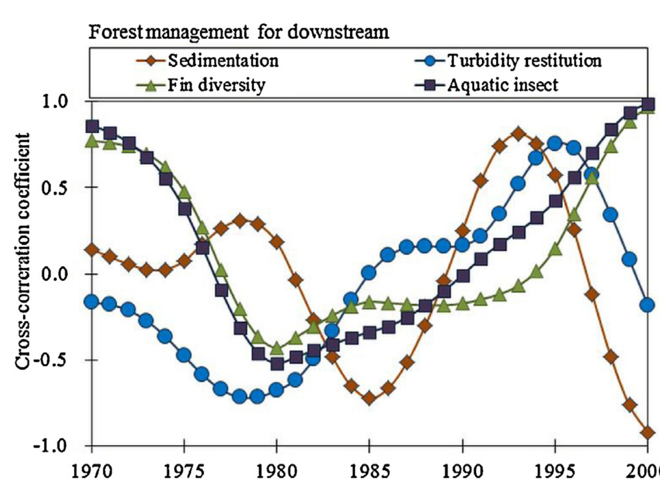

Fig. 8. Response relation of the various catchment environmental agents in a forestry management context in Nagara River down stream.

4.3.3. Relationship between forest management and biotic diversity

Biotic diversity was positively correlated with forest management after a year (refer to Fig. 7). Forest management decreased after 11 years, and the diversity of fish species and benthic insects showed a corresponding decrease. Forest management decreased after 21 years, and fish and benthic insect diversity followed suit. Forest management decreased after 14 years, and fish and benthic insect diversity again showed a corresponding drop.

4.3.4. Relationship between a forest and a catchment environmental agent

In 2001, four sub-catchments of the Yoshida River Basin were added to questionnaire survey results conducted by year, covering specific phenomenon (the turbidity time-of-recovery delay and increase in the amount of sedimentation), biotic diversity regarding an earth-and-sand dynamic state, and related phenomenon (decrease of fish population and the benthic insect population). The relationship between insect populations and area covered by forest is shown in Fig. 9. Conversely, in catchments with higher percentages of cultivated land and buildings, sediment discharge would be less, but the number of species would also be expected to be smaller because of the influence of human activities. The forest serves as a supply source of sediment to downstream regions. A large increase in sediment yield could accompany a decline in forest management and changes in climate and would have a large influence on the biotic diversity of rivers.

5. Discussion

Fig. 6 shows the most important factors leading to environment change in the basin. The results show that worsening conditions accompanied the rapid economic growth in the period after 1970. A number of meaningful answers were provided for this period and the trends in the data can be shown quantitatively. Furthermore, changes in turbidity are clearly correlated with changes in forest management. A clear correlation was also found in the chronological change in forest management and fish diversity. The turbidity and river structure in the channel and the chronological variation in fish diversity also agreed, showing increasing and decreasing tendencies. Each environmental factor was considered in terms of its tendency to exhibit a time delay in its response to changes in other factors.

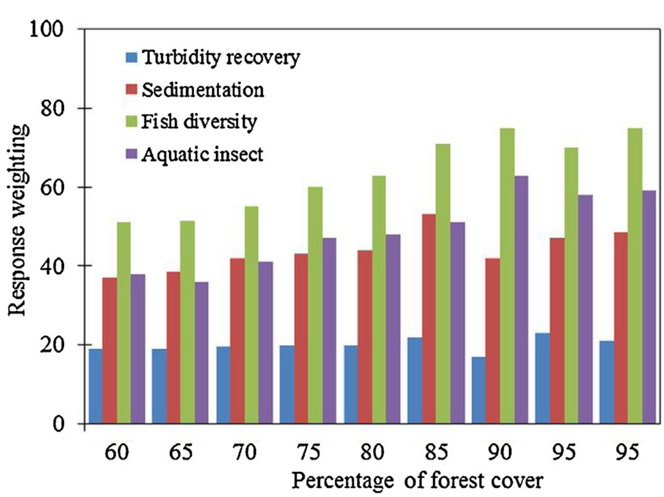

Fig. 9. Relationship between questionnaire survey results regarding forest area rate and various catchment environments of four selected sub-catchments (Kurisu River, Yoshida River, Itadori River, Tsubo River) of the Nagara River upper and middle streams.

We examined the chronological responses by cross-correlation analysis (as shown in Figs. 6–8) and noted which pairs of catchment historical environmental change factors were related to one another. Because of the cross-correlation of factors, further analysis of individual factors was difficult. Therefore, we examined the delay in particularly important combinations of factors. The interrelationships are summarized in Fig. 9. The decrease in water depth, increase in urbanization, and building of a concrete breakwater resulted in decreased transparency during fine-weather periods 2–3 years later and a decline in the groundwater level. A decrease in groundfish occurred 3–6 years later, and respondents indicated that a decrease in the *Plecoglossus altivelis altivelis* migration occurred approximately 10 years later (Mouri et al., 2010a, 2012b). The possible mechanisms of these changes are as follows.

1. Urban development resulted in decreased flows of subsurface water and groundwater because the land surface became more impermeable.
2. The impermeability of the land surface increased, which influenced the base flow to the river. The proportion of surface flow to the river increased during both fine weather and in rainy periods because water flowed over the impermeable land surfaces to the river channel, increasing the direct outflow component.
3. Forest management was a dominant factor influencing the subsurface flow to the river.
4. Construction of river structures decreased the input of subsurface flow; for example, the concrete breakwater interrupted existing flow paths of water below the waterway. The river flowed from outside the catchment through the study site during the non-flood period and drifted outside the catchment to the Nagara River during the flood period, thereby maintaining the quantity of river flow (Mouri et al., 2012b). In recent decades, imperfect forest management has resulted in an increase in the turbidity and decreases in both fish quantity and base flow. The base flow has also been decreased by construction in the river (Mouri et al., 2012b).
5. Urbanization and imperfect forest management have also contributed to a decrease in the base flow.
6. The decrease in the quantity of subsurface flow, as a result of human activity, has resulted in an increase in turbidity.
7. The increase in turbidity in the river water reduced the number of habitats resulting in a decrease in fish diversity.
8. The increase in turbidity was the factor responsible for reducing the quality of the groundwater.
9. As the turbidity of the river water increased, suspended sediment deposited in the riverbed following eutrophication and the cohesive deposition action of organic substances; thus the riverbed become a dysoxic environment. *Misgurnus anguillicaudatus* inhabits the riverbed sedimentation layer and is rapidly affected by a dysoxic environment.
10. After a time lag, the benthic fish species, represented by *Plecoglossus altivelis altivelis*, were influenced by habitation inhibition as water quality deteriorated due to the increased turbidity of the river water.

The catchment environment phenomena were influenced by the predisponency and the incitement. Environmental factors in the catchment were influenced by their tendencies and by direct forces. Human impacts such as river construction projects and declining forest management have been particularly important in recent decades. Such impacts have led to increased turbidity, which has consequently increased sedimentation and decreased aquatic insect populations.

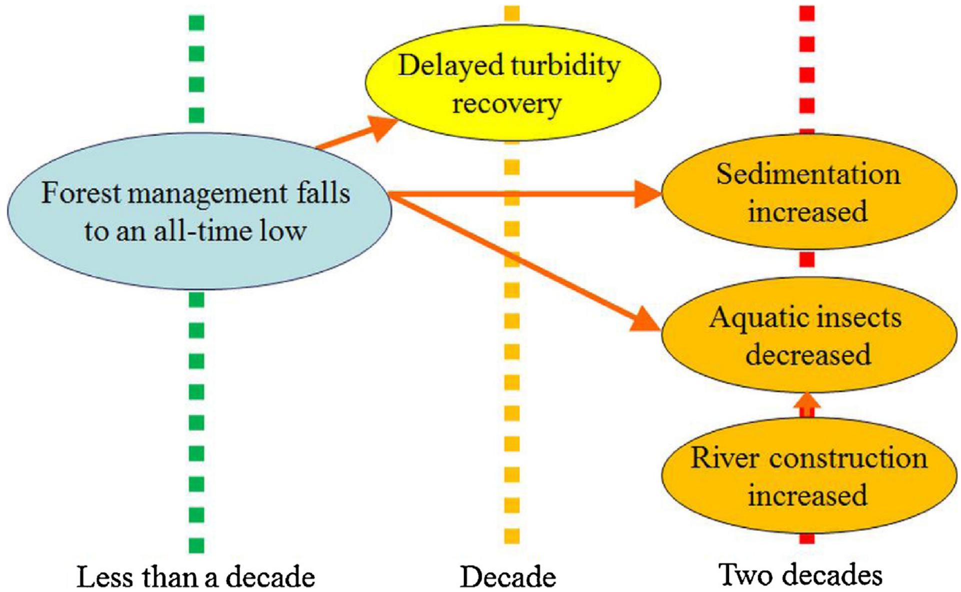

Fig. 10. Response mechanism between various catchment environmental agents of the Nagara River Basin.

6. Conclusions

Fig. 9 summarizes the aspects discussed above. The reduction in biotic diversity of a river can be considered to occur by the following mechanisms. Declining forestry management, such as pruning and tree thinning, is leading to increased amounts of water loss from forests. Therefore, the amount of soil moisture in forests is decreasing and the surface soil is becoming drier. The drying of the soil increases the amount of sediment yield and the amount of sedimentation on a riverbed. There is also a longer delay in the recovery from turbidity resulting from fine-grained sandy soil sand. The cloudiness of the water inhibits habitation by fish such as *Plecoglossus altivelis altivelis* and leads to a decline in the quality of seaweed, which is the staple food of the fish, thereby hampering their growth. An increase in the amount of riverbed sedimentation removes the habitat of benthic insects and has an impact on the carnivorousness fish species that prey on benthic insects. Concrete bank protection reduces the number of benthic insects and fishes for the same reasons as sedimentation. The delayed recovery from turbidity and increased amount of stream bed sediment deposition are not only a consequence of forestry management but also of climate change (especially changes in precipitation patterns)

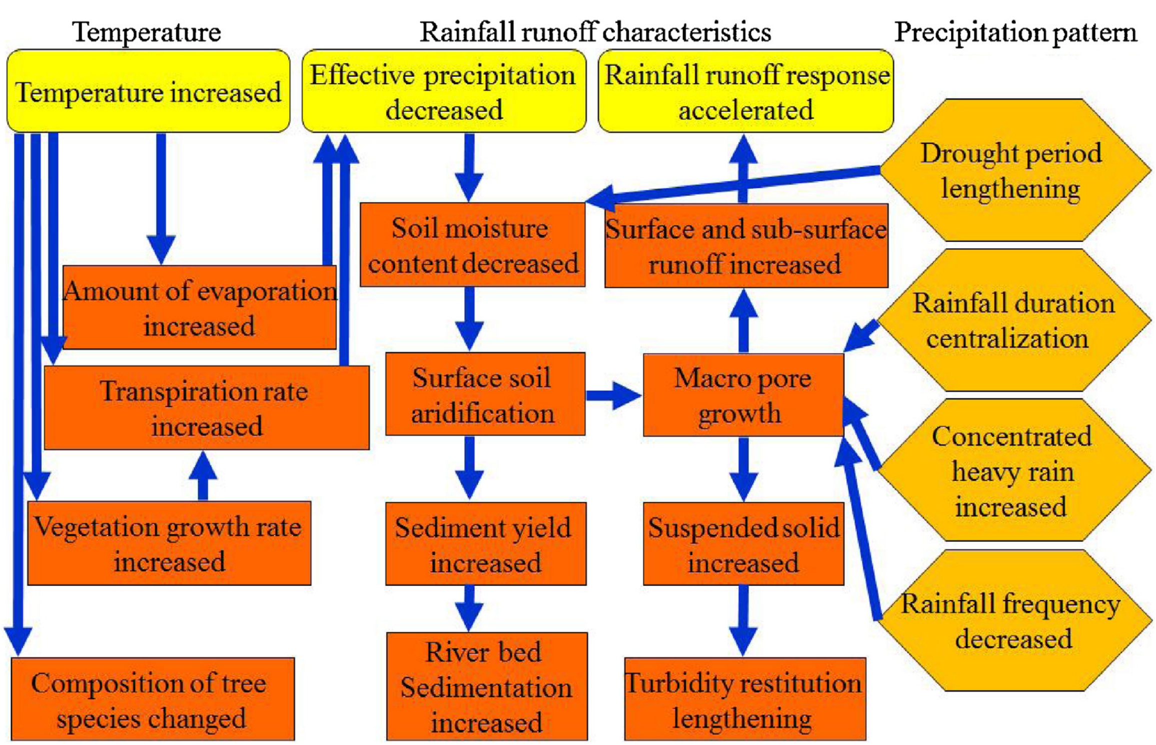

Fig. 11. Long-term change mechanism in a forest environmental context via climate change in the Nagara River Basin.

(Fig. 10). In the present and near future, forestry management will continue to decline, while at the same time global warming will increase. Climate change is also expected to result in the more frequent occurrences of events such as droughts and floods. The synergistic effects of these phenomena may result in serious problems that can currently only be estimated, and thus immediate adaptation based on forest management is recommended (Fig. 11).

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