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Spatio-Temporal Variations of Fish Guilds, Compositions, Water Chemistry and the Ecological Health Assessments in the Artificial Weir

Md. Mamun and Kwang-Guk An*
Department of Bioscience and Biotechnology, Chungnam National University, Daejeon-34134, South Korea
✉ kgan@cnu.ac.kr

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Abstract: The main objectives of this study were to determine how the weir affect spatial and seasonal distribution of fish assemblages and physicochemical water quality as well as chemical and biological health. Summer monsoon was the key determinant in regulating the weir discharge. It regulates the concentration of total phosphorus and total suspended solids in the downstream weir. The water temperature, concentrations of chlorophyll and chemical oxygen demand were increased due to habitat alterations from running to stagnant type. The relative abundance of tolerant fish was the highest in 2012, 2013 and 2014 during spring and fall but in 2017, the relative abundance of intermediate species was the highest during fall only. The constancy value was the highest for tolerant and exotic fish species whereas sensitive and herbivore fish species were disappeared. Due to the construction of weir, the migration of fishes has been disrupted. Therefore, the abundance of lentic type fish species has been increasing whereas lotic type fish species were on the decline. The overall abundance of omnivores and herbivores were dominant in whole study domain. Moreover, the chemical and biological health was in very poor and poor condition, respectively.

Key words: Fish guilds, physicochemical parameters, Juksan Weir, index of biotic integrity.

Introduction

In this century, river management in regulated rivers has been focused on a pressing issue for water managers, scientists, limnologists, and ecologists, in terms of maintaining the physical, chemical, and biological integrity. The natural water flow in rivers play a vital role in connecting the habitats and maintaining the upstream and downstream aquatic biota, support the aquatic ecosystems services for human beings like tourism, recreation, and swimming and also contribute to making the water cleaner which is essential for human use and wildlife (Postel and Richter, 2003; Poff et al., 2010).

The weir construction was addressed from the Korean government's five-year national plan of "Four Major Rivers Project" in July 2009 and invested 17.3 billion dollars (NRR, Korea 2009). The main objectives of the project were securing abundant water resources to solve problems of water scarcity, implementing monsoon-flood control measures, improving the water quality and restoring ecological river health, creating multipurpose spaces for local residents, and regional cultural development centered on the rivers (NRR, Korea 2009). The government tried to secure adequate water supply by constructing 16 weirs in the four major river watersheds among them the two weirs were constructed in the Yeongsan river watershed (NRR, Korea 2009).

*Corresponding Author

Contrary to the primary purposes, the ecological impacts of weir on freshwater systems are widely reported in USA (Holmquist et al., 1998), Canada (Townsend, 1975), United Kingdom (Lucas and Frear, 1997), Norway (Fjellheim and Raddum, 1996), Sweden (Rivinoja et al., 2001), and Australia (Gehrke et al., 2002). The introductions of weir into rivers alter the natural flow and affect the physical habitat, chemical water quality, and biological communities from upstream to downstream which negatively impacted the biodiversity and ecological integrity of rivers worldwide (Poff et al., 1997, 2010). The weir construction into rivers changes the current velocity which causes habitat alteration and converts the lotic ecosystems to lentic types.

The high siltation rates in upstream and leading substrate scouring to downstream weir were observed due to decreased and increased flow velocities, respectively (Bennett et al., 2002). In the downstream of the weir, sharply decrease of the water temperature had happened due to hypolimnion of water release (Clakrkson and Childs, 2000). The water temperature and siltation were increased in the regulated river systems due to low flow (Young et al., 2001). In the regulated river systems, the excessive growth of macrophytes is frequently observed due to reductions of flows (Suren and Riss, 2010). In downstream weir, the spawning areas increased with fine sediments and loss of microhabitats restructure the channel morphology due to high flow (Gopal and Das, 2013). Bank erosion was observed in the downstream weir because of high flow (Jowett, 2001; Gopal and Das, 2013).

The weir affects lotic ecosystems in many ways, and their impacts are often reflected in the spatial and temporal patterns of biological communities (fish, periphyton, and macroinvertebrates). The weir construction can fragment the watersheds and influence the fish assemblages directly by eliminating or reducing movement of fishes and leading to reduced upstream species richness, especially for migratory species (March et al., 2003). The water temperature of the river can be changed after weir construction where fish often reproduce according to specific water temperature thresholds and native fish may be unable to breed in rivers with altered temperatures (Thoms et al., 2000). Fragmentation of the river system by weir alters dispersal patterns of fish populations and converts free-flowing river to reservoir habitat (Young et al., 2001). Anadromous and catadromous fish populations are directly controlled by blocking their river migration routes and hampering their movement from the upstream to the downstream and downstream to upstream (Watt, 1989). Ganapati (1973) suggested that the construction of weirs reduced upstream migrations of shad (*Hilsailisha*) in several rivers in southern India. The salinity of the rivers can be increased after weir construction which can be detrimental to the eggs of some fish species and enough to eliminate native fish species and introduce new exotic species (Peters, 1982).

The weir construction has enormous negative impacts on the river and needs to assess the chemical and biological health of the upstream and downstream weir. Nutrient pollution index (NPI) has been used worldwide to diagnose the chemical health of aquatic ecosystems (Dodds et al., 1998). Total phosphorus (TP), chemical oxygen demand (COD) and chlorophyll (CHL) are the main factors to determine the stream health by using chemical metric-model where TP indicates the nutrient pollution and CHL are responsible for algal blooms in the waterbody (Kim and An, 2015).

Previous studies of US Environmental Protection Agency (EPA, 1993) developed a "rapid bioassessment protocol" (RBP) (Barbour et al., 1999) for diagnosing the stream health based on Index of Biotic Integrity (IBI) model which was originally developed by Karr (1981). These studies proposed that fish is the best indicator; hence can be used to diagnose the stream health as it is easy to collect, identify and spend their entire life in water and show sensitive responses to the change if any of it like chemical pollution or habitat degradation happens.

In Korea, numerous studies reported that hydrological modifications, algal blooms, and summer fish kills had happened due to weir construction in the river (Kim et al. 2009). Thus the government is worried about the deterioration of the river ecosystem. The objectives of the present study were how the weir affects the spatial distribution of fish assemblages and water quality condition and is there any significant variation of fish community structure and water quality condition in seasonally. In addition, we analyzed the chemical and biological health of the upstream and downstream weir based on chemical water quality parameters and fish communities, respectively.

Materials and Methods

Information of Sampling Sites

We collected the sample from three different sampling sites in the Yeongsan River watershed from upstream to downstream of Juksan weir (Figure 1). The watershed area of Yeongsan River is 3371 km^2 and the length of

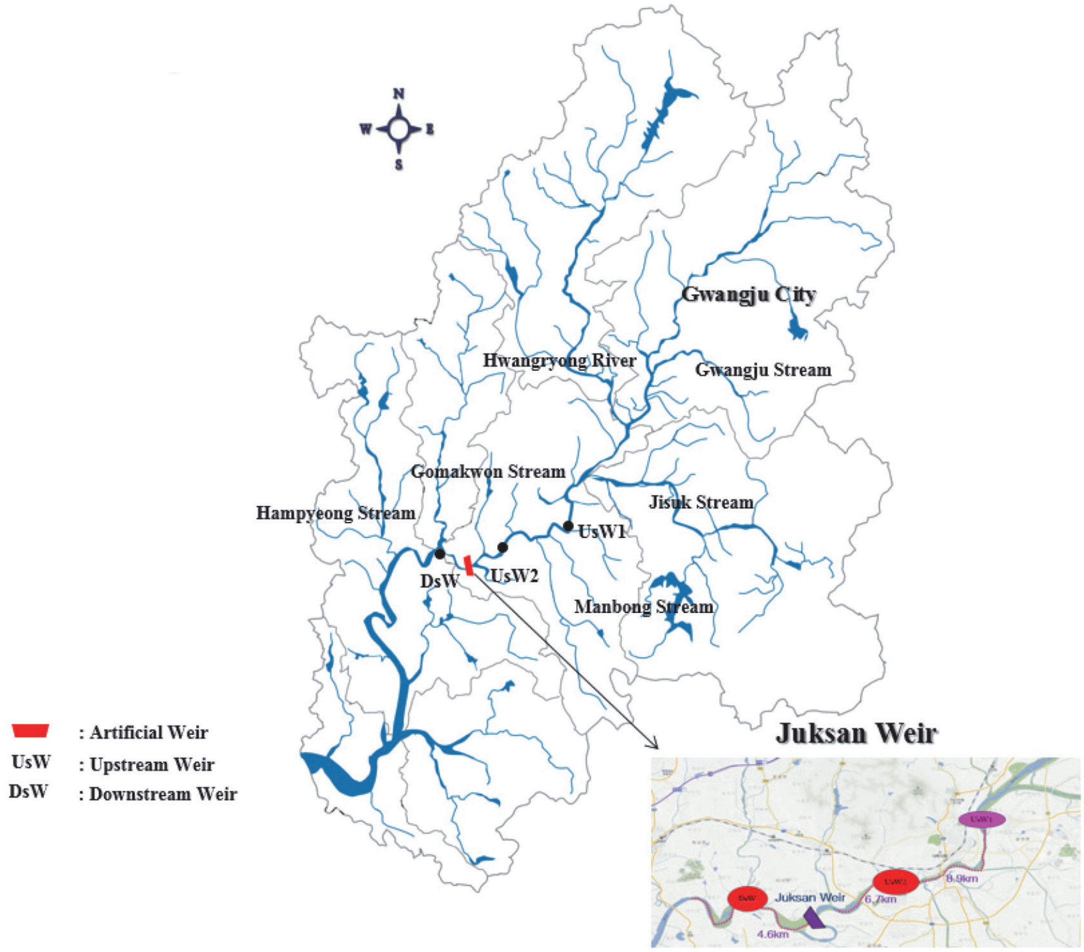

Figure 1: The map showing sampling sites in Yeongsan River watershed. UsW1 and UsW2 are the upstream weirs and DsW is the downstream weir.

the river is 136 km. The Yeongsan River watershed composed of different tributaries includes Hwangryong River, Jiseok stream, Gomakwon stream, Hampyeong stream, Manbong stream, and Gwanju stream. In Yeongsan River watershed, Juksan weir (longitude 12692″'62°; latitude 35°06'48″) was constructed from four major river restoration projects which is 4.85 m tall and 622 m wide and able to manage 3.5 m water level. The Yeongsan River watershed is largely influenced by the non-point pollution sources (rice paddy field, wastewater disposal plants etc.) which is more accelerated by the construction of Juksan Weir (MEK, 2012).

Fish Collections and Sampling Gears

We collected the fish sample in the premonsoon (May) and postmonsoon (September) during 2012, 2013, 2014 and 2017. Fish were collected from all habitats in the upstream and downstream weir of Juksan weir according to the Ohio (EPA, 1989) approach wading method. We used five types of sampling gears like casting nets, kick nets, fyke nets, gill nets, and trammel nets. In the shallow area, we used casting nets (7 × 7 mm) and kick nets (4 × 4 mm) for catching the fish for 60 mins in 200 m distance. In contrast, in deeper area, we used fyke nets (5 × 5 mm), gill nets (45 × 45 mm), and trammel nets (12 × 12 mm) for sampling the fish and fish were sampled after 24 hours installation of the gears. The trophic and tolerance guilds were analyzed based on previous regional studies (An et al., 2004). In exceptional cases, where the fish identification was difficult and detailed investigations were required, fish were kept in 10% formalin solution and transferred in the laboratory and after that identified and classified.

Analysis of Water Quality Parameters

In this study, we used some physicochemical water quality parameters like water temperature (WT°C), pH, dissolved oxygen level (DO), electrical conductivity (EC), total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS), chemical oxygen demand (COD), and chlorophyll (CHL) to see how much they are varied from upstream to downstream weir over the time and how they are correlated with trophic and tolerance guilds. The TN, TP, and TN:TP ratio was calculated as nutrient pollutant indicator. The physicochemical water quality data compiled from the Korean Ministry of the Environment (MEK) on monthly basis during 2012, 2013, 2014 and 2017 (http://water.nier.go.kr). In 2017, the physicochemical water quality data was compiled until August. A portable multi-parameter analyzer (YSI Sonde Model 6600) was used to measure the water temperature (WT^{0}C), pH (hydrogen ion concentration), electrical conductivity (EC) and dissolved oxygen (DO). The chemical testing standard method had been used to measure the TN, BOD, and COD which was adopted by the Ministry of the Environment, Korea (MOE, 2006). The total phosphorus (TP) has been analyzed by ascorbic acid method, which is also standardized by the Ministry of the Environment, Korea (MOE, 2006). Preweighted Whatman GF/C filters method was used for the determination of total suspended solids (TSS). Chlorophyll-a (CHL-a) concentration was measured by using a spectrophotometer (Bechman Model DU - 65) after extraction in hot ethanol (Marker et al., 1980). Nutrient analyses were performed thrice to ensure validity and CHL-a was measured twice.

Chemical Health Assessment Using Nutrient Pollution Index (NPI)

We used nutrient pollution index (NPI) model to assess the chemical health of the upstream and downstream weir which was developed by Kim and An (2015) and MLTM (2012). The NPI model composed of seven metrics such as M_1 – total nitrogen (TN, mgL^{-1}), M_2 – total phosphorus (TP, μgL^{-1}), M_3 – TN:TP ratio, M_4 – chemical oxygen demand (COD, mgL^{-1}), M_5 – total suspended solids (TSS, mgL^{-1}), M_6 – electrical conductivity (μScm^{-1}) and M_7 – chlorophyll (CHL, μgL^{-1}). In NPI, each metrics have been scored as 5, 3 and 1. The chemical health condition of the stream was evaluated by summing up all the scores of metrics and then the chemical health was categorized as Excellent (31-35), Good (25-29), Fair (19-23), Poor (13-17) and Very Poor (7-11).

Biological Health Analysis Using Index of Biotic Integrity (IBI)

In this study, the Index of Biotic Integrity (IBI) model using fish assemblages were used to assess the biological health condition of the upstream and downstream weir according to some previous studies (Karr, 1981; Choi et al., 2011; Kim and An, 2015; An et al., 2006). The IBI model composed of eight metrics like, M_1 – total number of native fish species, M_2 – number of riffle benthic species, M_3 – number of sensitive species, M_4 – proportion of individuals as tolerant species, M_5 – proportion of individuals as omnivore species, M_6 – proportion of individuals as native insectivore species, M_7 – total number of native individuals, and M_8 – percent of individuals with anomalies. Each metric was scored as 5, 3 and 1. The stream health condition was evaluated by five categories based on the obtained scores and the categories are Excellent (36-40), Good (28-34), Fair (20-26), Poor (14-18) and Very Poor (8-13).

Statistical Analysis

Most of the analysis was done in Sigma Plot 10.0 version. The Pearson's correlation analysis was conducted in PAST Software to know how the water quality parameters are correlated with trophic and tolerance guild.

Results and Discussions

Seasonal Water Quality of Physicochemical Parameters

The concentrations of physicochemical water quality parameters varied from upstream to downstream weir depending on the season (Figures 2 and 3). Some previous study pointed out that the weir construction in the river changes the physicochemical water quality, spatially and temporarily (Allan and Flecker, 1993; Thomas, 1996). The water temperature in the upstream weir (UsW) and downstream weir (DsW) did not show any kind of significant changes but it varied seasonally and revealed that the highest water temperature was observed in the monsoon period (UsW – 27.76°C and DsW – 27.17°C) compared to the premonsoon (UsW – 14.17°C and DsW – 16.35°C) and postmonsoon period (UsW – 16.41°C and DsW –27.17°C; Figure 2a) because of the summertime. It is well known that water temperature has a negative correlation with dissolved oxygen. During summer monsoon, heavy rainfall happened which triggered the heavy water discharge, causing lower dissolved oxygen level in the down weir (6.88 mgL^{-1}) than up weir (9.62 mgL^{-1}; Figure 2c). It strongly supports some previous studies on the weir (Young et al., 2001). In upstream weir, the pH level was high compared to downstream weir (Figure 2b). The pH level was lower in down weir (7.35) than up weir (7.98) during the summer monsoon. Electrical conductivity which is literally known as the ion concentration in the waterbody, was lowest in the monsoon season compared to premonsoon and postmonsoon due to rainfall water added into the watersheds (Figure 2d).

The total phosphorus (TP) concentration was highest during monsoon period due to a larger amount of chemicals and fertilizers added from the industrial waste material, urban areas, and agricultural lands to the watersheds (Figure 3a). During monsoon period, the particulate phosphorus was dominant and washed out quickly due to lower water residence time and responsible for the lower chlorophyll growth in the downstream weir (Figure 3a, f). The available nutrients (TP, TN) are responsible for the phytoplankton growth in the upstream weir due to lentic type systems and no light limitation (Figure 3f). The concentration of total nitrogen was lowest in monsoon period due to dilution by the heavy rainfall (Figure 3b). The TN:TP ratios are the indicator of phytoplankton growth and it showed distinct value from upstream to downstream weir depending on the season (Figure 3c).

Monsoon is one of the key determinants which regulates the TN:TP ratios and showed severe P-limitation (An, 2000). Values of total suspended solids (TSS) were lower in the upstream weir whereas it showed higher concentration in downstream weir due to precipitate of TSS which happened in the upstream weir and converted the system from river type (flowing water type) to lake type (stagnant water type; Figure 3d). The TSS concentration was noticeable during monsoon period (29.13 mgL^{-1}) in down weir because the rainfall water came to watersheds (Figure 3d). Our present finding concurred with some previous studies that TSS concentration can increase in downstream weir (Jowett et al., 2005). The chemical oxygen demand (COD) was highest in the upstream weir during monsoon period due to the organic matter added to the watersheds from the industry, agricultural farms or urban household materials (Figure 3e).

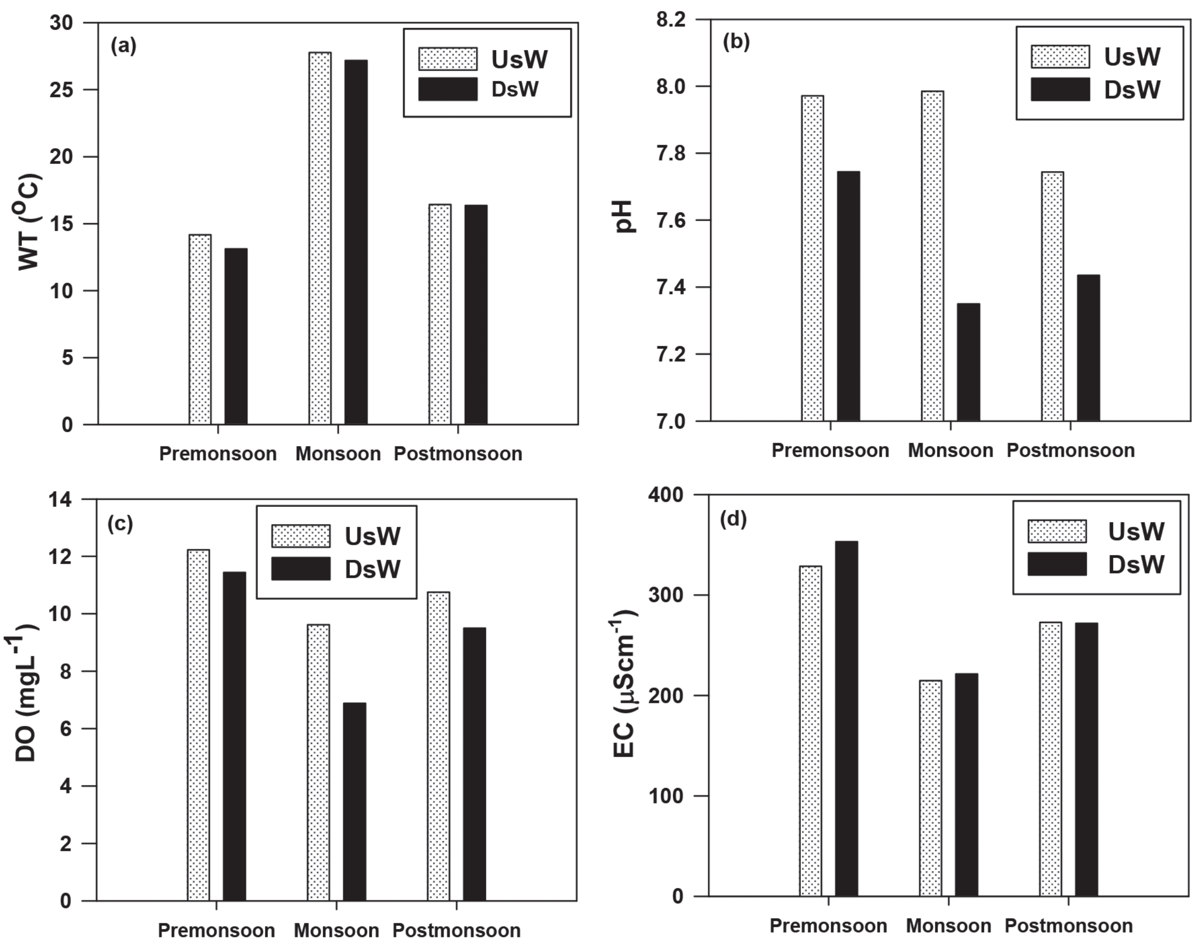

Figure 2: Seasonal variation of physical water quality characteristics in upstream and downstream weirs (UsW – upstream weir, DsW – downstream weir).

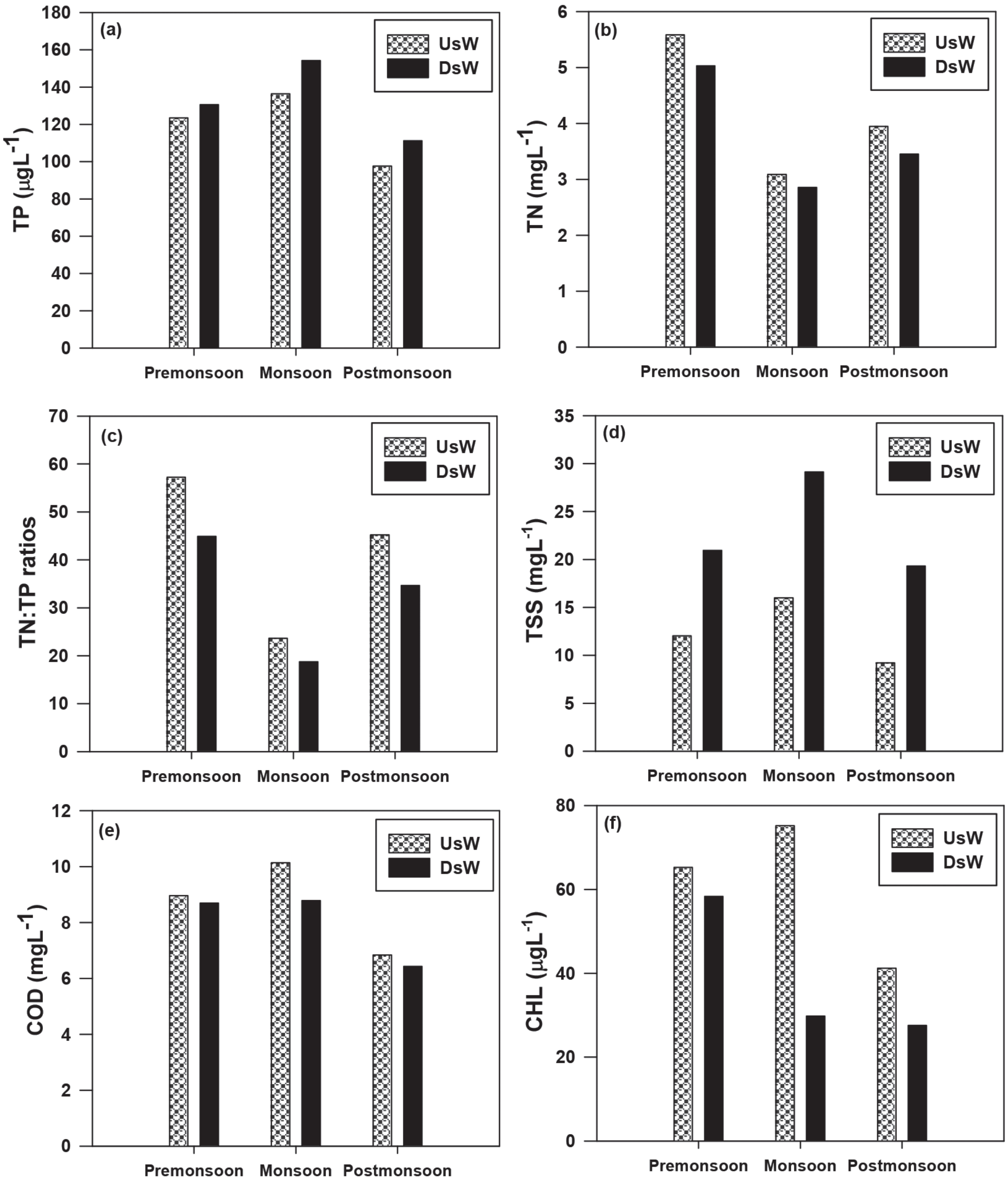

Figure 3: Seasonal variation of nutrients (TP, TN), organic matter and chlorophyll in upstream and downstream weirs (UsW – upstream weir, DsW – downstream weir).

Inter-Annual Seasonal Characteristics of Tolerance and Trophic Guilds

According to the analysis of tolerance guilds during the study period (2012, 2013, 2014 and 2017), there is no evidence of sensitive fish species (Figure 4). The relative abundance of tolerance fish species was dominant compared to intermediate fish species in 2012, 2013 and 2014 during spring and fall seasons while it was different in 2017 and showed that intermediate fish species was dominant during the fall season (Figure 4a, b). So, the weir has consistently negative impacts to the tolerance guilds and generally increase the tolerant fish species composition (Musil et al., 2012; Alexandre and Alemida, 2010).

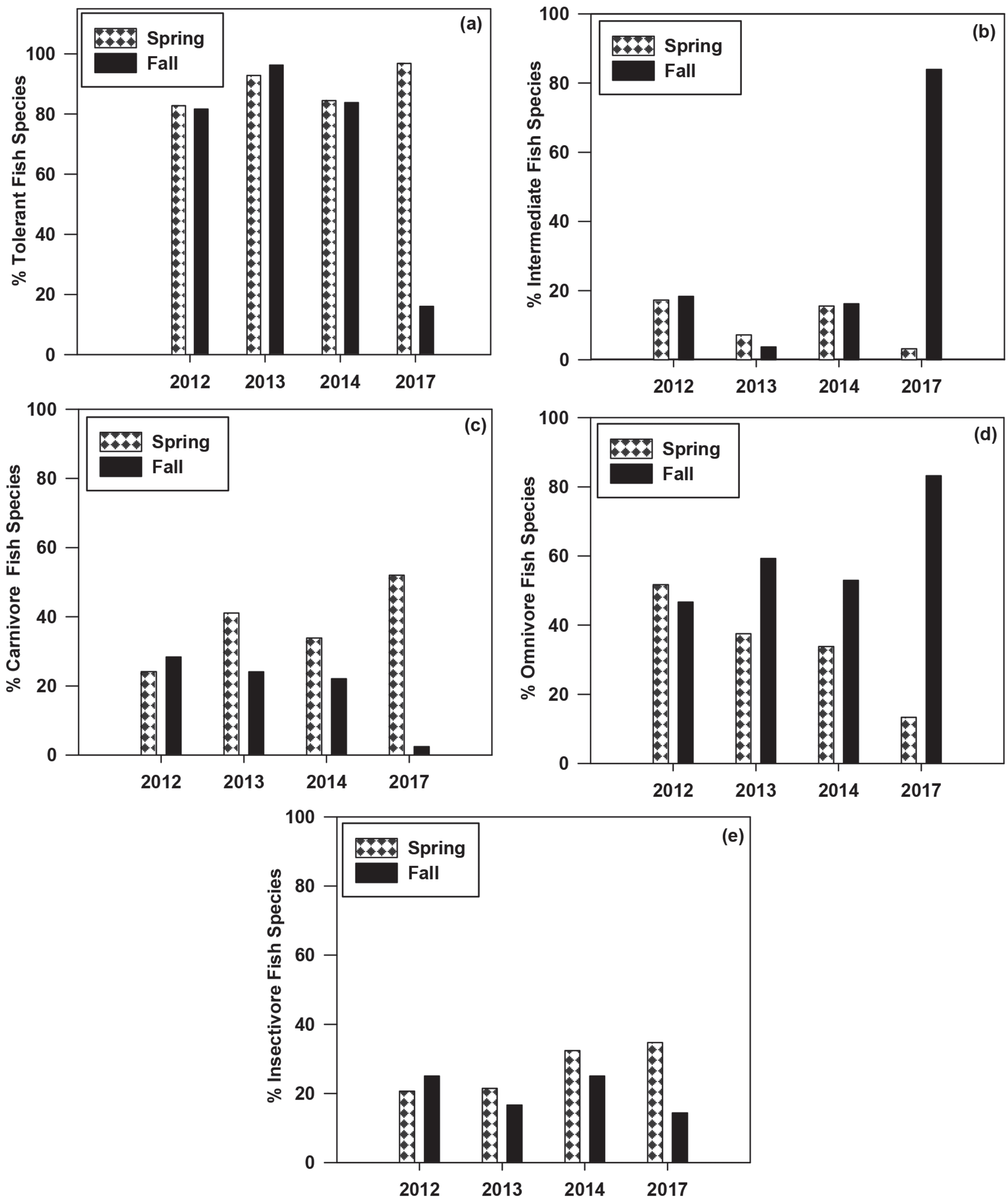

Figure 4: Inter-annual seasonal variation of tolerance and trophic guilds analysis.

The trophic guilds analysis indicated that the relative abundance of herbivore species was only present in 2012 and after that it disappeared (Table 1). According to trophic guilds analysis, the number of omnivore fish species was increasing from 2012 to 2017 during the fall season (Figure 4d). The carnivore fish species was all-time highest in abundance during the fall season in 2013, 2014 and 2017 (Figure 4c). The abundance

Table 1: Fish species composition and relative abundance of fishes in the artificial weir of Yeongsan river watershed on the basis of year and seasonal variation

Fish Species	*To*	*Tr*	*Ha*	*2012*		*2013*		*2014*		*2017*		*TNI*	*RA(%)*	C_V
				P_{RE}(RA%)	P_{OS}(RA%)	P_{RE}(RA%)	P_{OS}(RA%)	P_{RE}(RA%)	P_{OS}(RA%)	P_{RE}(RA%)	P_{OS}(RA%)			
Squalidus chankaensis tsuchigae	IS	O								42(2.19)	5438(83.06)	5480	62.26	0.25
Lepomis macrochirus/	TS	I		1(3.45)	4(6.67)	8(14.29)	7(12.96)	12(16.9)	9(13.24)	635(33.14)	927(14.16)	1603	18.22	1
Micropterus salmoides/	TS	C		5(17.25)	13(21.66)	21(37.6)	10(18.51)	19(26.76)	15(22.06)	986(51.47)	100(1.53)	1169	13.28	1
Squalidus japonicus coreanus	TS	O								166(8.66)		166	1.88	0.12
Zacco platypus	TS	O		13(44.82)	21(35)	15(26.79)	15(27.78)	18(23.35)	21(30.88)			103	1.18	0.75
*Coilia nasus**	IS	C								2(0.1)	50(0.76)	52	0.59	0.25
Carassius auratus	TS	O		1(3.45)	5(8.34)	4(7.16)	13(24.07)	4(5.64)	8(11.76)	13(0.68)	1(0.01)	49	0.55	1
Pseudogobio esocinus	IS	I		5(17.25)	11(18.33)	4(7.15)	2(3.71)	10(14.08)	7(10.29)			39	0.44	0.75
Opsarichthys uncirostris amurensis	TS	C		2(6.89)	4(6.66)	2(3.57)	3(5.56)	5(7.05)		5(0.27)	7(0.1)	28	0.31	0.87
Rhinogobius brunneus	TS	I	RB							23(1.2)	3(0.04)	26	0.29	0.25
Hemicultereigenmanni	TS	O			2(3.34)		2(3.71)	2(2.82)	2(2.95)	15(0.79)	2(0.03)	25	0.28	0.75
Acanthorhodeus macropterus	IS	O								13(0.68)		13	0.14	0.12
Cyprinus carpio/	TS	O		1(3.44)		2(3.53)	2(3.71)		2(2.95)	1(0.05)		8	0.09	0.62
Hemibarbus labeo	TS	I								6(0.31)	2(0.03)	8	0.09	0.25
Acanthorhodeus gracilis	IS	O								3(0.15)	2(0.03)	5	0.05	0.25
Pseudobagrus fulvidraco	TS	I									5(0.07)	5	0.05	0.12
Rhodeus uyekii	IS	O							3(4.42)			3	0.03	0.12
Acheilognathus lanceolatus	IS	O									3(0.04)	3	0.03	0.12
Hemibarbus longirostris	IS	I						1(1.4)	1(1.47)			2	0.02	0.25
Misgurnus anguillicaudatus	TS	O								2(0.1)		2	0.02	0.12
Culter brevicauda	TS	C								2(0.1)		2	0.02	0.12
Leiocassis nitidus	TS	I								1(0.05)	1(0.01)	2	0.02	0.25

Channa argus	TS	C									2(0.03)	2	0.02	0.12
Erythroculter erythropterus	TS	C									2(0.03)	2	0.02	0.12
*Mugil cephalus**	TS	H		1(3.45)								1	0.01	0.12
*Anguilla japonica**	IS	C								1(0.05)		1	0.0	0.12
Pseudorasbora parva	TS	O									1	1	0.01	0.12
Tridentigerbrevispinis	IS	I	RB								1	1	0.01	0.12
Total Number of Species				8	7	7	8	8	8	17	17			
Total Nunber of Individuals				29	60	56	54	71	68	1916	6564	8801		

(To - Tolerance guilds, Tr- Trophic guilds, Ha – Habitat guilds, TS - Tolerant fish, IS - Intermediate fish, RB - Riffle benthic fish species, C - Carnivores, I - Insectivores, O - Omnivores, H - Herbivores, \ - Exotic fish, * - Migratory fish, TNI – Total number of individuals, RA – Relative abundance, P_{RE} – Premonsoon, P_{OS} – Postmonsoon and C_V – Constancy value).

of insectivore fish species was showing increasing trend during the spring season in 2012 (20.68%), 2013 (21.41%), 2014 (32.39%) and 2017 (34.70%), respectively (Figure 4e). Analysis of trophic guilds indicated that the weir drastically changes the trophic guilds in the system and making suitable habitat for omnivore and carnivore fish species (Musil et al., 2012; Chick et al., 2006).

Inter-Annual Seasonal Characteristics of Exotic, Lentic, Lotic, Migratory and Riffle Benthic Fish Species

Our present study indicated that the relative abundance of exotic fish species has been increasing day by day which strongly agreed with some previous studies in the similar study area (Figure 5a; Kwak et al., 2016). The abundance of exotic species was highest in 2017 compared to other years (2012, 2013 and 2014) and the composition of exotic species was dominant by large mouth bass during the spring season (Figure 5a, b). The abundance of largemouth bass was highest in all the years than bluegill during the spring season (Figure 5b). Our present study concurred with some previous studies that the weir construction alters the habitat and creates favourable conditions for the exotic fish species especially for carnivore fish species (Musil et al., 2012; Quinn and Kwak, 2003).

The abundance of lotic fish species had been declined while the abundance of lentic fish species had been increasing over the time which was strongly approved that the weir construction in the river reduces the water flow and making the habitat more suitable for stagnant type fish (Figure 5c, d; Kanno and Vokoun, 2010; Kwak et al., 2016). The upstream migration of fishes has been interrupted by the weir construction in the river due to the low level of water and the present research revealed that the anadromous fish (0.77%) has been caught in a significant amount in 2017 during the fall season (Figure 5e; March et al., 2003). The riffle benthic species was also found in 2017 during spring and fall seasons (Figure 5f).

Spatial Seasonal Characteristics of Tolerance and Trophic Guilds

The tolerance and trophic guilds from upstream to downstream weir varied on the basis of the season (Figure 6). During premonsoon, the abundance of tolerant species was dominant in the upstream (UsW – 95.97%) and downstream (DsW – 96.91%) weir as compared to the postmonsoon season (UsW – 17.19%; DsW – 54.79%; Figure 6a). In contrast, the abundance of intermediate species was highest in the upstream (UsW – 82.80%) and downstream (DsW – 45.20%) weir during the postmonsoon season than a premonsoon season (UsW – 4.03%; DsW – 3.08%; Figure 6b). There is no evidence of sensitive species during our study time and suggested that the fragmentation of waterbody make the habitat suitable for tolerant fish species (Alexandre and Alemida, 2010).

Analysis of trophic guilds indicated that the percentage of carnivore fish species was dominant during the premonsoon (UsW – 48.15%; DsW – 56.84%) season than a postmonsoon (UsW – 2.17%; DsW – 43.15%) season in the upstream and downstream weir (Figure 6c). The relative abundance of omnivore fish species was 83.70% during the postmonsoon season in the upstream weir and it was highest compared to the premonsoon season (Figure 6d). The abundance of insectivore fish species during the premonsoon season did not show any kind of significant changes in the upstream (33.90%) and downstream (34.58%) weir while it was increased from upstream (14.12%) to downstream (34.93%) weir during the postmonsoon season (Figure 6e). The abundance of omnivore and carnivore species has been increasing over the time in the upstream and downstream weir due to habitat alteration (Chick et al., 2006).

Spatial Seasonal Characteristics of Exotic, Lentic, Lotic, Migratory and Riffle Benthic Fish Species

The abundance of exotic fish species was in highest number during the premonsoon season in both upstream (79.74%) and downstream (89.98%) weir than a postmonsoon season (UsW – 15.71%, DsW – 37.67%; Figure 7a). The abundance of largemouth bass was highest in the downstream weir during premonsoon (56.16%) season compared to the postmonsoon (8.90%) season (Figure 7b). During the premonsoon season, the abundance of bluegill did not change so much but it showed significant changes during postmonsoon season from upstream (13.77%) to downstream (28.09%) weir (Figure 7b). The lentic type fish species was dominant during the premonsoon and postmonsoon seasons than lotic type fish species due to less water flow after weir construction (Figure 7c, d; Kwak et al., 2016). During the postmonsoon season, in the downstream weir, the abundance of anadromous migratory fish species suddenly increased due to the low level of water (Figure 7e; March et al., 2003). The abundance of riffle benthic species was not high due to habitat alteration in the systems (Figure 7f).

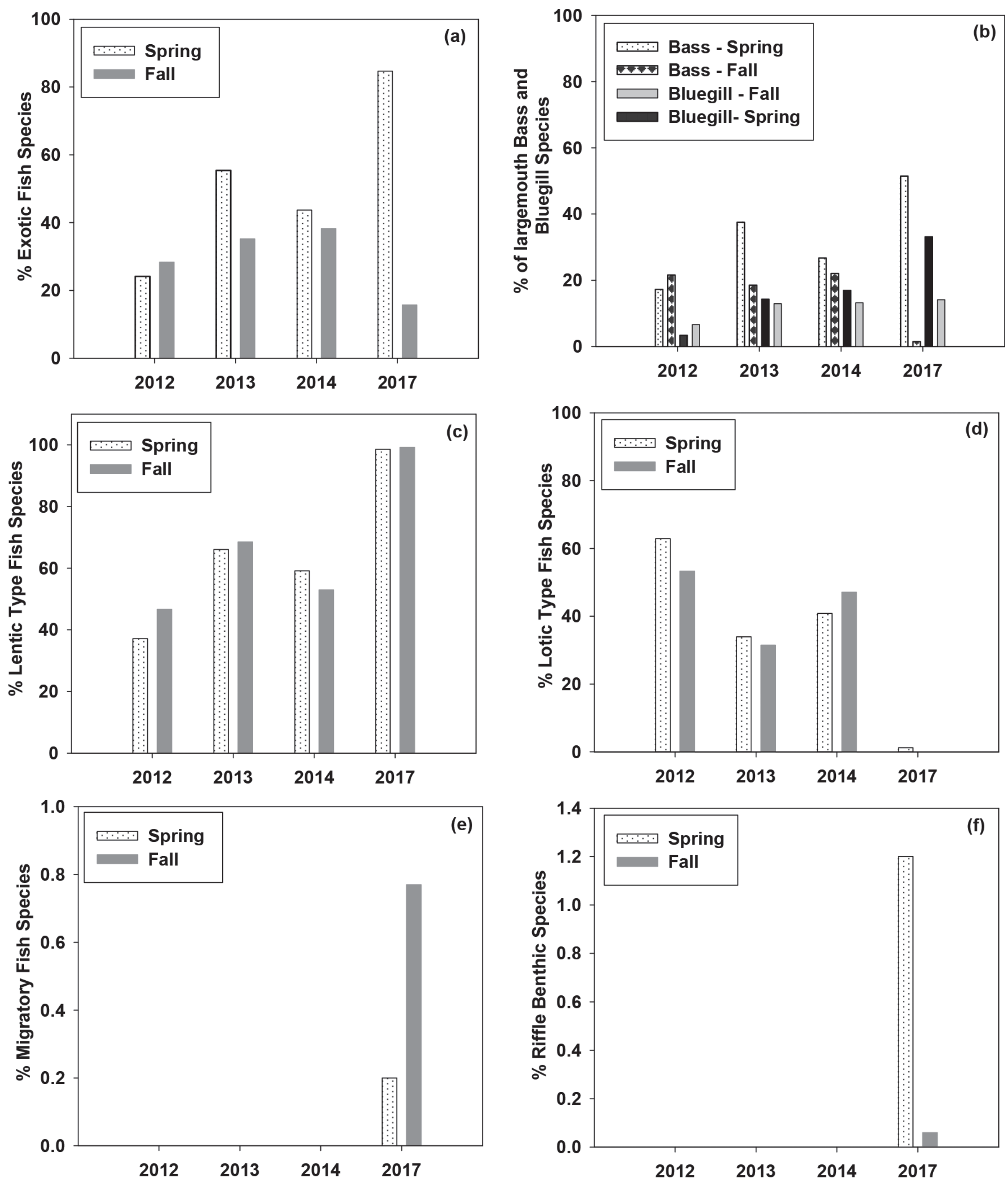

Figure 5: Analysis of inter-annual seasonal variation of exotic, lotic, lentic, migratory and riffle benthic fish species.

Analysis of Species Composition

During the study period, the population of *Squalidus chankaensis tsuchigae* was dominant (62.26%) but their constancy value was low and it was 0.25 (Table 1). Some earlier studies of Yeongsan River watershed indicated that the exotic species did not exist before the 1970s (Wui et al., 1977). Where these two species are sub-dominant species and their abundance likes *Lepomis macrochirus* (18.22%) and *Micropterus salmoides* (13.28%) and their constancy value was high and were 1 (Table 1). In 2012, only one herbivore (*Mugil cephalus*, 0.01%) was found and after that, it disappeared as it was migratory fish (Table 1). The previous report of Juksan weir in 2008 showed that *Zaccoplatypus* was dominant species (47%), but in 2017 it was totally disappeared. It supports that the weir construction

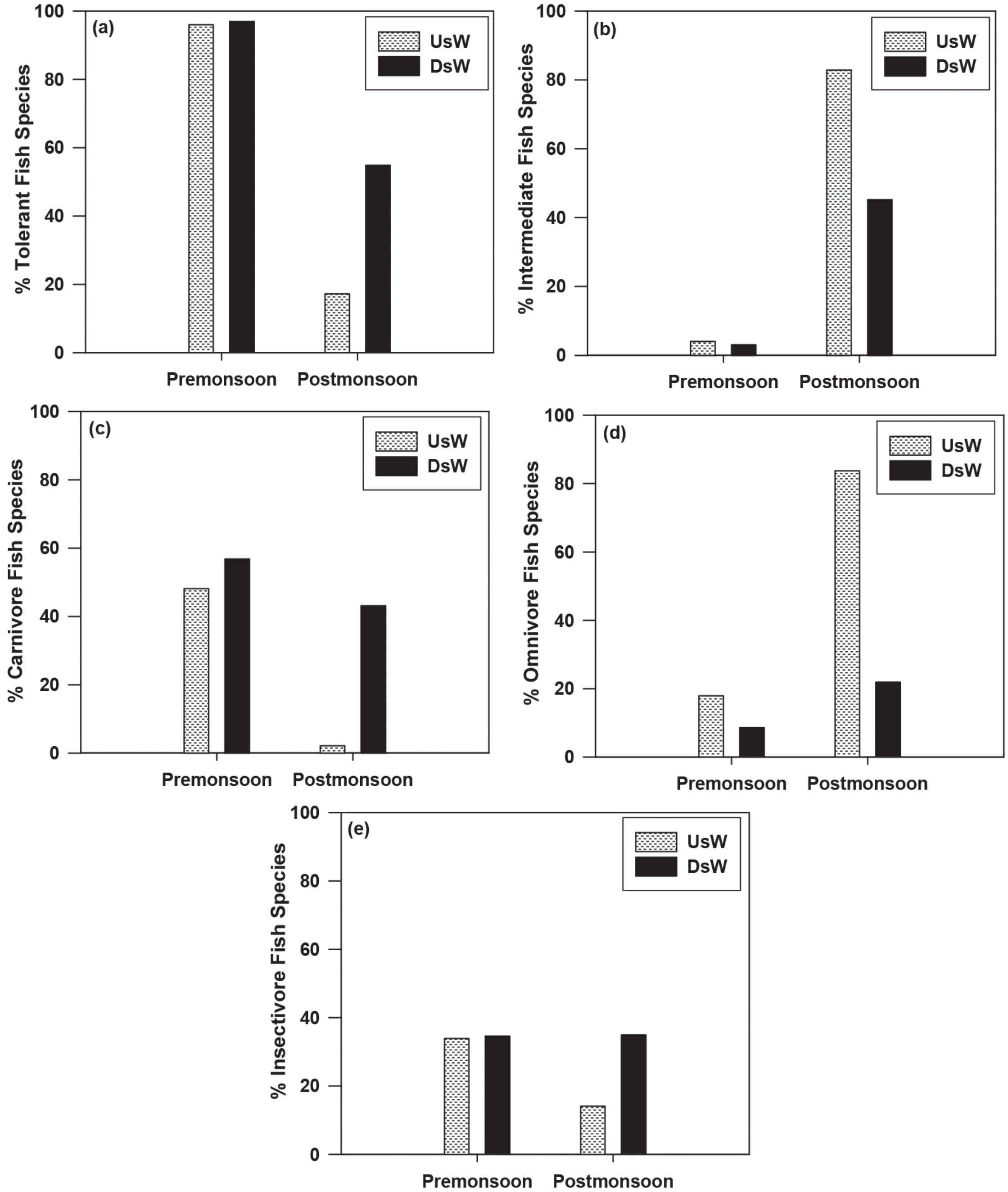

Figure 6: Seasonal variation of tolerance and trophic guilds in the upstream and downstream weirs (UsW – upstream weir; DsW – downstream weir).

changes the habitat and increases the abundance of non-native fishes (Table 1; Kwak et al., 2016; March et al., 2003). Due to reducing the water flow, the anadromous fish, *Coilanasus* was found in 2017 and the abundance was remarkable (0.59%). In 2017, the two riffle benthic species were also found *Rhinogobius brunneus* (0.29%) and *Tridentiger brevispinis* (0.01%). Kwak et al. (2016) reported that in 2011 there were a sensitive species but after 2012 it disappeared due to worse habitat and water quality conditions. The omnivore fish species was dominant indicated that the weir modified the habitat and water quality drastically (Kwak et al., 2016; Smith et al., 2017).

Chemical and Biological Health Assessment

Kim and An (2015) and MLTM, Korea (2012) developed the multi-metric nutrient pollution index (NPI) model which was used to determine the chemical stream health

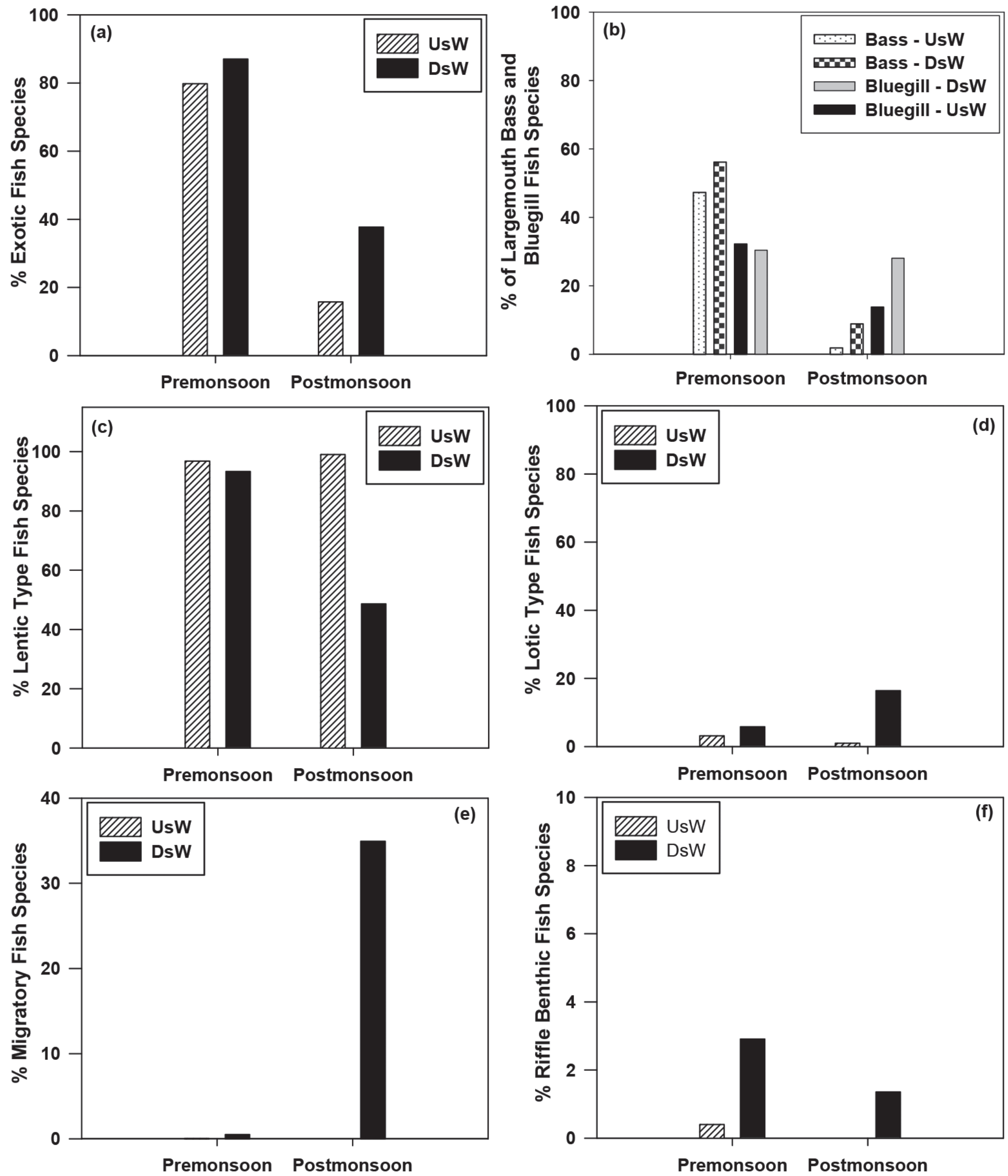

Figure 7: Seasonal variation of exotic, lentic, lotic, migratory and riffle benthic fish species in the upstream and downstream weirs (UsW – upstream weir; DsW – downstream weir).

condition of the Korean watersheds (Table 2). The NPI model was composed of seven metrics (M_1 - M_7) and each metric has been scored as 5, 3 and 1 based on their chemical concentrations. In upstream weir 1 (UsW1), the mean TN, TP, COD, TSS, and CHL concentrations were 4.72±1.84 µgL^{-1}, 131.64±90.40, 8.22±2.10 µgL^{-1}, 11.82±5.63 µgL^{-1} and 61.42±32.04 µgL^{-1}, respectively and indicates that the UsW1 was in eutrophic condition, hence then scored as 1. The UsW2 showed similar scores for TN, TP, TSS and CHL. The mean values of TN:TP and EC were 49.30±25.18 and 289.98±86.16 µScm^{-1}, respectively and scored as 3 in the UsW1. The UsW2 also showed similar scores for UsW2. The sum of all the metrics score indicates the chemical health of the stream. The sum of the NPI scores were 11 for Usw1 and UsW2 while it was 9 for downstream weir (DsW) and categorized as "very poor" condition. In NPI model, TP, TN, and TN:TP ratio are considered as the key determinants regulating the stream health (An and Jones, 2000).

Previous studies suggested that lower N:P ratios (<20) indicates polluted streams (Dodds et al., 1998). Our present study strongly supported the previous research and the upstream and downstream weir were assessed

Table 2: Chemical health assessment of upstream and downstream weir of Yeongsan River watershed using Nutrient Pollution Index (NPI) model

Category	*Model metric*	*Scoring criteria*			*Mean ±SD (Score)*		
					Upstream weir		*Downstream weir*
		5	*3*	*1*	*UsW1*	*UsW2*	*DsW*
Nutrient regime	M_1: Total Nitrogen (mgL^{-1})	< 1.5	1.5-3.0	>3	4.72±1.84 (1)	4.51±1.65 (1)	4.18±1.44 (1)
	M_2: Total Phosphorus (μgL^{-1})	20-40	40-100	>100	131.64±90.40 (1)	115.32±77.21 (1)	129.02±58.44 (1)
	M_3:TN:TP ratios	>50	20-50	<20	43.90±25.18 (3)	48.71±28.81 (3)	37.27±18.53 (3)
Organic matter	M_4: Chemical Oxygen Demand (mgL^{-1})	2-4	5-7	>8	8.22±2.10 (1)	8.69±2.94 (1)	8.04±1.87 (1)
Ionic contents and solids	M_5: Total Suspended Solids (mgL^{-1})	<4	4-10	>10	11.82±5.63 (1)	13.26±1.42 (1)	21.90±10.97 (1)
	M_6: Electrical Conductivity (μScm^{-1})	<180	180-300	>300	289.98±86.16 (3)	299.58±106.58 (3)	305.95±98.75 (1)
Primary production indicator	M_7: Chlorophyll (μgL^{-1})	<3	3-10	>10	61.42±32.04 (1)	60.56±43.39 (1)	44.25±28.25 (1)
Total scores					11	11	9
Chemical health status					Very Poor	Very Poor	Very Poor

UsW – Upstream weir, DsW – Downstream weir

to be "very poor" with respect to their chemical values. The TP, TN and TN:TP ratios are the key regulating factors for the algal production in the waterbody and responsible for the eutrophication (Smith, 1982). Our results showed that UsW and DsW were eutrophied and indicate abnormal health condition. COD is an indicator of organic matter pollution and showed anomalous condition. TSS is responsible for non-algal turbidity in the UsW and DsW. The impaired chemical health condition of the upstream and downstream weir is mainly due to the weir construction which convert the lotic systems to lentic systems.

The index of biotic integrity (IBI) model using fish assemblages were used to diagnose the biological health condition of the stream (Choi et al., 2011; Table 3). There is no evidence of sensitive fish species in the upstream and downstream weir and scored as 1 in UsW1, UsW2 and DsW due to intense chemical and organic pollutants deposited to the upstream and downstream weir after the weir construction in the watersheds. As the weir reduces the natural flow, the concentrations of toxic chemicals and nutrients can increase in the upstream and downstream weir. The overall IBI scores were 18 for UsW1, UsW2 and DsW, which indicate that the biological health was in "poor" condition. The annual analysis of IBI score suggested that the biological health was also in "poor condition" in both upstream and downstream weir (Figure 8). US EPA (1993) and Barbour et al. (1999) disclosed that abundance of tolerant, omnivore and carnivore species was higher while the abundance of sensitive and riffle benthic species was lower in a highly degraded waterbody which supports our present results (Table 3).

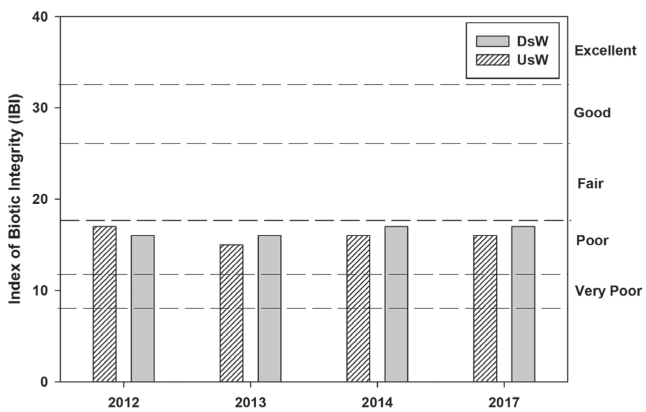

Figure 8: Inter-annual biological health assessment in the upstream and downstream weir of Yeongsan River watersheds (UsW – upstream weir; DsW – downstream weir).

Table 3: Biological health assessment in the upstream and downstream weirs of Yeongsan River watershed using Index of Biotic Integrity (IBI) model

Model category	*Model metric*	*Scoring criteria*			*Upstream weir*		*Downstream weir*
		5	*3*	*1*	*UsW1*	*UsW2*	*DsW*
Species richness and composition	M_1: Total number of native fish species	>20	10-20	<10	14 (3)	19 (3)	15 (3)
	M_2: Number of riffle benthic species	>10	5-10	<5	2 (1)	1 (1)	1 (1)
	M_3: Number of sensitive species	>10	5-10	<5	0 (1)	0 (1)	0 (1)
	M_4: Proportion of individuals as tolerant species	<5	5-20	>20	21.43 (1)	67.66 (1)	90.18 (1)
Trophic composition	M_5: Proportion of individual as omnivore species	<20	20-45	>45	80.70 (1)	39.65 (3)	7.97 (5)
	M_6: Proportion of individuals as native insectivore species	>45	45-20	<20	7.12 (1)	1.63 (1)	6.01 (1)
Fish abundance and condition	M_7: Total number of native individuals	>1000	500-1000	<500	5147 (5)	752 (3)	166 (1)
	M_8: Percent of individuals with anomalies	0	0-1	>1	0 (5)	0 (5)	0 (5)
Overall IBI scores					18	18	18
Biological health status					Poor	Poor	Poor

UsW – Upstream weir, DsW – Downstream weir

Conclusions

In the present study, the nutrient pollution index (NPI) and the biological model of the index of biotic integrity (IBI) was used to assess the ecological health of the upstream and downstream of Juksan weir. Due to the construction of weir, the water temperature, chlorophyll and chemical oxygen demand had been increased; as a result, the abundance of tolerant and intermediate fish species was in higher amount. The constancy value of exotic and tolerant species were higher and the migration of fishes has been disrupted. The overall ecological health of the upstream and downstream of Juksan weir was in abnormal condition and need proper actions for the management.

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