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Population Dynamics of *Zacco platypus* in Gap-Stream and Its Relation with Water Quality

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This study was to provide basic data for aquatic ecosystem research using fishes. Field sampling was carried out at five selected sites of Gap Stream, and fish samples, especially for a selection of sentinel species were collected three times in June, September, and October 2007. We analyzed total length distribution of *Zacco platypus* in relation with the season and the sampling sites, and then compared with total body weight, condition factor (K), and age distribution of the fish. The fish population data were compared with physico-chemical water quality, obtained from the Ministry of Environment, Korea. Water quality analysis showed a significant nutrient enrichment, based on total nitrogen (TN) and total phosphorus (TP), and organic matter pollution, based on biological oxygen demand (BOD) and chemical oxygen demand (COD) in the Site 5, which is directly influenced by wastewater disposal plant (WDP). Population analysis of the sentinel species showed that the total number of individuals, age distribution, and the population size-structure were influenced by the effluents from the WDP, and that reproductive failure of young-age population were evident in Site 5. According to the relation analysis of total weight to K, the disturbed population was mainly attributed to combined effects of habitat modifications and chemical degradations. Regression analysis of K values against water quality parameters showed significant ($p<0.05$) positive relations with nutrient and organic matter contents. Our data suggest that the population structure using a sentinel fish species reflected the ambient water quality in the stream and that diagnosis of aquatic ecosystem health using *Z. platypus* population may be practical for water resource and ecosystem conservations.

Key words : sentinel species, condition factor, fish population, water pollution, stream diagnosis

INTRODUCTION

A variety of internal and external stressors, such as habitat disturbance and nutrients input, incoming to aquatic ecosystem have indirect or direct effects on the structure and components of river ecosystem such as organisms, community, and ecosystem (Adams and Tremblay, 2003). Especially in case of urban stream environments, effluent water of wastewater disposal plants (WDPs) resulted in varieties of problems such as eutrophication, organic matter pollution, and toxic or hazard pollution along with habitat degradations (Lee *et al.*, 2006).

Previous studies on chemical water quality surveys in Gap-Stream (Kang *et al.*, 2000; Bae and An, 2006; Lee *et al.*, 2006) pointed out that the stream has a longitudinal difference of chemical water quality such as nitrogen and phosphorus

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along the main axis of upstream to the downstream (Bae and An, 2006; Lee and An, 2007) and the difference is mainly caused by the point pollution source of the wastewater disposal plants (WDPs) near the downstream (Bae and An, 2006; Lee *et al*., 2008a). For this reason, recently, water quality in the downstream is rapidly worsen as a result of point pollution source caused by industrial complexes and waste water disposal plant, so efficient management is required for the purpose of stream ecosystem conservation and protection. Furthermore, some physical habitat analysis, based on Qualitative Habitat Evaluation Index (QHEI), showed that habitat degradation occurred within the stream depending on the sampling sites (An *et al*., 2001a; Choi *et al*., 2007a; Bae *et al*., 2008; Kim *et al*., 2009) and that the plan of habitat restoration by the government is eminent in the stream.

Biological assessments, based on the bioindicator of fish assemblage (community), in Gap Stream during last several years indicated an impaired health condition by the criteria of index of biological integrity (IBI) (An *et al*., 2001b; Bae and An, 2006). Fishes are top consumers in aquatic ecosystem, have large mobility and sensitively respond to physicochemical changes of habitat (Barbour *et al*., 1999; Byeon *et al*., 2008; Choi *et al*., 2008). And they are affected by physical, chemical and biological changes that continued for a long time and have an wide range of effects on organism level to population, and community levels. For this reason, fishes in Gap Stream were used for diagnosis of water quality, because it is easy to predict influences by pollution source in the aquatic environment (Son *et al*., 1997; Seo, 2005). In this manner, study of aquatic environment management or evaluation using fishes requires long-term data, but past researches of freshwater fishes in Korea were almost about species distribution and community diversity (Choi *et al*., 2006a), so that these studies were insufficient to utilize the fish population dynamics. Recent studies find out population growth, obesity and robustness of fishes using the indices such as length-weight relationship, or condition factor (K) for the understanding of population dynamics. And through some previous studies tried to identify and determine the overall health of river ecosystems (Choi *et al*., 2006b; Choi *et al*., 2006c; Jang *et al*., 2007; Lee *et al*., 2008b), little is known about the fish population studies related to water quality and stream health.

Sentinel species in this study, the pale chub (*Zacco platypus*) usually inhabited riffle and run of midstream region in most of Korean river (Jang *et al*., 2007). This species was usually feed on epilithic periphyton, aquatic insects, and organic matter so that categorized in omnivore and its spawning usually occur during May to July, before monsoon period (Kim and Park, 2002). In addition, they are one of the most wide range of distribution in Korea and more pollution resistant than many other species. Thus, *Z. platypus* is adequate to the purpose of this study that find out the relationship between total length · total weight · condition factor values of the population and physicochemical water quality variables depending on sampling periods and sites. Also, the sentinel species may be effectively used for a key indicator for health assessments in relation to the conventional chemical water quality such as biological oxygen demand (BOD), chemical oxygen demand (COD), and nutrients (Lee *et al*., 2008c). Still, the information of the relationship between physicochemical water quality variables and reproduction · growth of fish population is insufficient. In this study, we analyzed some relations of total length · total weight · condition factor · relative age distribution of *Z. platypus* collected from five sites of Gap-Stream belongs to Geum river watershed, and compared these data with physico-chemical water quality data.

MATERIALS AND METHODS

1. Study sites and periods

Field sampling was carried out at five selected sites of Gap stream. Fish samples were collected three times in June (Pre monsoon, PRE), September (Monsoon, MON), and October (Post monsoon, POS) in 2007. Site 1 (S1) is located in outside of urban area, mainly surrounded by forest and some paddies and ordinary fields beside the stream, and is judged as a good habitat for fishes, based on previous study (Lee and An, 2007). Two sites of S2 and S3 could regard as artificially impacted-locations by nearby human activities in urban area, nutrient and organic inputs, and alteration of riverbed substrate by the urban constructions. Site 4 (S4) is directly influenced by artificial river-restoration construction and S5 had been impacted severely by sewages input from

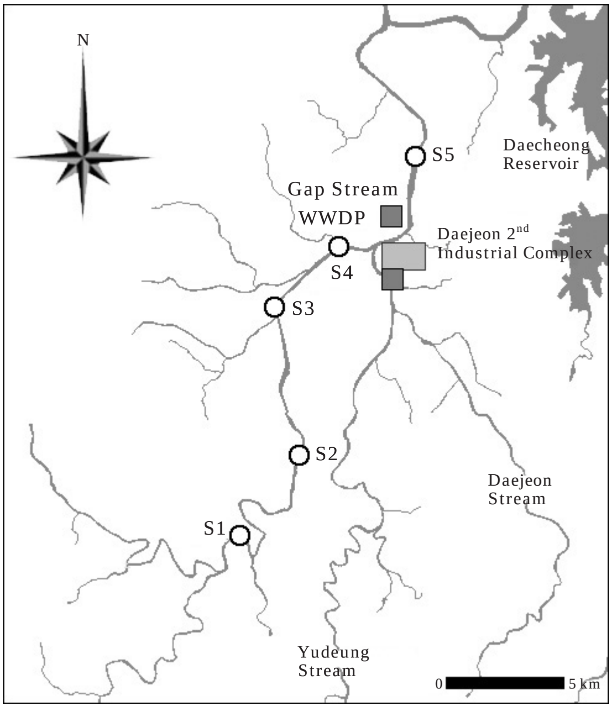

Fig. 1. Sampling sites in the Gap-Stream (S1: 36°16′N, 127°19′E, S2: 36°18′N, 127°21′E, S3: 36°21′N, 127°21′E, S4: 36°22′N, 127°22′E, S5: 36°24′N, 127°24′E).

the wastewater disposal plant so that it seems to be hardly contaminated. The sampling sites of Gap Stream are as follows:

S1: Bongoek 2nd bridge, Bongoek-dong, Seo-gu, Daejeon (3rd order)
S2: Gasuwon bridge, Jeongnim-dong, Seo-gu, Daejeon (4th order)
S3: Manyeon bridge, Wolpyeong-dong, Seo-gu, Daejeon (4th order)
S4: Daedeok bridge, Samcheon-dong, Seo-gu, Daejeon (4th order)
S5: Gapcheon bridge, Jeonmin-dong, Yuseong-gu, Daejeon (5th order)

2. Sampling methods

At the five sites, fishes were collected from all types of the habitats including riffle, run and pool according to the Wading method (Ohio EPA, 1989), modified by An *et al.* (2001). At each sampling location, stream distance sampled was 200 m and the sampling time elapsed was 50 minutes. For the fish capture, we used the sampling gears such as cast net (mesh 5×5 mm) and kick net (4×4 mm). Fish species collected were identified according to the methods of species identification (Nelson, 1994; Kim and Park, 2002). *Z. platypus* among fish species collected were transported to the laboratory with ice, and then total length and weight were measured.

3. Analysis of fish population

In this study, we analyzed condition factor (K) of sentinel species as a diagnostic measure of population health to determine the diverse physical, chemical, biological effects on the stream ecosystem.

1) Condition factor (K)

The condition factor or Ponderal Index expresses the condition of fish, such as abundance of food, and explained by high energy accumulation (Seo, 2005). Fulton-type condition factor (K) is generally explained as follows, and compared with length-weight relationship (Jang *et al.*, 2007). The equation by Anderson and Neumann (1996) is as follow:

$$K = T_W (T_L^3)^{-1} \times 10^n \ (n=2)$$

T_L indicates total length (mm), and T_W indicates total weight (g).

2) Relative age distribution

We analyze relative age distribution of *Z. platypus* population, was categorized using a total length (T_L) of fish. The age intervals (I-XV, unit=mm) as follows.

I: 21～30, II: 31～40, III: 41～50, IV: 51～60, V: 61～70, VI: 71～80
VII: 81～90, VIII: 91～100, IX: 101～110, X: 111～120, XI: 121～130
XII: 131～140, XIII: 141～150, XIV: 151～160, XV: 161～170

4. Physico-chemical water quality analysis

Total six parameters including biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), suspended solids (SS), and electric conductivity (EC) were analyzed in this study. We analyzed one year monthly dataset from January 2007 to December 2007 or dataset of three months (June, September, and October), obtained from water quality monitoring network (http://water.nier.go.kr/weis) of Ministry of Environment, Korea (MEK).

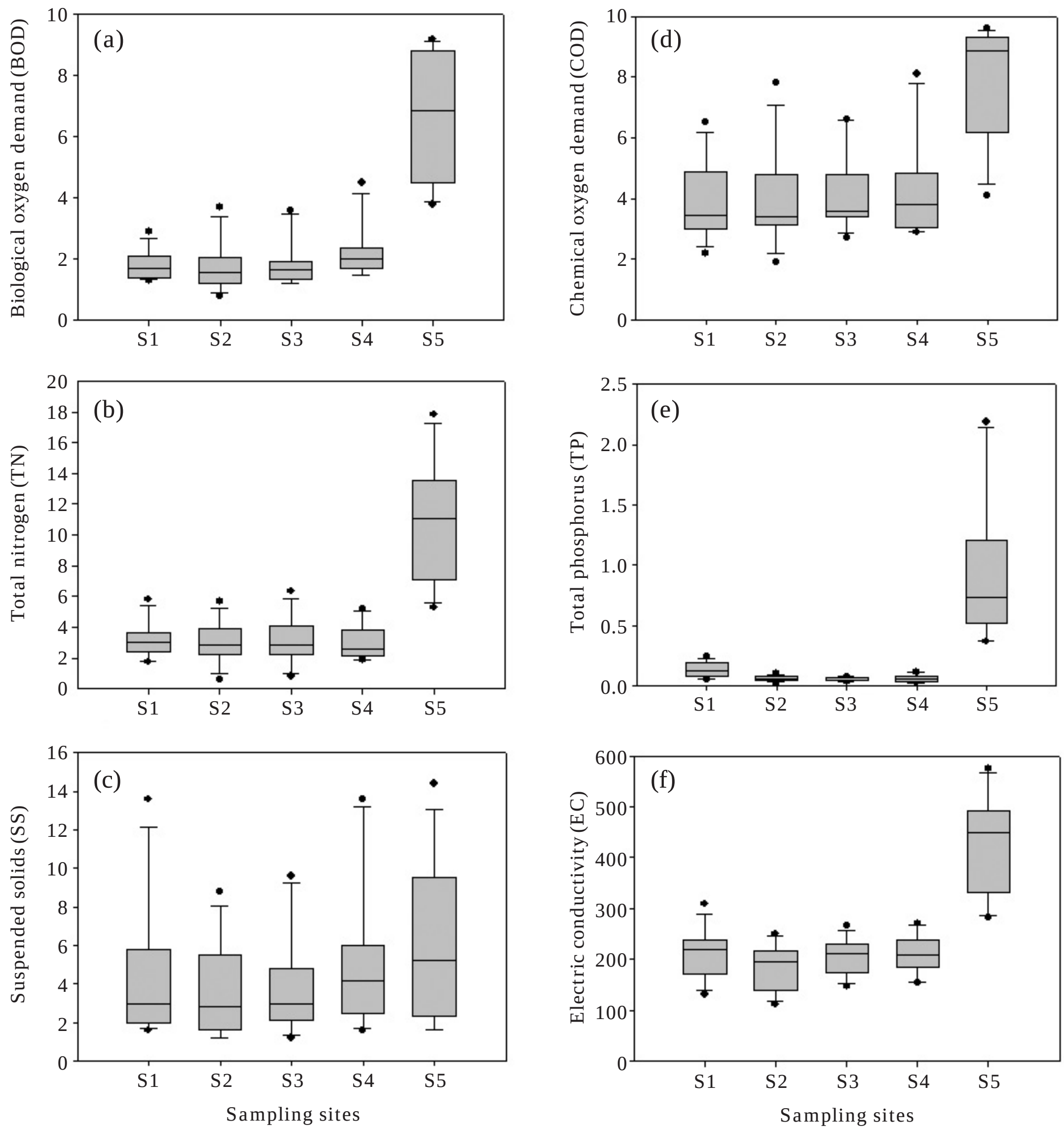

Fig. 2. Chemical water quality in the five sampling sites.

The criteria of physico-chemical water quality was based on 7-rank system by the Ministry of Environment, Korea.

RESULTS AND DISCUSSION

Water quality showed distinct longitudinal gradient of water quality along the main axis of headwater-to-the downstream in the Gap-Stream and the largest difference occurred in the downstream region. Organic matter pollutions, based on biological oxygen demand (BOD) and chemical oxygen demand (COD), were not significant in the upstream regions (S1~S3) but most pronounced in the downstream site (S5, Fig. 2a, d), which is influenced by the wastewater disposal plants (WDPs); mean values of BOD and COD were <3 mg L^{-1} and 4.5 mg L^{-1}, respectively in the upstream regions of S1~S3, but values were reached up to 6.7 mg L^{-1} in BOD and 7.9 mg L^{-1} in COD (Fig. 2a, d).

Nutrients of total nitrogen (TN) and total phosphorus (TP) in the stream showed similar pattern with BOD and COD (Fig. 2a, b, d, e), but the difference between the upstream and downstream was much greater than the differences in BOD and COD. Mean TN was 3.2 mg L^{-1} at the Site 1,

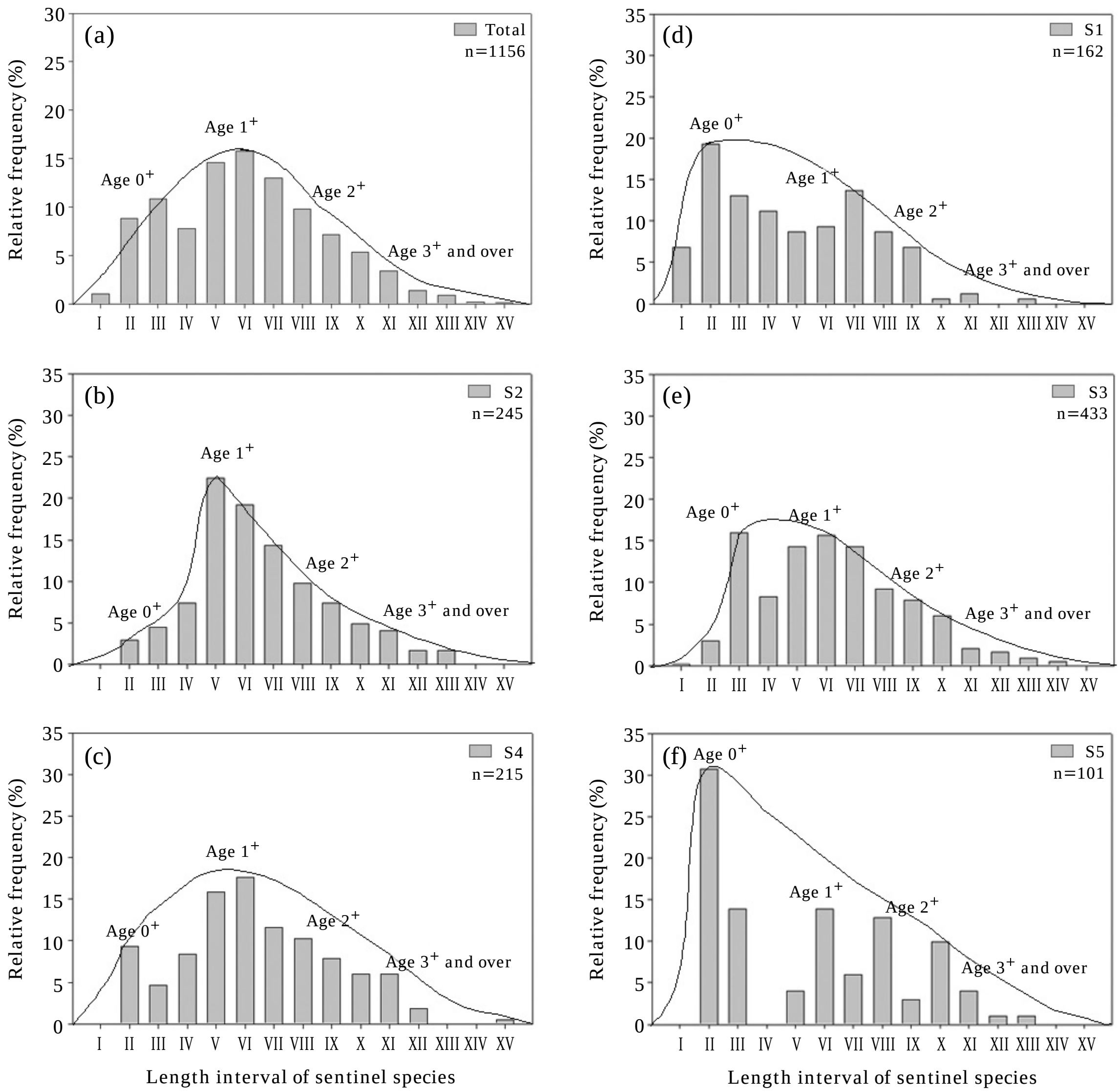

Fig. 3. Relative age distribution of *Z. platypus* by sampling site in relation to 15 total length interval of I (21~30 mm)~XV (161~170 mm). The curve indicates the overall tendency of age distribution. (a): Total sampling sites, (b): S2, (c): S4, (d): S1, (e): S3, (f): S5.

but increased up to 11.0 mg L^{-1} in the Site 5 near the WDP (Fig. 2b), resulting in difference of 5-fold between the two sites. Similarly, mean TP was 135 μg L^{-1} at the Site 1, but increased up to 963 μg L^{-1} at the Site 5 (Fig. 2e), resulting in difference of 5-fold between the two sites. This result indicates that nutrient enrichment was evident in the downstream location. Suspended solids (SS) averaged 4.6 mg L^{-1} and ranged from 3.5 mg L^{-1} to 5.9 mg L^{-1} depending on the sampling sites (Fig. 2c), indicating low spatial gradient compared to the nutrients of TN and TP. Electrical conductivity (EC) averaged 250 μS cm^{-1} during the study and showed a large spatial variations between the upstream (213 μS cm^{-1}) and downstream site (429 μS cm^{-1}, Fig. 2f). The higher ions in the downstream are due to direct wastewater discharge from the WDP (Bae and An, 2006). Thus, there were significant differences ($p < 0.05$) in the BOD, COD, TN, TP, and electrical conductivity (EC) between S5 and other sites (S1~S4), indicating distinct influences of wastewater on the stream water from the WDP.

Relative age distribution of sentinel species,

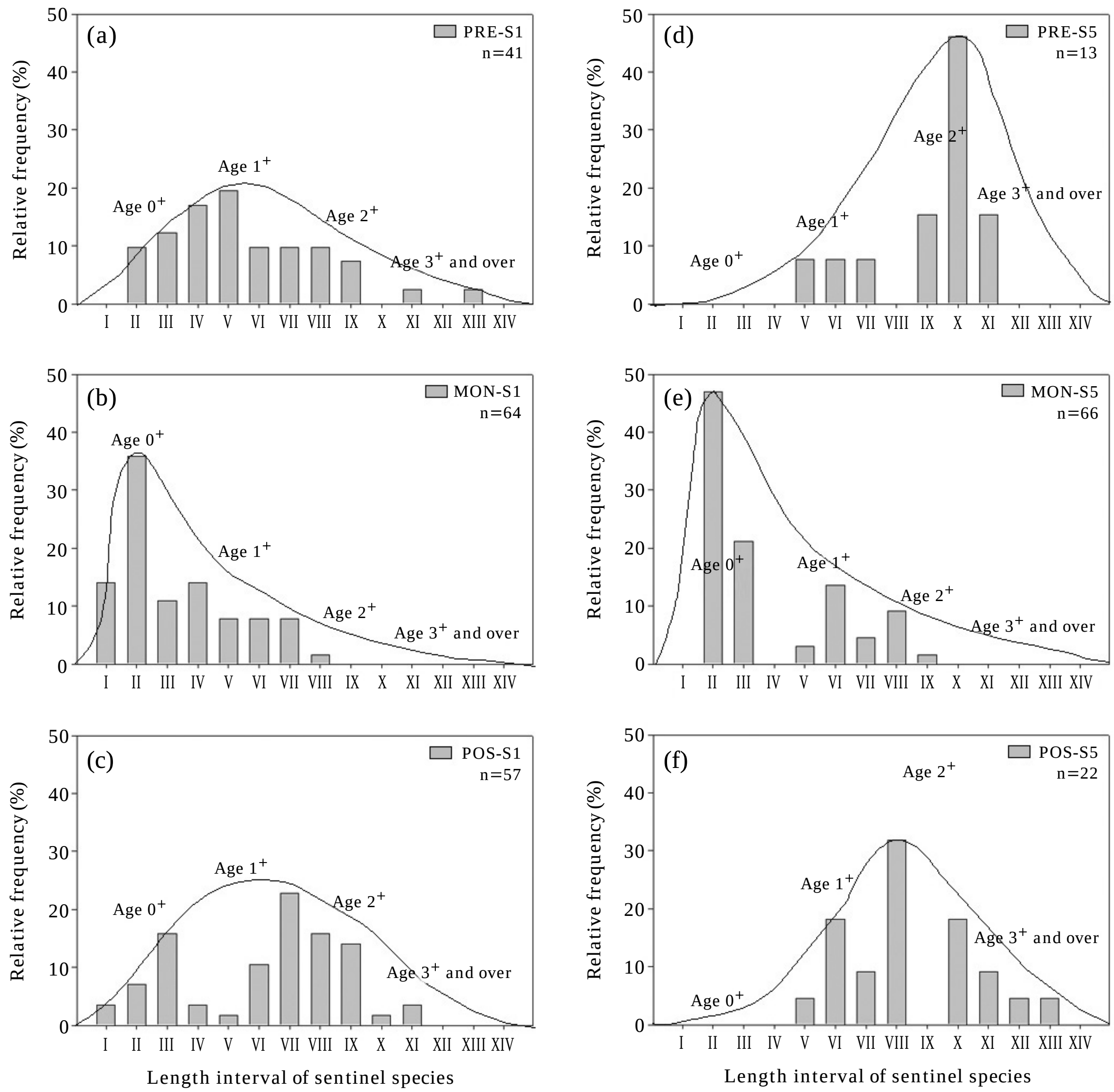

Fig. 4. Relative age distribution of *Z. platypus* by three seasons (PRE=premonsoon, MON=monsoon, POS=postmonsoon) in relation to 15 total length interval of I～XV in the control site (S1) and the impacted downstream (S5). (a): Premonsoon, S1, (b): Monsoon, S1, (c): Postmonsoon, S1, (d): Premonsoon, S5, (e): Monsoon, S5, (f): Postmonsoon, S5.

Zacco platypus, in the combined data of all sites (n=1156) showed a normal distribution over the length interval. As shown in the Fig. 3, age of sentinel species showed maxima (15%) in the Age 1^+ which is in the length interval of V～VI along with minima in the Age 0^+ with the length interval of I～III and Age 3^+ and over with the length interval of XI～XV (Fig. 3a). In the Site 1 (S1), total number of *Z. platypus* sampled was 162 in the 3rd order stream and the relative frequency peaked in the Age 0^+ with the length interval of II (Fig. 3d). The peak frequency value declined over the length intervals of II (Age 0^+)～XV (>Age 3^+; Fig. 3d), thus, the maximum of the frequency was slightly skewed in the left side. Total number of *Z. platypus* sampled in S2, S3, and S4 was 245, 433, and 215. respectively and the numbers were significantly ($p<0.05$) greater than the number of S1 (Fig. 3b, c, e). The relative frequency values of sentinel species in the S2, S3, and S4 were normal distribution over the length interval and these maxima fell into the nearly Age 1^+ with the length interval of V～VI (Fig. 3b, c, e). In contrast, in the Site 5, the maxi-

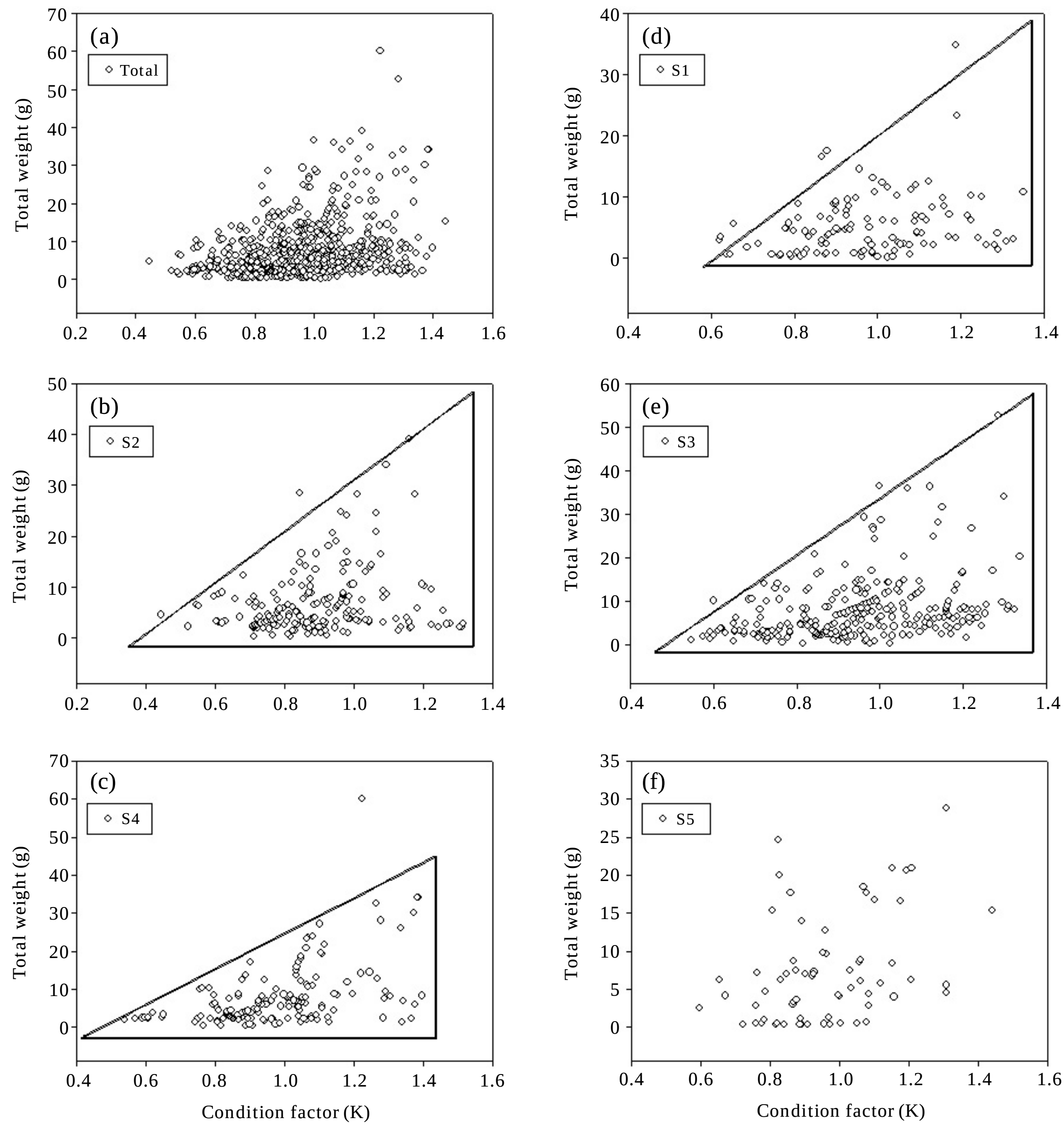

Fig. 5. The relationship between the condition factor (K) and total weight (TW) of the sentinel species. The triangle indicates that as the condition factor increase, total weight increase in the all sites except for the Site 5, impacted by the wastewater disposal plants. (a): Total sampling sites, (b): S2, (c): S4, (d): S1, (e): S3, (f): S5.

ma of relative frequency value in *Z. platypus* was Age 0^+ with the length interval of II and the total number of individual (*Z. platypus*) sampled was 101, which is much lower than the values in the sites 1～4 (S1～S4; Fig. 3f). Thus, in the S5, the values were largely skewed in the most left side (Fig. 3f), indicating a disturbance of the population in *Z. platypus*. This phenomenon is demonstrated by the chemical impacts by high BOD, COD, and nutrients (TN, TP) from the wastewater disposal plants (WDP), as shown in Fig. 2. In fact, total number of the sentinel species and the population size-structure were influenced by the effluents from the WDP.

We also compared three seasons on the population variations of sentinel species, *Z. platypus* in the two sites of upstream (S1) and downstream (S5). We found that during the premonsoon, the

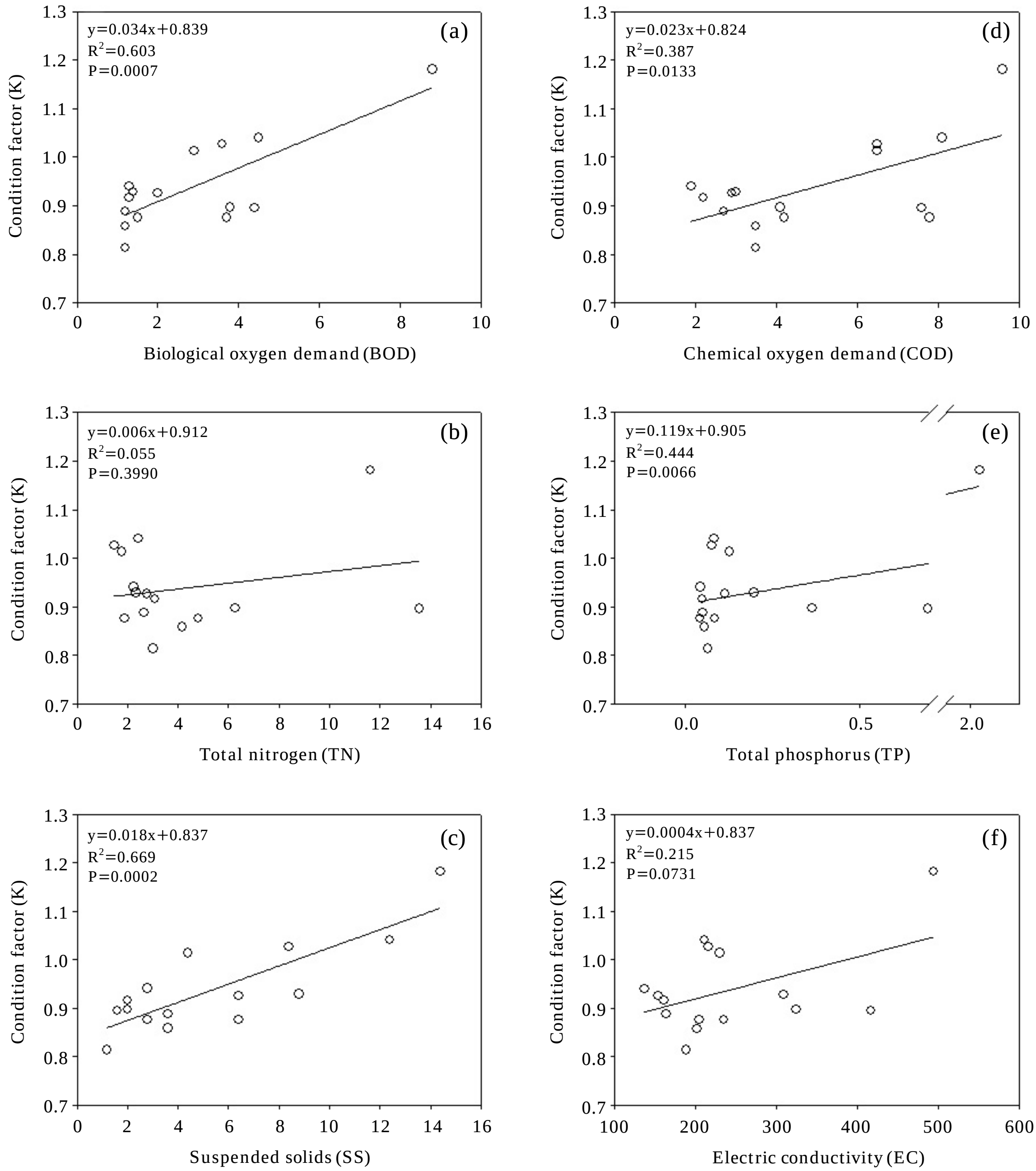

Fig. 6. The relations of the condition factor (K) to the water quality.

maximum frequency of sentinel species occurred in Age 1^+ with the length interval of V in the upstream reach and the frequency of occurance in the Age 0^+ was less than 18% (Fig. 4a). During the monsoon, the maximum frequency of sentinel species in the upstream reach moved to the Age 0^+ with the length interval of II and the frequency of occurance in the Age 0^+ was greater than 35% (Fig. 4b). During the postmonsoon, the frequency of sentinel species with Age 0^+ increased in the upstream reach along with large increases of Age 2^+ (VII ~ X) and > Age 3^+ (XI; Fig. 4c). This result indicates that the spawning of *Z. platypus* in the upstream during the premonsoon increased 15% young age population during the monsoon and thereby increased older population (Age 2^+ ~ Age 3^+ and over) during the postmonsoon.

In contrast, in the downstream reach (S5), the old-age population with the length interval of IX ~XI dominated in the premonsoon (Fig. 4d) and the young-age population (II~IV) abruptly increased during the monsoon (Fig. 4e) but not at all in young-age population with the length interval of I~IV during the postmonsoon (Fig. 4f). These data suggest that the young-age population in the upstream reach got a reproductive success but a failure of recruiting of young-age population in the downstream. The reproductive failure phenomenon of young-age population was evidently attributed to the water pollution by nutrient enrichment and high organic matter (BOD, COD) along with a physical habitat degradations (urban developments) in the downstream. This outcome is supported by previous studies of ecological health assessments (index of biological integrity, IBI) using fish (An *et al.*, 2005; Bae and An, 2006; Kim *et al.*, 2009) and qualitative habitat health assessments (qualitative habitat evaluation index, QHEI) between the two locations of Gap-Stream (An *et al.*, 2001a).

The relations of total weight to condition factor (K) in the sentinel species showed a distinct difference between the un-polluted sites (S1~S4) and the polluted site (S5). As the condition factor (K) increases over the range of 0.2~1.6, the variation range of total weight in the population increased in the sites 1~4, but not in Site 5 (Fig. 5). In all sites (S1~S4) except for Site 5 (S5), the overall shapes in the condition factor-total weight were triangle, but not in the S5 (Fig. 5). In the S5, total weight values did not show any trend over the condition factor of 0.6~1.4. The population structure in S5 was modified because of the habitat degradation by the chemical pollution, compared to that of the undisturbed sites.

The relations of the condition factor (K), based on an equation of Anderson and Newmann (1996), and the water quality are shown in Fig. 6. Regression analysis of condition factor (K) against the water quality parameters showed significant positive relations with BOD (R^2=0.603; $p<0.001$, n=15; Fig. 6a) and COD (R^2=0.387; $p<0.05$, n=15; Fig. 6d). Also, values of K had significant positive linear relations with TP (R^2=0.444; $p<0.01$, n=15; Fig. 6e), and total suspended solids (SS, R^2=0.669; $p<0.001$, n=15; Fig. 6c), but not with TN ($p>0.05$; Fig. 6c) and electrical conductivity ($p>0.05$; Fig. 6f). It is evident that nitrogen seems to be enough for the system, even though the TN is much higher in the S5 than any other sites and that phosphorus is limited due to high N : P ratios in the system. For this reason, the condition factor was directly related with TP but not with TN (Fig. 6c, f). According to previous studies (Da Costa and Araújo, 2003; Anene, 2005; Choi *et al.*, 2007b; Yeom *et al.*, 2007), generally, as values of K increase in a fish, the health conditions of fish population get worse. Our data suggest that the high values of K increased with the degradations of water quality or greater nutrients/organic matter input in the stream environments.

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