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Temporal and Spatial Variation Analysis of Suspended Solids, Ionic Contents, and Habitat Quality in the Woopo Wetland Watershed

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The main objective of present study was to evaluate how seasonal rainfall influenced natural habitat conditions of 10 metric habitat variables along with ionic conditions and suspended solids in the Woopo Wetland during August 2002-July 2003. Largest spatial variabilities in total suspended solids (TSS) occurred during the summer monsoon and the inorganic suspended solids (ISS), expressed as a inorganic proportion of total solids, showed linearly increasing trend from the upstream to downstream. This phenomenon was mainly attributed to counter flow of turbid water from the main Nakdong-River. During the flooding, ISS : TSS ratio showed large increases (92%) in the downstream than the upstream (43%). For this reason, transparency declined (mean=0.13 m, range=0.08-0.21 m) largely in the downstream reach and thus, chlorophyll-*a* concentration showed low values (range: 4.2-8.6 μg L^{-1}), indicating a direct influence on primary productivity or algal growth by inorganic turbidity. In the 2nd survey, ISS averaged 4.0 mg L^{-1} (3.3-4.8 mg L^{-1}), thus the ISS decreased by 14 fold, compared to the ISS in the 1st survey during the flooding, while organic suspended solids (OSS) values were greater than those of ISS, indicating a dominance of organic solids. This condition was similar to solid contents in the 3rd survey, but showed a large difference compared to the 4th survey during the growing season. Habitat health assessments, based on 10 metric habitat variables, showed that QHEI values were greatest in the growing season (May) than any other seasons and largest spatial variations occurred in the 2nd survey. Overall, dataset suggest that seasonal episodic flooding during the monsoon may largely contribute nutrient cycling and sediment contents in the Woopo Wetland and Topyung Stream.

Key words : ionic content, habitat health, wetland, suspended solid, QHEI, seasonality

INTRODUCTION

Recent studies (An *et al*., 2002) pointed out that seasonal rainfall influences suspended solids, ionic salinity, and nutrient contents through alteration of flow volume. These hydrological and chemical variations resulted in physical habitat conditions in the lotic and lentic ecosystems (An *et al*., 2002). Such variations in North America and European waterbodies are evident in spring and fall seasons when major precipitation occur. For this reason, concentrations of non-volatile suspended solids (NVSS) showed minimum during summer and maximum in the spring or fall. Thus, habitat condition are

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stable during the summer, but largest variations in the fall or spring. This patterns, however, may be opposite in Korean ecosystems. This difference comes from the seasonal distribution of rainfall in Korea where typically one third or half of the total annual precipitation occurs in short period of July-August. Little is known about how the seasonal monsoon rainfall influence the ionic contents and solid dynamics and physical habitat health conditions.

Especially, ecological functions and habitat dynamics are not known in wetlands and some streams surrounded by the wetland, in spiteal of various important of high species diversity (Son and Jeon, 2003), biological treatment of pollutant such as nitrogen or phosphorus (US EPA, 1993; Yang, 2003), flood control capacity (Ann *et al*., 2003), erosion control capacity (Park, 2001), and recreation use [i.e., wildlife observations and fishing etc. (Adamus and Stockwell, 1983)] in wetland ecosystem. Major studies in Woopo Wetland are included basic fauna research of water quality, fish community, bird, and planktons, and aquatic macroplants (Koo and Kim, 2001; Kim, 2001) along with structures and functions of the wetland (Kwon, 2006). However, still there is little known about the functions of habitat quality and modification in the wetland. This study was conducted in Woopo Wetland and Its nearby Topyung Stream, which was designated as "Ecosystem Special Protection Zone" in July 1997 and was also designated as the protecting wetland in International Ramsar Convention. In this study, we evaluated dynamics of ionic salinity, suspended solids, and physical habitat conditions with seasons and sampling stations.

MATERIAL AND METHODS

1. Sampling sites

This study was conducted in Woopo Wetland and Topyung Stream, which is located in the Changryung gun, Korea during August 2002-July 2003. Two study sites were selected from the Woopo Wetland; one was the site of W1, which was directly influenced by ISS, in other words inorganic turbidity during the monsoon period of the study. Another was the site of W2, where free-floating plants dominated the aquatic plants and inorganic turbidity was not found. Also, five study sites (S1-S5) were selected in the Topyung Stream and the selection was based on the physical habitat evaluation methods (Barbour *et al*., 1999; Plafkin *et al*., 1989). The site of S1 is located in the upstream and the location is close to the wetland, while S5 is located in the downstream, which is directly connected with mainstream of Nakdong River. Overall, study sites of Topyung Stream (S1-S5) and Woopo Wetland (W1-W2) are as follows (Fig. 1)

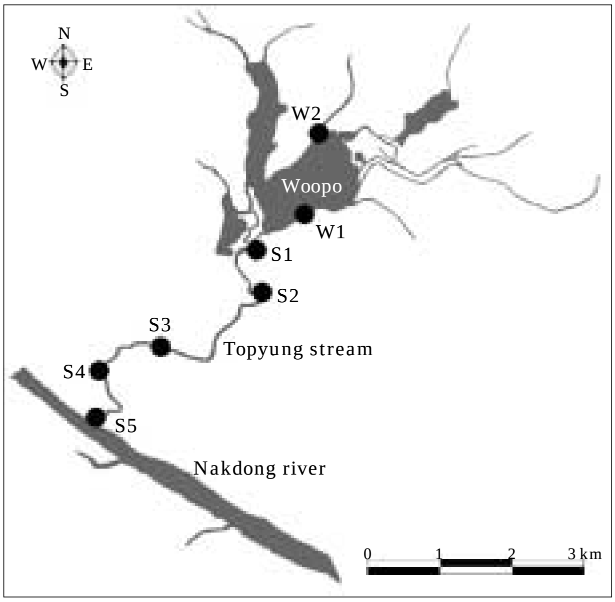

Fig. 1. The map showing the survey sites in the Woopo Wetland and Topyung Stream.

S1. Dabutou Sejin-ri Yueo-myeon Changnyeong-gun Gyeongnam Province
S2. Galdaegol Sejin-ri Yueo-myeon Changnyeong-gun Gyeongnam Province
S3. Gahang-ri Yueo-myeon Changnyeong-gun Gyeongnam Province
S4. Baemal Seongsan-ri Ibang-myeon Changnyeong-gun Gyeongnam Province
S5. Yoourkyo upper Yueo-myeon Changnyeong-gun Gyeongnam Province
W1. Duntou upper Yueo-myeon Changnyeong-gun Gyeongnam Province
W2. Somok lower Yueo-myeon Changnyeong-gun Gyeongnam Province

2. Survey period

Physical habitat analysis in Topyung Stream were conducted over four times of 1st survey to 4th survey. The 1st survey was done during the monsoon of August 14-15, 2002 to evaluate an effect of rainfall on the stream habitat quality. The 2nd and 3rd survey was done on November 11-20, 2002 and December 8-9, 2003 when the flow is reduced and the vegetation is reduced due to low temperature. The final survey as done on May 10-11, 2003 when physical conditions, based on flow, is stable and the vegetation is quickly growing. The survey seasons of physical habitat were as follows:

- Dates sampled in Topyung Stream and Woopo Wetland
  1st survey: August 14-15, 2002
  2nd survey: November 20-21, 2002
  3rd survey: February 8-9, 2003
  4th survey: May 10-11, 2003

3. Parameters analyzed

Surface water samples were collected from 7 sites for suspended solid analysis and then measured in the laboratory within 12-36 hours. Specific conductivity (at 25°C, YSI Model 33) and Secchi transparency (20 cm disk) were measured at the time of sample collection. Chlorophyll (Chl-*a*) concentration was measured by using a spectrophotometer (Bechman Model DU-65) after extraction in hot ethanol (Sartory and Grobbelaar, 1984). TSS were determined by filtering water through preweighted Whatman GF/C filters. Filters were weighted after drying at 103°C for 1 hour. ISS or NVSS were determined by combustion at 550°C for 1 hour (APHA, 1985) and OSS were determined by differences, and appropriate corrections were made for blanks.

Also, we conducted physical habitat quality using QHEI, which was introduced by Plafkin *et al.* (1989) and then developed by Barbour *et al.* (1999). For the application of index, multi-metric model was applied for the habitat evaluation of Topyung Stream. Ten metric variables included were as follows: M1: epifaunal substrate cover (ESC), M2: pool substrate characterization (PSC), M3: pool variability (PV), M4: sediment deposition, SD), M5: channel flow status (CFS), M6: channel alteration (CA), M7: channel sinuosity (CS), M8: Bank stability (BS), M9: bank vegetative protection (BVP), and M10: riparian vegetative zone width (RVZW). Each parameters were categorized as "optimal", "sub-optimal", "marginal" and "poor conditions" after the criteria of US EPA (1993). The physical habitat health, based on the sum of the ten variables, was diagonized as follows. First grade (I) indicate an excellent habitat condition, which is comparable to the reference conditions (CR): range of CR > 90%* 139, score: > 125. Second grade (II) indicates good habitat condition, which means supporting (S): range of S = (75-89%)*139, score: 104-124. Third grade indicates partially damaged habitat condition, which means partially supporting (PS): range of PS = (60-74%)*139, score: 83-103. Fourth grade indicates inappropriate habitat condition, which means non-supporting (NS): range of NS < 59%, score: < 82.

RESULTS AND DISCUSSION

1. Dynamics of suspended solids and ionic dilutions

According to the 1st survey of habitat conditions during the flooding period (August 14-15, 2002), ISS increased in the stream, resulting in high contribution of total solids relative to organic solids. Concentrations of ISS averaged 57.8 mg L^{-1} during the flooding season and the values showed continuous longitudinal increases from 18 mg L^{-1} in the upstream (S1) to 142 mg L^{-1} in the downstream (S5; Fig. 2). The concentrations of ISS at Site 5 (S5) was similar to the values (range: 138-151 mg L^{-1}) which was measured from the main stream of Nakdong River. This indicates that inorganic solids in the down stream was originated from the main stream of Nakdong River and the continuous declines of ISS toward the upstream was due to a sedimentation of highly turbid water as the counter water from the mainstream of Nakdong River moved toward the upstream. Waters in the S1-S5 and W1-W2 showed low conductivity values of < 120 μs cm^{-1} and there were no significant differences among the sites (Fig. 2), indicating an ionic dilution of the previous water by the counter water. The counter water was frequently observed in previous studies and this phenomenon is known to be very important for maintenance of water level throughout the year in the Woopo Wetland (Gersberg *et al.*, 1987; Son and Jeon, 2003). In contrast, concentrations of OSS were low, except for the upstream site (S1), which is more influenced by the wetland water than the back water

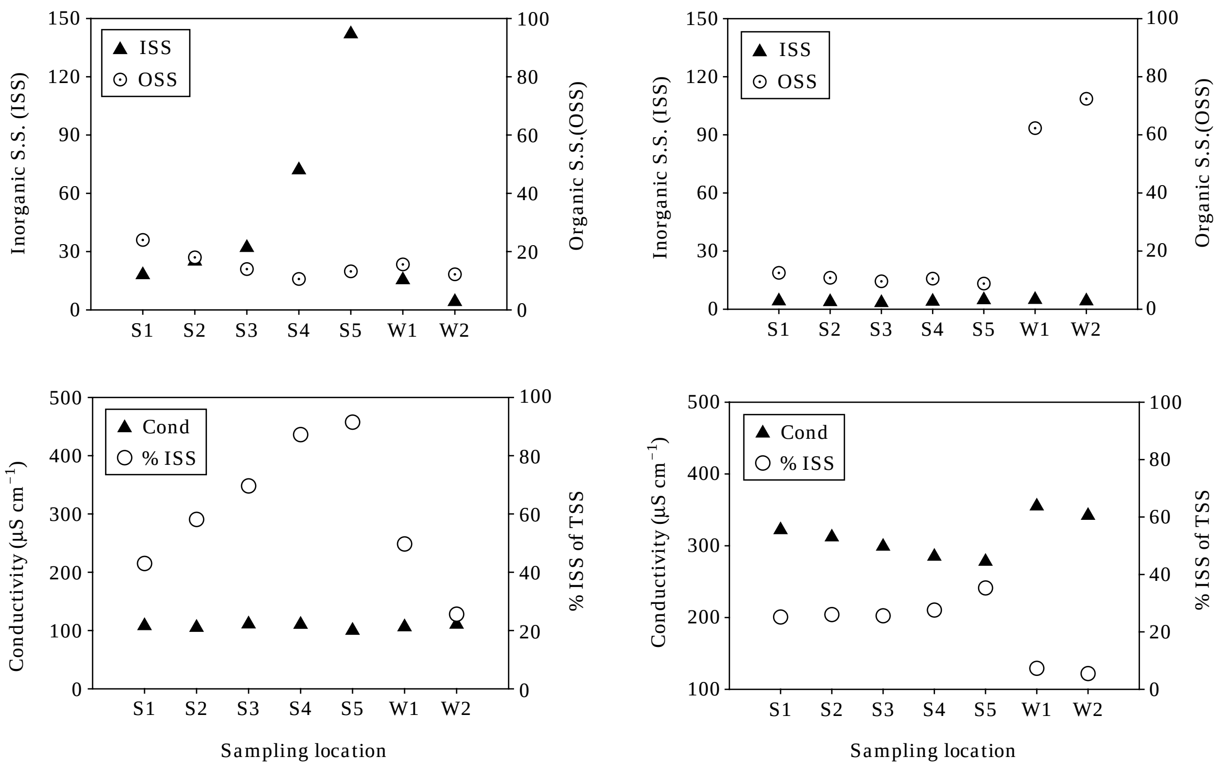

Fig. 2. Spatial variations of inorganic suspended solids (ISS), organic suspended solids (OSS), specific conductivity during 1st survey (left panel) and 2nd survey (right panel), and the ISS proportion of TSS (=ISS : TSS ratio) in the Topyung Stream (S1-S5) and Woopo Wetland (W1-W2).

(i.e., downstream water).

The relative proportion in inorganic solids of TSS, expressed as a ISS:TSS ratio, showed large increases (92%) in the downstream (S5) than ratio (43%) in the upstream (S1) than in the downstream (Fig. 2). For this reason, in the downstream reach (S4-S5) transparency, measured as Secchi depth, averaged 0.13 m (range=0.08-0.21 m), which means severe light attenuation in the water column. This reduced light penetration during 2-3 weeks after the intense monsoon rain reduced chlorophyll-a concentration (range: 4.2-8.6 μg L^{-1}), indicating a direct influence on primary productivity or algal growth of phytoplankton and periphyton. Also, increased suspended solids or fine sand in the water column may decrease the population size of filer feeding fish and macroinvertebrates by mechanical erosion of gill or filter clogging. Also, the inorganic sediments containing nutrients of nitrogen or phosphorus may contribute eutrophication and the deposition of the sediment may influence the water level of Woopo Wetland. These overall processes may influence the long-term physical habitat conditions.

The 2nd survey, after the waterbody was stabilized, showed that concentrations of ISS averaged 4.0 mg L^{-1} (3.3-4.8 mg L^{-1}), thus the ISS decreased by 14 fold, compared to the ISS in the 1st survey during the flooding (Fig. 2). Especially, the content of ISS in the downstream (S5) declined up to 30 fold, compared to the monsoon data. In contrast, at all sites concentrations of OSS were greater than those of ISS, indicating a dominance of organic solids. Increased light and reduced inorganic turbidity increased phytoplankton growth (Chl-*a* > 20 μg L^{-1}). Also, conductivity averaged 299 μs cm^{-1} during the 2nd survey and the values showed a serial longitudinal decline from 332 μs cm^{-1} in the upstream (S1) to 278 μs cm^{-1} in the downstream (S5). Ionic salinity during the 2nd survey increased by 3 fold, compared to the flooding season (Fig. 2), thus ionic condition diluted during the flooding returned previous conditions. The seasonal dilution pattern was agreed with previous study of Kim (2001),

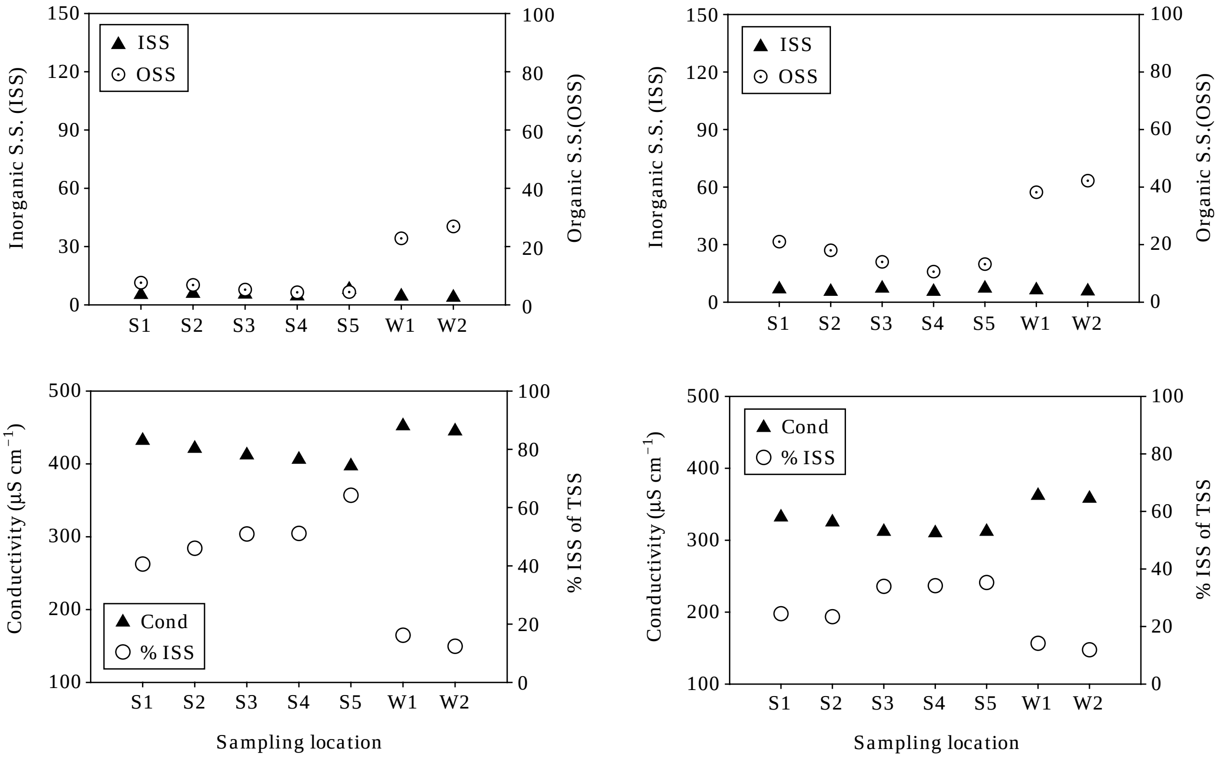

Fig. 3. Spatial variations of inorganic suspended solids (ISS), organic suspended solids (OSS), specific conductivity during 3rd survey (left panel) and 4th survey (right panel), and ISS : TSS ratio in the Topyung Stream (S1-S5) and Woopo Wetland (W1-W2).

even if the ionic concentrations showed differences between this study and Kim's (2001).

Concentration of TSS ranged between 4.5 and 7.9 mg L^{-1} in the 3rd survey (Fig. 3) when water temperature declined to 3°C and flow was minimal. This values did not show a difference, compared to TSS values in the 3rd survey, but values of OSS increased 2 fold than those in the 3rd survey (Fig. 3). The ratios of ISS : OSS were nearly 1, and conductivity values were greater than 390 μs cm^{-1} in the all sites of Topyung Stream (Fig. 3). The conductivity values were highest among the all seasons. Mean chl-*a* was 10 μg L^{-1}, based on all the sites of Topyung Stream and 13 μg L^{-1} in the Woopo Wetland, This indicates that primary productivity was not high, in spite of high availability of light, as a result of low temperature.

As water temperature increased up to 20°C in 4th survey of the growing season, content of OSS increased up to 3 times than that in the 3rd survey (Fig. 3). Contents of ISS, however, were less than 8.0 mg L^{-1} and ranged between 3.3 and 4.8 mg L^{-1}, which is similar to previous values from the 3rd survey (Fig. 3). In the mean time, conductivity values showed a declining phenomenon (ionic dilution) due to intermittant spring rainfall. Comparisons of ionic content between the premonsoon (4th survey) and summer monsoon (1st survey) showed that summer flooding resulted in 300% ionic dilution. These dataset suggest that the counter current from the mainstream of Nakdong River played an important role in supplying inorganic solids, containing nutrients of nitrogen and phosphorus, and ionic dilution to Woopo Wetland along with plenty of water supply. Thus, seasonal count water may be important for maintaining the ecosystem of Woopo Wetland.

2. Qualitative habitat evaluation

Habitat analysis, based on 10 metric model of Qualitative Habitat Evaluation Index (QHEI), showed that habitat quality varied depending on locations and seasons sampled in the Topyung

Stream. In the 1st survey, largest variations occurred in the BS, SD, CS, and CFS. Habitat health, based on ESC, judged as an optimal condition in the upstream (S1) and sub-optimal condition in the remaining sites (S2-S5), according to the criteria of US EPA (1993) and Barbour *et al*. (1999). PSC showed sub-optimal condition in the reach of S1-S3, while S4 and S5 showed marginal and poor condition, respectively, indicating that the habitat quality of PSC degradated from the upstream to downstream (Fig. 4). PV ranged between 12 and 15, which is judged as a sub-optimal condition in the all stream sites and CFS ranged 18-1, indicating an optimal condition during the flooding period. These conditions resulted in high sediment deposition, and especially, the downstream reach (S4 and S5) showed poor condition due to high inorganic sediment deposition inflowed from the mainstream of Nakdong River. During the flooding, values of CS ranged between 8 and 13, indicating a poor condition, while CA showed a sub-optimal in S2 and S5 and marginal condition in the remaining sites. The bank stability was judged as a sub-optimal condition in the stream reach of S1-S3 and marginal condition in the downstream reach (S4-S5). BVP in the S1-S2, S3, and S4-S5 showed a sub-optimal, optimal, and marginal conditions, respectively (Fig. 4). In the mean time, RVZW showed a marginal or poor condition. Such results suggest that intense monsoon rain produced a large amount of counter water from the mainstream of Nakdong River, thus modified the habitat conditions, as shown in the habitat variables. These conditions may have ecological disturbances on water chemistry, species composition and distribution of aquatic biota, and habitat health.

QHEI, based on 10 metric parameters, ranged 111-124 in the S1-S3, indicating a supporting condition after the criteria of US EPA (1993), and QHEI in the downstream reach (S4 and S5) averaged 89, indicating partially supporting condition. These index values suggest that counter water inflowed from the mainstream of Nakdong River might have been contributed to physical habitat instability.

After the intensive rainfall during July-August stopped, habitat condition of the Topyung stream showed large differences compared to the previous condition. According to the 2nd habitat evaluation on the November, four habitat parameters such as ESC, PV, CFS and CS revealed large degradations in the downstream reach (S4 and S5). The degradation was mainly considered due to fine particles and sediments inflowed during the flooding of the monsoon period. This fact was evident from sediment deposition of the downstream, which was measured on November. For that reason, ESC, PV, SD, CFS, and CS were judged poor conditions, which indicate greater degradation in the 2nd survey. In contrast, in the downstream reach, bank stability, bank vegetative protection, and riparian vegetative zone width got better than the previous conditions (Fig. 4), resulting in optimal to marginal conditions, based on the criteria of US EPA (1993) and Barbour *et al*. (1999). Mean QHEI, based on overall parameters, was 127 in the S1 and 128 in the S2, indicating that the habitat is comparable to reference conditions for aquatic biota. Whereas, mean QHEI was 97 in the S3, indicating partially supporting condition, and 67 in the downstream reach, indicating a Non-supporting condition. In other words, elevated water level during the flood resulted in optimal habitat conditions in the upstream reach but poor conditions in the downstream.

The 3rd survey showed that RVZW and the coverage of BVP decreased, compared to 2nd survey, in the upstream reach along with degradation of PSC (Fig. 5). Thus, the habitat health was judged as a supporting condition for aquatic biota and this conditions was due to an influence of habitat simplifications such as heavy sand deposition, and reduced annual grasses. In the mean time, S3 (partially supporting) and S4-S5 (non-supporting) in the 3rd survey did not differ from the habitat health measured in the 2nd survey (Fig. 5). Low variations between the 2nd and 3rd survey was considered as a result of little differences in the temperature, hydrological changes such as flow, and vegetation growth.

The 4th survey of physical habitat was conducted during the growing season in the stream and high stability in the hydrology, thus the habitat health was best among the seasons (Fig. 5). During the growing season, QHEI averaged 119 (range: 99-135), which is judged as a supporting condition after the criteria of US EPA (1993) and Barbour *et al*. (1999). Especially, the upstream reach of S1 and S2 showed an optimal condition at this time. Thus, overall QHEI values at all site largely increased compared to the 3rd survey and this was attributed to increased RVZW,

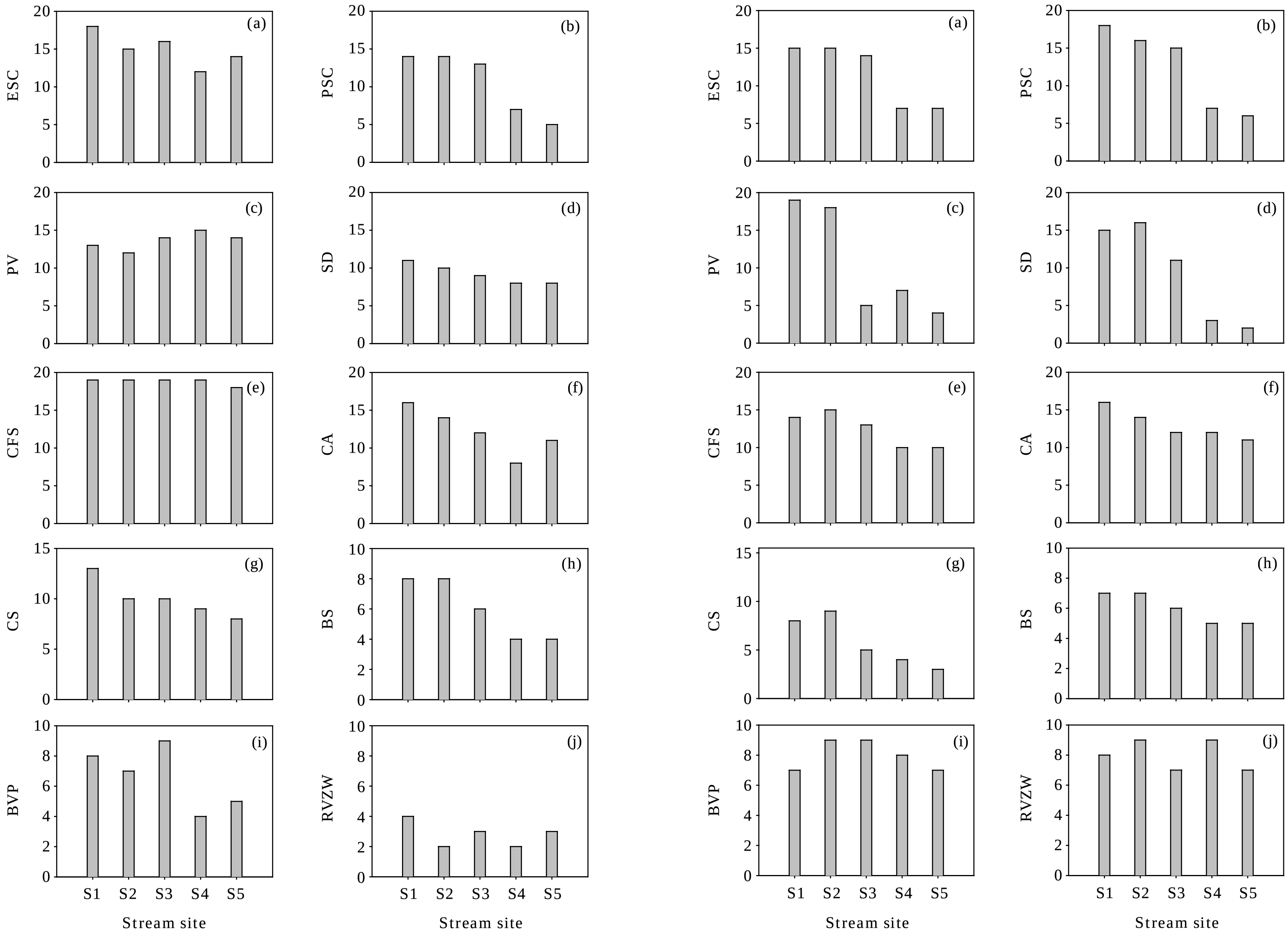

Fig. 4. Habitat Evaluations of various parameters in Topyung Stream during 1st survey (left panel) and 2nd survey (right panel): (a) ESC (epifaunal substrate cover), (b) PSC (pool substrate characterization), (c) PV (pool variability), (d) SD (sediment deposition), (e) CFS (channel flow status), (f) CA (channel alteration), (g) CS (channel sinuosity), (h) BS (bank stability), (i) BVP (bank vegetative protection), and (j) RVZW (riparian vegetative zone width).

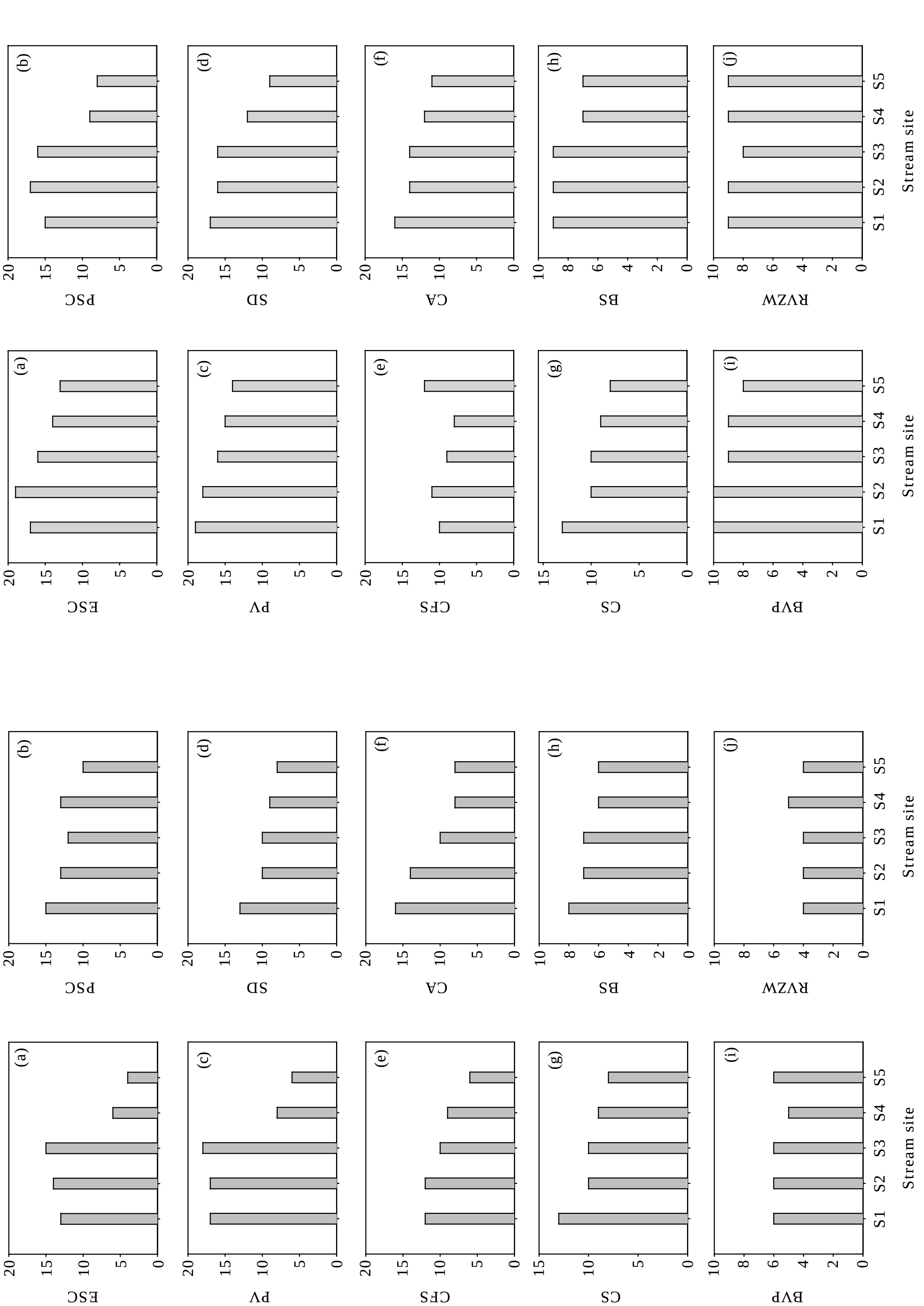

Fig. 5. Habitat Evaluations of various parameters in Topyung Stream during 3rd survey (left panel) and 4th survey (right panel). Specific terms of (a) to (j) are shown in Fig. 3.

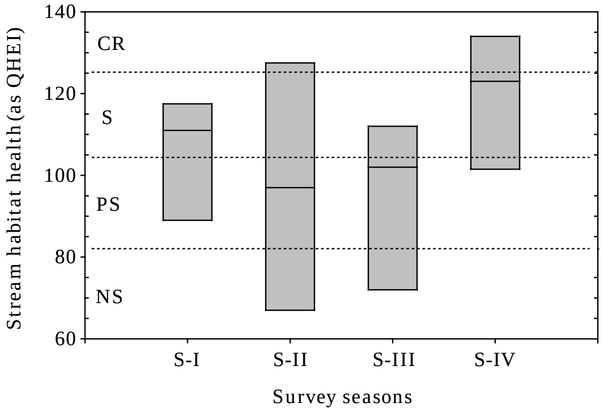

Fig. 6. Habitat health condition, based on 10 metric model values of QHEI, in the sampling seasons; S-I (1st survey, August), S-II (2nd survey, November), S-III (3rd survey, February), S-IV (4th survey, May); CR=comparable to the reference condition (Optimal), S=supporting, PS=partially supporting, and NS=Non-supporting.

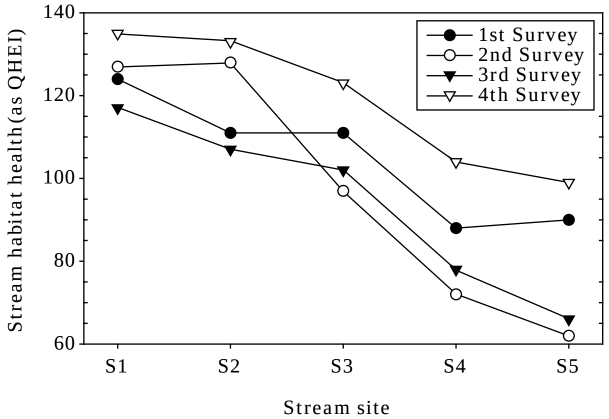

Fig. 7. Habitat health assessments, based on 10 metric habitat variables of QHEI. The sites of S1 and S5, indicate upstream and downstream location, respectively. The survey periods are as follows: 1st survey (August), 2nd survey (November), 3rd survey (February), and 4th survey (May).

greater BVP, and less SD. Greater physical habitat index in the growing season may be closely associated with high nutrient supplies of nitrogen and phosphorus inflowed in the previous flood period from the mainstream of Nakdong River. This conditions might resulted in rapid vegetation growth in the spring. Thus, such nutrient inputs may be an important role for the riparian growth and the vegetation growth may uptake the nutrient from the water column and the riparian zone, resulting in reduced eutrophication in the ecosystem. Habitat health assessments, based on 10 metric habitat variables of QHEI, showed that QHEI values were greatest in the growing season (May) than any other seasons and largest spatial variations (mean=96, range=67-127) occurred in the 2nd survey (Fig. 6). QHEI values showed linearly decreasing trend from the upstream to downstream (Fig. 7).

Overall, dataset suggest that seasonal episodic flooding during the summer monsoon may largely contribute nutrient cycling and energy flow in the Woopo Wetland and Topyung Stream. Further works should be done for an elucidation of the ecological functions in the ecosystems.

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<국문적요>

우포늪 수계에서 부유물, 이온농도 및 서식지 특성에 대한 시·공간적 변이 분석

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본 연구에서는 2002년 8월부터 2003년 7월까지 우포늪 수계에서의 이온농도, 부유물 농도 및 서식지 특성에 대한 계절성 강우패턴의 영향을 평가하였다. 총부유물질(TSS)의 공간적 변이는 하절기의 장마기간 동안 가장 현저하게 나타났다. TSS 중 무기부유물의 상대비율(ISS : TSS)은 크게 증가했으며 이는 상류에서 하류로 갈수록 증가하는 양상을 보였다. 이런 현상은 낙동강 본류로부터 역류하는 탁수에 기인하는 것으로 사료되었다. 장마기간 동안 ISS : TSS의 비율은 상류(43%)보다 하류(92%)에서 크게 증가한 수치를 보였다. 또한 투명도는 하류역으로 갈수록 감소였으며(평균=0.13 m, 범위=0.08-0.21), 탁수는 조류생장 및 1차생산력에 직접적으로 영향을 미쳐 낮은 엽록소-*a* 값(범위=4.2-8.6 μg L^{-1})을 보였다. 2차 조사 시 ISS 농도는 평균 4 mg L^{-1} (범위=3.3-4.8 mg L^{-1})였고, 이런 값은 홍수기 조사인 1차 조사에 비해 14배나 감소한 수치였다. 한편, ISS는 크게 감소한데 비해 OSS의 상대비는 높게 증가했다. 이러한 현상은 3차 조사에서도 같은 양상으로 나타났으나 5월에 실시된 4차 조사에서는 상이한 결과를 보였다. 10개 변수를 기반으로 한 정량적 서식지 평가에 따르면, QHEI는 4차 조사에서 최대값을 보였으며, 2차 조사에서는 가장 큰 공간적 변이를 보였다. 결과적으로, 장마기간의 집중강우는 토평천과 우포늪에서의 토사 침전 및 영양물질 순환에 크게 기여하는 것으로 사료되었다.