Responses of Fish Functional Group Structure and Diversity to Land Use Types in the Taizi River Basin: Postprint

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Date: 2017-11-01T00:00:00+00:00

Abstract

Investigating the impacts of riparian land use patterns on river biological communities is crucial for riparian zone management and river ecosystem restoration. This study examined the relationship between land use types (forest land, forest-cropland, cropland, and urban construction land) and fish functional groups in the riparian zone of the Taizi River, and the results showed that habitat quality parameters exhibited significant differences among different land use types. Forest land areas exhibited lower mean values of electrical conductivity, total dissolved solids, silt, and substrate sand content ratio (105.05 s/cm, 80.38 mg/L, 65.00 mL, and 0%, respectively), with cobble-dominated substrate; cropland areas exhibited the highest mean values for water depth, flow rate, and silt (186.83 m, 80.11 m³, and 5333.33 mL), with sand- and silt-dominated substrate. Fish functional groups in the Taizi River basin were classified into 5 types (18 subcategories), which showed significant differences among land use types: forest land had the highest proportions of piscivorous, cobble-dwelling, insectivorous, and adhesive egg functional groups; forest-cropland had the highest proportions of herbivorous and benthic-dwelling functional groups; cropland had the highest proportions of sand-dwelling, mid-lower water column, and nest-spawning functional groups; urban construction land had the highest proportions of silt-dwelling, pollution-tolerant species, mid-lower water column, and omnivorous functional groups. The study revealed that areas with high habitat assessment scores and complex habitats supported higher individual abundances, whereas areas with low habitat scores and substrate dominated by silt exhibited lower individual abundances.

Full Text

Preamble

ACTA ECOLOGICA SINICA ChinaXiv Partner Journal
Vol. 37, No. 20, Oct. 2017
DOI: 10.5846/stxb201608181693

Relationships between Structure and Diversity of Fish Functional Groups and Land Use in the Taizi River

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Abstract

Understanding the effects of riparian land use on river biota is crucial for riparian management and river ecosystem restoration. This study investigated the relationship between riparian land use types (forest land, forest-farmland mosaic, farmland, and urban construction land) and fish functional groups in the Taizi River Basin. Habitat quality parameters showed significant differences among land use types. In forest land areas, the mean values of conductivity, total dissolved solids, and sediment sand content were relatively low (105.05 s/cm, 80.38 mg/L, 65.00 mL, and 0%, respectively), with substrates dominated by sand and silt. In farmland areas, water depth, flow rate, and silt percentage were highest (186.83 m, 80.11 m, and 5333.33 mL, respectively). Fish functional groups in the Taizi River Basin were classified into five types (18 subcategories), with significant differences observed among the four land use types. The proportions of piscivorous, stone-dwelling, insectivorous, and sticky egg functional groups were highest in forest land areas. Herbivorous and benthic-dwelling functional groups peaked in forest-farmland mosaic areas. Sand-dwelling, mid-lower water column, and nest-building functional groups were most prevalent in farmland areas. Silt-dwelling, mid-lower water column, and omnivorous functional groups dominated urban construction land areas. Fish abundance was positively correlated with habitat quality scores but negatively correlated with substrate roughness. Areas with complex habitats supported higher fish abundance, while areas with silt-dominated substrates had lower abundance. These findings demonstrate that different land use types alter aquatic environments, which in turn drives changes in fish functional group composition. Forest land and forest-farmland mosaic habitats provided the best conditions for maintaining fish community integrity. Therefore, land use planning should prioritize forest land and forest-farmland mosaic configurations.

Keywords: land use type; functional groups; environmental factors; fish; community structure

1. Materials and Methods

1.1 Study Area

The Taizi River Basin (122°30 –124°50 E, 40°30 –41°40 N) is located in eastern Liaoning Province, China. Originating from the Changbai Mountains in Xinbin County, the river flows westward through Benxi City and merges with the Hun River at San Cha to form the Daliao River before discharging into the Bohai Sea. The basin covers an area of 13,880 km^2 with a main channel length of 413 km. The region experiences a temperate monsoon climate with large annual temperature variations. Precipitation is concentrated, accounting for 71.2% of total annual rainfall. The basin exhibits a clear gradient of human activity intensity, with agricultural and urban land use proportions increasing from upstream to downstream. Four land use types were delineated: forest land, forest-farmland mosaic, farmland, and urban construction land [Figure 1: see original paper].

1.2 Data Collection

1.2.1 Fish Sample Collection Fish samples were collected from 40 sites across the four land use types in May 2012. At each site, a combination of electrofishing and gillnetting was employed. For wadeable streams (depth 1.5 m), electrofishing was conducted along the shoreline for 30 minutes using a backpack electrofisher. For non-wadeable reaches (depth 1.5 m), gillnets with three mesh sizes (6 cm×6 cm, 12 cm×12 cm, and 20 cm×20 cm) were deployed in deep water areas for 12 hours, supplemented by electrofishing in shallow zones. Fish were identified to species in the field and released. Specimens that could not be immediately identified were preserved in formaldehyde solution and transported to the laboratory for further identification using *Fauna of Liaoning Province* and *Fauna Sinica: Osteichthyes* as references.

1.2.2 Habitat Survey Habitat characteristics were assessed following established protocols [23-24]. Parameters included Qualitative Habitat Evaluation Score (QHES), substrate index (IOS), depth, velocity, flow, width, substrate sand content, electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO). The substrate index was calculated as:

$$IOS = 0.08\% \times V_{\text{boulder}} + 0.07\% \times V_{\text{large cobble}} + 0.06\% \times V_{\text{small cobble}} + 0.05\% \times V_{\text{large pebble}} + 0.04\% \times V_{\text{small pebble}} + 0.0$$

where V represents the volume percentage of each substrate type (>256 mm, 64-256 mm, 16-64 mm, 8-16 mm, 4-8 mm, 2-4 mm, 1-2 mm, and <1 mm). Substrate sand content was measured using a nested sieve set (16, 8, 4, 2, and 1 mm mesh). Water chemistry parameters were measured using a YSI Pro 2000 water quality analyzer. Depth and velocity were measured with a current meter.

1.2.3 Land Use Type Characteristics Forest land areas were predominantly located in the upper reaches of the Taizi River headwaters with minimal human disturbance, high forest coverage, and substrates dominated by boulders, large cobbles, and pebbles in riffle habitats, resulting in high habitat diversity. Forest-farmland mosaic areas had 25-50% forest and 25-50% farmland, with moderate human disturbance, clear water quality, and substrates of pebbles, small stones, and minor sand components. Farmland areas were mainly distributed in the middle and lower reaches with >50% agricultural land, significant human disturbance, turbid water, and substrates dominated by sand and silt (sand content ~80%). Urban construction land areas in the lower reaches had >50% impervious surface, severe human disturbance, no riparian vegetation, odorous water, and silt-dominated substrates with severely eroded banks.

1.3 Data Analysis

To examine relationships among land use type, habitat quality, and fish functional groups, we analyzed habitat characteristics and fish data across the four land use types. Fish community structure parameters included species richness, percentage of sensitive species individuals, and percentage of tolerant species individuals. Shannon-Wiener diversity index and Pielou's evenness index were calculated. Sensitive species included *Phoxinus lagowskii* and *Opsariichthys bidens*, while tolerant species included *Carassius auratus*, *Paramisgurnus dabryanus*, and *Pseudorasbora parva*.

Fish functional groups were classified based on: (1) Trophic guilds: omnivorous, piscivorous, herbivorous, insectivorous, and benthivorous [27]; (2) Tolerance: tolerant, moderately tolerant, and sensitive [28]; (3) Substrate type: stone-dwelling, sand-dwelling, and silt-dwelling [19]; (4) Spawning type: sticky eggs, floating eggs, sinking eggs, nest-building, and special spawning; (5) Water column position: upper, mid-lower, and benthic.

Canonical correspondence analysis (CCA) was used to examine relationships between fish community/functional groups and habitat factors. Multi-response permutation procedures (MRPP) were conducted in PC-ORD 5.0. One-way ANOVA in SPSS 17.0 was used to test differences in habitat parameters and fish community structure among land use types, followed by Tukey HSD post-hoc tests when significant differences were detected ($p<0.05$). BiodiversityPro was used to calculate diversity indices, and Origin 8.5 was used to create visualizations of functional group structure and diversity across land use types.

2. Results

2.1 Fish Species Composition and Community Structure

A total of 21 fish species were collected in the Taizi River Basin. Dominant species included *Nemachilus nudus* (34.6% of total individuals), *Phoxinus lagowskii* (5.3%), *Abbottina rivularis* (5.4%), and *Zacco platypus* (7.3%). Rare species such as *Lampetra morii*, *Huigobio chinssuensis*, and *Hypseleotris swinhonis* were also collected, primarily in forest and forest-farmland mosaic areas. MRPP analysis revealed significant spatial heterogeneity in fish community structure among the four land use types ($p<0.001$).

One-way ANOVA showed significant differences in fish abundance among land use types ($p<0.05$), with the highest mean abundance in forest land (314.53 individuals). The percentage of sensitive species individuals differed significantly ($p<0.001$), peaking in forest-farmland mosaic areas (0.60). The percentage of tolerant species individuals also varied significantly ($p<0.001$), reaching maximum values in urban construction land (0.81). Species richness and Shannon-Wiener diversity index showed no significant differences among land use types ($p>0.05$) .

2.2 Classification of Fish Community Functional Groups

Fish functional groups in the Taizi River Basin were classified into 18 subcategories across five main types. Trophic structure analysis revealed that piscivorous and insectivorous functional groups were most abundant in forest land, herbivorous groups peaked in forest-farmland mosaic areas, and omnivorous groups were more prevalent in farmland and urban areas. Tolerance-based analysis showed that sensitive and moderately tolerant groups were highest in forest land, while tolerant groups dominated urban construction land. Spawning type analysis indicated that sticky egg and special spawning groups were most common in forest land, sinking egg groups peaked in forest-farmland mosaic areas, nest-building groups were highest in farmland, and floating egg groups dominated urban areas. Water column position analysis showed that benthic groups were most abundant in forest-farmland mosaic areas, mid-lower column groups peaked in farmland, and upper column groups were highest in urban areas. Substrate type analysis revealed that stone-dwelling groups dominated forest land, while silt-dwelling groups were most prevalent in urban construction land.

Forest land contained 13 functional groups, forest-farmland mosaic areas had 15, while farmland and urban areas each had 12. However, sensitive species, stone-dwelling, herbivorous, and insectivorous functional groups occurred at low frequencies in farmland and urban construction land .

2.3 Basin-Wide Habitat Characteristics

One-way ANOVA indicated highly significant differences in habitat characteristics among land use types ($p<0.001$). Forest land areas had significantly lower mean conductivity, total dissolved solids, and substrate sand content (105.05 s/cm, 80.38 mg/L, and 0.00%, respectively). Farmland areas exhibited the highest mean water depth and flow rate (186.83 m and 80.11 m, respectively). Urban construction land areas had the lowest habitat evaluation scores and highest conductivity and total dissolved solids (8.59, 0.53, 105.17 s/cm, and 80.38 mg/L, respectively) .

2.4 Correlation Between Fish Community Structure and Environmental Factors

Canonical correspondence analysis revealed that total dissolved solids, habitat evaluation score, and substrate sand content were stronger drivers of fish community structure than pH, velocity, flow, and depth. Different land use types showed distinct environmental drivers: dissolved oxygen, IOS, and substrate sand content were primary drivers in forest land; flow and conductivity drove farmland communities; and habitat evaluation score and substrate sand content influenced forest-farmland mosaic areas. All six environmental factors showed significant effects on fish communities across the basin ($p<0.05$) [Figure 3: see original paper].

2.5 Correlation Between Fish Functional Groups and Habitat

CCA analysis demonstrated that total dissolved solids and conductivity were key drivers of floating egg functional groups ($p<0.05$). Dissolved oxygen drove sticky egg functional groups. Substrate sand content and flow influenced insectivorous functional groups. Omnivorous groups were affected by total dissolved solids and conductivity. Mid-upper and mid-lower water column groups were driven by substrate sand content and flow. Sensitive and moderately tolerant groups were primarily influenced by dissolved oxygen. Substrate sand content was the main driver for sand-dwelling and stone-dwelling functional groups. Tolerant functional groups were affected by total dissolved solids and conductivity [Figure 4: see original paper].

3. Discussion

Habitat quality, particularly substrate type, significantly influences fish functional groups in the Taizi River Basin [6]. Substrate changes affect food availability and benthic fish habitats, thereby altering functional group composition. In the upper reaches, forest land areas with minimal pollution and stone-dominated substrates supported piscivorous and sensitive functional groups, represented by clean-water species such as *Phoxinus lagowskii*. In contrast, lower reach farmland areas with high pollutant and particulate inputs had silt-dominated substrates, supporting tolerant and silt-dwelling functional groups represented by pollution-tolerant species like *Carassius auratus* and *Misgurnus anguillicaudatus*. These findings align with studies by Goldstein et al. [30] and Putman et al. [31].

The distinct substrate differences among land use types indicate substantial habitat heterogeneity in the basin [32], leading to significant variation in fish functional groups. MRPP analysis confirmed significant spatial heterogeneity in fish community structure among the four land use types ($p<0.001$), likely driven by differences in riparian land use. Forest land areas with extensive vegetation cover had better water quality, lower conductivity and total dissolved solids, and higher fish abundance and sensitive species percentages. Conversely, downstream areas dominated by farmland and urban construction land had higher conductivity and total dissolved solids, silt substrates, lower fish abundance, and higher percentages of tolerant species.

Canonical correspondence analysis showed that habitat evaluation score, IOS, and substrate sand content were primary factors influencing fish community structure, consistent with findings by Ding et al. [24, 34] for the Taizi River Basin. However, studies in the Wei River Basin [14] identified different primary drivers (elevation, dissolved oxygen, permanganate index, clay and grassland proportions), possibly due to differences in topography and land use patterns.

Functional group composition reflects ecosystem stability [15]. Poff et al. [19] demonstrated that hydrological variability influences fish functional groups, with more variable rivers supporting greater functional diversity. The Taizi River Basin' s diverse land use types create distinct habitat conditions from headwater forest land to downstream urban areas, resulting in significant differences in fish community structure and a stepwise decline in fish abundance. To protect fish communities and maintain structural integrity, riparian management should prioritize forest land protection in upstream areas and increase forest coverage while reducing farmland and urban development in middle and lower reaches.

4. Conclusion

A total of 21 fish species were collected in the Taizi River Basin, with functional groups classified into 18 subcategories. Piscivorous, insectivorous, and sticky egg functional groups were most abundant in forest land. Sinking egg functional groups peaked in forest-farmland mosaic areas. Nest-building functional groups were highest in farmland. Upper water column functional groups dominated urban construction land. Different land use types alter aquatic environments, subsequently affecting fish functional group composition. Forest land and forest-farmland mosaic areas provided better habitat quality and more effectively maintained fish community integrity. Therefore, riparian land use planning should prioritize forest land protection supplemented by forest-farmland mosaic configurations.

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Appendix 1. Fish Species Occurrence Frequency and Functional Group Types in the Taizi River Basin

[TABLE:Appendix]

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.