Differences in Growth and Maturation of Blacknose Dace (Rhinichthys atratulus) across an Urban-Rural Gradient

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To investigate changes in the biology of blacknose dace (Rhinichthys atratulus) populations accompanying watershed urbanization, we sampled dace from four watersheds in the Baltimore, Maryland area, representing a gradient from urbanized to rural conditions. Dace from the most urbanized watershed grew to greater standard lengths during their first year of life when compared to dace from other watersheds but grew little during their second year. Dace from the other watersheds showed slower growth during their first year but continued to grow through age II. Approximately 90% of age I dace from the most urbanized watershed were mature at age I, whereas only 25% of age I dace from the other watersheds were mature. Dace from the most urbanized watershed also reached maturity at shorter standard lengths than dace from the other watersheds. Growth and maturation of dace from the most rural watershed were similar to those reported for dace from other regions. We conclude that watershed urbanization results in increased growth rates of young blacknose dace, and in heavily urbanized (> 90% urban land use) watersheds, decreased age and size at maturity.

Urbanization of watersheds leads to hydrological changes and pollutant inputs to streams. These changes can affect the biology of stream organisms by altering food availability, amount and distribution of favorable habitats, number of competitors and predators, and disturbance regimes (McDonnell and Pickett, 1990). The sum of these changes may result in different selection pressures on the biota. In particular, changes in resource availability, mortality rates, or both may result in changes in population characteristics such as growth, age and size at maturity, fecundity, and survival (Stearns, 1992). Ultimately, if populations cannot respond to environmental changes associated with watershed urbanization, either by rapid evolution (Thompson, 1998; Hendry and Kinnison, 1999) or phenotypic plasticity, they will be eliminated from streams draining urbanized watersheds (Collins et al., 2000).

Many studies have documented negative effects of watershed development on abundances of stream fishes (e.g., Limburg and Schmidt, 1990; Weaver and Garman, 1994; Kemp and Spotila, 1997). Fewer studies have investigated the effects of human alterations of stream environments on life-history characteristics of individual fish populations. Schlosser (1982) found that younger age classes grew faster, and recruitment was more variable in a channelized headwater stream in Illinois when compared to a similar unmodified headwater stream in an adjoining watershed. Tsai (1972) documented greater first year growth and higher fecundity in a population of tessellated darters (Etheostoma olmstedi) occupying a sewage-polluted stream when compared with a conspecific population occupying the cold tailwaters below a reservoir. We know of no studies that have systematically addressed the effects of watershed urbanization on life-history characteristics of stream fishes.

In this study, we gathered life-history data from blacknose dace (Rhinichthys atratulus) populations in four headwater streams across an urban-rural gradient in the Baltimore, Maryland, metropolitan area to investigate possible urbanization-induced changes in the biology of dace populations. Our approach involved substituting space for the long-term dynamics of watershed urbanization by comparing dace biology among streams draining urbanized watersheds (Collins et al., 2000). Studies have addressed the effects of watershed urbanization on the biology of stream fishes.

Materials and Methods

Study sites.—Four streams in separate watersheds were selected on the basis of similarities in size and variation in the amount of urbanization in the headwaters (Fig. 1). All streams flow southeast across the Piedmont physiographic province, ultimately flowing across the Atlantic Coastal Plain and through the city of Baltimore.
into the Chesapeake Bay. Because blacknose dace are confined mainly to the headwaters of these streams (Maryland DNR, unpubl. data), and each watershed is separated by tidally influenced portions of the Chesapeake Bay, we consider blacknose dace populations in these streams to be isolated (i.e., no recent genetic exchange).

Herring Run lies almost entirely within the city of Baltimore and has a long history of urbanization. The headwaters of Jones Falls and Gwynns Falls lie just north of Baltimore. Because urban sprawl has proceeded north and northwest of the city, these watersheds have more recently been converted from primarily agricultural land use to mixed residential and commercial land use. The Beaver Run watershed remains mainly in agricultural land use and has only recently been developed with isolated residential areas.

We quantified land use upstream from each of our sampling locations using a geographical information system (GIS) and a 1994 database of land use produced by the state of Maryland. The 1994 database was the closest date to our sampling efforts available. However, qualitative inspections of the watersheds suggested little change had taken place in the Gwynns Falls, Jones Falls, and Herring Run watersheds between our sampling and the collection of land use data; in the Beaver Run watershed, several smaller residential developments had begun between 1994 and our sampling, suggesting our estimates of urban land use are slightly lower than conditions at the time of our sampling. For analysis, we aggregated land use categories into three main categories: (1) urban—low, medium, and high density residential, commercial, industrial, and mining; (2) agricultural—cropland, pasture, orchards, feed operations, and row and garden crops; and (3) forest—deciduous, evergreen, and mixed forest, brush, and wetlands. We delineated watershed boundaries upstream from our sample locations based on digital line graph images of 7.5’ quadrangle maps obtain from the U.S. Geological Survey. We calculated the percentage of each watershed occupied by the three general land-use types as a quantitative representation of our urbanization gradient.

Field collections.—We sampled blacknose dace during the breeding season in May and June 2000. Fish were collected by setting block nets at each end of a ~ 75 m stream reach and making three passes with a backpack electroshocker. All fish collected were identified and their SL recorded. In the field, we selected from 24 to 63 blacknose dace representing the size range of dace in each sample, preserved them in 10% formalin and returned them to the laboratory for analysis. After five days in 10% formalin, fish were transferred to 5% buffered formalin for storage until they were processed.

Comparison of life-history characteristics.—We estimated age from thin-sectioned sagittal otoliths. We removed the left and right otoliths from each specimen and mounted the left otolith, medial side down, on a small piece of acetate. To prepare otoliths for viewing, we sanded down the lateral side of the otolith using fine silicon carbide sand paper and then polished the resulting surface using Crocus paper. Each otolith was examined and scored independently by two or more observers using a dissecting microscope (45x) and a lateral light source. When observers disagreed on age, or age could not be resolved by the left otolith, we prepared and examined the right otolith as described above. In all cases, the right otolith resolved aging discrepancies. Length-frequency histograms were used to validate ages determined from otoliths (Fig. 2).

We used an ANCOVA model to investigate differences among watersheds in the relationship between age and SL of dace. SLs were $\log_{10}$-transformed before analysis to meet the assumptions of the statistical analysis. Because there was a significant interaction between watershed and age (see Results), we analyzed relationships between SL and age separately for each watershed using simple linear regression. We also used simple linear regression to investigate the relationship between mean SL of fish from each watershed and percent of urbanisa-
tion in the watershed. Untransformed length data were used in these analyses because we were interested in determining whether size and percent of watershed urbanization showed a linear relationship.

We removed gonads to determine sex and maturity of each specimen. We classified individuals as mature when they had white, opaque testes or yolked eggs. Calculation of gonadosomatic indices (GSI) based on dried mass of somatic and gonad tissues verified our classification; mean GSI was 2.3 ± 0.1% and 9.0 ± 0.7%, and 0.9 ± 0.1% and 1.1 ± 0.2% (mean ± SE) for immature and mature females and males, respectively. We used a series of Fisher’s exact tests to compare the proportions of mature individuals within age classes among watersheds and logistic regression to compare the relationship between SL and maturity among watersheds. From the resulting logistic regression models, we calculated the size-at-maturity for each population as the mean size at which there was a 0.50 probability of a fish being mature. To examine relationships between age-at-maturity and size-at-maturity, and percent urban land use in the watershed, we again used simple linear regression.

RESULTS

Our sample locations spanned an urban-rural gradient ranging from Herring Run, with 95% of its watershed under urban land use, to Beaver Run with 21% of its watershed under urban land use. Gwynns Falls and Jones Falls had 28% and 66% of their watersheds urbanized, respectively. The amount of agricultural land use increased across the gradient from Herring Run to Beaver Run (Herring Run—0%, Jones Falls—19%, Gwynns Falls—36%, and Beaver Run—52%). Percent of forest land was low in all watersheds (Herring Run—5%, Jones Falls—15%, Gwynns Falls—36%, and Beaver Run—26%).

Mean size of dace varied significantly among watersheds but was dependent on age ($F = 14.1; P < 0.001$ for the interaction term in the ANCOVA model). Dace from Herring Run, the most urbanized watershed, reached the largest mean size at age I but grew little from age I to age II (as indicated by similar sizes of age I and age II fish from this watershed; Fig. 2). In contrast, dace from the two less urbanized watersheds were smaller at age I but continued to grow from age I to age II (as indicated by larger sizes at age II than age I for fish from these watersheds; Fig. 2). Although age I dace from Jones Falls were, on average, smaller than age I dace from Herring Run, the maximum size of age I fish from these watersheds was similar (Fig. 2). The size of dace at age I was positively correlated with percent of watershed urbanization ($R^2 = 0.92, P = 0.042, n = 4$; Fig. 3A), but
the size of age II fish was not ($R^2 = 0.19$, $P = 0.559$, $n = 4$; Fig. 3B). Additionally, growth rates during the second year of life, calculated as mean fish size at age II minus mean fish size at age I, was negatively correlated with percent of watershed urbanization ($R^2 = 0.99$, $P = 0.006$, $n = 4$).

Age-at-maturity and size-at-maturity varied among watersheds, but, in contrast to growth, relationships among age-at-maturity, size-at-maturity and percent of watershed urbanization were not linear. The proportion of mature dace at age I differed significantly among watersheds ($P < 0.001$). In Herring Run, the majority of dace (90%) were mature by age I, whereas a small proportion of age I dace were mature in populations from the other watersheds (Beaver Run = 0.25; Gwynns Falls = 0.21; Jones Falls = 0.22). Furthermore, the proportion of mature age I fish was significantly ($P < 0.001$) higher in the Herring Run population when compared to the other populations, but there were no significant differences ($P > 0.050$) in the proportion of mature age I fish among the other populations. The majority of age II fish were mature in populations of all watersheds (Beaver Run = 0.83; Gwynns Falls = 0.60; Jones Falls = 0.10; Herring Run = 0.96), and there were no significant differences ($P = 0.057$) among watersheds in the proportions of mature age II fish.

Size-at-maturity followed a similar pattern; dace from Herring Run reached maturity at a smaller size than dace from the other watersheds (Fig. 4). Logistic regression indicated significant differences among watersheds in the relationship between size and the probability of a fish being mature ($\chi^2 = 26.28$; $P < 0.001$ for the interaction term in the logistic regression model). A series of logistic regression analyses comparing relationships among individual watersheds indicated the relationship between size and the probability of a fish being mature for the Herring Run watershed differed significantly ($P < 0.001$) from all other watersheds, but there were no significant ($P > 0.050$) differences among the other watersheds. Estimated size at maturity was 45.0 mm SL, 47.7 mm SL and 50.5 mm SL for Beaver Run, Gwynns Falls, and Jones Falls, respectively. The individual logistic regression for Herring Run was not significant ($P = 0.205$) because most fish (92%) collected from Herring Run were mature. Using the minimum size of a mature dace from Herring Run (39.6 mm) as an estimate of size at maturity for Herring Run dace, there was no correlation with percent of urbanization in watersheds and estimated size at maturity ($R^2 = 0.21$, $P = 0.540$, $n = 4$).

**DISCUSSION**

Watershed urbanization, and the changes in stream environments that accompany it, have affected the growth and reproductive biology of blacknose dace in the Baltimore metropolitan area. Growth of age I fish increased in an almost linear pattern with increasing percent of watershed urbanization. In contrast, age and size-at-maturity showed more complex relationships with watershed urbanization. The majority of blacknose dace from streams draining watersheds with $< 70\%$ of their watersheds urbanized matured at age II and at similar sizes. In contrast, the majority of blacknose dace from a stream draining a heavily urbanized (> 90%) watershed matured at age I and at smaller sizes.
Although our results could be interpreted as a natural cline that covaries with the locations of our study watersheds across the Atlantic Coastal Plain (from east to west; Fig. 1), this is unlikely because the degree of variation that we observed among four regional watersheds is greater than variation reported throughout the range of blacknose dace. Size ranges of age I blacknose dace from New York, Iowa, and Nebraska streams ranged in size from 29–41 mm SL, 37–54 mm SL, and 22–44 mm SL, respectively (Traver, 1929; Noble, 1965; Bragg and Stasiak, 1978). In comparison, age I blacknose dace from Beaver Run, our least urbanized watershed, ranged from 28–52 mm SL, whereas age I dace from Herring Run, the most urbanized watershed, ranged from 41–68 mm SL. Furthermore, studies documenting age-at-maturity all report most blacknose dace maturing at age II (Traver, 1929; Noble, 1965; Tarter, 1969), a result similar to our findings for the three watersheds with lower levels of urbanization (≤ 66%).

In contrast to most other studies, we collected no age III fish. Populations from Iowa, Kentucky, Massachusetts, and Nebraska report the occurrence of age III fish (Noble, 1965; Reed and Moulton, 1973; Bragg and Stasiak, 1978). Comparison of maximum lengths and size range of age III dace (from the one study reporting them) with our results suggest that age III fish were absent from our samples. Bragg and Stasiak (1978) reported a maximum length of 81 mm SL and a size range of 68–81 mm SL for age III dace from Massachusetts. The largest dace we collected was 68.7 mm SL from the Herring Run watershed. In all previous studies reporting the occurrence of age III dace, age III fish made up a small proportion of the population (> 8%), suggesting survival of dace to age III is low. Because we collected no more than 63 fish from any population, it is possible that age III dace occur in some or all of the populations we studied but were not included in our sample.

Our results are consistent with previous studies of the response of stream fish population characteristics to human alterations of stream ecosystems and are similar to the effects of intensive fish stock exploitation. Schlosser (1982) and Tsai (1972) reported increased growth rates of young fish associated with agricultural land use and channelization and point-source sewage release into streams, respectively. Schlosser and Tsai attributed increased growth of young fish to increased production rates in both systems. Additionally, intensive exploitation often leads to maturation at earlier ages and smaller sizes (Upton, 1992; O’Brien et al., 1993), as we observed among dace from the heavily urbanized Herring Run watershed. Shifts in size and age at maturity in exploited stocks are hypothesized to be related to increased adult mortality rates but also may be partially related to density-dependent changes in resource availability. The more frequent and intense high and intermittent flow events characteristic of streams draining urban areas (Hollis, 1975; Arnold and Gibbons, 1996; L. B. Leopold, U.S. Geological Survey Circular 554, 1968, unpubl.) may lead to lower survival rates of dace. Finally, differences in temperature across the urban-rural gradient (Collins et al., 2000) will affect growth and may indirectly affect size and age-at-maturity (Wootton, 1998). Thus, overall, future studies that address changes in production rates, temperatures, and survival rates across the urban-rural gradient will provide a more mechanistic understanding of the response of stream fish to watershed urbanization.

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