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Comparison of Age and Growth Estimates for River Carpsuckers Using Scales and Dorsal Fin Ray Sections

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Abstract.—Several studies have indicated that use of scales to age river carpsuckers *Carpiodes carpio* is difficult. Thus, an alternative body structure may reduce variability in aging this species and provide more accurate estimates of the growth history and age structure of river carpsucker populations. We compared the precision of age determinations and means of back-calculated lengths at age of river carpsuckers between two readers and between the use of scales and dorsal fin ray sections from 172 individual fish collected in the Missouri River. Age agreement between the two readers was 71% for both scales and fin rays. Similarly, age agreement between scales and fin rays within readers was 68% and 72%. Precision of age determination by both readers declined after age-5 for both structures. Generally, more annuli were detected on fin rays than scales as fish age exceeded 5 years. Means of back-calculated lengths for ages 1–4 were significantly greater ($P < 0.05$) for fin rays than scales. Excluding ages lacking agreement between scales and fin rays had no significant influence ($P > 0.05$) on back-calculated length-at-age estimates. We recommend the use of scales as the primary aging structure when growth and mortality dynamics of the young and most abundant age-classes (e.g., age ≤6 years; total length ≤400 mm) are the primary interest. If estimates of annual mortality are to be extended to older age-classes, fin rays should also be collected on river carpsuckers greater than 400 mm.

Determining ages and calculating growth metrics of fish are two important practices used by fisheries biologists to evaluate fish population responses to environmental factors and management regulations. Although there is some aging error inherent in most age and growth studies, several studies suggest that scales generally provide the least precise and less accurate age determinations and exhibit fewer annuli for long-lived fish than do other structures such as otoliths, fin rays, and spines (Beamish and Chilton 1977; Mills and Beamish 1980; Rupprecht and Jahn 1980; Beamish 1981; Goeman et al. 1984; Heidinger and Clodfelter 1987; Welch et al. 1993; Marwitz and Hubert 1995). Thus, age determinations from scales may result in inaccurate estimates of the age structure of populations and subsequently affect estimates of growth and mortality rates (Mills and Beamish 1980; O'Gorman et al. 1987; Beamish and McFarlane 1995). In most studies that examine the use of different bony structures for aging fish, precision of age assignments between structures is often the primary objective. However, precision of back-calculated length-at-age estimates derived from different structures has received little study (Heidinger and Clodfelter 1987).

The river carpsucker *Carpiodes carpio* is a long-lived species widely distributed in rivers and reservoirs (Purkett 1958; Schmulbach et al. 1975; Walburg 1976; Clark 1979; Lee et al. 1980; Sandheinrich and Atchison 1986; Braaten and Berry 1997). Several studies have examined the age and growth characteristics of river carpsuckers using scales (Buchholz 1957; Purkett 1958; Al-Rawi 1965; Morris 1965; Stucky and Klaassen 1971; Hesse et al. 1978, 1982). However, researchers have noted that false annuli, inconsistencies in the location of annulus formation on scales, and the lack of ''cutting over'' (commonly associated with annulus formation) make age determinations difficult (Buchholz 1957; Morris 1965). We are unaware of any studies that have validated (as detailed by Beamish and McFarlane 1983) ages and annulus formation or examined use of other bony structures for aging river carpsuckers.

The goal of this study was to determine if dorsal fin ray sections could be used to age river carpsuckers. Dorsal fin rays were selected as a potential aging structure because they are easily removed, and less invasive than other structures (e.g., otoliths). Our objectives were to compare (1) preci-

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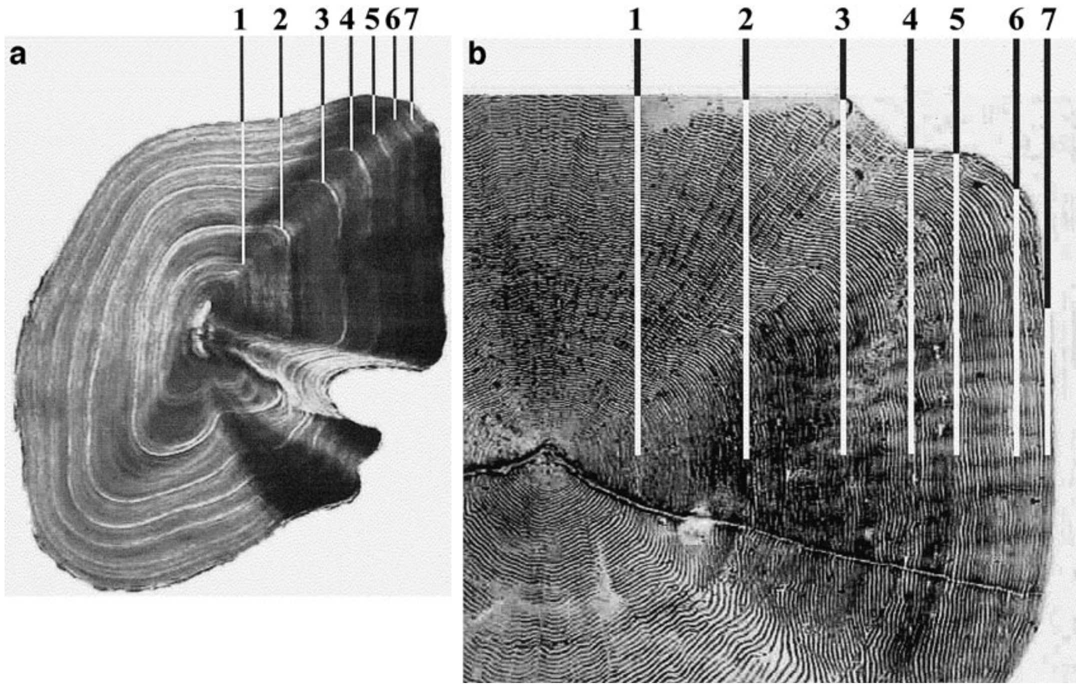

FIGURE 1.—Examples of (**a**) a dorsal fin ray section and (**b**) a scale from a 465-mm river carpsucker. Annulus locations are marked (1–7) along the axis on which the structure's radius was measured. The fin ray section is representative of a ''good'' fin ray; the scale is representative of an ''average'' scale.

sion of age determinations from scales and dorsal fin ray sections between and within readers, and (2) back-calculated lengths at age derived from these structures.

Methods

River carpsuckers were collected from a variety of habitats in Kansas and Missouri portions of the Missouri River from May to September 1996. Total length of all individuals was measured to the nearest 1.0 mm. Approximately 15 scales were collected from the area between the lateral line and dorsal fin insertion (rows 2–4 above the lateral line) of each fish. The second dorsal fin ray (longest ray) was removed by clipping the fin ray with standard sidecutters at the skin surface.

Scales were either mounted between glass slides (fish <100 mm) or impressed on acetate slides and aged using a microfiche projector (44×). We measured the radius and distance between annuli in the lateral region of the scale (Figure 1) because we observed that annuli were most discernable and consistent in this area. Annulus characteristics (e.g., cutting over, changes in circuli spacing) were examined in all areas of the scale before annuli were quantified (Buchholz 1957; Morris 1965).

Dorsal fin rays were first air-dried and then sectioned by cutting a thin section (0.2–0.4 mm) from the proximal end of the fin ray using a jeweler's saw. The section was mounted on a glass slide with thermoplastic cement, allowed to cool, and then hand-sanded using 600-grit sandpaper. Fin ray sections were viewed under a stereomicroscope (40×) interfaced with a computerized image analysis system. Fin rays were viewed under transmitted light. Radii and annuli distances were manually measured from fin ray images along the anteromedial axis (Figure 1). Buchholz (1957) reported that annulus formation in river carpsuckers occurs during May. For those fish collected in May that had not formed an annulus, the structure edge was considered the annulus.

Fin rays and scales were independently aged once by two readers. The readers were inexperienced at aging river carpsuckers but did have experience aging other species prior to initiation of the study. Initial observations of river carpsucker scales by both readers indicated that scales were difficult to interpret. These observations, in conjunction with literature sources that discussed the difficulties of aging this species using scales (Buchholz 1957; Al-Rawi 1965; Morris 1965), prompted our study. Scales were aged first by both readers. Fin ray ages were determined without knowledge of the ages assigned to scales.

Based on assigned ages for each structure, we constructed age bias plots (Campana et al. 1995) to determine bias and precision of age determinations between and within readers for both structures. Age bias plots were developed by averaging age values assigned by one reader that corresponded to a single age value assigned by the other reader. For example, if reader 2 assigns five fish as age1, but reader 1 assigns ages 1, 1, 2, 2, and 3 to the same fish, then the average age assigned by reader 1 is 1.8. Age bias plots include 95% confidence intervals about the mean age assigned by one reader for all fish assigned a given age by the second reader. Precision in age estimates between readers and structures was determined by calculating a coefficient of variation (CV; Chang 1982; Campana et al. 1995).

We conducted three analyses to determine the similarity in back-calculated lengths at age between fin rays and scales. In the first analysis, radius measurements from a single reader (reader 2) were used to develop fish length to body structure relationships for scales and fin rays. The intercept (*a*-value) from these relationships was used to back-calculate lengths at age using the Fraser–Lee technique (Busacker et al. 1990). The fin ray and scale data sets used in back-calculations were identical (i.e., full data sets containing all fish), except for assigned ages that differed for some individuals (see Results). We compared mean back-calculated lengths at age derived from fin rays and scales using *t*-tests when parametric assumptions were met or Wilcoxon two-sample tests when parametric assumptions were not met. Because lengths at older ages are dependent on lengths at earlier ages, incremental age comparisons within structures are not statistically independent. However, our objective was to determine the similarity of back-calculated lengths between fin rays and scales at all ages, not to compare back-calculated lengths at age for an individual body structure. An alpha level of 0.05 was selected for all *t*-tests and maintained for multiple comparisons using a Bonferroni adjustment (Trippel and Hubert 1990; Clapp and Wahl 1996). In the second analysis, we repeated this comparison using only individuals for which the reader assigned the same age to fin rays and scales (i.e., reduced data set). In the third analysis, we compared means of back-calculated lengths at age for scales and fin rays between the full data set (all fish) and reduced data set (100% agreement in ages) to determine whether precision in age estimates influenced back-calculated length-at-age estimates. All statistical analyses were conducted using SAS (SAS Institute 1988).

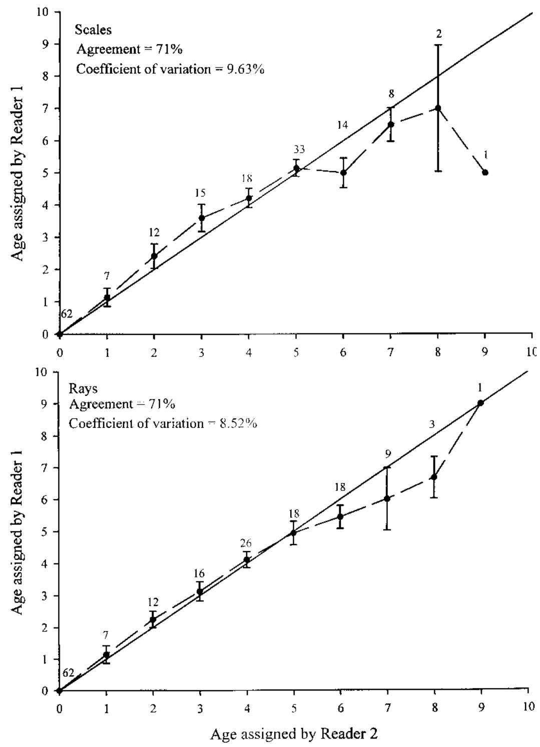

FIGURE 2.—Between-reader age bias plots (mean age ± 95% confidence interval, percent agreement, coefficient of variation) for scales and dorsal fin rays of river carpsuckers. The solid diagonal line represents 1:1 agreement between readers. Values above data points delineate sample size.

Results

A total of 172 river carpsuckers were aged by both readers. Overall age agreement between readers for scales and fin rays was 71% (Figure 2). Between-reader precision (defined by the proximity to the 1:1 agreement line) for scales and fin rays was also similar (CV = 9.63 and 8.52). Age agreement was high through age 5 but declined at older ages. For scales, 100% agreement between readers existed for age-0 fish, and the 1:1 agreement line was contained within the 95% confidence intervals for five age-classes (ages 1, 4, 5, 7, and 8). Complete agreement between readers for fin rays was achieved for age-0 and age-9 fish, and the 95% confidence intervals contained the 1:1 agreement line for six age-classes (ages 1, 2, 3, 4, 5, and 7).

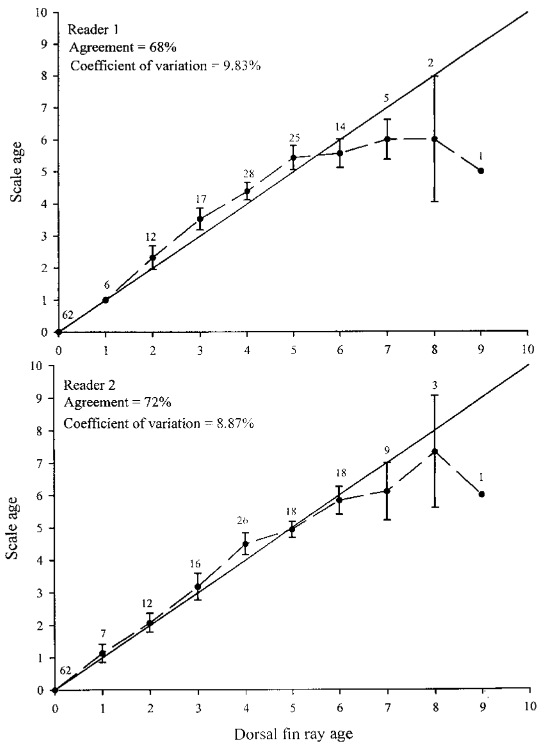

FIGURE 3.—Within reader age bias plots (mean age ± 95% confidence interval, percent agreement, coefficient of variation) for scales and dorsal fin rays of river carpsuckers. The solid diagonal line represents 1:1 agreement within readers. Values above data points delineate sample size.

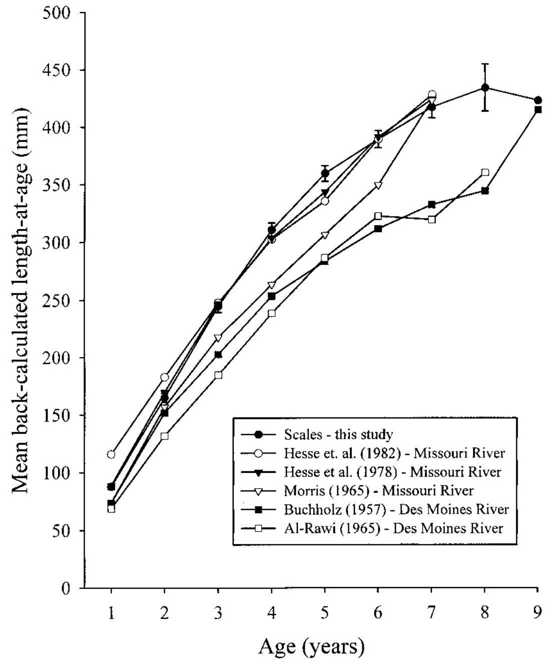

FIGURE 4.—Means of back-calculated lengths at age (±SE) of river carpsuckers based on scales in this and other studies (SE were not available in other studies).

Overall agreement between scales and fin rays was 68% and 72% for readers 1 and 2, respectively (Figure 3). Precision was similar between readers (CV = 9.83 and 8.87). Reader 1 assigned significantly older ages to scales at fin ray ages 3–5, whereas reader 2 assigned a significantly older scale age at fin ray age 4. For ages greater than 6 years, both readers generally assigned older ages to fin rays than scales.

Back-calculation was conducted on the same 172 river carpsuckers used in age comparisons. Regressions of body length on structure radius were significant for scales ($P < 0.0001$, $r^2 = 0.99$, body length = 13.9 + 54.9 [radius]) and fin rays ($P < 0.0001$, $r^2 = 0.96$, body length = 29.5 + 3.4 [radius]). Back-calculated lengths at age from scales in this study were generally similar to those reported by Hesse et al. (1978, 1982) in the Missouri River but greater than those reported by Buchholz (1957), Al-Rawi (1965), and Morris (1965) at age 3 or greater (Figure 4).

Based on the full data sets containing all river carpsuckers, mean back-calculated lengths at age of river carpsuckers from fin rays were significantly greater ($P < 0.05$) than those from scales at ages 1–4 (Figure 5). Differences in mean length at ages 1–4 years varied from 15 to 37 mm.

Body structure radius and annuli distances from reader 2 were used to compare back-calculated lengths at age between structures for individuals in which age agreement was 100%. Excluding age-0 fish, 62 of 114 river carpsuckers were assigned identical ages. This sample included 6, 9, 11, 13, 13, 6, 4 individuals in age-classes 1, 2, 3, 4, 5, 6, and 7, respectively. Regressions of body length on structure radius were significant for scales ($P < 0.0001$, $r^2 = 0.96$, body length = 17.0 + 54.8 [radius]) and fin rays ($P < 0.0001$, $r^2 = 0.89$, body length = 49.3 + 3.2 [radius]). Back-calculated length-at-age estimates from fin rays were significantly greater ($P < 0.05$) than scales at ages 1–4 years (Figure 5). Differences in mean length at ages 1–4 varied from 22 to 35 mm.

For both scales and fin rays, there were no significant differences ($P = 0.08$–0.96) in mean back-calculated lengths at age between the full and reduced data sets for ages 1–7 years (Figure 5). Differences in mean lengths were small and varied

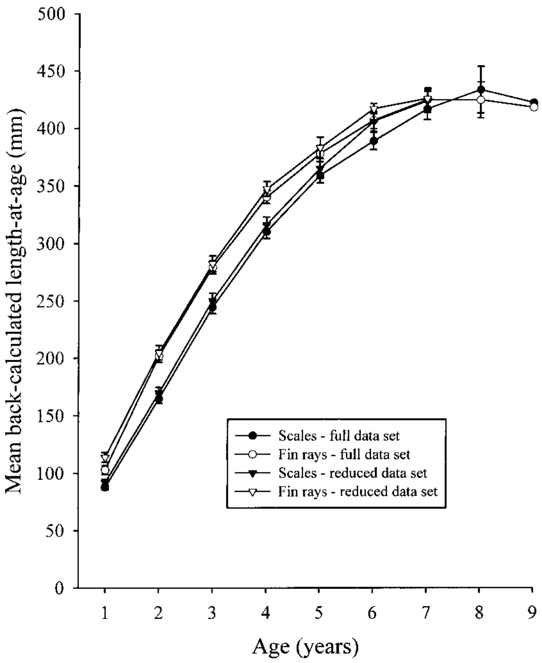

FIGURE 5.—Means of back-calculated lengths at ages (±SE) of river carpsuckers based on scales and fin rays for the full data set (all fish) and reduced data set (100% age agreement between fin rays and scales).

from 4 to 17 mm (scales) to 3–11 mm (fin rays). No comparisons could be made at ages 8–9 years because these ages were not present in the reduced data set.

One potential source of differences in back-calculated lengths at age between fin rays and scales was the intercept (*a*-value) used in the Fraser–Lee method. For example, the *a*-values were higher for fin rays than scales in both the full and reduced data sets. To examine the influence of the *a*-value on mean back-calculated length-at-age estimates, we back-calculated lengths for fin rays based on direct proportion (i.e., body length:ray radius is proportional with the intercept at the origin). For the reduced data set, means of back-calculated lengths at age were 78, 185, 271, 342, 382, 417, and 427 mm for ages 1–7 years, respectively. For the full data set, means of back-calculated lengths at age were 81, 189, 273, 337, 377, 407, 426, 426, and 420 mm for ages 1–9 years, respectively. With the exception of age-1, mean back-calculated lengths based on direct proportion were similar to those using the regression intercept.

Discussion

Previous studies have shown that fin rays can be used to age fish and often exhibit more annuli than scales (Beamish and Chilton 1977; Mills and Beamish 1980; Rupprecht and Jahn 1980; Beamish 1981; Welch et al. 1993). Our results for river carpsuckers corroborate these findings. However, precision between readers of age estimates from fin rays is not noticeably different than scales. Similarly, precision within readers closely matched precision between readers. Mills and Beamish (1980) reported agreement between scales and fin rays in lake whitefish *Coregonus clupeaformis* of 8–93%; agreement between readers for fin rays and scales was 61% and 44%, respectively. We observed that when scales from an individual fish were difficult to age (e.g., false annuli, poorly developed annuli) the fin ray section from the same individual was difficult to age. Thus, fin ray sections do not necessarily improve the ability of readers to age river carpsuckers. Beamish (1981) suggested growth patterns may be more easily discernable in fin rays than other structures but indicated that the fin ray method is not effective for all species.

Because we did not have fish of known age, we are unsure which structure more accurately depicted the true age of river carpsuckers. If agreement among different body structures is used as an index of true age of an individual, in the absence of age validation (Beamish and Chilton 1977; Beamish 1981), then we have strong evidence that accurate ages were assigned to individuals through age-5. Because fin ray sections typically had more annuli than scales for older individuals (≥6 years), age determinations from scales may underestimate the true age of older individuals. Further studies are needed to validate (Beamish and McFarlane 1983) the age of river carpsuckers and discern consistencies among body structures in the formation of annuli.

Mean back-calculated lengths at age based on scales from the full and reduced data sets were generally similar to other Missouri River studies (Hesse et al. 1978, 1982), except for Morris (1965), which was conducted during and preceding river modifications in the lower Missouri River that may have affected growth rates. Similarly, differences in mean back-calculated lengths at age from scales between our study and those in the Des Moines River (Buchholz 1957; Al-Rawi 1965) may be due to differences in environmental conditions between rivers. The similarity in mean back-calculated lengths at age between Missouri River studies (excluding Morris 1965) provides evidence that scales provide precise length-at-age estimates. In contrast, mean back-calculated length-at-age estimates based on fin rays from the reduced and full data sets exceeded those for scales at ages 1–4 years (15–37 mm difference). These results indicate that different bony structures in river carpsuckers will provide different estimates of mean back-calculated lengths at age. Heidinger and Clodfelter (1987) found that different structures (i.e., otoliths and scales) generally provided similar back-calculated length-at-age estimates in walleye *Stizostedion vitreum*, striped bass *Morone saxatilis*, and smallmouth bass *Micropterus dolomieu*, but there were species-specific and age class-specific differences. Mills and Beamish (1980) reported that growth estimates from fin rays were generally lower than those from scales because fin rays exhibited more annuli. Beamish and Chilton (1977) also found mean lengths of lingcod *Ophiodon elongatus* were greater from scales than dorsal fin rays.

For both scales and fin rays, there were no significant differences in means of back-calculated lengths at age between the full (all individuals) and reduced (100% age agreement) data sets. Thus, the removal of individuals for which scale and fin ray ages were not in agreement had little influence on back-calculated lengths at age. However, this does not imply that aging imprecision will not affect back-calculated lengths at age in all situations. Although agreement between fin rays and scales was relatively low (68–72%), differences in mean age assignments between structures was usually less than 1 year for ages 1–6 (Figure 3). Greater imprecision (e.g., differences in mean age assignments >2 years) may contribute to differences in back-calculated length-at-age estimates. Heidinger and Clodfelter (1987) deleted from their analysis fish with scale and otolith ages that did not agree with the known age of the individual. This resulted in the removal of 20–29% of the individuals studied. Excluding age-0 individuals, 46% of the river carpsuckers were excluded in our analysis. Results from Al-Rawi (1965) similarly emphasized the difficulty in aging river carpsuckers. This author noted that scales from 90 (11%) of 855 river carpsuckers were judged to be unreadable.

In conclusion, we suggest either scales or fin rays may be used to age and back-calculate lengths at age of river carpsuckers. However, there are advantages and disadvantages in using either structure. Under the assumption that marks or discontinuities on either structure are formed annually in this species, fin rays exhibit more annuli and would provide more accurate estimates of annual mortality and population age structure than scales. Because back-calculated lengths at age from rays are greater than scales, both structures cannot be used simultaneously (e.g., in the same study) for back-calculations. In addition, the lack of information based on fin rays for river carpsuckers in previous studies precludes comparisons of means of back-calculated lengths at age based on fin rays. Scales should be used if comparisons to populations previously studied are of interest. We recommend the use of scales as the primary aging structure when growth and mortality dynamics of the young and most abundant age-classes (e.g., age ≤6; ≤400 mm total length) are the primary interest. If estimates of annual mortality are to be extended to older age-classes, fin rays should also be collected on river carpsuckers greater than 400 mm.

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