

DISTRIBUTION, ECOLOGY, AND REPRODUCTIVE BIOLOGY
OF THE ORANGEFIN MADTOM (NOTURUS GILBERTI)

by

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(ABSTRACT)

Distribution of the orangefin madtom (Noturus gilberti) was determined from 347 sites sampled in Virginia and North Carolina. This species inhabited 264 stream kilometers, over twice the reported range, in the following systems: Craig Creek, Roanoke River, Dan River, Big Chestnut Creek, South Mayo River, Pigg River, and Smith River. The orangefin madtom was somewhat common; 33% (Dan River) to 70% (Craig Creek) of the sites sampled were occupied.

Negative interspecific associates of orangefin madtoms included chubs, mountain redbelly dace, rosyside dace, crescent shiners, and crayfish; only Roanoke darters were considered positive associates. Sand and silt levels were significantly lower at sites with N. gilberti, while percentage of small cobble, local gradient, and depth were significantly higher. Discriminant function analysis identified large gravel, local gradient, silt, and occurrence of rosyside dace and crayfish, as significant predictors of the occurrence of the orangefin madtom.

Seasonal samples from Craig Creek consisted of three age groups. The smallest individual captured was 33 mm total length (TL) and the largest was 111 mm TL. Mortality appeared moderate from age I until summer of the third year, when most individuals apparently died shortly after spawning. Spawning habitat of orange-fin madtoms in Craig Creek appeared to be fast-water riffles dominated by small cobble substrate.

Attempts to induce N. gilberti spawning in the laboratory were unsuccessful due to high mortality of captive fish. Field-collected margined madtom egg masses, however, were successfully hatched, and subsequent survival was significantly greater for fry fed ground trout chow versus live brine shrimp nauplii.

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INTRODUCTION

BACKGROUND AND JUSTIFICATION

The North American endemic catfish family, Ictaluridae, comprises six genera, including madtoms in the largest genus Noturus (Taylor 1969). This genus consists of 25 described and one undescribed species, ranging from east of the Rocky Mountains, north to Hudson Bay and south to the Gulf of Mexico (Mayden 1983). Madtoms are relatively small and secretive, typically residing under rocks during daylight; most species are considered nocturnal. They frequently occur in small, isolated populations (Lee et al. 1980), with diversity highest in the east-central United States (Taylor 1969).

Most published studies on Noturus have been primarily of a taxonomic nature, with little ecological information reported (Mayden and Burr 1981). Madtom literature prior to 1967 was summarized by Taylor (1969). Subsequent studies have been devoted to age and growth (Carlson 1966), fecundity (Mahon 1977), hybridization (Menzel and Raney 1973), selected life history aspects (Mayden et al. 1980), and toxicity of madtom stings (Birkhead 1972). Several life history studies were also completed since 1980 (Burr and Dimmick 1981, Mayden and Burr 1981, Burr and Mayden 1982a, Burr and Mayden 1982b,

Mayden and Walsh 1984, Miller 1984, Shute 1984, Whiteside 1984, Burr and Lee 1985, Starnes and Starnes 1985).

As more information on madtoms was gathered, it became apparent that several species were rare, occurring in disjunct populations with few individuals. In the early 1970's, Miller (1972) considered 10 species to be "threatened" within various states. Deacon et al. (1979) also listed 10 species as endangered, threatened, or of special concern throughout their ranges; only four overlapped with Williams' (1981) most recent list. One species, the Scioto madtom (N. trautmani), has been federally listed as endangered. Since 1981, the yellowfin madtom (N. flavipinnis) and the smoky madtom (N. baileyi) have each been federally listed as threatened (Williams 1981, USFWS 1984). Several other species are currently under consideration for addition to the federal list. These include the Carolina madtom, N. furiosus, orangefin madtom, N. gilberti, Ouachita madtom, N. lachneri, frecklebelly madtom, N. munitus, Neosho madtom, N. placidus, pygmy madtom, N. stanauli, and Caddo madtom, N. taylori (Dodd et al. 1985). Habitat destruction is believed responsible for the decline of all these madtom species (Williams 1981).

Decline of many Noturus species over the last 20 years has prompted development of policies and procedures for their conservation. Conservation measures for two of the three federally listed species have been delineated in recovery

plans (USFWS 1983, USFWS 1984). Objectives of these plans include the protection of existing populations, range expansions through continued surveys or reintroductions, and ultimately, delisting.

Legal and planning aspects of recovery programs (i.e., using existing legislation to protect extant populations) are established by law (Williams 1981). However, biological components, such as captive breeding and rearing of madtoms, are recommended but untested. Delisting a species presumably relies not on preservation of existing numbers but on manipulation for increasing the number of populations. Therefore, introduction and reintroduction procedures are clearly needed. Success of such programs requires that the species be bred and reared in captivity, and released in areas suitable for its habitation. While almost half of the madtoms are considered (officially or unofficially) vulnerable, information needed for their recovery, beyond basic life history aspects, is largely unavailable.

ORANGEFIN MADTOM

The orangefin madtom, Noturus gilberti, was selected for thesis research because 1) it is under review for federal listing (Anonymous 1980, Dodd et al. 1985), considered threatened in Virginia (Jenkins and Musick 1980), and probably endangered in North Carolina (Simonson and Neves 1986);

2) there is little published information on the species; and
3) a status survey was needed to identify its distribution and habitat requirements. This species could become extirpated from a significant portion of its present range in the foreseeable future, yet no vital recovery data are currently available.

Discovered and described by Jordan (1889), N. gilberti is considered a unique madtom, lacking the distinctive, cryptic markings typical of most Noturus (Taylor 1969). LeGrande (1981) suggests that the orangefin madtom was the first to diverge from a hypothetical Noturus-Pylodictis common ancestor (Lundberg 1975). The orangefin madtom was considered an atypical member of the subgenus Shilbeodes, closely resembling the stonecat, N. flavus, of the monospecific subgenus Noturus (Taylor 1969). Jenkins and Burkhead (1986) currently place N. gilberti in the subgenus Noturus, an action first proposed by LeGrande (1981).

A relatively small madtom reaching about 85 mm standard length, N. gilberti has a narrow head, subterminal mouth, short barbels, reduced eyes, and short spines (Figure 1). The dorsum and upper sides are medium brown to grey, sides are pale grey to olive, and ventral surfaces are white with a slight pink cast. All fins have a slight to moderate yellow wash, sometimes colorless but rarely orange unless unspread. The dorsal fin has a dark basal blotch, and the anal fin often has a submarginal dusky brown area. The caudal fin is sub-

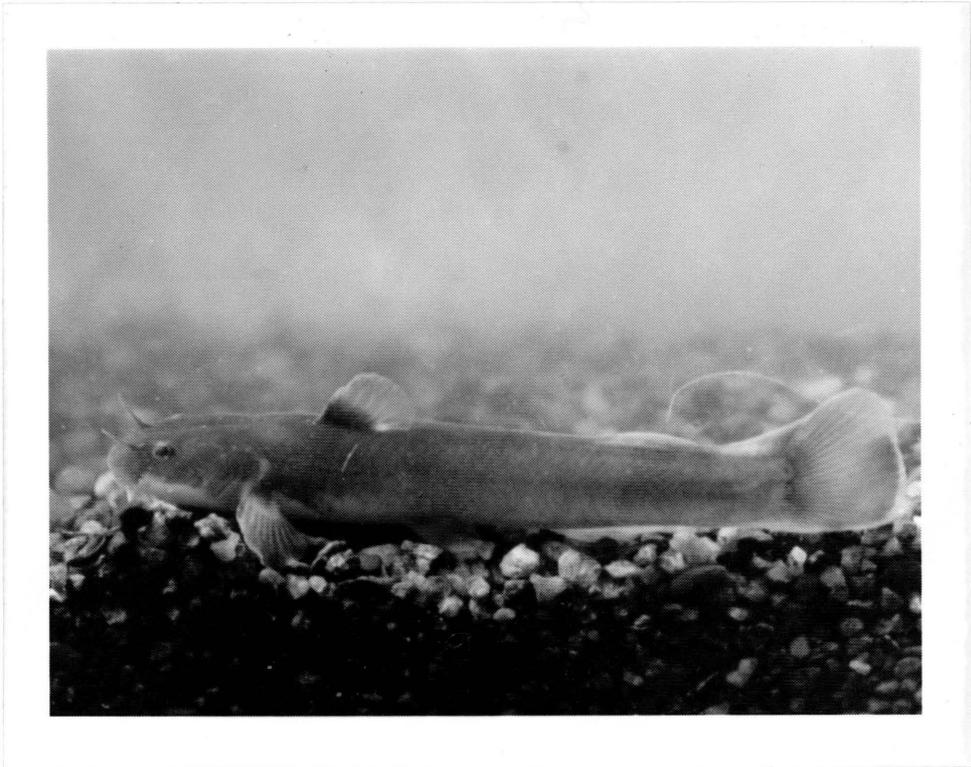


Figure 1. Photograph of an adult orangefin madtom (85 mm SL) captured from the Pigg River in Franklin County, Virginia.

marginally medium to dark brown, usually becoming less intense towards the base. The upper caudal margin is pale to medium yellow, narrowing at the base. A more complete description is provided by Jenkins and Burkhead (1986).

DISTRIBUTION

The orangefin madtom was first collected by Jordan (1889) in the upper Roanoke River near Alleghany Springs, Virginia. It was virtually uncollected between 1900 and 1940, due primarily to lack of adequate effort (Jenkins 1977). During the 1950's through 1970's, populations were discovered in the Pigg, Mayo and Dan River systems (Roanoke River drainage) and in Craig Creek (upper James River drainage). Its range as of 1984 (Figure 2), compiled from recent and historic records, encompassed 128 stream kilometers (SK) in Virginia and North Carolina and included the systems listed below. (Jenkins 1977, Burkhead 1983).

Craig Creek System, James River drainage, Craig County, VA: The geographic extremes in Craig Creek were upstream, at the State Route 311 bridge (7.9 SK above John's Creek mouth) and downstream, just above the State Route 606 bridge (9.7 SK below John's Creek mouth). In John's Creek it had been taken about 1.6 SK above it's mouth on Craig Creek. Total range in this system was about 19 SK.

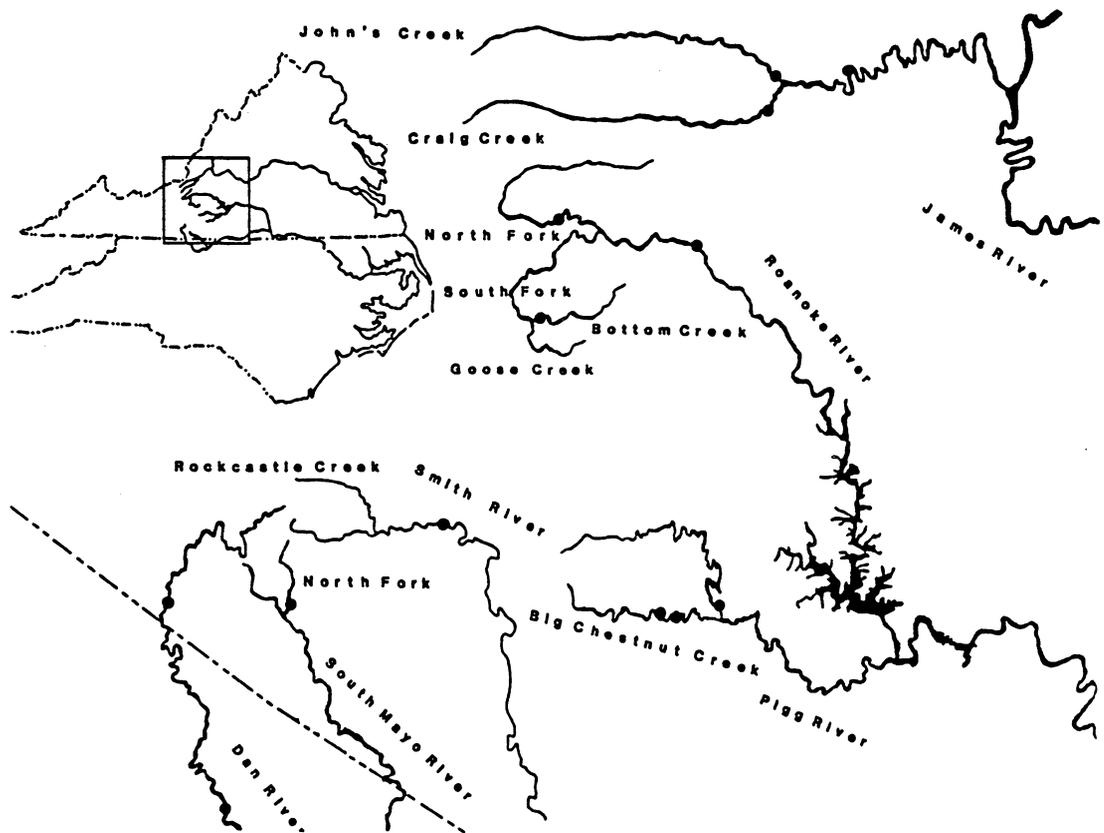


Figure 2. Range limits of the orangefin madtom in Virginia and North Carolina, as of 1984.

Roanoke River System Proper, Roanoke River drainage, Roanoke and Montgomery Counties, VA: This, the earliest and best known population, extended from central Salem upstream into the lower two miles of the North Fork and throughout the South Fork, including lower Bottom Creek. Total occupied range was about 56 SK.

Dan River System, Roanoke River drainage, Patrick County, VA and Stokes County, NC: On the Dan River proper, the geographic extremes were the State Route 103 bridge in VA (upstream) and the State Route 1152 bridge, 0.3 miles ESE of Danbury, NC (downstream). Total range in the Dan River was about 48 SK.

Big Chestnut Creek, Pigg River system, Roanoke River drainage, Franklin County, VA: Two specimens were taken at the State Route 718 bridge, 2.4 air miles E of Sydnorsville (Hambrick 1973). The downstream limit was below the State Route 619 bridge, 4 air miles ENE of Sydnorsville. Total range was about 5 SK.

Mayo River System, Dan River basin, Roanoke River drainage, Patrick County, VA: One specimen was collected from the North Fork of the South Mayo River in 1952, two miles NW of Stuart, VA on U.S. Highway 58 (Taylor 1969).

Smith River System, Dan River basin, Roanoke River drainage, Patrick County, VA: One unverified specimen was reported from Rockcastle Creek at the State Route 8 bridge,

2.5 air miles NW of Woolwine, VA (M. Thomas, pers. comm. 1984).

Although this species is presently considered a candidate for federal protection, knowledge of its range is based primarily on incidental or taxonomic collection records. This is apparently true for most species of Noturus, since few ranges are accurately delineated. Baseline survey data are needed to compare historic, present, and future trends in this species' range and status.

HABITAT

Hubbs and Raney (1944; as cited in Taylor 1969) first commented on N. gilberti's ecology and suggested that the species occurred beneath large stones in fast-water riffles. They also considered the margined madtom (N. insignis) to be commonly associated with N. gilberti. Burkhead (1983) considered three interrelated features; current velocity, substrate size and lack of silt deposition, to be the most important components of the orangefin's microhabitat. Riffles containing these critical features occur more often in upstream sections, suggesting that the species' distribution may be functionally related to stream gradient.

N. gilberti appears to be a strict intersticene dweller; no diel variation in habitat use has been observed. This adherence to riffle interstices may have resulted from com-

petitive exclusion by the larger, more abundant, and occasionally sympatric margined madtom (Burkhead 1983).

LIFE HISTORY

Aspects of the orangefin madtom life history have been recently reported by Jenkins (1977) and Burkhead (1983). This species is apparently short-lived; both sexes probably live three full years. Growth is fastest during the first year. The sex ratio is reportedly skewed towards females. Mortality rates among age groups have not been documented.

Feeding habits of N. gilberti were determined by Burkhead (1983), based on 60 specimens from the upper Roanoke River. Simuliids, chironomids and trichopterans constituted the majority of food items. No diel variation in diet or stomach fullness was found, indicating continuous rather than nocturnal feeding habits. The orangefin madtom is probably a gustatory feeder, consuming the most abundant or available prey.

There are no described spawning habits for N. gilberti, but it is believed to reproduce in late April to May, based on ovarian development and musculature dimorphism (Jenkins 1977). Most males and females achieve reproductive maturity in the second year of life (age I), and few age III individuals spawn. Fecundity of N. gilberti is relatively low; 32 to 70 large (3 mm diameter), mature ova per female are re-

ported. Reproductive behavior is presumed similar to other madtom species. Generally, males select a nesting cavity under rocks, clear out fine sediments, and remain with the brood until fry disperse. Habitat used in reproduction is not documented.

Detailed investigations of Noturus reproductive biology are available for 13 species (Mayden 1983, Mayden and Walsh 1984). By late spring and early summer, mature adults have fully developed gonads, and preparation for spawning takes place. Males develop swollen lips and epicranial musculature, which is presumably of value in nest excavation (Mayden et al. 1980). During this period, females are recognized by their distended abdomens. Balon (1975) classified madtoms as speleophils, preferring cavities as nest sites. Males presumably guard the brood (Clark 1977, Mayden et al. 1980). Feeding, at least by males, does not occur during nesting (Burr and Dimmick 1981, Burr and Mayden 1982a, Mayden 1983). Menzel and Raney (1973) and Mayden and Burr (1981) have hypothesized that madtoms are polyandrous.

Current knowledge of Noturus captive breeding and rearing is limited to short anecdotes from observations in aquaria. Mayden (1983) reported the observation of spawning N. miurus. Excellent success in aquarium spawning and larval rearing has been reported by Burr and Lee (1985), who indicated that propagation techniques are needed for large scale production of madtoms.

STUDY OBJECTIVES

This study was initiated to assess the current status of N. gilberti, describe selected life history aspects, and provide baseline information required for future conservation efforts.

Specific objectives were to 1) delineate N. gilberti's distribution and relative abundance, and assess associated environmental factors; 2) describe population structure of this species and gather information on reproduction from a natural population; and 3) develop techniques for the captive breeding and rearing of N. gilberti. The long-term goal of this and subsequent studies is to provide techniques and information necessary for establishing new (or re-establishing historic) populations of this and other madtom species.

METHODS

STUDY AREA

Since the entire range of the orangefin madtom was to be determined, all streams of known or possible occurrence were sampled. Streams and stream sections known to be inhabited by this species were described in the Introduction. Most of these watersheds are primarily forested and relatively undeveloped. The Roanoke River system, however, flows through a major urban area (Roanoke and Salem, Virginia), and much of the North Fork's watershed has been cleared for agricultural crops and livestock grazing (Burkhead 1983). Also, the South Mayo River system drains portions of a small urban area (Stuart, Virginia).

All streams sampled were small to moderate - sized montane systems draining the Ridge and Valley (Craig Creek and Roanoke River), Blue Ridge (Smith River), and Blue Ridge foothills of the Piedmont Plateau, or "Inner Piedmont" (Dan River, South Mayo River, and Big Chestnut Creek) physiographic provinces (Hoffman 1979).

The Ridge and Valley province is characterized by extensive Paleozoic sedimentary rock formations. The Piedmont is largely crystalline volcanic and micaceous, which upon weathering chokes small streams with silt. Considerably more

resistant rocks such as granite, schist, greenstone, and slate form the Blue Ridge province. Climax vegetation for the entire area is the typical Oak-Chestnut (now largely Oak-Hickory) forest type (Hoffman 1979).

STREAM SURVEYS

Present distribution of N. gilberti was determined during the summers of 1984 and 1985. Sampling was conducted first at recently reported locations for this species (Jenkins 1977, Burkhead 1983). Riffles upstream and downstream of the last reported range were censused until the madtom was consistently absent in collections. Streams with no record of N. gilberti were sampled if they appeared suitable for this species, based on previous collecting experience and advice from Dr. R. E. Jenkins, Roanoke College (pers. comm.). Stream reaches where the orange-fin madtom was discovered or rediscovered were walked or canoed and sampled at relatively close intervals.

Locations of sampling sites were plotted on and described from USGS 7.5 minute quadrangle topographic maps and county highway maps of the Virginia Department of Highway and Transportation. Stokes County Tax Office, Danbury, North Carolina, provided a map of that county.

Riffles were sampled using a Coffelt model BP-1C backpack electrofishing unit with approximately 120 watts direct

current output (voltage varied with stream conductivity). Fish were collected at each riffle by shocking (and kicking substrate) downstream into a stationary 6 mm (1/4") mesh, 4.6 m long seine. The field crew consisted of three people, two net attendants and one shocker.

At each riffle, date, county, locality, width (m) and length (m) sampled, and effort (2 - 5 minutes depending on riffle area) were recorded. Mean local gradient (percent slope) of the stream bed was obtained for most sites using an Abney level and range pole (flagged at eye level) at 3 to 4 locations parallel to the stream bank. Depending on riffle length sampled, four to eight transects were set up perpendicular to the stream bank at 1 to 2 m intervals. Substrate was categorized by the points-sampling method (Orth 1983). Dominant and subdominant substrate size, an index of siltation, and depth were recorded at "points" spaced 1 m apart (for a 1m^2 area) along each transect. Substrate size was described by a modified Wentworth scale (Hamilton and Bergersen 1984; Table 1). Siltation was characterized using a modified embeddedness scale (Platts et al. 1983; Table 2). Depth was recorded to the nearest 1 mm using a meter stick, and water temperature was recorded at most sites. The points-sampling method therefore provided roughly 20 to 30 point measures of the substrate, silt, and depth variables.

All captured fish were identified to species, enumerated, and released with few exceptions. Orangefin madtoms

Table 1. Substrate classes used in this study (modified from Hamilton and Bergersen 1984).

Code	Name	Size class (mm)
0	Sand	1-4
1	Small gravel	4-20
2	Large gravel	20-60
3	Small cobble	60-120
4	Large cobble	120-250
5	Small boulder	250-500
6	Large boulder	>500
7	Bedrock	-

Table 2. Classification of silt levels used in this study (modified from Platts et al. 1981).

Code	Description
1	silt free (<5% coverage)
2	slight silt (5-25% coverage)
3	moderate silt (25-50% coverage)
4	heavy silt (50-75% coverage)
5	extreme silt (>75% coverage)

were measured in total length (TL; mm) and standard length (SL; mm). Wet weights (0.1 g) were measured from a subsample of fish that included the range of sizes captured. Species not identified on site were fixed in 10% formalin and later identified. Voucher specimens of N. gilberti, retained from newly established range limits, were also fixed in 10% formalin and preserved in 70% ethanol. Voucher materials are to be permanently housed in the fish collection at Roanoke College, under the supervision of Dr. Robert E. Jenkins.

In fall 1985, once the stream survey was completed, 41 additional riffles in Craig Creek were sampled as previously described, except that local gradient was measured with Abney level, transit and level rod. Three-depletion samples, with one blocknet at the downstream end, were collected by electrofishing at each site. Abundance of each species was obtained with the maximum-weighted-likelihood removal estimator (Carle and Strub 1978). The probability of capture among individual orangefin madtoms was assumed to be equal. However, individuals may occupy varying depths within the substrate, making them differentially susceptible to electrofishing. Because of the apparent interstitial habits of N. gilberti, one downstream blocknet was judged to adequately reduce emigration during and between sampling runs. During underwater observations, orangefin madtoms sought the nearest available cover when disturbed. The assumption of equal probability of capture among sampling runs appeared

valid but was not tested. It is possible that some fish were more vulnerable after the first or second samples, if they occupied different levels of the substratum. However, sites were typically bedrock-based, with relatively shallow substrate. Immigration into the sampling area was considered negligible, again, due to the interstitial, isolated nature of this species and the short duration of sampling.

Simple linear regression analysis was used to develop a model of the absolute abundance obtained by the removal estimator from the number of orangefin madtoms taken on the first depletion run. The results were used to determine if the number taken in one sample was an adequate predictor of abundance.

The Wilcoxon signed rank test (Hollander and Wolfe 1978) was used to test the hypothesis that the paired local gradient measures (Abney versus transit) did not differ at each site. Results of this test were used to determine the utility of Abney level readings as acceptable local gradient measures.

Substrate was categorized for all sites by determining the proportion of dominant point-measures for each category (Paragamian 1981). For example, if 30 points were sampled and 15 were visually scored as dominated by small cobble, then 50 percent of that riffle was considered dominated by small cobble. This procedure was repeated for each substrate category at each site. Subdominant categories were highly

correlated with their respective dominant categories and were excluded from analysis.

One variable was used to describe siltation. Occurrences of silt-free points (Table 2) were summed for each site and divided by total point-measures. This value was considered the proportion of the riffle that was free of silt. Subtracting the value of this variable from 1 resulted in the proportion which was at least slightly silted. This approach was taken because of the paucity of measurements observed for the "high" silt categories.

Range of the orangefin madtom was determined to the nearest stream kilometer from USGS 7.5 minute quadrangle topographic maps, using a map wheel. Total distribution was assumed to include the entire stream reach between documented range limits.

Relative abundance of this species in each stream was estimated by calculating the proportion of sites at which it occurred and the mean number per site sampled. Habitat (range) occupied by the orangefin madtom was then estimated by multiplying the percent occurrence in a stream system by the total stream length (km) encompassing its range.

The status of this species was based on examination of its total range, an estimate of its occupied habitat, relative abundance, and availability of suitable habitat.

SPECIES AND HABITAT ASSOCIATIONS

The orangefin madtom's occurrence with other riffle inhabitants (fish and crayfish) was analyzed with Hurlbert's (1969) coefficient of interspecific association. Presence or absence of N. gilberti at each of 216 sites was cross-classified with the presence or absence of each species captured during the survey. Significance of each interspecific relationship was assessed using Pearson's chi-square statistic (Hurlbert 1969). Each species collected with the orangefin madtom was tested, but only those significantly associated with this species, and occurring throughout its range, were included in further analyses.

To test the hypothesis that presence or absence of the orangefin madtom was related to the physical habitat measured at 142 sites during this study (Table 3), univariate analysis of variance (ANOVA) tests were conducted for each variable, using presence and absence as the classification variables (SAS 1985). Two-group discriminant function analysis was then used to develop a predictive model for occurrence (presence versus absence) of N. gilberti (Layher et al. 1982, E. Smith, pers. comm.). This procedure evaluates the probability of a collection location belonging to a given class, based on the explanatory variables, and then compares its classification or group assignment to actual class membership. The results of these procedures are useful for pre-

Table 3. Variables tested to account for orangefin madtom occurrence and relative abundance.

Class	Description	Type
Physical	Sand	continuous (%)
	Small gravel	continuous (%)
	Large gravel	continuous (%)
	Small cobble	continuous (%)
	Large cobble	continuous (%)
	Small boulder	continuous (%)
	Large boulder	continuous (%)
	Bedrock	continuous (%)
	Depth	continuous (cm)
	Local gradient	continuous (% slope)
	Siltation	continuous (%)
Biotic	Species richness	multinomial
	Species presence or absence	binomial (1 or 0)

diction but are purely correlative; causal relationships cannot be inferred.

In order to determine which variables best distinguished sites with and without the madtom, physical and biotic variables in Table 3 were first subjected to stepwise discriminant analysis, STEPDISC (SAS 1985). Sites falling outside the natural range of the species were removed from the analysis. Significance level for a variable to enter and remain in the model was set at 0.15, and was based on the partial F statistic. Variables selected in this phase were entered into the discriminant function analysis, DISCRIM (SAS 1985). Correct assignment into each category was evaluated. Following Layher et al. (1982), misclassified locations were printed and examined on distribution maps. The discriminant functions, based on criteria established by my data, allow prediction of orangefin madtom occurrence, given the values of variables selected by STEPDISC.

Several approaches were examined to determine factors correlated with the density of this species. First, a stepwise multiple regression procedure was used. This analysis resulted in significant relationships between density and the explanatory variables, but the fits were poor ($R^2 < 0.2$) and these models were of little predictive value. Principle components analysis resulted in a good classification of categorical densities but had little predictive capability (Matthews 1985). Multiple regression of principle components

scores also inadequately fit the data. The final approach was to split density into classes, based on a frequency plot of all sites sampled, and conduct a discriminant function analysis. While it is important to assign these groups a priori (Klienbaum and Kupper 1978), no basis for reasonable density cutoffs was available. Exploratory analyses were therefore conducted with several combinations of 'low', 'medium', and 'high' density classes. Using three categories generally resulted in poor classification, particularly of the 'medium' density class. Several two-group tests resulted in good classification, and reasonable cutoffs were assigned as follows: 'low', 1 to 9 N. gilberti / 100 m²; and 'high', 10 or more / 100 m². The low category included 78% (64) of the sites used in this analysis. Significance of all explanatory variables in separating the high and low density sites was determined using ANOVA. Density classes of N. gilberti were modeled in a manner similar to that described above for distribution, using STEPDISC and then DISCRIM.

The mean of each variable significantly related to distribution of the orangefin madtom was obtained for each stream system sampled. The relative amount of suitable habitat available was determined by ranking the variables across systems, from best (1) to worst (5).

LIFE HISTORY AND REPRODUCTION

Reproductive chronology and spawning habitat of N. gilberti were examined at 23 sites throughout Craig Creek, from April to July 1985. Adjacent riffle and pool areas were sampled for reproductively active orangefin and margined madtoms (Noturus insignis). Blocknet and shocker techniques, as described previously, were used in riffle areas, and a backpack shocker and dip-nets were used in pool areas. At each site, I recorded the date, location, water temperature, effort, predominant substrate, and the number and sex (when discernible) of both species. To avoid killing individuals for development of reproductive indices such as the Gonadosomatic Index (GSI), sexual maturity of this species was based on typical Noturus reproductive dimorphism (i.e., swollen, distended abdomens in females and broad, enlarged head musculature in males). The proportion of mature males and females in samples taken over several weeks was plotted, and resulted in a graph similar to that obtained when using GSI.

In May 1985, searches for nests were conducted by snorkeling in areas determined to harbor young-of-year N. gilberti, based on surveys done in 1984. At each site, snorkelers moved upstream from the base of the riffle, turning over large rocks. By raising rocks slowly from the downstream side, presence of a territorial male and(or) egg

mass could be determined despite strong water current velocities.

Age, growth, and population structure of the orangefin madtom throughout Craig Creek were determined from length-frequency histograms constructed for the months of September 1985, May 1986, and July 1986. Fish were aged based on the length-frequency histograms to avoid spine-removal aging techniques injurious to these small madtoms. Each age group was assigned upper and lower total length bounds, and mean lengths were calculated for all individuals, males, females, and those of undeterminable sex, for each age and season. A growth curve was constructed by plotting mean length at age (in months). Mortality was estimated from the number, proportion, and catch per unit effort (minutes of electrofishing) of each age class in five samples from May 1985 through July 1986. This approach assumes a stable age distribution, since seasonal samples did not follow all cohorts throughout their lives.

Length-weight regressions were developed for all fish combined, and for discernible males and females collected in Craig Creek during spring 1986.

CAPTIVE BREEDING

Captive breeding of the orangefin madtom, attempted during spring 1986, consisted of three phases. Two involved

scaled-down versions of channel catfish (Ictalurus punctatus) pen spawning techniques, where pairs are placed in small enclosures with spawning receptacles (Brown and Gratzek 1980). The third phase involved removal and mixing of mature ova and testes.

Propagation of N. gilberti was conducted using four stainless steel raceways (20 cm deep x 36 cm wide x 4.3 m long). One raceway was equipped with a series of plexiglas paddlewheels powered by an electric motor. The second was unaltered and used as a holding tank. The remaining two raceways were divided, using plastic 4 mm mesh screen, into 14 equal-sized pens (spawning sections) measuring 20 cm x 30 cm x 36 cm (Figure 3).

The system was supplied with town water (dechlorinated) to a headbox having a standpipe (emptying into biofilter) and two outlets, each shared by two raceways. Water leaving the raceways through 20 cm high standpipes flowed back to a limestone biofilter equipped with a 240V/4500W heating element. A thermostatic sensor in the headbox regulated water temperature in the biofilter. Once filtered and heated to the desired temperature, water was pumped back to the headbox through a passive aspirator. A drain in the biofilter allowed either completely closed recirculation or partial flush of clean water through the system. Water flow rate through the flumes averaged 4.3 l / minute.

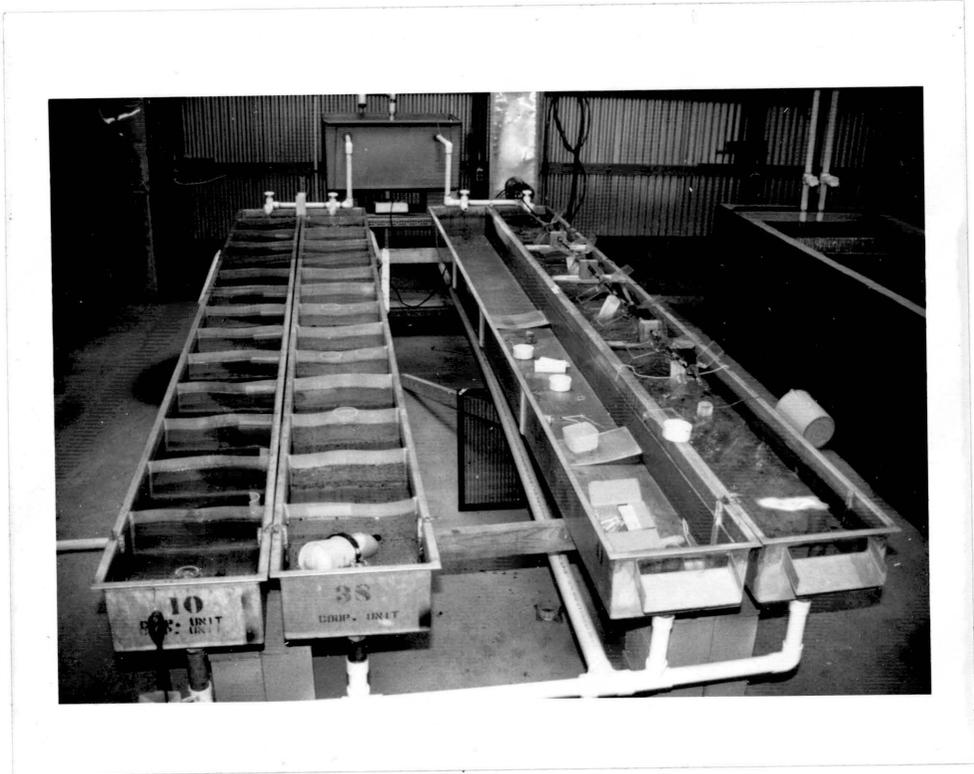


Figure 3. Photograph of the laboratory set-up, showing flumes used during captive breeding experiments.

In order to test whether techniques used to spawn channel catfish could be used to induce spawning of N. gilberti, 48 mature (age II) individuals (24 per sex) were selected from fish captured in Craig Creek during early May 1986. Only ripe fish were used. Females were considered gravid if the abdomen was obviously distended; males were retained if dorsal head musculature and lip swelling was apparent, indicating that the fish were in spawning condition (Mayden and Burr 1981).

Males were randomly assigned to the 24 spawning sections on 3 May 1986. Each section contained two nest-cover types; one 4 cm diameter x 15 cm long PVC pipe (full-shelter) and one transverse section of 4 cm diameter x 15 cm long PVC pipe (half-shelter). Females were paired with males of comparable size following Brown and Gratzek (1980) on 7 May 1986, and were intramuscularly injected with human chorionic gonadotropin (HCG) at about 2 IU per g body weight (Huner and Dupree 1984). Hormone was suspended in sterile, freshwater fish physiological saline (Prosser 1973) and injected at about 0.05 cc every 24 hours for the first three days, and every 48 hours thereafter (Huner and Dupree 1984). HCG was also administered to 12 randomly selected males five days after pairing. Needles were changed after every 10 injections.

Where possible, the test environment simulated natural conditions. Temperature was slowly raised from ambient

(based on field studies) at roughly 0.1°C per day. Natural photoperiod was maintained by skylights. Since several authors reported that feeding by males does not occur during the nesting period, pairs were fed periodically (brine shrimp, chopped meal worms, sinking commercial fish food) to assess proximity to spawning.

Spawning sections were examined for embryos every 48 hours, which disturbed the pairs and forced them to re-select a shelter. At this time, shelters were periodically rearranged. Frequency of cover type utilized, observations on activity, and any mortalities were also recorded.

Based on results of the first phase, a second study was initiated on 10 June 1986 to document the influence of HCG on fish attributes indicative of spawning. Nine pairs of sexually mature orangefin madtoms (based on external characters) were selected from collections made in Craig Creek from 5 to 10 June 1986. Males were each assigned to a spawning section that contained one half-shelter placed over fine substrate material (1.5 to 3 mm). After acclimation (at least three days), females of comparable sizes were paired with males, and each pair was randomly assigned to either injection of HCG (2 IU per g) every 48 hours or no injection.

Changes in male anteriodorsal musculature and activity, presumably related to nest construction, were recorded daily; female activity and weight change over the 8-day study period were also recorded. Frequency of apparent nest construction

activity between the two treatment groups was tested using contingency table analysis (Fienberg 1978); differences in female weight change over time were tested by the Wilcoxon rank sum statistic.

An attempt was made to artificially fertilize ova of N. gilberti. Ovaries were dissected from five mature females and placed in a small, glass bowl. Testes were then removed from four males showing secondary sexual characteristics. The excised testes were placed with the ovaries. Ovarian tissue was broken to free the ova, a small quantity of water was added to the gonads, testes were agitated with a small paint brush, and the entire solution was thoroughly mixed. After about two minutes, the ova were separated into two groups and placed in 4 mm mesh baskets, suspended in the paddlewheel hatching trough. The clutches were checked after 24 hours to determine the number of fertilized (live) ova.

EMBRYO HATCHING AND LARVAL FEEDING

Egg masses of the margined madtom were collected from the New River near McCoy, Virginia, from 13 to 23 June 1986. Each clutch was placed in one of two basket types, either a fine mesh (1 mm) or coarse mesh (4 mm) container. Each basket was suspended in a raceway (described previously), equipped with 6 paddlewheels driven by an electric motor to simulate the males presumed role of embryo agitation and aeration

(Bardach et al. 1972). Ages of embryos were determined by developmental stage following Mayden and Burr (1981), and the days to hatching were recorded. Dead embryos were counted and removed from the clutch daily.

Once hatching occurred, sibling larvae were moved into the previously described spawning sections of raceways. Physical appearance of the larvae was recorded daily, and onset of exogenous feeding was determined. Small groups of larvae were placed in jars, acclimated for 15 minutes, and provided with live brine shrimp nauplii. Acceptance of the diet and onset of feeding was determined by recording the proportion ingesting food.

Suitability of two diets, nauplii and ground trout chow, for madtom larval survival was assessed in the following manner. Eight clutches started on brine shrimp nauplii were divided into 18 groups and randomly assigned to either nauplii or ground (1 mm mesh mill) trout chow. These groups were fed in excess twice daily. Uneaten food was removed prior to each feeding. Deaths in each group were recorded daily and mortality of the two diet-groups were compared using the Wilcoxon rank sum statistic.

RESULTS

DISTRIBUTION AND RELATIVE ABUNDANCE

A total of 347 sites were sampled for the orangefin madtom during the summers of 1984, 1985, and 1986. The current range of the orangefin madtom, based on these efforts and reports of other recent collections, is summarized in Figure 4 and Table 4. Detailed maps and site descriptions are presented by Simonson and Neves (1986). Present distribution is described below, by river system.

Craig Creek System

Stream reaches above and below the reported range of the orangefin madtom in Craig Creek yielded several specimens; two were retained as vouchers. The new upstream record is above the State Route 621 bridge, 0.2 air miles NE of Webbs Mill, Craig County and the downstream record, at the U.S. Route 220 bridge near the mouth of Craig Creek on the James River, 1 air mile ENE of Eagle Rock, Botetourt County. Total stream length now known to be inhabited by N. gilberti in Craig Creek is 107 SK.

Specimens of N. gilberti were collected an additional 15 SK upstream in John's Creek, just above Simpson's Branch, Craig County. Present range in this tributary is 17 SK. One

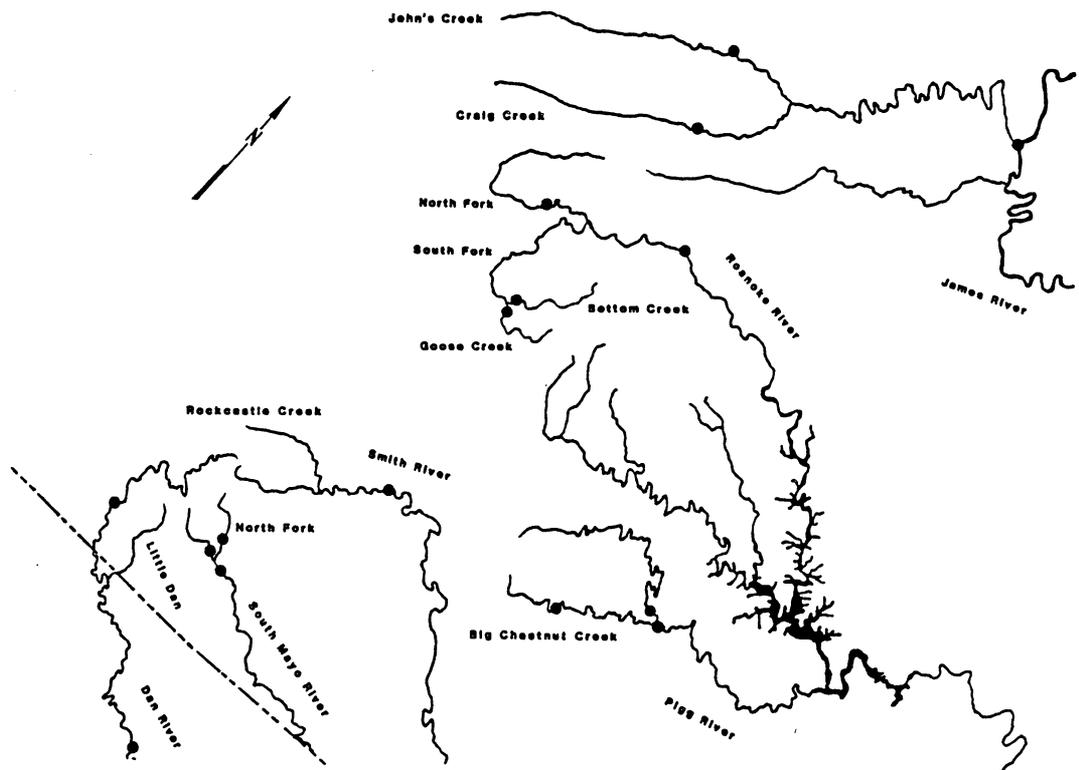


Figure 4. Current range of the orangefin madtom in Virginia and North Carolina.

Table 4. Distribution of the orangefin madtom (OFM) in Virginia and North Carolina, with pre-1984 versus 1986 records.

Stream system	Total sites	Sites with OFM	Range (SK)	
			pre-1984	1986
Craig	109	76	19	124
Roanoke	29	13	56	59
Dan	29	9	48	54
Big Chestnut	24	9	5	25
South Mayo	52	19	<1	7
Pigg	63	1	0	<1
Smith	41	0	<1	<1
Total	347	127	128	269

voucher specimen was retained. Total distance inhabited by the orangefin madtom in the Craig Creek system is now 124 SK.

Upper Roanoke River System

This system was not intensively sampled during this study because recent records have been well documented by Burkhead (1983). He reported the downstream limit of the orangefin as just below (400 m) the Eddy Street bridge in Salem, VA. In the North Fork, the reported upstream limit is along State Route 603 at the mouth of Craigs Branch, 5.25 air miles ESE of Lusters Gate, Montgomery County. I captured no orangefin madtoms at 11 sampling sites in the North Fork. Burkhead (1983) reported N. gilberti throughout the South Fork, and I corroborated his records. Jenkins (1977) reported the orangefin madtom from the lower two miles of Bottom Creek, and I also found it persisting there. Additionally, I discovered N. gilberti in Goose Creek, just below a small (5 m) dam. Total range in the upper Roanoke River system is now about 59 SK.

Dan River System

N. gilberti was found an additional 6.1 SK upstream from the reported limit in the Dan River mainstem. One voucher specimen was retained. The species was present at most sites sampled on the Dan River downstream into Stokes County, North Carolina. The orangefin madtom was not captured beyond the downstream limit reported by Jenkins in 1977. The river rapidly becomes unsuitable downstream from this point, be-

coming wide, shallow, and slow with a predominantly sand bottom.

One collection of the orangefin madtom has been reported from the Little Dan River at the State Route 103 bridge, 2 air miles WSW of Dry Pond, VA (R. Jenkins, pers. comm. 1985). The Little Dan River was intensively sampled above and below the last reported record (State Route 103 bridge), but no orangefin madtoms were captured. Total range of the orangefin in the Dan River is now about 54 SK.

Pigg River System

Specimens of N. gilberti were found throughout Big Chestnut Creek. The new upstream limit, below the State Route 718 bridge, 1 air mile S of Sydnorsville, Franklin County, is just downstream from a dam impounding about 5 SK. The downstream record is below the State Route 715 bridge, 2.35 air miles WNW of Dickinson, Franklin County. Two vouchers were retained, one each from the upper and lower limits. Also, one N. gilberti was captured in the Pigg River, 3.7 SK above the Big Chestnut Creek confluence. Total range in Big Chestnut Creek is now known to be 25 SK. The apparently disjunct Pigg River record encompasses less than one stream kilometer.

South Mayo River

I captured N. gilberti in the Mayo River system for the first time in 33 years. This 'discovery' is probably due to insufficient effort in previous sampling. Of the 51 col-

lections made on the North Fork of the South Mayo and the South Mayo River, 19 of the sites had N. gilberti, with a total of 38 specimens captured. The upper limit on the North Fork is along State Route/U.S. Route 8/58, 1.05 air miles N of benchmark 1227 in SW Stuart, Patrick County. The upstream record for the orangefin madtom on the South Mayo River, from which it had not been previously collected, is above a private bridge off State Route 631, 0.8 air miles W of benchmark 1193 in SE Stuart, Patrick County. The downstream limit on the South Mayo is 0.1 air mile below (east) the State Route 8 bridge in SW Stuart, Patrick County. Total range of the orangefin madtom in the South Mayo River system is therefore 7 SK, about 3.5 SK in each the North Fork and the South Mayo River mainstem.

Smith River System

No orangefin madtoms were found at 16 sites on Rockcastle Creek above and below the ostensible record. This unsubstantiated collection could have been a field misidentification. In a 1985 Smith River rotenone survey, one orangefin madtom was taken about 300 m upstream of the Shooting Creek confluence (W. Adams, pers. comm. 1986; confirmed by G. Burgess). However, I found no orangefin madtoms in my survey of the Smith River mainstem. The species is undoubtedly rare in this river.

Total Range

As defined by sampling efforts in 1984 and 1985, total

range of the orangefin madtom now includes about 269 SK (Table 4).

In addition to sampling streams with historic or recent records of the orangefin madtom, collections were also made on the following rivers and streams: James River, Dunlap Creek, Potts Creek, Catawba Creek, and Cowpasture River, all in the James River drainage (Simonson and Neves 1986). No orangefin madtoms were collected in these systems.

Frequency of occurrence of the orangefin madtom was somewhat greater than anticipated (Table 5). Of the 243 sites surveyed within its probable range, 126 (52%) yielded at least one specimen. Occurrence of the species ranged from 31% of sites sampled in the Dan River to 70% in the Craig Creek system. Over 400 individuals were captured during two summers of sampling. Intensive collecting in the Craig Creek system, as part of this study, contributed significantly to this number. However, N. gilberti is apparently common in some stream reaches, averaging from 0.52 individuals captured per riffle on the Dan River to 2.7 per riffle in the Craig Creek system (excluding the Smith River). Sampled area of all riffles averaged 100 m². At sites with N. gilberti, its density ranged from 1.6 (Big Chestnut Creek) to 3.8 specimens per riffle (Craig Creek), with an overall mean of 3.2 individuals per riffle.

Lengths of stream reaches actually inhabited by this species were estimated from the frequency of occurrence at

Table 5. Occurrence and relative abundance of the orangefin madtom in stream systems sampled during the summers of 1984 and 1985.

Stream system	Sites sampled	Sites present(%)	No. taken	Mean number per riffle	
				all sites	when present
Craig	109	76 (70)	292	2.7	3.8
Roanoke	29	13 (45)	41	1.4	3.2
South Mayo	52	19 (37)	43	.83	2.3
Pigg ¹	24	9 (38)	14	.58	1.6
Dan	29	9 (31)	15	.52	1.7
Smith	41	0 (0)	0	0	0
Total ²	243	126 (52)	405	1.7	3.2

¹includes only Big Chestnut Creek data.

²excludes Smith River data.

sites sampled. An average of 52% of sites surveyed within this species total range were occupied. Habitat actually occupied is therefore considerably less than the total of 269 SK. Based on computations summed for all stream systems, N. gilberti is estimated to inhabit about 144 SK in Virginia and North Carolina (Table 6).

Simple linear regression analysis indicated that the number of madtoms captured on the first depletion run was a good predictor of the estimated abundance at each site (maximum weighted likelihood method). The model was significant ($F = 273.987$, $p > 0.0001$, $r^2 = 0.88$; Figure 5), with the following regression equation:

$$Y = 0.361 + 1.629 X$$

where Y is an approximate orangefin madtom abundance and X is the number captured on the first run. Using this equation, the number captured on the first removal run was used to predict N. gilberti abundance for all sites sampled. Approximate density was obtained by dividing predicted abundance by area sampled.

The Wilcoxon signed rank test indicated that paired local gradient measures (Abney versus transit) at sites on Craig Creek were not significantly different ($TS^+ = 0.0944$, $p = 0.9248$). A Hodges-Lehmann estimate of the median dif-

Table 6. Summary of total range and habitat occupied by orangefin madtom populations in Virginia and North Carolina.

Stream system	Total range (SK)	Occurrence (%)	Habitat occupied (SK)
Craig	124	70	87
Roanoke	59	45	27
Dan	54	31	17
Pigg	25	38	10
Mayo	7	37	3
	—	—	—
Total	269	52	144

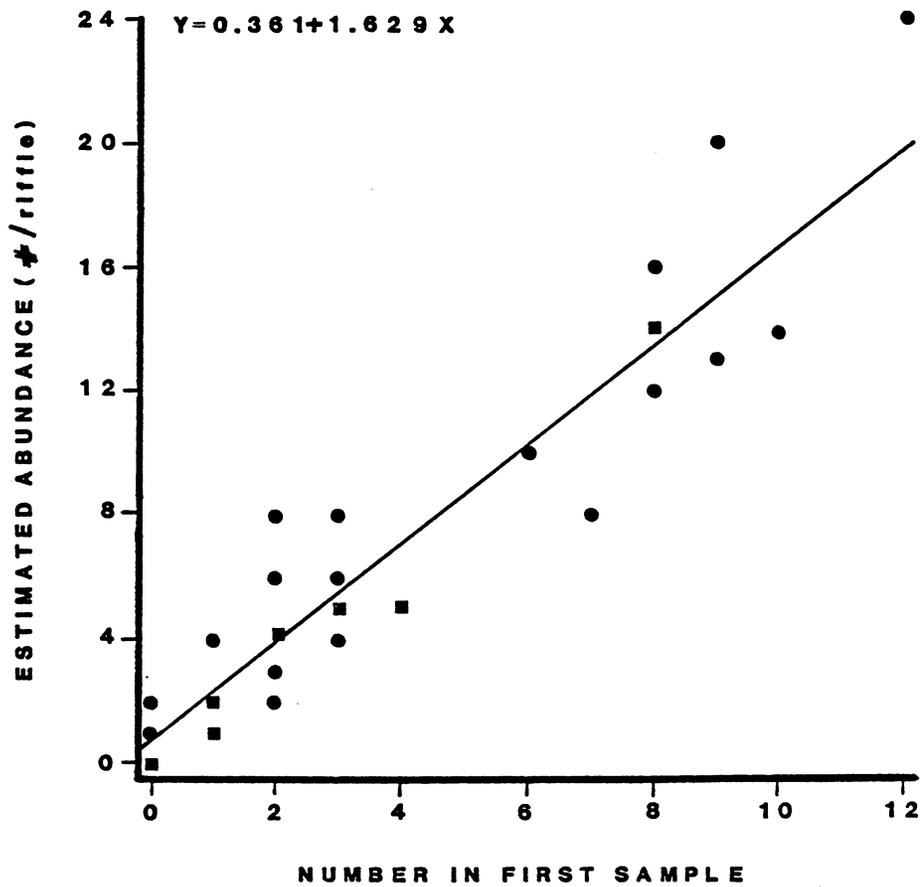


Figure 5. Relationship between orangefin madtom estimated abundance and the number taken during the first depletion sample. A square indicates 2 to 4 observations.

ference was 0, with 95% confidence interval -0.25 to 0.30. Abney level readings were therefore used in subsequent analyses of local gradient.

SPECIES AND HABITAT ASSOCIATIONS

Several riffle-dwelling species were significantly associated with orangefin madtom presence or absence, based on Hurlbert's coefficient (Table 7). Common and scientific names of all species captured during this study are provided in Appendix A, and follow Robins et al. (1980). In some cases, similar species were combined for this analysis. Three chub (Nocomis) species; bluehead, river, and bull, were combined due to difficulty in distinguishing them during non-breeding periods. The syntopic northern and Roanoke hog suckers were combined because they are morphologically similar and show no obvious habitat segregation (Jenkins 1980). Crayfish genera (Cambarus and Orconectes) were also combined. Significant negative associates included chubs, mountain redbelly dace, rosyzide dace, crescent shiners, and crayfish. One species, the Roanoke darter, was positively associated with the orangefin madtom. Presence of rosyzide dace, chubs, crescent shiners, and crayfish reduced the probability of orangefin madtom occurrence, while the Roanoke darters were indicative of its presence. In further analyses, species are expressed as occurrence; means of categorical binomials (0 =

Table 7. Species collected within the orangefin madtom's range, and their levels of association.

Species (N=216 sites)	Coefficient of Association	Significance ¹
Stoneroller	-0.050	NS
Cutlips minnow	+0.091	NS
Chub	-0.142	*
Mountain redbelly dace	-0.180	*
Rosyside dace	-0.267	**
Crescent shiner	-0.167	*
Rosefin shiner	-0.034	NS
Torrent sucker	+0.062	NS
Black jumprock	+0.001	NS
Hog sucker	-0.104	NS
Margined madtom	-0.123	NS
Mottled sculpin	+0.111	NS
Roanoke darter	+0.258	**
Fantail darter	-0.047	NS
Crayfish spp.	-0.247	**

¹p > 0.05 (NS); p < 0.05 (*); p < 0.01 (**)

absent, 1 = present) are equivalent to the proportion of instances they were present.

Analysis of variance (ANOVA) results suggested that five physical habitat variables were significantly related to the orangefin madtom's distribution (Table 8). Univariate tests identified local gradient, percentage of silt, riffle depth, percentage of sand, and percentage of small cobble as significantly different at sites where this species was present or absent (Table 8). This suggests that sites with steeper gradient, low silt levels, and increased depth are more likely to have N. gilberti. Lower percentages of sand and higher percentages of small cobble also contributed to its utilized habitat.

The stepwise discriminant function procedure, which included both the physical and biotic variables, identified large gravel, local gradient, silt, species richness, and presence or absence of rosyside dace, crescent shiner, and crayfish as the variables best contrasting sites with and without N. gilberti, based on partial F statistics (Table 8).

Use of discriminant function analysis, which included only variables selected by the stepwise procedure, resulted in excellent classification of sites with and without the madtom (Table 9). The model correctly classified 87.5% of the sites where N. gilberti was absent and 84.6% of sites occupied by this species. The discriminant function derived

Table 8. Means of variables measured at 142 sites sampled for the orangefin madtom, and results of statistical analyses.

Variable (type)	Sampled Sites		Probability	
	present (n=78)	absent (n=64)	ANOVA	STEPDISC
Physical (%)				
Sand	2.25	5.14	0.0171*	NS ¹
Small gravel	6.29	6.73	0.8368	NS
Large gravel	15.46	19.83	0.2096	0.0057
Small cobble	36.41	27.85	0.0237*	NS
Large cobble	19.05	16.79	0.4384	NS
Small boulder	11.12	11.25	0.9595	NS
Large boulder	4.20	6.86	0.1783	NS
Bedrock	5.22	5.56	0.8990	NS
Gradient (% slope)	2.31	1.41	0.0001*	0.0001
Silt	8.94	36.00	0.0001*	0.0001
Depth (cm)	22.99	20.39	0.0116*	NS
Biotic				
Species richness	7.23	7.37	0.4239	NS
Rosyside dace				0.0057
Mountain redbelly dace				NS
Chub spp.				NS
Crescent shiner				NS
Roanoke darter				NS
Crayfish				0.0002

¹not selected by stepwise discriminant analysis (STEPDISC)

*considered significant ($p < 0.05$)

Table 9. Classification results of the discriminant function analysis to predict orangefin madtom occurrence.

Actual Class	Predicted Class		Total
	Present	Absent	
Present	66 (84.6%)	12 (15.4%)	78
Absent	8 (12.5%)	56 (87.5%)	64

from this analysis is provided in Appendix B and can be used to predict the orangefin madtom's presence or absence.

Given the presence of N. gilberti, ANOVA test results indicated that no variables differed significantly at sites with low and high densities of orangefin madtoms (Table 10). Stepwise discriminant function analysis identified two variables that contrasted sites of low and high density of madtoms, percentage of small gravel and presence or absence of the crescent shiner (Table 10). Subjecting these variables to discriminant function analysis resulted in good classification of low and high density sampling sites. This discriminant model correctly classified 72.3% of the low density sites and 84.6% of the high density locations (Table 11).

The variables selected to discriminate density at sampling sites were similar to those used in contrasting sites with and without the orangefin madtom. This, coupled with the fact that only two variables were needed to satisfactorily separate the two density classes, suggests that most of the variability associated with predicting density is already explained by the species' presence. Classification was adequate with the selected variables, but important factors related to N. gilberti's density were apparently not addressed in this study.

Suitable habitat for the orangefin madtom appears to have relatively low levels of sand and silt, and infrequent

Table 10. Means of variables at 78 sites of low and high orangefin madtom density, and results of statistical analyses.

Variable (type)	Density		Probability	
	low (n=65)	high (n=13)	ANOVA	STEPDISC
Physical (%)				
Sand	2.59	0.55	0.1915	NS ¹
Small gravel	5.38	10.82	0.1746	0.0315
Large gravel	14.32	21.16	0.2108	NS
Small cobble	36.28	37.05	0.9136	NS
Large cobble	18.45	22.05	0.4762	NS
Small boulder	12.46	4.39	0.0818	NS
Large boulder	4.73	1.57	0.1959	NS
Bedrock	5.79	2.40	0.4786	NS
Gradient (slope)	2.32	2.22	0.7975	NS
Silt	10.61	0.61	0.1165	NS
Depth (cm)	22.70	24.41	0.3785	NS
Biotic				
Species richness	7.28	7.00	0.7220	NS
Rosyside dace				NS
Mountain redbelly dace				NS
Chub spp.				NS
Crescent shiner				0.0058
Roanoke darter				NS
Crayfish				NS

¹not selected by stepwise discriminant analysis (STEPDISC)

Table 11. Classification results of the discriminant function analysis to predict relative density of orangefin madtoms.

Actual class	Predicted class		Total
	Low	High	
Low	47 (72.3%)	18 (27.7%)	65
High	2 (15.4%)	11 (84.6%)	13

occurrence of rosyzide dace, chubs, crescent shiners, and crayfish. Relatively high levels of small cobble, high local gradient, and deeper water are similarly indicative of habitable areas for the orange-fin madtom. Each variable was ranked across stream systems sampled (Table 12), 1 being the best of the five systems and 5, the worst. The ranks were summed for each system, with the lowest sum considered the best combination of habitat available. This approach assumes that the variables have equal weight in influencing this species, since I have no basis for assigning their importance.

Availability of suitable habitat features was highest in Craig Creek, followed by the Dan, Big Chestnut, Roanoke, and South Mayo stream systems, respectively (Table 12). The Dan River system had the lowest proportion of sand, followed by Craig Creek. Proportion of small cobble substrate was highest in Craig Creek, followed by the Dan River system. Siltation appears to be a problem in all but the Dan and Craig stream systems (Table 12), where these watersheds are mostly forested with no major urban centers. The Roanoke River was low in proportion of sand and high in average local gradient, but was also low in available small cobble and extremely high in average proportion of silt per riffle. Of the important biotic variables, occurrence of rosyzide dace, chubs, crescent shiners, and crayfish was lowest in the Craig Creek system. The Roanoke River had the highest occurrence of

Table 12. Means (ranks) of significant habitat and biotic variables for each stream system sampled.

Variable	Stream system				
	Craig	Dan	Pigg	Roanoke	Mayo
Physical					
Sand	2.3 (3)	1.6 (2)	6.3 (4)	.51 (1)	7.6 (5)
Small cobble	42 (1)	35 (2)	30 (3)	24 (5)	26 (4)
Gradient	1.8 (3)	1.7 (4)	1.4 (5)	2.6 (1)	2.0 (2)
Silt	5.5 (1)	7.2 (2)	31 (4)	51 (5)	23 (3)
Depth	22 (3)	25 (1)	23 (2)	21 (4)	17 (5)
Biotic					
Rosyside dace	.09 (1)	.22 (3)	.14 (2)	.32 (4)	.48 (5)
Chub spp.	.60 (1)	.74 (2)	.82 (3)	1.0 (5)	.92 (4)
Crescent shiner	.27 (1)	.57 (2)	.73 (3)	1.0 (5)	.85 (4)
Crayfish	.49 (1)	.74 (3)	.55 (2)	.88 (5)	.77 (4)
Rank total	15	21	28	35	36

these species, with the exception of rosyside dace, which was ubiquitous in the Mayo River system (Table 12).

LIFE HISTORY AND REPRODUCTION

Three distinct age classes of N. gilberti were identified in Craig Creek, based on length frequency plots for three seasons (Figure 6). Samples taken in May 1985 (N=177) consisted of 57 (32%) apparent age I and 120 (68%) age II orangefin madtoms. Collections from June to July 1985 (N=118) consisted of 100 (85%) age I+ and 18 (15%) age II+ orangefin madtoms. No age 0 specimens were captured (Table 13). By September 1985, age 0+ madtoms were vulnerable and 91 (44%) were captured. Age I fish made up 56% (117 individuals) of the fall sample and only one was considered age II+. May 1986 samples were similar to May 1985, and consisted of 53 (50%) age I and age II orangefin madtoms. Summer (July 1986) collections were dominated by age I+ individuals (98%), and only one age 0+ and one apparent age II+ were sampled.

The largest individual was collected in fall (111 mm TL) and was considered to be three months into its third year. The first and smallest age 0 orangefin madtom collected (early July 1986) was 33 mm TL, and was probably less than two months old. The mean total length of each age class, by sex (when possible) and season, are shown in Table 14. One

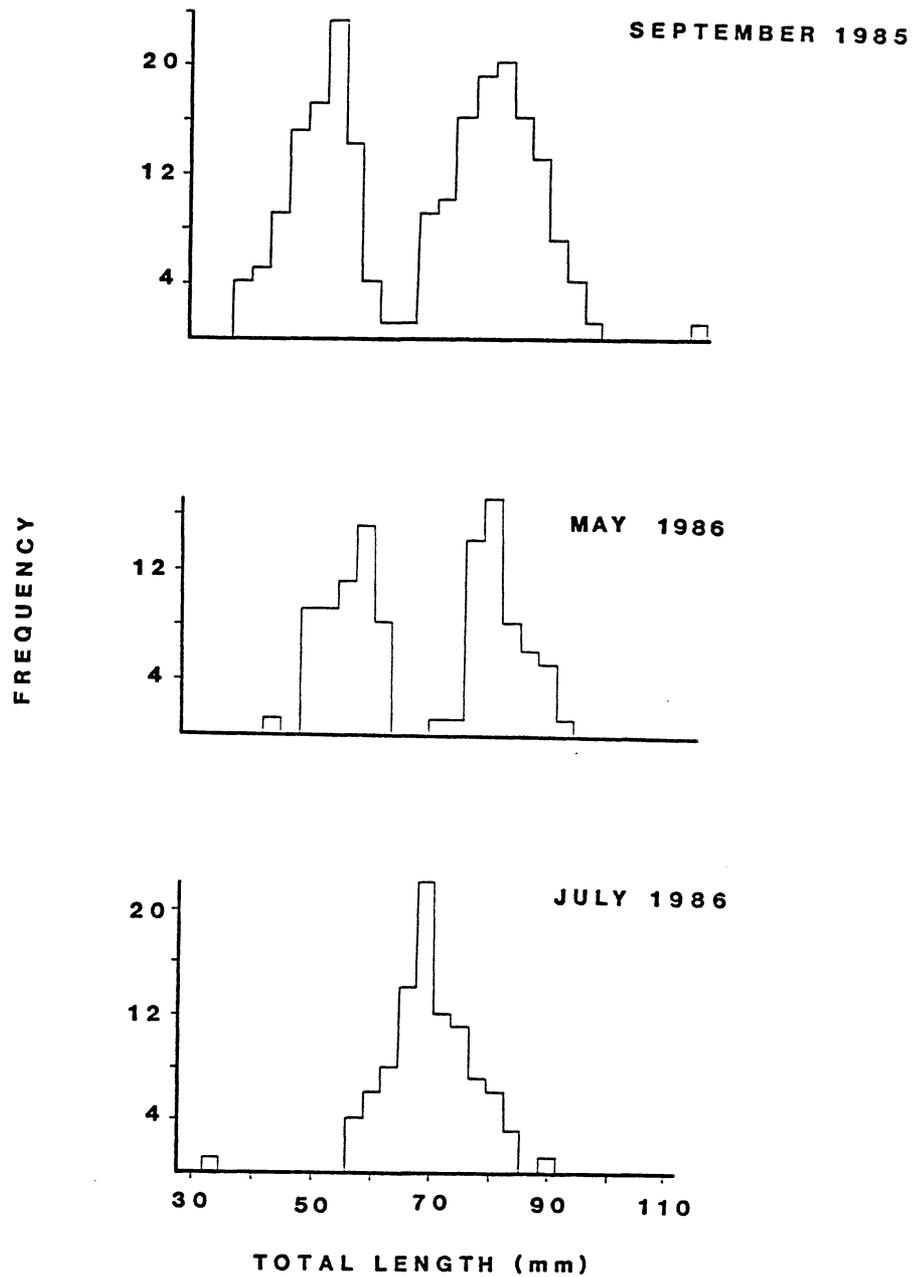


Figure 6. Seasonal length frequency distributions of orangefin madtoms from Craig Creek, Virginia.

Table 13. Occurrence of each orangefin madtom age group in seasonal samples from Craig Creek, Virginia.

Capture period (N)	Effort (min)	Age 0			Age I			Age II		
		No.	%	CPUE ¹	No.	%	CPUE	No.	%	CPUE
5/85 (177)	269	0	0	-	57	32	.21	120	68	.45
6-7/85 (118)	191	0	0	-	100	85	.52	18	15	.09
9/85 (209)	418	91	43	.22	117	56	.28	1	1	.002
5/86 (106)	248	0	0	-	53	50	.21	53	50	.21
7/86 (95)	261	1	1	.004	93	98	.36	1	1	.004

¹Catch per unit effort, expressed as the number of orangefin madtoms per minute of electrofishing effort.

Table 14. Mean total length of orangefin madtoms taken in Craig Creek, by age and sex (when discernable).

	Spring		Summer			Fall		
	I	II	0+	I+	II+	0+	I+	II+
Total length (mm)	53.9	79.1	33.0	69.9	89.0	48.0	76.8	111
Male	-	79.9	-	83.0	-	-	-	-
Female	-	79.1	-	73.3	-	-	-	-
Sex unknown	-	73.0	-	63.9	-	-	-	-

young-of-year orangefin madtom collected in July, grew to 33 mm TL. By fall, age 0+ fish averaged 48.0 mm. Age I specimens averaging 53.9 mm in May, were 69.9 mm by summer; those exhibiting secondary sexual characteristics were somewhat longer (Table 14). Age I+ fish were 76.8 mm by fall. Sexes were not externally discernible at that time. Age class II averaged 79.1 mm in spring. Males and females were similar in length but individuals not sexually dimorphic were, on the average, somewhat smaller (Table 14). Only one age II+ specimen of 89 mm was taken in summer. The fall sample also contained only one age II+ madtom of 111 mm. Almost half of adult size was attained by the first 3 to 4 months of life (Figure 7). Thereafter, rate of growth declined, with the greatest numeric increases over the summer months.

MORTALITY

Based on field observations and examination of the catch, it appears that orangefin madtoms were not fully recruited to my sampling until age I (Table 13). Mortality during the first year of life is undoubtedly high. Mortality appears moderate from age I in May to age II the following spring. Catch per unit effort (CPUE) during this period went from about 0.52 (age I) to 0.21 (age II) orangefin madtoms / min (Table 13). From age II in May to age II+, loss of in-

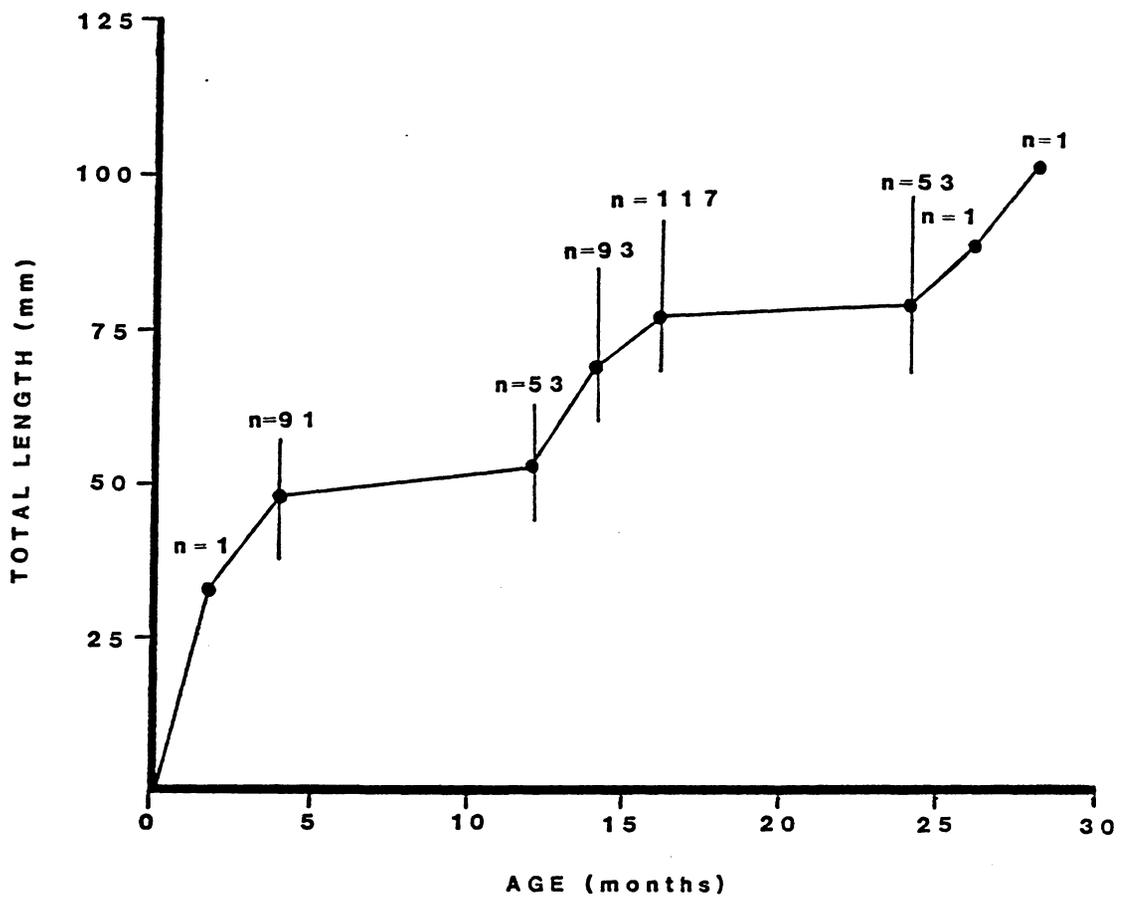


Figure 7. Estimated growth (TL) of orangefin madtoms in Craig Creek, based on mean length and range (indicated by bars) at each age. Age is considered 0 in May.

dividuals was greatest, with CPUE decreasing to 0.002 orangefin madtoms / min by September. Instantaneous mortality from age I to age II+ was estimated to be 0.23, based on a catch curve of age (months) versus CPUE, starting with age I fish (Figure 8). In both years, age II+ fish were virtually absent in July and September samples. Therefore, mortality in the third summer, notably during reproduction, appears extremely high. Most individuals have an apparent longevity of 25 to 28 months.

LENGTH-WEIGHT RELATIONSHIPS

Length-weight relationships were similar (Figure 9) for unsexed individuals (n=34, $r^2=.86$) and discernible males (n=25, $r^2=.57$). Females in reproductive condition (n=25, $r^2=.83$) exhibited a slope significantly higher than that of males, during spawning ($T = 1.93$, $p < 0.05$). No other slope comparisons were significant. Equations for all individuals, males, and females are given below, respectively:

$$\ln Y = -10.31 + 2.687 \ln X \quad (\text{unsexed})$$

$$\ln Y = -7.632 + 2.077 \ln X \quad (\text{males})$$

$$\ln Y = -11.40 + 2.962 \ln X \quad (\text{females})$$

where Y is wet weight and X is total length.

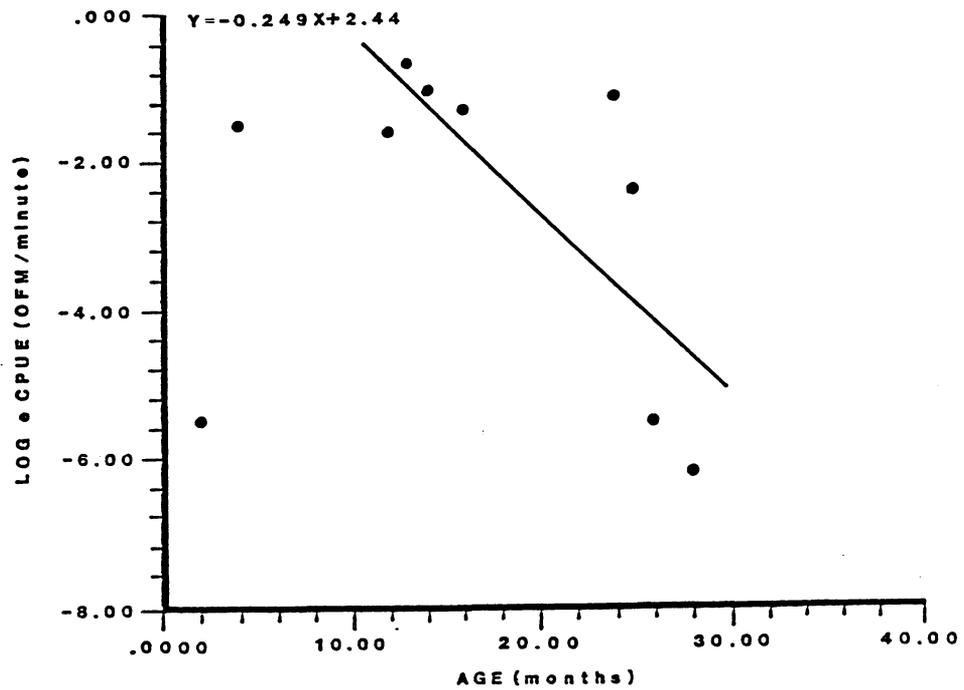


Figure 8. Catch curve for orangefin madtoms captured in Craig Creek from May 1985 to July 1986. May is considered the time of occurrence of the age 0 cohort.

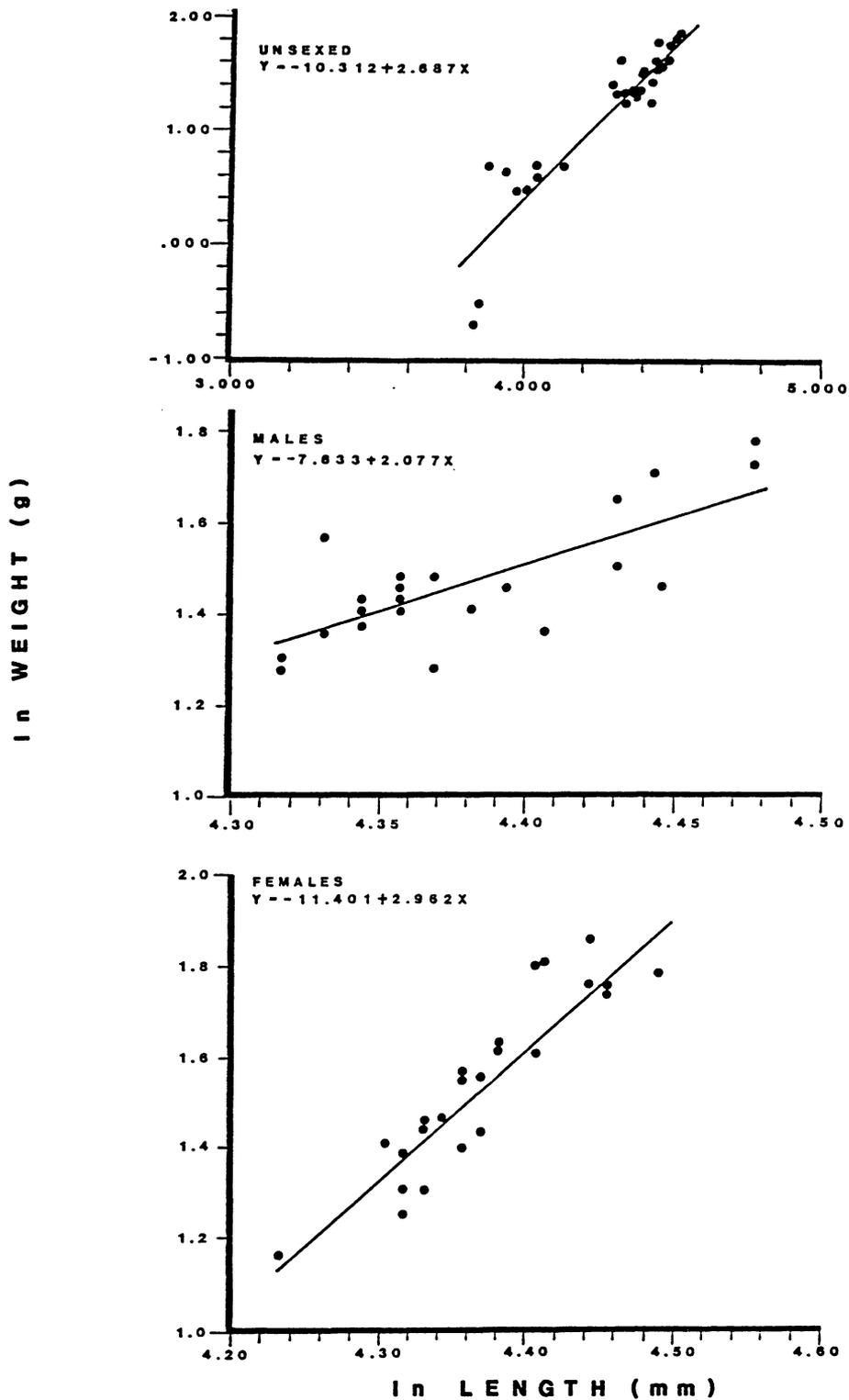


Figure 9. Length-weight relationships for unsexed individuals, males, and females from Craig Creek, Virginia.

Because previous madtom studies have used standard length, the equation to correct N. gilberti total to standard length ($p < 0.0001$, $r^2 = 0.99$) is:

$$Y = -0.7413 + 0.8627 X$$

where Y is standard length and X is total length.

REPRODUCTIVE CHRONOLOGY AND HABITAT

The spawning period, determined by the proportion of individuals in reproductive condition (all males and females divided by total sample size; Table 15), began in late April (water temperature 18°C) and appeared to peak in early to late May when water temperatures were 19°C to 20°C (Figure 10). Proportion of fish in spawning condition declined from late May to late June, and were essentially absent by July, corresponding to the apparent death of age II+ fish. A second small peak in late May resulted from the occurrence of larger, apparently mature age I+ madtoms.

Very few age I+ specimens were considered sexually mature, while almost all age II+ fish displayed secondary sexual features. A chi-square test of homogeneity showed a significant difference in proportion of ripe age I and age II madtoms ($X^2 = 196.4$, $p < 0.0005$); fewer than expected age I were ripe. Age I+ fish did not begin to exhibit these traits until late May, 1985 (Table 15), and those age I+

Table 15. Number of male (M), female (F), and unsexed (US) orangefin madtoms collected in Craig Creek during 1985.

Date	Temp. (C)	Sample size	Age I			Age II		
			US	M	F	US	M	F
3/26	9	0	-	-	-	-	-	-
4/4	9	2	-	-	-	2	-	-
4/23	18	2	1	-	-	-	1	-
5/2	19	62	23	-	-	2	17	20
5/4	19	15	2	-	-	-	7	6
5/6	20	49	14	-	-	-	17	18
5/10	20	6	2	-	-	-	3	1
5/13	20	4	1	-	-	-	1	2
5/20	21	32	9	1	3	3	9	7
5/22	22	2	1	-	-	-	1	-
5/27	22	3	-	-	-	1	1	1
5/28	23	4	1	-	-	1	1	1
6/10	22	11	3	-	-	4	3	1
6/17	23	12	4	1	-	4	2	1
6/27	24	63	57	2	3	1	-	-
7/2	25	32	30	-	-	1	1	-
Total		299	148	4	6	19	64	58

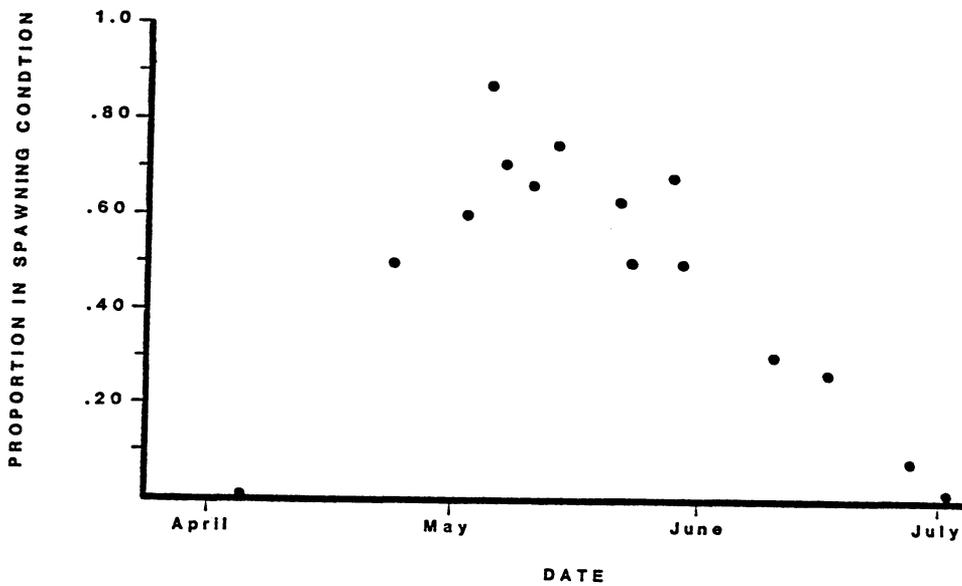


Figure 10. Reproductive chronology of the orangefin madtom in Craig Creek, Virginia, based on the proportion of age I and II individuals in apparent reproductive condition.

madtoms showing sexual dimorphism were larger than average (Table 14). Contribution, if any, to reproduction by age I madtoms was considered negligible. It appears, based on length frequency analysis, that most age II+ individuals die shortly after spawning. Males, however, appear to live somewhat longer than females, but this is based on limited data (Table 15).

Spawning habitat was determined to be fast-water riffle areas, based on sampling available habitat types (Table 16). I found no N. gilberti in pool habitats during the spring spawning period, or in summer or fall. The predominant substrate at sites harboring mature orangefin madtoms was small cobble. Large cobble, small boulder, large gravel, and bedrock occurred less frequently at these sites. A chi-square test of independence indicated significant differences in habitat utilization by margined and orangefin madtoms ($X^2 = 148.95, p < 0.0005$). In Craig Creek during spring, orangefin madtoms occupied riffles while margined madtoms were more frequently associated with pool habitats.

A total of 15 man-hours was spent searching for nest sites by snorkeling during May 1985. Areas known to contain young-of-year in 1984 (and later in 1985) were searched, but no N. gilberti nests were found. Only two orangefin madtoms were observed, at one site, during this nest survey. Both were small (about 60 mm) and left the area immediately when uncovered. The apparent seclusion of this species when

Table 16. Habitat use by orangefin (OFM) and margined (MGM) madtoms in Craig Creek, based on electrofishing effort (E in minutes).

Date	Temp. (C)	Habitat					
		Riffle			Pool		
		OFM	MGM	E	OFM	MGM	E
3/26	9	0	0	45	0	0	60
4/4	9	2	0	60	0	0	70
4/23	18	2	5	65	0	0	60
5/1	19	1	0	60	0	1	60
5/4	19	15	0	55	0	1	65
5/10	20	6	1	15	0	17	194
5/13	20	4	0	20	0	1	55
5/20	21	13	0	28	0	4	137
5/20	21	7	0	16	0	3	25
5/20	22	12	0	20	0	1	50
5/22	22	2	10	30	0	4	60
5/27	22	3	0	15	0	0	60
5/28	23	4	0	10	0	0	50
6/10	22	11	0	25	0	1	55
6/17	23	12	0	25	0	1	55
6/27	24	13	0	26	0	0	45
6/27	24	40	0	50	0	0	40
6/27	25	10	2	20	0	0	35
7/2	25	17	0	25	0	0	45
7/2	26	15	0	20	0	0	25
Total		189	18	630	0	34	1246

nesting is exemplified by the fact that 101 specimens were captured with electrofishing gear in early May (water temperature 19.5°C) at this site in two consecutive days.

CAPTIVE BREEDING

Attempts to induce orange-fin madtom spawning in the laboratory using channel catfish techniques were unsuccessful. During the first phase, when all females and 12 males were injected with HCG, 56% of the madtoms died over the 20-day period (Table 17). The sexes differed only slightly in death rate; male mortality was 62% and female mortality was 50%. Of the 27 deaths, 20 (74%) were subjected to hormone injections. A number of those not receiving injections also died.

No egg clutches were spawned during the first experiment. Eight days after pairing the adults, however, a single dead embryo and an empty chorion were found with one pair. The female's abdomen appeared flaccid and was not as distended as other females. The following day, two embryos were discovered with another pair, after injections were administered. At this time, I was able to force an additional ovum from the female. No other females extruded ova when examined. Over the subsequent four days, females from three additional pairs released ova when I applied external pressure to their abdomens. In each case, the ova ruptured upon

Table 17. Summary of deaths during the first and second phases of the orangefin madtom captive breeding study.

	Phase I (5/3 - 5/29/86)	Phase II (6/14 - 6/27/86)
Number of fish	48	18
Number of deaths (%)	27 (56)	10 (56)
Males (%)	15 (56)	5 (50)
Females (%)	12 (44)	5 (50)
Injected (%)	20 (74)	9 (90)
Not injected (%)	7 (26)	1 (10)

exiting the oviduct. Nothing was extruded from males when their abdomens were similarly pressured.

Observations on pair activity showed no active feeding by these madtoms; food introduced in the evenings remained uneaten the following morning. Also, no typical ictalurid spawning behavior was observed from dawn through dusk. Night observations were not made in order to maintain natural photoperiod. Typically, the pairs resided together in the half-shelters, versus the full, cylindrical covers. Throughout the study, madtoms occupied full-shelters 41 times and half-shelters 805 times. Furthermore, after the first eight days, no full-shelters were occupied. Therefore, only half-shelters were provided during the second phase of laboratory investigations.

Prior to the second experiment (half the pairs randomly assigned HCG injection), difficulty was experienced in locating sufficient numbers of mature adults from Craig Creek by mid-June (see Mortality); only nine pairs were used. Of the 18 individuals, 10 (56%) were dead after the eight-day study. Again, male and female mortality was similar and individuals receiving injections died more frequently (Table 17). Of the ten deaths, nine had received injections. As was noted in the previous phase, no fertilized ova were found. Also, no changes in male or female morphometry were noted and, therefore, no differences were evident between injected and non-injected madtoms.

Pairs typically shared the provided shelters, but no activity considered courtship or breeding behavior was noted. The only activity observed was the construction of mounds in the shelter openings. These small-pebble piles were usually formed between observation periods. On rare occasions, males were seen carrying the stones in their mouths and expelling them at the shelter opening. The frequency of this behavior (presence of mounds) did not differ between injected and non-injected males ($X^2 = 0.21$; $p < 0.7$), and in one case where the male had died, these mounds were built by the lone female. Differences in weight change between injected and non-injected females were not significant based on the remaining five injected and eight non-injected individuals; no individuals exhibited any appreciable change.

Attempts at artificial fertilization of eggs were unsuccessful. All eggs were dead after 24 hours.

EMBRYO HATCHING AND LARVAL FEEDING

Eleven N. insignis embryo masses from the New River, near McCoy, Virginia, were returned to the laboratory. Initially, three clutches were placed in 1 mm mesh screen baskets. All of these embryos were dead after four days. Subsequently collected clutches were put in 4 mm mesh plastic baskets. Thereafter, no deaths occurred during incubation. Clutches that hatched required three to ten days at 20°C,

depending on developmental stage of the embryos at the time of collection. Developmental age of the clutches ranged from three to seven days post-fertilization, and all ages successfully hatched.

Larvae tended to cluster together in large groups after hatching. These groups remained on the tank bottom, and larvae moved very little. Five to six days after hatching, larvae began to darken in color, and the groups dispersed somewhat. At this time, exogenous feeding presumably began even though yolk-sacs were still evident on individuals. Two groups were not fed during this period, and both experienced significant mortality (83% and 59%). Throughout the development of subsequent groups, 8 to 13 individuals were removed, placed in a small jar with live brine shrimp nauplii, and observed. None ingested food prior to five days post-hatching, and all were observed feeding after seven days. Exogenous feeding therefore began prior to complete yolk-sac absorption and coincided with dispersal.

Mortality was significantly higher in groups fed live brine shrimp ($C = 67.5$; $p < 0.01$), based on the rank sum test, corrected for ties. Average mortality for groups fed ground trout chow was 17%, while those fed brine shrimp averaged 44% over the 20 day period (Table 18).

Table 18. Mortality of margined madtom larvae fed two experimental diets.

	Brine shrimp			Trout chow		
	initial number	deaths	mortality (%)	initial number	deaths	mortality (%)
	13	1	8	44	0	0
	43	29	67	21	3	14
	22	14	64	24	2	8
	5	1	20	9	2	22
	27	14	52	19	5	26
	36	11	31	21	8	38
	12	6	50	34	7	21
	35	12	34	26	6	23
	61	40	66	35	0	0
Total	254	128		238	33	
Average			44			17

DISCUSSION

DISTRIBUTION AND STATUS

The orangefin madtom was found to be more widespread and abundant than previously recorded. This is probably attributable to more extensive and intensive sampling efforts specific to locating this benthic species. Present range of this madtom in the Craig Creek system has apparently increased seven-fold, and it is relatively common at most sites. Based on these surveys and field observations, it appears that this species now occupies most suitable habitat in Craig Creek. Sites sampled above the established limit were dominated by bedrock substrate, which provides little madtom cover (see Species and Habitat Associations). Downstream, this species occurs to the confluence of Craig Creek with the James River. Although collections made in the James River contained no orangefin madtoms, habitat appeared suitable for its occurrence, as did other sites sampled on upper James River tributaries. The orangefin madtom could potentially spread throughout the upper James River drainage.

Percent occurrence and abundance of this species was highest in the Craig Creek system, as was available habitat. This population is considered by some to have resulted from stream capture of the upper Roanoke River by the adjacent

James River drainage (Robins and Raney 1956; Ross 1969; Jenkins et al. 1972). Others more recently hypothesize that bait bucket introductions may be a more likely explanation (Jenkins 1977; Burkhead 1983). Although past collection efforts in this system have been sparse, N. gilberti may have rapidly expanded its range there. Survey results appear to support the "bait bucket" hypothesis, since introduction of a species typically results in rapid dispersal, given the presence of suitable habitat (Krebs 1985). Alternatively, this species may have occupied Craig Creek since the alleged stream piracy. This theory seems more appropriate because 1) the interstitial nature of this species would make it difficult to capture with traditional methods (seine). Relatively recent use of electrofishing gear coincides with the orangefin madtom's apparent range expansion; 2) sampling effort (technique and magnitude) was inadequate in the upper James River system prior to the 1970's (Jenkins 1977); and 3) several other fish species, originally thought to be endemic to the Roanoke River drainage, have also recently "spread" throughout the upper James River basin (Ross 1969). It seems unlikely that all the taxa discussed by Ross were introduced by bait fishermen.

The orangefin madtom was found throughout Big Chestnut Creek. Only three specimens were known from there prior to this survey, despite relatively recent collecting efforts (Hambrick 1973, James 1979). Previous studies in this stream

monitored fish populations at readily accessible stations. I rarely found the orangefin madtom at road-crossings. Bridge construction may alter physical habitat at these sites, which could negatively influence N. gilberti occurrence for several years. Survey efforts at road-stream intersections may therefore be inappropriate or result in considerable bias.

The madtom's range on the upper Dan River has remained relatively unchanged, and most suitable habitat appears to be occupied. Downstream, most sites surveyed were predominantly sand, and the river becomes wide, shallow, and slow as it enters the Piedmont physiographic province. Upstream, this species' expansion may be blocked by lack of suitable substrate or cool water temperature. Sites upstream of the established limit typically consisted of small and large boulder substrate (see Species and Habitat Associations). Water temperature regimes in this reach of the Dan River are undoubtedly altered by hypolimnetic discharges from upstream reservoirs (Burkhead 1983). Although water temperature was not monitored during this study, this stream appears to be about 3°C cooler than others sampled during the same time period. Of the stream reaches inhabited by N. gilberti, the only one in designated "Trout Waters" occurs in the Dan River.

The N. gilberti population in the Dan River is widespread, with 20% of the species' total range in this river.

However, its percent occurrence and abundance in the Dan River is the lowest of any stream system sampled, making actual range considerably less. The inhabited reach of the Dan River, however, is apparently second only to the Craig Creek system in high quality physical habitat for this species. The low population level may be a result of altered water temperature regimes described previously.

Habitat availability was relatively low in the entire upper Roanoke River system, due to the poor habitat suitability of the North Fork. Range has remained relatively unchanged there, but the species may have been extirpated from the heavily silted North Fork. The upper Roanoke River population may also be jeopardized by pending flood control and water supply projects (e.g. RT&W-N 1985, VWRRC 1985, VWRRC 1986). Protection for this population, however, would result from federal listing of the Roanoke logperch, an action currently under consideration (Simonson and Neves 1986). Populations in the South Mayo and Big Chestnut stream systems were found persisting at moderate to low levels, apparently reflecting limited habitat suitability. The recently discovered populations in the Smith and Pigg River mainstems also appear to be of limited size and of low density. No detailed habitat data were gathered at these latter locations.

Essential habitat for N. gilberti is considered to be the following:

1. Craig Creek system, from its confluence with the James River, upstream into upper Craig and John's Creeks (Craig and Botetourt Counties).
2. Upper Dan River system, from the headwaters, downstream to Danbury, NC (Patrick County, VA and Stokes County, NC).
3. Upper Roanoke River system, upstream from Smith Mountain Reservoir into the North and South Forks (Roanoke and Montgomery Counties, VA).
4. Pigg River system, particularly Big Chestnut Creek (Franklin County, VA).
5. South Mayo River System, particularly the upper South Mayo River mainstem and the North Fork of the South Mayo River, in the vicinity of Stuart, VA (Patrick County, VA).
6. Smith River system, upstream from Philpott Reservoir, including Rockcastle Creek (Patrick County, VA).

A potential threat to the orangefin madtom in some streams may be its use as bait by fishermen; the extent to which it is collected, however, is unknown. Use of "madtoms" by area fishermen is extensive (e.g. VCGIF 1985a, 1985b; VCGIF 1986a, 1986b), and Jenkins (1977) believes that the Craig Creek population resulted from an introduction by bait fishermen.

The number and relative status of orangefin madtom populations, assuming no change in environmental conditions, appears stable at this time. As judged by all data presented, it appears that the orangefin madtom will maintain its present status into the foreseeable future.

SPECIES AND HABITAT ASSOCIATIONS

Results of distribution classification indicate that this species' presence is related to relatively lower proportions of sand and silt, higher proportions of small cobble, higher local gradient, and relatively deep, riffle areas. These relationships are purely correlative, but possible causal mechanisms are discussed below.

Lower sand levels are intuitively related to high interstitial volume (i.e., available spaces between rocks) at a given site and would therefore increase the chances of N. gilberti habitation. Also, sand is relatively poor habitat for benthic invertebrates (Hynes 1970), and this substrate type may limit madtom food abundance. A large proportion of small cobble substrate may result in more optimally-sized interstitial spaces, which could be too small for potential predators or competitors, yet large enough for the orangefin madtom. Interstices in predominantly gravel riffles would likely be too small for this species, and sites dominated by boulder would result in larger between-rock spaces. Occurrence and diversity of simuliids, chironomids, and trichopterans, the primary food of N. gilberti (Burkhead 1983), is relatively high in cobble-dominated (rubble) riffle areas (Hynes 1970).

High local gradient influences substrate size, maintains high current velocity, and would therefore scour away smaller

particles such as sand, silt, or organic fines (Smith and Stopp 1978), which generally support fewer invertebrates (Angermeier 1985). Food production should therefore be better under higher gradient conditions. Silt within and covering the substrate may have effects similar to that of sand; both presumably fill interstitial spaces. Silt may also have detrimental effects on N. gilberti reproduction. Embryo suffocation caused by silt has been documented for many other warmwater stream fishes (Muncey et al. 1979). Also, sedimentation reduces stream macroinvertebrate production (Farnworth et al. 1979), and therefore food availability for madtoms. Deeper water increases the cross-sectional area at a site, which is directly proportional to stream discharge, based on Manning's equation (Orth 1983). Increased depths may therefore assist in scouring fine materials. Turbulence appeared related to riffle gradient, and steeper areas may provide increased dissolved oxygen, which could influence food abundance or survival of orangefin madtoms during critical life history stages.

My observations indicate that stream sections inhabited by this species were primarily mid-stream reaches. N. gilberti was never found in areas I would classify as headwaters, having larger substrate, lower water temperatures, and higher overall gradient. Downstream, lower gradient stream sections with increased pool to riffle ratios were also rarely occupied. This species may therefore be

ecologically restricted to mid-reaches of streams having moderate overall gradient. Stream gradient has been shown to determine longitudinal distribution of stream fishes, and may comprise several interrelated factors influencing microhabitat (Hocutt and Stauffer 1975).

Two riffle species significantly associated with N. gilberti distribution further support this "mid-reach" hypothesis. The orangefin madtom was found to be negatively related to the occurrence of rosieside dace and mountain redbelly dace, two species documented to inhabit cooler, headwater reaches (Jenkins and Freeman 1972, Hocutt and Stauffer 1975, James 1979).

Other species negatively related to orangefin madtom distribution were chubs and crescent shiners. Differences in microhabitat utilization between these species and the orangefin madtom is the probable reason for their non-overlapping occurrences. Although no habitat parameters were summarized for chubs or crescent shiners, my observations indicate that they occupy riffles of relatively slow current velocity, with larger substrate (i.e., predominantly boulder), and lower gradient. This riffle-type is hypothesized to be more "mosaic", having a variety of habitat patches supporting greater species richness. The presence of chubs and crescent shiners therefore appears to indicate marginal habitat quality for N. gilberti.

Crayfish were also found to be negatively associated with orangefin madtom occurrence. Although sampling efficiency for crayfish was untested, I believe that the presence of crayfish may reduce the ability of N. gilberti to colonize an area. Crayfish also inhabit between-substrate spaces and may prey on orangefin madtom nests. Crayfish, large darters, and madtoms have been reported to prey upon Noturus embryos and larvae (Mayden et al. 1980, Mayden and Burr 1981, Burr and Mayden 1982). The highest occurrence and abundance of N. gilberti was in Craig Creek, which also contained the lowest occurrence of crayfish. Stream systems supporting fewer orangefin madtoms all had a greater proportion of riffles occupied by crayfish.

The margined madtom, suggested by Hubbs and Raney (1944) to be a common associate of the orangefin madtom, was not related to N. gilberti distribution, based on occurrence among the stream systems sampled in this study. Burkhead (1983) indicated that these madtoms were negatively associated, and I found that they partitioned pool and riffle habitat in Craig Creek during spring and summer. This segregation may result from competitive exclusion, as suggested by Burkhead (1983).

The Roanoke darter co-occurred with N. gilberti. Matthews et al. (1982) described habitat of the Roanoke darter in the upper Roanoke River as extremely swift riffles (up to 125 cm / second). Also, occurrence of this darter was

highest in small cobble substrate (6.3 - 16 cm diameter). Matthews et al. (1982) reported that density of benthic food items was highest at sites inhabited by the Roanoke darter. These results support my observations on orangefin madtom habitat.

The discriminant model used to predict occurrence of the orangefin madtom was judged to be adequate based on the good classification obtained. Apparent error rate (AER) for the model, based on misclassifications, was 0.141. AER values less than 2 are indicative of excellent discrimination between classes (E. Smith, pers. comm.). Most (88%) sites without the madtom, that were predicted to contain it, were in Craig Creek. Habitat at most sites in Craig Creek appeared suitable; either the orangefin madtom evaded capture at these locations, or some factor limiting its occurrence was not considered. Sites classified as having the orangefin madtom when it was actually absent were most common in the Dan River (69%). As indicated previously, physical habitat in the Dan River was considered ideal, but other variables appeared to influence orangefin madtom distribution in this stream system.

At sites having the orangefin madtom, density was not significantly related to any variable measured, although density categories were classified with some certainty. Tested variables apparently could not be refined to levels indicative of low and high density. The abundance estimates

using removal methods were more precise than estimates for other madtoms based on mark-recapture techniques (Burkhead 1983, Shute 1984), but error in predicting abundance from one sample was relatively high. Density of the orangefin madtom could also be regulated by predation or climatic conditions, particularly spring water flow and temperature. It is apparent that orangefin madtom density cannot be accurately predicted using my data. Further study is warranted if density information for this species is required.

REPRODUCTION AND LIFE HISTORY

The captive breeding experiments were meant to test and adopt the simplest techniques shown successful for other ictalurids. However, unknown environmental cues or "releasing factors" are apparently required for spawning. Water flow or available substrate may interact with temperature and photoperiod to cue "placement of eggs or young in the right place at the right time" (Bond 1979). I found that orangefin madtoms occupied fast-water, cobble areas throughout the spawning period, based on electrofishing samples. Flow through the laboratory flumes was considerably less than velocities observed for typical riffle areas. Therefore, increased success in captive breeding of this species may require a more realistic simulation of natural habitat.

Other researchers have indicated success in spawning several Noturus species. Mayden and Burr (1981a) induced spawning in N. exilis, and indicated that "one 2-year-old female (73.0 mm SL) layed two clutches of eggs with a single male in an aquarium". Nothing was mentioned about use of hormones or duration of pairing. N. exilis has a life span of about 46 months and matures at age II (Mayden and Burr 1981a). Spawning of N. miurus, which lives 36 months (Mayden and Burr 1981b), was reported by Mayden (1983), but only behavioral observations were noted. Three pairs of N. nocturnus, brought into captivity in breeding condition, were successfully spawned after "several" injections of HCG, using 50 IU at 0.05 ml per injection (Burr and Mayden 1982b). This species lives 56 months and apparently reaches maturity at age I.

Most species that spawned in captivity are relatively long-lived pool inhabitants, reproducing in successive years as adults. However, N. hildebrandi, whose population structure is similar to N. gilberti's, was successfully spawned in aquaria after HCG injection (Mayden and Walsh 1984). Six egg clutches were obtained from 15 adults. This species apparently lives only 18 months and dies shortly after spawning. Mayden and Walsh (1984) found that spawning occurred 2.5 to 5 weeks after injections but did not indicate how long the specimens were held prior to ambient spawning date, or how many HCG injections were used.

Margined madtom egg clutches were successfully hatched and reared during this study, and Mayden and Burr (1981), Burr and Mayden (1982a), and Burr and Lee (1985) indicated similar success in hatching and rearing other madtoms. Starnes and Starnes (1985) found that brine shrimp adhered to N. eletherus larvae, causing suffocation in 34% of the clutch. This problem was not observed in my study, and I believe the differential survival between groups fed brine shrimp versus trout chow was related to nutritional requirements. Trout chow, which was formulated for fish, may provide essential dietary components lacking in brine shrimp.

The limiting factor to successfully propagating N. gilberti appears to be obtaining fertilized ova. Results concerning the spawning and hatching of other madtoms suggest that a modified experimental design could produce viable orangefin madtom embryos and larvae. Bringing age I+ N. gilberti into the laboratory during fall, acclimating them to controlled conditions, and providing realistic flow regimes may improve success in breeding this species. This approach would avoid subjecting weakened, disease-susceptible fish to a radically different environment just prior to spawning (Roff 1984).

Another technique for spawning the orangefin madtom would be to hold pairs in situ within stream enclosures, periodically check them for embryos, and return clutches to the laboratory. This would alleviate the problem of locating

nests with embryos, a difficult task given the secrecy of this species, and take advantage of proven hatching and rearing techniques.

The apparent life history strategy of the orangefin madtom (i.e., spawning at age II and dying) undoubtedly contributed to the difficulty I experienced in propagating this species, and will have implications for future efforts to spawn N. gilberti and other short-lived madtoms that spawn only once. Fish (age II) brought into the laboratory in May 1986 for captive breeding attempts apparently had only one or two more months to live. The numerous deaths prior to spawning were attributed to frequent handling and injections required to administer HCG, compounding the physiological stress associated with reproduction (Roff 1984).

This madtom species has an apparent longevity of about two years, with few individuals surviving beyond 25 months. My observations differ from those of Jenkins (1977) and Burkhead (1983), who both tentatively indicated a life span of three full years, based on length-frequency plots from several collection dates and locations. The largest orangefin madtom captured during my study was 111 mm TL (95 mm SL), 10 mm longer than the previously reported maximum of 101 mm TL (85 mm SL; Taylor 1969).

An important aspect of N. gilberti populations is that mortality appears catastrophic two or three months into the third year of life. Most orangefin madtoms apparently spawn

only once at age II; very few fish considered to be age I were in spawning condition. The orangefin madtom therefore appears to reproduce at age II, and dies shortly after spawning. The aging method used, which assumes separate, normal distributions of lengths at each age, was not validated and may under-represent older age classes. However, Clugston and Copper (1960), Mahon (1977), and Starnes and Starnes (1985) indicated agreement between hard-structure (spines and vertebrae) and length-frequency aging techniques for madtoms.

Maximum ages and lengths of madtom species, obtained from the literature, were positively related ($r = 0.92$, $p < 0.0005$, Figure 11). Values presented here for N. gilberti fell within the 95% prediction interval for the mean age in months (38.82 ± 20.17) at a maximum length of 95mm for this relationship. These data, though somewhat variable, indicate a definite trend and suggest that my orangefin madtom age assignments are reasonable.

Examination of available data on age at first spawning for Noturus species that species less than 100 mm SL generally mature at age II, spawn once or twice before death, and live less than 36 months. N. gilberti is most like N. albater, which reaches 85 mm SL, spawns at age II, and lives about 26 months (Mayden et al. 1980). Little information is available for the 13 other species having maximum lengths less than 100 mm. Maximum ages are known for only three: N. hildebrandi, 18 months; N. miurus, 36 months; and N.

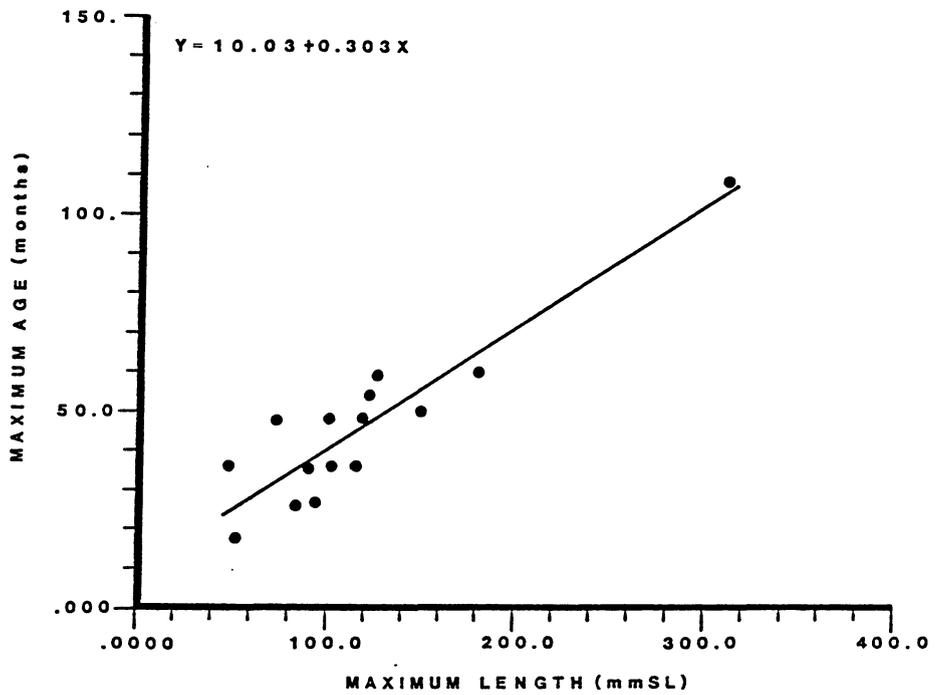


Figure 11. Relationship between maximum length and maximum age for several Noturus species for which information is available.

eletherus, 48 months (Burr and Mayden 1982b, Mayden and Walsh 1984, Starnes and Starnes 1985).

Noturus life histories appear to represent a gradient of strategies strongly related to maximum size. At one extreme, N. hildebrandi reaches a maximum SL of 53 mm, spawns once at age I, and dies in 18 months (Mayden and Walsh 1984). Several species, ranging from 73 to 180 mm, mature at age II and live from 26 to 60 months (Mahon 1977, Mayden et al. 1980, Mayden and Burr 1981, Mayden and Burr 1982a, Mayden and Burr 1982b, Burr and Mayden 1984, Shute 1984, Starnes and Starnes 1985). N. flayus, at the other extreme, reaches a maximum size of 312 mm SL, matures at age III, and has a longevity of 108 months (Walsh and Burr 1985).

Smaller madtoms may forgo reproduction at earlier ages, when energy reserves are probably insufficient to produce (and protect) an optimum number of large offspring having enhanced survival. Successive year-class failures, however, could result in some local extirpations of species that presumably spawn once and die. These populations would probably recover slowly, making them susceptible to further perturbations. It is interesting to note that while only 47% of the 15 "common" species reach maximum lengths less than 100 mm SL, 91% (10 of 11) of the species either federally listed (threatened or endangered) or under consideration for listing, grow to 101 mm SL or less. Unfortunately, little is known about these smaller, shorter-lived madtom species.

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APPENDIX A. SPECIES LIST

Appendix A. Common and scientific names of species captured during this study (Robins et al. 1980). A (*) indicates the species was rarely collected.

Common	Scientific	Location ¹					
		C	R	D	M	B	S
brown trout	<u>Salmo trutta</u>		x	x			x
rainbow trout	<u>Salmo gairdneri</u>	x		x			x
stoneroller	<u>Campostoma anomalum</u>	x	x	x	x	x	x
blacknose dace	<u>Rhinichthys atratulus</u>	x		x	x	x	x
longnose dace	<u>Rhinichthys cataractae</u>	x	x	x			x
cutlips minnow	<u>Exoglossum maxillina</u>	x	x	x			
bluehead chub	<u>Nocomis leptocephalus</u>						
river chub	<u>Nocomis micropogon</u>	x	x	x	x	x	x
bull chub	<u>Nocomis raneyi</u>						
rosyside dace	<u>Clinostomus funduloides</u>	x	x	x	x	x	x
mountain redbelly dace	<u>Phoxinus oreas</u>	x	x	x	x	x	x
crescent shiner	<u>Notropis cerasinus</u>	x	x	x	x	x	x
redlip shiner	<u>Notropis chiliticus</u>			x			
rosefin shiner	<u>Notropis ardens</u>	x	x		x	x	
torrent sucker	<u>Moxostoma rhothoecum</u>	x	x	x	x	x	x
rustyside sucker*	<u>Moxostoma hamiltoni</u>			x	x		x
black jumprock	<u>Moxostoma cervinum</u>	x	x	x	x	x	x
bigeye jumprock*	<u>Moxostoma ariommum</u>					x	
hog sucker	<u>Hypentelium nigricans</u>	x	x	x	x	x	x
Roanoke hog sucker	<u>Hypentelium roanokense</u>		x	x	x		
flat bullhead*	<u>Ictalurus platycephalus</u>			x			
margined madtom	<u>Noturus insignis</u>	x	x	x	x	x	x
mottled sculpin	<u>Cottus bairdi</u>	x	x	x		x	x
rock bass*	<u>Amploplites rupestris</u>	x	x	x	x	x	x
smallmouth bass*	<u>Micropterus dolomieu</u>	x	x				x
Roanoke logperch*	<u>Percina rex</u>		x			x	x
Roanoke darter	<u>Percina roanoka</u>	x	x	x	x	x	x
fantail darter	<u>Etheostoma flabellare</u>	x	x	x	x	x	x
longfin darter	<u>Etheostoma longimanum</u>	x					
riverweed darter	<u>Etheostoma podostemone</u>		x	x	x	x	x
crayfish	<u>Cambarus, Orconectes</u>	x	x	x	x	x	x

¹C = Craig Creek system, R = Roanoke River, D = Dan River, M = Mayo River system, B = Big Chestnut Creek, S = Smith River.

APPENDIX B. LINEAR DISCRIMINANT FUNCTION: ORANGEFIN MADTOM OCCURRENCE

Appendix B. Linear discriminant function produced by the DISCRIM procedure (SAS 1985), using data collected at 142 locations in Virginia and North Carolina.

Explanatory Variable	Class Variable	
	present	absent
Constant	-13.20650656	-9.25866681
Large gravel	0.01108095	0.04333411
Local gradient	2.64255430	1.25133102
Silt	0.11960504	0.08603731
Species richness	1.35174219	1.12351003
Rosyside dace	-2.15053518	-0.55931494
Crescent shiner	-0.00331279	0.92765128
Crayfish	-0.36943632	1.61183556

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