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The Development of Anatomical Features in Larval Fish in Conjunction with the Onset of Exogenous Feeding

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Irene

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THE DEVELOPMENT OF ANATOMICAL FEATURES IN LARVAL FISH IN CONJUNCTION WITH THE ONSET OF EXOGENOUS FEEDING

A Thesis

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In Partial Fulfillment

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Master of Science

by

Irene Kokkala

March 1984

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THE DEVELOPMENT OF ANATOMICAL FEATURES IN LARVAL FISH
IN CONJUNCTION WITH THE ONSET OF EXOGENOUS FEEDING

Recommended March 28, 1984
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Dean of the Graduate College

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THE DEVELOPMENT OF ANATOMICAL FEATURES IN LARVAL FISH IN CONJUNCTION WITH THE ONSET OF EXOGENOUS FEEDING

Irene Kokkala March 1984 45 pages
Directed by: R. D. Hoyt, G. E. Dillard, L. N. Gleason and J. R. McCurry
Department of Biology Western Kentucky University

Observations were made on the appearance and development of anatomical features such as neural receptors (free neuromasts and taste buds), lateral line canals and bone elements of the mandibular and hyoid regions of the skull associated with the larval stages of the spotted bass (*Micropterus punctulatus*) and northern hog sucker (*Hypentelium nigricans*). The results were related to known feeding habits and habitat selection.

Free neuromast development and appearance of the lateral line canal system in the spotted bass preceded that of the northern hog sucker. This accelerated development of the spotted bass was related to earlier activity in feeding, including piscivory, and presence among emergent shoreline vegetation. The northern hog sucker was more sedate in occupying quiet rock-outcrop shoreline areas. It was found to exhibit more diverse feeding habits.

Taste buds played a secondary role in early larval ecology being present throughout all developmental stages and showed little importance in early feeding compared to free neuromasts. The taste buds present on the hyoid region

of the northern hog sucker indicated a future bottom feeding habit.

The teeth on the basihyal and jaw bones of the spotted bass larvae supported its early predaceous habit. The development of jaws in the northern hog sucker at the start of the mesolarval stage was the most important developmental feature relating to the onset of exogenous feeding.

INTRODUCTION

The ecology and behavior patterns of fishes are determined by the combination of neural receptor organs and complex learned traits. These characters are highly developed and reinforced in post-juvenile and adult fishes but cannot be used to explain the success of larval or newly hatched fish species in selecting protective habitat areas and in feeding successfully.

Progressing from the prolarva through the juvenile stage, fundamental changes observed in various anatomical features are indicative of the developmental stage of the fish (O'Connell 1981). Features of development increase in complexity and size throughout the larval period, expanding functional capabilities and ecological interaction. O'Connell (1981) found that changing developmental features include appearance and disappearance of transient structures, but more often relate to differentiation and graduate recruitment of new elements into an anatomical system. Behavior patterns tend to change gradually in close conjunction with these recruitment processes. According to Dijkgraaf (1962), structural and functional specializations of the lateral line system are related to the fish's habitat and mode of living. The same applies in the case of taste buds (Reutter et al. 1974) and jaw development (Gregory 1959).

The objectives of this study were to identify and describe the time of appearance and development of anatomical structures such as free neuromasts, lateral line canals, taste buds, and jaw elements in the larval stages of the spotted bass and northern hog sucker. These observations were related to major events or changes in the ecology of feeding (Timbrook 1983) and habitat partitioning by the two species (Floyd 1983).

METHODS AND MATERIALS

The larval fish used in this study were collected from the Middle Fork of Drake's Creek, Warren County, Kentucky, by Floyd (1983) from 25 April 1982 through 15 July 1982. Collection methods used included seines (mesh size 0.5 mm), 0.5 m conical ichthyoplankton nets (mesh size 0.5 mm) and light traps (Floyd 1983). Upon collection, the larval fish were immediately fixed in 10 percent formalin.

Larvae of spotted bass (*Micropterus punctulatus*) and northern hog sucker (*Hypentelium nigricans*) were randomly selected from the above-mentioned collections and total body length (TL) measured using a dissecting microscope equipped with an ocular micrometer. The developmental stage of the larvae was also determined according to Fuiman (1979).

For each species, five specimens were selected from each total length class of 7 through 23 mm, except northern hog suckers from 8-10 mm TL, not represented in Floyd's (1983) collection, and these were placed in a solution of three percent gluteraldehyde in 0.1 M cacodylate buffer (pH 7.2-7.4) for approximately two months. Lower jaws and the associated hyoid apparatus were dissected from a number of specimens and these were treated in the same manner as the intact specimens. The specimens were rinsed for 8 h, three times, in cacodylate buffer (0.1 M, pH 7.2-7.4). Specimens were then postfixed in one percent osmium tetroxide in 0.1 M cacodylate buffer for 1.5 h and rinsed for 20-24 h, three times, in the buffer. This was followed by dehydration in a graded series of ethanol at concentrations of 10, 20, 30, 40, 50, 70, 80, 90 and 95. The fish were left in each solution for 5 to 8 h. Final dehydration was accomplished in two changes of 100 percent ethanol, each of 2 h duration.

Following dehydration the specimens were critical point dried in a Samdri-790 critical point drier, mounted on aluminum stubs using silver paint, coated with gold-palladium in a NRC 3117 vacuum evaporator and observed with an ISI Super IIIA scanning electron microscope at 1.5 kV. The surface of the specimens was scanned for the presence of anatomical features such as taste buds (specifically on the surface of the tongue, lips and hyoid region), free neuromasts and lateral line canals on the head region and trunk. Micrographs of representative anatomical features were taken using type 55 Polaroid film.

Additional specimens, five of each TL class, were cleared and stained using the procedure of Dinkerkus and Uhler (1977) for the demonstration of bone and cartilage. These specimens were fixed and preserved in 10 percent formalin. Specimens were washed in several changes of distilled water for a period of ten days to remove the formalin. The eyes were removed and the fish were placed in a solution of 10 mg alcian blue 8GN, 80 ml ethanol and 20 ml glacial acetic acid for three days. The fish were hydrated in a series of ethanol - 95, 75, 40 and 15 percent - for a duration of from 10 to 24 h each until immersed in the ethanol. Then they were washed twice, for 4 to 8 h, in distilled water.

The fish were placed in an enzyme solution of 30 ml saturated aqueous sodium borate, 70 ml distilled water and four grams of pancreatin. This solution was renewed at 24 h and the process continued until the bone and cartilage were clearly visible and blue color was absent from the flesh. Total time for this process was approximately 60 h. The specimens were transferred to a solution of 0.5 percent aqueous KOH, to which alizarin red S was added to turn the solution deep purple, and left until the bones were distinctly red, approximately 24 h. The fish were then transferred through a 0.5 percent KOH-glycerine series (3:1, 1:1, 1:3) to pure glycerine. To the first two solutions, three to four drops of three percent hydrogen peroxide were added per 100 ml of solution to bleach the dark pigments.

The cleared specimens were stored permanently in pure glycerine to which a few crystals of thymol were added to inhibit the growth of molds and bacteria. Specimens were studied using a dissecting microscope and drawings made of the bones in the mandibular and hyoid regions of the skull.

Free neuromast lines and lateral line canals were identified according to Branson and Moore (1962) and are shown in Figure 1.

Figure 1a. Antero-lateral view of a teleost showing the outline of the free neuromast series (according to Branson and Moore 1962).

SO = supraorbital line

ST = supratemporal line

IO = infraorbital line

M = mandibular line

PML = postmaxillary line

Op = opercular line

LL = lateralis line (trunk)

Figure 1b. Antero-lateral view of a teleost showing the outline of the lateral line canals and pores (according to Branson and Moore 1962).

SO = supraorbital canal

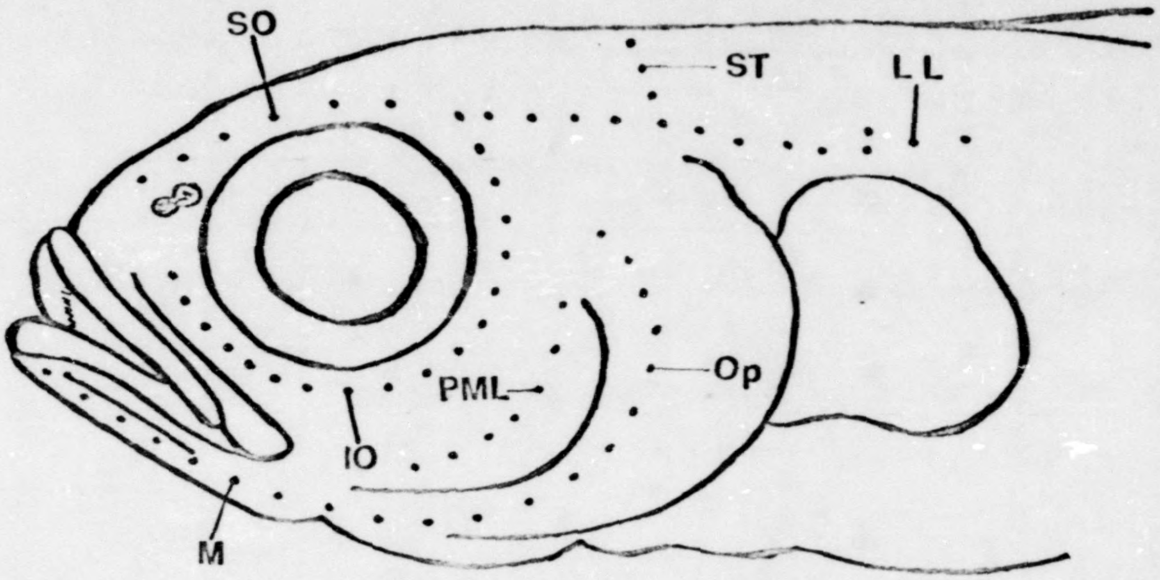
ST = supratemporal canal

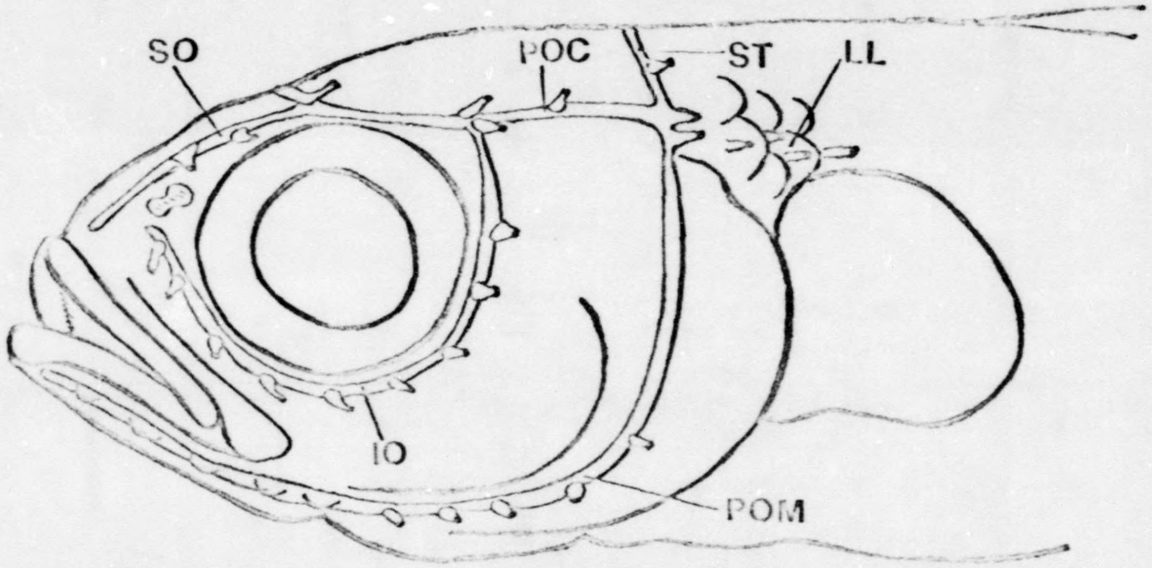
IO = infraorbital canal

POM = preoperculomandibular canal

POC = postorbital commissure

LL = lateralis line (trunk)


SO
ST
LL
PML
Op
IO
M


SO
POC
ST
LL
IO
POM

RESULTS

A total of 170 spotted bass (70 mesolarvae, 100 metalarvae) and 140 northern hog suckers (10 prolarvae, 80 mesolarvae, 50 metalarvae) was used in the study. Larvae of both species used in the study ranged from 7-23 mm TL. Spotted bass 7-13 mm TL were determined to be mesolarvae and those 14-23 mm TL metalarvae. No prolarvae of spotted bass were included in this study. Northern hog sucker larvae of 7 mm TL were considered to be prolarvae, those 11-18 mm TL mesolarvae and those 19-23 mm TL metalarvae.

Receptor Organ Development

Receptor organ development in and around the oral cavity and on the surface of the body and head included free neuromasts, taste buds and cephalic lateral line canals. Free neuromasts and taste buds were the first organs observed in the developing larvae on the surface of the head and in the oral cavity, respectively. Free neuromasts preceded lateral line canal development and, with the exception of the postmaxillary line, approximated the same general outline on the surface of the head and the body as the future canal systems.

Spotted Bass Mesolarvae

The antero-lateral view of a spotted bass mesolarva (9 mm TL) is shown in Figure 2. Free neuromasts were

Figure 2. Antero-lateral view of spotted bass (9 mm TL) (50X).

H = hyoid region

S = horizontal skeletogeneous septum

P = pectoral fin

O = operculum

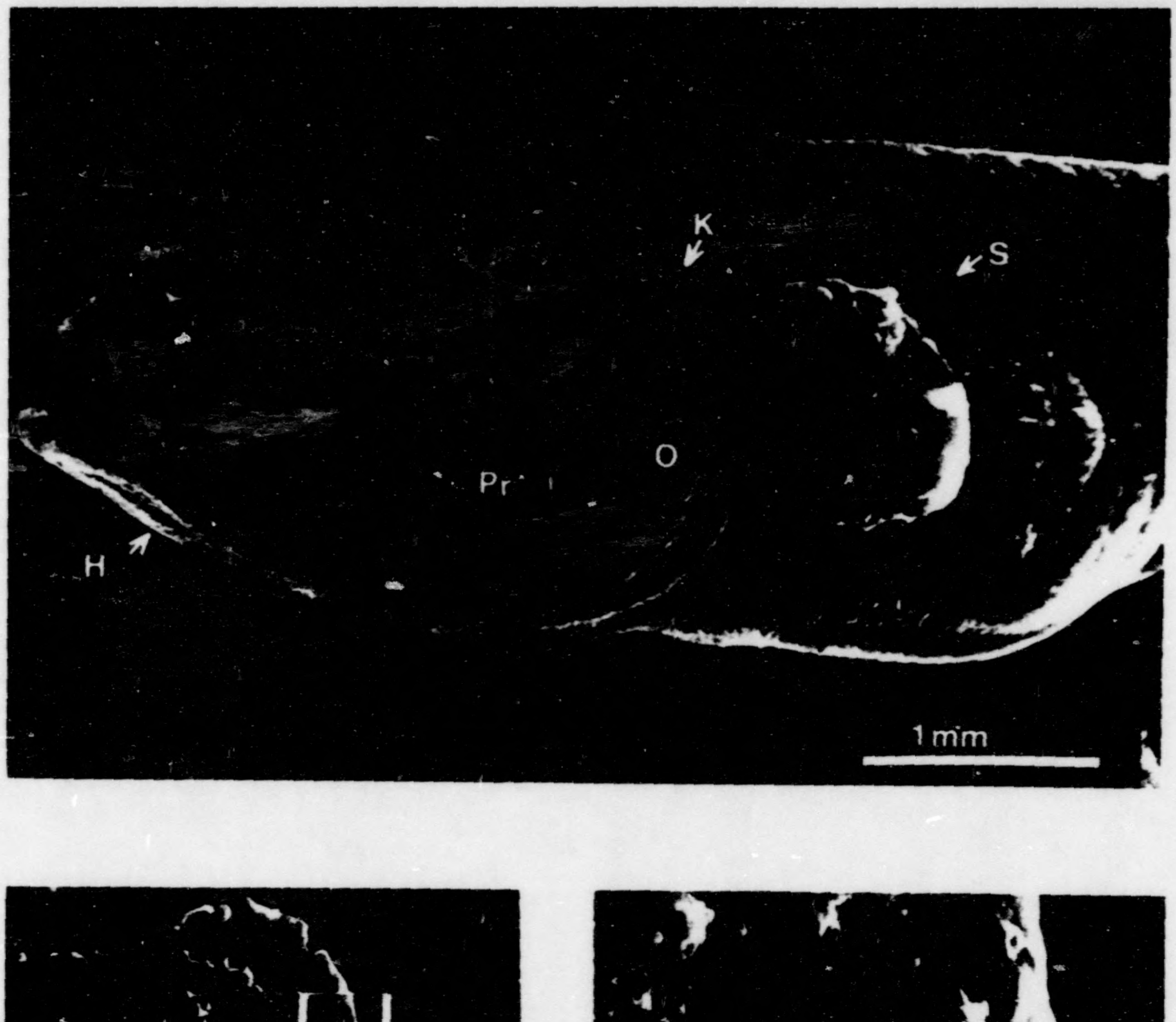
K = cleithrum

Pr = preoperculum

Figure 3. Ventral view of the head of spotted bass (7 mm TL) showing the hyoid region (100X). Inset details free neuromasts of the mandibular lines (1100X).

H = hyoid region

F = free neuromasts


K
S
O
Pr
H
1 mm
F
200 μ

observed on 7 mm TL larvae in the hyoid region at the anterior end of the mandibular portion of the future preoperculo-mandibular (POM) free neuromast line (Figure 3). Taste buds were observed as early as 7 mm TL inside the oral cavity on the lower lip and tongue and are shown at 9 mm TL in Figure 4. At 8 mm TL, the mandibular line of free neuromasts had continued developing posteriorally to the end of the dentary bones. This condition was illustrated in a 9 mm TL and 11 mm TL specimens in Figures 5 and 6.

By 11 mm TL, taste buds were observed along the lateral margins of the tongue (Figure 7). The time of most intense receptor organ development occurred at the 12 mm TL stage. Free neuromast series continued to develop with the appearance of these organs in the infraorbital, postmaxillary (Figures 8-11), dorsal-opercular region of the POM series (Figure 12), and the postocular commissure (Figure 13). Also, the POM cephalic lateral line began to develop with the appearance of the canal groove and the first canal pore at the end of the dentary bone (Figure 14).

Spotted Bass Metalarvae

At 14 mm TL, all free neuromast cephalic lines were completely developed. Free neuromast organs were fully developed reaching maximum size and final shape and showing detailed features including peripherally located mantle cells and the central sensory cells with their long prominent kinocilia and shorter, more delicate stereocilia (Figure 15).

Figure 4. Enlarged view of the jaw apparatus of 9 mm TL spotted bass (160X). Inset shows taste bud on lower jaw amid teeth on the dentary bone (1600X).

T = developing teeth

B = taste bud

Figure 5. Ventral view of the head of spotted bass (9mm TL) showing the hyoid region (160X). Inset details free neuromasts of the mandibular line (800X).

N = free neuromasts

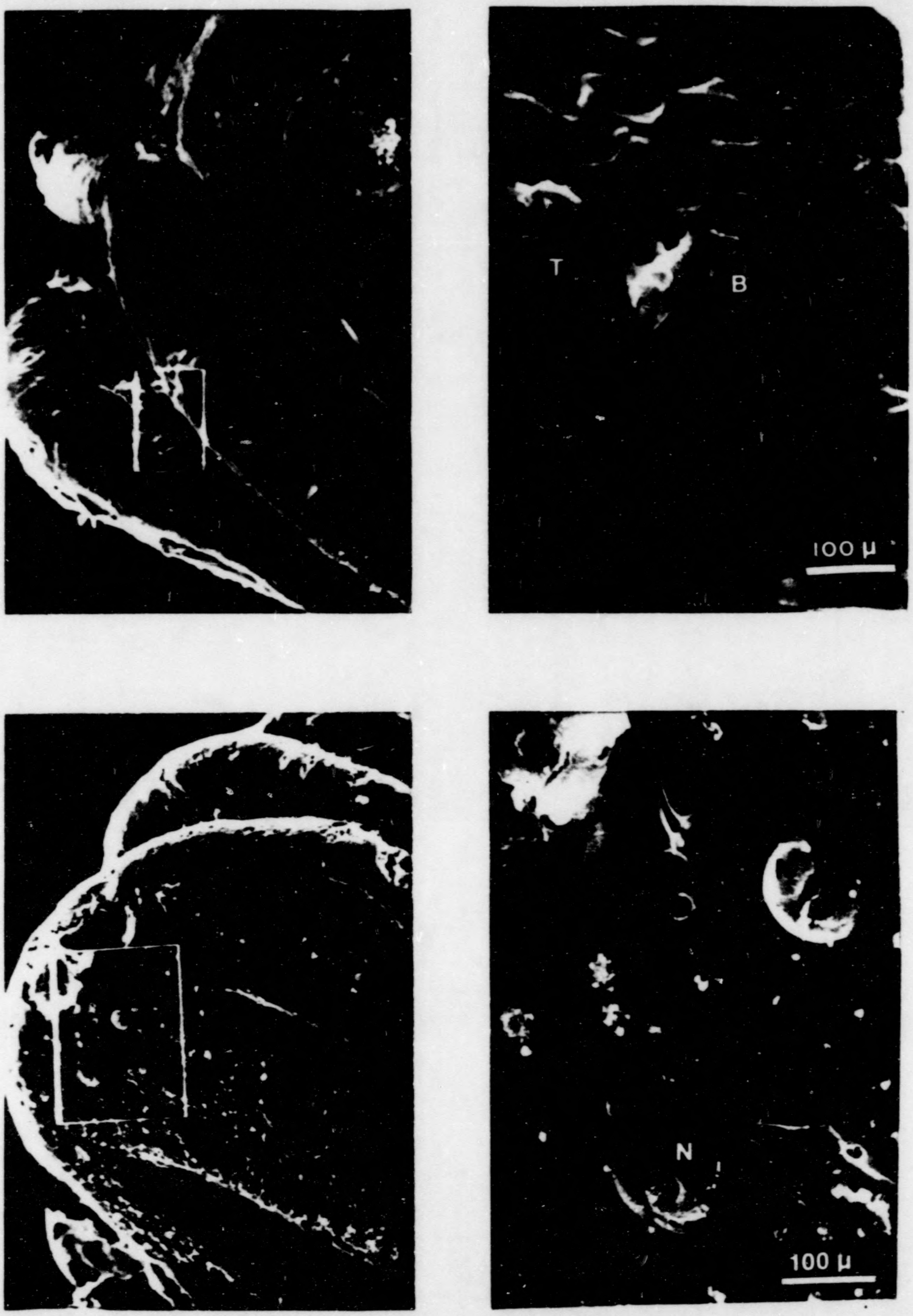

T
B
100 μ
N
100 μ

Figure 6. Ventral view of the head of spotted bass (11 mm TL) showing hyoid region (230X) and continuing development of free neuromasts along the mandibular line. Inset shows detail of free neuromast with kinocilia (2300X).

N = free neuromasts

Figure 7. Ventral view of floor of oral cavity of spotted bass (11 mm TL) showing tongue surface and distribution of the taste buds (110X). Inset shows magnified taste buds (1100X).

B = taste buds

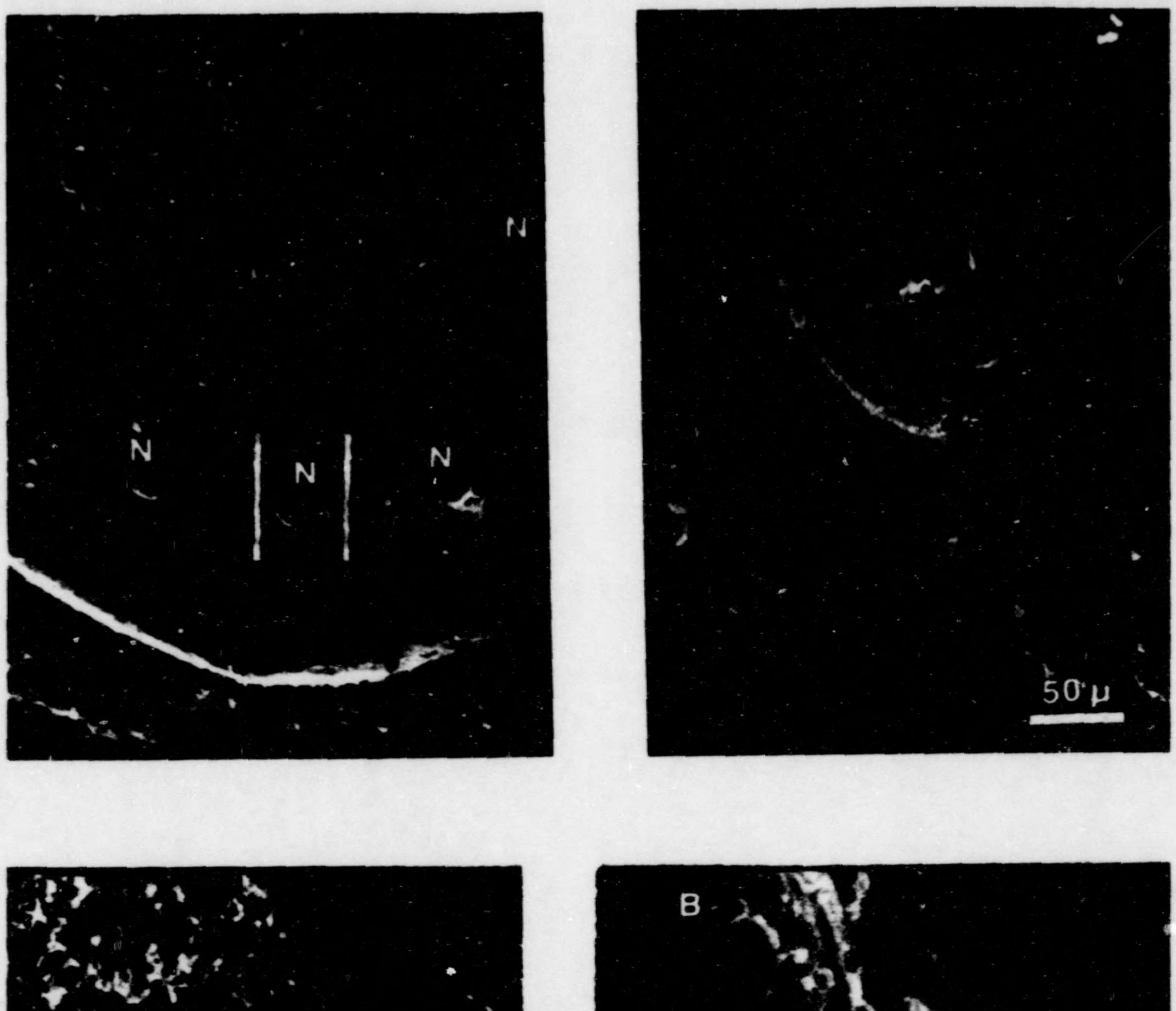

N
N
N
N
50 μ
B
B
100 μ

Figure 8. Lateral view of the left cheeck of spotted bass (12 mm TL) showing free neuromasts along the infraorbital and postmaxillary lines (170X).

E = eye

Pr = preoperculum

I = free neuromasts of the infraorbital line

P = free neuromasts of the postmaxillary line

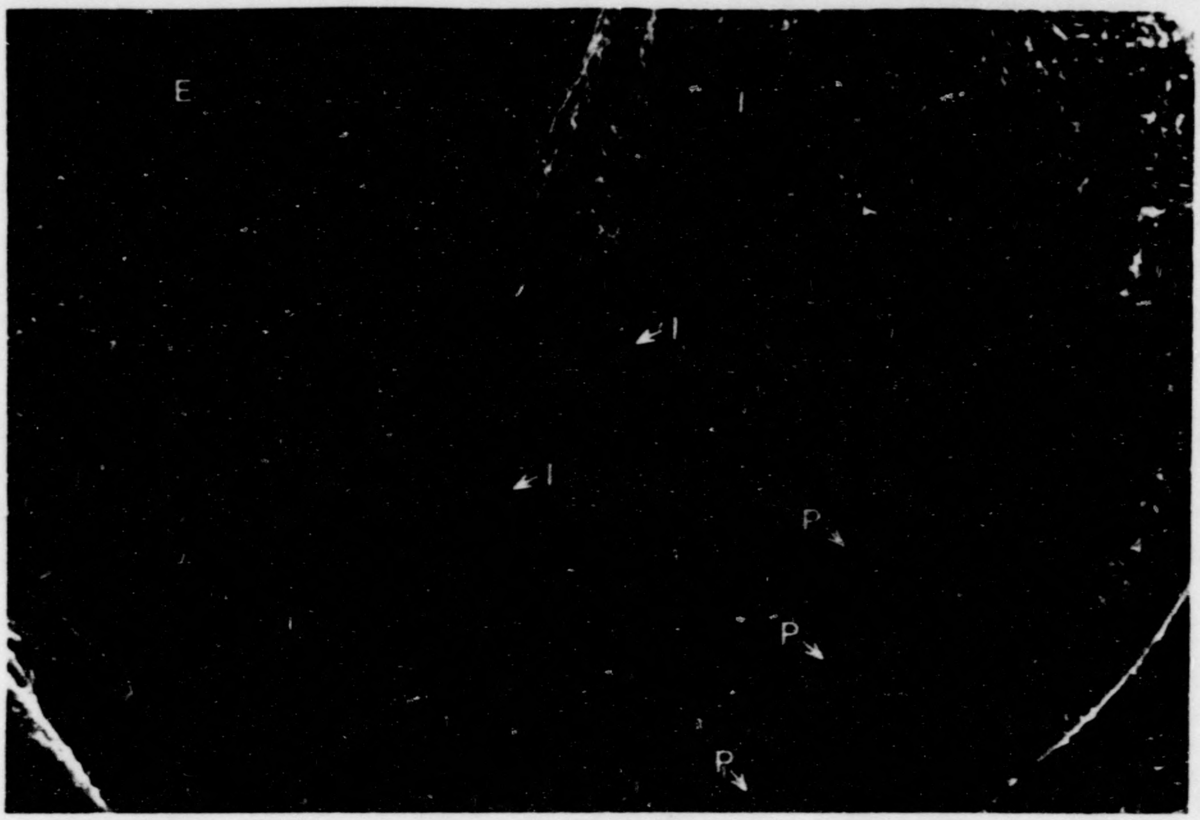
Figure 9. Lateral view of the left cheek of spotted bass (12 mm TL) showing free neuromasts along the infraorbital and the postmaxillary lines (120X). Inset shows magnified free neuromast (1200X).

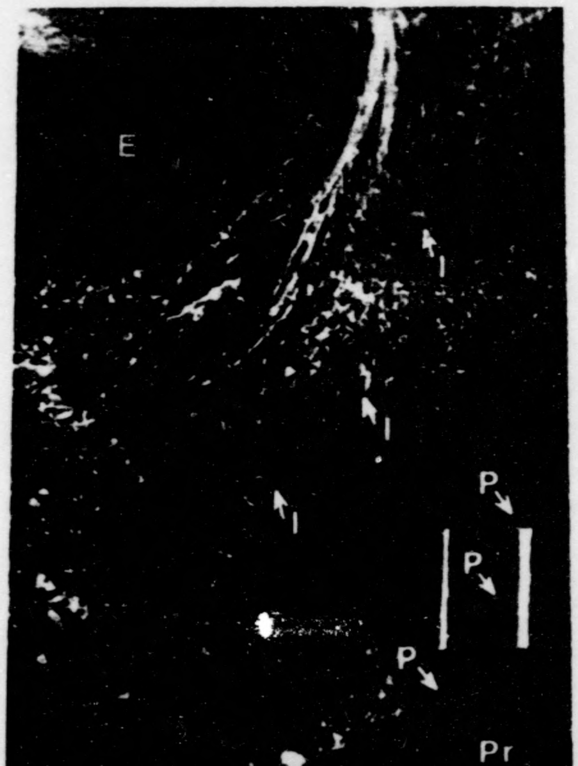
E = eye

Pr = preoperculum

I = free neuromasts of the infraorbital line

P = free neuromasts of the postmaxillary line


E
I
I
I
P
P
P


E
I
I
I
P
P
P
Pr


100 μ

Figure 10. Lateral view of the left side of the head of spotted bass (12 mm TL) showing infraorbital region between eye and maxillary bone (120X). Inset shows magnified free neuromast along the infraorbital line (1200X).

E = eye

Mx = maxillary bone

Figure 11. Lateral view of left side of head of spotted bass (12 mm TL) detailing the nasal region between jaw and eye (120X). Inset shows free neuromast at anterior end of infraorbital line (1200X).

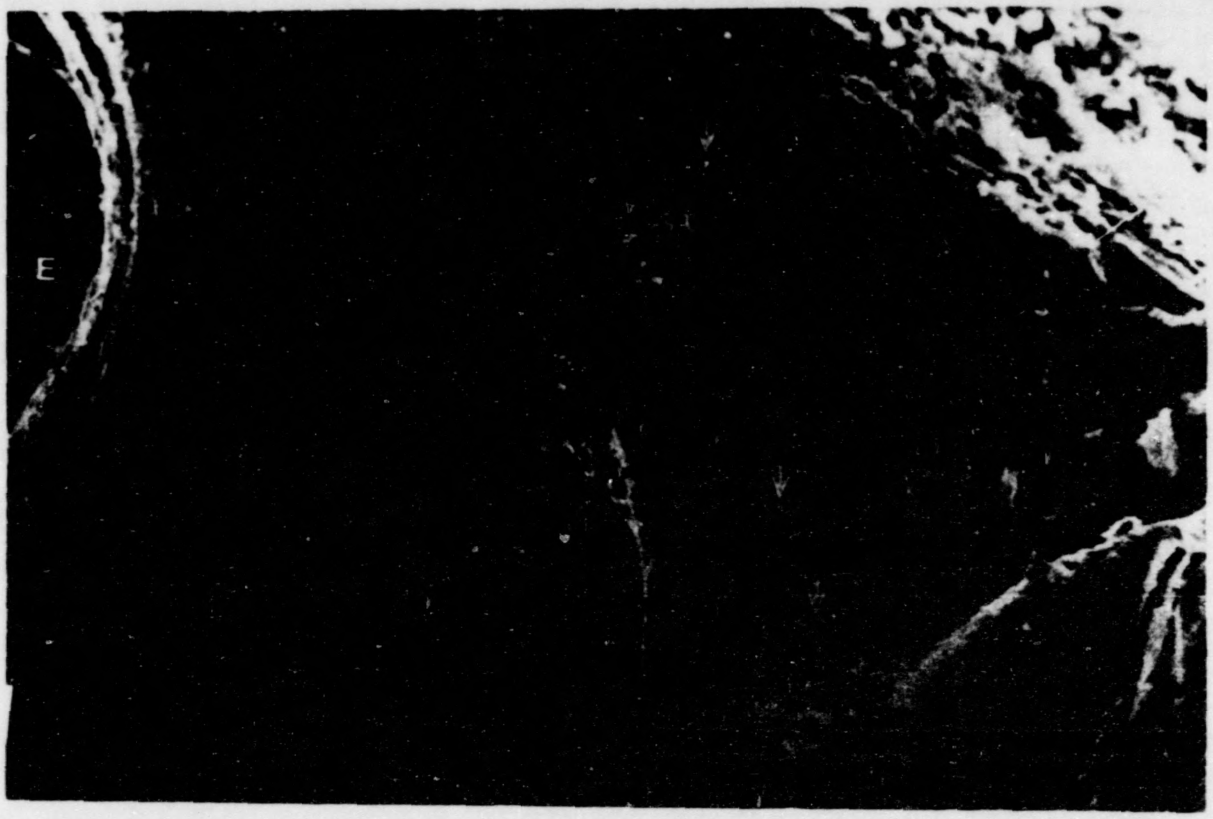
Figure 12. Lateral view of head of spotted bass (12 mm TL) showing postocular region (170X). Arrows identify free neuromasts of the upper opercular line (1700X).

E = eye

Pr = preoperculum

Figure 13. Dorso-lateral view of the head of spotted bass (12 mm TL). Arrows identify free neuromasts of the posterior supraorbital line and the postocular commissure (170X).

E = eye


E


E
100 μ

Figure 14. Ventral view of the head of spotted bass (12 mm TL) showing jaw apparatus (70X). Inset shows free neuromasts at the end of the mandibular line and the first pore of the preoperculomandibular canal (700X).

C = preoperculomandibular canal impression

N = free neuromasts

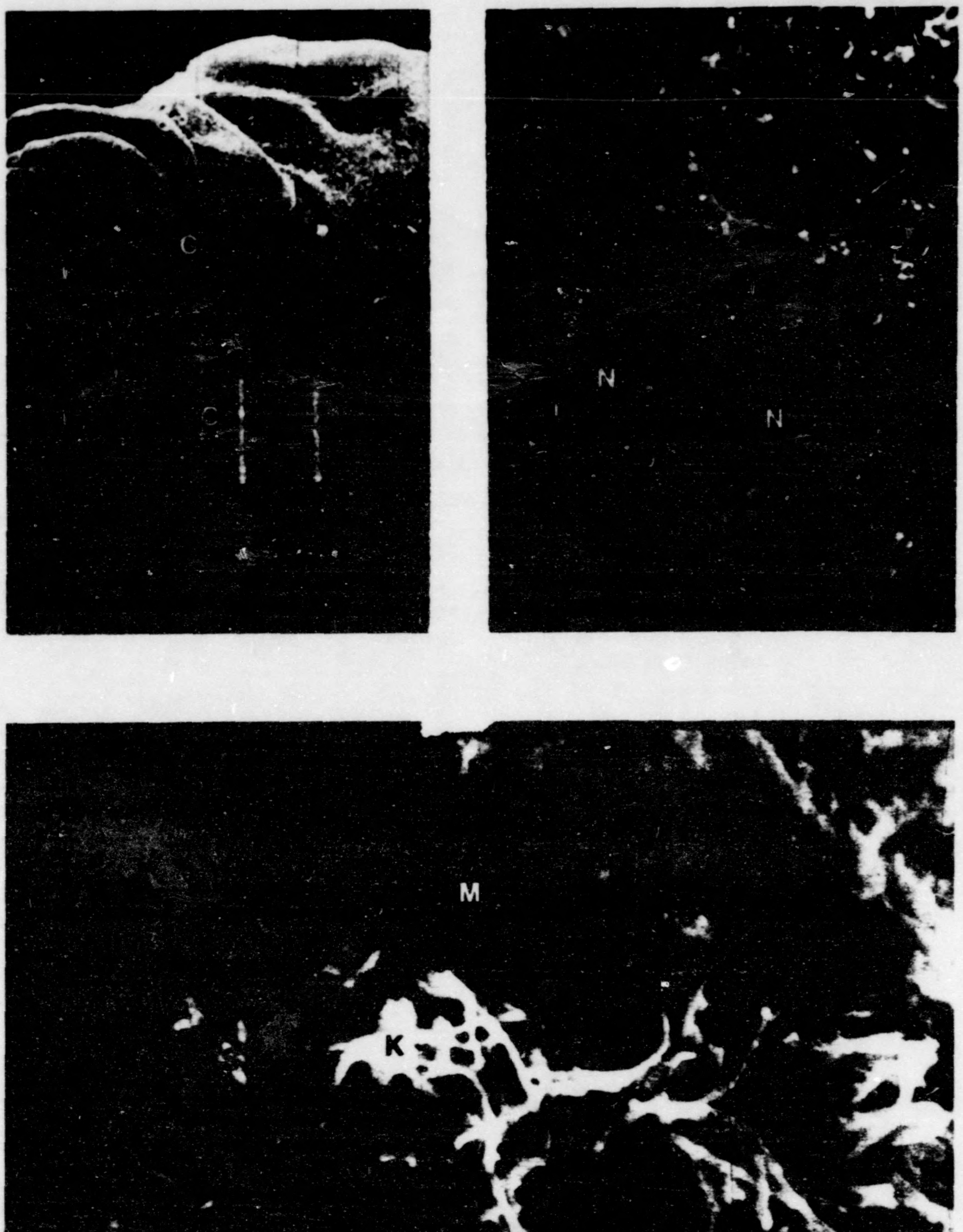
P = pore of the POM canal

Figure 15. Detail of a free neuromast of spotted bass (14 mm TL) (9000X). Well developed kinocilia, stereocilia and mantle cells are present.

K = kinocilia

S = stereocilia

M = mantle cells


C
C
N
N
M
K
M

Free neuromasts were first observed along the future trunk lateral line canal at this length. Above and slightly behind the pectoral girdle, free neuromasts were arranged in pairs, one above the other, extending posteriorally to the region of the origin of the soft dorsal fin (Figures 16 & 17). From this point, posteriorally to the tail, the free neuromasts were arranged in a single line along and above the horizontal skeletogeneous septum (Figure 18). At the base of the caudal fin, the neuromasts were present in pairs above and below the trunk lateral line (Figure 19). Neuromast organs in the trunk lateral line series were morphologically similar to those along the cephalic lines.

At 15 mm TL, the canal and pore series of the mandibular and opercular bone portions of the POM cephalic canal were completed and clearly outlined (Figures 20 & 21). The free neuromasts corresponding to the future trunk lateral line reached maximum size and final shape (Figure 22). By 18 mm TL, while the free neuromasts of the cephalic lines persisted, the canal and pore series of the anterior mandibular portion of the POM cephalic lateral line were completed and clearly outlined (Figure 23). At 20 mm TL, the trunk lateral line canals were not observed but the free neuromasts of the trunk lateral line persisted (Figure 24). The same conditions were observed in metalarvae of 23 mm TL.

Northern Hog Sucker Prolarvae

No receptor organs were observed in prolarvae of 7 mm

Figure 16. Free neuromasts of the cephalic line and the trunk lateral line of spotted bass (14 mm TL) (110X).

K = cleithrum

P = pectoral fin

D = dorsal fin

C = free neuromast of the cephalic line

T = free neuromasts of the trunk lateral line

Figure 17. Dorso-lateral view of the pectoral region of spotted bass (14 mm TL) (45X). Inset shows free neuromasts along trunk lateral line (450X).

K = cleithrum

P = pectoral fin

O = posterior end of the operculum


K
T
C

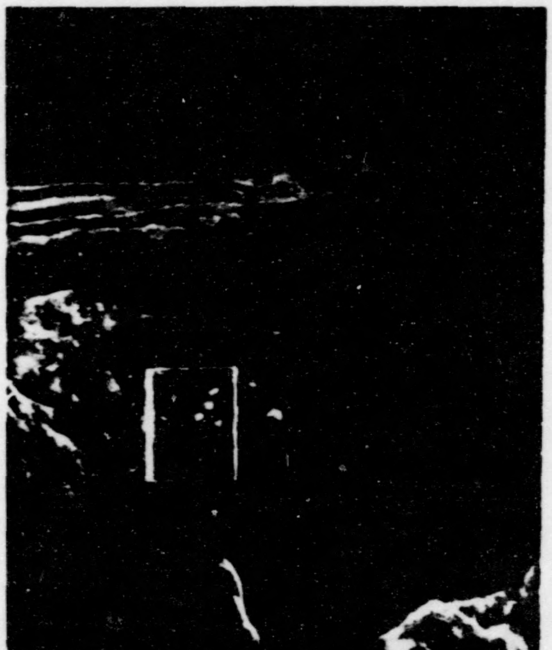


Figure 18. Dorso-lateral view of the side of spotted bass (14 mm TL). Free neuromasts outline the trunk lateral line (110X).

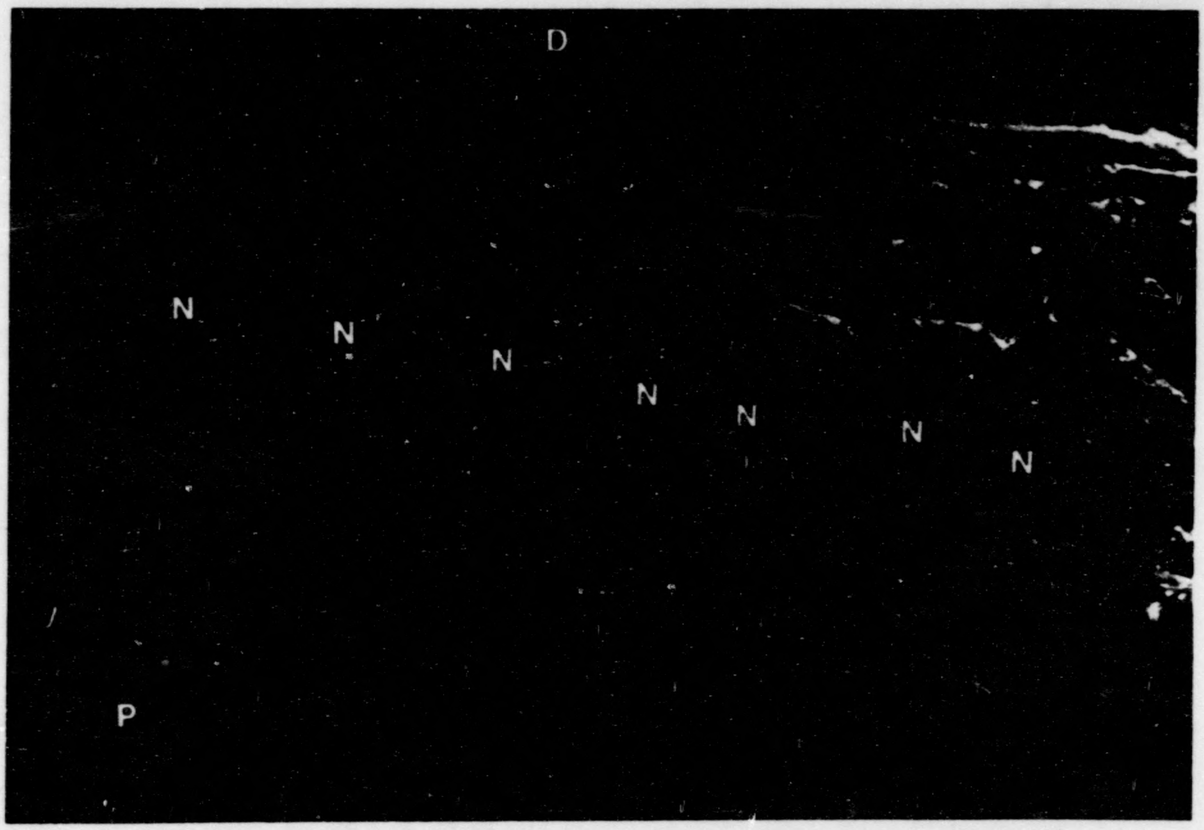
D = dorsal fin

P = pectoral fin

N = free neuromasts

Figure 19. Lateral view of the caudal peduncle - hypural plate region of spotted bass (14 mm TL) (110X). Free neuromasts are shown along the trunk lateral line and the base of the tail.

N = free neuromasts


D
N
N
N
N
N
N
N
P

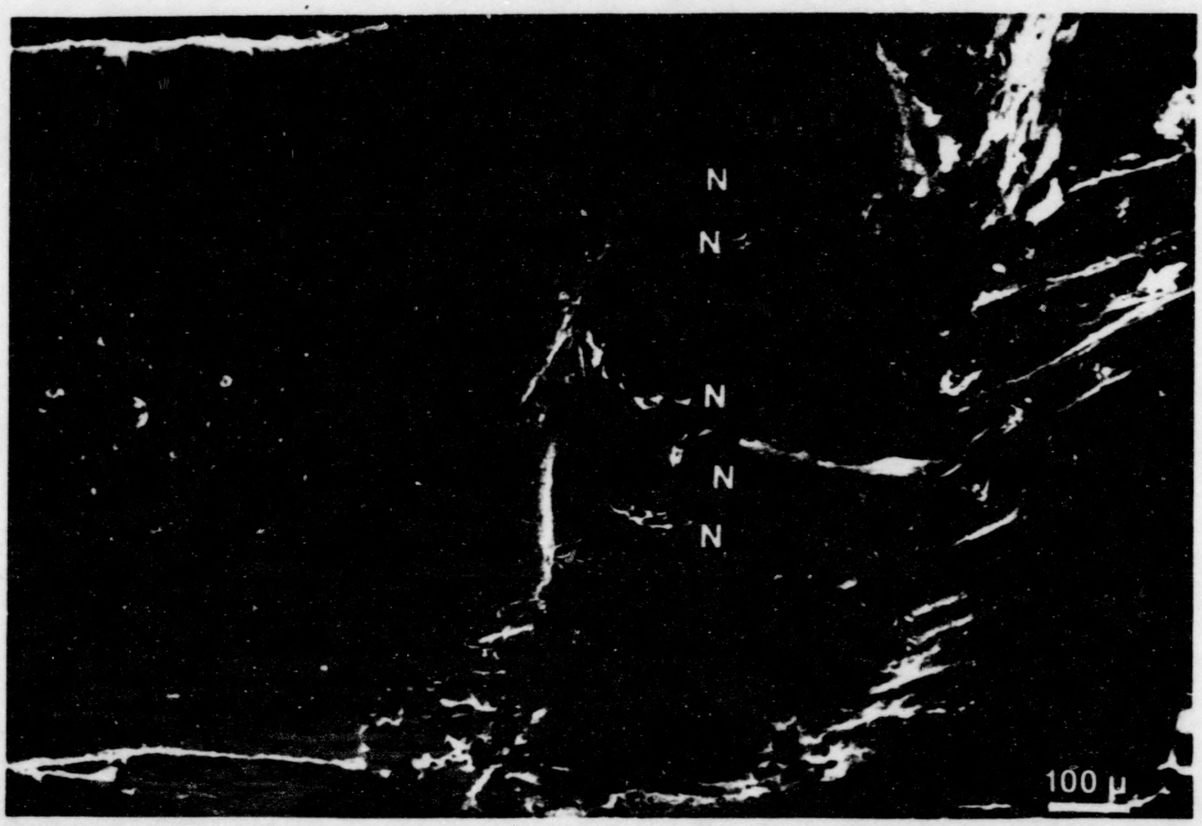

N
N
N
N
N
100 μ

Figure 20. Lateral view of the head of spotted bass (15 mm TL) showing developing pores of the POM lateral line canal (45X).
P = pores of the POM canal

Figure 21. Ventral view of posterior dentary bone of spotted bass (15 mm TL) showing development of pores of the mandibular lateral line canal (80X). Inset shows fully developed free neuromasts along-side developing pores of mandibular lateral line canal (800X).
P = pore of the mandibular lateral line canal
N = free neuromasts


P
P
P
P
N
N
100 μ

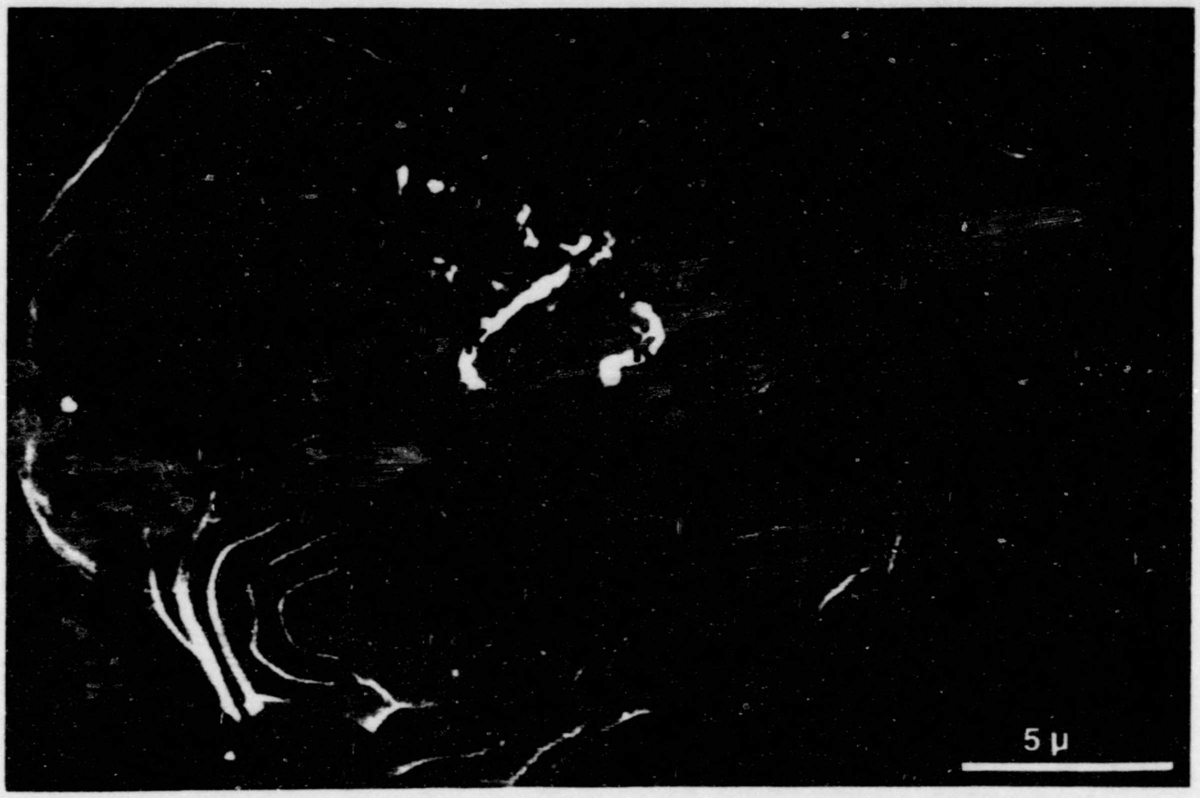
Figure 22. Detail of a free neuromast of spotted bass (15 mm TL) (5000X). Well developed kinocilia are shown.

K = kinocilia

Figure 23. Ventral view of the head of spotted bass (18 mm TL) showing hyoid region with developing pores of the anterior mandibular lateral line canal and free neuromasts (150X).

P = pores of anterior mandibular lateral line canal

N = free neuromasts


5 µ


N
N
P

Figure 24. Lateral view of the left side of the caudal peduncle and hypural plate of spotted bass (20 mm TL) showing continued presence of the free neuromasts along the trunk lateral line (80X).

N = free neuromasts

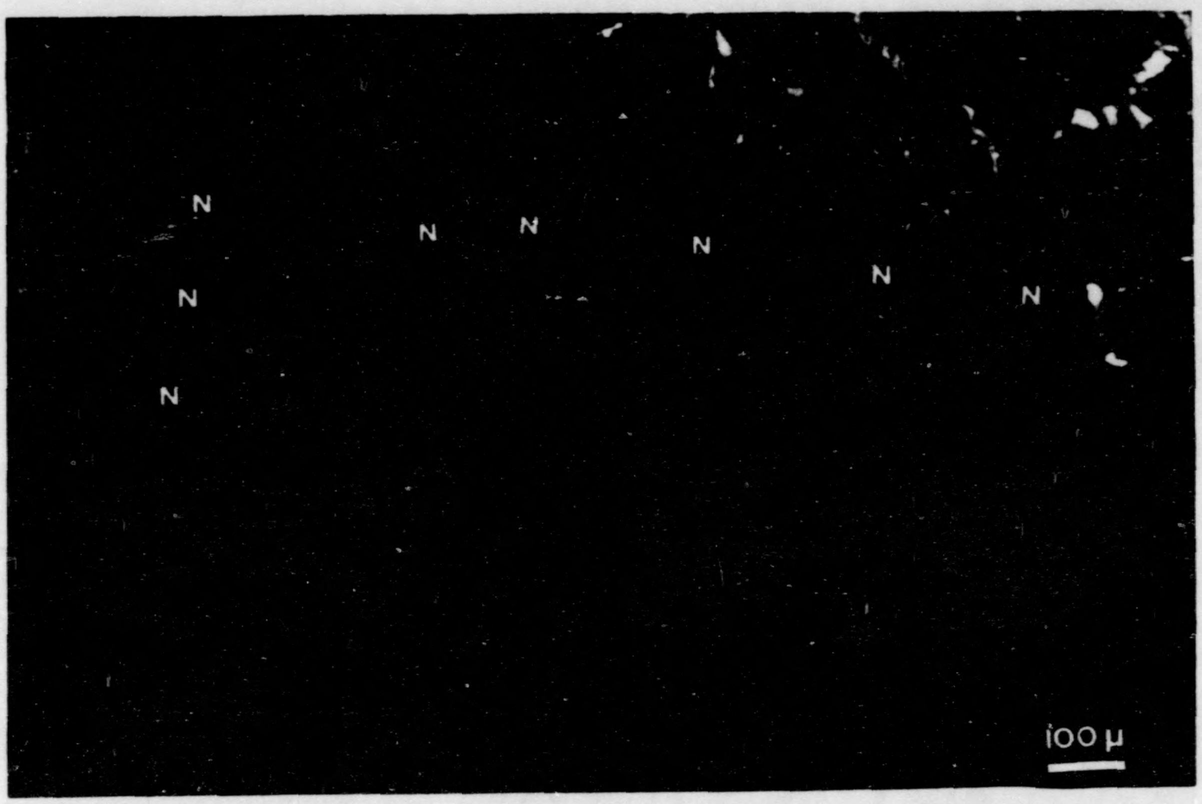
Figure 25. Ventro-lateral view of the head of the northern hog sucker (14 mm TL) (110X).

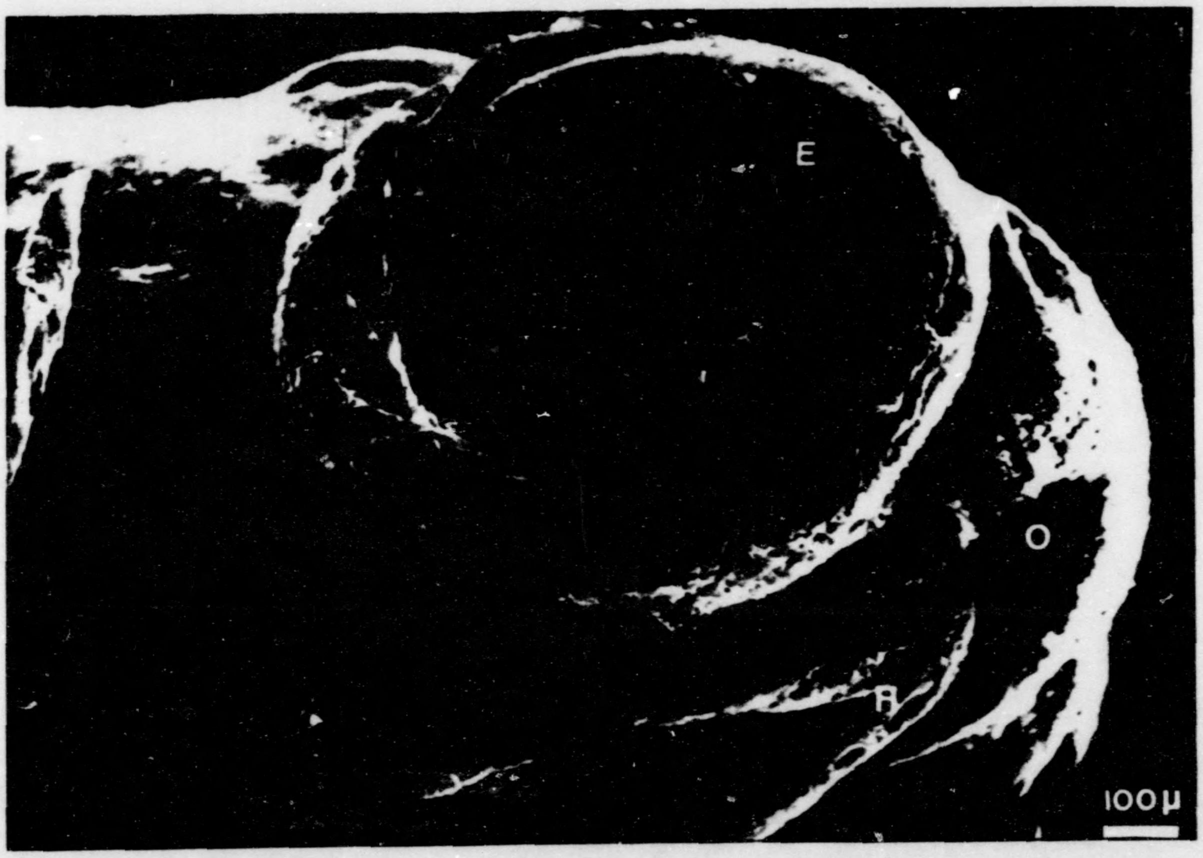
E = eye

P = pectoral fin

H = hyoid region

O = oral cavity


N
N
N
N
N
N
N
N
100 μ


E
O
R
100 μ

TL which was the maximum length for this stage.

Northern Hog Sucker Mesolarvae

The antero-lateral view of a spotted bass mesolarva (14 mm TL) is shown in Figure 25. Receptor organs were observed in mesolarvae of 14 mm TL. Free neuromasts were observed on the hyoid region at the anterior end of the mandibular portion of the POM line (Figure 26). Taste buds appeared on the outer surface of the lower lip (Figure 27). By 18 mm TL, all cephalic free neuromast lines were completely developed. The development of the taste buds extended onto the surface of the tongue (Figure 28), on the hyoid region (Figure 29), and on the inside surface of the lower lip (Figure 30).

Northern Hog Sucker Metalarvae

At 20 mm TL, free neuromasts of the trunk lateral line appeared (Figure 31), while the free neuromasts of the cephalic lines persisted showing full development (Figure 32). At 23 mm TL, the trunk and cephalic lateral line canals had not appeared.

Jaw Development

Skeletal elements of the maxillary, mandibular and hyoid regions of the skull were examined. The time of appearance and pattern of spatial development of the following bones were outlined: maxillary, premaxillary, palatine, parasphenoid, metapterygoid, hyomandibular, dentary, articular, angular,

Figure 26. Ventral view of the head of the northern hog sucker (14 mm TL) showing the hyoid region (110X). Inset shows detail of developing free neuromast at anterior end of the mandibular line (1100X).

N = free neuromast

Figure 27. Ventral view of the head of northern hog sucker (14 mm TL) showing taste buds on the lower lip (750X).

B = taste buds

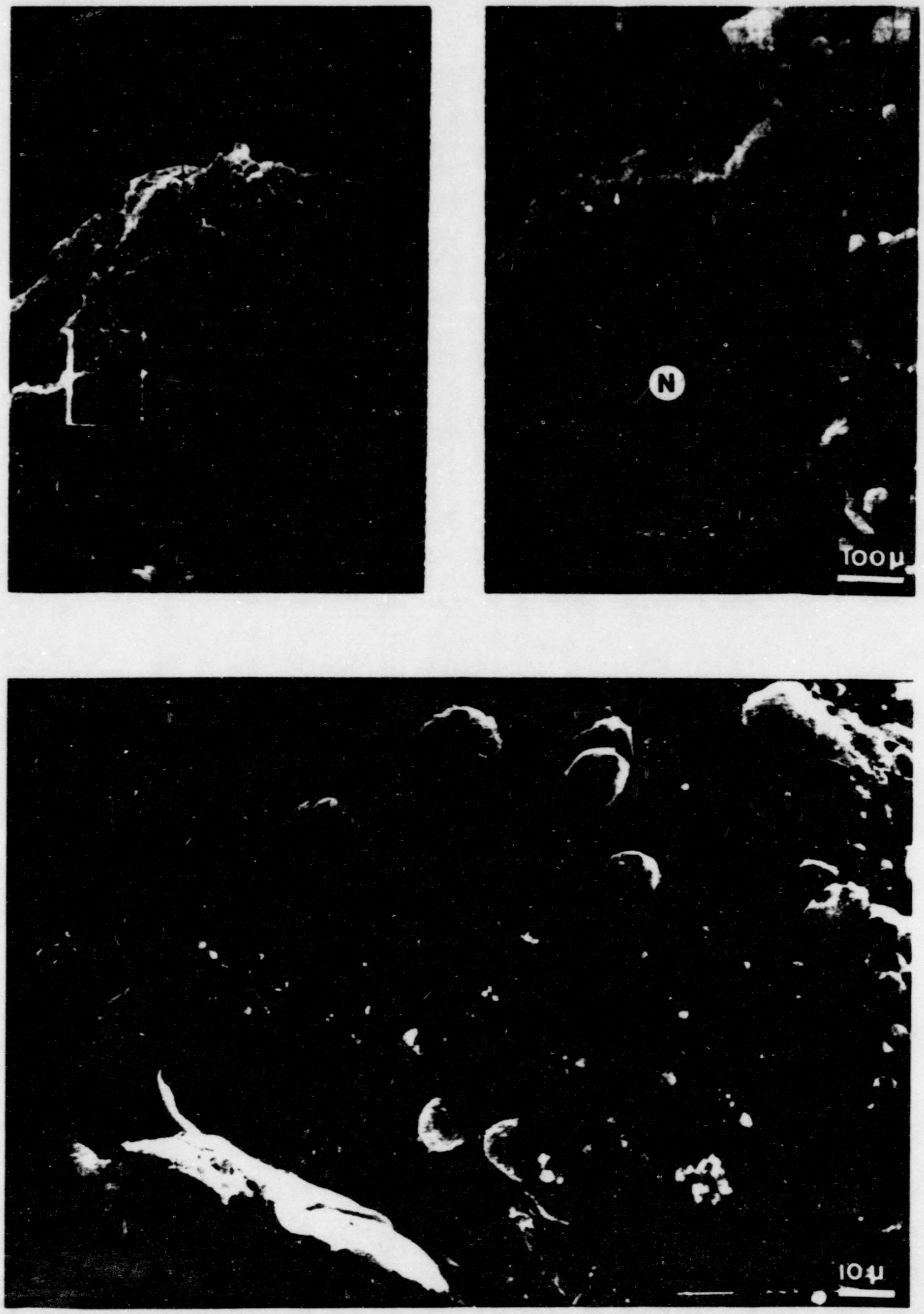

N
100μ
10μ

Figure 28. Ventral view of the oral cavity of the northern hog sucker (18 mm TL) showing the lower jaw and the tongue (150X). Inset shows detail of taste buds on the tongue (750X).

T = tongue

L = lower jaw

B = taste buds

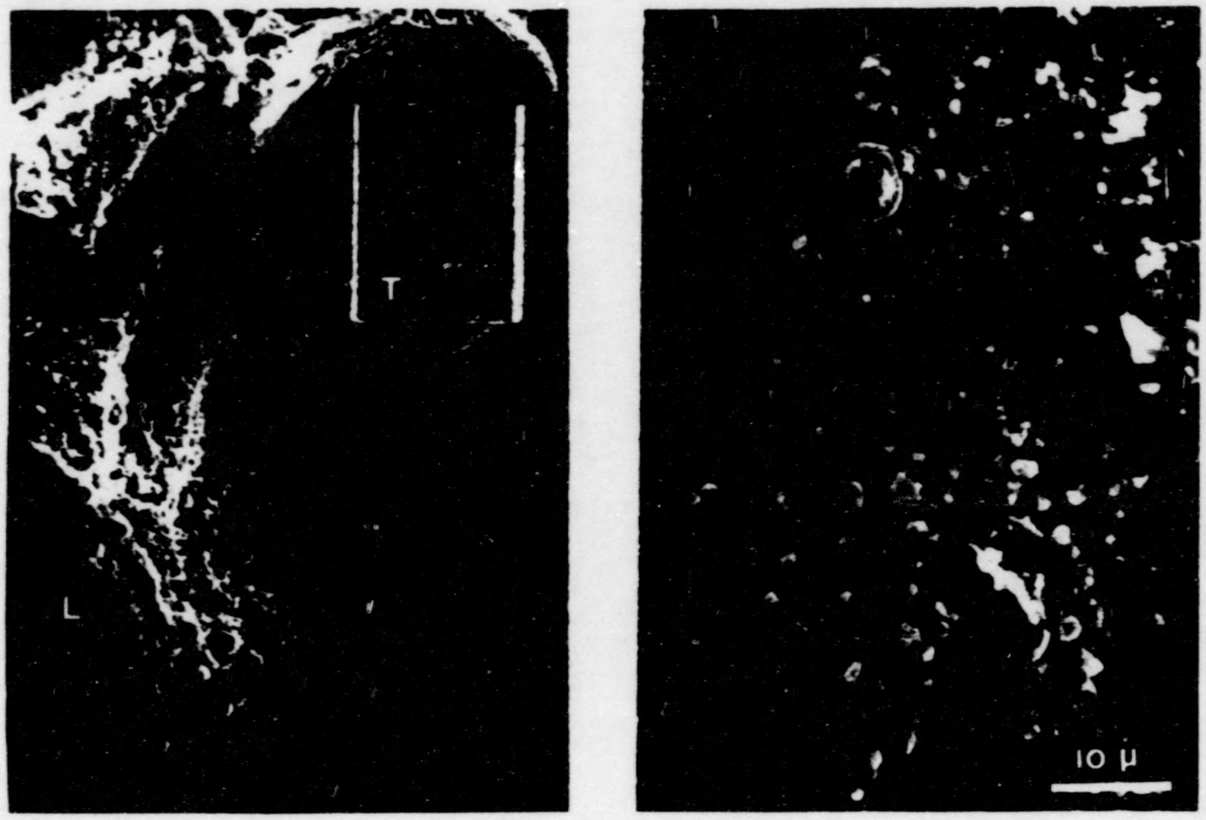

T
L
10 µ

Figure 29. Ventral view of the head of northern hog sucker (18 mm TL) showing the hyoid region (200X). Inset shows detail of developing taste bud (2000X).

B = taste bud

Figure 30. Ventral view of the oral cavity of the northern hog sucker (18 mm TL) showing the lower jaw and tongue (150X). Inset shows detail of the taste buds on the lower lip (750X).

T = tongue

L = lower jaw

B = taste bud

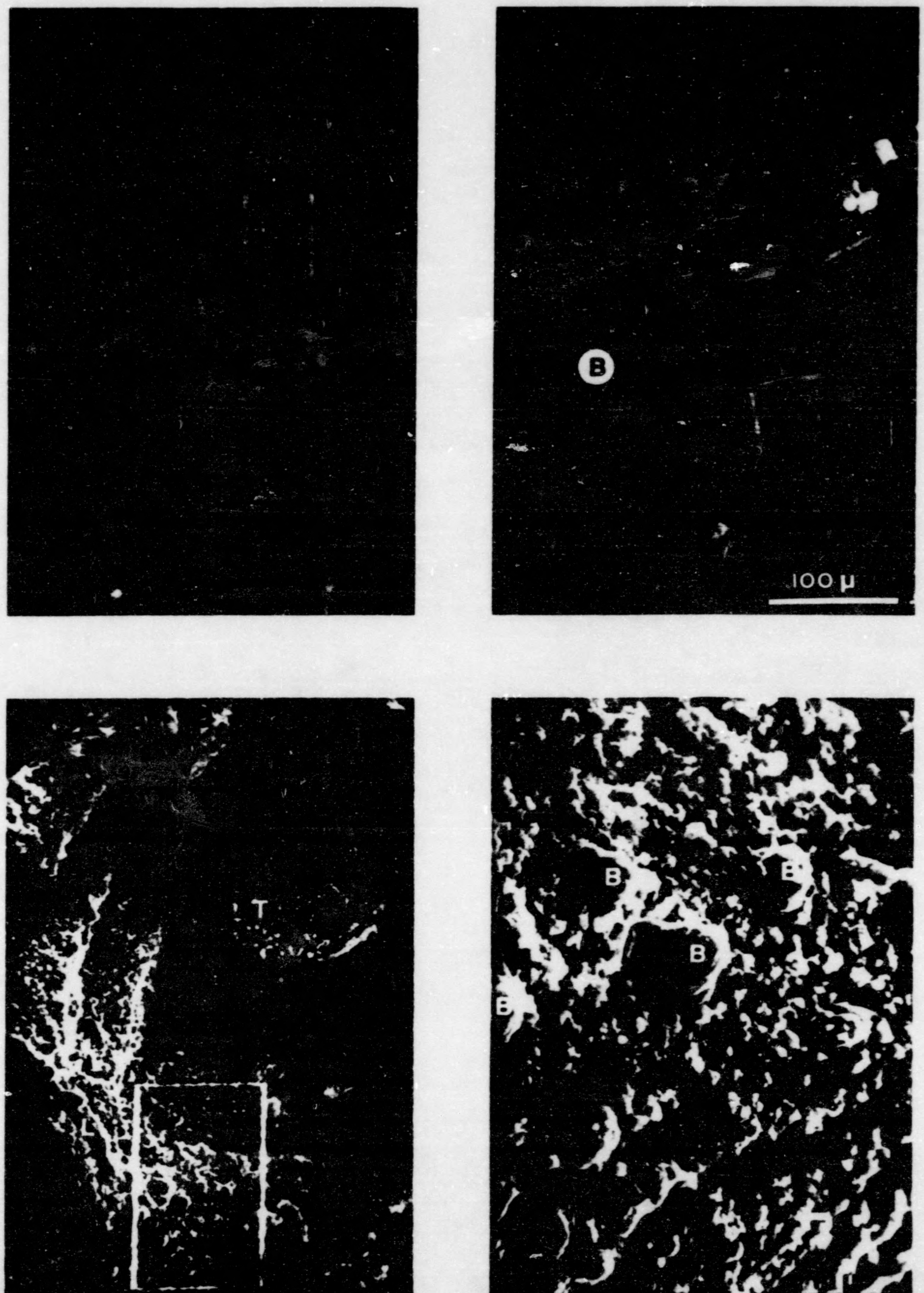
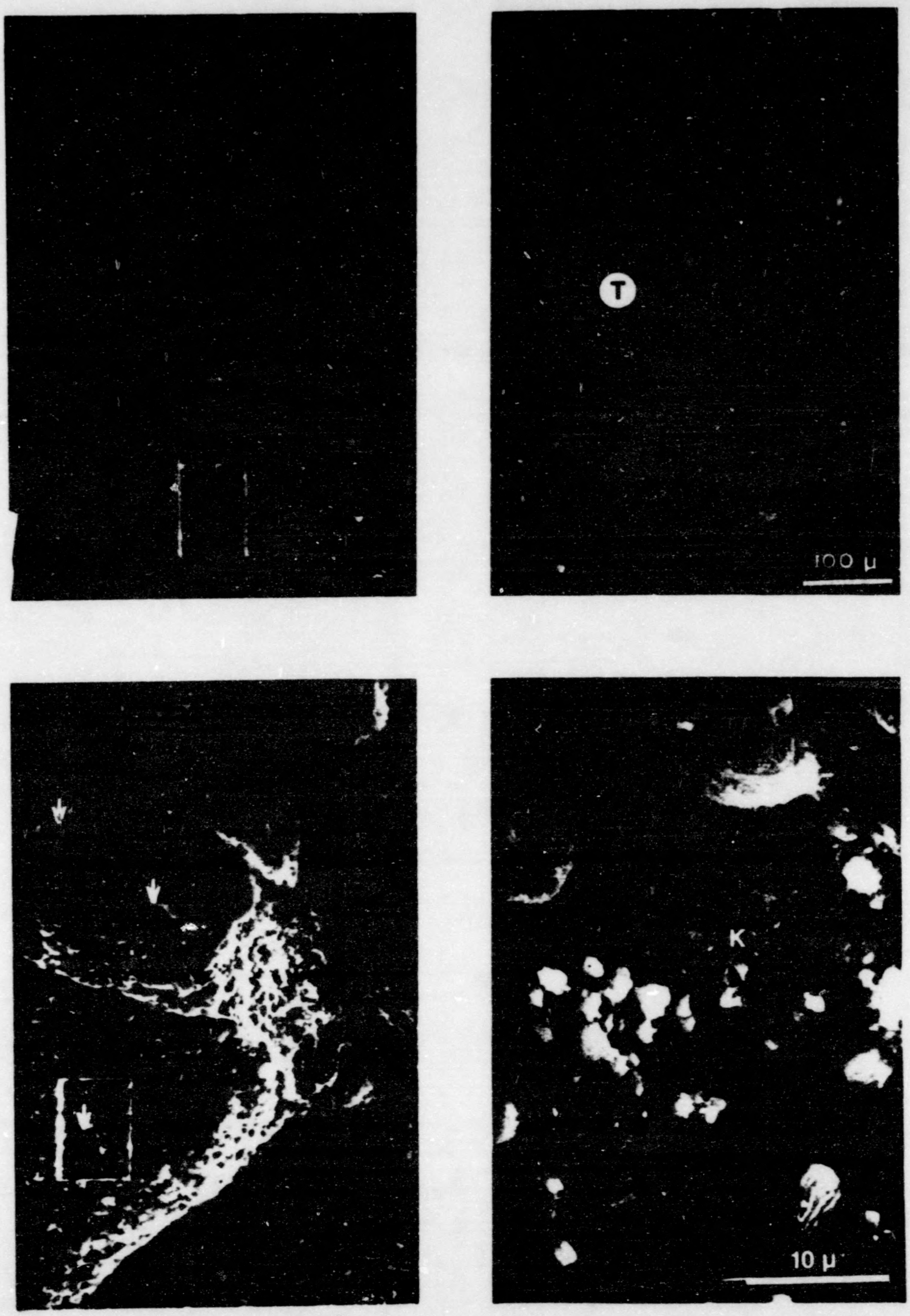

B
100 μ
T
B
B
B
B

Figure 31. Lateral view of the caudal peduncle of northern hog sucker (20 mm TL) (160X). Inset shows free neuromast developing along the trunk lateral line (1600X).

T = free neuromast

Figure 32. Ventral view of the head of northern hog sucker (20 mm TL) showing the hyoid region (230X). Inset shows detailed view of the free neuromast of the mandibular line (2300X).

K = Kinocilia


T
100 µ
K
10 µ

quadrate, symplectic, basihyal, hypohyal, ceratohyal, epihyal and interhyal.

Spotted Bass

The smallest specimen studied was a 7 mm TL mesolarva. At this stage, most of the elements of the jaw apparatus were developed to some degree with marked fusion of some elements such as the quadrate-metapterygoid and the angular-articular (Figure 33a). Although present, most elements were small and not fully outlined. Some, such as the quadrate-metapterygoid-symplectic complex, graded into a peripheral mass of cartilage which was in a stage of progressive dissolution following the cartilage replacement bone forming process (endochondral bone formation). Small elements, such as the interhyal and basihyal, were not evident at this early stage. Teeth were present in small numbers and in delicate condition in the anterior mid-region of the dentary bones only.

By 8 and 9 mm TL, tooth development was obvious on the premaxillary bones (Figure 34) and extended posteriorally along the dentaries. Articulation of the elements was complete by the mesolarval stage, specifically the quadrate-angular and hyomandibular-symplectic-interhyal complex.

Northern Hog Sucker

The smallest specimen studied was a 7 mm TL prolarva (Figure 36a). At this stage most of the elements of the mandibular and hyoid regions were developed to some degree

Figure 33a. Lateral view of the mandibular and hyoid region bones of spotted bass mesolarva (7 mm TL).

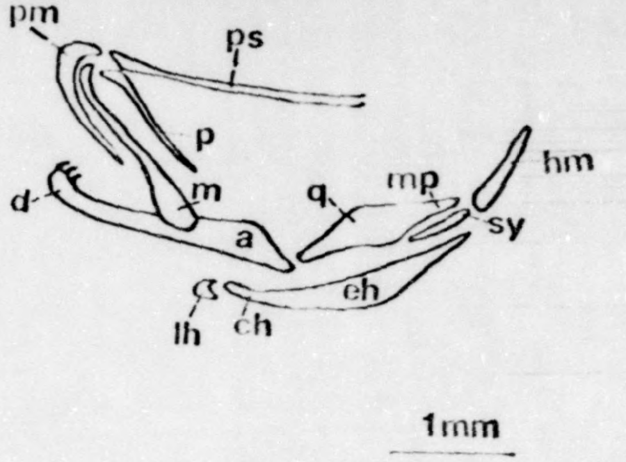
a = articular
ch = ceratohyal
d = dentary
eh = epihyal
hm = hyomandibular
lh = lower hypohyal
m = maxillary
mp = metapterygoid
p = palatine
pm = premaxillary
ps = parasphenoid
q = quadrate
sy = symplectic

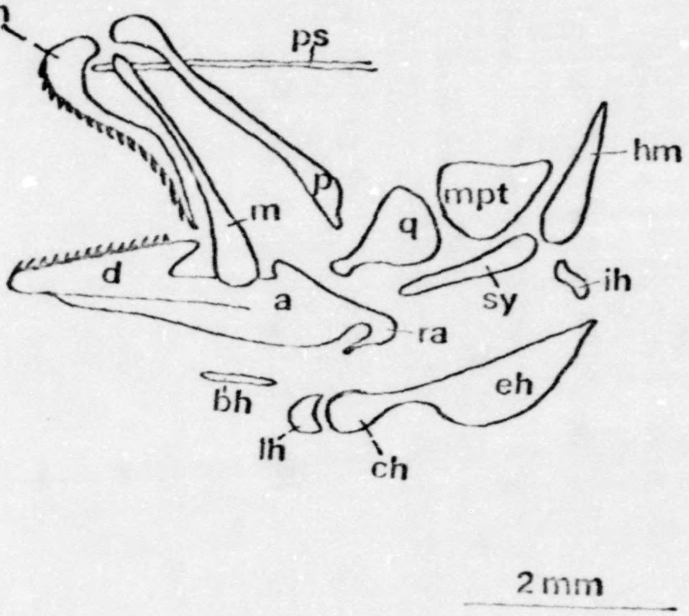
Figure 33b. Lateral view of the mandibular and hyoid region bones of spotted bass early metalarva (14 mm TL).

As above and
bh = basihyal
ih = interhyal
ra = angular

Figure 33c. Lateral view of the mandibular and hyoid region bones of spotted bass late metalarva (23 mm TL).

As above


pm
ps
p
hm
m
q
mp
d
sy
a
eh
lh
ch
1mm


pm
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ih
a
sy
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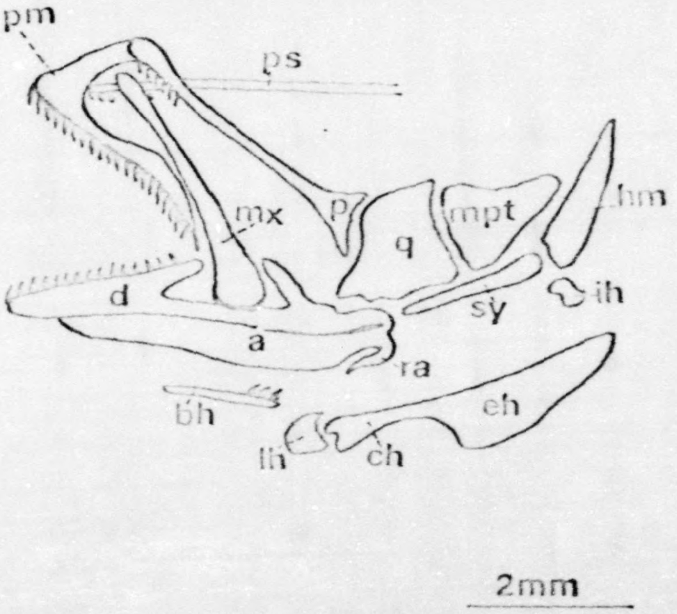
bh
lh
ch
2mm


pm
ps
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mpt
hm
mx
q
d
ih
sy
a
ra
eh
bh
lh
ch
2mm

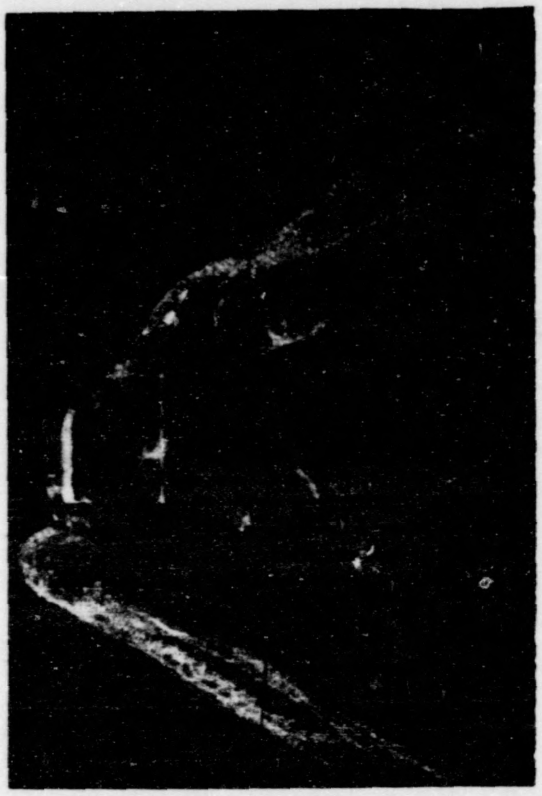
Figure 34. Antero-lateral view of head of spotted bass (9 mm TL) showing jaw configuration (110X). Inset shows development of teeth on premaxillary bones (1100X).

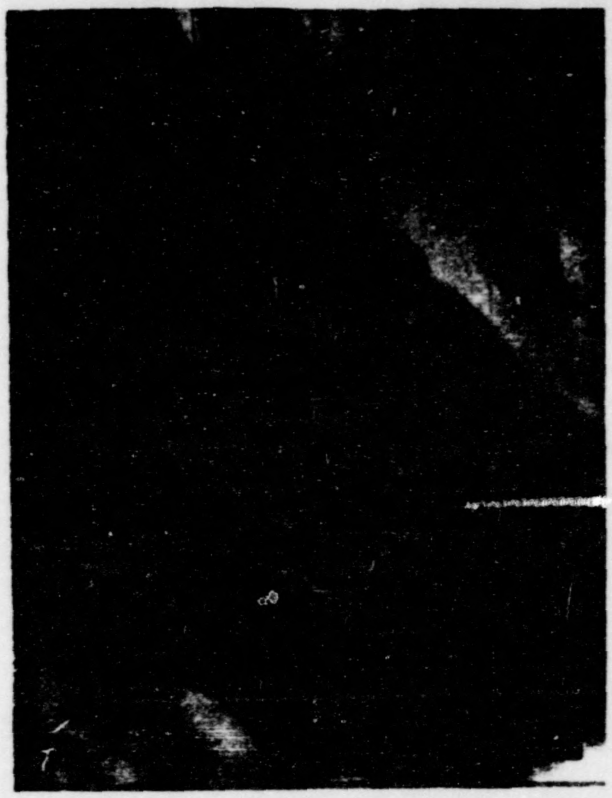
T = developing teeth

Figure 35. Postero-dorsal view of the tongue of spotted bass (20 mm TL) showing tooth development (1100X).

T = tooth

B = taste bud






B
T
B
10 μ

Figure 36a. Lateral view of the mandibular and hyoid region bones of the northern hog sucker prolarva (7 mm TL).

a = articular

ch = ceratohyal

d = dentary

eh = epihyal

hm = hyomandibular

m = maxillary

mp = metapterygoid

ps = parasphenoid

q = quadrate

s = symplectic

bh = basihyal

ih = interhyal

Figure 36b. Lateral view of the mandibular and hyoid region bones of the northern hog sucker metalarva (23 mm TL).

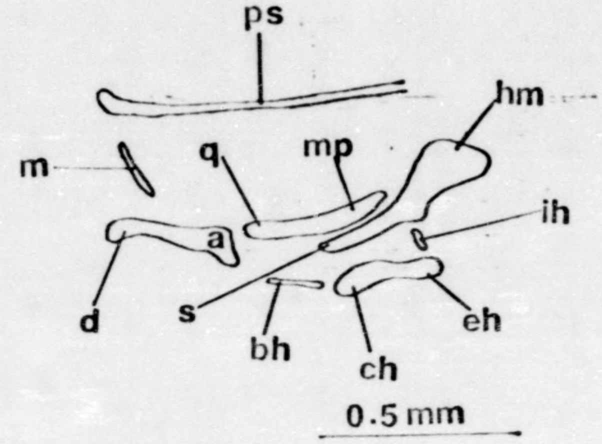
As above and

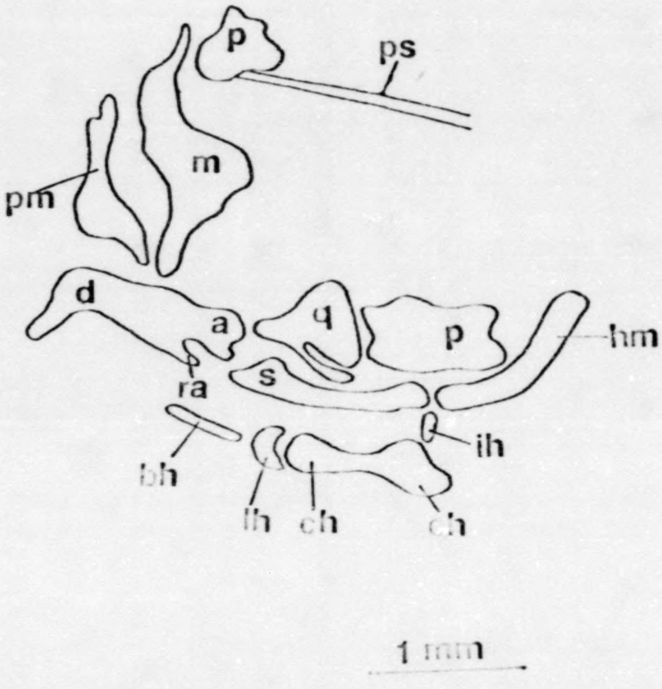
lh = lower hypohyal

p = palatine

pm = premaxillary

ra = angular


ps
hm
m
q
mp
ih
a
d
s
bh
ch
eh
0.5 mm


p
ps
m
pm
d
a
q
p
hm
ra
s
ih
bh
ch
1 mm

with marked fusion of certain elements such as the quadrate-metapterygoid, angular-articular, symplectic-hyomandibular and ceratohyal-lower hypohyal. The palatine bone was not evident. In the maxillary region separate premaxillary and maxillary bones were not observed; instead, a small mass of cartilage was present in that area.

At the time of stanza change from pro- to mesolarva, 11-12 mm TL, all elements started appearing with total completion at the metalarval stage (Figure 36b). All the future bones were present with the appearance of the maxillary, premaxillary, palatine and lower hypohyal at 12 mm TL mesolarvae.

Articulation of the elements was complete by the mesolarval stage, specifically the quadrate-angular and hyomandibular-symplectic-interhyal complex.

DISCUSSION

The attainment of a successful foothold in life by any organism is determined by the time involved in the development of those neural receptor organs and behavior patterns which will convey competitive success. Nowhere is this observation more important than in larval fish. Two specific receptor organs that are widespread in distribution over the body of fishes and extremely important in the early life history stages of most fishes are neuromast organs and taste buds. While these organs have been extensively studied and described in adult fishes, little has been reported on their time of appearance and functional importance in larval fishes.

Neuromasts may be of two types depending upon the species or the time of the life cycle: free neuromasts on the surface of or in pits in the skin or those in bony canals or grooves of the head and body (Bond 1970). Most generalized neuromasts are oval shaped (van Bergeijk and Alexander 1962) with free neuromasts being smaller than canal organs (Hoyt 1969, Rosen and Mendelson 1960). Neuromast systems are variously developed on different species and used in a number of ways such as rheotaxis, detecting objects or displacements, locating food items, identifying physical structures (Moyle and Cech 1982) and schooling behavior (Cahn et al. 1965).

Neuromasts typically consist of two layers of cells: a dorsal, centrally located layer of sensory or innervated cells and a ventral layer of central, supporting or sustentacular cells with a peripheral ring of mantle cells (Hoyt 1969). The sensory cells are separable on the basis of the types of cilia they support: those having long hair-like kinocilia and those having short, robust stereocilia (Flock 1965; Hamma and Yamada 1977; Lane and Whitear 1982). These cilia are embedded in the base of a large mucoid body, the cupula, which rests on the sensory cells in the center of the organ. This cupula is said to be secreted by the supporting or sustentacular cells and serves to amplify the stimuli to the sensory cells (Petraitis 1966, Dijkgraaf 1962, Iwai 1967).

The pattern of neuromast development in the spotted bass and northern hog sucker, free neuromasts preceding canal organs and appearing sequentially in the various series, has been reported for other species such as _Menidia beryllina_ and _M. menidia_ (Cahn et al. 1965) and _Oryzias latipes_ (Iwai 1967). However, fish species differ according to the time of formation of neuromasts and the formation of the cupula (Iwai 1963a,1963b,1964,1965,1967; Thomopoulos 1957; Cahn and Shaw 1962). For example, many marine fishes have fully developed cupulae at the time of hatching and exhibit immediate darting and swimming movements; however, most freshwater species do not develop cupulae until sometime after hatching and at different larval stages according to the species (Iwai 1967). This observation was made in the present study with free neuromast development and the appearance of the canal lateral line system in the spotted bass preceding that of the northern hog sucker. Early life histories of the spotted bass and northern hog sucker have been described by Floyd (1983) and Timbrook (1983). The spotted bass was reported to be spawned in vegetated shoreline areas, subsequently spending its entire larval stage therein. Its feeding history included a wide variety of small food types as a mesolarva with a reduction to fewer, larger forms as a metalarva. Northern hog suckers were reported to be spawned in areas influenced by a current with subsequent migration to rocky, quiet shoreline areas after hatching. The feeding history of this species included little feeding as prolarvae but great diversity in food types as both meso- and metalarvae. The observation of early habitat partitioning by the two species (Floyd 1983) might be related to the earlier development and completion of the free neuromast series and appearance of the canal organ system in the spotted bass. Moyle and Cech (1982) generalized that, as a rule, the more active fishes have a greater percentage of canal neuromasts than the more sedate species. The canals tend to serve a protective function against the constantly moving external environment.

The lines or series of free neuromasts observed on the two species in this study were generally similar to the future canal series of organs as reported by Branson and Moore (1962). The time of appearance of the fully developed free neuromast lines in the spotted bass corresponded to the end of the mesolarval period. At that time, the bass larvae changed dietary habits from the ingestion of small zooplankters to larger prey, including larvae of other fish species (Timbrook 1983). This advanced predaceous feeding habit as metalarvae was supported by the appearance of certain components of the cephalic lateral line system. In the northern hog sucker, the completion of the free neuromast lines also corresponded to the end of the mesolarval stage, but at a later period or larger size than that observed for the spotted bass. However, with the change from meso- to metalarva, the composition of the diet did not change in taxa consumed but rather in numbers and size of organisms ingested. No developing cephalic lateral line canals were observed in any hog suckers examined in this study, thereby precluding any major conclusions about ecological changes on the part of the species with its development.

In this study the fate of the free neuromasts could not be determined since canal organs, specifically in the case of the spotted bass, were just developing and the free neuromasts were still functional. In the early life stages of fish, free neuromasts with cupulae are present (Cahn and Shaw 1962; Thomopoulos 1957; Iwai 1963a,1963b,1964,1965,1967) and later a number of them change into canal organs related to scales on the trunk and specific bone structures on the head region (Harrington 1955). The cephalic lateral line canals appeared on the spotted bass at 12 mm TL during the mesolarval stage. Hoss and Baxter (1982) documented the first appearance of the cephalic lateral line at a TL of 17 mm on the Atlantic menhaden, Brevoortia tyrannus. Baxter and Denton (1976) reported that the lateral line developed between 19 and 45 mm TL on the herring, Clupea harengus. According to Flock (1967), where canal organs occur free neuromasts are still present along the canals. Branson and Moore (1962) reported six free neuromasts persisting along the ventral opercular line on adult spotted bass.

Fish are unique among the vertebrates in that some of them have many external taste buds. Gustatory chemoreception is a close range sense in most of the fish species, and it is very important for the identification of food items and noxious substances (Moyle and Cech 1982).

Taste buds have a structure similar to free neuromasts but lack cupulae, and the sensory cells have microvilli instead of cilia (Trujillo-Cenoz 1961; Storch and Welsch 1970; Kapoor et al. 1975). Taste buds, like free neuromasts, are distributed on the surface of the head and body as well as throughout the oropharyngeal cavity (Whitear 1971; Ezeasor 1982). Their distribution patterns differ depending on the feeding habits of the species. There are basically three types of taste buds on fishes according to Reutter et al. (1974). Types I and II are placed on elevated epidermal papillae with Type I occupying the anterior oral cavity and Type II the posterior. Type III is never elevated and is present in the metabranchial region of the pharynx. It has been postulated by Reutter et al. (1974) that there is a functional difference among the types of taste buds with Types I and II being mechanoreceptors and chemoreceptors while Type III buds are only chemoreceptors. Ezeasor (1982) postulated a relationship between taste bud types and feeding habits.

Generally, the taste buds observed on the spotted bass and the northern hog sucker were of Types I and II. The time of appearance, their numbers and their distribution did not correspond to any major changes in the feeding habits of the two species except for two important observations. In the spotted bass, two taste buds of Type III appeared on the middle of the tongue surface in association with teeth, as opposed to information reported by Reutter et al. (1974), and corresponded with the metalarval stage and the onset of piscivory. In the northern hog sucker the taste buds appeared on the hyoid region and the outer surface of the lower lip indicating that this organism will develop into a bottom feeding adult.

Structures in the oropharyngeal cavity correlate with food type and feeding habits (Moyle and Cech 1982). Gregory (1959) emphasized the modification of jaw bones according to the type of feeding mode and food items consumed by different fish species. Modifications condition the size, position and direction of the mouth itself. Gregory (1959) and Hobson and Chess (1976) also noted individual development changes between earlier and later larval stages. Many piscivorous fishes, such as the spotted bass, possess firm jaws lined with sharp teeth. In the northern hog sucker the jaws are modified for suction feeding. The jaws are shortened to make the gape smaller while the oropharyngeal expandibility is maintained (Moyle and Cech 1982). This mouth type is typical for bottom feeders like suckers (Lagler et al. 1977).

The importance of the development of the jaws, mandible and hyoid bones in spotted bass, was shown by a) the completion of the articulation of quadrate-angular, b) the appearance of the interhyal bone, c) the completion of the support of the lower jaw, and d) the appearance of the complete series of teeth on all teeth bearing bones. Most of the above occurred during the mesolarval stage and were completed in the metalarval stage. These events were concurrent with major changes in feeding habits, including the consumption of larger food items and the initiation of piscivory. In the case of the northern hog sucker the most important change was the development of functional mouthparts at the beginning of the mesolarval stage, the time of the onset of exogenous feeding (Timbrook 1983). This was in agreement with the findings of Buynak and Mohr (1978), who noted incomplete mouthparts in prolarvae of northern hog sucker, and of Fuiman (1979), who reported functional mouthparts in a terminal position in 13.3 mm TL mesolarvae. The diversity of the diet during the meso- and metalarval stages could not be explained by this study since the developing mouthparts did not have teeth or other features supporting the predaceous tendency observed by Timbrook (1983). A possible explanation might be a strong suction force produced by the relationship between the protractile properties of the jaw apparatus, the interlocking upper and lower jaws (Edwards 1926), and the force produced by the branchial pump of respiration.

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