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Epidemiology of Ulcerative Mycosis in Atlantic Menhaden in the Tar–Pamlico River Estuary, North Carolina

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Abstract.—Ulcerative mycosis was observed on Atlantic menhaden *Brevoortia tyrannus* collected in pound-net and trawl samples obtained from the Tar–Pamlico River estuary, North Carolina, during May 1985–April 1987 and in cast-net samples obtained during October–November 1986. The disease was most prevalent on Atlantic menhaden caught in pound nets during November 1986 and January 1987, and in trawls during May 1986 and November 1986. Disease was also most prevalent among yearlings in the spring and was probably acquired in the estuary.

Ulcerative mycosis (UM) is a cutaneous malady of Atlantic menhaden *Brevoortia tyrannus* (Noga and Dykstra 1986). The disease was identified as a distinct clinical entity affecting estuarine finfish in 1984. During the summer of that year, epidemics of an ulcerative disease were reported in the Tar–Pamlico River estuary, North Carolina, and the Rappahannock River, Virginia (Hargis 1985; Noga and Dykstra 1986). Atlantic menhaden with similar lesions were also observed in the St. Johns River, Florida, during fall 1984 (Te Strake and Lim 1987). Extensive fish kills have been associated with the disease (Noga and Dykstra 1986).

Atlantic menhaden affected with UM develop focal ulcers that often penetrate deep into the abdominal cavity (Noga and Dykstra 1986; Noga et al. 1988). The lesions are typically circumscribed and singular with a red margin. At least two genera of oomycete fungi, *Aphanomyces* spp. and *Saprolegnia* spp., have been associated with the development of UM (Dykstra et al. 1986; Noga and Dykstra 1986). Fungal hyphae have been routinely observed in scrapings obtained from UM ulcers (Dykstra et al. 1986) and in granulomas present in histopathologic sections of affected tissues (Noga et al. 1988).

Although UM is now recognized as a regional problem in mid- and south Atlantic estuaries (Dykstra et al. 1989), little is known about the dynamics of the disease in Atlantic menhaden populations. In this paper, we describe the occurrence of the disease among Atlantic menhaden collected during an estuarine disease survey conducted in the Tar–Pamlico River estuary.

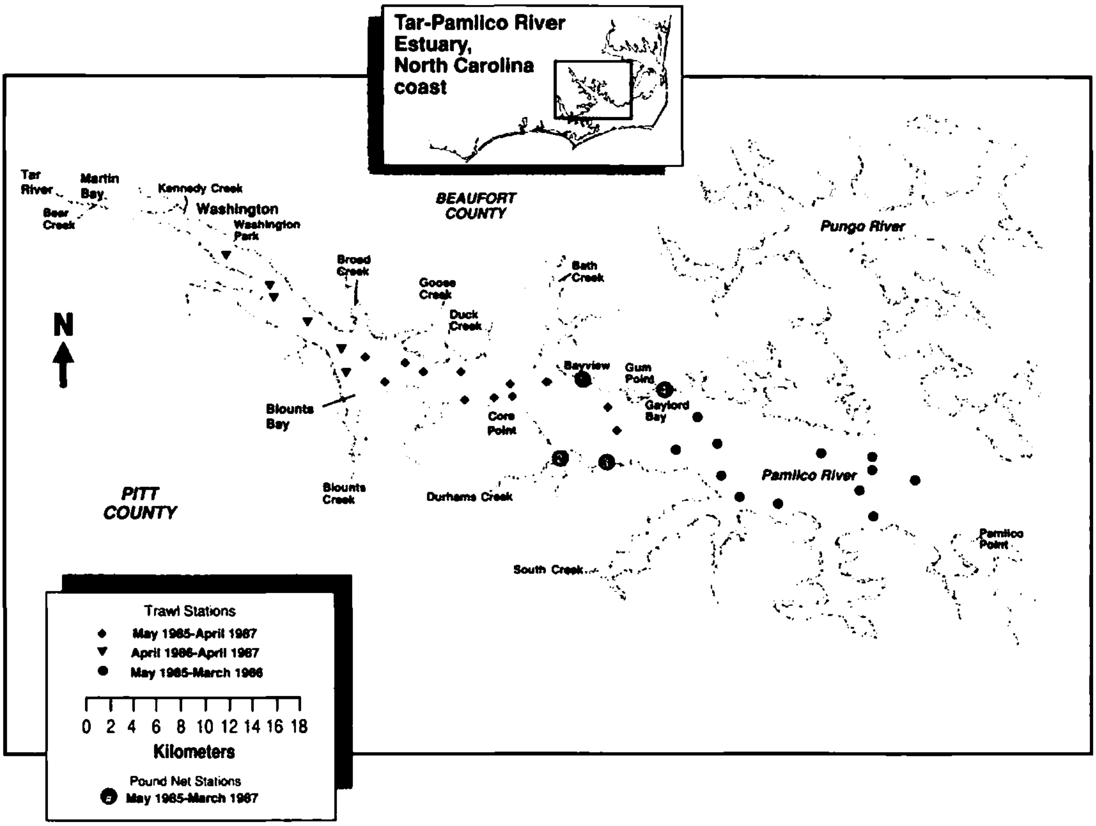


FIGURE 1.—Trawl and pound-net sampling sites in the Tar–Pamlico River estuary.

Methods

Pound-net and trawl surveys were conducted to document the occurrence of UM in estuarine finfishes in the Tar–Pamlico River estuary during May 1985–April 1987. Estuarine fish were collected at four pound-net sites located at the midsection of the Pamlico river (Figure 1; Levine et al. 1990). The nets were set perpendicular to the shore and were nonselective for estuarine finfish species longer than 70 mm fork length (FL). Sampling was attempted biweekly, but was not continuous. Individual nets were unavailable at various times during the study due to structural damage, severe weather conditions, or equipment failure. The nets were emptied the day before sampling, and a 24-h sample was obtained the following day. Because fish tended to stratify in the net, subsamples were obtained from the top, middle, and bottom of the net and pooled for analysis.

Trawls were conducted at 24 sites from Blounts Bay to Pamlico Point during May 1985–March 1986 (Figure 1; Levine et al. 1990). The stations were randomly selected from 300 0.8-km^2 grids and represented a variety of river habitats. Climatological conditions altered the salinity regime and distribution of Atlantic menhaden in the estuary in 1986. Accordingly, the sampling regime was shifted during the spring of 1986 into the upper part of the river to accommodate the movement of fish. During April 1986–April 1987, sampling was conducted from Washington Park to Gum Point after upstream sampling sites were added and the number of stations was reduced from 24 to 18 due to labor constraints. Gear- or weather-related problems sometimes limited sampling of individual stations. Trawls were pulled at a speed of 75 m/min for 10 min. A crab trawl with 10.2-cm-stretched-mesh wings and a 3.8-cm-stretched-mesh tailbag was used during May–June 1985. However, after a series of gear comparisons were conducted in July 1986, a three-seam net that maximized our ability to collect Atlantic menhaden was selected for the remainder of the study. The net had a 6.1-m-long headrope and 3.8-cm-stretched-mesh wings and tailbag, and fished 2.7 m of water. Trawling was initially conducted during the day (May 1985–January 1986), but a comparison of day and night trawls conducted during February 1986 documented that more Atlantic menhaden could be collected after dusk. Therefore, nocturnal trawling was used during the latter part of the study (March 1986–April 1987).

Fish collected by both gears were examined for lesions characteristic of UM. The lesions were checked microscopically, and the presence or absence of fungal hyphae in the lesions was noted. Ulcers containing fungal hyphae were considered compatible with a diagnosis of UM (Dykstra et al. 1986). The weight (g) and length (FL, mm) of 30–100 specimens were recorded to estimate the size distribution of those predominately affected by the disease (Levine et al. 1990).

Atypically elevated salinities resulting from an extended drought during summer and fall 1986 facilitated the movement of Atlantic menhaden into the Tar River and numerous small tributaries of the Pamlico River above our sample sites. Laboratory studies previously documented that a fungus associated with the lesions grew optimally in salinities between 2 and 8‰ (Dykstra et al. 1986). Accordingly, we extended the range of our survey into these tributaries during October–November 1986 to determine if fish were affected in locations where the salinity was in the range that supported growth of our test fungus in the laboratory. A cast net was used in the tributaries because the water depth and bottom strata precluded the use of our trawl gear. Eleven sites between Whichard Beach and Martin Bay in the Tar River were sampled. Atlantic menhaden were located visually and collected with a 2.5-m-diameter nylon-mesh cast net thrown from a small workboat. The net was cast five times at each site. Collected specimens were weighed (g), measured (FL, mm), and examined for lesions. Lesions on fish collected during this cast-net survey were not examined for fungal hyphae, but were considered positive if they had the characteristic appearance of UM ulcers.

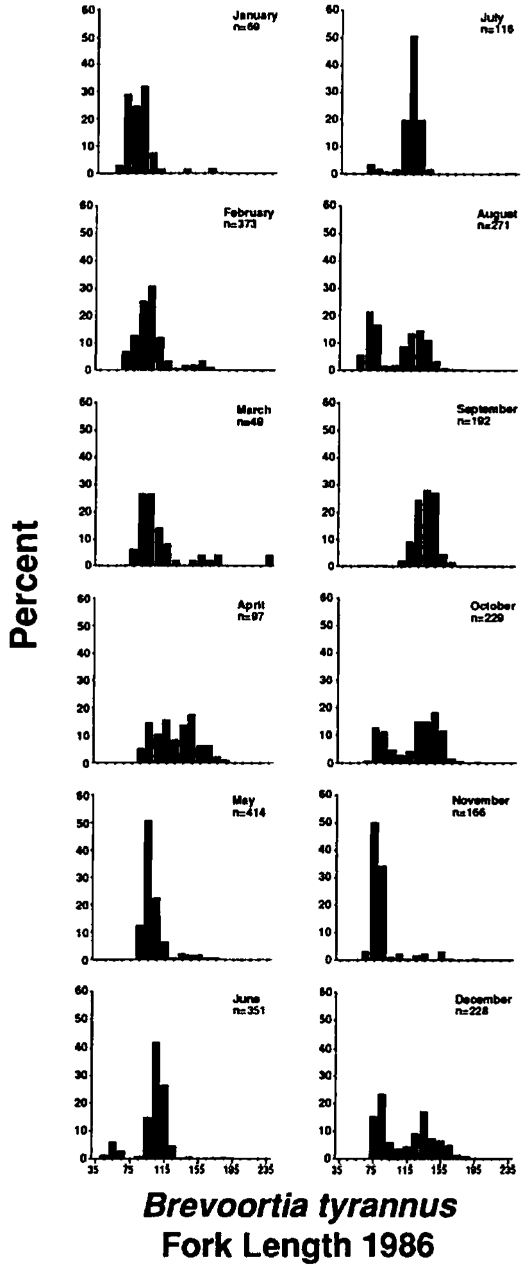


FIGURE 2.—Length frequencies (fork length, mm) of Atlantic menhaden collected in trawl samples during 1986 in the Tar–Pamlico River estuary; n = sample size.

Results

The majority of Atlantic menhaden collected in both pound nets and trawls were young-of-year (age-0) and age-1 fish. Atlantic menhaden ranged in size from 33 to 243 mm FL (mean, 104.7 mm; SD, 26.4 mm) in trawl samples. The length of fish collected in trawls during January–May 1986 (Figure 2) suggests movement of the previous year's spawn back into the estuary. In June, new recruits were present, resulting in a bimodal length distribution. Although similar trends were observed during 1985, relatively few fish were collected during spring 1985, precluding reasonable comparison with the 1986 catch. Atlantic menhaden collected in pound nets ranged in size from 42 to 244

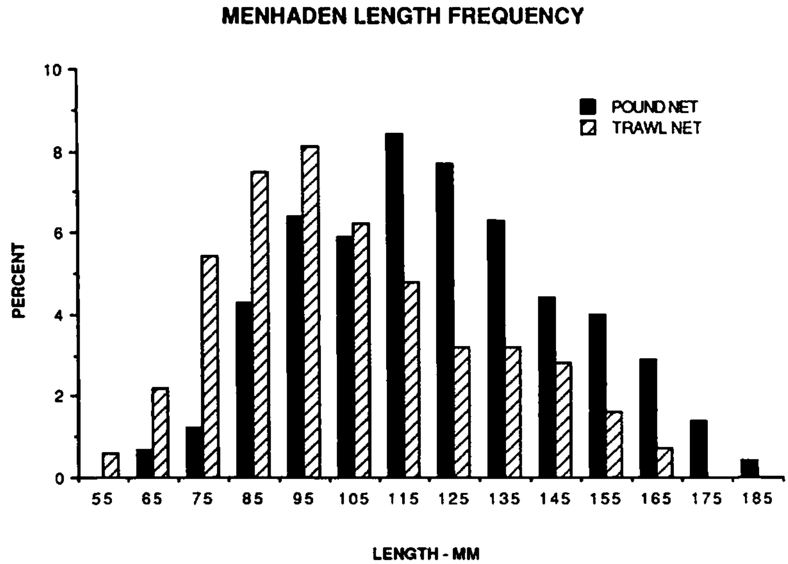


FIGURE 3.—Length frequencies (fork length) of Atlantic menhaden collected in trawl and pound-net samples during May 1985–April 1987 in the Tar-Pamlico River estuary.

mm FL and displayed the same bimodal length-frequency distribution observed in trawl samples. However, fish collected in pound nets were longer (mean length, 122.7 mm; SD, 26.6 mm; Figure 3) than fish in trawl samples.

Ulcerative mycosis was most prevalent among Atlantic menhaden collected in trawl samples during April–May 1986, October–November 1986, and March 1987 (Figure 4), and in pound-net samples during November 1986 and January 1987 (Figure 5). The disease was also prevalent during May–June 1985, January–May 1986, and February 1987; however, few fish were collected during these periods. A small number (<1%) of Atlantic menhaden with UM were found at other times throughout the year. Age-0 fish were the most frequently affected (Figure 6).

During epidemics, the proportion of fish with lesions in individual pound-net and trawl samples was quite variable (Table 1). Although almost 19% of the fish collected in pound net two during November 1986 had UM, less than 2% in pound net one were affected. The proportion of affected fish in pound-net samples differed greatly from that observed in trawl samples (Table 1).

The relatively high percentages of UM-affected Atlantic menhaden observed in trawl and pound-net samples were also noted in the 2-month cast-net survey conducted during 1986 (Figure 7). Based on length data (Nicholson 1975), all affected fish were age-0 (Table 2). In October, the disease was more prevalent at cast-net sites (salinities, 2.5–9.6‰) than at sites sampled by trawl or pound net. Although lesions were observed on 31% (N = 187) of fish collected at trawl stations in the upper part of the system west of Goose Creek (salinities, 6.2–13.5‰; Figure 1), no lesions were observed on fish (N = 40) collected by trawling east of the creek (salinities, 13.5–15.7‰). Only two (0.4%) affected fish were observed in pound-net samples (salinities, 15.3–21.4‰). In November, although few fish were collected by cast net, fish with UM were collected by trawl and in pound nets.

The ulcerative lesions were most frequently observed along the ventrum of affected fish particularly near the anus (Figure 8). Few lesions were observed on the head or dorsum. All three stages of lesions previously reported (Noga et al. 1988) were observed. Lesions observed on fish during the beginning of an outbreak were variable in size, but often limited to a cavity with local swelling circumscribed by a distinct red ring. As outbreaks progressed, lesions were larger, with substantial necrosis. Fungal hyphae were present in 91.2% of lesions observed on Atlantic menhaden collected in trawls and 80.5% of lesions on fish collected in pound nets (Levine et al. 1990). Characteristic lesions without fungal hyphae were infrequently observed. Lesions often had opaque mats of fungal hyphae and necrotic tissue overlying the wounds. However, extremely advanced lesions (end-stage lesions), in which substantial adjacent

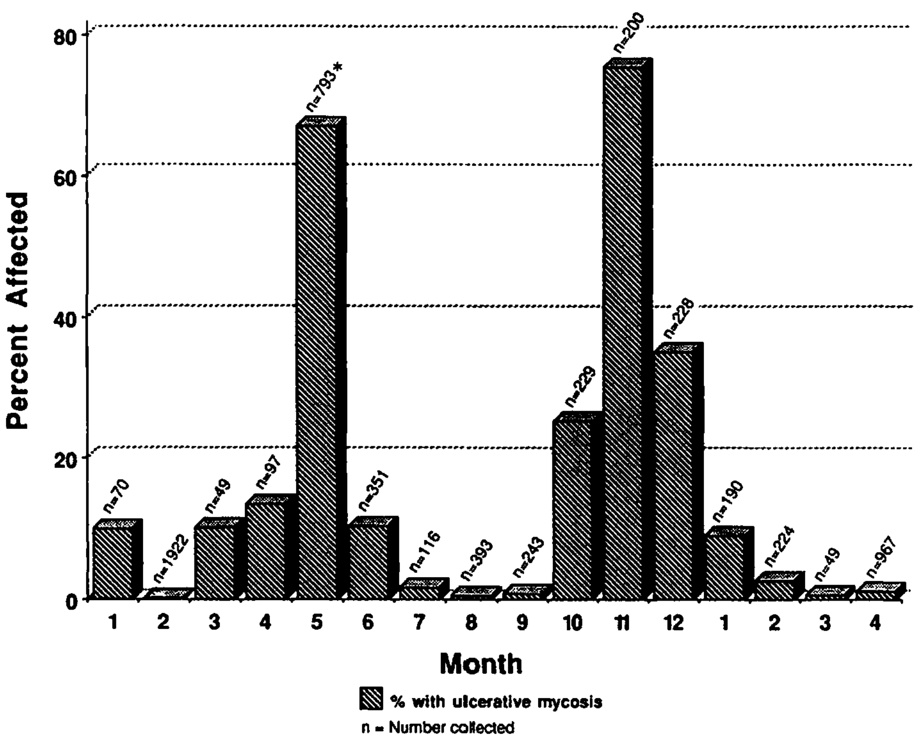


FIGURE 4.—Temporal distribution of ulcerative mycosis prevalence among Atlantic menhaden collected in trawls in the Tar–Pamlico River estuary during January 1986–April 1987, months in which more than 40 fish were collected. Month: 1 = January, 2 = February, etc.

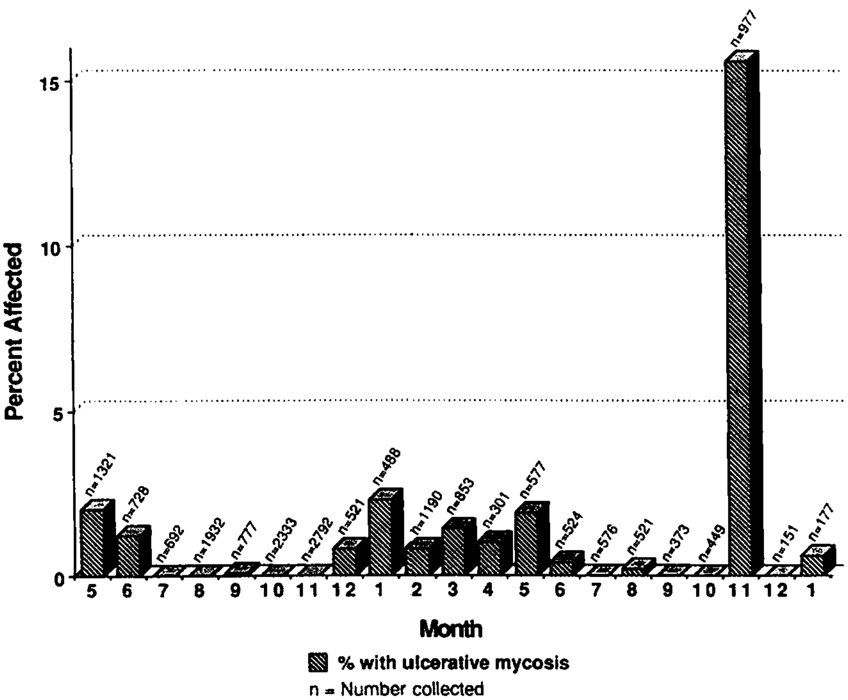


FIGURE 5.—Temporal distribution of ulcerative mycosis prevalence among Atlantic menhaden collected in pound nets in the Tar–Pamlico River estuary during May 1985–January 1987. Month: 1 = January, 2 = February, etc.

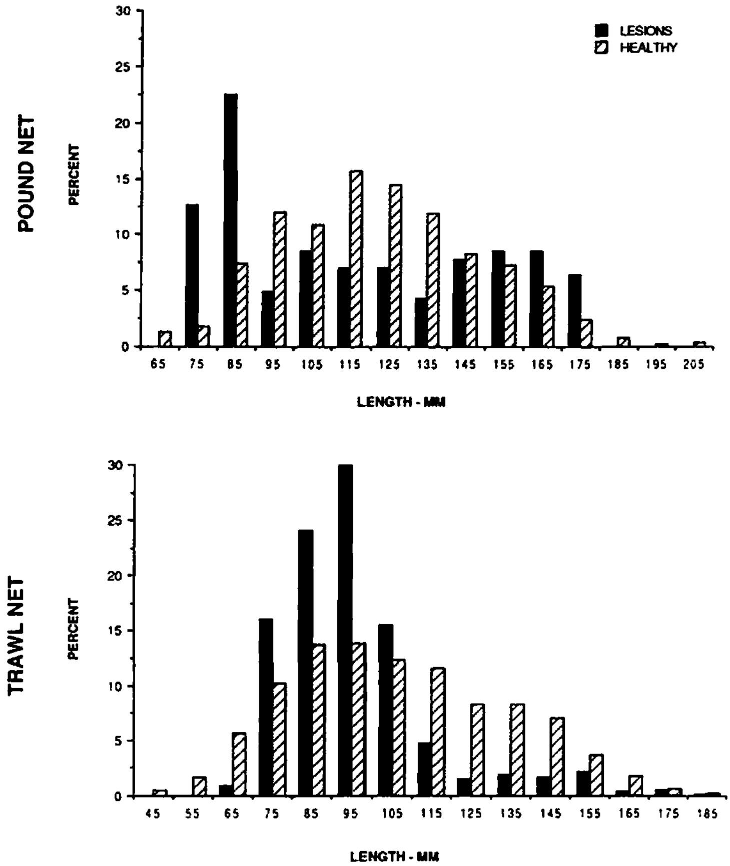


FIGURE 6.—Length frequencies (fork length) of Atlantic menhaden affected with ulcerative mycosis in trawl and pound-net samples during May 1985–April 1987 in the Tar–Pamlico River estuary.

tissue was necrotic or had sloughed, at times did not contain fungal hyphae.

Discussion

Atlantic menhaden appear to acquire UM within the Tar–Pamlico River estuary. They spawn during winter and early spring off the coast of North Carolina (Nicholson 1971). Larval Atlantic menhaden emerge in open, offshore areas and then move into coastal inlets, where they disperse upstream (Lewis and Mann 1971). In these lower-salinity upstream areas, they metamorphose into juveniles (Wilkens and Lewis 1971). Juvenile Atlantic menhaden (age 0) then move to higher-salinity areas, and the majority leave the estuary during late summer and fall. A portion return to the estuary as age-1 fish the following spring and migrate out of the system again later in the year. During fall 1986 in the Tar–Pamlico River estu-

TABLE 1.—Proportions of Atlantic menhaden with ulcerative mycosis (UM) in trawl and pound-net samples from the Tar–Pamlico River estuary, November 1986.

Gear	Station	*N*	Number of fish with UM	Percent of fish with UM
Pound net	1	168	3	1.8
	2	809	150	18.5
Trawl (stations where ≥4 fish were collected)	5	11	4	36.4
	7	8	8	100.0
	8	9	2	22.2
	25	4	2	50.0
	26	4	2	50.0
	27	4	2	50.0
	28	38	27	71.1
	29	84	77	91.7
	30	22	19	86.4
Trawl (stations where <4 fish were collected)		27	13	48.1

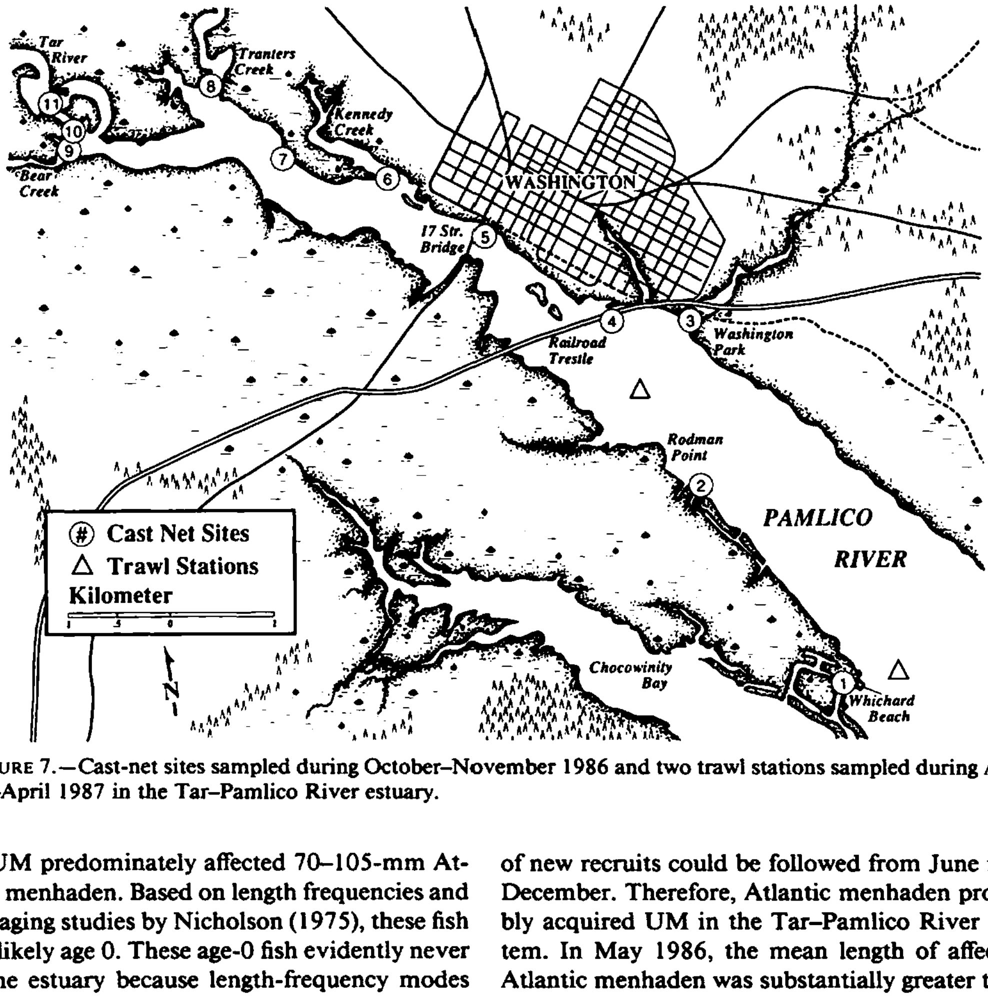


FIGURE 7.—Cast-net sites sampled during October–November 1986 and two trawl stations sampled during April 1986–April 1987 in the Tar–Pamlico River estuary.

ary, UM predominately affected 70–105-mm Atlantic menhaden. Based on length frequencies and prior aging studies by Nicholson (1975), these fish were likely age 0. These age-0 fish evidently never left the estuary because length-frequency modes of new recruits could be followed from June into December. Therefore, Atlantic menhaden probably acquired UM in the Tar–Pamlico River system. In May 1986, the mean length of affected Atlantic menhaden was substantially greater than

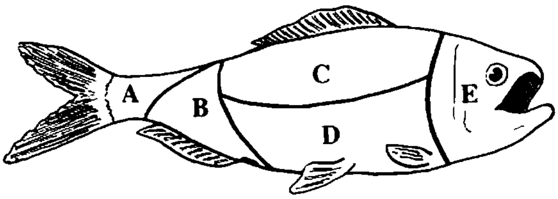
TABLE 2.—Occurrence of ulcerative lesions on Atlantic menhaden collected by cast net[a] in the Tar–Pamlico River and tributaries during October–November 1986. Site numbers refer to locations shown in Figure 7; N = number of fish examined; NS = station not sampled.

Site	Fish collected on: 23 October 1986			30 October 1986		
	N	Fork length (mm)	Number with lesions (%)	N	Fork length (mm)	Number with lesions (%)
(1) Whitchard Beach Canal	123	70–100	8 (6.5)	55	67–82	7 (12.7)
(2) Mumford's Canal	426	71–86	57 (13.4)	473	63–82	66 (14.0)
(3) Runyan Creek	91	73–99	13 (14.3)	140	72–89	28 (20.0)
(4) Railroad trestle	36	70–84	8 (22.2)	NS		
(5) 17th Street Bridge	NS			NS		
(6) Kennedy Creek	63	71–85	17 (27.0)	455	74–83	96 (21.0)
(7) Between Kennedy and Tranters creeks	NS			NS		
(8) Tranters Creek	286	73–91	86 (30.1)	365	73–85	36 (9.9)
(9) Bear Creek	241	71–94	9 (3.7)	32	71–89	2 (6.3)
(10) 0.4 km from Bear Creek	NS			54	68–85	4 (7.4)
(11) 0.8 km from Bear Creek	NS			NS		

[a] Data represent five net casts per station for each date.

Lesions with fungal hyphae

Body Location	Number of lesions	Percent of lesions
A	75	7.1
A,B	52	4.9
B	359	33.4
B,C	17	1.6
B,D	201	18.9
C	56	5.3
D	210	19.8
D,E	13	1.2
E	22	2.1
C,D	32	3.0
C,E	11	1.0
*	15	1.4
Total	1,063	100.0



Lesions without fungal hyphae

Body Location	Number of lesions	Percent of lesions
A	28	20.1
A,B	6	4.4
B	31	22.8
B,C	2	1.5
B,D	9	6.6
C	9	6.6
D	35	25.8
D,E	1	0.7
E	10	7.4
C,D	3	2.2
C,E	1	0.7
*	1	0.7
Total	136	100.0

FIGURE 8.—Body location of lesions with fungal hyphae (ulcerative mycosis [UM] lesions) and without fungal hyphae (UM- like lesions) on Atlantic menhaden. Lesions involving two sites are indicated by designating both locations (e.g., A,B). Lesions involving three sites are designated by an asterisk.

that observed in the fall and apparently represented either the movement of age-1 fish back into the estuary or the overwintering of some fish in the system. Commercial fishermen have not routinely recognized affected fish in the oceanic Atlantic menhaden catch. Oceanic sampling by the National Marine Fisheries Service has shown little evidence of UM (J. Merriner, personal communication), and in preliminary studies off the coast of Georgia and South Carolina, we also found no UM-affected fish in oceanic waters. Although the age-1 fish we observed with UM may have spent some time outside the estuary, they apparently also acquired the disease in the Tar–Pamlico River system.

More Atlantic menhaden affected with UM were collected in trawls during epidemics than in pound nets. The higher percentage of diseased fish in trawl samples is most likely due to the inability of diseased fish to avoid a mobile net (Ahrenholz et al.

TABLE 2.—Extended.

Fish collected on					
13 November 1986			21 November 1986		
N	Fork length (mm)	Number with lesions (%)	*N*	Fork length (mm)	Number with lesions (%)
3	72–78	3 (100)	0		
1	68	0 (0)	0		
19	62–81	19 (100)	1	84	1 (100)
NS			NS		
NS			12	80–84	2 (16.7)
1	78	1 (100)	0		
61	74	27 (44.3)	NS		
1	74	1 (100)	5	157–168	0 (0))
85	75–90	4 (4.7)	0		
9	72–80	7 (77.7)	2	81–83	0 (0)
66	76–85	7 (10.6)	NS		

1987). The proportion of Atlantic menhaden affected with lesions in individual trawl and pound-net samples appears to reflect the movement of these fish in the estuary. During epidemics, the infection rate in individual schools of Atlantic menhaden collected with trawls was variable, but routinely exceeded that observed in pound nets. Individual pound-net samples represented the collective movement of multiple schools of Atlantic menhaden into the nets over a 24-h period. Because the infection rate in individual schools was different, the overall rate of infection in pound-net samples was diluted by the movement of non-infected groups of fish into the nets. The proportion of affected fish in pound-net samples may have also reflected the location of the pound nets in the estuary. The mean length of Atlantic menhaden collected in pound nets was larger than in trawls. If young of the year are more susceptible to the disease, then the proportion affected in the pound nets would intuitively be less than in the trawls.

The variable disease rate observed in individual schools of Atlantic menhaden suggests that at least one critical component of the disease process is not uniformly distributed in the estuary. The movement of Atlantic menhaden in the system apparently passes them through specific portions of the estuary that contain this important but unidentified factor associated with the development of UM. Fish failing to enter these specific regions are seemingly not exposed and therefore do not develop lesions. Alternatively, unaffected schools could already be exposed, but may not have yet developed lesions. Although a portion of fish in unaffected schools may have been exposed, embracing this hypothesis requires an assumption of uniform exposure to this factor. However, this is unlikely. The disease is apparently routinely fatal because healed lesions are scarce (Noga et al. 1988).

Laboratory studies indicate that the fungus associated with the lesions thrives in salinities between 2 and 8‰, but is inhibited as salinity rises (Dykstra et al. 1986). During October 1986, age-0 Atlantic menhaden collected in cast nets appeared to acquire the disease in the Tar River and tributaries of the Pamlico River, where salinities were relatively low (2.5–9.6‰). The proportion of affected fish collected by cast net at individual sites increased as we moved upriver toward lower salinities, but then decreased as we approached fresh water (Table 2). However, the number of fish collected by cast net declined drastically in November as the fish began to leave the estuary. Atlantic menhaden with UM were observed in both pound-net and trawl samples as the fish moved downriver. Young of the year apparently developed UM in the upper part of the system at optimum salinities for fungal growth and then dispersed throughout the system.

Ulcerative mycosis lesions occur predominately on the ventrum, particularly near the anus, of affected Atlantic menhaden. This ventral distribution may represent (1) location-specific differences in cutaneous defenses; (2) contact with materials in the sediment in shallow areas that predispose the fish to infection on the ventrum; (3) tissue trophism of an unidentified infectious agent; or (4) the release of excretory materials from the digestive tract that provide nutrients for initial zoospore infection and growth (Noga et al. 1988) or that promote the proliferation of lesions by altering the protective mucous film. Although each of the above is a plausible explanation for the site-specific occurrence of lesions, little is known about the normal morphology, gastrointestinal flora and fauna, or normal cutaneous response of Atlantic menhaden to injury. Pathogens such as pox viruses and rhabdoviruses display specific tissue trophisms in terrestrial vertebrates, and a rhabdovirus has been previously associated with ulcerative diseases in finfishes (Jensen 1983). However, knowledge of aquatic animal virology is in its infancy. Additional studies are needed to describe the normal homeostatic response of Atlantic menhaden and other finishes to injury, and to expand our knowledge of the pathogens that affect aquatic vertebrates.

The Tar-Pamlico River estuary serves as one of several nursery areas for the Atlantic menhaden stock. Although a large proportion of age-0 and a smaller proportion of age-1 Atlantic menhaden collected during outbreaks of UM were affected by lesions, apparently no loss of an age-class has occurred that would suggest that UM has had a profound short-term effect on the fishery (Merriner and Vaughan 1987). However, the cumulative effect of this insidious loss of Atlantic menhaden, in terms of lost income to the commercial fishing industry, may prove to be substantial over a 10- or 15-year period.

The epidemics of UM and other ulcerative skin diseases observed since 1984 on finfishes in south Atlantic coastal estuaries are an apparently new problem. Stress, associated with the cumulative effect of human activity, has been suggested as the unknown factor predisposing fish to the development of these ulcers. The discussion about causality, however, should not focus on the general term "stress," but on the elucidation of specific natural and anthropogenic components of the disease process.

Acknowledgments

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