Predation on Horsehair Worms *(Phylum Nematomorpha)*

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ABSTRACT

Field observations revealed cases of predation on horsehair worms by brown trout (*Salmo trutta*) in Maryland and Minnesota, a rock bass (*Ambloplites rupestris*) in Kentucky, and a crayfish in Wisconsin. Some fish contained more than one worm and may have consumed reproductive aggregations. In laboratory feeding trials with *Gordius robustus*, most individuals of several fish species either ignored the horsehair worms or rejected them after taking them into their mouths briefly, but a green sunfish (*Lepomis cyanellus*) consumed both individual worms and a compact ball of 18 worms. A literature review yielded cases of predation on horsehair worms by at least 12 fish species. Horsehair worms usually were only a trace component of the diet, but some individual fish had eaten multiple worms.

INTRODUCTION

Although horsehair worms (Phylum Nematomorpha) are widely distributed as a group, the details of their natural history and the geographic ranges of individual species are poorly known. Recent reviews of horsehair worm biology (Pennak 1989, Poinar 1991) have included no mention of predation. In this paper, we report five cases of predation on adult horsehair worms in Kentucky, Maryland, Minnesota, and Wisconsin, we present the results of laboratory feeding trials in which horsehair worms were offered to fish, and we review the scattered published accounts of horsehair worms in fish diets.

METHODS

Field observations of predation on horsehair worms were made during fish collections at the locations listed below. Horsehair worms encountered as prey

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items were preserved in 70% ethanol and archived in the invertebrate collection at the Milwaukee Public Museum. Unless otherwise specified, all worms were identified as *Gordius robustus* based on the presence of males with bilobed posteriors and postcloacal crescents and females with unlobed posteriors (Poinar 1991), either among the prey items themselves or among free-living worms in the same general vicinity.

Gordius robustus used in laboratory feeding trials were obtained from cold spring runs tributary to the West Twin River in Manitowoc County, Wisconsin. Two worms were obtained on 16 July 1996 at Maribel Caverns County Park (T21N, R22E, S13) and used in feeding trials on 18 July. Thirty-one worms were obtained on 3 September 1997 from a spring run approximately 100 m downstream from the mouth of Kriwanek Creek (T21N, R23E, S19) and used in trials on 5 September. All fish used in the trials were collected in Manitowoc or Brown counties, Wisconsin, and had been held in captivity for 3-9 months.

RESULTS

We observed five cases of predation on adult horsehair worms in the field. (1) Four brown trout (*Salmo trutta*) and a brook trout (*Salvelinus fontinalis*), ranging in total length from 20 cm to 31 cm, were collected by angling on 15 July 1995 in Garvin Brook at Farmers Park, Winona County, Minnesota (T106N, R8W, S8). One brown trout contained at least two male and nine female worms. Because some worms were fragmented, these counts are minimum estimates based on distinguishable end pieces. That most of the worms were entangled in a mass extending from the stomach into the anterior intestine indicated that the trout had consumed a reproductive aggregation. It was decided to examine the gut contents of the trout after four worms (a male and three females) were found earlier that day in Garvin Brook. Two were found within a few centimeters of each other on the open silt bottom of a shallow (< 0.4 m) pool, and two were positioned approximately 1.5 m apart on the open bottom of a deeper (1-1.3 m) pool. The worms were whitish in color and contrasted sharply with the darker substrate, but they were similar in color and diameter to the exposed roots of associated aquatic macrophytes (watercress, *Rorippa* sp., and white water buttercup, *Ranunculus* sp.). Water temperature was 10.5°C at 0815 h.

(2) An unidentified horsehair worm was found in the intestine of a large (standard length: 146 mm) rock bass (*Ambloplites rupestris*) collected on 30 July 1996 in Little South Fork approximately 1650 m downstream from Green Church Ford, Wayne County, Kentucky (Latitude/Longitude: 36°41'22"/84°43'30").

(3) During collection of trout in Jambo Creek, Manitowoc County, Wisconsin (T21N, R23E, S25) on 2 August 1996, a crayfish was observed with a horsehair worm held in its chelae. The worm was alive but damaged at both ends. A male *G. robustus* was found in a quiet marginal area elsewhere in Jambo Creek on the same date. Water temperature was 14°C.

(4) A brown trout (standard length: 285 mm) collected on 10 October 1996 in Fifteen Mile Creek at Oldtown Road, Allegany County, Maryland, contained not only a horsehair worm, but also the remains of a large grasshopper. It is possible that the worm had parasitized the grasshopper but had not yet emerged when the

latter was consumed by the trout. A male *G. robustus* was collected elsewhere in the same drainage (Murley Branch), also in Allegany County, in September 1996. (5) A brown trout (total length: 26 cm) was collected on 21 August 1997 in Gilmore Creek on the St. Mary's University campus, Winona County, Minnesota (T107N, R7W, S29). Its posterior intestine contained two horsehair worms, which, although damaged, appeared to be *G. robustus*. A female worm was collected at the same site on 27 September 1997.

In 1996, the two *G. robustus* used in laboratory feeding trials initially were placed inside a glass test tube before separate presentations to adult and juvenile smallmouth bass (*Micropterus dolomieu*) and an adult bluegill (*Lepomis macrochirus*). Although movement by the worms attracted some attention, none of the fish made any attempt to attack. The bluegill made no attempt to attack the worms even after they were removed from the test tube, but a large bluntnose minnow (*Pimephales notatus*) briefly mouthed a worm at its midsection. Mottled sculpins (*Cottus bairdi*) ignored the worms.

In 1997, an adult largemouth bass (*M. salmoides*) ignored a pair of worms dropped past its snout. A subadult smallmouth bass in the same tank took a worm into its mouth, rejected it, oriented toward the worm as it sat on the bottom, and then ignored it. Subsequently, it took a compact ball of 26 worms completely into its mouth before rejecting them. Another subadult smallmouth bass in a separate tank ignored each of two worms as they fell through the water column. An adult bluegill oriented briefly toward a worm after it settled on the bottom and then ignored it and two additional worms subsequently dropped past its snout. A subadult rock bass took a worm completely into its mouth, spit it out, took it partly into its mouth three times, and then ignored it. Finally, an adult green sunfish (*Lepomis cyanellus*) ate four worms in succession as they fell through the water column and then consumed a compact mass of 18 worms. Each of the fish tested, with the exception of the bluegill, readily consumed mealworms (*Tenebrio* sp.) subsequent to the trials with the horsehair worms, an indication of motivation to feed on relatively novel prey items. These fishes were normally fed pieces of fish fillet or commercial pellets.

DISCUSSION

We are unaware of previous research focussed on the predators of horsehair worms, but scattered through the voluminous literature on the food habits of freshwater fishes are listings of horsehair worms as diet items (Table 1). This list is not meant to be exhaustive, but it represents the results of our review of several hundred papers. We suspect that horsehair worms found among the gut contents of fishes are sometimes dismissed as gastrointestinal parasites and not reported. Nevertheless, and despite their broad geographical distributions and wide range of reported habitats (Poinar 1991), horsehair worms apparently occur in the diets of only a small proportion of fish populations. Moreover, in those few cases in which horsehair worms have been reported as prey items (Table 1), they usually constitute at most a trace component of the diet.

The data provided by McLennan and MacMillan's (1984) study of trout in New Zealand rivers are somewhat exceptional in that they permit quantitative analyses. Although horsehair worms amounted to only 1.96% by number of the prey consumed by brown trout in the Mohaka River and only 0.05% of the prey consumed by rainbow trout (*Oncorhynchus mykiss*), 19 of 66 brown trout and two of 32 rainbow trout had eaten them, and the proportion of brown trout that had eaten worms was significantly greater than that for rainbow trout. Similarly, in an analysis of paired samples from several rivers, horsehair worms were found significantly more often in brown trout than in rainbow trout. Examination of gut contents of individual trout in Appendices 2-4 of McLennan and MacMillan (1984) suggests that horsehair worms were nonrandomly distributed among individual stomachs. For example, although 29 of 46 brown trout contained no horsehair worms, other individuals contained totals of 6, 8, 9, and 63. This is consistent with our observation in the present study of multiple worms within single fish, and it may reflect a tendency for trout to consume the tangled reproductive aggregations ("Gordian knots") for which horsehair worms are well known.

Table 1. Published reports of horsehair worms in the diets of fishes. The species or genera of horsehair worms involved are not indicated because in most cases that information was not provided.

Acipenser fulvescens (lake sturgeon): Wisconsin (Probst and Cooper 1954, Kempinger 1956).

Semotilus atromaculatus (creek chub): Illinois (Forbes 1883).

Salvelinus fontinalis (brook trout): Newfoundland (Pippy 1965).

Salmo trutta (brown trout): New York (Clemens 1928); Newfoundland (Scott and Crossman 1964); New Zealand (McLennan and MacMillan 1984).

Oncorhynchus mykiss (rainbow trout): New Zealand (Stokell 1936, McLennan and MacMillan 1984).

Coregonus clupeaformis (lake whitefish): Ontario (Hart 1931).

Galaxias vulgaris (common river galaxias): New Zealand (Cadwallader 1975).

Urophycis regia (spotted hake): New Jersey (Rachlin and Warkentine 1987). This is a marine example. Also, by interpretation of the authors' methodology, horsehair worms (*Nectonema* sp.) were also consumed by *U. chuss* and/or *U. tenuis*.

Macquaria australasica (Macquarie perch): Australia (Cadwallader and Eden 1979).

Morone chrysops (white bass): Indiana (Riggs 1952).

Lepomis macrochirus (bluegill): Indiana (Evermann and Clark 1920).

Although horsehair worms apparently do not form an important component of the diet of any fish species, that does not necessarily mean that predation is not a potentially important source of horsehair worm mortality. Even if the probability that an individual fish consumes a horsehair worm upon encountering it is low, a slowly moving horsehair worm may be exposed to numerous fishes during the course of its adult life. Furthermore, our feeding trials confirmed the possibility suggested by our field observations and those of McLennan and MacMillan (1984) that a single fish may consume an entire reproductive aggregation of worms in a single predation event. Thus, it is not surprising that at least some horsehair worms display traits that may reduce their exposure and vulnerability to fish predation.

First, recent collections by the senior author suggest that *Gordius robustus* is especially frequent in cold spring runs or other spring-fed habitats (Cochran, unpublished data), where it often occurs in the absence of large fish. In some cases, such as those reported in the present study or those listed in Table 1, horsehair worms are exposed to predation by trout in cold, spring-fed streams, but those trout are often not native to the systems in question.

Second, we have noticed that *G. robustus*, at least in many spring-fed habitats, tends to be whitish in color and similar in appearance to the exposed roots of aquatic macrophytes in the same locations, a resemblance that may confer some protection from predators. Poinar (1991) described adult horsehair worms as "dark." Pennak (1989) did not include white among the colors he listed for horsehair worms, but he did note considerable variation within species in coloration and size. Smith (1991) described *Parachordodes lineatus* as white or yellowish-white. Leidy (1870) implied that the horsehair worms he encountered were dark in color, but he also noted that it took some practice to observe them because they were readily confounded with blackened, decomposing vegetable fibers found in the same habitat.

Finally, our laboratory trials suggest that some characteristics of horsehair worms lead to their frequent rejection by fish that have taken them into their mouths. We suspect that the worms' stiff texture contributes to their apparent lack of appeal. That the lake sturgeon (*Acipenser fulvescens*) has been reported to consume horsehair worms (Probst and Cooper 1954, Kempinger 1996) may reflect its predilection for feeding on mollusks and other hard-bodied benthic prey (i.e., it may be less likely than other fishes to reject horsehair worms upon ingesting them).

Some apparent predation by fish on adult horsehair worms may actually represent predation on the invertebrate hosts in which the parasitic larval stages mature. When these hosts are terrestrial species, such as grasshoppers or crickets, they are thought to be somehow induced to move to the water's edge when the adult worms are ready to assume their free-living aquatic existence (Poinar 1991). At this time, the hosts may be more likely to fall or jump into the water and be consumed by aquatic predators. In fact, the invertebrate hosts may be more recognizable and preferable as prey items to most fish than the worms themselves, and it would not be surprising if the behavioral patterns induced by horsehair worms in their hosts included a tendency to seek out habitats such as headwater springs or vernal pools that are less likely to contain fish. Our observation of a horsehair worm in the gut of a brown trout that had also eaten a large grasshopper represents a potential case of secondary predation. Forbes (1883) pointed out that two creek chubs (*Semotilus *atromaculatus*) that contained numerous horsehair worms were not the same individuals that were found to contain grasshoppers.

Any consideration of predation by fish on horsehair worms is complicated by the potential for horsehair worms to parasitize fish (Nigrelli 1941, Nigrelli 1943, Blair 1983). Typically this would occur when a preparasitic larva is eaten by a fish, burrows into its tissue, and then encysts (Poinar 1991), but Evermann and Clark (1920) suggested that horsehair worms found either free in the lower intestine or coiled up and encysted in the inner organs may have infected the fish through the grasshoppers they consumed. Perhaps whatever features enable adult worms to escape from their definitive invertebrate hosts at the appropriate time may also enable them on occasion to "escape" from a fish's gut into its body cavity after being consumed either as free-living worms or before leaving the invertebrate host.

An ancillary result of our field observations is the extension of the known range of *Gordius robustus*. Horsehair worms have not been formally reported from Minnesota (Chandler 1985). However, Johnson et al. (1949) mentioned that "occasional hair-worms (Gordiaceae)" were taken during a biological survey of the Root River basin, and Fago and Hatch (1993) listed "Gordiidae" among the invertebrates that were collected in the lower St. Croix River basin, apparently on the basis of power company reports. Our collections of *G. robustus* in Manitowoc County, Wisconsin, are the first reported from that county (Watermolen and Haen 1994).

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LITERATURE CITED

Blair, D. 1983. Larval horsehair worms (Nematomorpha) from the tissues of native freshwater fish in New Zealand. New Zealand J. Zool. 10:341-344.

Cadwallader, P.L. 1975. The food of the New Zealand common river galaxias, *Galaxias vulgaris* Stokell (Pisces: Salmoniformes). Australian J. Mar. Freshwater Res. 26:15-30.

Cadwallader, P.L. and A.K. Eden. 1979. Observations on the food of the Macquarie perch, *Macquaria australasica* (Pisces: Percichthyidae), in Victoria. Australian J. Mar. Freshwater Res. 30:401-409.

Chandler, C.M. 1985. Horsehair worms (Nematomorpha, Gordioidea) from Tennessee, with a review of taxonomy and distribution in the United States. J. Tennessee Acad. Sci. 60:59-62.

Clemens, W.A. 1928. The food of trout from the streams of Oneida County, New York State. Trans. American Fish. Soc. 58:183-197.

Evermann, B.W. and H.W. Clark. 1920. Lake Maxinkuckee: a physical and biological survey. Vol II. Indiana Dept. Conserv. Publ. No. 7, 512 pp.

Fago, D. and J. Hatch. 1993. Aquatic resources of the St. Croix River basin. Pp. 23-56 *in*: Hesse, L.W., C.B. Stalnaker, N.G. Benson, and J.R. Zuboy (eds.).

Proceedings of the symposium on restoration planning for the rivers of the Mississippi River ecosystem. U.S. Dept. Interior, National Biol. Surv., Biol. Rep. 19.

Forbes, S.A. 1883. The food of the smaller fresh-water fishes. Bull. Illinois St. Lab. Nat. Hist. 1:65-94.

Hart, J.L. 1931. The food of the whitefish *Coregonus clupeaformis* (Mitchill) in Ontario waters, with a note on the parasites. Contrib. Canadian Biol. Fish. (Series A, General, No. 6), No. 21:445-454.

Johnson, R.E., J.B. Moyle, and W.A. Kenyon. 1949. A biological survey and fishery management plan for the streams of the Root River basin. Minnesota Dept. Conserv. Fish. Res. Invest. Rep. No. 87.

Kempinger, J.J. 1996. Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. North American J. Fish. Manag. 16:102-114.

Leidy, J. 1870. The gordius, or hair-worm. American Entomologist and Botanist 2:193-197.

McLennan, J.A. and P.W.H. MacMillan. 1984. The food of rainbow and brown trout in the Mohaka and other rivers of Hawke's Bay, New Zealand. New Zealand J. Marine Freshw. Res. 18:143-158.

Nigrelli, R.F. 1941. Hairworms as parasites of fishes. J. Parasitol. 27(supplement):38.

Nigrelli, R.F. 1943. Causes of diseases and death of fishes in captivity. Zoologica (New York) 28:203-216.

Pennak, R.W. 1989. Freshwater invertebrates of the United States, 3rd ed. John Wiley & Sons, New York, 628 pp.

Pippy, J.H.C. 1965. Studies on the parasites of fresh-water fishes (Salmonidae and Coregonidae) of insular Newfoundland. M.S. Thesis, Memorial University of Newfoundland, 170 pp.

Poinar, G.O., Jr. 1991. Nematoda and Nematomorpha. Pp. 249-283 *in*: Thorp, J.H. and A.P. Covich (eds.). Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego, 911 pp.

Probst, R.B. and E.L. Cooper. 1954. Age, growth, and production of the lake sturgeon (*Acipenser fulvescens*) in the Lake Winnebago region, Wisconsin. Trans. American Fish. Soc. 84:207-227.

Rachlin, J.W. and B.E. Warkentine. 1987. Dietary preference of the spotted hake, *Urophycis regia*, from the inner New York Bight. Annals N.Y. Acad. Sci. 494:434-437.

Riggs, C.D. 1952. Studies on the life history of the white bass, *Lepibema chrysops* (Rafinesque), with special reference to Shafer Lake, Indiana. Unpublished Ph.D. dissertation, University of Michigan, Ann Arbor, 224 pp.

Scott, W.B. and E.J. Crossman. 1964. Fishes occurring in the fresh waters of insular Newfoundland. Queen's Printer, Ottawa, 124 pp.

Smith, D.G. 1991. Observations on the morphology and taxonomy of two *Parachordodes* species (Nematomorpha, Gordioida, Chordodidae) in southern New England (USA). J. Zool. London 225:469-480.

Stokell, G. 1936. The nematode parasites of Lake Ellesmere trout. Trans. Royal Soc. New Zealand 66:80-96.

Watermolen, D.J. and G.L. Haen. 1994. Horsehair worms (Phylum Nematomorpha) in Wisconsin, with notes on their occurrence in the Great Lakes. J. Freshwater Ecol. 9:7-11.

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