North American Journal of Fisheries Management 29:352–360, 2009

DOI: 10.1577/M08-085.1

[Management Brief]

Voluntary Ingestion of Soft Plastic Fishing Lures Affects Brook Trout Growth in the Laboratory

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Abstract.—Thirty-eight brook trout *Salvelinus fontinalis* were fed a commercial trout diet mixed with a free-choice assortment of soft plastic lures (SPLs) over a 90-d period. Fish growth was recorded and compared with that of a control group. The brook trout readily ate the SPLs from the water's surface as well as from the tank bottom. At the conclusion of the study, SPLs were recovered from the stomachs of 63% of the test fish. Several fish stomachs contained multiple lures. Twelve percent of the fish voluntarily ingested more than 10% of their body mass in SPLs. These fish lost a significant amount of weight during the study, had a significant decrease in body condition factor, and began displaying anorexic behaviors. For these reasons, anglers should be discouraged from discarding used SPLs in trout waters.

Soft plastic lures (SPLs) are very popular among many angler groups, including those targeting black basses (Centrachidae), freshwater perches (Percidae), and salmonids (Salmonidae). Available in a variety of sizes, colors, shapes, scents, and degrees of biodegradability, SPLs are readily observed littering the bottoms of Maine's lakes and ponds, particularly those waters supporting bass fisheries. The voluntary ingestion of SPLs has become an increasing fisheries management concern for brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta*, landlocked Atlantic salmon *Salmo salar sebago*, and lake trout *Salvelinus namaycush* in Maine because undigested aggregates of SPLs have been found in the stomachs of these species by anglers and fisheries managers. In January 2003, the stomachs of 56 lake trout harvested during an ice fishing derby on Sebago Lake (Naples, Maine) were examined for ingesta. Twenty-five percent contained SPLs (F. Brautigam, unpublished data). The SPLs, used primarily during summertime bass angling on the lake, accumulate in lake trout stomachs as a result of voluntary ingestion and form gastric bezoars. Gastric bezoars are masses or concretions of food and foreign material (e.g., hair, stones, plastic, etc.) found accumulating in the stomach (Figure 1). Bezoars have been found and studied in many vertebrate species, and they are usually associated with postprandial fullness and malaise. When undiagnosed and untreated, gastric bezoars result in gastric ulceration, bleeding and perforation, intussusceptions, small bowel obstruction, anorexia, decreased fecal output, weight loss, and depression. Derraik (2002) demonstrated that when seabirds voluntarily ingested plastic litter, they subsequently ate less and lost weight.

No data on the effects of voluntary SPL ingestion were found for any fish, nor were any data found on the prevalence of voluntary SPL ingestion in fish from literature searches in Pub Med and Aquatic Sciences and Fisheries Abstracts using the search terms "lure consumption," "lure ingestion," "bezoar," "fish pearls," "Mustika pearls," or "gastric foreign bodies." Radomski et al. (2006) estimated the tackle loss for five Minnesota waters to be 0.0127 lure pieces/h; 80% of boat anglers interviewed reported tackle loss. Without an estimate quantifying voluntary SPL consumption and ingestion's injurious effects, it is impossible to determine the extent to which SPL litter puts fish populations at risk.

In addition to the negative health implications of SPLs from physical irritation of the gastric area, the chemical composition of these lures makes them dangerous pollutants to the environment and potential health hazards to humans, fish, and wildlife. Plasticizers render SPLs resilient and flexible. Phthalates are a family of chemical plasticizers known to cause health problems (Staples et al. 1997). A study conducted on the effects of phthalates on freshwater fish showed that exposure to such chemicals altered the activity of liver

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Received April 15, 2008; accepted August 27, 2008
Published online March 30, 2009

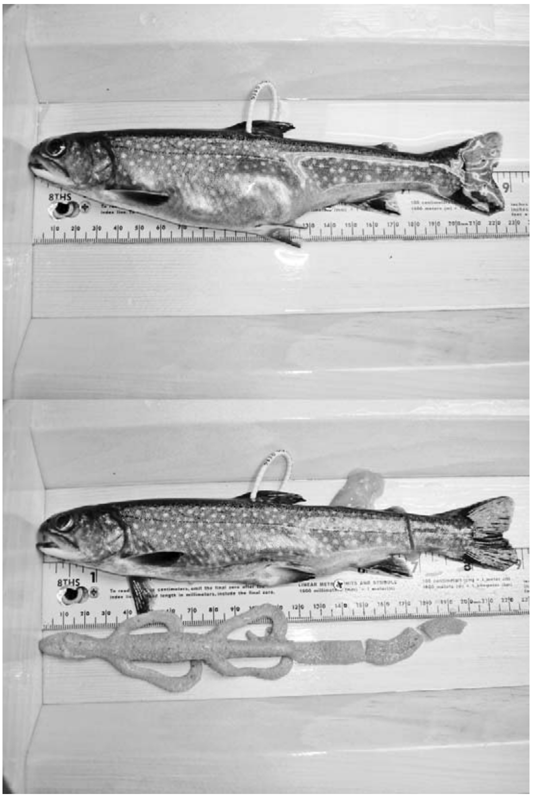

FIGURE 1.—Visibly distended coelom of a brook trout fed a commercial diet supplemented with a choice of SPLs (top) and lure removed from the stomach of a brook trout at the conclusion of the study (bottom). Undigested lures may form bezoars and lead to chronic health problems, including ulcers, anorexia, and weight loss. Plastic lures may remain in the aquatic environment for decades.

and certain muscle enzymes, which could have more harmful effects on fish from prolonged exposure (Ghorpade et al. 2002). Phthalate exposure has also been linked to tumors in rats (Vossa et al. 2005), underdevelopment of the testes and reduced sperm count in male rats exposed prenatally (Gray et al. 2005), the global decline of amphibians (Lee et al. 2005), chemical imbalances in several tissues and organs, including the liver (Bell 1982; Hinton et al. 1986), and deleterious effects on human reproductive health (Lovekamp-Swan and Davis 2003). Sha et al. (2007) demonstrated that plastics also have the ability to absorb inorganic substances from sediments. Overall, they are dangerous to the aquatic environment because of both their solid waste and their chemical composition.

Thus, this study was designed to measure voluntary ingestion rates of SPLs by catchable brook trout, to assess the ingestion volumes of these soft plastic bezoars, and to measure the associations between voluntary SPL ingestion and brook trout growth and health.

Methods

Fish.—Juvenile brook trout (234 ± 20 mm [mean ± SD]) were obtained from the Maine Department of Inland Fisheries and Wildlife (MDIFW), Palermo Fish Rearing Facility, Palermo. The Palermo facility obtained the fish as fry from MDIFW's Governor Hill Fish Hatchery, Augusta, one of the department's broodfish hatcheries. The fish were transported to Unity College, Unity, Maine, for the study. The two strains of brook trout that were used comprised 38 Kennebago Lake strain brook trout, representing a heterogeneous population, and 38 Maine hatchery strain brook trout, representing a fast-growing but very homogenous population (Bonney 2005). An equal number of each strain was assigned to the control and the study tank.

Feeds and feeding.—Fish were fed a 3-mm sinking pelleted Vigor salmonid feed (50% protein, 20% fat; Corey Feeds, Fredericktown, New Brunswick). Beginning in March 2007, the fish were fed 0.5% of their combined body weight per day. Each week a different type of soft plastic lure was offered to the fish during a single feeding. Fish were kept in two 1-m × 1-m × 0.75-m fiberglass tanks, each receiving 100 L/min of recirculated filtered and ultraviolet light-sterilized water kept at 9 ± 1°C. A 1-cm^2-mesh net was placed over each tank after the first day because seven fish jumped out of the tank and were found dead on the floor. Data from these fish were removed from subsequent statistical analyses. The photoperiod was 12 h light : 12 h dark, and lights were turned on at 0700 hours. Water quality in the aquaculture facility was monitored and recorded. All temperature, dissolved oxygen, and pH data were unremarkable.

Study design.—This observational epidemiological study was designed to scrutinize the occurrence of morbidity and mortality in cohort groups relative to exposure to SPLs. This was an observational cohort study without strict experimental research methodology (Thrusfield 2005). The study's design, variables, statistical analysis, assumptions, and power are listed in Table 1. This study proposes probable inference from a specific case where brook trout are fed trout feed mixed with or without SPLs. The starting point is healthy individuals that are followed for 3 months, during which time they are exposed to the putative agent (i.e., SPLs) and compared with a control group that is not exposed. Table 2 provides the chronology of SPL exposure and SPL recovery from the study tank or a fish's gastrointestinal tract (GI). Some lures were

TABLE 1.—Hypotheses tested in a study of the ingestion of soft plastic lures by brook trout. Two strains of brook trout were studied, a Maine hatchery strain ($n = 38$) and the Kennebago strain ($n = 38$). The Shapiro–Wilk W-test was used to evaluate the normality of the data. The Mann–Whitney U-test was used to test the statistical hypotheses, the Wilcoxon signed rank test to test the post hoc hypotheses. The level of significance was set at 0.05.

Study design, variables, statistics, assumptions, and power	
Scientific hypothesis	Ingestion of indigestible soft plastic lures by trout may be influencing their growth in Maine waters.
Study design	Observational cohort study
Subjects	Brook trout ($n = 76$)
Strains	Maine hatchery strain ($n = 38$); Kennebago strain ($n = 38$)
Groups	Treatment (α_1): fed diet of fish food and soft plastic lures. Replicates = 0 Control: (α_2): fed diet of fish food only. Replicate = 0.
Statistical hypotheses	H_{0_1}: $TM\alpha_1 - TM\alpha_2 = 0$. Body mass of the treatment group is not be significantly different than the mass of the control group at any time period (day 0, 30, 60, or 90). H_{α_1}: Not H_{0_1}. H_{0_2}: $TL\alpha_1 - TL\alpha_2 = 0$. Total body length of the treatment group is not significantly different than the length of the control group at any time period (day 0, 30, 60, or 90). H_{α_2}: Not H_{0_2}. H_{0_3}: $K\alpha_1 - K\alpha_2 = 0$. Condition factor of the treatment group is not significantly different than condition factor of the control group at any time period (day 0, 30, 60, or 90). H_{α_3}: Not H_{0_3}. H_{0_4}: $HCT\alpha_1 - HCT\alpha_2 = 0$. Hematocrit of the treatment group is not significantly different than the hematocrit of the control group at study's conclusion (day 90). H_{α_4}: Not H_{0_4}. H_{0_5}: $TP\alpha_1 - TP\alpha_2 = 0$. Plasma protein level of the treatment group is not significantly different than the plasma protein level of the control group at the study's conclusion (day 90). H_{α_5}: Not H_{0_5}. H_{0_6}: $GLU\alpha_1 - GLU\alpha_2 = 0$. Blood glucose level of the treatment group is not significantly different than the blood glucose level of the control group at the study's conclusion (day 90). H_{α_6}: Not H_{0_6}.
Independent variable	Diet
Dependent variable	Total body length (TL), total body mass (TM), condition factor (K), lure mass (LM), hematocrit (HCT), total plasma protein (TP), blood glucose (GLU)
Normality test	Shapiro–Wilk (W)
Statistica test	Mann–Whitney U-statistic
Statistical assumptions	Two independent samples collected from similarly shaped distributions measured on an ordinal or continuous scale
Significance level	$P < 0.05$
Decision rules	Reject H_0 when $P < 0.05$ with df = 1
Computations	Indepentently evaluated
Post hoc hypotheses	H_{0_7}: $TL\alpha_1$ (day 0) $-$ $TL\alpha_1$ (day 90) = 0. Total body length of the treatment group at commencement (day 0) is not significantly different than the total body length at the study's conclusion (day 90). H_{α_7}: Not H_{0_7}. H_{0_8}: $TL\alpha_2$ (day 0) $-$ $TL\alpha_2$ (day 90) = 0. Total body length of the treatment group at commencement (day 0) is not significantly different than the total body length at the study's conclusion (day 90). H_{α_8}: Not H_{0_8}.
Post hoc analysis	Wilcoxon signed ranks statistic (paired data)

TABLE 2.—Number of soft plastic lures fed and number recovered in a study of the ingestion of such lures by brook trout, by week and lure type. The column headed GI shows the number of lures collected from the stomachs of fish. The color or shape of the lures was varied each week. Some lures were never recovered owing to digestion, data error, or loss inside the recirculating system. Week 13 has been omitted because no lures were fed that week.

Week of study	Lure type	Week of study													
		1	2	3	4	5	6	7	8	9	10	11	12	14	GI
1	Zoom green lizard	7/2	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0
2	Zoom brown lizard		6/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0
3	Berkley brown worm			6/2	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0
4	Kinami worm				8/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	6
5	Kinami lobster					2/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1
6	Gulp red worm						5/0	0/0	0/5	0/0	0/0	0/0	0/0	0/0	0
7	Zoom purple lizard							2/0	0/0	0/0	0/0	0/0	0/0	0/0	1
8	Zoom green lizard								2/0	0/0	0/0	0/0	0/0	0/0	0
9	Zoom brown lizard									2/0	0/0	0/0	0/0	0/0	0
10	Gulp red worm										2/0	0/0	0/0	0/0	5
11	Zoom brown lizard											2/0	0/0	0/0	2
12	Zoom green lizard												2/0	0/0	4
14	Berkley brown worm													2/0	10

TABLE 3.—Median values and 95% confidence intervals of the variables examined in a study of the ingestion of soft plastic lures by brook trout. A check in the N column indicates that the data were normally distributed. Since so many dependent variables did not meet the normality assumption, it was decided to report the results with the more conservative nonparametric statistics.

				Lure diet		Control	
Variable	Units	Day	N	*n*	Median (95% CI)	*n*	Median (95% CI)
Total length	mm	0	✓	38	236 (225–243)	38	232 (227–239)
		30	✓	38	227 (224–240)	31	240 (230–245)
		60	✓	37	237 (230–247)	31	240 (233–248)
		90		38	237 (227–248)	31	247 (240–251)
Total mass	g	0		38	127 (118–150)	38	125 (118–152)
		30		38	138 (114–152)	31	134 (118–150)
		60		38	120 (104–140)	31	138 (127–150)
		90		38	121 (104–132)	31	156 (140–178)
Condition factor	g/mm^3	0	✓	38	1.030 (0.929–1.147)	38	1.073 (0.923–1.167)
		30		38	1.042 (0.945–1.158)	31	1.013 (0.929–1.114)
		60		38	0.951 (0.873–0.998)	31	1.007 (0.917–1.071)
		90	✓	38	0.947 (0.902–0.997)	31	1.056 (0.987–1.135)
Hematocrit	% red blood cells	90		33	27 (23–31)	27	35 (32–38)
Total protein	mg/dL	90	✓	30	3.0 (2.6–3.4)	26	3.1 (2.7–3.9)
Glucose	mg/dL	90		37	91 (85–111)	31	295 (113–327)

immediately eaten, while other lures remained in the tank available to the fish for the remainder of the week. Uneaten SPLs were removed from the tank before the next type of SPL was fed to the fish. This study design cannot control for extraneous factors that may distort the results (e.g., tank effect) but does provide a useful measure of association upon which subsequent experiments can be designed.

Animal care and use.—A peer review group composed of fisheries biologists, hatchery personnel, and academics reviewed this study prior to initiation and served as the Animal Care and Use Committee (ACUC) during the study. The study was designed and carried out within the published guidelines for the use of fish in research (Nickum et al. 2004). Sixty fish from each brook trout strain were tested and found to be negative for pathogens of regulatory concern in Maine prior to commencing the study according to fish health inspection procedures (USFWS and AFS–FHS 2004).

Anesthesia.—To facilitate growth measurements, fish were anesthetized with tricaine methanesulfonate (MS-222; Finquel, Argent Chemical Co., Redman, Washington) following manufacturer-suggested dosing for salmonid fishes, and the level of anesthesia was monitored according to the scalar stages of anesthesia in fishes (Brown 1993). Fish were anesthetized to stage II, plane 1.

Surgical procedures.—After anesthesia to stage II, plane 2, a looping tag with a specific number was inserted laterally and transecting the supracarnalis muscles caudal to the dorsal fin using an initially sterilized trochar needle as directed by the manufacturer (Hallprint Tags, Australia). The fish were randomly assigned to either the control or treatment group and visually monitored during recovery from anesthesia. The fish were allowed to acclimate to the new environment for 1 week.

Growth measurement.—Fish were individually weighed for total mass (TM; ES6R Ohaus Corp., Pine Brook, New Jersey), and measured for total length before the study and then monthly. Condition factor (K) was calculated as

$$K = (\mathrm{TM}/\mathrm{TL}^3) \times 10^{-5}.$$

Euthanasia.—At the conclusion of the study, fish were euthanatized with an overdose of MS-222 and placed on wet ice for immediate necropsy (AAZV 2007; AVMA 2001; Hartman 2007).

Necropsy.—All fish were dissected immediately after euthanasia, and the ingested masses of the SPLs in the GIs were counted and weighed. A whole-blood sample was collected directly from the caudal vein into a microhematocrit tube, filling the tube approximately two-thirds full. The tube was sealed on one end with clay and centrifuged (5,000 × gravity for 5 min at 20°C). The percentage of packed cells to total volume (HCT) was determined by direct measurement (Stoskopf 1993). Total protein was measured using a handheld refractometer. Blood glucose was measured by placing a single drop of whole blood on a test strip for an Accu-Chek Glucose Meter (Roche, Basel, Switzerland). Soft plastic lures were removed from the GI and placed in Whirlpak plastic bags (Nasco, Ft. Atkinson, Wisconsin). The bags were individually weighed.

Data analysis.—Data from each dependent variable were tested for normality by means of a Shapiro–Wilk

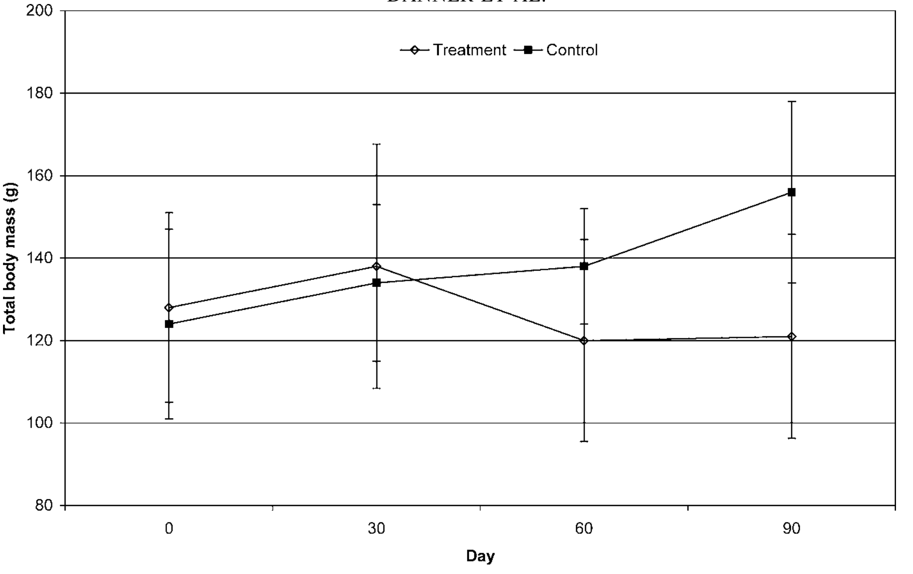

FIGURE 2.—Median body mass of brook trout fed a diet that included soft plastic lures (the treatment group) vis-à-vis that of the control group at 0, 30, 60, and 90 d. Both groups grew initially, but after about 30 d the fish fed the diet with lures began to loose weight while the control group continued to gain weight. The error bars indicate interquartile ranges.

test (Analyze-it Software, Leeds, UK). Histograms of the data were visually assessed along with calculated values for skewness and kurtosis to evaluate if the distributions deviated grossly from a bell-shaped Gaussian distribution. A column in Table 3 indicates which dependent variables met the strict normality assumptions. Many of the dependent variables did not meet Normality assumptions; therefore, the data were analyzed with more conservative nonparametric statistics. After reviewing the data, decisions about when to use parametric versus nonparametric statistics were made about the entire data set rather than mix-and-match statistical analyses within this same data set. Figures correspondingly illustrate nonparametric values as well.

Results

Ingestion of SPLs

Overall, 24 of 38 (63%) fish in the treatment group voluntarily ingested at least one SPL. Eighteen fish (47%) ingested a single SPL, five fish (13%) voluntarily ingested two SPLs, and one fish (3%) ingested more than three SPLs. Only one fish (3%) had a lure extending caudally into its small intestine. In all the other fish, the SPLs were retained within the gastric fundus. One fish (3%) in the study group died during the study with a single SPL in its stomach. The median mass of the SPLs recovered from the fish stomachs was 1.1 g. Three fish (13%) voluntarily ingested more than 10 g of SPLs, accounting for more than 10% of their TM. Overall, SPL mass accounted for 1% of the affected fish TM. In the more "wild" or heterogeneous Kennebago strain, 15 of 18 fish (83%) voluntarily ingested at least one SPL, while only 9 of 18 domesticated Maine hatchery strain brook trout (50%) voluntarily ingested the SPLs.

Growth and Health Assessment Variables

Mann–Whitney U-tests were used to formally test for differences between the medians (Table 2). At the commencement of this study, there were no differences in TL (U = 700.0; df = 1; P = 0.8351) between Kennebago and Maine hatchery strain brook trout; however, as expected Maine hatchery strain brook trout had greater TM (U = 1,015.5; df = 1; P = 0.0021) and K (U = 1,290.0; df = 1; P = 0.0001) than the wild Kennebago strain. After randomly allocating individual fish from each strain to either the study or control group, there was no group difference in TL (U = 623.5; df = 1; P = 0.3082), TM (U = 687.0; df = 1; P = 0.7198), or K (U = 763.0; df = 1; P = 0.6663). After 30 d and exposure to four different types of SPLs, there was no group difference in TL (U = 679.0; df = 1; P = 0.2770), TM (U = 569.5; df = 1; P = 0.8140), or K (U = 505.5; df = 1; P = 0.3138). After 60 d and exposure to additional types of SPLs, there was no group difference in TL (U = 597.0; df = 1; P = 0.9230), TM (U = 678.0; df = 1; P = 0.2828), or K (U = 718.0; df = 1; P = 0.1197). The TM measurement for day 30 and day 60 evaluations included the mass of any SPL retained within the GI potentially masking weight loss associated with SPL ingestion. The final evaluation (day 90)

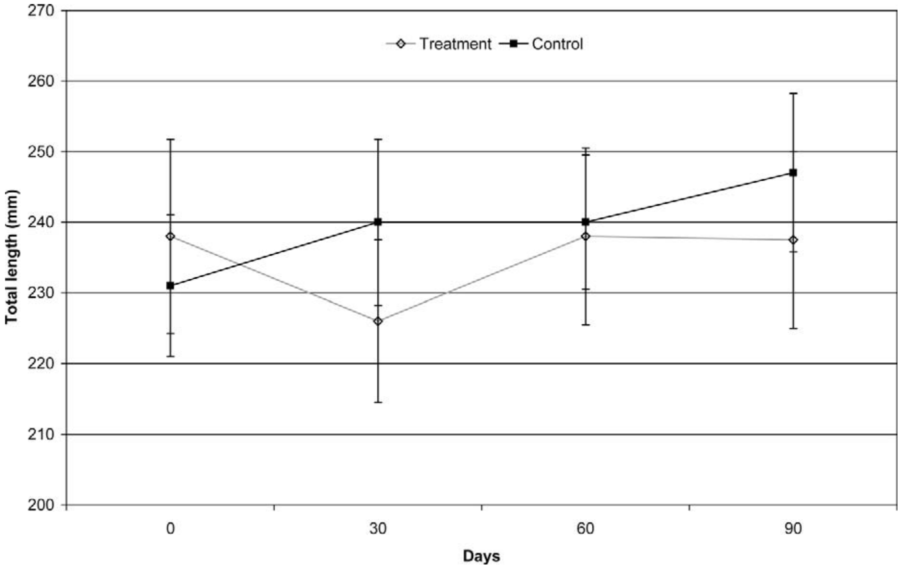

FIGURE 3.—Median total body length of brook trout fed a diet that included soft plastic lures (the treatment group) vis-à-vis that of the control group at 0, 30, 60, and 90 d. The control group grew throughout the study, while the treatment group showed no significant growth. The error bars indicate interquartile ranges.

included both a gross TM and net TM after the SPLs were removed and weighed. There was a significant difference at day 90 in gross TM ($U = 753.5$; df = 1; $P = 0.0472$), net TM ($U = 770.0$; df = 1; $P = 0.0290$), and K ($U = 752.5$; df = 1; $P = 0.0486$), but not in TL ($U = 710.0$; df = 1; $P = 0.1438$). Post hoc analysis of TL data demonstrated that there was significant TL growth within the control group ($W = 64.5$; df = 1; $P = 0.0003$) but not the treatment group ($W = 319.0$; df = 1; $P = 0.9477$). Changes in median TM in each group during the study may have begun to appear as early as 30 d (Figure 2). Changes in TL were not as apparent as changes in TM, requiring post hoc analysis of within-group differences to demonstrate that SPLs were retarding the growth of the study group (Figure 3).

Glucose was significantly higher in the control group ($U = 851.5$; df = 1; $P = 0.0006$) than in the treatment group. Hematocrit was significantly higher in the control group ($U = 649.5$; df = 1; $P = 0.0024$) than in the treatment group; however, there was no difference in TP ($U = 466.5$; df = 1; $P = 0.2088$). There were no differences in TL ($U = 130.0$; df = 1; $P = 0.2494$), TM ($U = 144.5$; df = 1; $P = 0.4768$), K ($U = 182.0$; df = 1; $P = 0.6718$), GLU ($U = 129.5$; df = 1; $P = 0.3236$), TP ($U = 131$; df = 1; $P = 0.3297$), or HCT ($U = 157.5$; df = 1; $P = 0.3101$) between the 63% of fish in the treatment group with at least one lure in their stomach on day 90 and the 37% of fish in that group that did not have a lure in their stomach.

Discussion

Fishing with SPLs has become increasingly popular among anglers; however, the use of these lures may have deleterious effects on fish and hence presents some serious concerns for fisheries managers. Soft plastic lures are manufactured into sizes, shapes, and colors useful for catching a variety of species and fishes of different sizes. Their use is more socially acceptable than impaling a live nematode, crustacean, or small fish on a barbed hook. The lures are disposable and can be disinfected to minimize the spread of aquatic invasive species and pathogens of aquatic organisms. Several types of SPLs claim to be biodegradable, and some may be digestible. Unfortunately, indigestible and unbiodegradable SPLs are contributing to aquatic benthic litter and gastric bezoars in salmonids.

An initial literature search for articles examining the effects of consuming SPLs on the growth of fish was unsuccessful; thus, this study was designed and executed to measure any association between voluntary SPL ingestion and subsequent effects on brook trout growth or health.

Voluntary SPL Ingestion Rates

The results of this short-term observational investigation suggest that SPLs are readily ingested by "catchable" brook trout without momentous effort. Simply by distributing SPLs in the tank simultaneously with fish pellets, we got more than one-half of the brook trout to voluntarily ingest them; 83% of the Kennebago strain fish did so. The voluntary lure ingestion rates observed in this study are greater than anecdotal field observations by MDIFW fishery biologists. This may indicate that field observations underestimate the prevalence of SPL gastric bezoars in brook trout. The observation that wild brook trout voluntarily ingested SPLs more readily (3:2 [Kennebago : Maine hatchery strains]) than domesticated brook trout also forewarns of the impact of plastic litter on wild brook trout populations. Fish in this study were fed a balanced diet at a rate that should promote growth and satiation. Nevertheless, voluntary lure ingestion rates exceeded 50%.

We attempted to measure the brook trout's ability to voluntarily regurgitate the lures by using different colors and types of lures throughout the study. Presumably, brook trout have the ability to regurgitate these lures, but data on the recovery of lures indicate that they are not regularly regurgitated (Table 2). Some lures were never recovered during the study; this could indicate digestibility, although it is also possible that they remain trapped someplace within the tank's recirculation system.

Voluntary SPL Ingestion Affects Growth

In this study, the relative risk of weight loss was seven times as great in brook trout that voluntarily ingested SPLs than in controls. The treatment group lost a median of 6 g during the study, while the controls gained 31 g. During the 90 d of this study, there was no TL or TM growth within the treatment group. Even fish in the treatment group necropsied and found to be without an SPL in their stomach did not grow as well as controls. This may indicate that digesting or regurgitating lures has a prolonged effect on growth or that the competitive dynamic of a shoal's feeding behavior is affected by individuals carrying masses of SPLs. Video of the study group's feeding behavior taken about a month into the study showed a marked lethargy in comparison to the feeding behavior of the controls. If SPL ingestion can be linked to changes in feeding behavior, then the effects of SPL gastric bezoars will directly impact brook trout fishing and management. Presumably, brook trout ingesting SPLs will have reduced growth rates, be more vulnerable to predation, and have lower catch rates than unaffected brook trout.

Voluntary SPL Ingestion Affects Health

Soft plastic lure ingestion does not appear to be acutely lethal to brook trout. Only a single fish died during the study (mortality rate = 3%) with an ingested lure. However, there were significant decreases in the GLU and HCT of brook trout that ingested SPLs. While GLU levels are transient indicators of food consumption and metabolic state, HCT is a good indicator of general health. Neither group's GLU level indicated hypo- or hyperglycemia, but the control group's GLU was significantly higher than that of the study group's under the same study conditions. Likewise, the HCT of both groups was within the normal range; overall, however, the treatment group's HCT was significantly lower than that of the control group, and in this instance four fish with large SPL bezoars had HCTs below 20%. If SPL ingestion were to be linked with chronic anemia, its implications for fisheries management would be significant. From this study, it is not possible to determine if the decreased HCT is a direct result of malnutrition from postprandial fullness or discomfort, or whether the SPL's chemical composition is affecting the HCT.

Since plastics have been implicated in a variety of toxicities in other vertebrates, we hypothesized that the ingestion of SPLs may be associated with toxicities in fish. Where brook trout and other salmonids occur either naturally or are stocked, and are managed for growth and survival to older age, study results suggest that plastic ingestion may impede attainment of growth and size expectations in the development of desirable sport fisheries. Where "legal-size" trout are stocked to provide seasonal put-and-take fisheries of short duration, foraging on SPLs by newly stocked trout poses fewer potential adverse management implications. These legal-size trout are immediately vulnerable to harvest and experience fewer opportunities to forage prior to harvest. However, if ingestion occurs soon after stocking and causes behavioral changes (such as increased lethargy and reduced frequency and duration of feeding), these changes could diminish angler catch rates associated with these fisheries.

Field observations by anglers and biologists of SPLs in salmonid stomachs are generally associated with fish much larger than those tested in this investigation. Large, old-age fish have greater opportunity (exposure time) to accumulate SPLs and experience any associated adverse impacts over an extended period of time. One large lake trout harvested from on Mousam Lake (Acton, Maine) during the winter of 2002 (Brautigam, personal communication) was found to contain 18 SPLs. Also, these older individuals may represent important adult broodfish in self-sustaining wild populations. Any diminishment in health and body condition could negatively influence fecundity and desired recruitment important to the maintenance of the fishery. The chronic retention of an SPL may have additional influences on a fish's overall health and well-being.

Several studies concerning plastics have shown harmful effects from exposure to improperly disposed of plastics (Staples et al. 1997). These harmful effects range from the esthetic deterioration of aquatic environments to acute and chronic health effects on terrestrial wildlife due to the potential ingestion of pieces of SPLs or exposure to the harmful chemicals within the plastics (Bell 1982; Cashman et al. 1992; Derraik 2002; Islam and Tanaka 2004; Radomski et al. 2006; Barse et al. 2007). Plastics continue to be one of the most abundant sources of environmental pollution worldwide, particularly in aquatic ecosystems (Islam and Tanaka 2004). These plastic remains are indestructible for decades, and many of them will eventually settle in the sediments of aquatic ecosystems.

Future investigations are warranted to more fully assess the management implications associated with fishing with SPLs. A subsequent investigation should examine the effect of SPL ingestion on larger fall yearling stocked salmonids, and should monitor the effects over a much longer period of time with stricter experimental research methodologies. Larger salmonids are routinely stocked in southern and coastal Maine because larger fish appear to withstand higher levels of interspecific competition and predation. The use of SPLs is very common in bass, perch, crappie, and salmonid fisheries in the aforementioned region of Maine. Gonad development should be included as a monitoring parameter, as should an assessment of behavioral changes that could affect fish catchability by sport anglers. A comparison of biodegradable plastic products and those not labeled as such should be investigated to determine if the rates of biodegradation in fish stomachs are different and whether the rate of decomposition associated with the biodegradable product reduces the apparent negative influence on fish growth and condition. Available product information should be obtained from the manufacturers of biodegradable SPLs to identify any completed research to assess environmental fate. Input should be solicited from key angler organizations regarding the scope of a subsequent study to cultivate a vested interest in the study outcome, which may not reflect favorably on the continued use of some popular SPLs commonly used by anglers. Meanwhile, anglers should be discouraged from disposing of SPLs in the water.

Acknowledgments

Financial support for this research project was provided by the Maine Department of Inland Fisheries and Wildlife. Unity College provided space in their aquaculture laboratory to conduct the study. The authors would like to thank the ACUC for peer group review, Barry Woods for statistics and editing assistance, and the anonymous reviewers.

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