INGESTION OF PLASTICS BY TELEOST FISHES

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ABSTRACT

Ingestion of plastic debris by many types of animals such as turtles and seabirds is well documented and considered to be a serious threat to their survival. Marine fishes also ingest plastic debris but the amount ingested and the effect of the ingested debris are not well documented. If large amounts of inert plastic debris were ingested, it might affect the fishes' well-being by blocking the digestive tract and reducing the feeding drive. Also, certain types of debris could cause injury to the digestive tract and, depending on its chemical composition, might even have a toxic effect.

In this paper we review the literature to determine what is known about ingestion of plastics by marine fishes and report on our studies on ingestion of plastic particles by larvae and juveniles. There is at present no comprehensive list of fishes known to have ingested plastic. However, observations made incidental to other studies indicate that many species do at least occasionally ingest plastic. Plastics have been found in larvae, juveniles, and adults of both pelagic and demersal species. Currently, there is no clear evidence that juvenile and adult fish have been affected by ingesting plastic. Studies in the field on larval fish have suggested that swallowed plastic spheres could cause intestinal blockage and that polychlorinated biphenyls associated with the surface of the spherules could have toxic effects.

Laboratory experiments to determine the effects of plastic ingestion on larval and juvenile fish have been equivocal. In some cases the fish were observed to take particles, but then reject them.

We have found in our laboratory studies on larvae that five of six species tested--Atlantic menhaden, *Brevoortia tyrannus*, pinfish, *Lagodon rhomboides*, spot, *Leiostomus xanthurus*, striped mullet, *Mugil cephalus*, and two species of flounder, *Paralichthys* spp.--will feed on polystyrene microspheres. However, only spot and mullet were found to have particles in their gut. Particles passed from the gut after a period of time and larvae subsequently fed on brine shrimp larvae.

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INTRODUCTION

Plastic debris is a common contaminant of marine waters and is potentially available for ingestion by marine life. Since the report of Carpenter and Smith (1972) on contamination of the Sargasso Sea surface by plastic particles, numerous surveys have reported on finding various types of plastics in waters from around the world (Carpenter et al. 1972; Kartar et al. 1973; Venrick et al. 1973; Colton et al. 1974; Hays and Cormons 1974; Morris and Hamilton 1974; Wong et al. 1974; Gregory 1977; Shaw 1977; Shaw and Mapes 1979; Shiber 1979, 1987; Morris 1980; Dahlberg and Day 1985; Day et al. 1986; Ignell and Dahlberg 1986). A more extensive discussion of the worldwide distribution of plastics in the sea is given by Pruter (1987).

Ingestion of plastic debris by many types of animals (e.g., marine turtles and birds) is, in fact, well documented and in many cases considered to be a serious hazard (Balazs 1985; Day et al. 1985; Azzarello and Van Vleet 1987; Fry et al. 1987; Gramentz 1988). For marine fishes, the ingestion of plastic debris and its subsequent effect is not well documented, but it is assumed that they, like other marine animals, will be unable to distinguish between normal prey and small pieces of plastics. Fish may swallow pieces mistaken for prey or ingest pieces incidental to normal feeding. Once ingested, this debris may block the digestive tract, lessen feeding, and cause ulceration or other physical injury to the stomach lining. It has been suggested that ingested plastics may also release toxic chemicals (Day et al. 1985). Animals weakened by the adverse effects of ingestion may then be more susceptible to disease and predators (Laist 1987).

The objectives of this paper are twofold:

1. to review what is known about the ingestion of plastics by marine fishes, and

2. to present recent field and laboratory data on plastic ingestion in larval and juvenile fishes.

REVIEW OF INGESTION

Larvae and Juveniles

The best documentation for ingestion of plastic by marine fishes is, somewhat surprisingly, for larval and juvenile stages. Carpenter et al. (1972) were the first to report larval fishes feeding on plastic. They reported that of 14 species of fishes collected by oblique plankton tows, 8 species contained plastic in their guts (Table 1). These authors found bacteria and polychlorinated biphenyls (PCB's) present on surfaces of the plastic particles. They speculate that a main effect of ingesting the particles may be intestinal blockage in some of the smaller fish.

Kartar et al. (1973), working in the Severn Estuary, United Kingdom, in 1972-73, found as many as 30 polystyrene particles in the stomachs of

Table 1.--Larval and juvenile fishes collected in the field with plastics in their gut.

Species	Mean size (mm)	Source
Clupeidae		
Brevoortia patronus, gulf menhaden	7.6	Govoni (pers. commun.)
Clupea harengus, Atlantic herring	42	Carpenter et al. 1972
Gadidae		
Ciliata mustela, five-beard rockling	--	Kartar et al. 1976
Pollachius virens, pollock	30	Carpenter et al. 1972
Atherinidae		
Menidia menidia, Atlantic silverside	16	Carpenter et al. 1972
Sciaenidae		
Micropogonias undulatus, Atlantic croaker	6.3	Govoni (pers. commun.)
Labridae		
Tautogolabrus adspersus, tautog	91	Carpenter et al. 1972
Gobiidae		
Govius minutus, sand goby	--	Kartar et al. 1976
Cottidae		
Myoxocephalus aenus, grubby	5.8	Carpenter et al. 1972
Cyclopteridae		
Liparis liparis, striped seasnail	--	Kartar et al. 1976
Pleuronectidae		
Platichthys flesus, flounder	20-50	Kartar et al. 1973
Pseudopleuronectes americanus, winter flounder	4.6	Carpenter et al. 1972

0+ and 1+ year class flounder, *Platichthys flesus* (Table 1). In more recent work in the same estuary, Kartar et al. (1976) found only a few particles in the sediment and none in four common species of fish which previously contained plastics. Flounder contained particles, but the numbers found per fish had declined between 1973 and 1975. They conclude that this type of plastic pollution has almost ceased in this particular estuary.

The gut contents of over 3,000 larval gulf menhaden, *Brevoortia patronus*, spot, *Leiostomus xanthurus*, and Atlantic croaker, *Micropogonias undulatus*, from the northern Gulf of Mexico were examined at the Beaufort

Laboratory, National Marine Fisheries Service (NMFS), between 1979 and 1982. Inert material, some of which was plastic, was found in only 20 of the fish (Govoni pers. commun.). Although this research was not designed to look specifically for plastic, it is certain that particles would have been observed had they been present in the gut in amounts found by Carpenter et al. (1972) and Kartar et al. (1973).

Colton et al. (1974) examined over 500 larvae from 22 species collected in water containing high concentrations of plastic spheres and found no plastic particles in the gut contents. They followed up their field work with laboratory experiments to determine if fish held in tanks would feed on these plastic particles and, if so, to measure any resulting effects of ingestion. Five species were tested over a 2-week period (Table 2). Samples were taken at regular intervals to determine if they had fed on the plastic particles. No particles were found in the guts of juveniles or larvae. Tomcod, *Microgadus tomcod*, and striped killifish, *Fundulus majalis*, juveniles were observed to feed on the particles, but they either rejected the particle or it passed through the gut with no harmful effect. These authors concluded that at present levels of abundance, the ingestion of plastics by larvae and juveniles would be minor compared to other pollution problems.

In the laboratory, Hjelmeland et al. (1988) demonstrated that larval Atlantic herring, *Clupea harengus*, would ingest polystyrene spheres (Table 2). The spheres, which had no nutritional value and were not degradable by digestive enzymes, nevertheless induced digestive secretion. However, the response was significantly lower than that obtained when the larvae were fed living prey.

Adults

To our knowledge, there has been no study specifically directed at ingestion of plastics or the effects of ingestion of plastics on adult fish. Most available information has been collected incidental to other studies. This is in spite of the fact that ingestion of plastics is continually cited as a potential hazard to fish (Laist 1986; U.S. Congress 1986).

There are several feeding studies that report finding plastics in the guts of fish incidental to the main objective of the study. A series of papers by Manooch (1973) and various coauthors (Manooch and Hogarth 1983; Manooch and Mason 1983; Manooch et al. 1984, 1985) are a good example. These authors found plastics of various types in five species of pelagic fishes and one anadromous fish (Table 3).

It is assumed that these plastic items were eaten accidentally or that they were mistaken for natural prey. Tuna, *Thunnus* spp., and dolphin, *Coryphaena hippurus*, seem to have the most diverse collection of plastics in their guts (Fig. 1), and this is probably due to both their feeding habits and their association with drift lines where plastic and other debris are known to collect (Manooch and Mason 1983; Manooch et al. 1984). These authors suggested that gut contents of dolphins could serve as indicators of surface water quality.

Table 2.--Results of laboratory experiment using plastic microspheres.

Species	Life stage	Results
Clupeidae		
Clupea harengus, Atlantic herring	Larval	Ingested pellets.[a]
Gadidae		
Melangrammus aeglefinus, haddock	Larval	Ingestion negative no plastic in gut.[b]
Microgadus tomcod, tomcod	Juvenile	Ingested plastic but rejected or passed it.[b]
Cyprinodontidae		
Fundulus majalis, striped killifish	Juvenile	Ingested plastic but rejected or passed it.[b]
Gasterosteidae		
Gasterosteus aculeatus, threespine stickleback	Juvenile	Ingestion negative no plastic in gut.[b]
Pleuronectidae		
Pseudopleuronectes americanus, winter flounder	Larval and juvenile	Ingestion negative no plastic in gut.[b]

[a]Hjelmeland et al. 1988.
[b]Colton et al. 1974.

There is some observational evidence (Manooch pers. commun.) that plastics may remain in the guts of fish for long periods of time and be encysted in the stomach or gut lining. The long-term effect of this is not known but could hardly be beneficial to the fish.

Plastic cups were reported from the stomachs of cod, *Gadus morphua*, whiting, *Micromesistius poutassou*, and pollock, *Pollachius virens*, off the coast of the United Kingdom (Anonymous 1975). One pollock was found to contain four cups. Apparently the source of the cups was from the cross-channel ferries. The author concludes that the fish will eventually die since the cups are indigestible, but no evidence is presented for this statement.

CURRENT NATIONAL MARINE FISHERIES SERVICE RESEARCH

Previous studies have shown a high degree of patchiness in plastic distribution in the sea. This patchiness is attributable to currents, winds, and differential inputs (Shaw and Mapes 1979). In recent years scientists have focused increasingly on oceanographic fronts for numerous

Table 3.--Plastic found in adult marine fishes.

Species	Type of plastic	Source
Gadidae		
Gadus morphua, Atlantic cod	Plastic cups	Anonymous 1975.
Micromesistius poutassou, blue (pout) whiting	Plastic cups	Anonymous 1975.
Pollachius virens, pollock	Plastic cups	Anonymous 1975.
Percichthyidae		
Morone americana, white perch	Plastic pellets	Carpenter et al. 1972.
Morone saxatilis, striped bass	Plastic cigar holder	Manooch 1973.
Coryphaenidae		
Coryphaena hippurus, dolphin	Nylon rope, bottle, packaging, colored fragments	Manooch et al. 1984.
Scombridae		
Acanthocybium solanderi, wahoo	Fragment of black plastic sheeting	Manooch and Hogarth 1983.
Euthynnus alletteratus, little tunny	Packaging	Manooch et al. 1985.
Thunnus albacares, blackfin tuna	Plastic bag, colored fragments	Manooch and Mason 1983.
Thunnus atlanticus, yellowfin tuna	Colored fragments	Manooch and Mason 1983.
Triglidae		
Prionotus evolans, striped searobin	Plastic pellets	Carpenter et al. 1972.

reasons; among them are the observations that fishes (as well as sea turtles, marine mammals, and seabirds) are often aggregated about these zones along with the flotsam and other debris.

Both adult and larval fishes, including species of economic importance, have been observed in aggregations along frontal zones, but there has been little work describing the possible effects of associated debris.

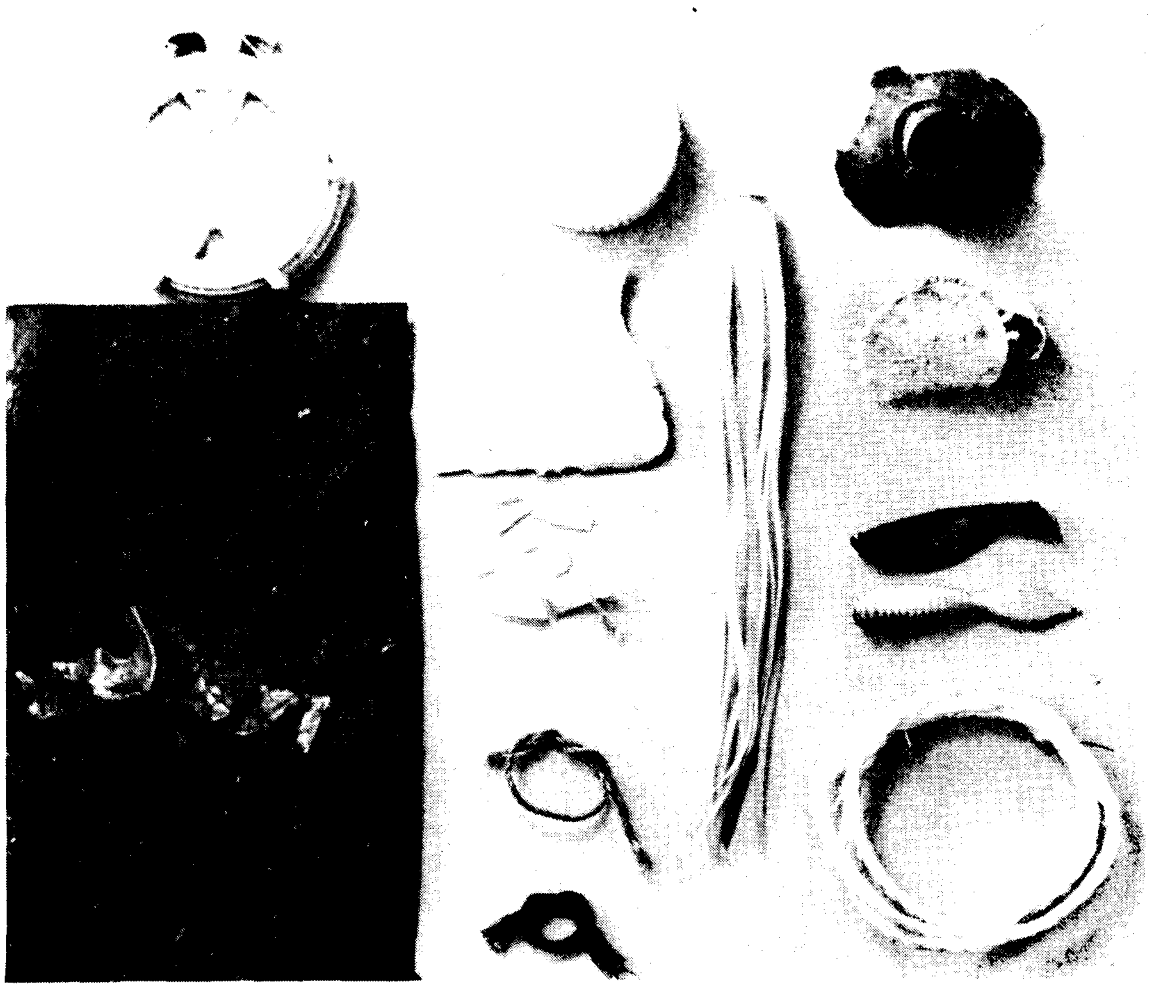

Figure 1.--Material removed from stomachs of adult dolphin and tuna by Manooch (see Table 3).

The objectives of the ongoing studies are to:

- continue to characterize and quantify microdebris particles in coastal waters in and around fronts, and
- determine if larval and early juvenile fish will ingest plastic particles under laboratory conditions, and if so, to assess the effect of the particles on the fish (e.g., prevention of feeding).

Distribution and Characterization

Although plastic pellets have been reported in average densities of 1,000 to 4,000 km^2 on the surfaces of the North Atlantic, South Atlantic, and Pacific Oceans (Carpenter et al. 1972; Carpenter and Smith 1972; Colton et al. 1974; Morris and Hamilton 1974; Wong et al. 1974; Gregory

1977; Shiber 1979; Day 1980), their distribution and abundance in the Gulf of Mexico is not well documented. We examined samples from three sites in the northern Gulf of Mexico (Cape San Blas, Florida, the plume of the Mississippi River, and Galveston, Texas) collected on a cruise in 1981. At each of these sites, sample tows were made with a multiple opening and closing net and environmental sensing system (MOCNESS) (Wiebe et al. 1976) at the surface, mid-depth, and bottom of the water column. Water samples from these stations were examined for the presence of small plastic particles such as those found by Carpenter et al. (1972) and Colton et al. (1974) (Fig. 2).

Of the 51 samples examined from the December collection, 27 were from the surface and the remaining 24 were from the middle of the water column. The greatest number of particles were found in the upper 7 m of the water column in the vicinity of Southwest Pass (Tester et al. 1987) (Table 4). This may be a reflection of both the high utilization of this area by shipping and industry and the outflow of the Mississippi River.

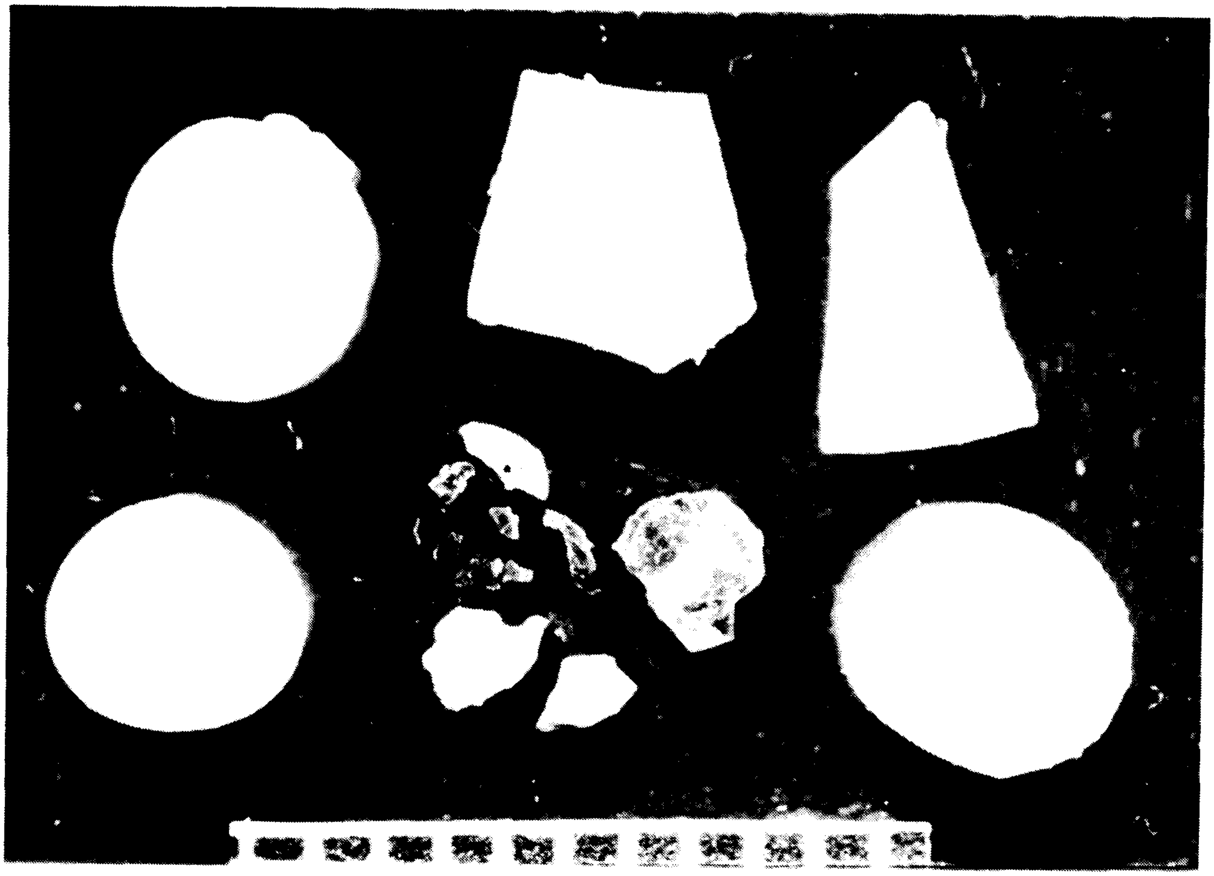

Figure 2.--Plastic material removed from samples collected at three sites in the northern Gulf of Mexico. Scale at bottom in millimeter.

Feeding Experiments

During 1988 and 1989, we conducted a series of feeding experiments (Settle et al. in prep.) to determine 1) if early life stages of marine fishes would ingest plastic particles in the laboratory, and 2) what effects ingestion might have. A similar, but inconclusive, investigation was attempted by Colton et al. (1974). We used polystyrene microspheres sorted to appropriate food particle size (100-500 μm). All plastic particles were "aged" in algae-rich seawater for at least 2 weeks. Six species of fish were used: Atlantic menhaden, *Brevoortia tyrannus*, pinfish, *Lagodon rhomboides*, spot, *Leiostomus xanthurus*, striped mullet, *Mugil cephalus*, southern flounder, *Paralichthys lethostigma*, and flounder, *Paralichthys* spp. Menhaden were laboratory spawned; all others were collected from the Newport River estuary, North Carolina. Fish were maintained in 5-L tanks and starved for 48 h prior to the introduction of plastic particles. Particle concentrations ranged from 200 to 1,000 L^{-1}.

All species except *Paralichthys* spp. were observed ingesting plastics, but rejection was also commonly observed (Table 5). Experiments lasted from 10 min to 19 h. At the end of the experimental period, fish were killed and their guts examined. Four of the six species had plastic particles in their alimentary tract. Thus, even though some plastics were rejected, some were fully ingested as well. Mullet and spot ingested the greatest quantity of particles, with some containing over 30 particles (maximum 45) (Fig. 3).

These results showed conclusively that these species would ingest aged plastic particles when deprived of food for 48 h, and in some cases retain particles in the gut for several hours.

Based on these results, a second series of experiments were conducted on mullet (21-25 mm SL) and spot (16-23 mm) to investigate if plastic ingestion would cause mortality. As in the previous work, the fish were starved for 2 days prior to the start of the experiment. The fish were initially fed plastic spheres (1,000 L^{-1}), with brine shrimp, *Artemia* spp., added after 10 min. These experiments were conducted for 10 days during which brine shrimp were added on a daily basis. Plastic spheres were left in the tank throughout the experiment.

Both spot and mullet were observed to ingest plastic particles when they were first added. They also were observed to reject some of the particles. Spot took plastic from the water column and off the bottom while mullet fed only from the water column. When brine shrimp were present, both species appeared to select them over the plastic and usually rejected plastic if ingested. There was no experimental mortality observed during the 10-day period and the fish were observed defecating. Therefore, it does not appear that the plastic blocked the gut.

At the end of the experiment the fish were sacrificed, measured, and examined for plastic in their guts. Six of twenty-four spot contained plastic. It is likely that spot ingested particles throughout the experiment, either those resuspended in the water each day or those on the

Table 4.--Small plastic particles in the Gulf of Mexico. Samples were taken from the surface to near bottom. Stations A1, B1, and D1 were only in 18.3 m (10 fathoms) of water, and A2, B2, and D1 were in 91.4 m (50 fathoms) of water. Plastics were collected only at the depths indicated.

Region	Station	Sample depth (m)	Particles per 100 m^3
Mississippi River	A1	1	26
		2	67
		5	31
		5	19
		6	5
		7	60
	A2	1	2
		2	1
Cape San Blas, Florida	B1	1	5
		3	1
		8	2
	B2	1	1
		30	1
		31	2
Galveston, Texas	D1	1	4
		5	9
	D2	1	1

bottom. Particles were well distributed throughout the alimentary tract, giving the impression that they were being effectively passed (Fig. 4). None of 20 mullet contained pellets at the end of the 10 days although they were observed to feed on them during the course of the experiment.

DISCUSSION AND CONCLUSIONS

There is now ample evidence to state that marine fish of many species will eat plastic debris. Larval and juvenile fishes have been collected in the field with plastic fragments and raw plastic pellets in their guts. Adult fishes have been found with a wide variety of material in their guts ranging from unidentified fragments to whole cups and bottles. There is almost no evidence, however, to determine the magnitude of the problem or to determine if ingestion is an important cause of mortality in fish.

Table 5.--Results of aged polystyrene microsphere feeding experiments (Settle et al. in prep). (+ indicates plastics were ingested, - indicates plastics were not ingested.)

Species	Size range (mm)	Particle size (m)	Ingestion	Percent with plastic in gut
Clupeidae				
Brevoortia tyrannus, Atlantic menhaden	9-29	100-500	+	0
Sparidae				
Lagodon rhomboides, pinfish	11-14	350-500	+	15
Sciaenidae				
Leiostomus xanthurus, spot	19-25	350-500	+	15
Mugilidae				
Mugil cephalus, striped mullet	18-25	210-350	+	75
Bothidae				
Paralichthys lethostigma, southern flounder	13-15	210-250	+	6
Paralichthys spp., flounder	10-15	350-500	-	0

It has been suggested that ingestion of plastic production pellets by larval and juvenile fishes may cause blockage of the digestive tract and prevent normal feeding. There is no experimental evidence that we know of to support this. In those laboratory experiments where larvae have fed on pellets (Colton et al. 1974; Hjelmeland et al. 1988; Settle et al. in prep.), the pellets have either been rejected or passed through the gut. In our experiments the larvae subsequently fed on brine shrimp nauplii and appeared healthy. Had the larvae been fed angular particles or particles containing toxic chemicals, the results may have been different. In the sea, dead larvae would seldom if ever be collected because of rapid decomposition.

Food habit studies confirm that large fish also eat plastic material, but the frequency and quantity of material eaten is not well documented. Ingestion of large pieces of plastic by fish may cause a health problem. Many predatory fish have large mouths and can swallow large pieces of plastic. They cannot digest the plastic, however, and it may prove to be too large to pass from the stomach into the gut and out the anus. If the fish cannot regurgitate the piece, it may block the intestine or cause ulceration.

Figure 3.--Spot, *Leiostomus xanthurus* (17 mm standard length), with ingested polystyrene microspheres (350-500 μm) in the gut.

We conclude that the overall ingestion of inert plastic by larval and juvenile fish is probably not a significant mortality factor at this time in the ocean environment. Monitoring of larval fishes from different areas to determine if the frequency of occurrence of plastic in the guts is changing should be continued and incorporated into ongoing ichthyoplankton studies.

We also recommend that studies be conducted to determine if larger predatory fishes can swallow and subsequently pass large, irregular pieces of plastic. Additional mortality caused by plastic ingestion might be detrimental to populations of certain species of sport fish already under intense fishing pressure.

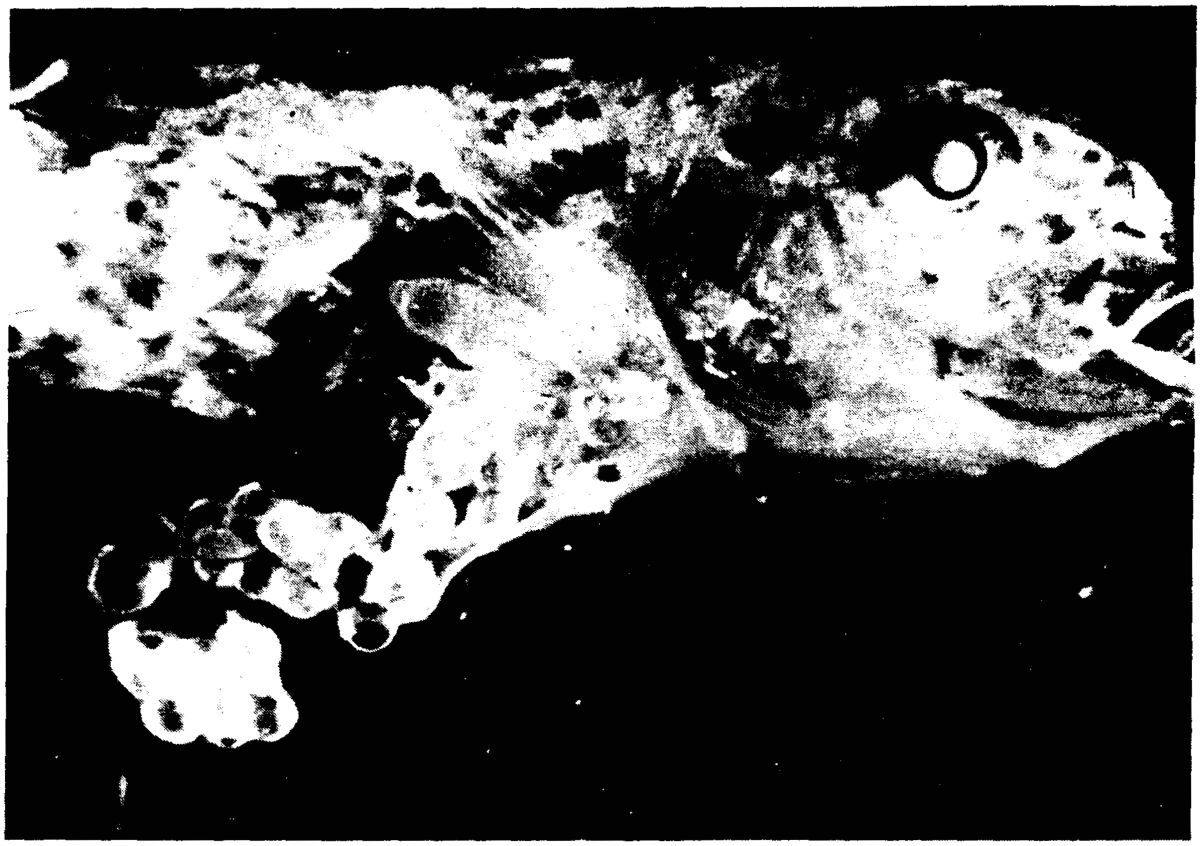

Figure 4.--Spot, *Leiostomus xanthurus* (17 mm standard length), partially dissected to show polystyrene microspheres (350-500 μm) distributed throughout the alimentary tract.

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