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The Effect of Inherited Contamination on Egg and Larval Winter Flounder, *Pseudopleuronectes americanus*

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ABSTRACT

The exposure of adult winter flounder, Pseudopleuronectes americanus, *to contaminated [illegible] environments and a possible impact of this exposure on their progeny was investigated. Polluted study areas included Gaspee Point in upper Narragansett Bay, RI, New Bedford Harbor in Buzzards Bay, MA, noted for its PCB contamination, and Apponagansett Bay, MA, a less contaminated site near New Bedford. Fox Island, a relatively clean area in lower Narragansett Bay, served as a reference area. Although adult winter flounder disperse offshore during the summer, a tag and recapture study verified their yearly residence and exposure to contaminants at Gaspee Point during the spawning season. A similar migratory pattern was assumed for Buzzards Bay fish. Growth, survival and contaminant residues were measured in the progeny of fish collected from the study areas. Eggs from New Bedford Harbor flounder contained significantly higher levels of PCB (39·6 μg g^{-1} dry weight), and larvae which hatched from these eggs, under clean laboratory conditions, were significantly smaller in length (2·96 mm) and weight (0·018 mg) than those from Fox Island fish (1·08 μg PCB g^{-1} dry weight, 3·22 mm, 0·022 mg). Linear regression analysis indicated a significant inverse relationship between PCB content of the eggs and length or weight at hatch. The adverse ecological consequence of small size at hatch is discussed.*

INTRODUCTION

Exposure to pollutants can affect individual fish directly or it may adversely impact succeeding generations through bioaccumulation in ovarian eggs.

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This is particularly true for organic pollutants which have an affinity for lipids, a major component of fish eggs. These eggs may exhibit reduced fertilization or increased embryo and larval mortality, reduced growth and abnormal development may result; all may decrease the chances for survival of the population (Sprague, 1971; Rosenthal & Alderdice, 1976). Our research examines the exposure of adult winter flounder to polluted natural environments prior to spawning, and a possible impact of this exposure upon their progeny.

METHODS AND MATERIALS

Study areas (Fig. 1)

Narragansett Bay, Rhode Island, is characterized by a gradient of anthropogenic contamination. To the north the upper bay receives wastes from the industrialized city of Providence including effluents from sewage treatment plants, jewelry and plating industries, chemical manufacturing, and pollution from harbor activities. Scientific investigations have confirmed elevated concentrations of heavy metals (Phelps & Galloway,

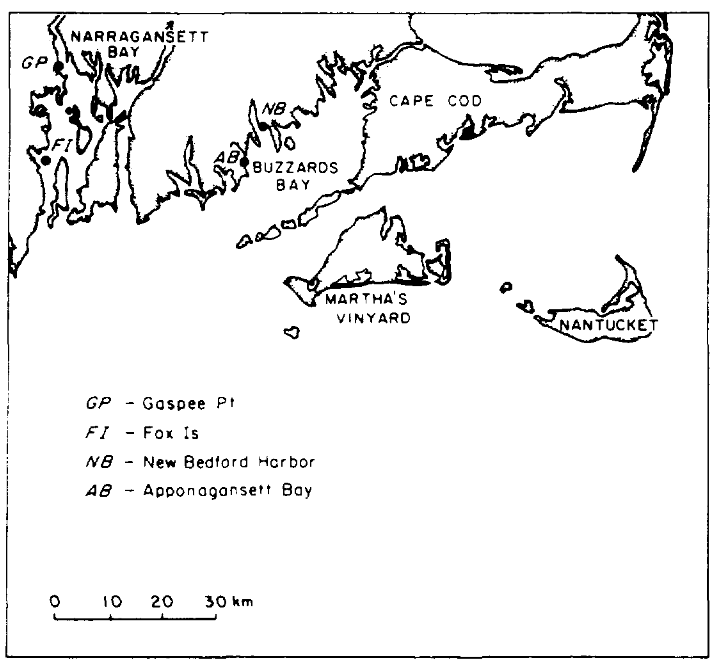

Fig. 1. Study areas in Narragansett Bay, RI, and Buzzards Bay, MA, where mature adult winter flounder were collected.

1980), petroleum hydrocarbons (Farrington & Quinn, 1973; Van Vleet & Quinn, 1977, 1978), and polychlorinated biphenyls (PCBs) along with other chlorinated organic compounds (Lake *et al.*, 1981; Lake, unpublished) and polycyclic aromatic hydrocarbons (Lake *et al.*, 1979). Gaspee Point lies near the mouth of the Providence River and was selected as a study site because it typifies the polluted upper bay. The area is permanently closed to shellfishing and commercial trawling for finfish, but it supports a population of winter flounder, *Pseudopleuronectes americanus*, and is sufficiently free of debris to allow sampling with a small otter trawl.

To the south, Narragansett Bay boasts high water quality (Phelps & Galloway, 1980) and productive commercial fisheries. Selected as a 'clean' study area, Fox Island lies in the lower bay and waters adjacent to it support a population of winter flounder.

New Bedford Harbor, located in Buzzards Bay, lies east of Narragansett Bay along the southern coast of Massachusetts and was selected as a study area heavily impacted by man's industrial activities. New Bedford is noted for its severe PCB pollution problem and the extent of contamination is sufficient to place it on the US Environmental Protection Agency's Superfund list of hazardous sites. PCBs were discharged into New Bedford Harbor via the Acushnet River, as well as into Buzzards Bay, through the New Bedford wastewater treatment plant at Clarks Point from 1947 to 1978 (Weaver, 1984). The PCB contamination from the harbor spread to other areas of the bay and led to closures in 1979 of shellfish, including lobster, and finfishing grounds in Buzzards Bay. The harbor is also a source of heavy metal contamination resulting from an 80 year history of industrial discharges. Copper, chromium and zinc are the major pollutants, but silver, cadmium and lead are also present at elevated levels (Stoffers *et al.*, 1977).

Sediment samples outside of New Bedford harbor in other areas of Buzzards Bay have high concentrations of PCBs and metals indicating the gradual spread of contaminants (Stoffers *et al.*, 1977; Weaver, 1984). The mouth of Apponaganset Bay was chosen as an impacted area of lesser contamination within Buzzards Bay.

Tag and recapture study

A tag and recapture study was conducted to ascertain the migratory habits of winter flounder. This study was confined to Narragansett Bay, at Fox Island and Gaspee Point, because we relied upon commercial and sport fisherman for tag returns, and the Buzzards Bay study areas are closed to fishing. Approximately 500 fish were captured by otter trawl, tagged and released at each station during March and April. The total length and sex of each fish were recorded. Peterson disk tags were used and a reward was offered for their return. The study was advertised by poster in local bait shops and commercial fishing operations. When a tag was returned, information on date, place, method of recapture and total length was requested.

Egg and larval rearing

In March 1979, mature winter flounder were collected by otter trawl at Gaspee Point and Fox Island in Narragansett Bay, and in March, 1981, similar collections were made at Fox Island and the two Buzzards Bay stations, New Bedford Harbor and Apponagansett Bay. Fish were transported in large polyethylene garbage cans filled with seawater from the collection site, then held at the laboratory in flowing unfiltered Narragansett Bay water at ambient temperature (5–10°C) until they spawned.

To induce spawning, injections of carp pituitary were administered following the procedure of Smigielski (1975) and all fish spawned within one week in 1979 and 17 days in 1981. When ready to spawn, total length of the female was measured and her eggs were stripped into a Nitex† screen (500 μm) basket, fertilized with a mixture of sperm from three Fox Island males and coated with diatomaceous earth to prevent clumping following the procedure of Smigielski & Arnold (1972). The eggs were rinsed thoroughly and the basket placed in a black polyethylene rearing tank (34 × 30 × 15 cm) containing 6 liters of filtered, UV treated sea water with 25 ppm penicillin and 25 ppm streptomycin added to retard bacterial growth. An air stone provided water circulation around the eggs. Each rearing tank contained eggs from only one female and was considered to be a replicate. Thus, in 1979, there were eleven Gaspee Point and four Fox Island replicates. Similarly, in 1981, there were ten New Bedford Harbor, three Apponagansett Bay and nine Fox Island replicates.

After hatch, which occurred within 11 days, two hundred larvae from each replicate were transferred by pipette to clean black polyethylene rearing tanks containing 6 liters of sea water treated as previously described. Again, each rearing tank contained larvae from only one female. The larval rearing methods were similar to Klein-MacPhee *et al.* (1980), with the exception that in 1981, a diet of laboratory-cultured rotifers (*Brachionus plicatilis*) was used, instead of a rotifer and wild plankton mixture, until the larvae were large enough to ingest *Artemia* nauplii. Throughout both years' experiments a temperature of 8 ± 1°C was maintained by floating the rearing tanks in a chilled water bath. Salinity of the rearing water ranged from 28 to 32‰ and the light regime was 12 h light/12 h dark.

† Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the US Environmental Protection Agency.

Biological measurements

A suite of biological variables were measured during egg incubation and larval rearing. The percentage of fertilization, indicated by appearance of the perivitelline space, was measured within 30 min after spawning. Percentage survival of the embryos was measured 1 day prior to hatch. At hatch, the total length of 20 individuals from each group was measured. After 8 weeks, survival and per cent metamorphosis were recorded. The total length and dry weight of each survivor were determined as follows. After length was measured, the larva was rinsed three times with ammonium formate solution to remove the salt water, placed on a tared aluminum pan, dried at 90°C for 24 h, cooled in a desicator, and weighed on a Perkin-Elmer microbalance. In the 1981 experiments, dry weight of newly hatched larvae was determined from five groups of five individuals using the method described above.

Chemical analyses

Prior to fertilization, egg samples from individual females were collected for chemical residue analyses. Samples for metals analysis were frozen in polyethylene bags. Samples for organic analysis were frozen in aluminium-foil-covered glass jars that had been combusted at 450°C for 6 h to remove organic contaminants.

For determination of petroleum hydrocarbons in 1979, samples were thawed, then extracted as outlined in Dimock *et al.* (1980). The first fraction (F1) obtained from this column contained the aliphatic material; the second fraction (F2) contained aromatic compounds. Naturally occurring olefinic compounds may be present in both fractions. Each fraction was volume reduced and analyzed on a 20 m SE-54 glass capillary column with a Hewlett-Packard 5840A gas chromatograph and flame ionization detection.

Eggs from the 1981 experiments were analyzed for PCBs using routine procedures described in Lake *et al.* (1985). The samples were extracted with a polytron and organic solvents, separated by column chromatography with silicic acid and analyzed by electron capture detection glass capillary column chromatography. The PCBs were analyzed and quantified as Aroclor 1254.

Trace metal analyses were performed on both 1979 and 1981 fish egg samples. Routine sample preparation included oven drying and concentrated nitric acid digestion and yielded 50 ml samples in 5% nitric acid solutions. Copper, iron, zinc, nickel, chromium, cadmium and lead concentrations were determined by flame atomization atomic absorption (AA) with a Perkin-Elmer (model 603) atomic absorption spectrophotometer. The AA instrument was equipped with D2 arc background correction and was calibrated before, during and after each set of samples for a given element. The instrument setup procedures for the flame AA determinations were in accordance with procedures described in *Methods for chemical analysis of water and wastes* (US EPA, 1979) and are also found in the manufacturer's reference manuals.

Statistical methods

Other research has shown that both the size of the adult female and the use of pituitary hormone injections to induce spawning can affect the biological responses and chemical residues that were measured in our study. For example, positive correlations between PCBs, as well as other organochlorines, and body weight have been found in lake trout and gurnards (Bache *et al.*, 1972; Ernst *et al.*, 1976). For both striped bass and herring, positive correlations have been found between adult size and egg size, which, in turn, may increase larval survival (Blaxter & Hempel, 1963; Rogers & Westin, 1981). The literature citing effects of pituitary hormone injections on progeny viability is conflicting. Some investigators report production of inferior gametes after induced spawning, while others report good fertilization, viable hatch, and normal larvae (Clemens & Sneed, 1962; Smigielski, 1975). Because of this evidence, and since the adult size and the number of hormone injections administered varied in our study, any relationship that existed between these adult variables and the embryo-larval variables should be considered. Therefore, an analysis of covariance, using adult length and number of hormone injections as covariates, was performed on the biological and chemical variables to determine if any significant ($\alpha = 0{\cdot}05$) differences existed among the sampling stations. Where one or both covariates had a significant relation with the dependent variable, adjusted means were calculated and differences among the adjusted means were tested using a Least Square Means pairwise comparison test. The arcsin $\sqrt{p}$ transformation was applied to percentage variables to stabilize the variances; 1981 PCB data was log transformed. Due to small changes in experimental method, each year was considered a separate data set and no between-year comparisons were made. The relationship between PCB concentration (untransformed) in the eggs and subsequent larval length and weight at hatch was examined using linear regression analysis.

RESULTS

Tag and recapture study

Of the 997 fish tagged, 196 tags (20%) were returned. Table 1 and Figs 2, 3 and 4 present the tag and recapture data. The yearly migration pattern for

TABLE 1
Data on Winter Flounder Tagged at Two Stations in Narragansett Bay, RI

	Gaspee Point	*Fox Island*
Number tagged	498	499
Male	113 (23%)	205 (41%)
Female	383 (77%)	292 (59%)
Unknown	2 (< 1%)	2 (< 1%)
Number recaptured	85 (17%)	111 (22%)
Male	17 (20%)	52 (47%)
Female	68 (80%)	59 (53%)
Recapture method		
Otter trawl	59 (70%)	101 (91%)
Rod and reel	19 (22%)	3 (1%)
Spear fishing	0 (0%)	1 (1%)
Unknown	7 (8%)	6 (5%)
Length at tagging		
Mean (range)	26·5 (18·8–44·6) cm	28·7 (19·0–45·9) cm
Length of recaptures		
Mean (range)	29·0 (19·8–44·7) cm	30·3 (18·4–44·0) cm

winter flounder tagged at each study area during March and April 1980 was determined from fish recaptured in 1980, 1981 and 1982. By summer (June–September) most fish had moved off the spawning grounds, with Gaspee Point fish concentrating in the lower bay and Fox Island fish moving offshore, although individuals from both populations were recaptured in areas offshore of Cape Cod, Nantucket and Martha's Vinyard. In the fall and winter (October–February) the fish migrated back into Narragansett Bay and began to be recaptured near the spawning areas again. In the spring (March–May) the majority of fish were recaptured on the spawning grounds where they were originally tagged and released, although some dispersion of both populations occurred near Prudence Island, between Conanicut Island and Aquidneck Island, and at the mouth of the bay. It is probable that flounder return to the spawning areas earlier than March; however, tag returns during the winter were few, due to declining fishing effort during cold weather. This is especially true at Gaspee Point, since commercial trawling is prohibited in the upper bay and recaptures from that area were solely by sport fishermen.

The migratory pattern revealed by recaptured fish shows that during the spring spawning season, Gaspee Point and Fox Island support distinct groups of winter flounder which return to their respective spawning grounds in subsequent years. It is during this season when body reserves are low due to harsh winter conditions and stress of spawning that the Gaspee Point

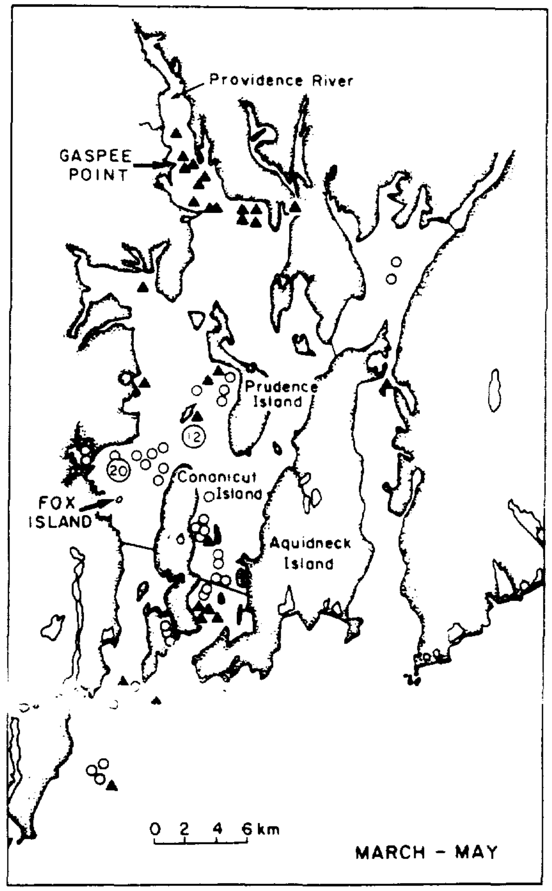

Fig. 2. March–May recapture locations of winter flounder tagged and released at Gaspee Point and Fox Island in Narragansett Bay, RI. Each symbol represents one return unless indicated by an inscribed number. Solid triangles represent fish captured, tagged and released at Gaspee Point; open circles, Fox Island.

group would be exposed to upper bay contamination. During the remainder of the year, these fish mix with the Fox Island group and reside in the relatively clean lower bay and offshore areas. There is no evidence that Fox Island fish move into the Providence River.

Egg and larval rearing

In 1981, significant covariate relations were found between adult length and percentage fertilization, larval survival, length at hatch, weight at hatch, final weight, copper concentration in the eggs, and PCB concentration in the eggs. The number of hormone injections administered prior to spawning was

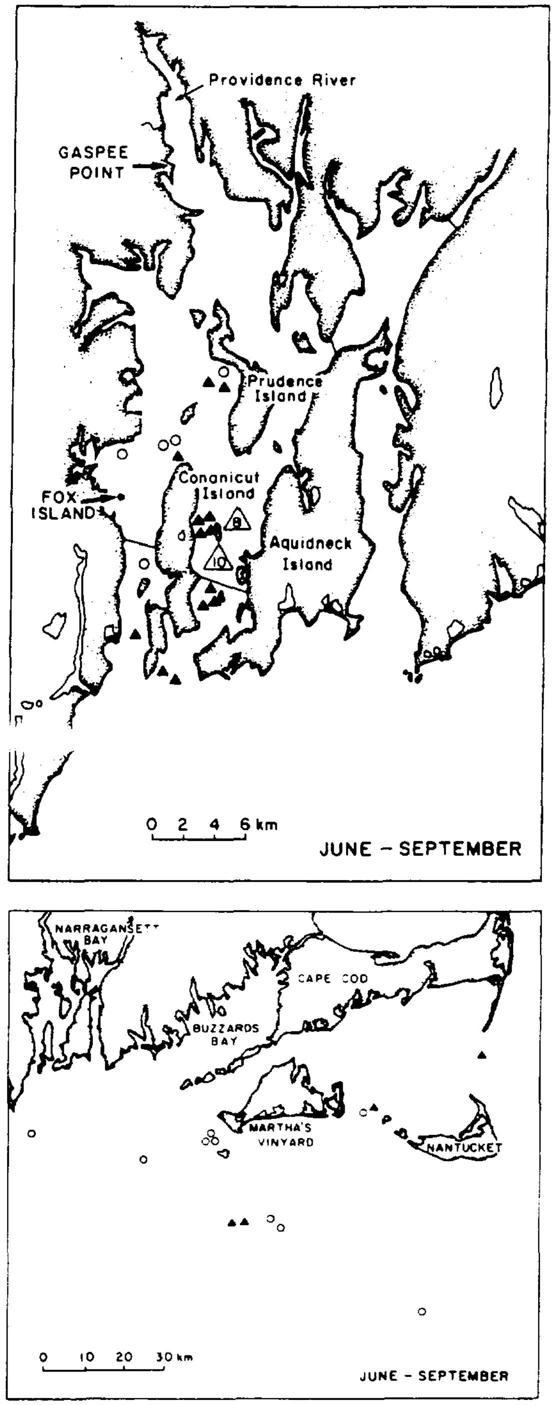

Fig. 3. June–September winter flounder recapture locations. Symbols as in Fig. 2.

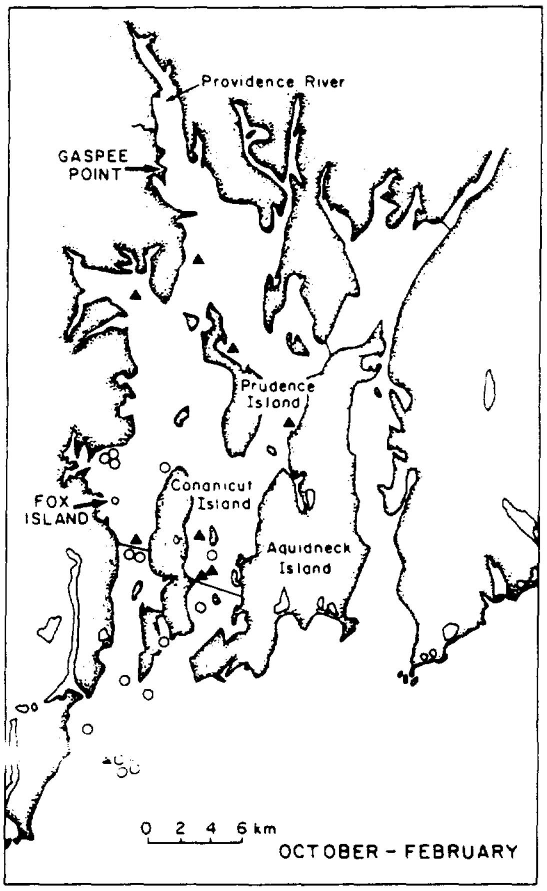

Fig. 4. October–February winter flounder recapture locations. Symbols as in Fig. 2.

related to embryo survival and iron concentration. No covariate relations were found for per cent metamorphosis, final length, and zinc concentration. In 1979, a significant covariate relation was found between adult length and larval survival, copper, zinc and iron concentrations.

Tables 2 and 3 present mean values, adjusted for significant covariation, and station comparisons of each biological response and chemical residue. In 1979, significant differences between stations were found in total hydrocarbon and F1 fraction hydrocarbon residues in the eggs; however, no inter-station differences were observed in the biological variables. Due to this lack of response, adult fish were collected in 1981 from two stations, New Bedford Harbor and Apponagansett Bay, in Buzzards Bay, Massachusetts, which is known to be more contaminated than Narragansett Bay. At the same time, another collection was made at Fox Island for comparison. Significant inter-station differences were observed in the PCB residues of these eggs, with New Bedford Harbor (39·6 $\mu g\, g^{-1}$ dry weight)

TABLE 2
Adjusted Mean Values with Standard Errors and Significant Station Differences for Winter Flounder Embryo-larval Biological Responses. Based on Results of Analysis of Covariance (AOCOV)

Biological response	*1979*				*1981*			
	Station[a]	*N*	*Mean (standard error)*	*AOCOV*[b]	*Station*	*N*	*Mean (standard error)*	*AOCOV*
Per cent fertilization	FI	3	87·3 (2·9)	a	FI	9	99·0 (1·1)	a
	GP	11	95·2 (2·6)	a	AB	3	80·2 (16·0)	b
					NB	10	98·5 (1·3)	a
Per cent embryo survival	FI	4	85·0 (4·8)	a	FI	9	84·1 (4·3)	a
	GP	11	82·4 (6·6)	a	AB	3	72·7 (17·0)	a
					NB	10	88·8 (9·4)	a
Per cent larval survival	FI	4	10·2 (2·9)	a	FI	9	16·5 (2·6)	a
	GP	11	8·1 (1·6)	a	AB	3	18·3 (4·9)	a
					NB	10	17·6 (5·8)	a
Per cent metamorphosis	FI	4	43·3 (8·5)	a	FI	9	18·8 (3·7)	a
	GP	10	32·7 (7·0)	a	AB	3	41·0 (1·5)	a
					NB	9	21·3 (4·5)	a
Length at hatch (mm)	FI	4	3·13 (0·13)	a	FI	9	3·22 (0·05)	a
	GP	11	3·17 (0·12)	a	AB	3	3·08 (0·11)	ab
					NB	10	2·96 (0·05)	b
Weight at hatch (mg)			(Not measured)		FI	9	0·022 (0·001)	a
					AB	3	0·020 (0·002)	ab
					NB	10	0·018 (0·001)	b
Final length (mm)	FI	4	8·38 (0·31)	a	FI	9	8·03 (0·14)	a
	GP	10	7·92 (0·18)	a	AB	3	8·57 (0·03)	a
					NB	9	8·10 (0·10)	a
Final weight (mg)	FI	4	0·728 (0·147)	a	FI	9	0·573 (0·037)	a
	GP	8	0·562 (0·165)	a	AB	3	0·749 (0·079)	a
					NB	9	0·536 (0·037)	a

[a] Station code: Fox Island, FI; Gaspee Point, GP; Apponagansett Bay, AB; New Bedford Harbor, NB.
[b] Values with different letters are significantly different ($\alpha = 0·05$). No between-year comparisons were made.

being the most contaminated and significantly different from Fox Island (1·08 $\mu g\ g^{-1}$), the least contaminated. Apponagansett Bay eggs (15·7 $\mu g\ g^{-1}$) were intermediate in PCB content, but not significantly different from New Bedford Harbor eggs. No differences between stations were found for metal residues. Two biological variables, length and weight at hatch, revealed station differences which varied inversely with the amount of PCB found in the eggs. Newly-hatched larvae from New Bedford Harbor females were 0·2 mm (6%) smaller in length and 0·004 mg (18%) smaller in weight than larvae from Fox Island. Larvae from Apponagansett Bay females were intermediate in size and not significantly different from either Fox Island or New Bedford Harbor progeny. Linear regression analysis of data from all sites indicated a significant inverse relationship between PCB content of the

TABLE 3

Adjusted Mean Values with Standard Errors and Significant Differences for Chemical Residues in Freshly-spawned Winter Flounder Eggs, Based on Results of the Analysis of Covariance

Chemical[a] *residue* *(µg g⁻¹ dry weight)*	*1979*				*1981*			
	Station[b]	*N*	*Mean (standard error)*	*AOCOV*[c]	*Station*	*N*	*Mean (standard error)*	*AOCOV*[c]
PCB	(not measured)				FI	9	1·08 (0·24)	a
					AB	3	15·7 (7·5)	b
					NB	8	39·6 (8·6)	b
Total hydrocarbons	FI	4	3·63 (1·02)	a	(not measured)			
	GP	11	9·77 (1·04)	b				
F1 (Aliphatic) hydrocarbons	FI	4	2·50 (0·82)	a	(not measured)			
	GP	11	7·95 (0·90)	b				
F2 (Aromatic) hydrocarbons	FI	4	1·13 (0·22)	a	(not measured)			
	GP	11	1·83 (0·24)	a				
Copper	FI	4	2·56 (0·29)	a	FI	9	2·20 (0·37)	a
	GP	11	2·43 (0·17)	a	AB	3	3·48 (0·78)	a
					NB	10	3·20 (0·36)	a
Zinc	FI	4	67·4 (5·2)	a	FI	9	60·6 (2·6)	a
	GP	11	62·4 (3·1)	a	AB	3	59·2 (0·9)	a
					NB	10	64·7 (2·5)	a
Iron	FI	4	14·2 (1·5)	a	FI	9	16·9 (1·0)	a
	GP	11	12·9 (0·9)	a	AB	3	17·0 (3·0)	a
					NB	10	17·6 (1·0)	a

[a] Wet weight:dry weight ratio is 5·59.
[b] Station code: Fox Island, FI; Gaspee Point, GP; Apponagansett Bay, AB; New Bedford Harbor, NB.
[c] Values with different letters are significantly different ($\alpha = 0{\cdot}05$). No between-year comparisons were made.

eggs and length or weight at hatch (Fig. 5 and Table 4). Inter-station differences which did not correspond to contaminant residue levels were found for per cent fertilization and will be discussed below. Nickel, chromium, cadmium and lead were measured in the eggs, but, for both years, residues were below the detection level of the methodology. Approximate detection limits were 2·5, 2·5, 0·8 and 1·7 $\mu g\, g^{-1}$, respectively.

TABLE 4

Results of Linear Regression Analysis of PCB Content of Eggs and Larval Size

		Weight at hatch	*Length at hatch*
PCB content of eggs	p	0·008 9	0·023 2
	r	−0·57	−0·50

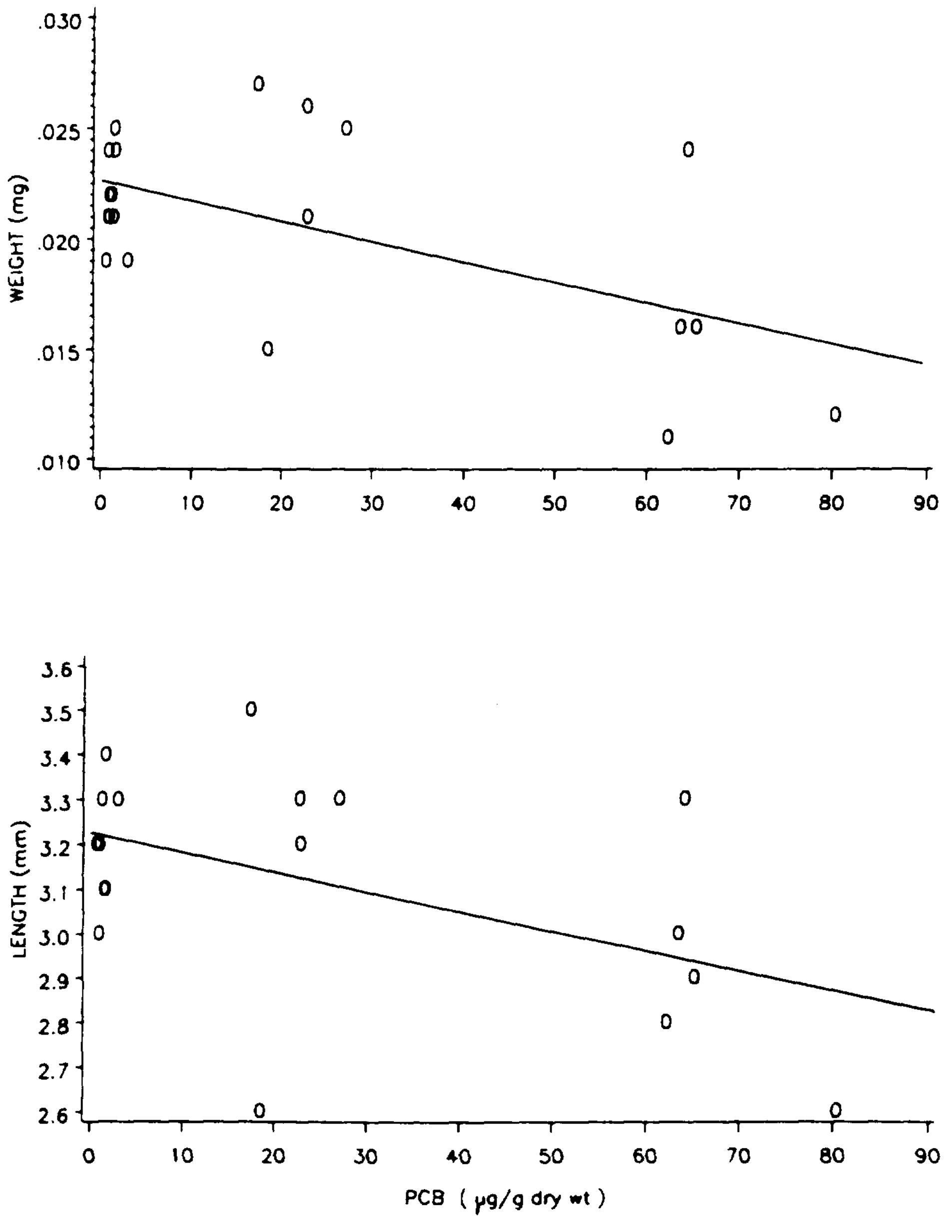

Fig. 5. Relationship between PCB concentration in winter flounder eggs and the larval length and weight at hatch.

DISCUSSION

Migratory habits

Fish are mobile and often migratory organisms; therefore, when making inferences about exposure of wild fish, one must be confident that the sample population is indeed exposed to the contaminated environment under study. Fish movement may be restricted by physical barriers such as a fresh water lake or confinement to cages or, as with winter flounder, behavioral characteristics may limit movement. Saila (1961) showed by tag and recapture studies that winter flounder from Green Hill Pond, Rhode Island, are dispersed in cooler offshore waters during the summer (June to November) but reassemble to spawn in Green Hill Pond during the winter (November to June). The present study confirmed this homing behavior for flounder in Narragansett Bay, verifying that exposure to contamination at Gaspee Point occurs at least during March through May and possibly earlier. It is assumed that similar migration occurs at the Buzzards Bay study areas.

The idea that contaminant bioaccumulation in adult fish would adversely affect their progeny is not new, and a review of this research, including effects of PCB's, DDT and heavy metals, is given by von Westernhagen *et al.* (1981). In our study the PCB content of eggs from the Buzzards Bay stations was significantly higher than that of Fox Island eggs and corresponding station differences were observed in larval size at hatch; that is, eggs from New Bedford Harbor with high PCB residues produced newly-hatched larvae that were smaller in length and weight than Fox Island larvae. Upon further examination of this inverse relation, significant linear correlations were found between PCB content and larval size parameters. Whether a cause and effect relationship exists is unknown, since it is very possible that other contaminants covarying with PCBs could produce the response. As these larvae grew to metamorphosis, in clean water free of predators and fed a diet known to support larval development, the station differences disappeared. Such recovery may be due to biotransformation and detoxification of contaminants via mixed-function oxidase enzyme systems known to exist in embryos of some teleost species (Binder & Stegeman, 1980).

To the authors' knowledge only one other study has examined the relationship between PCB content of eggs and larval growth. Westin *et al.* (1983) obtained eggs with different PCB residues from Hudson River striped bass (*Morone saxatilis*) and fed the hatched larvae diets differing in PCB content. After comparing the various treatments, they concluded that inherited and dietary PCB concentrations do not affect larval growth and survival 20 days after yolk sac absorption. If comparisons of larval size were made only at metamorphosis, which occurs several weeks after yolk sac absorption in winter flounder, our data would support a similar conclusion about inherited PCB residue. Westin *et al.* (1983) did not measure size at hatch, but they did observe retarded initial growth, at 10 days after yolk sac absorption, which they attributed to an experimental design that delayed feeding until yolk sac absorption was complete. Our data suggest that the influence of inherited PCB residue might also have contributed to the retarded growth.

For a larval fish, the consequence of smaller size at hatch may be severe, since the best survival strategy is rapid growth (Marr, 1956; Cushing, 1974; Ware, 1975). Small larvae are inefficient predators and at the same time more vulnerable to predation due to reduced visual and swimming ability. The high metabolic cost of inefficient prey capture reduces the energy available for growth, and due to a rudimentary digestive tract, they have inefficient digestion as well. In addition, small larvae have less yolk reserves to sustain them during the critical transition to exogenous feeding when prey capture behavior must be learned (Blaxter & Hempel, 1963; Laurence, 1977). Recently, Logan (1985) developed a size-dependent mortality model for young fish which accurately predicted the numerical decline of the 1975 cohort of Hudson River striped bass. According to his model, the greatest decrease in population size is caused by reductions in growth rate, length at hatch, and number of larvae at hatch, in the order of the magnitude of their effect. Recruitment is linearly related to the parental stock or number of eggs or larvae and exponentially related to growth or size. Logan states that 'environmental factors affecting survival rate through size could more strongly influence year class strength than initial number, which affects the subsequent population size directly but has little or no influence on survival rate'. His model may be applicable to other estuarine and marine species such as winter flounder, although this has not been demonstrated.

In the present study, no significant differences were found in embryo survival, larval survival or per cent metamorphosis, and although Apponagansett Bay eggs had a significantly lower per cent fertilization than the other groups, it was the result of exceptionally low fertilization (51%) of eggs from one female, and whether the sample is representative of the entire Apponagansett Bay population is unknown. The lack of effects on survival and fertilization is similar to Hansen *et al.* (1975) who found that water column exposure of adult sheepshead minnows (*Cyprinodon variegatus*) to PCB (Aroclor 1016) resulted in accumulation of up to 77 $\mu g\ g^{-1}$ (wet weight) in the eggs with no apparent effect on fertilization success, embryo survival, or fry survival to two weeks post hatch. In contrast, most other research has indicated detrimental influence of PCBs on these biological variables. For example, sheepshead minnow eggs with Aroclor 1254 levels greater than

$7\,\mu g\,g^{-1}$ exhibited decreased embryo survival to hatch and decreased fry survival one week post hatch (Hansen *et al.*, 1973). In a study similar in design to ours, von Westernhagen *et al.* (1981) observed consistently reduced viable hatch of progeny from Baltic flounder (*Platichthys flesus*) whose ovarian PCB content exceeded $120\,ng\,g^{-1}$ (wet weight). Hogan & Brauhn (1975) found 75% mortality in hatchery-reared rainbow trout containing $2800\,ng\,g^{-1}$ (wet weight) PCB compared to the previous years' 10–28% mortality in trout eggs with PCB content ranging from $310–1300\,ng\,g^{-1}$. Bengtsson (1980) found significantly reduced and delayed spawning activity of adult minnows (*Phoxinus phoxinus*) fed PCB-contaminated diets, as well as reduced and premature hatching of their progeny.

The only route of exposure examined in this study was inherited contamination from adult exposure to a polluted natural environment during oocyte maturation. The resulting progeny were reared under clean laboratory conditions and the observed response in the most contaminated group, New Bedford Harbor, was smaller size at hatch. Eight weeks later, at metamorphosis, compensatory growth had eliminated the significant differences between New Bedford Harbor and Fox Island fish. In the absence of predators and under the good water quality and nutritional conditions provided in the laboratory, these larvae were able to compensate for the initial retarded growth; however, the fate of larvae in New Bedford Harbor where contaminant exposure would continue throughout development is unknown.

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REFERENCES

Bache, C. A., Serum, J. W., Youngs, W. D. & Lisk, D. J. (1972). Polychlorinated biphenyl residues: Accumulation in Cayuga lake trout with age. *Science*, **177**, 1191–2.

Bengtsson, B.-E. (1980). Long-term effects of PCB (Clophen A50) on growth, reproduction and swimming performance in minnow. *Phoxinus phoxinus*. *Water Res.*, **14**, 681–7.

Binder, R. L. & Stegeman, J. J. (1980). Induction of aryl hydrocarbon hydroxylase activity in embryos of an estuarine fish. *Biochem. Pharmacol.*, **29**, 949–51.

Blaxter, J. H. S. & Hempel, G. (1963). The influence of egg size on herring larvae. *J. Cons. Perm. Int. Explor. Mer.*, **28**, 211–40.

Clemens, H. P. & Sneed, K. E. (1962). Bioassay and use of pituitary materials to spawn warm-water fishes. *Res. Rep. U.S. Fish Wildl. Serv.*, **61**, 1–30.

Cushing, D. H. (1974). The early life history of fish. (J. H. S. Blaxter (Ed.)). Springer-Verlag, New York, NY, 103–11.

Dimock, C. W., Lake, J. L., Norwood, C. W., Bowen, R. D., Hoffman, E. J., Kyle, B. & Quinn, J. G. (1980). Field and laboratory methods for investigating a marine gasoline spill. *Environ. Sci. Technol.*, **14**, 1472–5.

Ernst, W., Goerke, H., Eder, G. & Schaefer, R. G. (1976). Residues of chlorinated hydrocarbons in marine organisms in relation to size and ecological parameters. I. PCB, DDT, DDE and DDD in fishes and molluscs from the English Channel. *Bull. Env. Contam. Toxicol.* **15**, 55–65.

Farrington, J. W. & Quinn, J. G. (1973). Petroleum hydrocarbons in Narragansett Bay. I. Survey of hydrocarbons in sediment and clams (*Mercenaria mercenaria*). *Estuar. & Coast. Mar. Sci.*, **1**, 71–9.

Hansen, D. J., Schimmel, S. C. & Forester, J. (1973). Aroclor 1254 in eggs of sheepshead minnows: Effect on fertilization success and survival of embryos and fry. *Proc. 27th Ann. Conf. Southeastern Assoc. Game and Fish Commissioners*, 420–3.

Hansen, D. J., Schimmel, S. C. & Forester, J. (1975). Effects of Aroclor 1016 on embryos, fry, juveniles and adults of sheepshead minnows (*Cyprinodon variegatus*). *Trans. Am. Fish. Soc.*, **3**, 584–8.

Hogan, J. W. & Brauhn, J. L. (1975). Abnormal rainbow trout fry from eggs [illegible] high [illegible] PCB (Aroclor 1242). *Prog. Fish Cult.*, **37**, 229–30.

Klein-MacPhee, G., Howell, W. H. & Beck, A. D. (1980). *The brine shrimp*, Artemia. *Vol. 3 Ecology, culturing, use in aquaculture*. (Persoone, G., Sorgeloos, P., Roels, O. and Jaspers, E. (Eds)). Universa Press, Wetteren, Belgium, 305–12.

Lake, J. L., Norwood, C., Dimock, C. & Bowen, R. (1979). Origins of polycyclic aromatic hydrocarbons in estuarine sediments. *Geochim. Cosmochim. Acta*, **43**, 1847–54.

Lake, J. L., Rogerson, P. F. & Norwood, C. B. (1981). A polychlorinated dibenzofuran and related compounds in an estuarine ecosystem. *Environ. Sci. Technol.*, **15**, 549–53.

Lake, J. L., Hoffman, G. L. & Schimmel, S. (1985). Bioaccumulation of contaminants from Black Rock Harbor dredged material by mussels and polychaetes. Technical Report D-85-2, prepared by US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, RI, for the US Army Engineer Waterways Experiment Station, Vickburg, MS, 150 pp.

Laurence, G. C. (1977). A bioenergetic model for the analysis of feeding and survival potential of winter flounder, *Pseudopleuronectes americanus*, larvae during the period from hatching to metamorphosis. *Fish. Bull. Natl. Oceanic & Atmos. Adm. (US)*, **75**, 529–46.

Logan, D. T. (1985). Environmental variation and striped bass population dynamics. A size-dependent mortality model. *Estuaries*, **8**, 28–38.

Marr, J. C. (1956). The 'critical period' in the early life history of marine fishes. *J. Cons. perm. int. Explor. Mer.*, **21**, 160–70.

Phelps, D. K. & Galloway, W. B. (1980). A report on the Coastal Environmental Assessment Stations (CEAS) program. *Rapp. P.-v. Reun. Cons. perm. int. Explor. Mer.*, **179**, 76–81.

Rogers, B. A. & Westin, D. T. (1981). Laboratory studies on effects of temperature and delayed initial feeding on development of striped bass larvae. *Trans. Am. Fish. Soc.*, **110**, 100–10.

Rosenthal, H. & Alderdice, D. F. (1976). Sublethal effects of environmental stressors, natural and pollutional, on marine fish eggs and larvae. *J. Fish. Res. Bd. Can.*, **33**, 2047–65.

Saila, S. B. (1961). A study of winter flounder movements. *Limnol. Oceanogr.*, **6**, 292–8.

Smigielski, A. S. (1975). Hormonal-induced ovulation of the winter flounder, *Pseudopleuronectes americanus. Fish. Bull. Natl.*

Smigielski, A. S. & Arnold, C. R. (1972). Separating and incubating winter flounder eggs. *Prog. Fish Cult.*, **34**, 113.

Sprague, J. B. (1971). Measurement of pollutant toxicity to fish. III. Sublethal effects and 'safe' concentrations. *Wat. Res.*, **5**, 245–66.

Stoffers, P., Summerhayes, C., Forstner, U. & Pachineelam, S. R. (1977). Copper and other heavy metal contamination in sediments from new Bedford Harbor, Massachusetts: A preliminary note. *Environ. Sci. Technol.*, **11**, 819–21.

US Environmental Protection Agency (1979). Methods for Chemical Analysis of Water and Wastes. US Environmental Monitoring and Support Laboratory, Office of Research and Development, EPA/600-4-79-020.

Van Vleet, E. S. & Quinn, J. G. (1977). Input and fate of petroleum hydrocarbons entering the Providence River and upper Narragansett Bay from wastewater effluents. *Environ. Sci. Technol.*, **11**, 1086–92.

Van Vleet, E. S. & Quinn, J. G. (1978). Contribution of chronic petroleum inputs to Narragansett Bay and Rhode Island Sound sediments. *J. Fish. Res. Bd. Can.*, **35**, 536–43.

von Westernhagen, H., Rosenthal, H., Dethlefsen, V., Ernst, W., Harms, U. & Hansen, P. D. (1981). Bioaccumulating substances and reproductive success in Baltic flounder *Platichthys flesus. Aquat. Toxicol.*, **1**, 85–99.

Ware, D. M. (1975). Relation between egg size, growth, and natural mortality of larval fish. *J. Fish. Res. Bd. Can.*, **32**, 2503–12.

Weaver, G. (1984). PCB contamination in and around New Bedford, Mass. *Environ. Sci. & Technol.*, **18**, 22A–27A.

Westin, D. T., Olney, C. E. & Rogers, B. A. (1983). Effects of parental and dietary PCBs on survival, growth and body burdens of larval striped bass. *Bull. Environ. Contam. Toxicol.*, **30**, 50–7.