Abstract.—This study represents an attempt to distinguish between normal seasonal variations and pollutant-related changes in the blood chemistry of the windowpane flounder *Scophthalmus aquosus*. Three stations in Long Island Sound, USA, were chosen to provide a pollutant gradient. Windowpane flounder were collected from the three stations monthly, when possible, over a period of three years. Seasonal variations were noted in hematocrit, plasma osmolality, sodium, potassium, and calcium. Station-related differences were demonstrated in osmolality, hematocrit, and hemoglobin. The same species was subjected to 60-day laboratory exposures to mercury, cadmium, or copper. Neither copper nor cadmium produced a significant difference in any variable measured. Following exposure to mercury, there were significant differences between controls and exposed animals in plasma sodium and calcium.

Blood Chemistry of the Windowpane Flounder *Scophthalmus aquosus* in Long Island Sound: Geographical, Seasonal, and Experimental Variations

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The geographical situation of Long Island Sound presents unique questions on the distribution of anthropogenic pollutants and the effects of such pollutants on the resident animal population. The western end of the Sound is heavily populated and industrialized. Much of the bottom in the western portions of the Sound consists of fine-grained sediments, with a potential for adsorbing and retaining contaminants (Hunt 1979, Reid et al. 1979). Tidal flushing is limited in the far western end of the Sound; it has been reported that exchange with the East River adds 15 m^3/second of effluent to western Long Island Sound (Bowman 1976).

In contrast, the more eastern portions of the Sound are open to considerable tidal flushing and are bordered by less populated and less industrialized areas. There is a decrease in fine-grained sediments from west to east with a concomitant decrease in the capacity of the sediment to retain contaminants (Hunt 1979, Reid et al. 1979). The physical and geographical differences are reflected in an increase from east to west in sediment levels of heavy metals (Greig et al. 1977, Hunt 1979, NOAA 1988), PCBs (Chytalo 1979, NOAA 1988), and PAHs (NOAA 1988).

The present study is an attempt to assess the effects on a local species of the contaminant levels found in Long Island Sound. Stations were selected on the basis of providing a pollutant gradient and of being located within an area that could be sampled on a day-trip basis, thereby expediting monthly sampling (Fig. 1). Station 1 was off Roanoke Point, New York (lat. 40°58′50″N, long. 72°45′00″W), near the eastern end of the central basin. Reid et al. (1979) reported that this station had less than 5% fine-grained sediments. Greig et al. (1977) reported a sediment cadmium concentration of 1.1 mg/kg dry weight, a copper concentration of 4.0 mg/kg, and a lead concentration of <6.0 mg/kg. Station 2 was off Milford, Connecticut (lat. 40°09′01″N, long. 73°00′00″W), near the western end of the central basin. Reid et al. (1979) reported that this station had a fine-grained sediment level between 5 and 50%. Greig et al. (1977) reported sediment cadmium and mercury levels below detectable limits, a copper concentration of 43.3 mg/kg, and a lead concentration of 19.0 mg/kg. Station 3, Hempstead Harbor, New York (lat. 40°53′50″N, long. 73°49′90″W) is in the western end of Long Island Sound. Reid et al. (1979) reported a fine-grained sediment content of >50%. Greig et al. (1977) reported a cadmium concentration of 1.4 mg/kg, a copper concentration of 175.0 mg/kg, a mercury concentration of 0.7 mg/kg, and a lead concentration of 110.0 mg/kg in the sediment. NOAA (1988) reported a total PCB concentration of 255.5 μg/kg and a total PAH concen-

Manuscript accepted 26 March 1990.
Fishery Bulletin, U.S. 88:429-437.

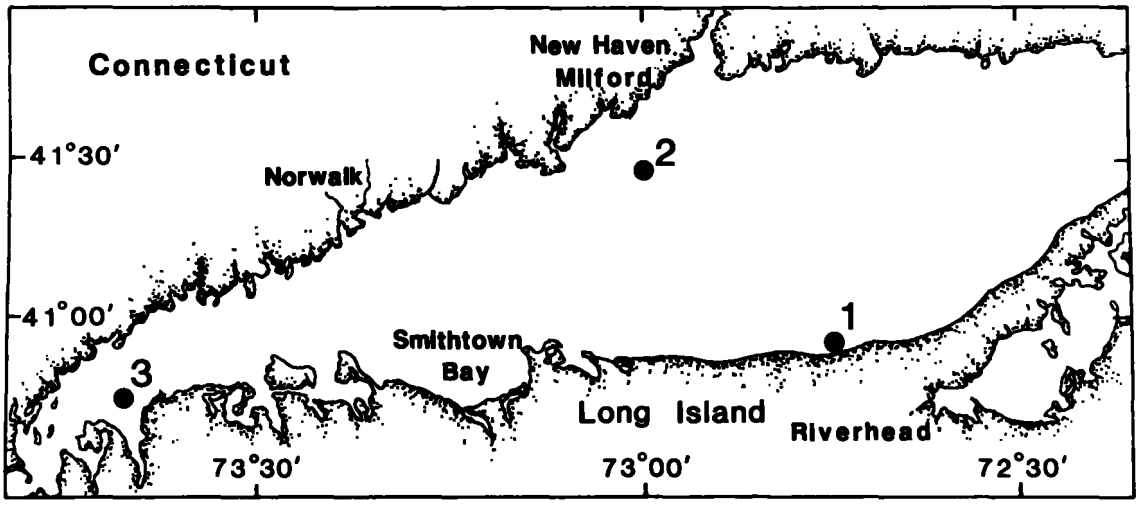

Figure 1

Long Island Sound stations sampled for *Scophthalmus aquosus*: Station 1, off Shoreham, NY, 5.5 m; Station 2, off Milford, CT, 15.2 m; Station 3, Hempstead Harbor, NY, 10.7 m.

tration of 5366 μg/kg in the sediments of Hempstead Harbor.

The windowpane flounder *Scophthalmus aquosus* was chosen as a test animal because it is one of the few species available in the Long Island Sound area throughout the year. The possibility of some movement between stations is a consideration in this type of study. However, Moore (1947) reported on the basis of tagging studies that, although individuals have been shown to move over large distances, no seasonal migration of windowpane flounder is indicated and that this species is relatively stationary.

This study utilized blood chemistry as an indication of stress in the fish. Several investigators have suggested that the study of blood may ultimately be as useful in assessing the health of fish as it is in diagnosing human health (Blaxhall and Daisley 1973, Hickey 1976). Fish blood chemistry has not received the same critical study as has human (Wedemeyer and Yasutake 1977). A given species of fish in its normal habitat is likely to be subjected to a wide range of natural conditions, any of which may be reflected in its blood chemistry. Johansson-Sjöbeck et al. (1975) noted that hematocrit increased and hemoglobin decreased in eels subjected to starvation, both returning to control levels within 164 days. DeWilde and Houston (1967) reported an increase in hematocrit and hemoglobin with an increase in acclimation temperature in rainbow trout; the degree of response depended on season. Effects of heavy-metal exposure on fish blood have been demonstrated (Christensen et al. 1972; Calabrese et al. 1975; Dawson 1979, 1982). Within the same species, freshwater-adapted fish often exhibit blood chemistry which is different from that of fish adapted to seawater (Courtois 1976). Snieszko (1960) emphasized the need to consider two sets of standards in using hemotological methods in hatcheries: one general standard for the species, and a second standard that determines a normal value for the parameter at a particular hatchery.

Although the objective of the present study was to obtain information on pollutant-related stress, it was necessary to consider seasonal changes as well in order to distinguish between the effects of pollutants and those that represent a normal response to changing natural conditions. Although seasonal changes in fish blood have received little attention in the literature, such changes have been documented in the winter flounder (Bridges et al. 1976), the striped bass (Lochmiller et al. 1989) and the rainbow trout (DeWilde and Houston 1967). In addition, the values for hematological measurements vary from species to species, but few species have received sufficient study to allow a realistic estimate of their normal ranges under a reasonable variety of conditions.

The field study described here was supplemented by a series of three laboratory exposures of the same species to heavy metals. Although laboratory exposures are subject to criticism on the grounds that they do not correspond closely to natural conditions, they do make it possible to attribute changes to a particular pollutant, which is not often possible in the field.

Materials and methods

Field study

Windowpane flounder for the field study were collected by otter trawl using 30-minute tows at the three desig-

nated stations and held in running seawater aboard the boat until blood samples were taken, generally within 1 hour after the fish were collected. On occasion, because of inclement weather, it was necessary to return to the laboratory and sample the fish at dockside; in that case, the interval between capture and sampling was up to 4 hours.

The stations were sampled monthly unless inclement weather or boat repairs precluded sampling. Generally, blood samples were taken from 20 fish at each station; if fewer fish were obtained, sample numbers were necessarily smaller. Of 102 collections used, 67 consisted of 20 fish each, 33 of 10–19 fish, and one each of 8 and 9 fish. Respective lengths of fish sampled at Station 1, 2, and 3 were 26.7 ± 0.13, 25.0 ± 0.16, and 25.6 ± 0.15 cm. Hematocrit (Hct), hemoglobin (Hb), plasma osmolality, sodium, potassium, and calcium were measured on each blood sample. Prior to each fish collection, a bottom-water sample was collected for measurement of temperature, salinity, and dissolved oxygen. Four preliminary collections were made at each station in 1979; intensive sampling continued from May 1980 through April 1983.

Exposure studies

Windowpane flounder were exposed to mercury, copper, or cadmium in the laboratory. Fish used in the exposure studies were collected by otter trawl using 15- or 30-minute tows in the vicinity of Milford, Connecticut, and transported to the laboratory in running seawater. They were held at the laboratory for at least 2 weeks prior to exposure. In general, exposures were conducted during the colder months when the fish do not normally feed much. However, they were given small amounts of minced surf clam *Spisula solidissima* weekly. The fish measured 24.8 ± 0.21 cm in length and 158.4 ± 4.2 g in weight.

Three 60-day exposures were performed: the first used $HgCl_2$ at a nominal mercury concentration of 5 or 10 µg/L, the second used $CuCl_2 \cdot 2H_2O$ at a nominal copper concentration of 10 or 20 µg/L, and the third used $CdCl_2 \cdot 2½H_2O$ at a nominal cadmium concentration of 5 or 10 µg/L. Measured concentrations were 5.1 ± 0.60 ppb and 12.7 ± 2.20 ppb for low and high cadmium concentrations, and 19.2 ± 1.4 for the high copper concentration. Background metal levels were below 1 µg/L for mercury, below 5 µg/L for copper, and below 1 µg/L for cadmium. The fish were exposed in 285-L fiberglass tanks filled to 225 L with sand-filtered Milford Harbor seawater by a proportional dilution apparatus (Mount and Brungs 1967). The diluter controlled the intermittent delivery of toxicant-containing or control seawater at a flowrate of 1.5 L every 2.5 minutes throughout the exposure period. This provided a flow of 864 L per day and an estimated 90% replacement time of 15 hours (Sprague 1969). The seawater was at ambient salinity during the exposures. The temperature was slightly above ambient because the water was held in the heated building during filtration and delivery.

Duration of the mercury exposure was 22 December 1979–20 February 1980. The salinity range during that time was 25.0–26.9‰. Temperature in the exposure tanks was 8°C at the beginning of the exposure, dropping to 3-4°C throughout most of the month of February when the exposure was completed. During the mercury exposure, each tank held 5 fish for a total of 20 fish per concentration and 20 controls.

The copper exposure ran from 7 January through 8 March 1983. Salinity during the exposure period was 24.4–26.4‰. Temperature was 9°C at the beginning of exposure, dropped to a low point of 6°C in mid-February, and gradually rose to 9°C at the end. Three tanks at each concentration held 4 fish per tank.

Duration of the cadmium exposure was 27 January–28 March 1984. Salinity range during that time was 22.6–25.9‰. Temperature was 6.5°C at the beginning of the exposure, rising to 8.5°C at the end. The lowest temperature recorded was 5.0°C on 3 February. Twenty fish were exposed per concentration, 5 fish per tank.

Blood chemistry

The parameters measured were hematocrit (Hct), hemoglobin (Hb), mean corpuscular hemoglobin concentration (MCHC), plasma osmolality, sodium, potassium, and calcium. Erythrocyte counts (RBC) and calculations of mean corpuscular hemoglobin (MCH) and mean corpuscular volume (MCV) were performed only on animals used in exposures.

Blood was collected from each animal by cardiac puncture using a 3-mL plastic syringe and a 20- or 22-gauge needle. The sample was transferred gently into an 8-mL glass vial containing 150 units of dried ammonium heparinate as an anticoagulant. Immediately following collection of the last blood sample, a portion of each blood sample was centrifuged at 12 000 g and the plasma frozen for later determination of osmolality, sodium, potassium, and calcium. The remaining whole-blood sample was used for the determination of hemoglobin, hematocrit, and erythrocyte counts. Hemoglobin was determined by the cyanmethemoglobin method using Hycel chemicals. Microhematocrits were determined following centrifugation for 5 minutes at 13 500 g. Erythrocyte counts were made in a hemacytometer; blood samples were diluted 1:200 with Yokoyoma's solution (Katz 1950). Plasma osmolality was determined with an

Table 1

Effects of 60-day exposure to mercury on blood of windowpane flounder *Scophthalmus aquosus* in Long Island Sound. Values are mean ± standard error, with number of samples in parentheses. Number of samples is often fewer than that of fish exposed because of clotting or pooling of samples.

		Mercury concentration	
Test	Control	5 μg/L	10 μg/L
Hematocrit (%)	22.00 ± 1.3 (17)	25.00 ± 1.4 (15)	24.00 ± 1.6 (18)
Hemoglobin (g/100 mL)	4.10 ± 0.2 (17)	4.30 ± 0.3 (15)	3.40 ± 0.2 (18)
Erythrocytes (10^6 cells/mm^3)	2.14 ± 0.17 (9)	2.13 ± 0.14 (9)	2.41 ± 0.29 (10)
MCV (μ^3/cell)	96.60 ± 5.7 (9)	109.80 ± 4.0 (9)	103.90 ± 9.1 (10)
MCH (pg/cell)	20.20 ± 1.6 (9)	21.10 ± 1.2 (9)	18.90 ± 1.2 (10)
MCHC (g/100 mL)	19.10 ± 1.0 (17)	18.40 ± 0.6 (15)	18.10 ± 0.5 (18)
Na (mEq/L)	179.00 ± 3.9 (11)	181.00 ± 3.5 (14)	*199.00 ± 3.3 (13)
K (mEq/L)	8.21 ± 0.85 (11)	6.93 ± 0.66 (14)	8.52 ± 0.81 (13)
Ca (mEq/L)	4.95 ± 0.23 (11)	*3.91 ± 0.18 (14)	*3.60 ± 0.19 (13)
Osmolality (mOsm)	338.00 ± 7.7 (9)	328.00 ± 4.0 (14)	331.00 ± 2.9 (12)

MCV = Mean corpuscular volume
MCH = Mean corpuscular hemoglobin
MCHC = Mean corpuscular hemoglobin concentration
*Significantly different from controls ($P<0.05$).

Advanced 3L osmometer; the effect of the added heparin on osmolality was negligible. Plasma sodium, potassium, and calcium concentrations were measured with a Coleman 51 flame photometer. At times it was necessary to pool the small plasma samples, resulting in slightly fewer samples for plasma ions and osmolality. Mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) were determined using the following equations (Platt 1969):

MCV in μ^3/cell = 10 Hct/RBC
MCH in pg/cell = 10 Hb/RBC
MCHC in g/00 mL packed red cells = 100 Hb/Hct

Statistical differences were determined by one-way analysis of variance and the Scheffe test (Hicks 1973).

Results

Exposure studies

Results of the 60-day exposure of windowpane flounder to mercury are summarized in Table 1. Red blood cells in the species appear to be unaffected by mercury at the test concentrations used in this study. Control flounder had a mean hematocrit of 22 ± 1.3%, a mean hemoglobin of 4.1 ± 0.2 g/100 mL, and a red cell count of 2.4 ± 0.17 × 10^6 cells/mm^3. Following a 60-day exposure of the fish to 5 or 10 μg/L mercury, none of these variables differed signficantly from control values, nor did the indices calculated from the three variables (namely, MCH, MCV, and MCHC). The mean plasma sodium level in flounders exposed to 10 μg/L mercury was 199 ± 3.3 mEq/L, significantly higher than the control value of 179 ± 3.9 mEq/L. Plasma calcium decreased from the control value of 4.95 mEq/L to 3.91 ± 0.18 and 3.60 ± 0.19 m/Eq/L in animals exposed to 5 and 10 μg/L mercury, respectively. There were no significant differences between controls and mercury-exposed flounder in plasma potassium or osmolality (Table 1).

No significant difference was demonstrated between controls and animals exposed to either concentration of cadmium or copper in any of the parameters measured.

Field study

The data from each season were divided by sex and compared using the Scheffe test; no significant sex-related differences were noted. The data were grouped into four size-classes (<20.0 cm, 20.1–25 cm, 25.1–30.0 cm, >30 cm) and compared for each season; no significant size-related differences were noted during any season. Because of the lack of differences, data from both sexes and all size-classes are shown together.

Overall, windowpane flounder taken from Station 3 had significantly higher hematocrits and hemoglobin concentrations than did those taken from Station 1.

Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 2

Hematocrits of windowpane flounder *Scophthalmus aquosus* in Long Island Sound. Values are percent ± standard error, with number of fish in parentheses.

Station	Winter	Spring	Summer	Fall
1	[a,b]20.6 ± 0.9 (78)	[c]23.2 ± 0.3 (172)	[d]24.9 ± 0.4 (140)	23.8 ± 0.4 (139)
2	[b]22.1 ± 0.4 (105)	24.0 ± 0.3 (182)	24.6 ± 0.5 (132)	23.9 ± 0.5 (137)
3	[b]23.2 ± 0.6 (93)	[a,c]26.6 ± 0.4 (178)	[d]25.4 ± 0.4 (136)	[a]25.9 ± 0.4 (139)

[a]Significantly different ($P<0.05$) from all other stations in a given season.
[b]Significantly different from all other seasons at a given station.
[c,d]Significantly different pairs of seasons at a given station.

Table 3

Hemoglobin concentrations of windowpane flounder *Scophthalmus aquosus* in Long Island Sound. Units are g/100 mL ± standard error, with number of fish sampled in parentheses. No significant seasonal variations were demonstrated. Values from Station 1 are significantly lower than those from Stations 2 and 3; however, no contrasts between stations were significant when the data were separated by season.

Station	Winter	Spring	Summer	Fall
1	3.5 ± 0.13 (89)	3.6 ± 0.11 (173)	4.2 ± 0.11 (164)	3.6 ± 0.12 (133)
2	4.0 ± 0.13 (113)	4.0 ± 0.11 (188)	4.0 ± 0.12 (145)	3.8 ± 0.11 (149)
3	3.8 ± 0.14 (84)	3.9 ± 0.10 (169)	4.1 ± 0.10 (153)	4.2 ± 0.14 (150)

Table 4

Seasonal variations in blood chemistry of windowpane flounder *Scophthalmus aquosus* in Long Island Sound. Values are mean ± standard error. Because of the lack of significant differences between stations in these variables, data from all stations are combined.

Variable	Winter	Spring	Summer	Fall
MCHC (g/100 mL)	17.00 ± 0.04 (256)	15.60 ± 0.03 (508)	15.30 ± 0.04 (408)	14.40 ± 0.04 (419)
Sodium (mEq/L)	[a]186.00 ± 0.4 (285)	170.00 ± 0.3 (515)	[b]157.00 ± 0.3 (409)	[b]157.00 ± 0.3 (405)
Potassium (mEq/L)	[a]4.10 ± 0.18 (285)	[b]5.16 ± 0.14 (515)	[b,c]5.48 ± 0.15 (409)	[d]4.25 ± 0.16 (405)
Calcium (mEq/L)	4.22 ± 0.12 (285)	[a]4.43 ± 0.10 (515)	3.79 ± 0.10 (409)	[b]3.49 ± 0.11 (405)

MCHC = Mean corpuscular hemoglobin concentration.
[a,b]Significantly different pairs.
[c,d]Significantly different pairs.

When the data from each station were separated by season, the difference between Stations 1 and 3 in hematocrit was significant during the winter, spring, and fall (Table 2). When the data on hemoglobin levels were separated by season, the difference between stations for any particular season was not significant (Table 3). Variations in hemoglobin from season to season were not significant (Table 3). At each station, the hematocrits of flounders collected during the winter were significantly lower than those of fish collected at any other season (Table 2).

Seasonal means in MCHC ranged from 14.4 to 17.0. There were no significant differences either between stations or between seasons (Table 4).

Plasma sodium levels varied by season but not by station. Because of the lack of difference between stations, the data from the three stations were treated together. The mean sodium value for winter-collected animals at all stations was 186 ± 0.4 mEq/L; this is significantly higher than the summer and fall values, both of which were 157 ± 0.3 mEq/L (Table 4).

Plasma potassium levels varied significantly by season but not by station. The highest levels were found in the summer. The mean value for summer-collected animals of 5.48 ± 0.15 mEq/L was significantly higher than either the winter value of 4.10 ± 0.18 mEq/L or the fall value of 4.25 ± 0.16 mEq/L (Table 4).

Table 5

Plasma osmolalities of windowpane flounder *Scophthalmus aquosus* in Long Island Sound. Units are mOsm ± standard error, with number of fish in parentheses. Within each station, groups which are not significantly different are underlined.

Station	Winter	Spring	Summer	Fall
1	*392 ± 5 (89)	*387 ± 2 (167)	390 ± 2 (129)	*401 ± 2 (124)
2	377 ± 2 (109)	377 ± 2 (170)	393 ± 3 (113)	*389 ± 3 (118)
3	380 ± 2 (87)	374 ± 2 (176)	*383 ± 2 (134)	*377 ± 2 (132)

*Significantly different ($P<0.05$) from all other stations at a given season.

There were no significant differences between stations in plasma calcium levels. The only seasonal variation was a significant difference between the spring value of 4.43 ± 0.10 mEq/L and the fall value of 3.49 ± 0.11 mEq/L (Table 4).

Overall, plasma osmolalities of fish collected from Station 3 were significantly lower than those of fish collected from Station 1. When the data were separated by season, the difference between Stations 1 and 3 for each season was significant (Table 5). During the winter, spring, and fall, plasma osmolalities from Station 2 were also significantly lower than those from Station 1. In general, the lowest plasma osmolalities were found in the spring at each station; the highest, in summer or fall. None of the season-to-season variations in plasma osmolality at Station 3 were significant.

The mean salinity was 27.6‰ at Station 1, 27.9‰ at Station 2, and 26.7‰ at Station 3. The total range of salinity measured was 22.9–30.4‰. The difference between stations for a single month was rarely more than 2‰. Bottom temperatures are summarized in Figure 2. In general, station-to-station differences were slight. Dissolved oxygen concentrations are presented in Figure 3. Station 3 tended to have a low oxygen concentration during the summer. During the cooler months, differences between stations in dissolved oxygen were less pronounced. Station 1 is 5.5 m deep; Station 2, 15.2 m; and Station 3, 10.7 m.

Discussion

This investigation was undertaken in order to observe windowpane flounder blood chemistry in the field and to use a series of laboratory exposures in an attempt to explain the inter-station differences. However, the exposures actually provided only negative information on the causes of differences in blood chemistry observed in the field. The Interstate Sanitation Commission (unpubl.) reported a median copper concentration in the water column of western Long Island Sound of 12 μg/L; the highest reported copper levels were above 60 μg/L. This indicates that the exposure concentrations of 10 and 20 μg/L were realistic in terms of a polluted environment. Few water column cadmium concentrations were above 5 μg/L and the median was 1.0 μg/L. Therefore, the exposure concentrations of cadmium were realistic to slightly high. Mercury levels used in the exposures were high compared with those measured in Long Island Sound waters; the highest measured mercury concentration was 1.8 μg/L and the median was <0.1 μg/L, compared with exposure levels of 5.0 and 10.0 μg/L. The limited effects of mercury at a high exposure level and the lack of effects of cadmium and copper at more environmentally relevant water concentrations clearly demonstrated that the differences between stations cannot be explained by the effects of these metals. The lack of effects of the exposures in the present study does not diminish the possible usefulness of this type of approach. The exposures performed here were by no means comprehensive; a more extensive program of exposures might mimic the inter-station differences.

Bridges et al. (1976) reported changes in blood chemistry and, specifically, the development of anemia in winter flounder held in the laboratory for over 50 days. Anemia was not noted in such animals in the present study; hematocrits and hemoglobin levels of laboratory-held fish were typical of those of animals collected in the field during the same season. However, the plasma potassium levels of windowpane flounder used for the mercury exposure were somewhat higher than those of fish sampled immediately after collection; this may be the result of the length of time that the fish were held in the laboratory.

The geographical range of the field study was limited to stations at which monthly sampling was feasible. This limitation made it possible to describe seasonal

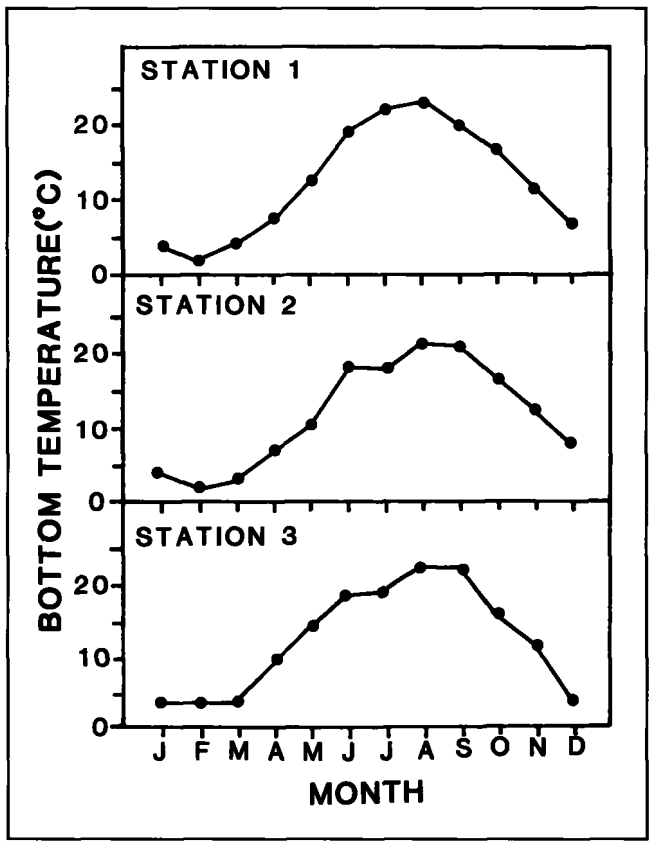

Figure 2
Yearly cycle of bottom temperatures at the three Long Island Sound stations. Each point is the mean of all samples taken from a given month and station throughout the study.

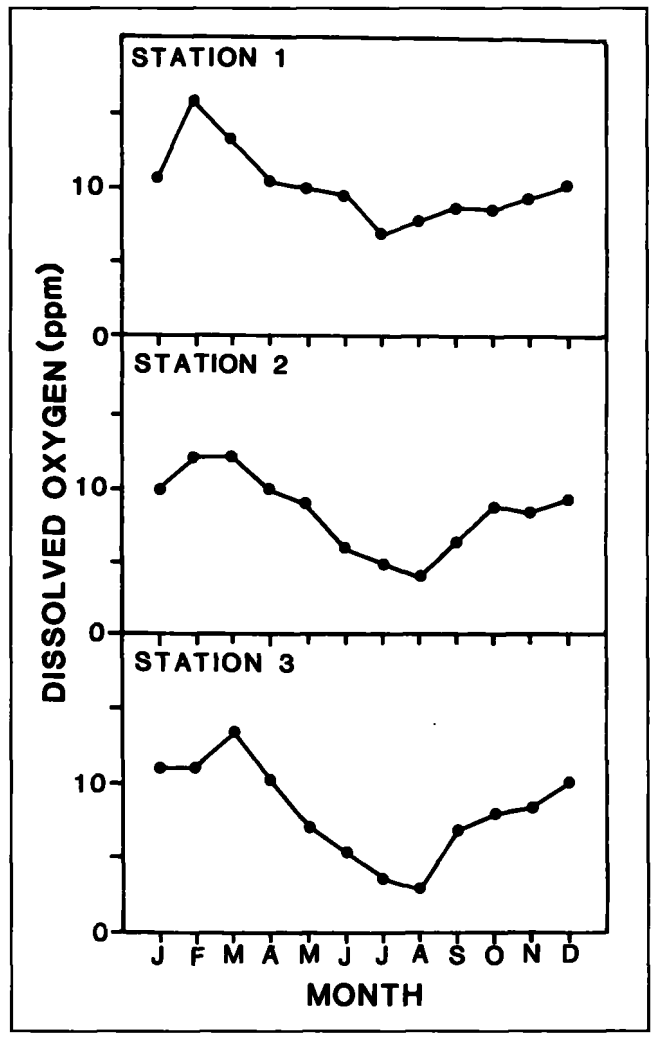

Figure 3
Yearly cycle of dissolved oxygen concentrations at the three stations in Long Island Sound. Each point is the mean of all samples taken from a given month and station throughout the study.

changes. Seasonal variations encompass a variety of parameters, including temperature, light, and nutrient availability. It was assumed that any variations which related to station rather than season were the result of differences in contaminant load. The low oxygen level at Station 3 during a portion of each summer may be indirectly a pollutant effect because low dissolved oxygen is often concomitant with organic pollution.

Mercury exposure produced more limited changes in windowpane flounder than in other species of fish exposed under similar conditions. Exposure to 10 μg/L mercury for 60 days produced no significant changes in the red cell component of windowpane flounder blood. Exposure of winter flounder *Pseudopleuronectes americanus* and striped bass *Morone saxatilis* to the same mercury concentration under similar conditions reduced hematocrit, hemoglobin, and red cell count by 18–48% of control values (Calabrese et al. 1975; Dawson 1979, 1982). The mercury-induced changes in plasma chemistry observed in this study paralleled those found in exposures of other species more closely than did the red cells. Both winter flounder and striped bass exhibited a significant increase in sodium and a decrease in calcium following mercury exposure, and winter flounder also had a drop in plasma calcium concentration (Dawson 1979, 1982). The lesser effects of mercury on the windowpane flounder suggest that this fish is generally less susceptible than striped bass or winter flounder or that the distribution of the metal within the animal differs from species to species. Pentreath (1976) reported that both gill and kidney accumulated high concentrations of mercury during the exposure of plaice *Pleuronectes platessa* L. to this metal. Accumulation in the gill and kidney would be likely to affect plasma chemistry; kidney accumulation may affect renal hematopoiesis as well.

This study produced no significant changes in windowpane flounder blood following copper exposure.

Other investigators have reported hematological effects of copper exposure in various fish species. Christensen et. al. (1972) reported significant increases in hematocrit and hemoglobin in the brown bullhead *Ictalurus nebulosus* following copper exposure. The exposure levels ranged from 27 to 107 μg/L, compared with our 10 and 20 μg/L, and the changes were noted in the fish exposed to 40–107 μg/L copper. It is possible that the lack of copper effects in the present study simply reflects a low exposure level.

The results of the cadmium exposure were similar to those obtained in an earlier exposure of the winter flounder *Pseudopleuronectes americanus*, to cadmium in this laboratory (Calabrese et al. 1975). In the earlier study, winter flounder were exposed for 60 days to 5 or 10 μg/L Cd, as were the windowpane flounder in the present study. No hematological changes were observed in winter flounder, although Na, K, and Ca were not measured. Larsson (1975) reported decreased hematocrits and hemoglobin concentrations following a 9-week exposure of the flounder *Pleuronectes flesus* L. to concentrations of cadmium as low as 5 μg/L. The same study demonstrated decreased calcium and potassium, but these were observed only at higher Cd concentrations.

Both the laboratory exposures and the field-sampling portion of this study suggest that the windowpane flounder is a hardy animal. The higher hematocrit and hemoglobin at the most polluted station compared with the least polluted station suggest an increase in hematopoiesis. The plasma osmolality, normally well below the osmolality of the surrounding water, was lower in fish collected from the most polluted station than in those collected from the cleanest station, indicating no loss of osmoregulatory ability. The limited effects of cadmium, copper and mercury exposures indicate that the species is not particularly vulnerable to these pollutants. These facts taken together suggest that the windowpane flounder at the most polluted station were subject to a stress, perhaps pollutant-induced, sufficient to challenge their metabolism, but a stress to which they were capable of adjusting.

Acknowledgments

The author thanks S. Schurman, D. Kapareiko, and D. Tucker for technical assistance.

Citations

Blaxhall, P.C., and K.W. Daisley
1973 Routine hematological methods for use with fish blood. J. Fish Biol. 5:771–781.

Bowman, M.J.
1976 Tidal locks across the East River: An engineering solution to the rehabilitation of western Long Island Sound. *In* Wiley, M. (ed.), Estuarine processes, Vol. I. Uses, stresses, and adaptation to the estuary, p. 28–43. Acad. Press, NY.

Bridges, D.W., J.J. Cech Jr., and D.N. Pedro
1976 Seasonal hematological changes in winter flounder, *Pseudopleuronectes americanus*. Trans. Am. Fish. Soc. 105: 596–600.

Calabrese, A., F.P. Thurberg, M.A. Dawson, and D.R. Wenzloff
1975 Sublethal physiological stress induced by cadmium and mercury in the winter flounder, *Pseudopleuronectes americanus*. *In* Koeman, J.H., and J.J.T.W.A. Strik (eds.), Sublethal effects of toxic chemicals on aquatic animals, p. 15–21. American Elsevier, NY.

Christensen, G.M., J.M. McKim, W.A. Brungs, and E.P. Hunt
1972 Changes in the blood of the brown bullhead *Ictalurus nebulosus* (Lesueur) following short and long term exposure to copper (II). Toxicol. Appl. Pharmacol. 23:417–427.

Chytalo, K.N.
1979 PCBs in dredged materials and benthic organisms in Long Island Sound. M.S. thesis, State Univ. New York at Stony Brook, 109 p.

Courtois, L.A.
1976 Hematology of juvenile striped bass, *Morone saxatilis* (Walbaum), acclimated to different environmental conditons. Comp. Biochem. Physiol. 54A:221–223.

Dawson, M.A.
1979 Hematological effects of long-term mercury exposure and subsequent periods of recovery of the winter flounder, *Pseudopleuronectes americanus*. *In* Vernberg, W.B., F.P. Thurberg, A. Calabrese, and F.J. Vernberg (eds.), Marine pollution: Functional responses, p. 171–182. Acad. Press, NY.
1982 Effects of long-term mercury exposure on hematology of striped bass, *Morone saxatilis*. Fish. Bull., U.S. 80:389–392.

DeWilde, M.A., and A.H. Houston
1967 Hematological aspects of the thermoacclimatory process in the rainbow trout, *Salmo gairdneri*. J. Fish. Res. Board Can. 24:2267–2281.

Greig, R.A., R.N. Reid, and D.R. Wenzloff
1977 Trace metal concentrations in sediments from Long Island Sound. Mar. Pollut. Bull. 8:183–188.

Hickey, C.R. Jr.
1976 Fish hematology, its uses and significance. N.Y. Fish Game J. 23:170–175.

Hicks, C.R.
1973 Fundamental concepts in the design of experiments. Holt, Rinehart, and Winston, NY.

Hunt, C.D.
1979 The role of phytoplankton and particulate organic carbon in trace metal deposition in Long Island Sound. Ph.D. thesis, Univ. Connecticut, Storrs, 265 p.

Interstate Sanitation Commission
Unpubl. Long Island Sound estuarine study historical data analysis for toxic contaminants in the water column. Unpublished report for the U.S. Environ. Prot. Agency, Office of Water, OMEP, Wash. DC, Agreement no. CX812842. Insterstate Sanitation Comm., 311 W. 43d, NY 10036, 68 p.

Johansson-Sjöbeck, M-L., G. Dave, Å. Larsson, K. Lewander, and J. Lidman
1975 Metabolic and hematological effects of starvation in the European eel, *Anguilla anguilla* L. — II. Hematology. Comp. Biochem. Physiol. 52A:431–434.

Katz, M.
1950 The number of erythrocytes in the blood of silver salmon. Trans. Am. Fish. Soc. 80:184–193.
Larsson, Å.
1975 Some biochemical effects of cadmium on fish. *In* Koeman, J.H., and J.J.T.W.A. Strik (eds.), Sublethal effects of toxic chemicals on aquatic animals, p. 3–13. American Elsevier, NY.
Lochmiller, R.L., J.D. Weichman, and A.V. Zale
1989 Hematological assessment of temperature and oxygen stress in a reservoir population of striped bass (*Morone saxatilis*). Comp. Biochem. Physiol. 93A:535–541.
Moore, E.
1947 Studies on the marine resources of southern New England. VI. The sand flounder, *Lophopsetta aquosa* (Mitchell); a general study of the species with special emphasis on age determination by means of scales and otoliths. Bull. Bingham Oceanogr. Collect. Yale Univ. 11(3):1–79.
Mount, D.I., and W.A. Brungs
1967 A simplified dosing apparatus for fish toxicology studies. Water Res. 1:21–29.
NOAA
1988 A summary of selected data on chemical contaminants in sediments collected during 1984, 1985, 1986, and 1987. NOAA Tech. Memo. NOS OMA 44. Natl. Oceanic Atmos. Adm., Natl. Ocean Serv., Rockville, MD, 15 p. + 4 appendices.
Pentreath, R.J.
1976 The accumulation of inorganic mercury from seawater by the plaice, *Pleuronectes platessa* L. J. Exp. Mar. Biol. Ecol. 24:103–119.
Platt, W.R.
1969 Color atlas and textbook of hematology. J.B. Lippincott, Philadelphia, 445 p..
Reid, R.N., A.B. Frame, and A.F. Draxler
1979 Environmental baselines in Long Island Sound, 1972–73. NOAA Tech. Rep. SSRF-738, Natl. Oceanic Atmos. Adm., Natl. Mar. Fish. Serv., 31 p.
Snieszko, S.F.
1960 Microhematocrit as a tool in fishery research and management. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 341, 15 p.
Sprague, J.B.
1969 Measurement of pollutant toxicity of fish. I. Bioassay method for acute toxicity. Water Res. 3:793–821.
Wedemeyer, G.A., and W.T. Yasutake
1977 Clinical methods for the assessment of the effects of environmental stress on fish health. U.S. Fish Wildl. Serv. Tech. Pap. 89, 18 p.