A SYNTHESIS OF WATER QUALITY AND CONTAMINANTS DATA FOR THE SPOT, LEIOSTOMUS XANTHURUS

FINAL DRAFT

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A SYNTHESIS OF WATER QUALITY AND CONTAMINANTS DATA FOR THE SPOT, LEIOSTOMUS XANTHURUS

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INTRODUCTION

The Chesapeake Bay is one of the largest and most productive estuaries in the world. This estuary provides spawning and nursery habitat for numerous species of fish. The abundance and distribution of fish species within the Bay are related to many variables such as climate, natural population cycles, reproductive potential, disease, predation, food and suitable habitat. Wohlfarth (1986) reported that overfishing and/or deterioration of habitat quality (contaminant and water quality problems) are usually the prime causes of dramatic and extended fish stock declines.

In recent years, degrading habitat conditions resulting from adverse water quality and chemical contaminants in nursery or spawning areas have been suspected in reducing populations of various Chesapeake Bay fish species (Klauda and Bender, 1987). Various resident and anadromous fish species have declined in Chesapeake Bay while stocks of oceanic spawners such as spot, Leiostomous xanthurus, have remained stable (Klauda and Bender, 1987). Spot spawn in nearshore marine waters in the winter but older larvae use the Chesapeake Bay as nursery areas in the spring. Juvenile spot are dominant in the Bay during the summer months.

The vulnerable early life stages of spot (eggs and young larvae) are not exposed to potentially toxic Chesapeake Bay aquatic habitat conditions. Although contaminant and water quality problems have not caused a decline of spot in Chesapeake

Bay, it is important to identify adverse conditions that may affect the survival of the species if adequate management plans are to be implemented. Synthesis of these data can also be used to identify suitable habitat requirements.

This document was developed to provide a synthesis and review of both water quality and contaminants data on various life stages of spot. Data contained in this document will be useful in the Toxics Reduction Strategy for the Chesapeake Bay program effort. A life history and ecology section on spot will be prepared by other investigators and merged with this document to provide a complete review on the species.

SUITABLE WATER QUALITY PARAMETERS

Several water quality parameters suitable for survival of various life stages of spot are presented in Table 1. Various life stages may live outside of the parameters listed in Table 1; however, such conditions would be stressful. Data in Table 1 were obtained from Hettler and Clements (1978), Bridges (1971), Stickney and Cueneo (1982), Johnson (1978), PSE&G (1978), Ogren and Brusher (1977) and Tsai et al. (1979). Toxic water quality conditions are presented in a separate section of this document (Table 2).

Suitable temperature ranges for eggs, larvae, juveniles and adults were > 14 C (upper limit not known), 10 - 37 C, 6 - 20 C and 6-36.7 C. The upper lethal limit for larvae (37 C) is 1 C below the Critical Thermal Maximum (CTM) at an acclimation

temperature of 30 C. The 6 - 20 C range reported for juveniles is a preferred range; temperatures of 1.2 to 35.5 C can be tolerated. Suitable salinity conditions for juvenile and adult spot were > 2 ppt. Dissolved oxygen concentrations > 5.0 mg/L were reported suitable for all life stages. Suspended solids concentrations below 50.6 g/L were suitable for juveniles.

TOXIC WATER QUALITY CONDITIONS

Toxic water quality conditions adversely affecting various life stages of spot are presented in Table 2. Each parameter is discussed separately in the following sections.

Temperature

Temperature effects on various life stages of spot were evaluated in 15 different studies. Hettler and Clements (1978) reported that spot embryos will not develop at temperatures below 14 C. These investigators reported that pre-gastrula embryos suffered 50% mortality or greater when exposed to temperature increases of 8 to 14 C; older embryos were not affected by these thermal increases. Post-fertilized eggs exposed to a 12 C thermal increase above ambient temperatures for 30 min. suffered approximately 20% greater mortality than controls (Hettler and Clements, 1978). An 8 C thermal shock above ambient temperature caused no significant effect.

Hettler and Clements (1978) reported that spot larvae can tolerate temperatures as low as 5 C. Although this temperature

can be tolerated, other investigators have reported that feeding was reduced at 10 C and ceased completely at 6 C (Hoss et al., 1974). These investigators also reported unexpectedly high respiration rates at 10 C thus indicating cold stress at this temperature. Hettler and Clements (1978) reported that exposure time was a critical factor in determining mortality of 1 to 20 d old larvae exposed to temperature increases of 12 C above ambient. Sixty min. exposures were lethal to larvae while exposures of less than 15 min. had minimal effect. Hoss et al., (1974) reported that 12 C increases for 40 min. did not reduce survival or effect weight gain after 14 d.

Bridges (1971) reported critical thermal maximum (CTM) values of 30, 34 and 38 C for spot larvae acclimated to 10, 20 and 30 C, respectively. CTM values increased with increasing fish size and increased salinity. Other investigators reported CTM values of 28.4, 30.4 and 31.1 C for larvae acclimated to 5, 10 and 15 C, respectively (Hoss et al., 1974). Middaugh et al., (1975) determined a CTM value of 35 C using a temperature increase of 1 C / 5 min above ambient temperatures of 20 C. A lower CTM of 31.1 C was reported for larval spot at acclimation temperatures of 15 C (Hoss et al., 1971). An ultimate upper incipient lethal temperature of 35.2 C has also been reported for postlarval and juvenile spot (Hodson et al., 1981).

Juvenile spot were reported to tolerate temperatures ranging from 1.2 to 35.5 C but preferred temperatures of 6 to 20 C (Stickney and Cuenco, 1982). A lower lethal temperature of 4 to

5 C was reported by these investigators. Public Service Electric and Gas Company (1978) reported 96 h LT50 temperatures of 10 and 4.5 C for juveniles acclimated to 25 and 10 C, respectively. A preferred temperature of 25 C was reported for juveniles by these investigators. Peters et al., (1972) reported that optimum feeding occurred at 24 C, which was approximately equal to the preferred temperature (25 C) reported by Public Service Electric and Gas (1978). Meldrim and Gift (1974) reported that juvenile (subadult) spot avoided 26 and 30 C when acclimated to 20 and 27 C, respectively, at 20 foot candles. Spot acclimated to 26 C and 2 foot candles avoided 33 C.

Burton (1979) reported 5 C increases in temperature above acclimation temperatures of 15 and 25 C caused significant increases in ventilation rate of juvenile spot. Increased ventilation rate was also reported after a 2.5 C increase in temperature above a 30 C acclimation temperature. This investigator also reported ventilation rates indicative of cold stress occurred at 5 C.

Field studies conducted by Galloway and Strawn (1974) demonstrated that spot (unknown age) were attracted to heated effluent during the cool winter months in Galveston Bay, Texas. Spot were most abundant at temperatures of 25 to 34 C but avoided temperatures greater than 37.5 C.

SALINITY

Salinity effects on juvenile and adult spot were evaluated

in three studies. Juvenile spot were reported to tolerate large reductions in salinity (34 to 0 ppt) in one hour although oxygen consumption was reduced (Moser and Gerry, 1989). After 8 h of exposure to freshwater, salinity was raised to 34 ppt and the oxygen consumption returned to normal. Public Service Electric and Gas Company (1978) conducted salinity tolerance tests using a wide range of salinity and temperature combinations and determined that survival of juvenile and adult spot was very low at salinity conditions less than 2 ppt. Perez (1969) showed that spot move faster in changing salinity regimes of 10 ppt but not 5 ppt. This investigator interpreted the increased swimming speed as avoidance behavior and suggested that rate of salinity change (not actual salinity) may limit the distribution of spot in estuaries.

DISSOLVED OXYGEN

Dissolved oxygen (D. O.) effects on spot were evaluated in 5 different studies. Middaugh et al. (1975) reported 29% mortality to spot larvae after 24 h exposures to 1.6 mg/L. Similar 24 h exposures to 3.5 and 6.5 mg/L did not cause mortality. Burton et al. (1980) reported a 96 h LC50 of 0.7 mg/L D. O. for juvenile and/or adult spot. Slightly lower LD50 values of 0.4 mg/L were reported for this species by Thorton (1975). This investigator reported that spot exhibited increased ventilation rates at less than 2.0 mg/L D. O. with maximum respiratory compensation at 0.94 mg/L D. O. Ogren and Brusher (1977) reported that juvenile spot

inhabit waters with D. O. concentrations as low as 1.3 to 5.4 mg/L. However, dissolved oxygen values above 5.0 mg/L were preferred.

SUSPENDED SOLIDS

The effects of suspended solids on spot were assessed in one study. Tsai et al. (1979) reported 24 and 48 h TLm values of 50.61 g/L for juvenile spot using fullers earth as a clean sediment source.

TOXICITY TO SINGLE CHEMICALS

Toxicity data for various life stages of spot exposed to eighty-three single chemicals in saline water are presented in Table 3. Most of these data were generated from acute flow-through tests with pesticides. Limited toxicity data were available with early life stages of spot (eggs and larvae). Engle and Sunda (1979) evaluated the effects of copper (measured as cupric ion activity pCu) on spot eggs. An equation was used to calculate the cupric ion activity with pH-dependent, conditional and apparatus-stability constants for copper-tris complex. Conversion to standard ug/L units was therefore not possible. These investigators reported that survival of spot eggs was reduced by 50 % in 24 h at pCu of 8.8 (0.1 mM Cu). Percent hatch was inhibited after 4 d at less than 9.4 pCu (greater than 0.02 mM Cu).

Two acute toxicity studies were available for spot larvae.

Foster (1987) reported a 96 h LC50 of 31 ug/L (nominal concentration) for spot larvae exposed to hexachloro-cyclopentadiene. Middaugh et al. (1975) reported a 120 h LC50 of 600 ug/L for spot larvae exposed to cadmium. No mortality was reported at 100 ug/L Cd after 200 h of exposure. These investigators also reported that exposure of spot larvae to Cd concentrations greater than 500 ug/L for 96 h decreased the critical thermal maximum and reduced resistence to low dissolved oxygen stress.

Toxicity data for juvenile and adult spot were grouped together and arranged alphabetically in Table 3. The most toxic chemicals to juvenile and adult spot based on acute toxicity values were Endosulfan (96 h LC50 = 0.09 ug/L), Antimycin A (48 h LC50 = 0.23 ug/L), Endrin (48 h LC50 = 0.3 ug/L) and Toxaphene (96 h LC50 = 0.92 ug/L). The least toxic chemicals to juvenile spot and adult spot were Mirex (48 h LC50 > 2000 ug/L), Ametryn (48 h LC50 > 1000 ug/L) and Atrasine (96 h LC50 = 8,500 ug/L).

CONCLUSIONS

1. Populations of spot have remained stable in Chesapeake Bay in recent years. Spot spawn in nearshore marine waters in the winter therefore the vulnerable egg and young larvae are not exposed to potentially toxic Chesapeake Bay aquatic habitat conditions.

2. Suitable temperature ranges for egg, larval juvenile and adult spot were > 14 C, 10 - 37, 6 - 20 and 6 - 36.7 C. Salinity ranges > 2 ppt were considered suitable for juveniles and adults. Suitable D. O. conditions for all four life stages were > 5 mg/L. Suspended solids concentrations much less than 50.6 g/L were suitable for juvenile spot.

3. Spot embryos will not develop at temperatures below 14 C. Larvae can tolerate temperatures as low as 5 C although feeding is completely reduced at 6 C. Exposure time was a critical factor in determining mortality of 1 - 20 d old larvae exposed to temperature increases of 12 C above ambient; sixty min. exposures were lethal to larvae while exposures less than 15 min. had minimal effect.

4. Critical thermal maximum (CTM) of 30, 34, and 38 C were reported for spot larvae acclimated to 10, 20 and 30 C, respectively. Juvenile spot were reported to tolerate temperatures ranging from 1.2 to 35.5 C but preferred temperatures of 6 to 20 C. Lower lethal temperatures of 4 to 5 C were reported for juvenile spot. Ventilation rates indicative of cold stress were also reported at 5 C.

5. Juvenile spot can tolerate large reductions in salinity (34 ppt to 0 ppt) although survival is significantly reduced below 2 ppt.

6. Dissolved oxygen concentrations of 1.6 mg/L caused 29% mortality to spot larvae in 24 h. Dissolved oxygen concentrations of 0.4 to 0.7 mg/L were lethal to juvenile spot.

7. Toxicity data were available for various life stages of spot exposed to eighty-three chemicals in saline water. Limited toxicity data were available for spot eggs and larvae. A 96 h LC50 of 31 ug/L was reported for spot larvae exposed to hexachloro-cyclopentadiene. A 120 h LC50 of 600 ug/L was reported for spot larvae exposed to cadmium. The most acutely toxic chemicals to juvenile and adult spot were Endosulfan (96 h LC50 = 0.09 ug/L), Antimycin A (48 h LC50 = 0.23 ug/L), Endrin (48 h LC50 = 0.3 ug/L) and Toxaphene (96 h LC50 = 0.92 ug/L).

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Table 1. Suitable water quality parameters for various life stages of the spot (NA = not available).

Life Stage	Temperature (C)	Salinity (ppt)	pH	Dissolved Oxygen mg/L	Suspended Solids g/L
Egg	> 14[a]	NA	NA	> 5	NA
Larvae	10 - 37[b]	NA	NA	> 5	NA
Juvenile	6 - 20[c]	> 2 ppt	NA	> 5	< 50.6[d]
Adult	6 - 36.7	> 2 ppt	NA	> 5	NA

[a] = Upper limit is not known

[b] = 1 C below the CTM at an acclimation temperature of 30 C

[c] = Preferred temperature range but can tolerate 1.2 to 35.5 C

[d] = The 24 and 48 h TLM was 50.61 g/L. Suitable ranges of survival would be much less.

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Table 2. Toxic water quality parameters adversely affecting various life stages of spot. (NA = not available).

Parameter	Life Stage	Data	Reference
Temperature	Embryos and larvae	Spot embryos did not develop at temperatures below 14C. Larvae tolerated temperatures as low as 5C.	Hettler and Clements, 1978
	Pregastrula embryos	Suffered 50% mortality or greater at shock temperatures of -8C delta to 14C delta T.	
	Early embryos	≈ 50% mortality at a delta T of 14C.	
	Mid-development embryos	Very little effect at temperature shocks as great as -delta T of 14C.	
	Post fertilized eggs	Eggs receiving a -delta T of 12C shock above ambient temperatures for 30 min. suffered ≈ 20% greater mortality than controls; 8C thermal shock showed no significant effect.	
	Larvae	60 min. exposures to -delta T of 12C caused high mortalities (68-100%) in larvae of different ages (1-21d old). Exposures of ≤ 15 min. to -delta T of 12C had little impact.	

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Table 2. (Continued)

Parameter	Life Stage	Data	Reference
Temperature	Larvae	Critical thermal maximum was determined to be ≈ 35C using a temperature increase rate of 1.0C/5 min. Acclimation temperature was 20C.	Middaugh et al., 1975
Temperature	Larvae	A 12C increase in temperature (15C acclimation) for 40 min. did not reduce survival or effect weight gain after 14d. CTM values of 31.1, 30.4 and 28.4°C were reported for fish acclimated at 15, 10 and 5C, respectively.	Hoss et al., 1974
Temperature	Larvae	Feeding ceased at 6C and was reduced at 10C. Mortality was also evident at ≤ 10C. Unexpectedly high respiration rates at 10C also indicates cold stress in spot larvae at ≤ 10C.	Hoss et al., 1988
Temperature	Post larvae and juveniles	Ultimate upper incipient lethal temperature estimated at 35.2C. Increases in salinity increased resistance time but decreased lethal temperature estimates.	Hodson et al., 1981

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Table 2. (Continued)

Parameter	Life Stage	Data	Reference
Temperature	Post larvae (19mm)	Fish acclimated to 10, 20 and 30C had CTM values of 30, 34 and 38C, respectively, using a temperature increase of 1C per min. CTM values increased with increasing fish size, age and increased salinity.	Bridges, 1971
Temperature	Post larvae	Critical Thermal Maximum = 31.1C using fish acclimated at 15C and 30ppt salinity (temperature increase 1C per min.)	Hoss et al., 1971
		A 5C thermal shock (15C to 20C) caused increased O_2 consumption. A 10C thermal shock (15C to 25C) killed 50% of the spot in 4h.	
Temperature	Post yolk-sac larvae	Fish acclimated to constant temperatures were equally sensitive to thermal shock as fish acclimated at cycling temperature ± 4C). Fish acclimated at base temperatures of 10, 15, and and 20C suffered 50% mortality at instantaneous 20 min. temperature increases of 18.5, 16 and 12C, respectively.	Hartwell and Hoss, 1979

DRAFT

Table 2. (Continued)

Parameter	Life Stage	Data	Reference
	Juveniles	As with larvae, there was no difference between cycling and constant acclimation temperatures. Fish acclimated at base temperatures of 15, 20 and 25C suffered 50% mortality at instantaneous 20 min. temperature increases of 19, 15 and 10.5C, respectively.	
Temperature	Juvenile	Tolerate 1.2 - 35.5C, but prefer 6 - 20C. Lower lethal temperature was between 4 - 5C.	Stickney and Cuenco, 1982
Temperature	Juveniles	5C increases in temperature above acclimation temperatures of 15 and 25C caused significant increases in ventilation rate. A 2.5C increase in temperature above a 30C acclimation also caused increased ventilation rate. No mortality was observed after these 15 min. thermal shock exposures. Ventilation rates indicative of cold stress occurred at 5C.	Burton, 1979
Temperature	Juvenile and Adults	Spot acclimated to 20 (4.5 ppt. salinity) and 27C (7.0 ppt. salinity avoided temperatures of 26 and 30C, respectively, when the light level was 20 foot-candles. Spot acclimated at 2 foot-candles light intensity.	Meldrim et al., 1974

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Table 2. (Continued)

Parameter	Life Stage	Data	Reference
Temperature	Juveniles and Adults	Fish were acclimated to a temperature range of 6 - 27C. At an acclimation of 6C, fish showed preference for 15C; at an acclimation of 27C, fish showed preference for 25°C. The ≈ preferred temperature was 25C. Fish acclimated to 10C avoided temperatures of 19 - 24C. Fish acclimated to 30C avoided 34C.	Public Service Electric and Gas Company, 1978
	Juveniles and Adults	96 h LT50 temperatures for fish acclimated at 25C and 10C was 10C and 4.5C, respectively, in cold shock experiments.	
Temperature	NA (wt 15-40g)	Optimum feeding occurred at 24C with decreased feeding as temperatures deviated from the optimum.	Peters et al., 1972
Temperature	NA	Fish sampling in Galveston Bay showed that spot were attracted to heated effluents during cool months. Spot were most abundant at temperatures of 25 - 34C but avoided temperatures ≥ 37.5C.	Gallaway and Strawn, 1974

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Table 2. (Continued)

Parameter	Life Stage	Data	Reference
Salinity	Juvenile	Spot demonstrated no aversion to crossing salinity gradients of 5 ppt. and 10 ppt. A drop in salinity from 34 ppt. to 0 ppt. in 1 hour caused a drop in oxygen consumption; however, after 8h the salinity was raised back to 34 ppt. and oxygen consumption returned to normal.	Moser and Gerry, 1989
Salinity	Juveniles and Adults	Low salinity tolerance tests were conducted over a range of of temperature and salinity acclimation. Overall, survival of spot was very poor at < 2 ppt. salinity.	Public Service Electric and Gas Company, 1978
Salinity	Juvenile and Adults	Spot demonstrated increased swimming speed during times of salinity change (10 ppt. change per hour; 12 ppt. - 17 ppt). Salinity changes of 5 ppt. per h did not elicit the same response. The increased swimming speed was interpreted as avoidance behavior.	Perez, 1969
Dissloved Oxygen (D.O.)	larvae	Exposure to 1.6 mg/L D.O. (at 20 ± 1C) caused 29% mortality in 24 h. Equal exposures to 3.5 and 6.5 mg/L D.O. had no effect on survival.	Middaugh et al., 1975

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Table 2. (Continued)

Parameter	Life Stage	Data	Reference
Dissolved oxygen	Juvenile	Inhabit waters with D.O. concentrations as low as 1.3 - 5.4 mg/L, but most prefer concentrations > 5.0 mg/L.	Ogren and and Brusher, 1977
Dissolved oxygen	Juvenile and Adults	96 h LC5 = 0.81 mg/L O_2 96 h LC50 = 0.7 mg/L O_2 96 h LC95 = 0.6 mg/L O_2 The lethal threshold conc. is approximately 0.7 mg/L O_2	Burton et al., 1980
Dissolved oxygen	NA (length 85-87 mm)	Spot died at a critical oxygen tension of PO_2 = 24mmHg	Subrahmanyam, 1980
Dissolved oxygen	NA	LD50 = 0.4 ml/L D.O. Spot exhibited increased ventilation rate at ≤ 2.0 m/L D.O. and maximum respiratory compensation at 0.94 m/L D.O.	Thornton, 1975
Suspended Solids	Juvenile	24 h and 48 h TLM value = 50.61 g/L using fullers earth as a clean sediment source.	Tsai et al., 1979

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Table 3. Toxicity data for Spot exposed to various single chemicals (NA = Not Available). All toxicity tests were conducted using flow-through conditions unless otherwise indicated as static.

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Eggs	Copper measured as Cupric ion activity	Saline	17	Survival of eggs was reduced 50% in 24 h in static conditions at pCu = 8.8 (0.1mMCu)(Cupric ion activity). Percent hatch was inhibited after 4 d at < 9.4 pCu (> 0.02mMCu).	Engel and Sunda, 1979
Larvae	Hexachloro-cyclopentadiene	Saline (22ppt)	25	96h LC50 = 31 ug/L (static) (Nominal)	Foster, 1987
Larvae	Cadmium	Saline (16-19ppt)	15-22	Approx. 120 h LC50 = 600 ug/L incipient LC50 = 200-300 ug/L. No mortality in 200 h at 100 ug/L.	Middaugh et al., 1975
Larvae	Cadmium	Saline (17-20ppt)	17-20	Critical Thermal Maximum significantly decreased in fish preexposed to ≥ 500 ug/L Cd for 96h. Significant reduction in resistance to low dissolved oxygen stress in fish preexposed to ≥ 500 ug/L Cd for 96h.	Middaugh et al., 1975
Adult	Acephate	Saline (20ppt)	25	96h LC50 > 100,000 ug/L (Static) (Nominal)	Foster, 1987

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Adult	Aldicarb	Saline (20ppt)	25	96h LC50 = 200 ug/L (Static) (Nominal)	
Juvenile	Aldrin	Saline (28ppt)	24	48h LC50 = 3.2 ug/L (Nominal)	
Juvenile	Ametryn	Saline (29ppt)	28	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Anilazine	(Saline (23ppt)	29	48h LC50 = 8.5 ug/L (Nominal)	
Juvenile	Antimycin A	Saline (28ppt)	25	48h LC50 = 0.23 µg/L (Nominal)	
Juvenile	Atrazine	Saline (29ppt)	28	48h LC50 > 1000 ug/L (Nominal)	
NA	Atrazine	Filtered seawater (12ppt)	22 ± 1	96h LC50 = 8500 ug/L (Nominal) (Static)	Ward and Ballantine, 1985
Juvenile	Azinphos-Methyl	Saline (21ppt)	21	48h LC50 = 28 ug/L (Nominal)	
Adult	Bensolide	Saline (21ppt)	25	48h LC50 = 320 ug/L (Nominal)	
Juvenile	Bromacil	Saline (18ppt)	13	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Bromate	Renewed Saline (5.1 ± 1.0ppt)	20.1 ± 0.25	10d LC50 = 278,600 ug/L	Richardson et al., 1981

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Juveniles	Bromine chloride	Saline (20ppt)	19 - 28	96h LC50 = 220 ug/L	Roberts and Gleeson, 1978
Adult	Cadmium	Saline (15ppt)	22 ± 1	48h LC50 = 35,000 ug/L (Static)	Hawkins et al., 1980
Adult	Cadmium	Saline (15ppt)	22 ± 1	48h exposures to ≥ 10,000 ug/L Cd caused severe renal damage. Proximal tubule cells demonstrated increased heterogeneous bodies and epithelial desquamation at ≥ 10,000 ug/L Cd. Mitochondria damage was also reported.	
Adult	Carbophenothion	Saline (20ppt)	25°C	96h LC50 = 500 ug/L (Static) (Nominal)	
Adult	Carbophenothion	Saline (24ppt)	26°C	96h LC50 > 210 ug/L (Measured)	
Juvenile	Chlordecone	Saline (26ppt)	22°C	48h LC50 = 130 ug/L (Nominal)	Foster, 1987
Adult	Chlordecone	Saline (18ppt)	25°C	96h LC50 = 6.6 ug/L (Measured)	
Juvenile	Chloropropylate	Saline (26ppt)	14°C	48h LC50 = 320 ug/L (Nominal)	
Juvenile	Chlorothalonil	Saline (22ppt)	11°C	48h LC50 = 32 ug/L (Nominal)	

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
NA	Total residual chlorine (TRC)	Saline	14.2 - 16	24h TLm = 140 ug/L TRC 96h TLm = 90 ug/L TRC After 96h: 100% mortality at ≥ 160 ug/L TRC; 0% mortality at ≤ 40 ug/L TRC.	Bellanca and Bailey, 1977
NA (length 33-115mm)	TRC	Saline (3-8ppt)	16 - 26	Avoidance reported at concentrations ranging from 30 - 300 ug/L TRC depending upon variables such as temperature, salinity and light level.	Public Service Electric & Gas Co., 1978
Juvenile	TRC	Saline (20-24ppt)	10 ± 0.5	Incipient LC50 = 120 ug/L TRC. No mortality was observed at 40 ug/L after 8 d.	Middaugh et al., 1977
Juvenile	TRC	Saline (20-24ppt)	15 ± 0.5	Incipient LC50 = 60 ug/L TRC (No mortality observed at 40 ug/L after 8 d). No pathological effects were noted in fish exposed to 600 ug/L TRC; however, fish exposed to 1,570 ug/L TRC demonstrated gill damage after 95 min. exposure.	

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Juvenile	TRC	Saline (19-22ppt)	10, 15 and 20 ± 0.5	A TRC concentration of 50 ug/L caused significant avoidance behavior at 15 and 20C. At 10, avoidance behavior was measured at 180 ug/L TRC.	
Juvenile	TRC	NA	15 acclimation; test temperatures of 15, 20, 25 and 28	Exposure to 50 - 70 ug/L TRC increased sensitivity to to thermal shock only in one condition (15C declimation to 28C for 60 min). Exposure to 340 - 520 ug/L TRC increased sensitivity to all thermal shock exposures.	
Juvenile	Chlorinated bromochlorinated condenser cooling water	Saline (2.0ppt)	29 - 32.4	No significant mortality reported at 20 - 81 ug/L total residual bromine after 19 d. Significant mortality was observed after 20 d exposure to 14 - 62 ug/L TRC compared to controls.	Liden and Burton, 1977

DRAFT

Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Juvenile	DDE	Saline (26ppt)	12	48h LC50 > 100 ug/L (Nominal)	
Juvenile	DEF	Saline (26ppt)	27	48h LC50 = 240 ug/L (Nominal)	
Adult	DEF	Saline (20ppt)	25	96h LC50 = 160 ug/L (Static) (Nominal)	
Adult	DEF	Saline (20ppt)	26	96h LC50 = 130 ug/L (measured)	
Juvenile	Demeton	Saline (27ppt)	26	48h LC50 = 320 ug/L (Nominal)	
Juvenile	Diamidfos	Saline (29ppt)	21	48h LC50 > 1000 ug/L (Nominal)	Foster, 1987
Juvenile	Dicamba	Saline (29ppt)	30	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Dichlofluanid	Saline (29ppt)	13	48h LC50 = 32 ug/L (Nominal)	
Juvenile	Dichlorvos	Saline (25ppt)	28	48h LC50 = 320 ug/L (Nominal)	
Juvenile	Dieldrin	Saline (25ppt)	12	24h LC50 = 3.2 ug/L (Nominal)	

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Juvenile	Dieldrin in acetone	Unfiltered sea water	NA	After 4d exposure to 1.35 ug/L, fish showed degenerative changes in gill and visceral tissue. No effects were reported at ≤ 0.135 ug/L after 35 d.	Parrish et al., 1973
Juvenile	Dimetilan	Saline (25ppt)	12	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Endothall Aquathol Plus	Saline (28ppt)	27	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Endrin	Saline (24ppt)	12	48h LC50 = 0.3 ug/L (Nominal)	
Juvenile	Endrin	Saline (23ppt)	17	24h LC50 = 0.45 ug/L Concentrations of Endrin < 0.05 ug/L were sublethal to juveniles after continuous exposure for 8 months.	Lowe, 1965
Adult	Endosulfan in acetone (Thiodan®)	Saline (mean = 18ppt)	mean = 25.0	96h LC50 = 0.09 ug/L (measured)	Schimmel et al., 1977
Adult	EPN	Saline (23ppt)	24	96h LC50 = 26 ug/L (measured)	Foster, 1987

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Juvenile	Ethion	Saline (31ppt)	27	48h LC50 = 70 ug/L (Nominal)	
Adult	Ethoprop	Saline (20ppt)	25	96h LC50 = 33 ug/L (Static) (Nominal)	
Juvenile	Fenac Sodium Salt	Saline (23ppt)	13	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Fenthion	Saline (23ppt)	19	48h LC50 = 1200 ug/L (Nominal)	
Juvenile	Fenuron	Saline (20ppt)	25	48h LC50 > 1000 ug/L (Nominal)	Foster, 1987
Juvenile	Fonofos	Saline (28ppt)	24	48h LC50 = 240 ug/L (Nominal)	
Juvenile	Heptachlor in acetone	Saline (20 ± 1.5ppt)	25 ± 1.5	100% mortality after 6d at a measured concentration of 2.55 ug/L.	Schimmel et al., 1976b
Juvenile	Technical-grade Heptachlor (65%) in acetone	Saline (20 - 21ppt)	23 - 26	96h LC50 = 0.85 ug/L	Schimmel et al., 1976a
Juvenile	Analytical grade Heptachlor (99.8%) in acetone	Saline (20 - 22ppt)	24.5 - 25.5	96h LC50 = 0.86 ug/L	

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Adult	Hexachloro-cyclopentadiene	Saline (24ppt)	25	96h LC50 = 37 ug/L (Static) (Nominal)	
Juvenile	Isobenzan	Saline (22ppt)	13	48h LC50 = 0.32 ug/L (Nominal)	
Juvenile	Kepone in food source	Saline (17.7 - 18ppt)	23 - 28	Fish fed a diet contaminated with 3.3 ug/g Kepone developed muscular tetany, fractured vertebral centra and abnormally thickened vertebrae over a 4 week period. Some mortalities occurred in 1 week.	Stehlik and Merriner, 1983
Juvenile	Kepone in food source	Saline (20.3 - 21.8ppt)	16 - 23	Fish fed diets of 0.59 and 0.3 ug/g Kepone for 56 d had increased incidence of vertebral and spinal fractures.	
Juvenile	Kepone in acetone	Saline (mean = 18.0ppt)	25	96h LC50 = 6.6 ug/L	Schimmel and Wilson, 1977
Juvenile	Leptophos	Saline (23ppt)	22	96h LC50 = 4.1 ug/L (measured)	

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Juvenile	Lindane	Saline (23ppt)	15	48h LC50 = 23 ug/L (Nominal)	
Juvenile	Malathion	Saline (24ppt)	19	48h LC50 = 320 ug/L (Nominal)	
Juvenile	Malathion	Saline (2.5 - 2.7ppt)	23 - 29	Exposed for 182d to 10 ug/L and no significant differences in growth or mortality were observed. Brain ChE was significantly lower in exper. groups, but 1 week after termination of the experiment, the fish had regenerated near normal levels of the enzyme.	Holland and Lowe, 1966
Adult	Mercuric Chloride	Saline (20ppt)	26	96h LC50 = 36 ug/L (Static) (Nominal)	
Juvenile	Methidathion	Saline (25ppt)	12	48h LC50 = 32 ug/L (Nominal)	
Juvenile	Methoxychlor	Saline (26ppt)	22	48h LC50 = 23 ug/L (Nominal)	
Adult	Methyl Parathion	Saline (12ppt)	22	96h LC50 = 59 ug/L (measured)	
Juvenile	Mirex	Saline (27ppt)	22	48h LC50 > 2000 ug/L (Nominal)	Foster, 1987

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Juvenile	Molinate	Saline (20ppt)	25	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Naled	Saline (20ppt)	20	48h LC50 = 240 ug/L (Nominal)	
Juvenile	Neburon	Saline (20ppt)	25	48h LC50 = 320 ug/L (Nominal)	
Adult	Nickel Chloride	Saline (21ppt)	26	96h LC50 = 70,000 ug/L (Static) (Nominal)	
Juvenile	Nitrapyrin	Saline (20ppt)	16	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Parathion	Saline (22ppt)	14	48h LC50 = 18 ug/L (Nominal)	
Juvenile	Pentron D-90	Saline (6.8ppt)	25 ± 1	No mortality after 96 hours at 5000 ug/L (Static)	Burton, 1980
Adult	Phorate	Saline (18ppt)	25	96h LC50 = 3.9 ug/L (measured)	
Juvenile	Phosphamidon	Saline (29ppt)	23	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Phoxim	Saline (29ppt)	29	48h LC50 = 2.8 ug/L (Nominal)	
Adult	Potassium dichromate	Saline (21ppt)	26	96h LC50 = 27 mg/L (Static) (Nominal)	

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Juvenile	Prometryn	Saline (29ppt)	28	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Ronnel	Saline (24ppt)	13	48h LC50 = 320 ug/L (Nominal)	Foster, 1987
Juvenile	Silvex Propylene glycol butylether ester (Kuron®)	Saline (20ppt)	16	48h LC50 = 360 ug/L (Nominal)	
Juvenile	2,4,5-T Propylene glycol butylether ester	Saline (20ppt)	16	48h LC50 = 320 ug/L (Nominal)	
Juvenile	Temephos	Saline (23ppt)	23	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Terpene Polychlorinates	Saline (27ppt)	25	48h LC50 = 3.2 ug/L (Nominal)	
Juvenile	Tetrachlor-vinphos	Saline (25ppt)	17	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Tetrasul	Saline (29ppt)	16	48h LC50 > 1000 ug/L (Nominal)	
Juvenile	Thanite	Saline (22ppt)	14	48h LC50 = 32 ug/L (Nominal)	
Juvenile	Toxaphene	Saline (25ppt)	12	48h LC50 = 3.2 ug/L (Nominal)	

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
Juvenile	Toxaphene (in acetone)	Saline (32 - 35ppt)	Ambient (min. temp = 18)	96h LC50 = 0.92 ug/L	Harder et al., 1983
	Degraded Toxaphene in acetone (allowed to degrade anaerobically in sediment for 20d at room temp).			96h LC50 = 1.10 ug/L	
NA	Contaminated Baltimore Harbor sediments suspended in water	Saline (5ppt)	25	48h TLm valves ranged from 0.06 g/L - 29.12 g/L (Static tests) of contaminated sediment from different Baltimore Harbor locations suspended in water. A TLm valve of 50.61 g/L was obtained with clean sediment. Baltimore harbor sediments contained high levels of metals, Hexane extracts and PCB's.	Tsai et al., 1979

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Table 3. (Continued)

Life Stage	Chemical	Water Type	Test Temperature (C)	Data	Reference
NA	Fish captured in Elizabeth River which is highly contaminated with polynuclear aromatic hydrocarbons (PAH)	NA	NA	Macrophage phagocytosis was markedly reduced in fish from the polluted Elizabeth River compared to a nonpolluted "control" River. Macrophage phayocytosis returned to "control" levels in Elizabeth River fish that were held in clean water for several weeks.	Weeks and Warinner, 1984
NA	Elizabeth River sediments heavily contaminated with PAH (2,500,000 - 3,900,000 ug/L PAH per dry weight of sediments). of sediments).	Saline (18.3 - 20.4ppt)	20 - 27.8	Spot developed penetrating integumental lesions within 8 d and later severe fin and gill erosion. Mortality was evident by d 2 with 30% mortality in 18 d. Pancreatic and liver alterations were also observed in treatment fish.	Hargis et al., 1984

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