Juvenile mussels (Mytilus edulis, ~20 mm) were exposed to three concentrations of tributyltin (TBT) in two site-specific, flow-through bioassays with unfiltered seawater. Mean TBT concentrations were 70, 80 and 200 ng/l in Test I (196 days) and 40, 50 and 160 ng/l in Test II (56 days). Treatments did not significantly affect juvenile mussel growth during the first 56 days of exposure in either test. After 63 days, all treatments significantly reduced growth in Test I. No significant mortalities occurred at any TBT concentration in either test. Increases in weights and lengths of Tank Control animals in Test II were much greater than during the first 56 days of Test I. Further, weight increases in the Pier Control were almost four times greater than in the Tank Controls during Test II. These data suggest that test animals were probably under significant stress induced by the bioassay test system. The data also suggest that the effects of TBT on juvenile mussel growth may have been overestimated in this and other studies.

Presented at Oceans 1987 Conference, Organotin Symposiums, Halifax, Nova Scotia, Canada, 27 Sep-1 Oct 1987.
TRIBUTYL Tin EFFECTS ON JUVENILE MUSSEL GROWTH

Michael H. Salazar and Sandra M. Salazar

Naval Ocean Systems Center
Environmental Sciences, Code 52
San Diego, California 92152

ABSTRACT

Juvenile mussels (Mytilus edulis <20 mm) were exposed to three concentrations of tributyltin (TBT) in a site-specific, flow-through bioassay with unfiltered seawater. Mean TBT concentrations were 70, 80 and 200 ng/l in Test I (196 days) and 40, 50 and 160 ng/l in Test II (56 days). Treatments did not significantly affect juvenile mussel growth during the first 56 days of exposure in either test. After 63 days, all treatments significantly reduced growth in Test I. No significant mortalities occurred at any TBT concentration in either test. Increases in weights and lengths of Tank Control animals in Test II were much greater than during the first 56 days of Test I. Further, weight increases in the Pier Control were almost four times greater than in the Tank Controls during Test II. These data suggest that test animals were probably under significant stress induced by the bioassay test system. The data also suggest that the effects of TBT on juvenile mussel growth may have been overestimated in this and other studies.

INTRODUCTION

Growth represents the integrated response of internal biological process. It is generally believed that in any environment the added stress of toxicants reduces animal growth rates and that juveniles are more sensitive than adults. Significant reductions in growth rate could adversely affect the population (1). A good measure of stress in juvenile mussels is shell growth since it is a significant part of total somatic production (2) and there is no interference by gametogenesis (3).

A number of investigators have studied the effects of tributyltin (TBT) on mussel (Mytilus edulis) growth. Several laboratory studies (4, 5, 6) and a single field study (7) have reported reduced mussel growth at TBT concentrations of 230 ng/l and greater in tests ranging from 7 days to 5 months. The interpretation and environmental significance of these data are unclear (8). First, these high concentrations are not characteristic of most harbor environments and are restricted to enclosed basins with poor tidal exchange and large numbers of organotin-painted vessels (9). Second, mussel growth in the field may be different than in laboratory studies with associated growth-inhibiting stresses. Third, reported reductions in mussel growth rates may be attributable to stress from unmeasured or unknown factors (10).

Extrapolation to the environment is difficult (8, 10, 11, 12) due to differences in conditions between the above laboratory studies with TBT (4, 5) and the field. The above field study (7) provided environmentally realistic test conditions, yet still failed to confirm a cause-and-effect relationship between TBT and mussel growth rates because of unmeasured variables, uncontrolled dosing, and an inappropriate control site. Limited sample sizes and short-term exposures in previous laboratory and field studies only permit estimating order-of-magnitude effects (10) on growth of mussels exposed to high TBT concentrations. These studies have not adequately assessed the subtle effects of realistic exposure states for low TBT concentrations of interest (13) near those predicted to be safe (50 ng/l) in the estuarine environment (14).

Two site-specific, flow-through bioassays with TBT were conducted in San Diego Bay using a Portable Environmental Test System (PETS) to evaluate the long-term effects of low TBT concentrations on juvenile mussel growth. This approach combined the advantages of controlled laboratory dosing with realistic field test conditions in an attempt to provide more meaningful results than previous studies. This report addresses results of those site-specific bioassays and their significance in relation to previous laboratory and field studies.

METHODS AND MATERIALS

PETS was evaluated over a 7-month period in San Diego Bay using TBT leachates. A more detailed description of the test site and the physical/chemical parameters monitored are presented elsewhere (15). As part of that evaluation, two overlapping tests were conducted with juvenile mussels (M. edulis). Test I lasted 196 days (June to December 1986). Test II lasted 56 days (October to December 1986). Test II was conducted concurrently with the last 56 days of Test I. During that time mussels from each test were in the same tanks and subjected to identical experimental conditions. Temperatures in PETS tanks ranged from 15.0 -
Seawater intake ranged from 14.0 - 25.9°C in Test I and 15.0 - 21.7°C (±0.8°C) in Test II. Bay temperatures at the seawater intake ranged from 14.0 - 21.9°C (±0.5°C) during the whole study. Growth rate estimation from changes in mussel length, the number of byssal threads, and three TBT concentrations were marked. Atomic absorption detection of concentrations was performed on log-transformed daily weight data from the seawater intake. Measured concentrations were markedly different from the expected values.

The experimental design consisted of a control and three TBT treatments: nominal 10, 25, and 100 ng/l. TBT concentrations were measured by hydride derivatization and atomic absorption detection (5) and reported as tributyltin chloride. All plastic holding trays were leached for 2 weeks in the laboratory with filtered flow-through seawater. Mussels were collected from the rubber tire fenders on the pier. The purpose was to determine if the test system affected growth. Without sufficient numbers of mussels from the same site, Test II animals were collected from the rubber tire fenders on the Coronado Bay Bridge approximately 1 km from the test site.

Whole-animal wet weights and lengths were measured weekly using vernier calipers and an electronic balance. Byssal threads were carefully counted prior to removing mussels from the trays for measurements. Presence/absence of byssal threads was recorded weekly as another measure of environmental stress (16, 17, 18).

Statistical analyses were conducted only on survivor data. For each treatment, cumulative percent increases in length and weights were calculated to normalize size effects and to estimate relative growth rates for graphical presentation. Serial ANOVAs (P < 0.05) were performed on pooled weight and length data among replicate TBT concentrations at each sampling interval to test the null hypothesis: TBT exposure has no effect on juvenile mussel growth. If the null hypothesis was rejected, Duncan's new multiple-range test was used to determine which TBT concentrations significantly affected growth. In addition, a series of linear regression analyses were performed on log-transformed data to compare the slopes of estimated growth rates. If slopes differed by more than two standard deviations (P < 0.05), growth rates were considered significantly different.

RESULTS

Growth rate estimates from changes in mussel weights and lengths over time are given in Table I. Figure 2 gives the slopes of regressions performed on log-transformed 196-day weight and length data from Test I. In Test I significant reductions in growth were found between 61-196 days in all TBT concentrations. Growth was increasingly suppressed with increasing TBT concentration. At the highest concentrations, growth rate was approximately half that of the control. After 196 days, mussel weights and lengths in the Pier Controls and the 200 ng/l TBT treatments increased by 45%, 250%, and 65% and 37%, respectively. Mussels exposed to the lowest TBT treatments increased by 55% and 53%.

Both the multiple-range test on weekly length and weight measurements and the linear regression analyses on the 196-day growth rates gave the following results: Control (70 ± 80) mg; Pier Control and Tank Controls (70 ± 80) mg; 160 ng/l TBT treatments increased by 55% and 53%; both the multiple-range test on weekly length and weight measurements and the linear regression analyses on the 196-day growth rates gave the following results: Control (70 ± 80) mg; 160 ng/l TBT treatments increased by 55% and 53%; both the multiple-range test on weekly length and weight measurements and the linear regression analyses on the 196-day growth rates gave the following results: Control (70 ± 80) mg; 160 ng/l TBT treatments increased by 55% and 53%; both the multiple-range test on weekly length and weight measurements and the linear regression analyses on the 196-day growth rates gave the following results: Control (70 ± 80) mg; 160 ng/l TBT treatments increased by 55% and 53%; both the multiple-range test on weekly length and weight measurements and the linear regression analyses on the 196-day growth rates gave the following results: Control (70 ± 80) mg; 160 ng/l TBT treatments increased by 55% and 53%.
There were no significant mortalities at any concentration in either experiment. In Test I after 56 and 196 days exposure to 200 ng/l TBT, survival was 100 and 94%, respectively. In Test II, after 56 days exposure to 160 ng/l TBT survival was 100%.

**Figure 1.** Cumulative percent change in juvenile mussel weights and lengths for Test I and Test II.

**DISCUSSION**

Compared to controls, significant reductions in juvenile mussel growth rate were measured in PETS after 196 days at TBT concentrations much lower than previously reported in other laboratory or field studies (4, 5, 6, 7). No significant effects were measured after 56 days. The principal reasons for detecting these subtle effects were longer exposures and larger sample sizes than in previous studies. Since the site-specific bioassay performed here may have combined the advantages of controlled laboratory dosing with realistic field test conditions in a relatively long-term (5 month) chronic study, these results may not be surprising. PETS provided more environmentally realistic test conditions than the laboratory studies cited here because of unfiltered seawater with natural phytoplankton populations and suspended sediment. However, differences in growth rates between the Pier Control and the Tank Control suggest that test conditions were not as environmentally realistic as expected due to system-induced stress. Differences in growth between Test I and II during the first 56 days of exposure indicate that test conditions were markedly different. Therefore, the TBT concentration affecting growth in Test I may be overestimated.
Table 1. Growth rates estimated from juvenile mussel weights and lengths.

|                  | **TEST I** |                 | **MEAN TBT CONCENTRATIONS** |                 |                 |
|------------------|------------|-----------------|----------------------------|-----------------|-----------------|
|                  | Pier       | Tank            | 70                         | 80              | 200             |
| Initial Weight (mg) | 119        | 299             | 330                        | 303             |
| Final Weight (mg)  | 1657       | 1285            | 1430                       | 1005            |
| Growth Rate (mg/wk) | 48         | 35              | 39                         | 25              |

|                   |            |                 | 0-56 days (mg/wk)         | 56-119 days     | 119-196 days    |
|-------------------|------------|-----------------|---------------------------|-----------------|-----------------|
| Initial Length (mm) | 14.52      | 14.20           | 14.68                      | 14.26           |
| Final Length (mm)  | 21.30      | 21.50           | 22.30                      | 19.40           |
| Growth Rate (mm/wk)| 0.33       | 0.26            | 0.27                       | 0.18            |

|                  | **TEST II** |                 |                           |                 |                 |
|------------------|------------|-----------------|---------------------------|-----------------|-----------------|
| Initial Weight (mg) | 293        | 302             | 278                       | 284             | 283             |
| Final Weight (mg)  | 1262       | 583             | 591                       | 530             | 477             |
| Growth Rate (mg/wk) | 140        | 40              | 45                        | 35              | 28              |

|                  |            |                 |                           |                 |                 |
|-------------------|------------|-----------------|---------------------------|-----------------|-----------------|
| Initial Length (mm) | 12.72      | 12.30           | 12.50                      | 12.50           | 12.60           |
| Final Length (mm)  | 21.76      | 16.50           | 16.50                      | 15.70           | 14.80           |
| Growth Rate (mm/wk)| 1.13       | 0.48            | 0.50                       | 0.40            | 0.28            |

* TBT concentrations were slightly different during these periods.

**Test Conditions**

As White and Champ (10) have suggested, some of the differences in results can be attributed to system-induced stress and differences in test conditions. Salazar et al. (15) have discussed temperature and nutritive stresses in the PETS system and suggested that tank conditions were more favorable for mussel growth in Test II than Test I. This was due to lower mean TBT concentrations, more optimum temperatures and reduced biomass during the last 56 days when the tests overlapped. Growth rates and byssal thread production of Test I mussels increased dramatically during this period. Bayne and Thompson (18) have described some of the physiological consequences of maintaining *M. edulis* in the laboratory as well as the specific effects of temperature and nutritive stress on reducing both growth rate and reproduction effectiveness (20, 21).

**Temperature Stress**

Even though experimental conditions were improved, reduced growth rates were expected in Test II since winter conditions generally reduce mussel growth due to lower temperatures and less phytoplankton (22, 23). However, growth rates of Tank Control animals were higher in Test II than the first 56 days of Test I.

Bayne et al. (1) have reported that above 20°C there is increased respiration and reduced filtration in mussels. Above 25°C there are adverse growth effects. A maximum temperature of 25.9°C and a mean temperature of 22.3°C during the early part of Test I suggests that juvenile mussels were under temperature stress. When temperature decreased in the latter part of Test I, growth rates increased in all treatments. San Diego Bay summer temperatures may reduce growth because they approach levels that adversely affect mussel physiology. Adverse temperature effects were aggravated by PET tanks which raised the temperature higher than ambient. Measured daily fluctuation was almost four times higher in PET tanks than in the bay.
To TcwD CD plumbing that never reached test tanks. As plankton stress in mussels exposed provided mussel suspended particulates. These authors predicted growth rates in PETS than in laboratory studies at concentrations up to 200 ng/l. TBT effects on survival and growth may have been over-estimated in the Valkirs et al. (3) and other laboratory tests due to nutritive stress.

Laboratory studies have generally been used to estimate TBT effects on mortality and growth. Valkirs et al. (5) reported a significant decrease in length for adult mussels exposed to 300 ng/l TBT with no significant changes in weight. However, these decreases are probably an artifact of statistical analyses. They also reported a 66-day LC-10 of approximately 125 ng/l TBT for adult mussels. There were no significant mortalities attributable to TBT exposure in either Test 1 or 2 of the PETS studies at concentrations up to 200 ng/l. TBT effects on survival and growth may have been over-estimated in the Valkirs et al. (3) and other laboratory tests due to nutritive stress.

Stromgren and Bongard (6) used juveniles much smaller than in PETS and reported significant reductions in mussel shell growth after only 7 days exposure to 400 ng/l TBT. While the laser measurement technique is interesting, reporting effects at such high levels in a test of such short duration with unmeasured treatment concentrations has little environmental significance.

Laboratory Studies

At test concentrations which produced no effects in PETS, Thain and Waldock (4) found a significant reduction in juvenile mussel growth. These growth reductions could be attributed to higher and more variable TBT concentrations than in PETS, but there is reason to believe that the results reflect the effects of uncontrolled test conditions (10) as such as the "TBT conditions. These conditions include using a single algal species for food, carrier solvents and no suspended sediment.

Laboratory test conditions affect growth in other ways. Waldock et al. (26) have shown reduced mussel growth with increased tissue concentrations of metals and hydrocarbons in the field. Waldock and Thain (25) have provided data that show reduced oyster growth with increasing tissue concentrations of TBT in the laboratory. Laughlin et al. (27) have shown that accumulation of TBT by mussels in the laboratory is different from that in the field. If accumulated TBT affects mussel growth rate, these results suggest that growth rates of mussels exposed to TBT in the laboratory would be different than in the field.

The major contributing factors to nutritive stress in PETS mussels were probably reduced phytoplankton levels and reduced suspended sediment compared to ambient bay water. Weekly maintenance revealed large amounts of sediment trapped in the plumbing that never reached test tanks. As evidenced by accumulated sediment in the bottom of the PETS tanks however, there was much more suspended sediment in PETS than in laboratory studies.

Kiorboe and Walsenberg (24) suggested growth rates in optimum laboratory studies do not approach growth rates in the field primarily because mussel derives additional nutrition from suspended particulates. These authors predicted growth rate increases of 30 - 70% with the addition of only 5 mg/l suspended sediment. Waldock and Thain (25) provided additional data showing a 72% enhancement in oyster growth with 75 mg/l suspended sediment. None of the previous laboratory growth studies with mussels exposed to TBT included suspended sediment. This may have resulted in nutritive stress. Mussels in any environment with suspended sediment and a natural diet may be under less total stress, grow faster and potentially more resistant to TBT.

Figure 2. Log transformed weight and length slopes for juvenile mussel growth in Test 1.

}\n
\textbf{Nutritive Stress}

The major contributing factors to nutritive stress in PETS mussels were probably reduced phytoplankton levels and reduced suspended sediment compared to ambient bay water. Weekly maintenance revealed large amounts of sediment trapped in the plumbing that never reached test tanks. As evidenced by accumulated sediment in the bottom of the PETS tanks however, there was much more suspended sediment in PETS than in laboratory studies.

Kiorboe and Walsenberg (24) suggested growth rates in optimum laboratory studies do not approach growth rates in the field primarily because mussel derives additional nutrition from suspended particulates. These authors predicted growth rate increases of 30 - 70% with the addition of only 5 mg/l suspended sediment. Waldock and Thain (25) provided additional data showing a 72% enhancement in oyster growth with 75 mg/l suspended sediment. None of the previous laboratory growth studies with mussels exposed to TBT included suspended sediment. This may have resulted in nutritive stress. Mussels in any environment with suspended sediment and a natural diet may be under less total stress, grow faster and potentially more resistant to TBT.
Field Studies

Field measurements provide a realistic test platform for long-term studies, but generally lack the control necessary for experimentation and establishing cause-and-effect relationships particularly with TBT (12). In a San Diego Bay field test Stephenson et al. (7) exposed mussels at four sites along a known TBT concentration gradient of 2 km. Significant differences in growth were observed after 150 days exposure to 210 ng/l TBT. The control site, however, was inappropriate in that it differed in many parameters other than TBT concentration. In addition, there were many other variables along that TBT gradient which may have affected mussel growth. Since mussel growth can exhibit extreme local variation (22, 28, 29), the utility of using mussel growth as an index of mussel stress at different sites in the field without appropriate experimental control must be challenged. White (30) has cautioned against the arbitrary use of mussel monitoring systems without developing the model to be tested.

Summary - PETS Study

Although the PETS did not duplicate the environment, it may have simulated more environmentally realistic test conditions than the laboratory because of unfiltered seawater, natural phytoplankton populations and suspended sediment. The leachate dosing system permitted greater experimental control than the field test. However, long-term exposures and large sample sizes permitted detection of significant TBT effects at concentrations much lower than previously reported. It must be emphasized that system-induced stresses also reduce juvenile mussel growth. It was impossible to quantify the relative effects of each. The 70 ng/l TBT that reduced growth rates in this study would not have an effect on mussel growth rates under most environmental conditions. Only under very stressful environmental conditions similar to those in PETS experimental tanks would this concentration affect growth. Further, 160 ng/l might have been the lowest concentration to reduce growth in PETS tanks after longer exposures and less stressful conditions. Uncontrolled stress in the site-specific bioassay precluded direct environmental extrapolation. The lowest TBT concentration affecting juvenile mussel growth under varying environmental conditions remains unknown.

The authors feel that results from the three laboratory studies, the field study and this site-specific bioassay were as much a function of uncontrolled test conditions and animal age as TBT exposure concentrations. To obtain meaningful biological measurements of TBT effects on juvenile mussel growth, the authors suggest combining laboratory, microcosm and field tests in more discriminate experiments designed to equate measured responses to the natural field response and answer specific questions about bioavailability. Further, to assess environmental significance, a leachate dosing system with TBT-coated panels similar to that used in the laboratory and in PETS should be developed for field use (in-situ). Theoretically, mussel growth rates could be used to compare dosed versus undosed animals with a control group close enough to be a true control in all other environmental parameters yet far enough away to be unaffected by TBT.

Acknowledgments

This research was sponsored by the Naval Facilities Engineering Command, Office of Chief of Naval Research and the David Taylor Naval Research and Development Center. We wish to thank P. Stang, A. Valkirs and M. Stalnand for chemical analyses and G. Pickwell, K. Richter and P. Seligman for editorial assistance. A special thanks is due to B. Davidson for maintaining the test system, conducting statistical analyses and editorial support.

References

(1) Bayne, B. L., D. A. Brown, K. Burns, D. R. Dixon, A. Ivanovici, D. B. Livingstone, D. M. Lowe, N. M. Moore, A. R. D. Stabbing, and J. Widdows. 1985. The effects of stress and pollution on marine animals. Praeger Special Studies, Praeger Scientific, New York.

(2) Widdows, J. 1985. Physiological responses to pollution. Mar. Poll. Bull. 16(4):129-134.

(3) Rodhouse, P. G., J. H. McDonald, R. I. E. Newall and R. K. Koehn. 1986. Gamete production, somatic growth and multiple-locus enzyme heterozygosity in Mytilus edulis. Mar. Biol. 90:201-214.

(4) Thain, J. E. and N. J. Waldock. 1985. The growth of bivalve spat exposed to organotin leachates from antifouling paints. International Council for the Exploration of the Sea (preprint).

(5) Valkirs, A. O., B. M. Davidson and P. F. Seligman. 1987. Sublethal growth effects and mortality to marine bivalves from long-term exposure to tributyltin. Chemosphere 16(1):101-220.

(6) Stang, T. and T. Bongard. 1987. The effect of tributyltin oxide on growth of Mytilus edulis. Mar. Poll. Bull. 18(1):10-11.

(7) Stephenson, M. D., D. R. Smith, J. Goetzl, G. Ichikawa and M. Martin. 1986. Growth abnormalities in mussels and oysters from areas with high levels of tributyltin in San Diego Bay. In: Proceedings, Oceans 1986 Conference, Washington D. C., 21-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1246-1251.

(8) Salazar, M. H. 1986. Environmental significance and interpretation of organotin bioassays. In: Proceedings, Oceans 1986 Conference, Washington D. C., 21-25 Sept 1986. Organotin Symposium, Vol. 4, pp. 1140-1145.
(9) Grovengo, J. G., P. F. Seligman, G. Vafa and R. L. Franchon. 1986. Baseline measurements of butyltin in U. S. harbors and estuaries. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-26 Sept 1986, Organotin Symposium, Vol. 4, pp. 1281-1288.

(10) White, H. H. and M. A. Champ. 1983. The great bioassay hoax, and alternatives. In: R. A. Conway and W. P. Gullede (eds.), Hazardous and Industrial Solid Waste Testing: Second Symposium. ASTM STP 805. American Society for Testing and Materials. pp. 299-312.

(11) Malins, D. C., H. O. Hodgins, U. Vararasi, W. D. MacLeod, Jr., B. B. McCall and S.-L. Chan. 1984. Chemical measurements of organic pollutants and effects criteria. In: H. H. White (ed.), Concepts in Marine Pollution Measurements. Maryland Sea Grant Publication, College Park, University of Maryland, College Park, pp. 405-426.

(12) Stemberg, A. R. D. 1985. Organotins and water quality - some lessons to be learned. Mar. Poll. Bull. 16(16) 383-390.

(13) Pilson, M. E. Q. 1984. Should we know the fates of pollutants? In: H. H. White, (ed.), Concepts of Marine Pollution Measurements, Maryland Sea Grant College, College Park, Maryland, pp. 575-585.

(14) United States Naval Sea Systems Command. 1984. Environmental assessment for fleetwide use of organotin antifouling paint. U. S. Navy, Code 5617, Washington D. C.

(15) S. M. Salazar, B. M. Davidson, M. H. Salazar, P. M. Stang, and H. Meyers-Schulte. 1987. Field assessment of a new site-specific bioassay system. This Conference.

(16) Reish, D. J. and J. L. Ayers, Jr. 1968. Studies on the Mytilus edulis community in Alamitos Bay, California. III. The effects of reduced dissolved oxygen and chlorinity concentrations on survival and byssus thread formation. Veliger 10:384-388.

(17) Van Winkle, W., Jr. 1970. Effect of environmental factors on byssal thread formation. Mar. Biol. 7:143-148.

(18) Salazar, M. H. 1974. Byssal thread production as a toxicity test. In: Proceedings, Conference on Marine Biology in Environmental Protection, San Clemente Island, California, 13-15 November 1973, NUC TP 443, pp. 103-113.

(19) Bayne, B. L. and R. J. Thompson. 1970. Some physiological consequences of keeping Mytilus edulis in the laboratory. Heigo. Meeza. 20:526-522.

(20) Bayne, B. L., P. A. Jackson and J. Widdows. 1975. Some effects of stress in the adult on the eggs and larva of Mytilus edulis. J. Mar. Biol. Assoc. U. K. 55:673-689.

(21) Bayne, B. L. D. L. Holland, M. M. Moore, D. M. Lowe and J. Widdows. 1978. Further studies on the effects of stress in the adult on the eggs of Mytilus edulis. J. Mar. Biol. Assoc. U. K. 58:835-841.

(22) Seed, R. 1976. Ecology. Marine mussels: their ecology and physiology, pp 13-65. Edited by B. L. Bayne. Cambridge: Cambridge University Press.

(23) Newell, R. C. 1979. Biology of intertidal animals. 3rd ed., Marine Ecological Surveys Ltd., Faversham, Kent, 791 pp.

(24) Kiørboe, T., F. Mohrback and O. Nohr. 1981. Effect of suspended bottom material on growth and energetics in Mytilus edulis. Mar. Biol. 61:283-288.

(25) Waldock, M. J. and J. E. Thain. 1983. Shell thickening in Crassostrea gigas: organotin antifouling or sediment induced? Mar. Poll. Bull. 14(11):411-415.

(26) Widdows, J., D. K. Phelps, and W. Galloway. 1981. Measurement of physiological condition of mussels transplanted along a pollution gradient in Narragansett Bay. Mar. Environ. Res. 4:181-194.

(27) Laughlin, R. B., Jr., W. French and H. E. Guard. 1986. Accumulation of bis(tributyltin) oxide by the marine mussel Mytilus edulis. Environ. Sci. Tech. 20:884-900.

(28) Bayne, B. L. and C. M. Worrall. 1980. Growth and production of mussels Mytilus edulis from two populations. Mar. Ecol. Prog. Ser. 1:117-128.

(29) Thompson, R. J. 1984. Production, reproductive effort, reproductive value and reproductive cost in a population of the blue mussel Mytilus edulis from a subarctic environment. Mar. Ecol. Prog. Ser. 13:249-257.

(30) White, H. H. 1984. Mussel madness: use and misuse of biological monitors of marine pollution. In: H. H. White (ed.), Concepts in Marine Pollution Measurements. Maryland Sea Grant Publication, University of Maryland, College Park, pp. 324-337.
END
DATE
FILMED
5-88
DTIC