Marine Mining, Volume 8, pp. 303–315
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0149-0397/89 $3.00 + .00

Effects of Marine Mining Dredge Spoils on Eggs and Larvae of a Commercially Important Species of Fish, the Mahimahi (*Coryphaena hippurus*)

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Abstract *Eggs and early larval stages of the pelagic fish* Coryphaena hippurus *(commonly known as mahimahi) can survive prolonged exposure to concentrations of suspended sediment that greatly exceed levels caused by marine mining, coastal construction, and ocean disposal of dredge spoils. Sediments do not appear to present a direct threat to the early life stages of this economically important species at concentrations and exposure times that might result from typical ocean mining and ocean dumping operations. Results of this study support conclusions of previous investigations on effects of sediment on inshore and freshwater fishes. Lack of detrimental effects has also been reported in similar studies involving effects on phytoplankton, zooplankton, and adult pelagic fish. The results must be viewed with caution because these experiments did not evaluate the impact of sediments on complex ecological interactions, and did not evaluate the impact of possible toxicants that could be associated with some types of waste.*

Keywords Sediment, turbidity, fish larvae, fish eggs.

Introduction

Ocean mining, large-scale coastal construction projects, and ocean dumping can increase the suspended load of sediments over large areas of ocean. Organisms inhabiting estuaries, rivers, and bays have evolved in an environment that is often subjected to naturally occurring conditions of high turbidity. In contrast, organisms of the tropical pelagic realm live in water that is very low in suspended matter. Studies on the environmental impact of mining operations on phytoplankton, macrozooplankton, and adult fish have been conducted (Ozturgut et al. 1980; Chan and Anderson 1981; Hirota 1981; Lavelle and Ozturgut 1981; Lavelle et al. 1982; Matsumoto 1984). The impact of particulates on the survival and growth of pelagic fish larvae has not been addressed adequately, as emphasized by Hirota (1981) and Matsumoto (1984). A review of available information led Matsumoto (1984) to the following conclusion: "Most of the changes to the environment resulting from mining, such as increased suspended sediment particles, reduced illumination due to turbidity, mixing of cold bottom water with surface water, and changes in trace metals, salinity, and oxygen levels of the surface water, are not extensive enough to endanger tuna and billfish eggs and larvae."

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Direct experimentation involving the effect of sediments on eggs and larvae of pelagi species has not been conducted previously. The present study was designed to develoj preliminary data in this area. Lack of such data is due to difficulties involved in th laboratory culture of pelagic fish. The species chosen for this study was the dolphin *Coryphaena hippurus*, known as the mahimahi in Hawaii. This is a commercially im portant species of food fish throughout its range.

Methods

Experiments were conducted at the Kewalo Research Facility of the Southwest Fisherie Center Honolulu Laboratory, where the mahimahi has been cultured through its life cycle.

Production of Eggs and Larvae Used in the Experiments

Adult mahimahi brood stock was maintained at the Kewalo Research Facility in large circular tanks of 7.2 m diameter and 1 m depth. The tanks were supplied with a continuous flow of aerated seawater providing a turnover time of <1 h. The fish were maintained at water temperatures of 23–25 °C and fed a diet of squid, fish, and vitamins. The brood stock typically spawned every other day.

Mahimahi eggs are spherical (1.5–1.7 mm diameter) and buoyant. They were normally collected within an hour of spawning with a fine-mesh dip net as they floated near the surface. Eggs were transferred into cylindrical laboratory aquaria of 150 L volume that contained mildly aerated filtered seawater. Under these conditions the eggs hatch within 50–60 h after spawning. Newly hatched mahimahi larvae measure approximately 4.5–5.5 mm standard length. Marine microalgae, cultures of *Tetraselmis* sp. and *Isochrysis* sp., were added to maintain water quality. At 25–26 °C the yolk is absorbed within 2 days of hatching, so the tank was inoculated at that time with planktonic rotifer, *Brachionus* sp., at a concentration of approximately 2 mL^{-1}. This concentration of food was maintained throughout the entire experiment.

Selection of Sediment Types and Sedimentation Levels to Be Tested

A marine mining operation (reviewed in Matsumoto 1984) typically has a discharge concentration on the order of 6 mg L^{-1} of suspended solids. Waste materials mix or sink rapidly in the water column, and are diluted within 15 min to a concentration of <1 mg L^{-1}. After 24 h the discharge plume dissipates to a concentration of <0.05 mg L^{-1}.

Typical ocean dumping operations of dredge spoils off Oahu caused a measurable increase in turbidity of the receiving waters for a relatively short period of 2–5 h (Environmental Protection Agency 1980), although a visually noticeable plume can sometimes persist for much longer (J. Naughton, personal communication). The highest concentration observed in the water immediately after dumping was 60 mg L^{-1} (Chave and Miller 1977). The suspended material in this case was rapidly dissipated to a concentration of 1 mg L^{-1} or less.

Suspended solid concentration in the surface waters immediately downstream of the Barbers Point channel dredging operation (February 1983 to October 1983) was approximately 20 mg L^{-1} or less (Harrison 1987). Again, this value rapidly diminished to levels of 1 mg L^{-1} or less as the plume dispersed offshore. The most turbid inshore waters found in Hawaii are in disturbed areas that have been previously dredged and filled (e.g., Honolulu Harbor, Oahu or Keehi Lagoon, Oahu). These worst-case situations typically have a maximum suspended solid load of approximately 6 mg L^{-1} (Chapman 1979), but these solids are quickly diluted to levels well below 1 mg L^{-1} as they are carried offshore by currents.

In sum, the highest concentration of suspended sediment resulting from ocean mining, ocean dumping, or coastal construction is between 5 and 50 mg L^{-1}, but these areas are highly localized. In general, larger areas of ocean are subjected to plumes with a suspended load of 1 mg L^{-1} or less of suspended solids. In those situations exposure times of larvae to concentrations of suspended solids of from 5 to 50 mg L^{-1} is probably less than 15 min, but prolonged (1–2 h) exposure to suspended solid levels of less than 1 mg L^{-1} could occur.

The initial tests described in this report were designed to exceed the anticipated typical environmental loading level of approximately 1 mg L^{-1} by several orders of magnitude. Six treatments were established with loading levels of 0, 500, 1000, 2000, 4000, and 8000 mg L^{-1}. These are the same concentrations used by Boehlert et al. (1983) and Boehlert and Morgan (1985) in studies of the effect of suspended solids on the eggs and larvae of the Pacific herring.

Incubation Chambers

One of the technical problems encountered in this study was the design of an apparatus that could keep the sediment suspended in the water while providing the low-turbulence conditions required for the maintenance of the larvae. An apparatus previously developed in a series of experiments on the effects of turbidity on feeding abilities of larvae of the Pacific herring (Boehlert and Morgan 1985) was employed in the initial tests. This apparatus consists of small (volume = 1 L) incubation chambers that are gently flushed with circulating seawater. The initial two experiments that evaluated effects of sediment on egg development on hatching were conducted in this apparatus. The chambers did not appear to influence egg development or hatching rate, but inflicted high mortality on the larvae of *C. hippurus*. Larger containers were developed for use in the larva tests. A series of four experiments was designed to compare 24-h larval mortality in the Boehlert and Morgan (1985) apparatus with mortality in large volume (30-L) chambers previously used at the Kewalo Research Facility to culture the mahimahi larvae. All *C. hippurus* larvae died within 24 h in the smaller chambers regardless of flow rate, level of turbulence, or age of larvae. Very low rates of mortality occurred in the 30-L control containers. Larvae of *C. hippurus* seem to be far more sensitive to mechanical damage than herring larvae. They were unable to withstand damage inflicted by bumping into the walls of small containers. Therefore, the larger containers were used in all tests involving larvae.

Sediment was suspended in the experimental system by placing an airstone in the vertex of the concave bottom. The containers used were 40 cm in diameter with vertical walls of 25 cm that sloped to a maximum depth of 30 cm in the center of the container. An air flow of 500 cm^3 min^{-1} created enough water motion to keep the clay and silt in suspension, while not damaging the larvae. Little or no sediment adhered to the steep container walls. The convection current induced by the airstone was sufficient to prevent settling of fine suspended material. Temperature was maintained at 26 ± 1 °C by holding the containers in a thermally regulated water bath. All experiments were conducted at the same level of controlled illumination (approximately 50 cm from fluorescent 40-W tubes). An artificial day-night cycle (13 h on and 11 h off) was maintained throughout the experiment.

Sediment Types

Several types of sediment were tested. Different materials that are representative of potential pollutants in the pelagic environment of the larval mahimahi were tested. These included sediments typical of the type produced by coastal construction, dredging for harbor construction and maintenance, ocean mining, and ocean dumping. Most of these materials are chemically inert minerals. Potential toxins and high organic biochemical oxygen demand could be a problem with certain sediments (i.e., as harbor dredge spoils). Grain-size distribution of all materials used in these experiments was determined with a Coulter counter using the method of Hirota (1981). Results of the sediment analysis are shown in Table 1. A description of these sediments follows.

Kaolin. This form of hydrated aluminum silicate is one of the primary end weathering products of volcanic rock and ferromagnesian minerals. A pure form of this silicate clay (Sigma Chemical Company K-73752) consisting of particles in the 0.1- to 4-μ size range was used in these experiments.

Bentonite (Montmorillonite). This aluminum-magnesium silicate clay is another of the primary weathering products of volcanic rock and ferromagnesian minerals. In the weathering series it is a precursor of kaolin. A pure form of this clay (Sigma Chemical Company B-3378) was used. This clay has a high swell-to-shrink ratio and is often used to seal water reservoirs against seepage.

Table 1
Results of Coulter Counter Analysis of Size Distribution for Material Used in These Experiments

Sediment size fraction (μm)	Sediment type[a]						
	R	P	M	K	C	D	B
1.30–1.59	0.2[b]	2.5	2.2	61.1	1.5	6.2	16.9
1.60–1.99	0.0	3.4	2.9	27.3	2.0	9.0	16.6
2.00–2.49	0.3	4.8	7.1	8.5	3.9	13.3	15.2
2.50–3.19	0.5	6.8	10.0	2.5	7.0	15.7	13.6
3.20–3.99	0.7	8.0	10.3	0.7	10.9	13.3	10.7
4.00–4.99	1.0	9.2	10.0	0.3	15.7	11.6	8.7
5.00–6.29	2.5	10.0	8.6	0.1	15.7	9.1	4.8
6.30–7.99	6.0	0.6	9.2	0.2	4.7	6.8	4.1
8.00–10.19	13.4	10.6	9.3	0.7	9.0	5.0	4.0
10.10–12.69	23.1	9.0	8.7	1.3	7.8	3.5	3.0
12.70–15.99	24.8	6.8	8.3	1.6	5.8	4.3	2.2
16.00–20.19	15.2	7.5	6.4	0.0	3.3	0.2	0.1
20.20–25.39	7.3	7.6	4.6	0.0	1.4	2.1	0.6
>25.4	5.1	3.1	2.8	0.0	1.3	0.0	0.1

[a] B = bentonite; C = calcareous ooze; D = dredgings from Barbers Point Deep Draft Harbor; K = kaolinite; M = manganese crust; P = dredgings from Pearl Harbor; R = red clay.

[b] Values in table are % of total sample within each size range.

Pelagic Carbonate Clay. Calcarious ooze dredged from near Gardiner Pinnacles was used in these experiments. It is typical of material that might be brought to the surface of the ocean during ocean mining operations at shallower depths.

Pelagic Red Clay. Red clay dredged from near Gardiner Pinnacles was used as a typical sediment from the deeper ocean that is commonly associated with manganese nodules.

Pulverized Manganese Crust. Samples of manganese crust taken from the exclusive economic zone in the northwestern Hawaiian Islands were pulverized into fine sediment with a mortar and pestle and passed through a 100-μm mesh sieve. The pulverized material represents one type of fine sediment that might result from an ocean mining operation.

Barbers Point (Oahu) Deep Draft Harbor Dredge Spoils. Mud was dredged from the bottom of the inner Barbers Point Deep Draft Harbor near the completion of dredging operations in July 1985. This harbor was dredged out of an emergent reef platform, and the dredge spoils consist almost entirely of carbonate materials. Organic matter was extremely low or absent in the spoils as indicated by lack of anoxia, even when the sediments were stored in a covered pail for many weeks. The material is a carbonate mud typical of that produced by dredging or erosion of coral reefs. The material was further fractionated by resuspension in water and the coarse fraction was allowed to settle within the fist 10 min. The water and suspended fine material was decanted into another container and allowed to fully settle.

Dredgings from Pearl Harbor, Oahu. Dredge spoils from harbors are commonly dumped at sea. Extensive sediment plumes result, with unknown consequences to the surrounding pelagic ecosystem (J. Naughton, personal communication). Material used in this study was dredged from the bottom of the main shipyard at Pearl Harbor, Oahu, Hawaii. This type of material differs from the others in that it has a higher organic content. Harbor dredgings often contain toxic substances as well, including heavy metals, hydrocarbons, and hydrogen sulfide.

Experimental Procedure

Drying can alter the chemical composition of sediments, so only moist samples of dredged materials and deep sea muds were used. The amount of moist sediment to be added to each treatment was calculated using measured wet to dry weight ratio for each sediment type. The proper amounts of moist sediment were preweighed and set aside. The sediments were reconstituted by mixing with seawater in a blender before being added to the experimental chambers.

Effects of Suspended Solids on Egg Survival, Development, and Hatching Rate

Experiment E-1 was designed to test the effect of sediment load on egg development. Sediment type was Barbers Point Deep Draft Harbor dredge tailings. The experiment was conducted in the chambers described by Boehlert and Morgan (1985) using four replicates each at six treatment levels (0, 500, 1000, 2000, 4000, and 8000 mg L^{-1}). Twenty fertile eggs (approximately 8 h postfertilization) were added to each of the 24 chambers. Duration of the experiment was 24 h, after which time the eggs were examined with a microscope for mortality or retarded development.

Experiment E-2 was run in the same manner as experiment E-1, except that fine kaolin was used as suspended solid, because the carbonate dredge tailings used in experiment E-1 did not produce egg mortality even at the extremely heavy loading of 8000 mg L^{-1}. Fine kaolin is very "sticky" and can adhere to surfaces.

Experiment E-3 was a continuation of experiment E-2, but the exposure time was extended from the original 24 h to a full 4 d of exposure to allow enough time for all eggs to hatch. We lengthened exposure time because no egg mortality occurred at 24 h, even at the highest concentration of 8000 mg L^{-1} of kaolin.

Effects of Suspended Solids on Larvae Mortality and Feeding

This series of experiments was designed to identify the most sensitive larval stage and also to identify possible differences in the impact of different types of sediment. All of the experiments on larvae were conducted in the same manner as described above using the larger containers of 30 L volume. The experimental aquaria were filled with 28 L of filtered seawater and allowed to equilibrate in the constant temperature water bath while being aerated at a rate of 500 cm^3 min^{-1}. Two liters of water were retained for later use in homogenizing sediment with a food blender and for rinsing the stock sediment from the blender into the experimental aquaria. Larval fish were gently added to each container since they are very easily damaged by handling. Mechanical damage was minimized by carefully scooping individual larvae from the rearing container into a bowl and gently placing them into the experimental chamber. For feeding larvae, the aquaria were stocked with rotifers at approximately 2 mL^{-1}. Sediment was then mixed into a slurry with a portion of the remaining liter of seawater in a commercial blender and slowly added to the experimental aquaria. The last portion of seawater was used to rinse the blender into the experimental aquarium.

The experiments differed from each other only in type of sediment, age of larvae, and exposure time. The differences between the various experiments are noted in Tables 3 and 4. Each experiment involved the use of six treatments run simultaneously. The series proceeded in a logical order, with each being based on results of the previous experiment. The experiments are extremely time-consuming, especially those involving larvae that were of feeding age. Also, the necessity of using very large containers to insure larval survival and limited space in the rearing laboratory precluded the use of multiple replicates. Therefore, it was necessary to run an experiment, review the results, and then plan the next experiment.

One important point must be emphasized. Long-term experience in the culturing of this fish species suggests that one can compare treatments only in a controlled experiment. All larvae must be taken from the same batch of eggs and all larvae used in an experiment must have been reared in the same container. Different batches of larvae can vary in sensitivity depending on many environmental, genetic, and nutritional factors that cannot be adequately predicted or controlled between batches. In work with such delicate fish larvae, mortality is often high within the control treatment. In general, the bioassay control should have less than 10% mortality (American Public Health Association 1985). The larvae must be transferred and counted, and some damage is inflicted, even with careful handling. Often there is a fairly high rate of mortality in newly hatched larvae, even without handling.

Results

General Observations

Egg Development, Mortality, and Hatching Rate. Nearly total egg survival was observed after 24 h in all treatments of experiment E-1 with no differences in rate of development, up to and including the highest sediment loading of 8000 mg L^{-1} (Table 2). The sediment used in the first experiment was carbonate material dredged from the Barbers Point Deep Draft Harbor on Oahu. In experiment E-2, eggs were examined periodically but did not show differences in development rate. In experiment E-3, egg hatch was nearly 100% in all treatments, as inferred by the empty egg cases with circular escape holes. A few eggs failed to hatch, but these were not restricted to any treatment and did not seem to be related to sediment loading level. This line of investigation was terminated because we observed little or no effect of sediment on development rate, egg mortality rate, and hatching rate even after 96 h of exposure to extremely high levels of suspended solids.

Larva Mortality Rate. Three facts are important in reviewing the results of the larval fish experiments presented in Tables 3 and 4. First, high mortality in control treatments was observed in some batches of larvae. Note results of experiments L-1, L-2, L-7, and L-8. Second, egg quality and the resultant larvae condition and survival may vary considerably among batches. We can legitimately compare results of treatments within an

Table 2
Summary of Egg Mortality and Hatching Data for Eggs of *Coryphaena hippurus*

Exp. No.	Stocking density (eggs L^{-1})	Sediment		Exposure time (h)	Egg mortality (%)	Normal egg development (%)
		Type[a]	mg L^{-1}			
E-1	1	D	0	24	0	100
			500	24	0	100
			1000	24	0	100
			2000	24	0	100
			4000	24	0	100
			8000	24	0	100
E-2a	20	K	0	24	0	100
			500	24	0	100
			1000	24	0	100
			2000	24	0	100
			4000	24	0	100
			8000	24	0	100
E-2b	20	K	0	96	5	100
			500	96	0	100
			1000	96	7	100
			2000	96	0	100
			4000	96	2	100
			8000	96	10	100

[a] D = dredgings from Barbers Point Deep Draft Harbor; K = kaolinite.

Table 3
Summary of Mortality Data for Larvae of *Coryphaena hippurus*

Exp. No.	Larva age (d)	Sediment		Time (h)	Larva mortality (%)
		Type[a]	mg L^{-1}		
L-1	0	K	0	2	14
			500	2	16
			1000	2	22
			2000	2	10
			4000	2	16
			8000	2	28
L-2	3	K	0	2	42
			500	2	—
			1000	2	20
			2000	2	12
			4000	2	30
			8000	2	50
L-3	0	B	0	2	0
			500	2	30
			1000	2	58
			2000	2	30
			4000	2	26
			8000	2	62
L-4	7	K	0	2	0
			500	2	4
			1000	2	4
			2000	2	0
			4000	2	12
			8000	2	12
L-5	3	B	0	2	0
			500	2	0
			1000	2	0
			2000	2	2
			4000	2	4
			8000	2	12
L-6	5	K	0	2	6
			500	2	30
			1000	2	26
			2000	2	26
			4000	2	52
			8000	2	100

Table 3 (*continued*)

Exp. No.	Larva age (d)	Sediment Type[a]	Sediment mg L^{-1}	Time (h)	Larva mortality (%)
L-7	3	K	0	24	20
			500	24	17
			1000	24	6
			2000	24	17
			4000	24	14
			8000	24	17

[a] B = bentonite; K = kaolinite.

experiment, but not between experiments. Third, the sediment loading was set at levels that are orders of magnitude greater than actual field loading values. There is a very large margin for error when applying the resulting mortality data (i.e., no mortality observed at high levels of sediment loading) to the real-world situation. In addition, the experimental fish larvae were stressed somewhat by handling and presumably were in poor condition compared to their wild counterparts. In this respect the data are conservative and can be

Table 4
Summary of Mortality Data for Larvae of *Coryphaena hippurus* for Various Sediment Types

Exp. No.	Larva age (d)	Sediment Type[a]	Sediment mg L^{-1}	Time (h)	Larva mortality (%)
L-8	4	None	0	24	26
		K	1000	24	68
		C	1000	24	54
		R	1000	24	32
		B	1000	24	100
		M	1000	24	46
L-9	7	None	0	2	0
		R	500	2	0
		R	1000	2	4
		M	500	2	0
		M	1000	2	4
		K	500	2	0
L-10	7	None	0	2	8
		P	500	2	8
		P	1000	2	6
		P	2000	2	0
		P	4000	2	3
		P	8000	2	11

[a] B = bentonite; C = calcareous ooze; K = kaolinite; M = manganese crust; P = dredgings from Pearl Harbor; R = red clay.

applied to field situations where the larvae are probably more capable of withstanding sediment stress.

In many of the experimental runs (experiments L-4, L-5, L-9, L-10), we observed little or no mortality at extremely heavy loading (1000 mg L^{-1} or more) of red clay, manganese crust, dredged material from the Pearl Harbor Shipyard area, kaolin, and bentonite. In other runs, we observed higher mortality that seemed to be related to the condition of the animals rather than the experimental treatments (experiments L-1, L-2, L-6, L-7, L-8). In either case the presence of extremely heavy loading of suspended solids had little apparent effect on the pattern of mortality.

An anomalous situation occurred in experimental treatments containing bentonite. This clay is atypical because it swells when wet and can form flocs when put into suspension. The flocs appeared to trap larvae and caused higher mortality (experiments L-3 and L-8). For reasons that we cannot explain, bentonite did not cause excessive mortality in experiment L-5. Perhaps the larvae were originally in better condition. In any event, this area needs more investigation. Any type of ocean mining or ocean dumping operation that precipitates flocs will be a cause of greater concern.

Larval Feeding Rate. Gut content analysis indicates that high concentrations of suspended solids severely impacted the ability of larvae to feed in the 2-h exposure (Table 5, experiment L-6) and the 24-h exposure (Table 5, experiment L-7). Even a 2-h reduction in feeding could be a serious problem for larvae in poor nutritional condition. Feeding inhibition appeared to be the cause of the 100% mortality in experiment L-6 after 2 h at the 8000-mg L^{-1} treatment level.

Larval Behavior in Relation to Sediment Plumes. During the course of the above experiments, it became apparent that the fish larvae were capable of rising above a turbidity plume. Larvae would rise to the surface as sediment slurry was slowly being added to the containers. Larvae caught by the plume quickly moved vertically into water above

Table 5

Feeding Activity (gut contents) at Various Sediment Concentrations for Larvae at Conclusion of Experiments L-6 and L-7

Exp. No.	Sediment concentration (mg L^{-1})	Gut contents		
		Rotifers	Cysts	Total items
L-6	0	16.3	3.1	19.4
	500	21.1	3.9	25.0
	1000	2.0	1.6	3.6
	2000	0.9	0.9	1.8
	4000	1.4	1.7	3.1
	8000	0	0	0
L-7	0	21.0	2.6	23.6
	500	9.1	1.4	10.5
	1000	3.2	1.6	4.8
	2000	0.8	0.4	1.2
	4000	2.6	2.2	4.8
	8000	0.6	1.0	1.6

the turbid layer. Aeration produced a gentle current in the containers that kept the larvae mixed throughout the water column. As soon as aeration was terminated, the sediments would begin to settle and the larvae would rapidly move into the clear water at the surface.

Discussion

Results of this investigation suggest that eggs and larvae of this fish are not extremely sensitive to the increased loading of sediment that might result from marine mining, ocean dumping, or coastal construction. As stated earlier, such activities might produce maximum loading levels of from 5 to 50 mg L^{-1} of suspended solids at the point of discharge, but sediment concentration decreases rapidly as the plume disperses. High concentrations are extremely localized (to within a few hundreds of meters from the discharge point) and do not persist very long (perhaps for 15 min) before mixing diminishes concentration to a few milligrams per liter. The increased density of water containing the solids leads to rapid sinking. Waves and currents rapidly disperse the remaining solids. A realistic loading level for a large plume is on the order of 1 mg L^{-1}. Eggs of *C. hippurus* were cultured at extremely high levels of suspended solids (up to 8000 mg L^{-1}) throughout the entire development time without any apparent increase in mortality or lowering of hatching success. Similar results on other species have been reported (Boehlert et al. 1983). Likewise, larvae were relatively insensitive to extremely heavy loading exceeding 500–1000 mg L^{-1} for a wide range of sediment types that most commonly impact the pelagic realm because of human activity. The results of these experiments with eggs and larvae of the mahimahi are consistent with results of a larger body of literature on effects of suspended solids on other pelagic biota. Failure to inflict mortality even at extremely high concentrations of sediment led to discontinuation of this experimental series.

Suspended solid concentration did not influence mortality in most situations, but did have a dramatic impact on feeding rate, as previously shown by Boehlert and Morgan (1985) for the Pacific herring. However, available field data suggest that real-world turbidity plumes will not be of sufficient density or persistence to severely impact larval feeding rate.

Larvae have a very limited swimming ability and would seem to be unable to avoid sediment plumes. We noted that although horizontal swimming speed is low in larval fishes, their vertical rate of movement (sinking or rising) can allow them to easily escape plumes in stratified water masses. The vertical movement required to escape a surface plume is only a matter of a few meters, whereas horizontal movement needed to escape the spreading of a plume might be on the order of hundreds of meters.

In conclusion, heavy loading of various types of sediments did not appear to inflict mortality on eggs or larvae of mahimahi. This general observation is in agreement with the conclusions of other workers such as Hirota (1981), who conducted experiments with zooplankton, and Matsumoto (1984), who summarized existing data on fishes and fish larvae. As stated by Scarratt (1987), "Virtually no evidence exists of adverse impacts from ocean mining on Canadian fisheries, but projections from other marine activities such as fishing itself, dredging, and other marine discharges give reason for caution." Effects of human activity on modification of these parameters might have a far greater impact on fish stocks than the direct effect of high levels of sediments. Data produced in the present study, however, must be viewed with some caution. Ellis (1987) discusses the four major impacts of turbidity, seabed smothering, contamination, and toxicity caused by marine mining. Further, he points out that we must evaluate the derived impacts of reduced biological production, biomagnification, and food pathology as well as stock mortalities. Further studies in many of these areas will be required.

Acknowledgments

Samples of pelagic red clay, carbonate ooze, and manganese crust were provided by E. DeCarlo. Dredgings from Pearl Harbor, Oahu, were provided by D. Somerton. Size grain analysis of suspended material used in the experiments was done by J. Finn. R. Y. Ito and T. K. Kazama provided support throughout the investigation in rearing the larvae and their food. G. Boehlert provided valuable guidance in the design of the experiments and offered many constructive observations on the original manuscript.

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