1989

RICE SEASON TOXICITY MONITORING RESULTS

California Regional Water Quality Control Board
Central Valley Region
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FOREWORD

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C-029768

C-029768

TABLE OF CONTENTS

C-029769

C-029769

LIST OF TABLES

C-029770

C-029770

LIST OF APPENDICES

C –0 2 9 7 7 1

C-029771

LIST OF FIGURES

C–029772

C-029772

EXECUTIVE SUMMARY

This is the final report of data originally submitted as a Central Valley Regional Water Quality Control Board memorandum (Foe, 1989). Three changes were made to the memorandum: First, the 1989 U.S. EPA toxicity identification evaluation report has now been added to the 1988 one in Appendix A. Second, a final report entitled, "Toxicity of water samples from Colusa Basin Drain and the Sacramento River to larval striped bass and opossum shrimp" by Bailey et al is included in Appendix C. Finally, U.S. EPA changed several of their reported 1989 pesticide concentration values in their final report from what they had verbally informed Board staff. This has resulted in several changes in Table 2. None of the above additions alter any of the conclusions of the original memorandum.

Agricultural discharge water collected from Colusa Basin Drain (CBD) in 1989 was acutely toxic to the invertebrate component (Ceriodaphnia) of the EPA three species test for 19 days in May and June. Water from CBD and other rice-producing areas appeared to cause significant invertebrate mortality (30-50% kill in 8 days) as far downstream on the Sacramento River as the City of Rio Vista (furthest downstream sampling site tested, approximately 75 river miles, south of CBD). Similar high invertebrate mortality has been noted in water collected from CBD and other rice-associated agricultural drains during each of the previous years monitored (1986, 87 and 88). Apparent downstream Sacramento River impacts were noted in both 1986 and 1987. Invertebrate toxicity at CBD during 1988 was caused by the discharge of the pesticides carbofuran and methyl parathion. The 1989 toxicity resulted from the release of both of the above compounds and malathion. Both carbofuran and methyl parathion are extensively used in rice cultivation. The source of malathion at CBD is, as of yet, unknown. Board staff conclude that the annual release of pesticides in rice runoff water at concentrations which cause invertebrate toxicity is a violation of the Basin Plan's narrative toxic objective.

Pesticides in rice discharge water may be responsible, in part, for the decline in size of the striped bass population in the Sacramento-San Joaquin Delta. A correlation between the pounds of methyl parathion applied annually to rice fields divided by the flow rate of the Sacramento River and the annual difference between the predicted and observed number of larval bass in the Delta is statistically significant ($P<0.01$, time period: 1970-1986). Inclusion of an apparent Sacramento River pesticide concentration factor into the California Department of Fish and Game's Delta striped bass index would account for 42% of the unexplained variance between the index and catch data for the above time period. Two hypothesis are proposed to explain the toxicity of rice discharge water.

1. One or more chemicals associated with the rice discharge are toxic to larval bass while the organisms are located in the Sacramento River and western Delta and/or

2. The associated chemicals are toxic to the bass's principal food organisms resulting in a lower ration and poorer survival for larval fish while located in the River and Delta.

Data supporting both hypotheses are presented. Ten of fourteen water samples collected from CBD during May and June of 1989 were acutely toxic to 24-48 hour old larval striped bass in 96 hour static bioassays. More limited data of a similar nature was also obtained in 1988. Fourteen of eighteen water samples collected from CBD in 1989 were also toxic to 24 to 48 hour larval Neomysis in 96 hour static bioassays. The ten most toxic of these samples killed 100% of the test organisms within 18 hours. A strong positive correlation was observed between the toxic response of Neomysis and Ceriodaphnia. Neomysis was the more sensitive of the two species.

BACKGROUND

In 1985 U.S. EPA (1985a) published protocols for conducting chronic toxicity tests with three freshwater species and is now recommending them as an assessment of compliance with State narrative toxic objectives (54FR23868) for implementing 40 CFR 122.44 et seq. In 1986 the Central Valley Regional Water Quality Control Board began placing these new testing requirements in permits. To date, approximately 25 NPDES and WDR permits contain provisions for conducting three species tests and for eliminating toxicity should instream impacts be predicted (Bruns, 1989). Simultaneously, Board staff began tests of ambient Sacramento River water to ascertain background water quality through a contract with Dr. Allen Knight, U.C. Davis. As part of this program, water samples have been collected for the last four years from agricultural drains during the initial release of rice irrigation water (May and June) to the Sacramento River. Each year water from one or more Drains has been acutely toxic to the invertebrate test organism (Ceriodaphnia) and in three of the four years downstream Sacramento River impacts were observed. Little or no invertebrate toxicity has been measured in water samples collected from the same sites during other times of the year.

A limited amount of chronic toxicity testing was conducted in 1986 with the algal and invertebrate test organisms (Shaner, 1986; Foe, 1987). Water samples collected on 29 May from Butte Slough and CBD were acutely toxic to the invertebrate test organism while water from Sacramento Slough only inhibited invertebrate reproduction. The apparent combined impact on the Sacramento River of all rice discharges was to suppress invertebrate reproduction as far downstream as the City of Sacramento (lowest sampling site tested). Methyl parathion and chlorpyrifos were detected in CBD water at 0.7 and 1.3 ppb, respectively. Toxicity was, at least in part, ascribed to the presence of these compounds. A second set of water samples was collected from each location on 24 June 1986. Only water from CBD was toxic, inhibiting invertebrate reproduction by approximately 85%. No downstream Sacramento River impacts were noted. Water was again collected from the same agricultural Drains on 11 November and 16 December, 1986. No invertebrate toxicity was noted on either occasion.

In 1987 Sacramento Valley agricultural drainage water was again found to be toxic during a short period of time coinciding with the initial release of rice irrigation water (Foe, 1988a). Water samples collected from CBD on 27 May killed 66 and 100% of the test fathead minnows and Ceriodaphnia, respectively. Discharge of the water to the Sacramento River apparently caused mortality to both test organisms at the edge of the zone of initial dilution (about two miles downstream, 40 and 47% mortality, respectively). Water collected from Sacramento Slough on 27 May was also toxic to fathead minnow larvae (50% mortality). Water samples collected from the Feather River at Verona on 27 May and 5 June killed 50 and 60% of the test invertebrates and fish, respectively. The latter toxicity was also, at least in part, attributed to rice agricultural return flows as Jack Slough was releasing rice return water into the Feather River at this time. Sacramento River and agricultural drain invertebrate toxicity surveys were conducted on four other occasions during the year (6 January, 23 April, 16 June and 15 September, 1987). Only one other instance of invertebrate toxicity was noted in agricultural drainage water. A 50% suppression in invertebrate reproduction was observed in water samples collected from CBD and from the Feather River on 15 September, 1987. This period coincided with the final release of rice irrigation water prior to harvesting.

In 1988 Regional Board staff continued, as in previous years, to conduct three species chronic toxicity tests on water samples collected from the Sacramento River (Foe, 1988b). However, the geographic scope of the sampling was enlarged to encompass the entire watershed (Shasta Dam to Rio Vista). The initial release of rice-return water occurred between early May and mid June. Acute invertebrate toxicity was measured in water samples collected from CBD on 15 May and 1 June, 1988 (100% mortality), from Sacramento Slough on 1 June (100% mortality), and from the Feather River on 1 and 13 June (90 and 40 % mortality, respectively). Toxicity was also noted in the Sacramento River downstream of all rice inputs on 15 May and 1 June. However, it is difficult to ascertain how much of the River's degradation was caused by rice discharge as significant invertebrate mortality was also measured simultaneously in water samples collected above all rice inputs. The latter impairment appears to have originated upstream of the City of Redding and to have continued intermittently since cessation of rice discharge.

Water collected at CBD during the 1988 rice season was not toxic to the fish bioassay organism. However, significant Fathead minnow toxicity was observed in River samples both above and below CBD. As with the invertebrate test organism, the toxicity appears to have originated in the top of the watershed.

In addition to River surveys, Board staff also collected water samples daily from CBD between 3 May and 20 June, 1988. Four-day acute fish and invertebrate toxicity tests were run on each of these samples until 29 May, whereupon the length of the tests was increased from four to seven days. Fifty percent or greater invertebrate mortality (within 96 hours) was measured on 17 of the 44 days of testing (figure 1a) and one hundred percent mortality (within 96 hours) was observed on three occasions. Mortality increased with increasing exposure time, as the death rate in the 7 day tests was greater than that in the 4 day bioassays on 16 of the 18 days of concurrent testing (figures 1a and b).

Water samples collected from CBD on 17 May and 1 June, 1988, were determined to be toxic and were subsequently sent to U.S. EPA Duluth for toxicity reduction evaluations (TRE). TREs are new procedures designed to determine the identity of the contaminants causing aquatic toxicity. EPA verified that both samples were toxic and established that the responsible chemicals were methyl parathion and carbofuran (Ms. Teresa Norberg-King, U.S. EPA, Appendix A). Ordram was present in the May 17 sample at about 100 ppb but did not contribute to the invertebrate toxicity. Bench top testing indicated that the acute toxicity of methyl parathion and carbofuran was additive and that the 48-hour Ceriodaphnia LC50 of each was about 2.6 ppb. Both pesticides were present together in the water samples at sufficient concentrations to cause the observed toxicity. Also, both pesticides are extensively used in rice cultivation and, at least, carbofuran is known to be in CBD during May and June as a result of rice cultivation (Mr. Rudy Schnagl and Ms. Carol Rowell, CVRWQCB, Appendix B; Nicosia, 1989).

Several River and Drain samples were sent to Dr. Serge Doroshov, U.C. Davis, for 96-hour static larval striped bass bioassays. The purpose of the testing was to ascertain whether rice discharge might be a direct contributing factor in the bass decline. Water samples collected from CBD killed significantly more larval

C-029776

bass than did laboratory control water on two of the three occasions tested (15 May and 1 June, 1988). Furthermore, CBD-and or other discharges may have impacted the Sacramento River as a water sample collected at Rio Vista on 15 May was also toxic (Howard Bailey, U.C. Davis, Appendix C).

1989 RICE SEASON RESULTS

Board staff have continued in 1989 to monitor both CBD and the Sacramento River watershed during the initial release of rice irrigation water to better characterize both temporally and spatially the extent of the problem, the chemicals involved and, to a much smaller extent, the potential impact of rice discharge water upon the local aquatic community. The 1989 results are summarized in five general areas: Acute _Ceriodaphnia_ and _Fathead minnow_ toxicity results, analytical pesticide data, Sacramento River survey results, toxicity reduction evaluations, and acute striped bass and _Neomysis_ toxicity testing results. Also included is a brief discussion of the significance of the results and how this years data differed from that of previous years.

Acute Ceriodaphnia and Fathead minnow toxicity testing results

As in 1988, grab water samples were collected almost daily from mid April through mid June at the intersection of Road 99E and CBD for 96 hour Fathead minnow and _Ceriodaphnia_ toxicity screening. The purpose of this testing was to temporally define the pattern of toxicity at the Drain and to select the more toxic samples for pesticide analysis, toxicity reduction evaluations, and _Neomysis_ toxicity testing. Toxicity screening was conducted at Dr. Allen Knight's laboratory under a joint laboratory use agreement between U.C. Davis and the Regional Board, employing the same procedures as in 1988. These are similar to methods outlined in EPA (1985a) with the following exceptions. _Ceriodaphnia_ stock populations and test organisms were fed on a trialgal diet of _Chlamydomonas_ _reinhardti_, _Chlorella minutessa_, and _Ankistrodesmus_ _falcatus_ and were about 24 hours old at the start of testing. Fathead minnow larvae were more variable in age (2 to 9 days) at commencement of testing. Drain water was collected in translucent polyethylene cubi-type containers and was stored in the dark at 4-8^{0}C until used.

Thirty percent or greater _Ceriodaphnia_ mortality (within 96 hr) was measured on 21 of the 51 days of testing (table 1, figure 2). The majority of toxicity occurred between 15 and 31 May. Significant invertebrate mortality was measured in the control samples after 9 June. This has tentatively been traced to a spent resin column used in preparing the laboratory control water. As a result, care should be taken in interpreting the June results. However, the toxicity reported on 9 June appears real as EPA also found water samples collected on that day to be acutely toxic to _Ceriodaphnia_ (personal communication, Ms Teresa Norberg-King).

Ordram is typically applied 7-10 days after seeding and in 1989 was required to be held on rice fields for 14 days before discharge (personal communication, R. Schnagl, CVRWQCB). We have employed Ordram application information as a timing device to ascertain the stage of rice cultivation which is associated with high invertebrate toxicity in CBD. The data may also be useful in indicating a possible interim control strategy. In 1989 the greatest 96 hour invertebrate

C—029777

C-029777

mortality occurred simultaneously with peak Ordram application (Figure 3). No or a reduced level of toxicity occurred during rice planting (7-10 days earlier) and during the subsequent holding period and the release of the herbicide contaminated water to the drain (14 days after herbicide application). We interpret this as indicating that rice farmers are releasing significant amounts of irrigation water prior to applying herbicides and this results in the release of other previously applied pesticides. This interpretation is consistent with the 1988 results (Figure 4). However, that data is somewhat more difficult to interpret as both the Ordram and toxicity patterns were bimodal in shape. Finally, the data suggest that invertebrate toxicity in the Drain (and presumably in the River) might be reduced significantly if there was no discharge of rice irrigation water between the time of seeding and the end of the holding period (20-25 days after planting). This interim control strategy might be possible if rice farmers were able to employ fallow rice fields as short-term holding ponds to contain their rice discharge water (personal communication R. Schnagl).

No Fathead minnow toxicity was detected in CBD during 1989 (Table 1).

Pesticide Chemical analysis

Because of a lack of funds, only the most toxic invertebrate samples collected at CBD were analyzed for organophosphorus and carbamate pesticides. These two scans were selected as U.S. EPA (Appendix A) indicated that these two classes of chemicals were the likely cause of invertebrate toxicity. Carbofuran was detected at concentrations between 0.16 and 1.50 ppb in all water samples collected in May and June (Table 2). Methyl parathion and malathion concentrations were more variable and ranged between 6.4 and undetected (<0.4 ppb) and 14 and undetected (<0.2 ppb), respectively. Analyses of split samples by different laboratories supported the conclusion that all three pesticides were present in the Drain. However, agreement on actual concentrations was poor (see for example CDFA and Eureka results for CBD samples taken on 17 and 22 May).

Little information exists on past concentrations of carbamate or organophosphorus pesticides in rice discharge water despite the fact that the pesticides have been extensively used since 1977 (Figure 3, Appendix B). Finlayson et al. (1982) measured methyl parathion in CBD in May and June of 1980-81 at concentrations ranging from undetected (<1 ppb) to 3.0 ppb (Table 3). No follow-up work was conducted until 1988 when U.C. Davis and U.S. EPA measured methyl parathion in every sample analyzed at concentration ranging from 0.1 to >1.8 ppb. U.C. Davis also detected methyl parathion in the Sacramento River at the City of Sacramento on each date sampled (Keydel et al., 1988).

Most of our information on past concentrations of carbofuran have been collected by the California Department of Fish and Game (CDFG) as part of their evaluation of the Food and Agriculture's (CDFA) rice herbicide program. In 1987 the Department measured carbofuran in CBD during May and June at concentrations ranging from <1 to 13.0 ppb (Table 3). On three occasions that year carbofuran was detected in the Sacramento River at the City of Sacramento (1.4, 2.1, and 1.7 ppb). Carbofuran was also measured by CDFA during rice season in Butte and Sacramento Sloughs at concentrations ranging from 2.3 to 11 ppb. Sacramento, but not Butte Slough, was discharging its rice waste water to the Sacramento River at this time.

In 1988 CDFA conducted a special study to determine the source of the carbofuran in CBD during May and June. Nicosia (1989) concluded that the pesticide was from rice cultivation. As part of this study, she monitored carbofuran in CBD and found that the concentrations ranged from undetected to 4.4 ppb. All samples (N = 8) taken between 25 April and 19 May contained carbofuran at concentrations of 1.4 ppb or more. In 1988 Keydel et al. (1988) measured carbofuran in every CBD and Sacramento River water sample taken between 19 April and 13 June (N=4). Concentrations of carbofuran in the River at the City of Sacramento ranged from 0.01 to 0.4 ppb (Table 3).

Only a limited amount of malathion is used annually in rice cultivation (Appendix B). To our knowledge Keydel et al. (1988) were the first to detect malathion in CBD during spring rice season. They measured the pesticide on three of the four dates sampled (Table 3). No malathion was detected in the Sacramento River at the City of Sacramento. As of yet, it is not known whether malathion releases are the result of rice or some other agricultural practice.

Sacramento River Surveys

As in 1988, a series of Sacramento River surveys were conducted before, during, and after rice season to assess both spatially and temporally changes in water quality in the Basin. Testing protocols were as specified by EPA (1989) with the exception that all samples were one time surface grabs subsequently used as daily renewals. Only the Ceriodaphnia data is presented here. Site locations (figure 5) were the same as in 1988 and are described in Connor (1989). Briefly, sites were situated above, in, and below all major River inputs. The only exception was in the upper watershed where for about 150 miles there are no major inputs. Four sites were placed in this River stretch between the Cities of Redding and Colusa.

Rice return water principally enters the Sacramento River through five drains (Butte Slough, Reclamation District 108, Colusa Basin Drain, Sacramento Slough, and Jack Slough). Both Butte Slough and Reclamation District 108 discharge to the Sacramento River between the sampling sites at the City of Colusa and upstream of CBD. Neither Drain was sampled in 1989. Jack Slough is located on the Feather River east of the City of Marysville. Jack Slough was also not sampled in 1989, however, the Feather River at Verona was. Our Feather River sampling location is about 30 miles downstream from Jack Slough.

Five River surveys were conducted to assess rice impacts (Table 4). The surveys in April, May, June, and July were scheduled to assess water quality before, during, immediately after, and about 40 days after the initial release of rice irrigation water. Only the acute invertebrate mortality data is presented here. The pattern of Ceriodaphnia mortality suggests toxicity in the upper Sacramento River watershed on each day sampled. However, the toxicity did not appear to extend below the City of Redding with the possible exception of on 26 April. On that date 20% Ceriodaphnia mortality was observed in water samples from the City of Hamilton and upstream of CBD. The precise source of this toxicity is unknown, however, it may have resulted from the upper watershed. Additional information on the potential sources and causes of aquatic toxicity in the upper watershed are summarized in Connor (1989).

C—029779

C-029779

Several inches of rainfall fell in the watershed on the week prior to the first April monitoring River run. Thirty to fifty percent Ceriodaphnia mortality was observed in River samples from above and two sites below CBD (about 10 miles of River). Sacramento Slough also had 50% mortality. The source of contaminants causing this toxicity is unknown, however, they may have resulted from agricultural rain runoff. To date there is no information on its impact on River water quality. Urban wet weather runoff in the American River is toxic (Foe, 1987). Therefore, a second survey was conducted on 26 April. Twenty to thirty percent eight day mortality was recorded in Sacramento Slough and CBD, respectively. Discharge of rice return water is suspected to have caused this toxicity as CDFA measured 1.2 ppb carbofuran in CBD on that day (Table 2). More importantly though, little or no acute invertebrate toxicity is evident in either survey downstream in the Delta (Table 4).

The 24 May survey was conducted after CBD had discharged water that produced 30% or greater invertebrate mortality (within 96 hours) in tests for 12 days (Table 1). CBD and Sacramento Slough killed 90 and 80% of the test organisms, respectively. Neither the Feather nor the American Rivers were toxic. Thirty to fifty percent invertebrate mortality was observed at all downstream Delta sampling locations including our most seaward site (Rio Vista some 75 river miles south of CBD).

June 2 was selected for the first post rice season survey as invertebrate mortality at CBD appeared both more variable and on the decline (Figure 2). It was assumed that the discharge quality from other rice drains was also improving. The River survey results (Table 4) are consistent with the hypothesis of a decrease in toxicity from the major agricultural inputs. The Feather River and CBD had 50 and 90% invertebrate mortality, respectively, while Sacramento Slough was no longer toxic. Some downstream Delta sites such as Freeport and Clarksburg were also no longer toxic while other locations recorded 10 to 30% mortality. At all Delta sites the same or a lower mortality rate was recorded than on May 24.

July 5 was selected for the final River survey as it was about 40 days after the last measured release of toxicity from CBD. No invertebrate mortality was recorded at CBD, Sacramento Slough, or the Feather River. Sacramento River water quality, as measured by the invertebrate test organism, was also improved. Only Village Marina at the City of Sacramento appeared toxic (40% mortality).

In summary, these data demonstrate a continuing pattern of invertebrate toxicity in the top of the watershed and intermittent toxicity in the lower River and Delta which is positively correlated with toxic releases from CBD and other rice agricultural drains.

Toxicity reduction evaluations

On five different occasions (May 15, 17, 18, and 31 and June 6) water samples collected from CBD were sent to U.S. EPA Duluth for TRE analysis. Each of these had previously been identified as acutely toxic to Ceriodaphnia (Table 1). EPA reassessed their toxicity and found that each was still toxic although some appeared less so than when previously tested (Appendix A). Next EPA performed a TRE on the samples, as in 1988. Methyl parathion, carbofuran, and malathion were present in all five samples (Table 2). The toxicity of methyl parathion and carbofuran were demonstrated to be additive to Ceriodaphnia (Appendix A). Malathion, like the other two pesticides, is an acetocholinesterase inhibitor. Therefore, the toxicity of all three were assumed by EPA to be additive and together were at concentrations sufficiently high in Drain water to have caused the observed toxicity on each sampling occasion.

Possible impacts on local organisms

Striped bass are an important recreational fishery in the Sacramento-San Joaquin Delta Estuary. Adult bass move up the Sacramento and San Joaquin Rivers to spawn in the spring. About half to two thirds of the eggs are produced in the Sacramento River where spawning takes place between the Cities of Colusa and Sacramento from about May 10 to June 12 (CDFG, 1987a; Turner, 1976). Bass eggs are semi-buoyant and drift downstream with the current to hatch in about 36 hours. The drifting young begin feeding several days later at about 5.0 mm in length (Eldridge et al., 1981). The larvae collect in and around the entrapment zone in Suisun and Grizzly Bays where the young fish spend much of their first year. The travel time between the Cities of Grimes and Collinsville for drifting eggs and larvae are estimated to be between 5 and 8 days (Cornacchia et al., 1984).

On the San Joaquin River spawning takes place between Antioch and Venice Islands from April 23 to May 25 (Turner, 1976). During the spring a significant portion of the San Joaquin River is composed of Sacramento River water flowing across the Estuary via both the Delta cross channel and Georgiana Slough and also around Sherman Island and back up the San Joaquin River (CDFG, 1987a). San Joaquin River water quality may, therefore, not be much different than that of the Sacramento River.

The size of the bass population has declined significantly during the last decade. Studies by CDFG indicate that the critical problem is a decline in the survival of 6-8 mm larvae during May and early June as the fish drift down the Delta (CDFA, 1987a; Turner, 1987). On the Sacramento River the area of high mortality is located between the Cities of Rio Vista and Collinsville. On the San Joaquin River it is situated between Venice Island and the confluence with the Sacramento River. Similar, but much smaller, decreases in larval survival are also apparent in Suisun Bay (other major nursery area for larval bass in the Estuary). The decline in larval survival began about 1977 (figure 6a). Its cause is unknown.

The Sacramento Valley rice industry shifted from long to short stem rice cultivation between 1977 and 1979. This shift resulted in an increase in the number of acres of rice under cultivation and in the number and amount of pesticides being applied in the upper Valley (Cornacchia et al, 1984; Appendix B). Several of these are applied principally before or immediately after rice seeding and should be released into the River at their maximum concentrations during the initial discharge of rice return water in May and early June. Methyl parathion is one such chemical for which continuous rice application data exists since 1970 (CDFA, 1970-1986). A correlation between the yearly difference in the predicted and observed numbers of larval bass in the Delta (area between the two curves in figure 6a) and the pounds of methyl parathion applied to the rice fields divided by the average daily May flow-rate of the Sacramento River at the "I" Street bridge is statistically significant ($P<0.01$, figure 7). The correlation accounts for 42% of the difference between the predicted and observed numbers of bass during the period from 1970 to 1986. Essentially the relationship is one of fish mortality (unexplained disappearance of larval bass in the Delta) and concentration of one or more rice pesticides in the River and Delta during the fish's downstream migration. The 1983 data was omitted from the correlation as the Sacramento River was at flood stage in May 1983 and CBD did not release rice discharge water to the River but instead diverted it down the Toe Drain to enter the Delta via Prospect and Cache Sloughs. However, the above correlation is still significant with the 1983 data included ($P=0.01$). Figure 6b is a plot of the addition of an instream pesticide concentration term (-(3.34 lbs methyl parathion/Sacramento River flow rate + 2.83)) to CDFG Delta striped bass index. The correction improves CDFG index for the critical period after 1977 when the index performed most poorly. Two years (1977 and 1986) appear as outliers in figure 6. Both were hydrologically unusual. 1977 was a drought year with lower than normal Sacramento River flows whereas 1986 was an unusually wet year with a high spring flow. The corrected index predicts larval abundance better than the original index during both 1977 and 1983 but more poorly than in 1986 (figure 6b). Poor fit under both high and low flow years implies that additional factors may be important under these hydrologic regimes in determining bass survival. Inclusion of an instream pesticide concentration correction term in CDFG striped bass index appears, at least visually, to explain about as much of the variance after 1977 as the original index did before that period. This is important as it emphasizes the similarity in the pattern in larval bass recruitment in the Bay-Delta Estuary system before and after 1977, if changes in upstream agricultural practices are accounted for.

Two hypothesis are proposed to explain the apparent impact of rice discharge water to striped bass larvae.

1. One or more chemicals associated with rice discharge are toxic to larval bass while the organisms are located in the Sacramento River and Delta, and/or

2. The chemicals are toxic to the bass's principal food resulting in lower rations and poorer survival for bass while located in the River and upper Delta.

Data supporting both hypothesis are presented below.

Striped bass

Limited toxicity testing in 1988 suggested that CBD water might be toxic to larval bass (Appendix C). The purpose of the 1989 bass bioassays was to conclusively ascertain whether CBD was toxic and, if so, whether downstream impacts could be discerned. Water samples were collected twice weekly during rice season from CBD and from the Sacramento River both above (City of Colusa) and below (City of Walnut Grove) all rice inputs for bass bioassays at Dr. Serge Doroshov's laboratory, U.C. Davis. In addition, Drain water from the daily *Ceriodaphnia* acute tests was archived and employed in a one time striped bass acute toxicity test to ascertain the daily variability in Drain water quality. It is the latter data which is principally reported in Appendix C (Table 1). However, all the information gathered support the conclusion that the Drain was toxic to larval bass. In contrast, the River data is more variable and is based upon fewer samples. The data seems to suggest, at least on occasion, toxicity both above and below rice inputs. However, much of this latter information is still undergoing statistical analysis.

Ten of the fourteen Drain water samples tested were acutely toxic to bass larvae (Appendix C). However, of equal importance is the fact that some of the water collected at the Drain was not toxic. This demonstrates that there is no intrinsic change in water quality after passage over rice fields which renders it unable to support bass larvae. Rather the data suggest that rice discharge water is of variable quality. The assumption is made here that toxicity is the result of the presence of pesticides which were known to be highly variable in the Drain during the spring of 1989 (Table 2). There was no apparent correspondence between the toxic response of larval bass and the two test invertebrates (Ceriodaphnia and Neomysis), suggesting that the fish and invertebrates were responding to different toxicants. As of yet, the chemicals responsible for bass toxicity have not been identified.

Neomysis

Historically, the principal prey of larval bass in the Delta has been several species of copepods and the cladoceran, Eurytemora affinis (Miller, 1987). Of these Eurytemora appears the most important. However, the population abundance of all native zooplankton species, including Eurytemora, have declined significantly in the Delta since the mid 1970s (CDFG, 1987b). In particular, the abundance of Eurytemora in the lower Sacramento River has declined where bass probably originally first fed upon them. Lack of an adequate ration at the critical 5 to 8 mm life stage is hypothesized as a possible reason for poor larval bass survival now in the Delta (Kimmerer, 1989).

Neomysis is the principal prey of juvenile bass in the entrapment zone. The estuarine distribution of Neomysis is a function of salinity. Maximum mysid abundance occurs in and to the immediate east of the entrapment zone. In 1988 and 89 this was approximately 10 to 20 miles west of our furthest downstream sampling site (Rio Vista). A few mysids may range as far up River as the City of Rio Vista.

For the above reasons, Eurytemora, not Neomysis, is the preferred organism for use in investigating the potential impact of rice discharge upon the food stock of 5-10 mm larval bass. However, to my knowledge little culture and no toxicity work have been conducted with Eurytemora on the West coast. In contrast, methods for conducting acute and chronic toxicity tests with Neomysis are fairly well established. The assumption is made here that the toxicological response of Ceriodaphnia and Neomysis is roughly similar to that of native estuarine zooplankton, including Eurytemora. This assumption needs verification.

Dr. Doroshov performed eighteen toxicity tests with neonate Neomysis and CBD water. On fourteen occasions the water was acutely toxic; in ten instances complete mortality occurred within 18 hours (Table 2, Appendix C). A strong positive correlation was observed between the toxic response of Neomysis and Ceriodaphnia in Drain water. Neomysis was the more sensitive of the two species. The strong positive correlation between the response of the two species suggests that both are being impacted by the same suite of pesticides. This also needs verification.

Only one mysid bioassay was conducted with water collected downstream of CBD at Walnut Grove. No toxicity (96 hour) was detected. However, if more mysid bioassays of longer duration had been conducted, then toxicity probably would have been measured as 30 to 50% Ceriodaphnia mortality (within 8 days) was recorded on the Sacramento River from Walnut Grove to Rio Vista on May 24 (Table 4) and acute testing at CBD demonstrated that mysids were more sensitive to rice pesticides than was Ceriodaphnia.

On two occasions CDFG's Aquatic Toxicology Laboratory reassessed the toxicity of CBD water samples submitted by Regional Board staff to Dr. Doroshov at U.C. Davis (Brian Finlayson, CDFG, Appendix D). Good agreement was obtained between the two laboratories on the first occasion (CDFG test 38). Both laboratories reported 100% Neomysis mortality within 24 hours for water samples collected from CBD on May 21, 23, and 24. In contrast, poor agreement was obtained between U.C. Davis and CDFG in the second set of duplicate samples. Neither laboratory detected toxicity in the 6 June sample. However, CDFG measured greater mortality in the 3 June sample than did U.C. Davis (100 versus 30%) and less than they did in the 10, 12 and 14 June samples (nondetected versus 40, 40, and 70% respectively). The cause of this discrepancy is not known.

Both laboratories tested water collected from the Sacramento River at the City of Colusa (29 May and 1, 5, and 8 June). No Neomysis toxicity was detected. This is important as the samples represent an assessment of water quality prior to it's being removed from the Sacramento River for use as rice irrigation water.

CONCLUSIONS

EPA (1985b) has recommended both acute and chronic toxicity criteria to insure protection of aquatic life and help State's assess compliance with narrative toxic objectives (Table 5). Three parameters are considered in evaluating toxicity: magnitude, duration, and frequency of the excursion. EPA recommends in the case of acute toxicity that less than 0.3 acute toxic units[1] be present in a water body for less than one hour's duration once every three years.

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[1] Acute toxic unit = 100/LC50 where the LC50 is expressed as a dilution percentage.

Limited toxicity testing at CBD and other agricultural discharges in 1986 and 1987 suggested that exceedances of the acute criteria might be occurring (Table 5). More extensive testing in 1988 and 1989 confirmed the violation of EPA's recommended criteria at CBD. Laboratory testing indicated that more than one acute toxic unit was present in water samples collected at the Drain on 36 separate days during May and June of 1988 and 1989 (Table 1; Foe, 1988). Board staff surmise that similar toxicity was present and being simultaneously released from other rice associated agricultural drains as the River survey data demonstrated acute invertebrate toxicity in 1986 in rice discharge water samples collected from Butte Slough and CBD; during 1987 from CBD and the Feather River; during 1988 from CBD, Sacramento Slough, and the Feather River and; finally, in 1989 from CBD, Sacramento Slough, and the Feather River.

Discharge of acutely toxic rice water appears to produce both acute and chronic toxicity downstream on the Sacramento River. To protect aquatic life, EPA recommends that no more than one chronic toxic unit[2] be present for 96 hours once every three years (Table 5). In 1986 a 50% suppression in <u>Ceriodaphnia</u> reproduction (>1 chronic toxic unit) was measured 40 miles downstream of the last rice input. In 1987 a 50% invertebrate mortality rate (> 1 chronic toxic unit) was measured 2 miles downstream of CBD at the edge of the zone of initial dilution. In 1989 a 60% invertebrate mortality rate (> 1 chronic toxic unit) was measured at the furthest downstream sampling site (about 75 river miles below CBD). The 1989 results occurred after CBD had been discharging acutely toxic water to the Sacramento River for 12 days. However, in both 1988 and 1989 the Drain was acutely toxic for 18 days (Table 1; Foe, 1988). Therefore, during both years the duration of downstream impacts were probably greater than was measured in the limited River surveys.

Acute invertebrate toxicity at CBD in 1988 was produced by the discharge of the pesticides methyl parathion and carbofuran. In 1989 the toxicity resulted from the release of the above two pesticides and malathion. The toxicity of the three pesticides is assumed to be additive as the primary mode of action of each is to suppress the function of the central nervous system. EPA recommends a malathion maximum water quality criteria of 0.1 ppb to protect aquatic life (Marshack, 1989). The criteria assumes that malathion is the only pesticide present. Neither EPA nor the State has published water quality criteria for methyl parathion or carbofuran. Reported 1989 malathion concentrations for CBD range from undetected to 14.0 ppb (Table 2). The median malathion concentration was 1.1 ppb (n = 11). This is eleven times EPA's recommended criteria.

EPA validated their recommended acute and chronic narrative toxic criteria at eight NPDES sites (summarized in EPA, 1985b). At seven facilities their criteria predicted that instream impacts should occur. At each location differences were measured in the abundance and distribution of aquatic organisms below the site as compared to above it. Finally, at one facility, no difference was predicted by the EPA criteria and none was detected.

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[2] Chronic toxic unit = 100/NOEC where the NOEC is again expressed as a dilution percentage

To date, no one has undertaken a thorough evaluation of the potential impact that changes in rice cultivation practices in the late 1970s might have had upon the local aquatic community. Limited acute toxicity testing conducted this year demonstrated that rice discharge water is acutely toxic to both Neomysis and striped bass. Correlation analysis suggests that changes in rice cultivation practices may be important in explaining declines in the abundance of striped bass.

Traditionally the Central Valley Regional Board has only sought to enforce the Basin Plan's narrative toxic objective at point source discharges. At present the Board has adopted 25 NPDES and WDR permits which contain provisions for conducting three species testing and for eliminating toxicity should the results suggest that instream impacts are occurring (Bruns, 1989). However, the Region's aquatic resources can only be protected if toxicity is eliminated whenever it is detected, regardless of its source.

ACKNOWLEDGEMENT

The EPA three species tests were conducted under a joint laboratory use agreement between Dr. Allen Knight, U.C. Davis, and Regional Board staff. Many people helped with various aspects of this project. In particular, Sara Denzler, Wendy Wyels, Frank Moyer, and Paul Masaki helped in collecting water samples and Linda Deanovic, Risa Buck, and Devon Orland performed the EPA bioassays.

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C-029787

C-029787

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Table 1. Ceriodaphnia and Fathead minnow survival (%) in laboratory control (CTL) and Colusa Basin Drain (CBD) rice return water during 1989. All Ceriodaphnia tests commenced with 10 replicates of one neonate each while the fish tests began with 2 replicates of 10 fish each.

		Survival (%)							
		Ceriodaphnia (hrs)				Fathead minnows (hrs)			
Date	Site	24	48	72	96	24	48	72	96
April 23	CBD	100	100	100	100	95	95	95	95
	CTL	100	100	90	90	95	95	85	80
April 24[1]	CBD	90	90	80	70	100	100	100	95
	CTL	60	50	50	20	100	100	100	95
April 26	CBD	90	70	70	60	100	100	100	100
	CTL	100	100	100	100	100	100	100	100
April 27	CBD	100	100	100	100	100	100	100	100
	CTL	100	100	100	100	100	100	100	100
April 29	CBD	60	30	30	30	100	100	100	95
	CTL	90	90	90	80	100	100	90	90
May 1	CBD	100	100	100	100	100	95	95	95
	CTL	90	70	70	70	100	100	100	100
May 2	CBD	100	80	80	80				
	CTL	90	90	90	90				
May 3	CBD	100	100	100	100	95	95	95	95
	CTL	100	100	100	100	100	90	90	80
May 4	CBD	100	90	90	80	100	100	100	95
	CTL	100	100	100	100	100	90	90	80
May 6	CBD	100	100	100	100	100	100	100	95
	CTL	100	100	100	100	95	95	90	90
May 7	CBD	100	100	90	90				
	CTL	100	100	100	100				
May 8	CBD	100	100	100	90	100	95	95	95
	CTL	100	100	100	100	100	95	95	90
May 9	CBD	90	90	90	90				
	CTL	100	100	100	100				
May 10	CBD	100	90	90	80	100	100	100	95
	CTL	100	100	100	100	100	95	95	90

Table 1. (continued)

Date	Site	Survival (%) Ceriodaphnia (hrs) 24	48	72	96	Fathead minnows (hrs) 24	48	72	96
May 11	CBD	60	50	50	40	100	100	100	100
	CTL	100	100	100	100	100	100	100	100
May 12	CBD	70	70	60	60				
	CTL	100	100	100	100				
May 13	CBD	100	100	100	100	100	100	100	100
	CTL	100	100	100	100	100	100	100	95
May 14	CBD	100	100	90	50				
	CTL	100	100	100	100				
May 15	CBD	70	60	0	0	100	100	100	95
	CTL	100	100	100	100	100	100	100	100
May 16	CBD	100	90	10	0				
	CTL	100	100	100	100				
May 17	CBD	50	0	0	0	100	100	100	90
	CTL	100	100	100	100	100	100	100	95
May 18	CBD	100	100	100	50				
	CTL	100	100	100	100				
May 19	CBD	100	100	90	0	100	100	100	100
	CTL	100	100	100	100	100	100	100	95
May 20	CBD	100	90	90	90				
	CTL	100	100	100	100				
May 21	CBD	100	70	0	0				
	CTL	100	100	100	100				
May 22	CBD	40	40	0	0	100	100	90	90
	CTL	100	100	100	100	100	100	100	100
May 23	CBD	90	80	0	0				
	CTL	100	100	100	100				
May 24	CBD	0	0	0	0	100	100	100	100
	CTL	100	100	100	100	100	100	100	100
May 25	CBD								
	CTL								

C—029790

C-029790

Table 1. (continued)

Date	Site	Survival (%) Ceriodaphnia (hrs) 24	48	72	96	Fathead minnows (hrs) 24	48	72	96
May 26	CBD	80	40	30	30				
	CTL	100	100	80	80				
May 27	CBD	100	100	100	100				
	CTL	100	90	90	90				
May 28	CBD	100	100	100	100				
	CTL	100	100	100	100				
May 29	CBD	90	80	80	70				
	CTL	80	80	80	70				
May 30	CBD	60	60	60	50				
	CTL	80	80	80	80				
May 31	CBD	0	0	0	0				
	CTL	80	80	80	70				
June 1	CBD	90	80	40	40				
	CTL	100	100	100	90				
June 2	CBD	100	100	100	100				
	CTL	100	100	100	100				
June 3	CBD	90	60	50	50				
	CTL	100	100	90	80				
June 4	CBD	100	100	100	100				
	CTL	100	100	100	100				
June 5	CBD	100	100	100	90				
	CTL	100	90	80	80				
June 6	CBD	70	0	0	0				
	CTL	100	90	80	80				
June 7	CBD	90	90	90	80				
	CTL	100	90	80	80				
June 8	CBD	100	100	100	90				
	CTL	100	90	80	80				
June 9[1]	CBD	60	50	0	0	100	100	90	90
	CTL	100	90	60	60	100	100	100	100

C—029791

C-029791

Table 1. (continued)

Date	Site	Survival (%) Ceriodaphnia (hrs) 24	48	72	96	Fathead minnows (hrs) 24	48	72	96
June 10[1]	CBD	100	100	100	100				
	CTL	100	60	50	30				
June 11[1]	CBD	100	100	100	100	100	100	100	100
	CTL	100	60	50	30	100	100	100	100
June 12[1]	CBD	60	60	30	20	100	100	100	100
	CTL	100	90	60	60	100	100	100	100
June 13[1]	CBD	100	100	100	100				
	CTL	100	90	60	60				
June 14[1]	CBD	100	100	100	100				
	CTL	100	60	50	30				
June 15[1]	CBD	100	100	100	90				
	CTL	100	90	60	60				
June 16	CBD								
	CTL								
June 17[1]	CBD	90	90	90	90				
	CTL	100	90	60	60				
June 18[1]	CBD	90	90	90	90				
	CTL	100	90	60	60				
May 23[2]	CBD	100	90	80	70				
	CTL	100	100	100	100				
May 31[2]	CBD	100	100	100	100				
	CTL	100	100	100	100				
June 6[2]	CBD	100	90	90	80				
	CTL	100	100	100	100				
June 9[2]	CBD	100	100	100	90				
	CTL	100	100	100	100				

1. Greater than 30% control mortality.
2. Samples retested on July 24-28, 1989.

C—029792

C-029792

Table 2. Summary of carbofuran (C), methyl parathion (MP), and malathion (M) concentrations (ppb) in Colusa Basin Drain water samples collected during May and June of 1989.

Date	Eureka[1]			CDFA[2]			EPA[3]		
	C	MP	M	C	MP	M	C	MP	M
April 27				1.2[5]					
May 4				1.5[5]					
May 15				1.5[5]					
May 15				1.12	1.6	<0.1[4]	0.8	1.20	0.09
May 17	0.77	6.04	0.66	0.71	2.7	0.2	0.41	1.50	0.54
May 18				1.0[5]					
May 18				0.55	0.8	<0.1	0.59	0.54	0.20
May 21	0.56	0.47	3.30						
May 22				1.1[5]					
May 22	<0.2	0.38	0.89	0.62	0.4	1.3			
May 23	0.54	1.78	0.21						
May 24	0.53	3.90	<0.2						
May 25				1.1[5]					
May 31	0.72	0.16	1.18				0.69	0.09	1.34
June 1	0.53	0.5	1.1						
June 6	<0.2	<0.4	14.0				0.96	0.09	0.08

1. Eureka Laboratories, Inc., 6790 Florin Perkins Rd., Sacramento, CA.
2. California Department of Food and Agriculture, Sacramento, CA.
3. U.S. EPA, Environmental Research Laboratory, Duluth, MN, 55804
4. Detection limit.
5. Special carbofuran study (personal communication Mr. Marshall Lee).

C—029793

C-029793

Table 3. Reported carbamate and organophosphorus pesticide concentrations (ppb) in water samples collected from Colusa Basin Drain and the Sacramento River at Village Marina (City of Sacramento) during previous years.

Date	Year	Drain C[1]	Drain MP[2]	Drain M[3]	River C	River MP	River M	Reference
June 16	1980		0.8					Finlayson et al., 1982
June 27			<0.1					
July 3			2.3					
July 7			1.9					
July 15			2.0					
July 22			1.5					
September 8			0.2					
April 30	1981		<1.0					
May 18			3.0					
May 21			2.9					
May 26			1.8					
May 28			1.9					
June[4]			<1.0					
July[5]			<1.0					
August[6]			<1.0					
May 29	1986		0.7					Shaner, S. 1986
May 6	1987	2.0			<1.0			CDFA, 1987 (draft)
May 11		3.5			<1.0			
May 14		5.4			<1.0			
May 18		7.7			<1.0			
May 21		6.2			<1.0			
May 25		13.0			1.4			
May 28		9.9			2.1			
June 1		7.2			1.7			
June 4		2.0			<1.0			
June 8		<1.0			<1.0			
June 15		<1.0			<1.0			
April 25	1988	4.4						Nicosia, S. 1989
April 28		3.8						
May 2		2.7						
May 5		1.6						
May 9		3.2						
May 12		2.0						
May 16		1.4						
May 19		1.4						
May 23		ND[7]						
May 26		ND						
May 30		ND						
June 2		ND						
June 6		ND						

Table 3. (continued).

Date	Year	Drain C	Drain MP	Drain M	River C	River MP	River M	Reference
May 17	1988	>0.33	>1.8					Norberg-King et al., 1989 (appendix A)
June 1		>0.12	>1.4					
April 19	1988	1.74	0.41	0.01	0.40	0.32	ND	Keydel et al., 1988
May 15		0.92	0.21	0.50	0.25	0.08	ND	
June 1		0.34	0.110	0.211	0.05	0.06	ND	
June 13		0.14	0.20	ND	0.01	0.01	ND	

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[1] Carbofuran
[2] Methyl parathion
[3] Malathion
[4] Five sampling dates
[5] Four sampling dates
[6] Two sampling dates
[7] Non detected

C-029795

C-029795

Table 4. Eight day *Ceriodaphnia* mortality pattern in water samples collected from the Sacramento River watershed during the spring and summer of 1989. Mortality at all River sites is adjusted for the laboratory control death rate by taking the difference between the mortality at each site and the control. See Figure 5 for the location of each site.

		Mortality (%)				
Site (Station No.)	River mile	April 13	April 26	May 24	June 2	July 5
Shasta Lake (25)		20	20	0	40	0
Shasta Dam (1)	312	30	0	50	40	30
Whiskeytown Dam (26)		0	20	30	60	0
Keswick Dam (2)	302	40	0	20	0	20
Redding (3)	287	10	30	20	10	0
Red Bluff (4)	243	0	0	0	0	0
Hamilton (5)	168	0	20	0	0	0
Colusa (6)	143	0	0	0	0	0
Upstream CBD[1] (7)	91	50	20	0	50	0
CBD (8)	90	0	30	90	90	0
Downstream CBD (9)	88	30	0	50	70	0
Upstream Sac Sl[2] (10)	81	30	0	30	0	0
Sac Sl (11)	80	40	20	80	0	0
Feather River (12)	80	0	0	0	50	0
Village Marina (13)	61	0	0	40	40	40
American River (14)	60	0	0	0	30	0
Freeport Bridge (15)	47	0	0	50	0	0
Clarksburg (16)	42	20	0	50	0	20
Walnut Grove (17)	27	10	20	50	20	0
Isleton (18)	18	0	0	40	20	0
Steamboat Sl. (19)	15	0	0	50	20	10
Rio Vista (21)	12	0	0	50	10	10
Laboratory Control		(10)	(20)	(10)	(10)	(0)

[1] Colusa Basin Drain
[2] Sacramento Slough

C-029796

C-029796

Table 5. EPA recommended toxic criteria to protect aquatic life and the associated values recorded for 1986-89 during spring rice season at Colusa Basin Drain and downstream on the Sacramento River. See text for details.

	Acute			Chronic		
	magnitude (ATU[1])	duration (hr)	Frequency (per 3 yr)	magnitude (CTU[2])	duration (hr)	frequency (per 3 yr)
EPA recommended criteria	0.3	< 1.0	< 1	1.0	< 96	< 1
CBD (1986)[3]	exceeded	unknown				
Sacramento R.[3]				exceeded	exceeded	
CBD (1987)[3]	exceeded	unknown				
Sacramento R.[3]				exceeded	unknown	
CBD (1988)	exceeded	exceeded				
Sacramento R.						
CBD (1989)	exceeded	exceeded				
Sacramento R.[6]				exceeded	exceeded	

1 ATU = Acute toxic unit = 100/LC50
2 CTU = Chronic toxic unit = 100/NOEC
3 Sampling limited to 3 or less grab samples per rice season

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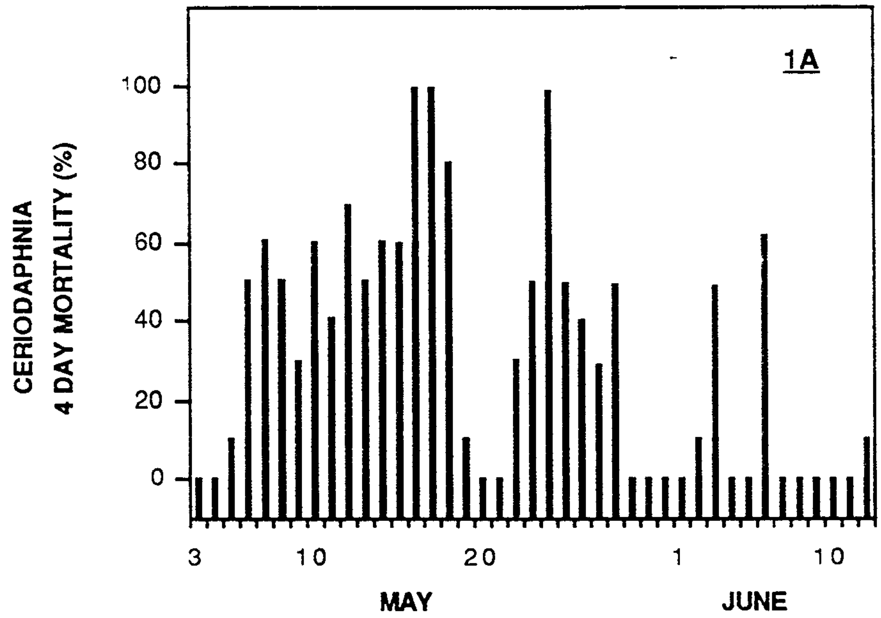
C-029797



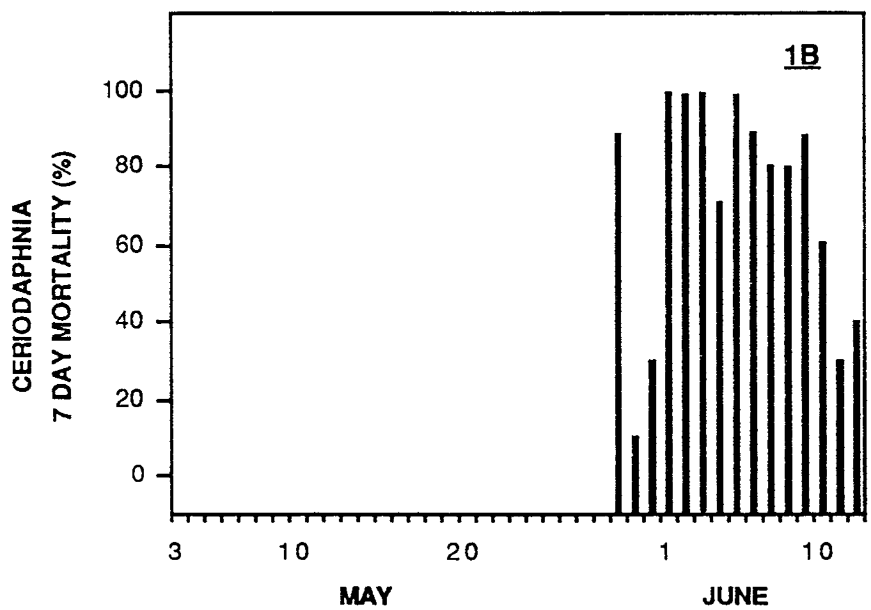


Figure 1a and b. Ceriodaphnia mortality pattern in water samples collected at Colusa Basin Drain during May and June of 1988. (a) 4 day mortality rate. (b) 7 day mortality rate. Testing was increased from 4 to 7 days on 29 May. Toxicity increased with increasing exposure in 16 of the 18 days of concurrent testing.

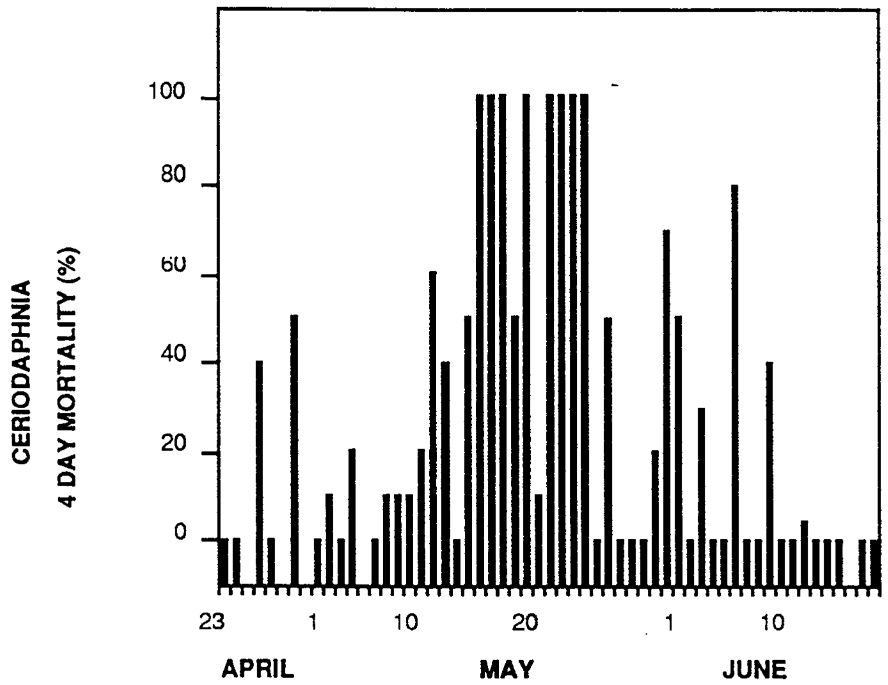


Figure 2. Four day Ceriodaphnia mortality pattern in water samples collected at Colusa Basin Drain during the Spring of 1989.

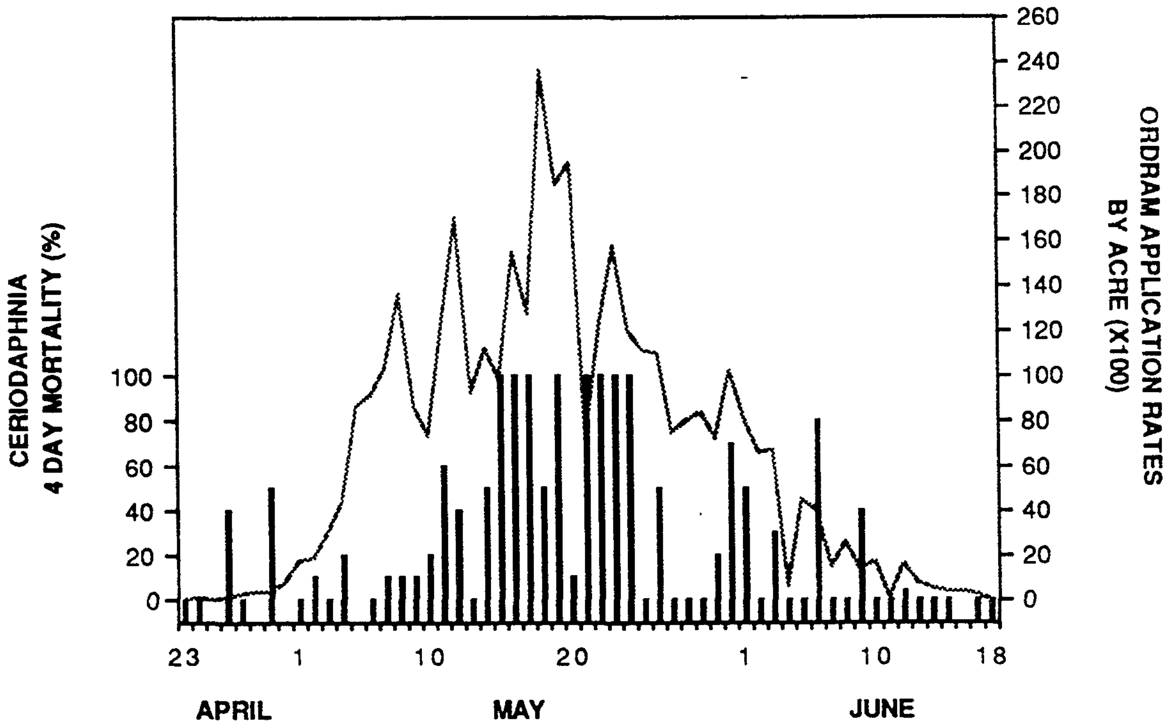


Figure 3. Comparison of the pattern of invertebrate mortality at Colusa Basin Drain (bar graph) in 1989 and the pattern of Ordram spraying by acreage.

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C-029800

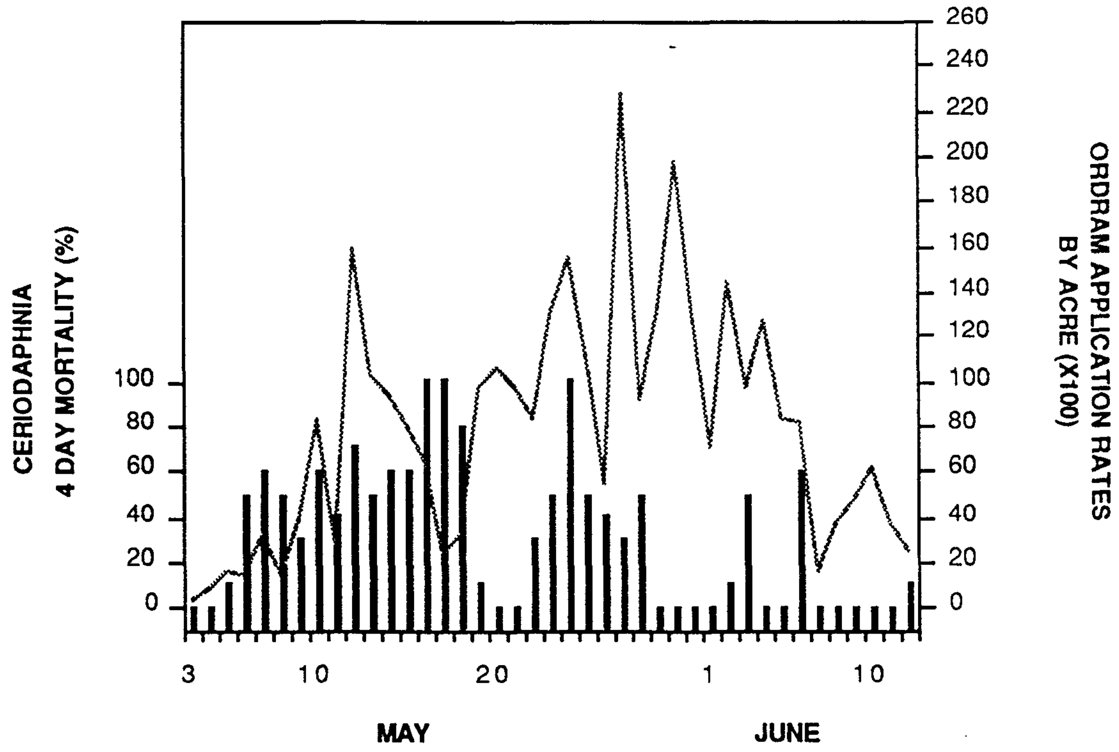

Figure 4. Comparison of the pattern of invertebrate mortality at Colusa Basin Drain (bar graph) and the pattern of rice ordram spraying by acreage in 1988. Invertebrate toxicity co-occured or slightly preceeded each of the two major applications of herbicide.

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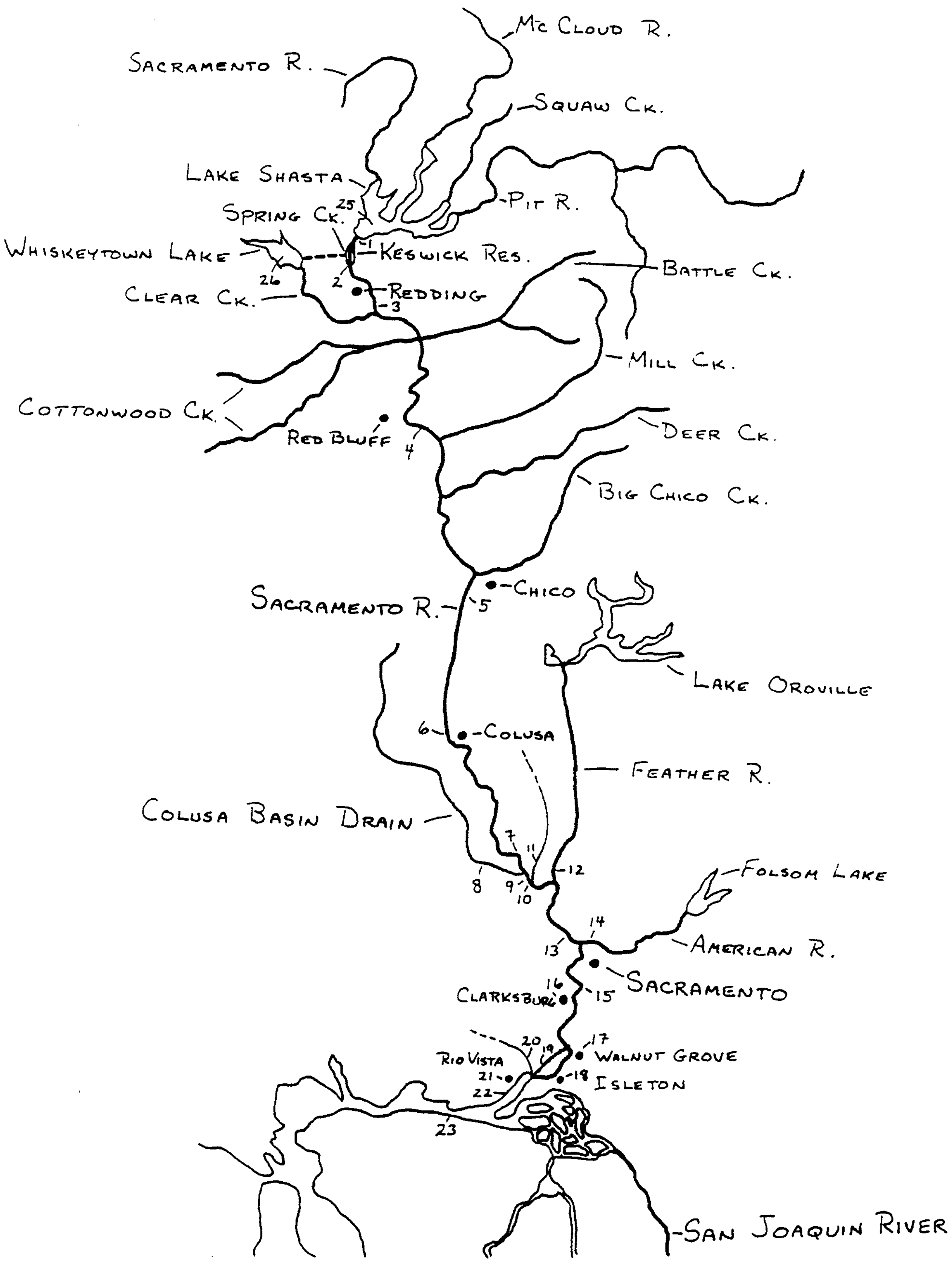

Figure 5. Map of Sacramento River watershed including the sampling locations.

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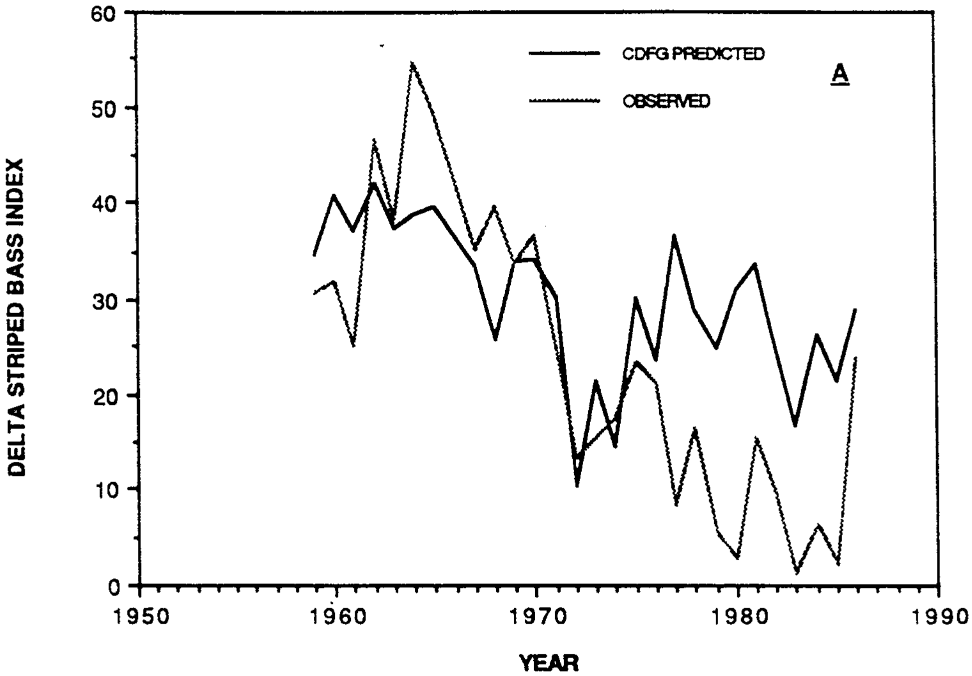

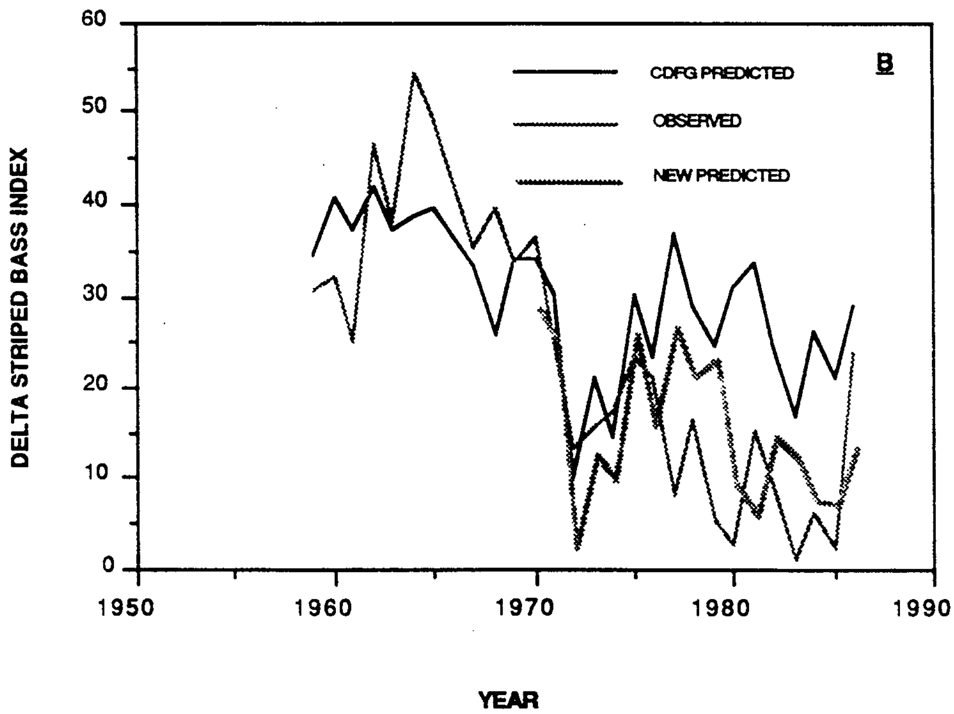

Figure 6a and b. (a) Relationship between the California Department of Fish and Game's Delta portion of the striped bass index and the actual number of fish observed in the Sacramento-San Juaquin Delta between 1959 and 1986. The index ceased to predict abundance well after 1977. Data provided by Mr. Lee Miller, CDFG, Stockton. (b) Same relationship as in 6a with the exception that the "new predicted" curve is the result of the inclusion of an additional term (- (3.34 (lbs methyl paration applied to rice fields/Sacramento River flow rate) + 2.83)) in the index. Th new equation improves the predictive power of the old index in all years after 1977 except for 1986.

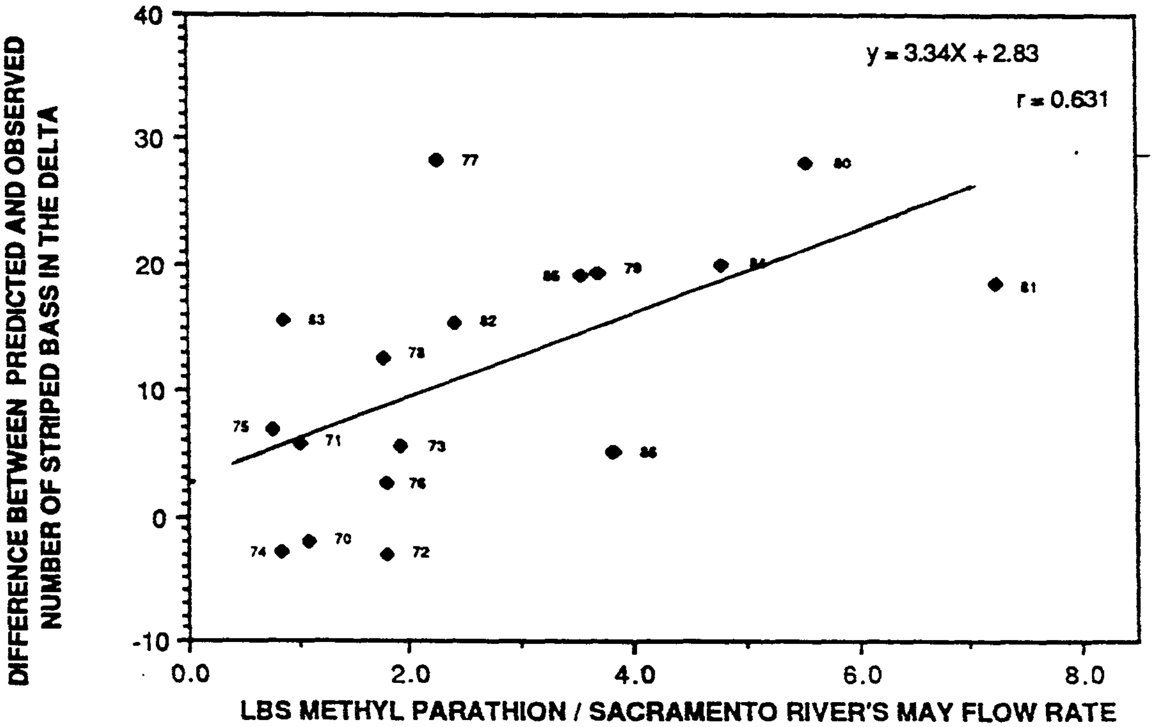

Figure 7. Correlation between the difference in the predicted and observed numbers of striped bass in the delta (difference between the two curves in Figure 6a) and the pounds of methyl parathion applied to rice fields divided by the Sacramento River's flow rate at the "I" Street bridge. Poundage of methyl parathion is from cdfa (1970-86) while the flow rate of the Sacramento River is from Table 26 of CDFG (1987a).