EFFECTS OF FINE SEDIMENT ON APACHE TROUT:

RESULTS OF A LABORATORY STUDY

Final Report

Arizona Game and Fish Heritage Fund

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DISCLAIMER

INTRODUCTION

Fine sediment is a natural component of all stream channel substrates. Variation in amounts of fine sediment result, in part, from geologic parent material of respective watersheds (Rinne and Neary 1996) and, in part, from land management activities (Rinne 1990). Much of the information on fine sediment in streams resulting from land use activities comes from the Pacific Northwest region of the U. S (Meehan 1991). Further, most of this information is on salmon and steelhead. Far fewer information on fine sediment in streams and its effects on trouts are available on inland, Rocky Mountain Province salmonids.

In the Southwest, there are three native trouts, the Gila trout, *Oncorhynchus gilae*, the Rio Grande cutthroat trout *Oncorhynchus clarki virginalis,* in New Mexico and the Apache trout, *Oncorhynchus apache,* in the White Mountains of east-central Arizona. Information on fine sediment content of streams, its sources, and its effects on these native trouts is lacking. Initial survey work of sediment content of Arizona streams commenced in the late 1980s (Rinne and Medina 1988, Rinne 1990). Based on this work, the threatened status of the Apache trout which was native to many of the streams (Rinne 1985, Rinne and Minckley 1985), and the establishment of an experimental Aquatics Laboratory in Flagstaff, Arizona in 1993, proposals were made to the Arizona Game and Fish Heritage Fund to conduct and closely related field and laboratory studies examining 1) levels of fine sediment in streams in the White Mountains containing Apache trout and 2) the effects of varying levels of fine sediment

(< 2 mm) on the emergence of Apache trout fry from artificial substrates in laboratory raceways. Both proposals were granted in spring 1994 (Heritage Grant Nos. I94006 and

O94007). Several presentations at scientific meetings, a final report (Rinne 1996), and one publication (Rinne and Neary 1996) have resulted from the granting of funds. This report will address 1) methods of the laboratory study, 2) results of laboratory experiments, and 3) discussion and conclusions of the laboratory study and of these results relative to the results of the field study, 4) and management implications. Ultimately, a publication combining the results of both studies will be produced.

METHODS

Equipment

All experiments were conducted in either standard modular, 16-ft or custom 10-ft fiber glass raceways approximately a foot deep and a foot wide (Figure 1). One and third HP chiller units were positioned on one end of the 10-ft raceways (Figs. 1, 2). On the large, 16-ft raceways a chiller unit was positioned on each end. Two smaller, submersible 0.25 HP garden pumps were placed in the non-experimental end of each raceway (Fig. 3) to circulate water over experimental, artificial gravel substrates (Fig. 4a, b). To reduce the probability of circulating pump loss through overheating, operation was alternated every 6 hours with the use of timers (see Fig. 2).

Experimental setup

Artificial substrates were created with the use of gravels of the size reported to be optimum for spawning Apache trout (Harper 1978). Small to medium gravels (mostly < 16 mm, see below) were washed and then placed in the streams to a depth of about 10 cm. Sieve analyses of gravel used revealed 3% in the 2-3.9 mm size range, 42% in the 4-7.9 mm size range, 48% in the 8-15.9 mm size range and 7% > 16 mm. A combination of distilled and tap water were used to mimic conductivity of water in the White Mountain areas (100-200 mhos). Chiller units were regulated to maintain water temperatures between 10 to 13 degrees Celsius (Table 1).

Experimental (treatment) substrates (percentage by weight) were created with the addition of silica sand (< 2mm; see Fig. 4) as a surrogate for natural fines. Sieve analyses indicated 28% of the sand was 1-2 mm in size and the remainder less than 1 mm.Percentage by weight fine sediment concentrations ranging from 10 to 40 percent were used in treatment redds. Substrate materials and fry were precluded from access to stilling basin for chiller units by fabricated screens (Fig. 2). Initially (1995) these were constructed of wood and fine mesh screen. However, because of a severe fungus problem, dividing screens constructed of plastic were utilized in 1996 experimentation.

Initially, acquiring natural fines from streams in the White Mountains was considered for experimentation, however, this approach was discarded because of the high probability of introducing bacteria and fungus that could induce additional variation into results of experiments. In 1995, washed gravel and sand substrates were mixed in a cement mixer and then added to the raceway. However, both observed and cursory measurements of fine vertical profile of fine sediment suggested settling of sand to lower half of artificial substrates in 1995 experimentation. Measurements taken at termination of these experiments indicated only a third of initial amounts of silica sand added remained in the upper half of the substrates. Such reduction of fines in the upper portions of the artificial substrates obviously would affect degree of emergence. Accordingly, in 1996, sand was added by hand at 4 and 6 weeks and mixed in by hand by stirring periodically over the 2-week period. This approach more closely mimicked the natural process of fine sediment deposition from spring runoff waters at the surface followed by gradual, progressive penetration into substrates.

Statistical

Chi-square analyses was used on 1996 data to determine the significance of observed (treatments) and expected (controls) measurements and to corroborate regressional plot.

Fish egg handling and placement

Apache trout eggs were obtained from the U. S. Fish and Wildlife Service's Williams Creek National Fish Hatchery near White River, Arizona. After standard procedural fertilization techniques by trained personnel at the Hatchery, eggs were selected randomly from available stock and transported on ice to the laboratory in Flagstaff. Here eggs were tempered, sorted for quality based on clarity or opaqueness and placed in hand-hewed "redd" areas in each raceway at a depth of approximately 5-8 cm. Eggs were deposition into control and treatment redds directly from cheese cloth "packets" and were not touched by hand. A hundred eggs were placed in each experimental redd within each redd area (ca. 3 ft in length; see Figs. 1, 4). One week prior to expected emergence, additional screens were placed in the raceways to separate redds and contain emerging fry to respective redds (Figs. 1, 4).

Percent reduction in emergence was based on emergence of fry in control redds of respective raceways. For example, if only 40 fry emerged in a control redd and 10 in one of the treatment redds, emergence would be reduced by 75%. That is, 10 (number fry emerged in treatment redd) divided by 40 (number fry emerged in control redd) = 25%; the reciprocal or 75% would be the calculated reduction in emergence.

General care of raceways during experimentation

A combination of properly-tempered water was added as need to keep water levels at a minimum of 5 cm in depth over substrates. Water temperature, dissolved oxygen, Ph, and specific conductance were measured daily to every three days with a Hydrolab unit (see table 1). In 1994 pilot experimentation, substrate DO was monitored in a half dozen standpipes extending from surface to bottom of artificial substrates. Periodic measurement revealed that DO concentrations in water above substrates and that in the substrate were most often identical or reduced very little (< 0.5 mg/l). Accordingly, substrate water DO reduction as a result of reduction of flow by silica sand was not considered important and therefore was not measured in 1995-96 experimentation.

Anti-fungus tablets (Myracin) were added weekly in 1995 experimentation, however, because of an apparent fungus buildup and loss of most of 1995 experiments (see results) formalin was added every 3 days to create a concentration of 1,000 ppm (Waterstrat and Marking 1995; personal communication, Roger Sorenson, Chief of Hatcheries, Arizona Game and Fish Department). Addition of formalin in combination with replacing wooden blocking partitions (Fig. 2) with plastic units removed the fungus problem in 1996 experimentation.

RESULTS

Results of research are presented by experiment commencing with pilot study efforts in winter 1994 to determine methodologies and possible problems with proposed design of study.

1994 Experiments

Initial experiments involved three experimental raceways with 10, 20 and 30 % by weight fines. Fry first emerged in 51 to 53 days. A profile of the dynamics of emergence for control and redds with 10% fines indicates that most fry emerged in the first week and fewer in the second week (Fig. 5). In contrast, in redds with 20-30% fines a bimodal pattern was evident, with modes at 3-5 and 7-11 days (Fig. 6). Overall, based on 4 redds in each replicate fine concentration, fry emergence was reduced less in the 10% fines redds and greater in the 30% (Table 2; Fig. 7). This pattern of increasing reduction in emergence with increasing fine content suggested that research design and methodologies were valid and conducting such research was feasible on a large scale.

1995 Experiments

In February 1995, upon granting of funds from the Heritage Program, the second set of experiments were set up. Concentrations of 10, 15, 20, 25, 30 and 40% were used in experimentation in order to 1) refine results at the 10, 20, and 30% levels and 2) detect thresholds of fines that commence to affect emergence between 20 and 30% (Fig. 7). Fry began to emerge in 49 to 51 days, however, in the course of two weeks results were both conflicting and did not follow the patterns of 1994 experimentation. First, no fry emerged from redds in 20 and 25% fines. In the 4 redds with 15% fines, emergence ranged from a 36% reduction to a 29 to 75% increase in emergence relative to the control. In the 4 redds with 30% fines all treatment redds displayed emergence ranging from 170 to 500% greater than the control. In 4 redds with 40% fines, emergence was reduced by an average of 84%.

In summary, except for results of 1995 experimentation were contradictory of each other and with those of 1994 experimentation. Accordingly, a second set of experiments designed to duplicate the initial run in 1995 was conducted. In the second set of experiments, a total of 30 redds, including controls, not a single fry emerged. Accordingly, reliable data acquisition was minimal to absent for 1995.

1996 Experiments

In February 1996, the final experimentation effort under the Grant was conducted. Six raceways were used in two sets of experiments: 1) two raceways with 25% fines and two with 30% fines and one control in each raceway, and 2) one raceway with 20% fines and one with 25% and one with 30%; each raceway as per experimental design contained one control.

In the initial experimentation, a total of 8 experimental redds each was positioned in each substrate fine concentration. Fry began to emerge in control redds in 44 days to 54 days. Reduction in emergence the 8 redds with 30% fines ranged from 72 to 100% and averaged 88% and 96% for each of the 4 redds in the two raceways (Table 2). Similarly, fry emergence from redds in the 25% substrate fines raceways was reduced from 50 to 100% and averaged 88 and 96% in each raceway.

In the second set of experiments, fry again emerged between 49 and 53 days. Reduction in emergence ranged from 0 to 50% in 20 percent fines (mean = 25%) (Table 2). By comparison, emergence was reduced from 60 to 90% in the two 25% substrates (mean 83 and 85%) and almost no emergence occurred in the 30% raceway raceways. The pattern in 1996 was more in agreement with 1994 pilot study experiments and results from respective raceways were not contradictory of each other.

Summarizing experiments from 1994 and the two experimental runs from 1996 indicates a definite pattern in the relationship of percent fines and reduction in fry emergence (Fig. 8). Reduction appears to be 20% or less in up to 20% by weight fines. Emergence is drastically reduced between 20 and 25% fines and remains at a mean of a little over 90% at 30% fines.

Chi-square analyses of 1996 emergence data further confirms this threshold. Differences between control and treatment emergence in 20% fines was not significant (X^2 = 2.5). By comparison, differences between controls and treatments were highly significantly different in both the 25 and 30 % substrates (X^2 = 138 and 246, respectively).

Discussion

Data collected from 1994-96 in a laboratory setting suggest fine sediment concentrations greater than 20% commence to reduced Apache trout fry emergence. Marked reduction occur at the 25% level of fines. The loss of over 90% of data from experimentation in 1995 affects robustness of results. However, a definite pattern is apparent in emergence reduction relative to increasing fines.

Success in initial pilot study efforts combined with inexperienced personnel involved in conducting the experiments in 1995 and the ultimately an extreme fungal infestation in 1995 greatly reduced the amount of data that would have been available for analysis. Additional experiments could be conducted in 1997 in case refinement is needed. However, I suggest the pattern in results will not lend itself to signification modification.

Relevance to field study

Results of field studies in streams in the White Mountains (Rinne 1996, Rinne and Neary 1996) suggest that fine sediment is perhaps on the threshold of becoming a contributing factor to reduction in Apache trout populations. That is, fine sediment concentrations in streams in this region range from 14 to 38% (mean = 22%) and the threshold for a dramatic or significant reduction in emergence is between 20 and 25%. However, the presence of substantially greater trout populations in streams on the Fort Apache Indian Reservation compared to the National Forest streams (Rinne 1995), in presence of means concentrations of 25% fines is a paradox and merits further study. However, two of the three streams on the Reservation contain brook and brown trout and may not be directly comparable.

MANAGEMENT IMPLICATIONS

Results of the laboratory study combined with the results of companion field studies suggest a vigilance must be maintained of input of fine sediment into streams containing Apache trout. Because streams on an average are on the borderline, additional input could become critical in delimiting or extirpating populations of Apache trout. Land use activities such as logging, road building, and ungulate grazing must be managed (Clarkson 1995, Neary and Medina 1995) carefully to preclude further input of fines to stream courses.

A protocol for sampling fine sediment in streams in the White Mountains should be adopted. Fine sediment should continue to be monitored at least every five years with grab samples, especially in streams with 20% or greater mean fine sediment concentration. In addition, pebble count methodology (Bevenger and King 1995) could be employed on a more frequent (every 2-3 years) basis to detect changes in substrate fine sediment.

FIGURE CAPTIONS

Figure 1. Overall view of aquatics laboratory at Flagstaff with large raceways in foreground and small raceways in background. Note chiller units, artificial substrates and redd dividers in raceway in foreground.

FIGURE 2. Closeup of chiller unit on a respective raceway.

FIGURE 3. View of two small, submersible garden pumps used to circulate water over redds in raceways.

FIGURE 4. Overhead view of artificial substrates separated by a screen divider. Figure 4a indicates a control (on left) and a 25% by weight fines redd; 4b a control (on right) and a 30% by weight fines content.

FIGURE 5. Emergence chronology of Apache trout fry in control (Fig 5a) and 10% (Fig. 5b) fine redds.

FIGURE 6. Emergence chronology of Apache trout fry in 20% (Fig. 6a) and 30% (Fig 6b) redds indicating the bimodal pattern of emergence.

FIGURE 7. Percentage fry emergence of Apache trout in treatment redds relative to the

control, 1994 experiments.

FIGURE 8. Summary of relationship of percent reduction in emergence of Apache trout fry relative to percent fines in substrate. All points represent four replicate redds each.

Table 1. Ranges of water quality conditions measured in raceway experiments in spring 1996. Ranges of data from 1994 and 1995 are within those for 1996 and are not presented here.

Raceway	n	temperature degrees C	Ph	DO mg/l	conductivity mhos
R-1	17	10.7-14.3	8.0-8.3	9.1-11.5	127-150
R-2	17	10.0-14.0	7.8-8.3	9.3-12.4	112-136
R-3	17	10.4-13.0	8.0-8.3	6.9-11.6	140-160
R-4	17	10.2-13.0	7.6-8.3	9.8-12.6	129-158
R-5	30	9.8-12.9	8.0-8.3	10.1-13.8	144-197
R-6	30	10.2-12.4	7.9-8.4	9.2-13.3	144-191

Table 2. Reduction in fry emergence in 1994-1996 experimentation. Values are raw numbers, and percentage reduction are in parentheses (not calculated for 1995 because of invalid data.

		Replicate redds				
Control	%	1	2	3	4	Mean
			1994			
55	10	35(36)	46(16)	60(0)		12
66	20	55(17)	30(55)	----		36
49	30	13(73)	----	----		73
			1995			
11	10	1	3	2		--
28	15	36	49	18	36	--
0	20	0	0	0	0	--
0	25	0	0	0	0	--
7	30	31	19	26	41	--
11	40	1	4	13	9	--

1996

13	25	1(92)	1(92)	0(100)	0(100)	96
2	25	0(100)	0(100)	0(100)	1(50)	88
40	30	11(72)	3(92)	4(90)	6(85)	85
12	30	0(100)	0(100)	0(100)	2(83)	96
6	20	5(17)	3(50)	7(0)	4(33)	25
19	25	2(89)	3(84)	4(79)	2(89)	85
10	25	4(60)	1(90)	1(90)	1(90)	83
48	30	0(100)	1(98)	1(98)	1(98)	94

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FIGURE 5A

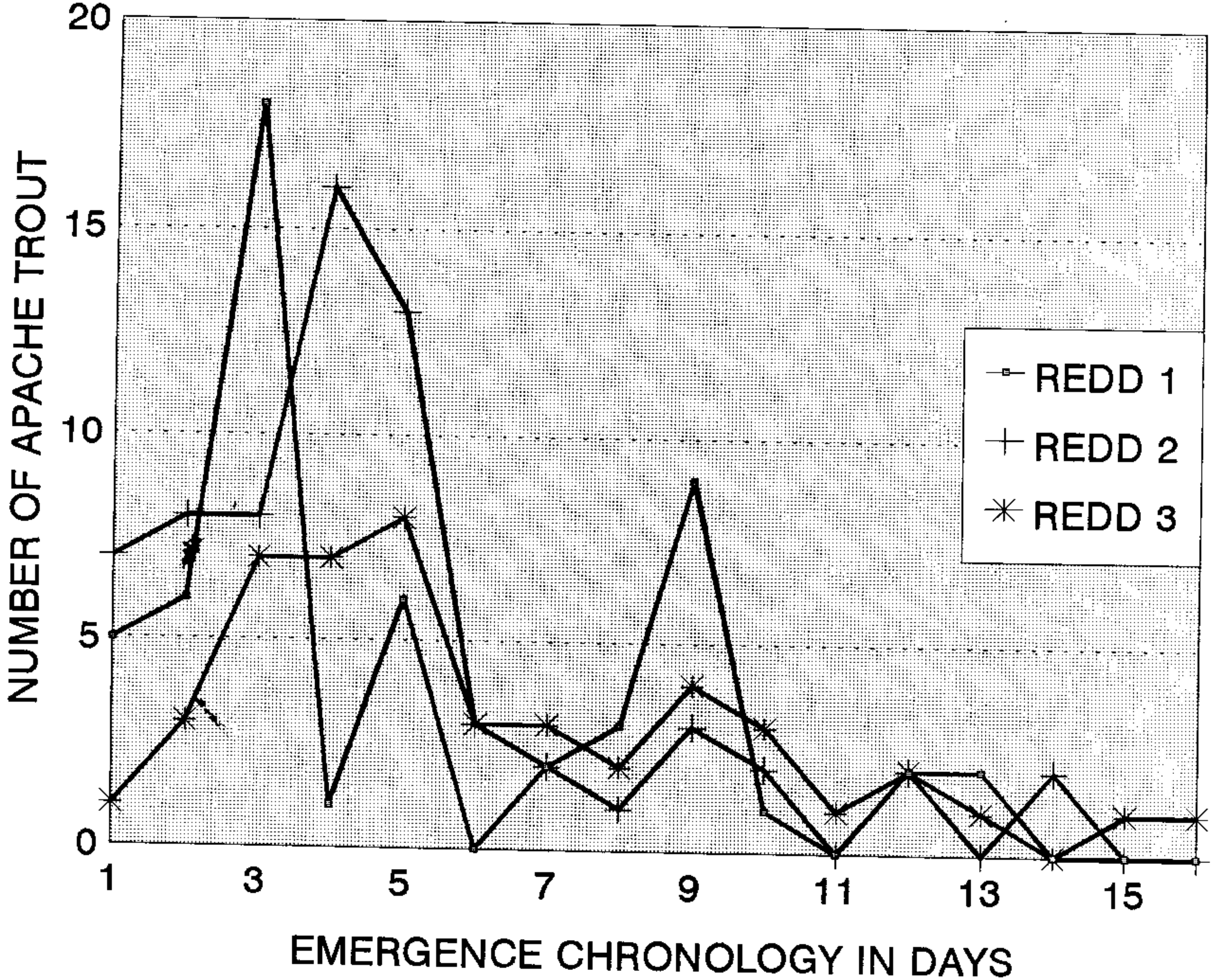
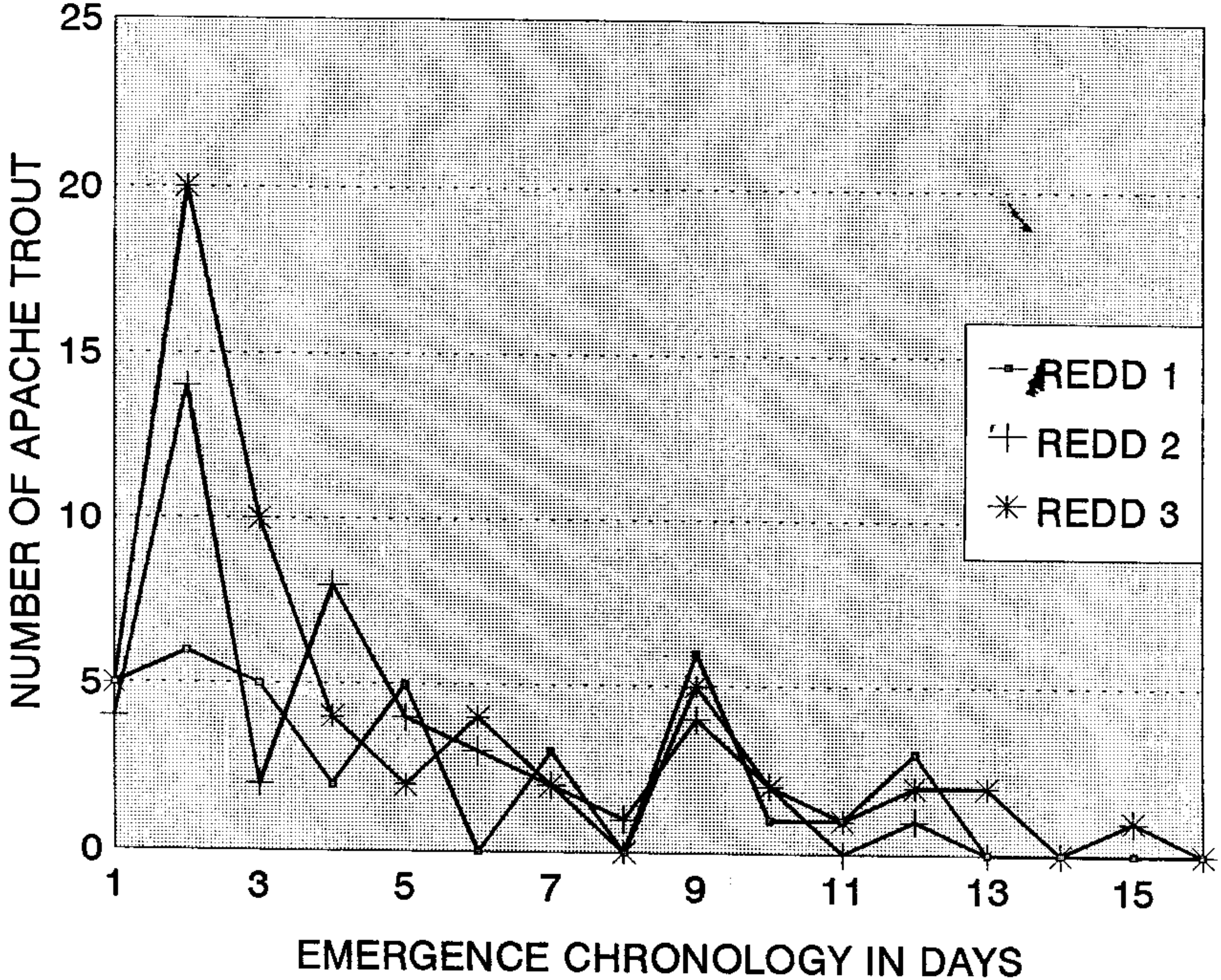
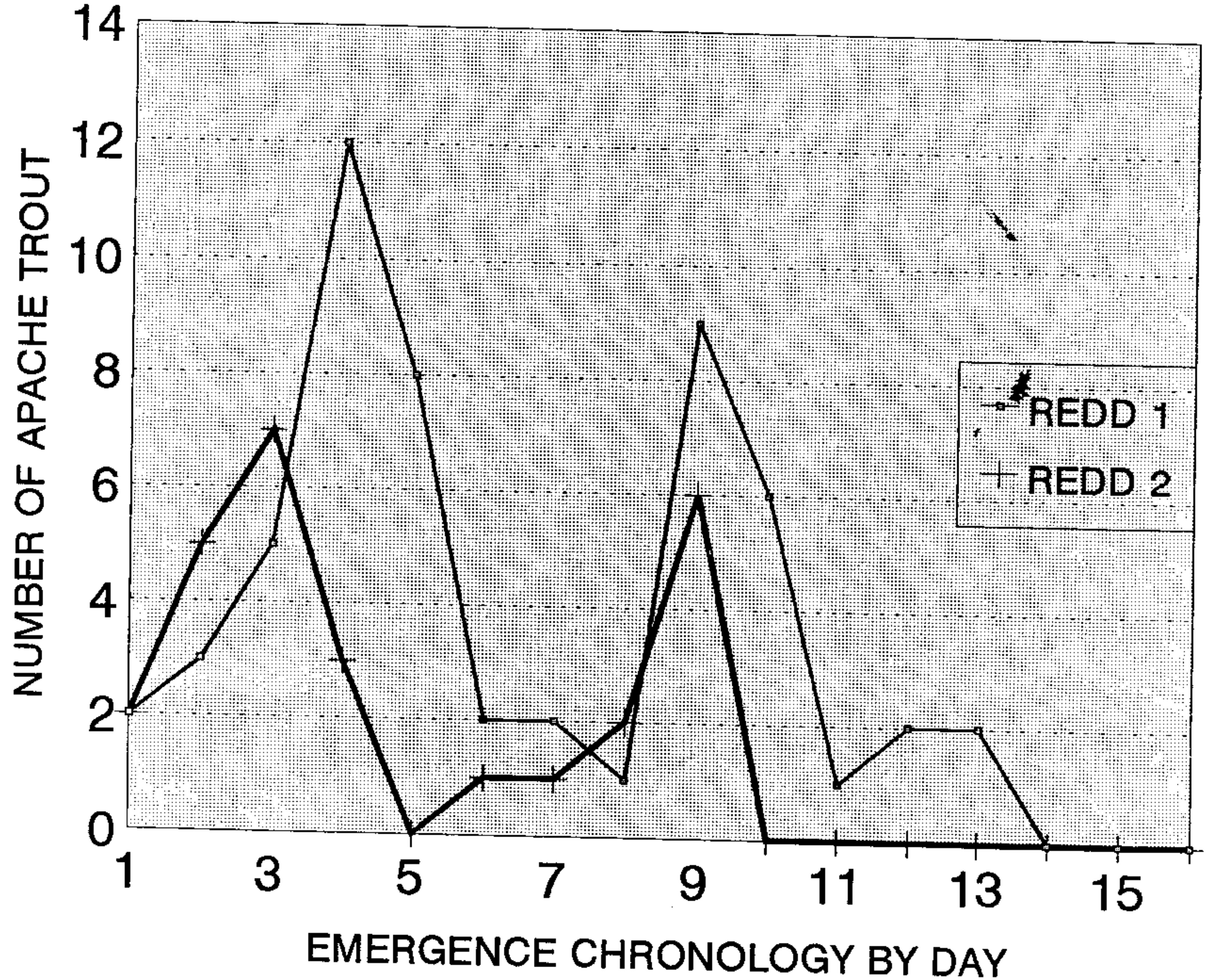

NUMBER OF APACHE TROUT
20
15
10
5
0
1
3
5
7
9
11
13
15
EMERGENCE CHRONOLOGY IN DAYS
REDD 1
REDD 2
REDD 3

FIGURE 5B



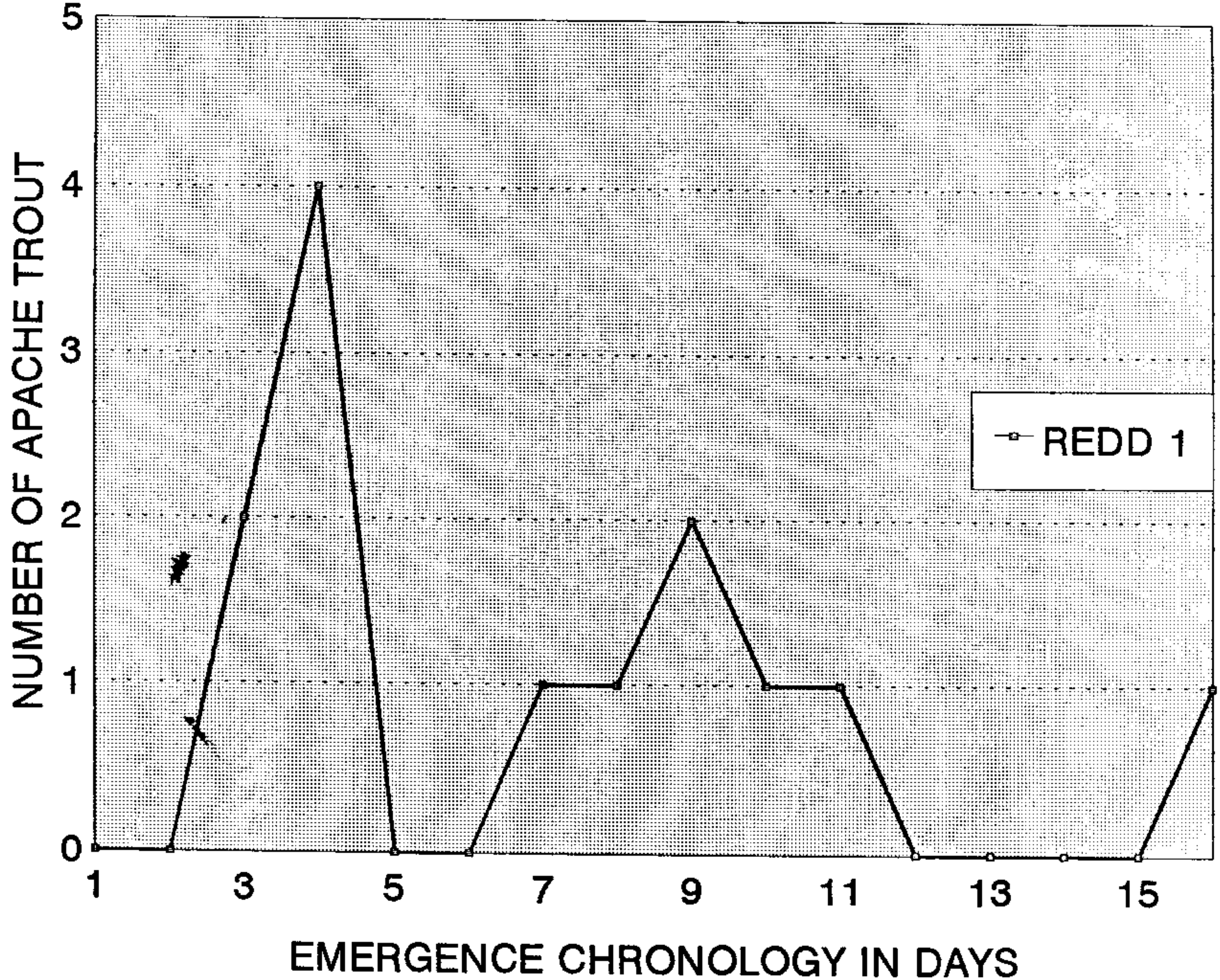
NUMBER OF APACHE TROUT
25
20
15
10
5
0
1
3
5
7
9
11
13
15
EMERGENCE CHRONOLOGY IN DAYS
REDD 1
REDD 2
REDD 3

FIGURE 6A



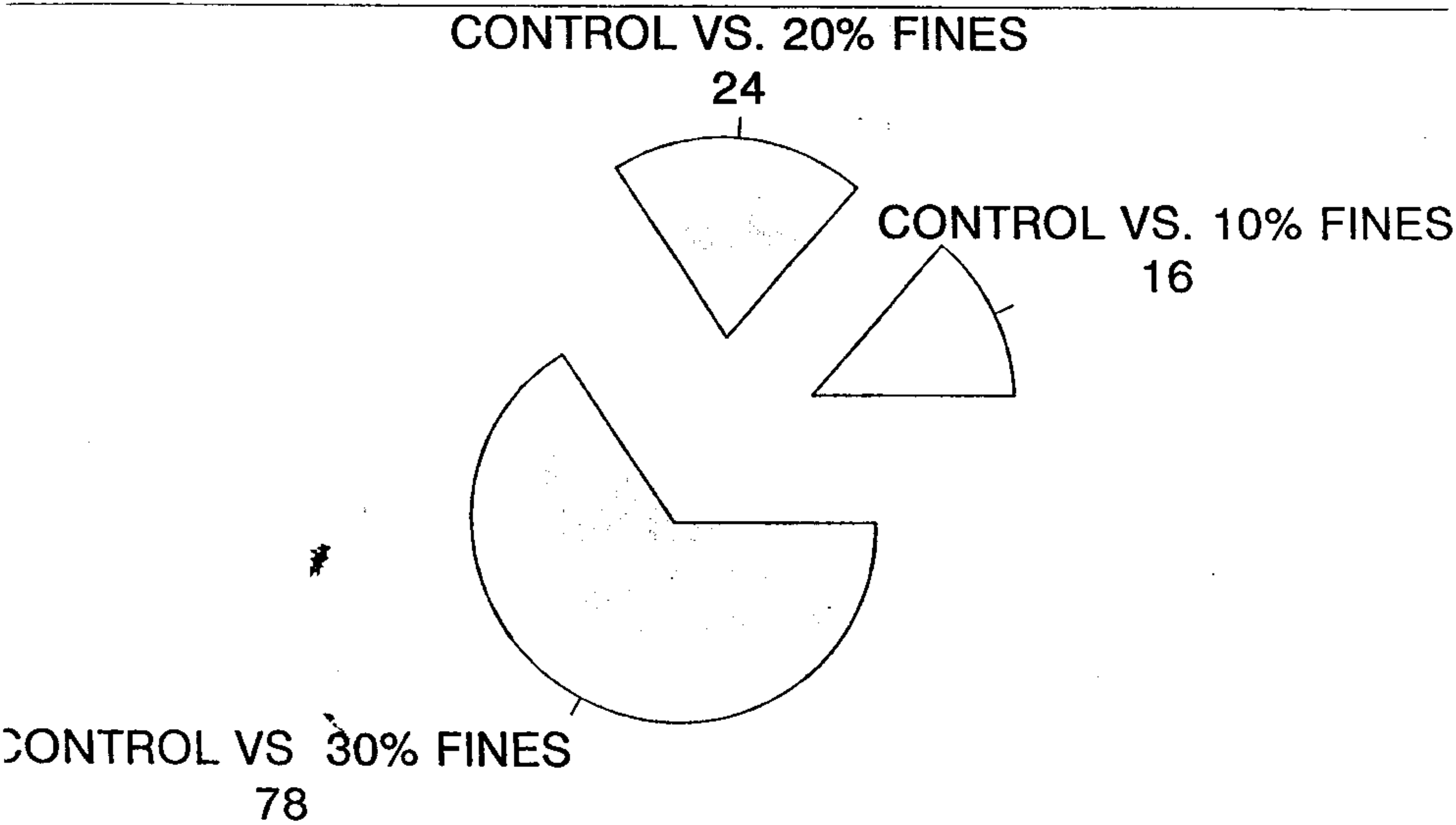
NUMBER OF APACHE TROUT
0
2
4
6
8
10
12
14
1
3
5
7
9
11
13
15
EMERGENCE CHRONOLOGY BY DAY
REDD 1
REDD 2

FIGURE 6B



NUMBER OF APACHE TROUT
0
1
2
3
4
5
1
3
5
7
9
11
13
15
EMERGENCE CHRONOLOGY IN DAYS
REDD 1

FIGURE 7


CONTROL VS. 20% FINES
24
CONTROL VS. 10% FINES
16
CONTROL VS 30% FINES
78

REGRESSION OF PERCENTAGE REDUCTION IN APACHE TROUT FRY EMERGENCE ON PERCENT FINE CONTENT OF SUBSTRATE

FIGURE 8