CUMULATIVE EFFECTS OF FOREST MANAGEMENT ON WATERSHEDS — SOME AQUATIC CONSIDERATIONS

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I. Introduction

Populations of aquatic organisms respond to stress by use of two major mechanisms: 1) resilience (tolerance) by use of phenotypic characteristics to short-term perturbation, and 2) resilience (adaption) by use of genetic composition to long-term changes.

Long-term changes, such as in climate, salinity, and isolation by the formation and aging of lakes, are adapted to by natural selection. Tolerance of short-term perturbations allows for populations to rebound by means of phenotypic characteristics such as fecundity, physiological tolerance to acute but temporary changes in environment and by flexibility in behavior, as in opportunistic feeding habits.

In this conference we are concerned with the relatively short-term changes associated with land management. Floods, landslide-caused sedimentation, deposition of organic debris into streams and lakes, and scouring of substrate of streams occur naturally and with varying frequencies during the life spans of populations of aquatic organisms. When these processes are accelerated through land use practices, cumulative effects can occur and they can be either additive or multiplicative (synergism is a term frequently used for certain multiplicative events) and as a result the resilience mechanisms (tolerances and adaptation) are stressed. Man has introduced another

major impact on populations of salmon, trout and other fishes by harvesting them during some time of their life cycle. In California, and as we have documented in the Northwest, the combination of harvesting and exposure to impacts from some land-use practices can produce cumulative effects on salmonid life cycles; in extreme cases to the point of stock extinction. The simple spawner-recruit curves of Ricker (Ricker 1958) are commonly used to determine "allowable harvest"; but, the principle of harvesting the surplus applies to stresses other than fishing in that the surplus (harvestable portion) at times of stress must be used for its original intent as "the area of (stock) resilience."

The spawner-recruit curves (Figs. 1 and 2) show the amount harvestable, or the resilient portion of the population curve, and define the optimum number of spawners necessary for maximum harvest (in this case resilience). This is an example of a compensatory mechanism. Once the population is depressed below a certain level the compensatory mechanisms break down and depensatory mechanisms take over; for example, the number taken by predators may be a constant resulting in a greater percentage of the population being removed at the lower levels. This may depress the population level below the level of replacement on the spawner-recruit curve (Fig. 2). There are many examples of populations driven to extinction by a combination of over-harvest and changes in environment.

An example of how a stock could be driven to extinction due to cumulative effects of natural and man-caused mortalities in the life cycle is shown in Table 1. The possible impacts on a coho salmon population are shown in four different cases, and it is evident that when land-use (logging) effects operate independent of a commercial fishery, they are not as significant as they are when the two effects

occur concurrently. In Table 1, case A represents a coho salmon life history under completely natural conditions where a substantial excess (4,250,000) of deposited eggs is available after each completed generation. Case B represents a life history when only the effects of logging are imposed on the pre-smolt stages of the salmon's life history. In this case fewer smolts are produced, but there is still an excess of eggs (500,000) at the end of the complete life cycle. Case C represents the same life cycle with only the effects of the various commercial and sport fisheries imposed on the adult stage of the coho life history. However in this case the high mortality of adults due to the 9-1 catch-to-escapement ratio has resulted in a deficit of eggs (–475,000) in the next generation. Case D is a situation that exists today in many areas of the West Coast where the effects of logging on the freshwater stages and the effects of the fishery on the saltwater stages are imposed over the natural mortality rates of the coho salmon. This latter case results in a deficit of eggs (–850,000) at the end of one life cycle. This results in a severely lowered recruitment potential. This is a simplified example of the cumulative effect of two different man-caused influences superimposed on the natural mortality rates of a coho salmon.[1] When the

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[1] In fisheries population analysis the cumulative effects are estimated using instantaneous mortality rates for each cause as given by

$$N_t = N_o e^{-(F+M)t}$$

where N = population numbers at time o and t. F and M are instantaneous mortality rates due to fishing and natural causes respectively. M in turn can be broken up into specific causes, i.e. sedimentation, temperature, scouring, low flows, etc.

logging influence is treated independently it is not enough to reduce the escapement beyond the required egg deposition; but, when the logging and fishery influences are operating concurrently they can lower the escapement significantly. This last case could eventually result in a stock of coho salmon being driven to the point of depensatory mechanism takeover.

Processes that are associated with land management that could operate in a cumulative manner upon aquatic populations are:

1. Increased stream sedimentation — either as suspended or deposited sediments.
2. Temperature changes, either diurnal or seasonal, resulting in extremes greater than that occurring naturally.
3. Changes in physical habitat — brought about directly or indirectly by either excessive debris loading or excessive stream clean-out.
4. Changes in water quality — other than temperature and sedimentation.
5. Changes in water quantity and flow patterns — the net gain or loss of stream flow by removal of vegetation (interception, absorption and transpiration).

II. How are these changes, brought about by land-use practices, measured?

The technologies of measuring the five processes listed above are available if each is to be considered independently. Under ideal field conditions we are able to measure the effects of these processes on biological populations, and it has been done for sediment, temperature and a variety of other water quality parameters. Technically, we are

capable of describing the ideal habitat for most fishes — including salmon and trout — and in some cases we can predict the effects of deviations from the ideal.

We are limited, however, in describing, and certainly in predicting, the cumulative effects of any combination of two or more of the above processes, unless the changes are severe. We are all aware of the intricacies of aquatic ecology, and there is no point in stultifying everyone with diagrams of complicated food webs and how they might respond under various stresses. Although modeling ecosystems is stimulating and it may even be a worthwhile pursuit, we do not need the final output (if there ever will be such a thing) before we can apply wise land management.

Sedimentation — Because of its conspicuousness and apparently obvious impacts, it has received the most attention as a process or extranality of land use practices. For example, we have taken more than 1,000 gravel samples during our eight years of study of the Clearwater River system on the Olympic Peninsula of Washington (Cederholm and Salo 1979). From localized sampling we have expanded our studies to describe the sources of sediment, its transport, the deposition of the fines in the intragravel environment and its effects on salmon eggs, and finally the flushing out of the fines. We are looking at sources of fines and predicting where, how much and how long the sources will be productive in natural and accelerated states. The technology has evolved from a statistically descriptive approach to a processes approach. Correlations to road construction and use have been established (Fig. 3 and Reid, in press).

The sediments have been broken down by size category and the sizes of particles of greatest influence on the environment of the fishes are those less than 6.0 mm in diameter. The definition of "fines" will vary with soils, geology, hydrologic regimes and relative importance as a stressing agent. In our work we commonly use 0.8 mm or less, for that is the size that has the greatest effect upon our salmonid resources (Tagart 1976) and is the size made available in our region through the processes of erosion. Once the definition of fines is established, methods are available for collecting and measuring them either as suspended or in bedload or intragravel deposition. A common denominator relating gravel composition to salmonid survival to emergence using the geometric mean sediment diameter has been suggested by Shirazi and Seim (1979) (Fig. 4).

References and recommendation on techniques for sampling the substrate of streams are given in Gibbons and Salo (1973), and Iwamoto et al. (1978).

Temperature — Methods of measuring and predicting temperature changes need not be reviewed at this time, and the topic can be dismissed with the following notes of caution:

1. The effects of fluctuating and cyclic temperature regimes are important. Daytime highs are much more tolerable if they are followed by nighttime lows.
2. A decrease in winter lows can be as important as the increase in summer highs.
3. The acceleration in the metabolism of biological communities is difficult to measure and isolate as to cause and effect as in determination of the effects of temperature when the trophic structure and habitat has also changed.

A study that isolates the effects of canopy removal from physical changes in habitat is being completed on a stream in western Washington by Martin et al. (in prep.). Preliminary results indicate (Martin, personal communication) that fish populations and food supply were not altered even though water temperature was significantly greater following canopy removal.

Physical Habitat — Although we have been able to describe the stream habitat of fishes in a general way for many years, the descriptions are primarily of habitats in equilibrium and considered "stable"; only infrequently have we adequately measured responses of fishes to change. Recent reports (Bisson and others) describe the changes that undisturbed (by man) streams in aging climax forests undergo in cases of windfall. The changes in small streams can be dramatic. The association of streams to their riparian vegetation is greatest in first-order streams, somewhat less in second- and third-order streams, and considerably less in the fourth- and fifth-order, but in each instance the processes affecting the first- and second-order streams in turn affect the higher order stream. The influences could eventually reach the estuary.

For the biologists, quantifying changes in physical habitat is still in the formative stages, and just recently we have adopted some of the methods used by the physical scientists. The incremental methods used by the USFWS (Colorado instream flow group, Bovee and Cochnauer 1977) define available habitat at various flows and models have been developed to predict the amounts of usable areas available to several species and ages of fishes at various flows. These methods have been improved and modified for West Coast use by June (in prep.). Also, the

use of photogrammetry for mapping streams and quantifying habitat parameters in a long stream reach is being investigated (Martin, personal communication).

III. How can these processes be evaluated?

Sedimentation — The spawning success of salmonids reflects the efficiency of habitat which declines as fines are introduced into the gravel. Rarely is it improved. The relationship between percentage of fines, mean diameter of the spawning gravels and the ratio of the sizes of gravel, and survival of embryos is well known. The critical diameter may change by species, fish stock and region. As an example, embryo (pre-emergent) cutthroat trout may be more tolerant than chinook salmon of accumulating fines.

The accumulation of intragravel sediments in relation to land use, particularly the use of logging roads, has been documented (Fig. 3). The hydraulic characteristics of the streams, degree of logging- or road-caused erosion, and the type of soils determine the rate of accumulation (Reid, in press). The relationships among roads, clearcuts and sediments have been described.

Habitat and Organic Debris — Organic debris (windfall and logging slash) has physical influences on the stream environment besides furnishing a base load of nutrients. Accumulated debris in a climax forest plays a positive part in creating habitat and in providing an essential detrital base. The rate at which trees decompose in the stream varies with the species, but for fir and hemlock it is roughly the number in years equal to the age of the tree. While in the stream,

large organic debris physically regulates the amount and distribution of pools and riffles. Organic debris also traps sediments and affects their distribution while the particle sizes are being sorted (Heede 1975). In some streams as much as 85 percent of the pool habitat is debris-oriented (Sedell et al. 1980).

Pool and riffle frequency and stability are highly dependent on the occurrence of large organic debris within the stream course (Meehan et al. 1977). The fish species diversity and production are dependent on a stable balance of pool and riffle habitat. When over-zealous stream cleanout occurs, as in some logging operations, the summer and winter habitat of salmonids can be destroyed. Differences in stability of habitat contributes to the diversity in production of our coastal streams (Bustard and Narver 1975a; Lestelle 1978).

The rate of contribution and quality of detritus changes with the succession from deciduous trees to conifers — so plant succession plays a role in maintenance of the detritus budget. The influences of short cuts (planting of climax species) in plant succession on stream ecology are unknown, as are the effects of fertilizers. The benthic fauna in streams can be grouped generally into functional groups: a) shredders, b) collectors, c) scrapers, and d) predators, and changes in the canopy and debris will affect the composition of these groups (Cummins 1974; Meehan et al. 1977).

IV. Identification and Prediction

We are improving our identification of sources and routing of sediments and the consequences of their deposition into streams. The contributions of slope failures, landslides, clearcuts and roads to

the sediment budget can be quantified. Our knowledge of preventative measures is greater than that of remedial actions. Temperature changes can be predicted, once the moderating effects of groundwater and springs are assessed. The role of organic debris is becoming appreciated.

We have the methodology for studying fish biology, but we are critically deficient in standardized field observations, understanding real-life population dynamics, and we are woefully deficient in assessing "multiplicative effects of cumulative stresses." We know what we should do, but we are frustrated by the rugged environment, limitations of field facilities, and reliable methods of monitoring fish without affecting their habits.

V. Identification of Information and Resource Needs

In spite of our shortcomings in understanding forest-aquatic ecotones and even with large gaps in our appreciation of cumulative effects, we have enough basic information to improve our land-management practices significantly. Needed are legislative actions for watershed planning. We need to manage the entire watershed and the estuaries rather than their components individually.

We are dreadfully short in trained investigators and in educated managers. We are very deficient in good base-line biological investigations.

When, where and if to leave buffer strips is only partially known, for often windfall in streamside management zones can cause more damage than clearcutting to the edge of the stream. Conversely, often the economics of leaving an adequate zone of trees on either side of the stream are distorted by undervaluing the food fishes produced during

the sixty or eighty years necessary for timber rotation. Techniques are being developed that will allow watershed managers to optimize the economic values of forestry and fishery resources region-wide (Everest 1978).

The chemical relationships of water and watershed soils need to be understood as "the water is no better than the soil it flows through."

Finally, too many of the problems of watershed management are social and political. Even at this conference, which was based on wholesome interchange, evident polarization of individuals and even groups precluded complete acceptance of facts and inhibited understanding. Objective regulations of forest practices may be far removed from reality; meanwhile subjective regulations are interpreted by the biased. Only education and training can solve the problem.

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TABLE 1

THE LIFEHISTORY OF A COHO SALMON BASED ON FOUR SCENARIOS OF NATURAL MORTALITY COMBINED WITH THE EFFECTS OF LOGGING AND FISHERY HARVEST IMPACTS

LIFEHISTORY STAGE	(A) COMPLETELY NATURAL	(B) LOGGING INFLUENCES ALONE	(C) FISHERY INFLUENCES ALONE	(D) LOGGING & FISHERY INFLUENCES TOGETHER
EGGS DEPOSITED	1,000,000	1,000,000	1,000,000	1,000,000
(AMOUNT NEEDED TO SEED TO CARRYING CAPACITY)	35%	15%	35%	15%
EMERGENT FRY	350,000	150,000	350,000	150,000
	30%	25%	30%	25%
PARR @ SUMMER LOW-FLOW	105,000	37,500	105,000	37,500
	50%	40%	50%	40%
SEAWARD MIGRANTS (SMOLTS)	52,500	15,000	52,500	15,000
	10%	10%	10%	10%
ADULT OCEAN SURVIVORS	5,250	1,500	5,250	1,500
			10%	10%
ADULT FISHERY SURVIVORS	—	—	525	150
ESCAPEMENT BOTH SEXES	5,250	1,500	525	150
ESCAPEMENT OF FEMALES	1,750	500	175	50
EGGS DEPOSITED TO SEED THE NEXT GENERATION	5,250,000	1,500,000	525,000	150,000
AMOUNT OF DEPOSITED EGGS NEEDED TO REACH CARRYING CAPACITY	1,000,000	1,000,000	1,000,000	1,000,000
	+4,250,000 (EXCESS)	+500,000 (EXCESS)	-475,000 (DEFICIT)	-850,000 (DEFICIT)

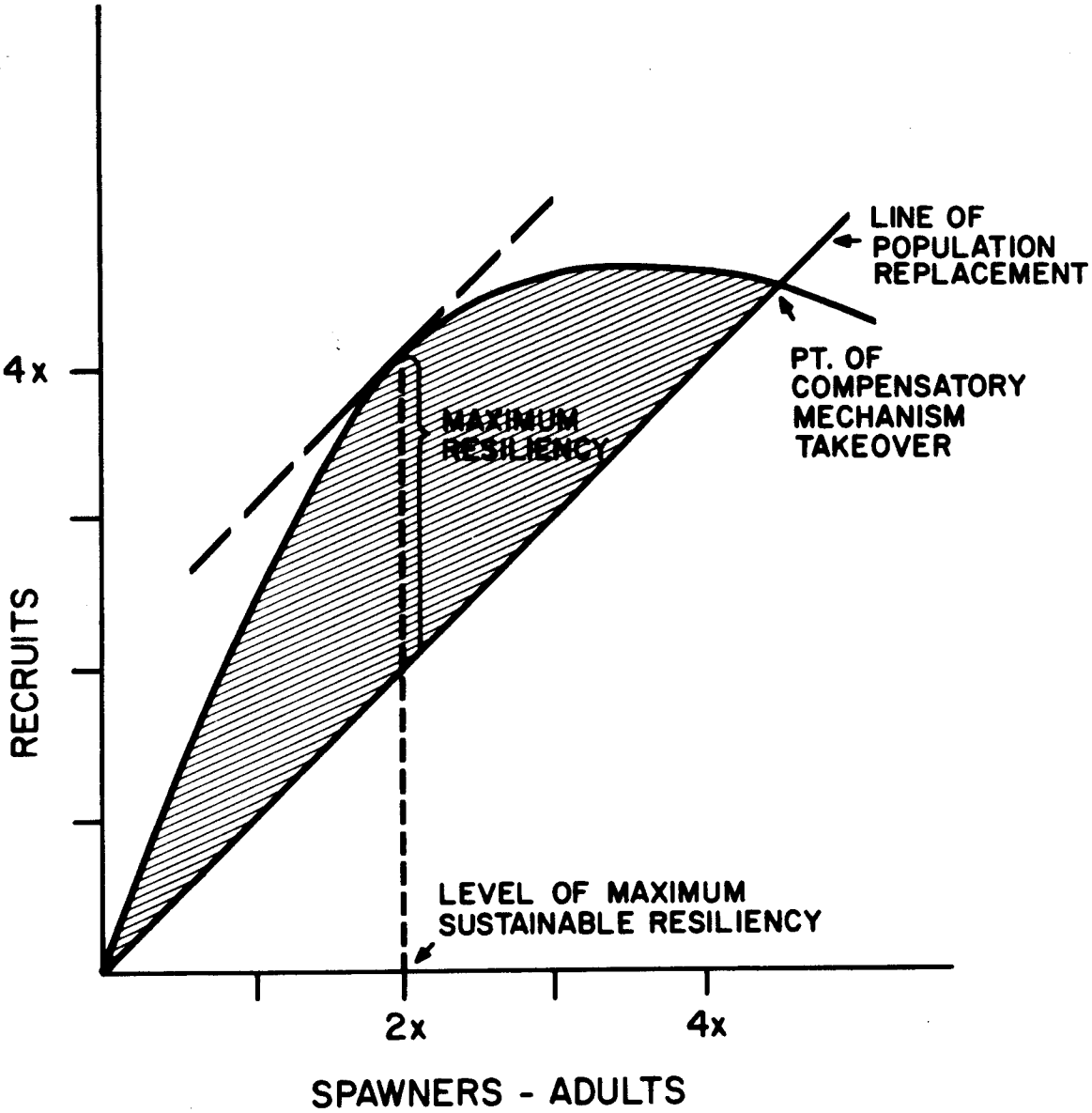

Fig. 1 - SPAWNER RECRUIT CURVE
WITH "NORMAL" REGULATORS (STRESSES)

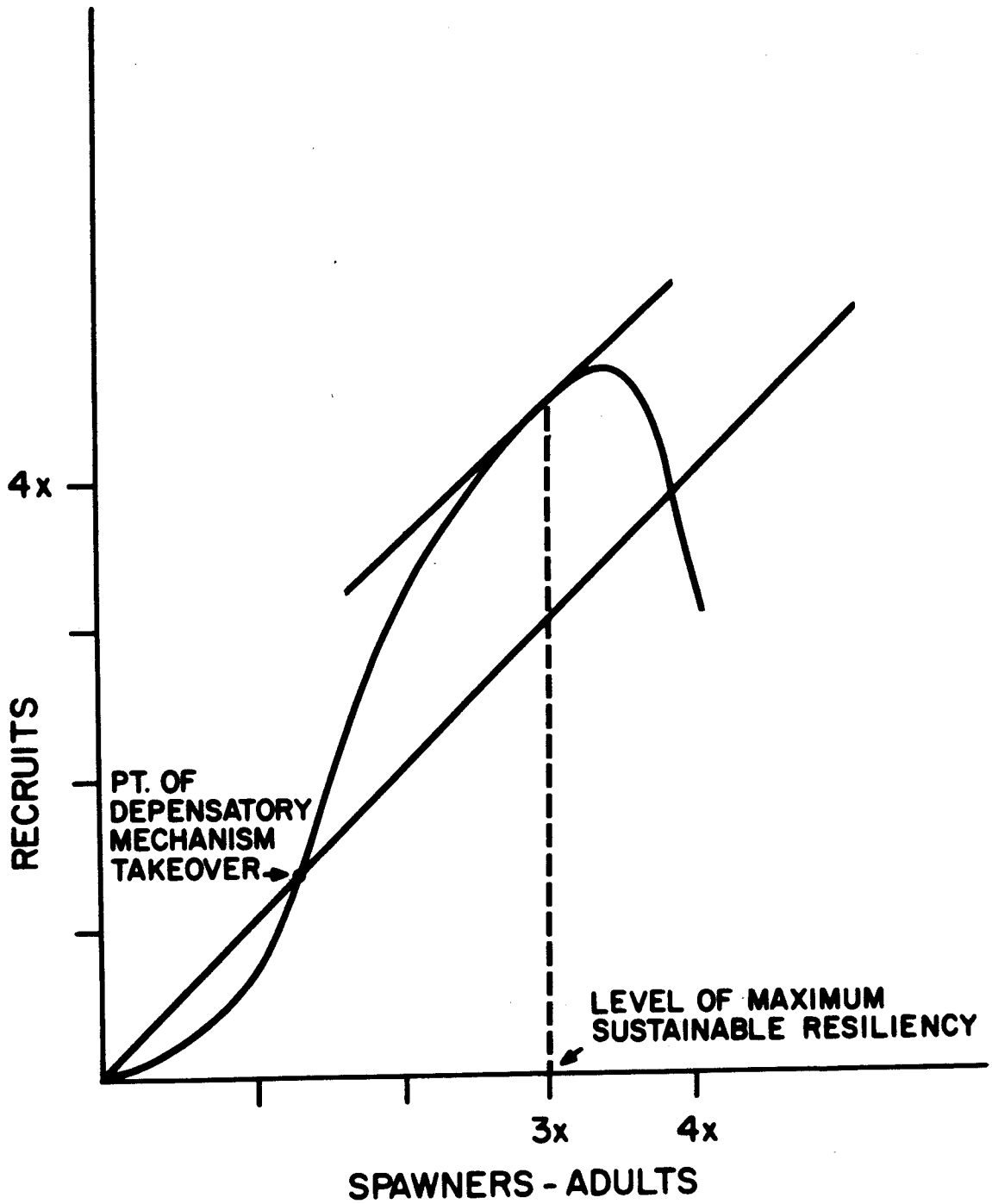

Fig. 2 - SPAWNER - RECRUIT CURVE
WITH CUMULATIVE STRESSES

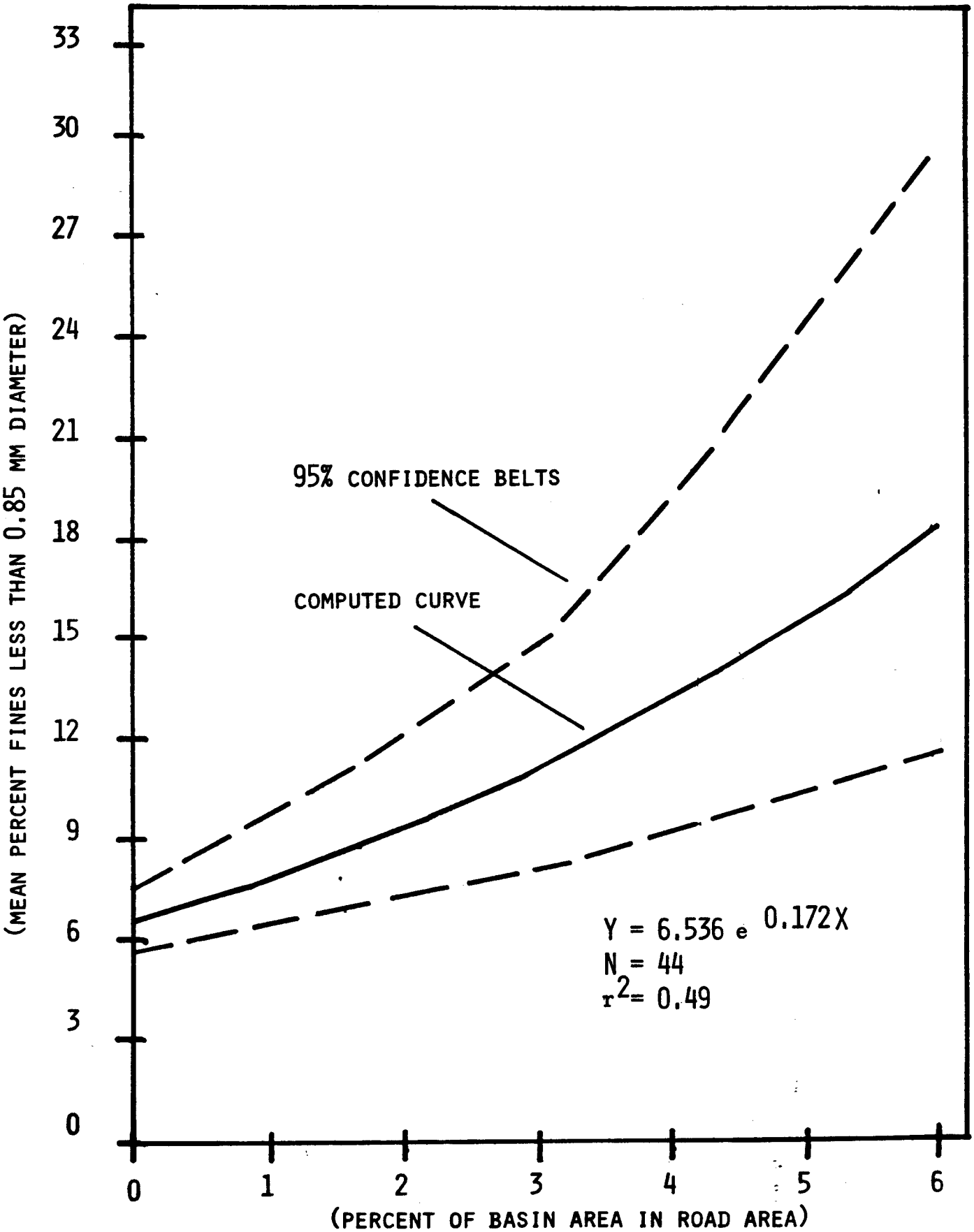

FIG. 3. RELATIONSHIP BETWEEN BASIN LOGGING ROAD AREA AND PERCENT FINES (MATERIAL LESS THAN 0.85 MM DIAMETER) IN DOWNSTREAM SALMON SPAWNING GRAVELS OF THE CLEARWATER RIVER AND SOME NEARBY STREAMS IN THE OLYMPIC NATIONAL PARK. (CEDERHOLM AND SALO, 1979).

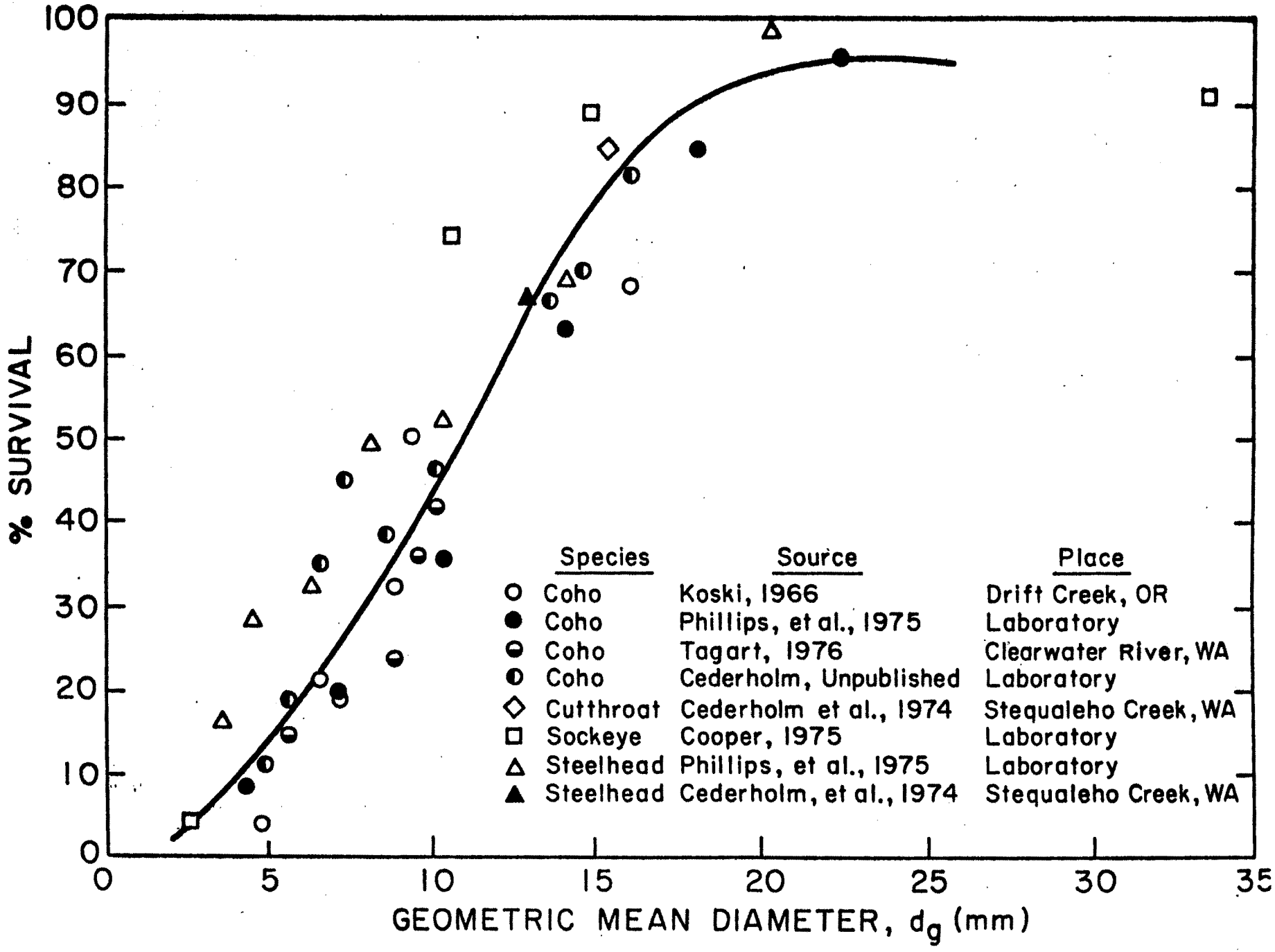

FIG. 4. RELATIONSHIP BETWEEN PERCENT EMBRYO SURVIVAL AND SUBSTRATE COMPOSITION EXPRESSED IN GEOMETRIC MEAN PARTICLE DIAMETER. (SHIRAZI AND SEIM, 1979).