Literature Reviewed for Gold and Fish Pamphlet, January, 1998

Badali, Paul J. 1988. Prepared Statement to State of Idaho, Dept. of Water Resources, Recreational Dredging Seminar, February 3, 1988. 13 pp.

Author's Summary: Turbidity from dredges, even large dredges, operating on medium and larger sized streams returns to background levels within a short distance downstream, and is present only when the dredge is actually operated; a few hours per day. It appears to have little effect on adult fish feeding.

Immediate habitat changes resulting from the excavation of the dredge hole does have a short lived effect on the benthic invertebrate population in the immediate area, but recolonization of the area is rapid. Inter cobble habitat is reduced downstream as sediments are deposited. But this change is also short lived on streams with high flushing spring flows, which most gold streams have, appears to be a beneficial change to some species, and is partially offset by the creation of new inter cobble habitat in the cobble pile.

Thomas (1985) speculated that flushing flows may carry unstable tailings downstream to fill in holes, important salient habitat. But other more extensive studies have shown that this rarely occurs, and that when it does, the hole created by the dredging activity replaces the lost habitat.

If there were sufficient bedload movement at high water to fill in the dredge holes, then the hydrodynamic conditions which originally created natural holes will likely reestablish them.

Spawning bed destruction by the dredging activity has not been shown to be a problem. Salmonids have been observed spawning in gravel beds which are made up mostly from sorted material washed downstream from previous dredge tailings piles. If anything, dredging appears to add to the spawning gravel budget of a stream. Also, the gravel budget of a stream does not appear to be a limiting factor on spawning activity, except on dammed streams, the substrate tends to become compacted with time. There is a reduction in the porosity and permeability of the gravel. With little bed movement, spawning gravel becomes scarce and of very low quality. The reduction in water flow through the gravel causes a corresponding reduction in oxygen levels, and very low yield from eggs. Without flushing flows, something else must be done to loosen up the substrate, and flush out fine sediments to create good spawning conditions if natural stocks are to survive. This is exactly what suction dredging will do. Suction dredging for gold should be encouraged by wildlife management agencies on waters with controlled flows as a conservation and fisheries management measure.

The presence of the dredger and dredge does not appear to be an annoyance to fish. Entrainment through the dredge of in-gravel life stages of salmonids produces unacceptably high mortality. On important spawning streams, dredging seasons should be retained or set to prohibit dredging when early life stages are expected to be present in the gravel. Fry, juveniles, and adults are rarely subjected to entrainment, and survive if and when entrainment occurs.

On Canyon Creek, the effects of multiple years of dredging, and multiple dredges on the creek do not appear to be cumulative. As a matter of fact, the Trinity River, and Klamath River in Northern California have received intensive suction dredge pressure in the last 15 years, and their fish populations are presently at their highest recorded numbers in ever (sic). There is no evidence to suggest these increases are due to hatchery supported runs. It appears to be an increase in natural stocks. If there is a cumulative effect, it would appear to be beneficial.

Reviewer's Comments: The author's biography states in part "In 1984 he discovered the joy and adventure of recreational gold mining, especially underwater gold dredging in Idaho and California. It became a passion. Since 1986 he has acquired 14 federal mining claims and state leases in Idaho and Utah, joined 4 mining clubs, and started a fifth in Salt Lake City. He is a past president of a California Chapter of the Western Mining Council, and current news letter editor of the Utah Gold Prospectors Club" (W.A.M.P. Biological Facts Information Pamphlet). The Conclusion and Recommendations section in this paper contains several best management practice recommendations for suction dredge and "highbanking" operations.

Berg, L. and T.G. Northcote. 1985. Changes in territorial, gill-flaring, and feeding behavior in juvenile coho salmon (**Oncorhynchus kisutch**) following short-term pulses of suspended sediment. Can. J. Fish. Aquat. Sci. 42: 1410-1417.

Authors' Abstract: The territorial, gill-flaring, and feeding behavior of juvenile coho salmon (**Oncorhynchus kisutch**) in a laboratory stream was disrupted by short-term exposure to sediment pulses. At the higher turbidities tested (30 and 60 nephelometric turbidity units (NTU), dominance hierarchies broke down, territories were not defended, and gill flaring occurred more frequently. Only after return to lower turbidities (0-20 NTU) was social organization reestablished. The reaction distance of the fish to adult brine shrimp decreased significantly in turbid water (30 and 60 NTU) as did capture success per strike and the percentage of prey ingested. Implications of these behavioral modifications suggest that the fitness of salmonid populations exposed to short-term pulses of suspended sediment may be impaired.

Reviewer's Comments: The increased gill flaring, defined as "an excessive opening of the gill opercula, gaping mouth, and a small but distinct forward movement of the fish", may have resulted from gill irritation by sediment particles. Mucus produced in reaction to the irritation, as well as any adhering sediment particles, are flushed out of the gills by the flaring action.

Bjornn, T.C. and six coauthors. 1977. Transport of granitic sediment in streams and its effect on insects and fish. University of Idaho. Forest, Wildlife and Range Experiment Station, Bulletin 17, Moscow, ID.

Authors' Abstract: We assessed the transport of granitic bedload sediment (< 6.35 mm diameter) in streams flowing through central Idaho mountain valleys and the effects of the sediment on juvenile salmonids and aquatic insects. We measured bedload sediment transported in the streams during the spring snowmelt runoff and the summer low-flow periods for 2 years, to test the applicability of the Meyer-Peter, Muller equation for estimating such transport. In both years the streams transported all the sediment available, including that under the armor layer of the stream bottom in the first year. The modified Meyer-Peter, Muller equation proved accurate in estimating the transport capacity of such streams using measurements of slope, hydraulic radius and mean diameter of streambed material.

In artificial stream channels, benthic insect density in fully sedimented riffles (> 2/3 cobble imbeddedness) was one-half that in unsedimented riffles, but the abundance of drifting insects in the sedimented channels was not significantly smaller. In a natural stream riffle, benthic insects were 1.5 times more abundant in a plot cleaned of sediment, with mayflies and stoneflies 4 and 8 times more abundant, respectively. Riffle beetles (Elmidae) were more abundant in the uncleaned plot.

During both summer and winter, fewer fish remained in the artificial stream channels where sediment was added to the pools. The interstices between the large rocks in the pools provided essential cover necessary to maintain large densities of fish. Fish in sedimented channels exhibited hierarchical behavior, while those in unsedimented channels were territorial in behavior. In small natural pools (100 to 200 square meters), a loss in pool volume or in area deeper than 0.3 m from additions of sediment resulted in a proportional decrease in fish numbers. We did not, however, find significant correlations between riffle sedimentation and fish density in the two natural streams we studied. Fish abundance was significantly correlated with insect drift abundance in one stream, but not in the other. The amounts of sediment in the two streams studied did not have an obvious effect on the abundance of fish or the insect drift on which they feed.

Reviewer's Comments: This study is often cited in papers discussing sedimentation effects on fish and fish habitat.

California Dept. of Fish and Game. 1994. Adoption of regulations for suction dredge mining. Final Environmental Impact Report. 174 pp.

Authors' Abstract: None

Reviewer's Comments: California's proposed regulations that provide for suction dredge mining in designated waters of the State while also protecting fish and wildlife resources. As stated by the authors, "Suction dredge mining can potentially result in the loss of fish production, temporary loss of benthic/invertebrate communities, localized disturbance to streambeds, increased turbidity of water in streams and rivers, and mortality to aquatic plant and animal communities. However, based on best available data, it is anticipated the project to adopt regulations for suction dredging as proposed, will reduce these effects to the environment to less than significant levels and no deleterious effects to fish" (p. 10). A point of interest noted by Harvey et al, 1995, is that this FEIR failed to address a means to regulate numbers of suction dredges operating in a particular stream reach.

California Dept. of Fish and Game. 1997. Adoption of Amended Regulations for Suction Dredge Mining. Draft Environmental Impact Report. 61 pp.

Authors' Abstract: None

Reviewer's Comments: California is proposing to amend their regulations to establish formal guidelines, procedures and process for the issuance of, or denial and appeal of, special suction dredge permits in compliance with the California Environmental Quality Act (CEQA) and the Permit Streamlining Act; to add additional restrictions on suction dredging where the Department has determined that current restrictions are inadequate to protect fish and/or fish habitat; eliminate or modify regulations and closures that are unnecessarily restrictive or burdensome; and make other nonsubstantive changes for clarification and consistency or to eliminate redundancy (p. I.2). One area of concern is that current regulations do not adequately address protection of adult salmon and steelhead in summer holding areas (p. I.5).

Their conclusion states in part: "Unregulated suction dredging can potentially result in the loss of fish production, temporary loss of benthic/invertrbrate communities, localized disturbance to streambeds, increased turbidity of water in streams and rivers, disturbance to certain adult fish in summer holding areas, and mortality to aquatic plant and animal communities. However, based on best available data, it is anticipated that the regulations, as amended by the proposed project, will protect fish and other related aquatic dependent resources and will not cause significant effects to the environment or deleterious effects to fish" (p. I.9).

Potential positive effects of suction dredging, as reported by active dredgers, included improvement of spawning gravels, removal of lead and mercury from the rivers, removal of submerged garbage, and fish feeding on dislodged invertebrates in the dredge discharge plume and near the intake nozzle (p. V.4).

Caplice. O. (Ed.) 1960. The effect of placer mining (dredging) on a trout stream. Pp. 75-97 in Job Completion Report, Project No. DJ F-34-R, Water Quality Investigations, Federal Aid in Fish Restoration, Idaho Dept. of Fish & Game, Moscow, ID. (Report prepared by W.E. Webb & O.E. Casey).

Authors' Abstract: A three year study, which measured the chemical, physical, and biological changes effected by dredging in a trout stream has been completed.

Chemical changes in the water were not detected during the study. Dissolved oxygen, pH, and alkalinity were not altered by the dredge.

Physical changes include a rise in the water temperature below the dredged area, reduction in area available to fish by shortening of stream, elimination of pools through channel straightening, filling in of the pools with silt, and a decrease in the value of the riffles for spawning.

Biological changes in the stream were greatest during the dredging activity. In the dredged area aquatic insects and fish were reduced by 99 per cent during dredging, but recovered within one year.

Aquatic insects .3 mile below the dredge were not affected. Whitefish was the species of fish most adversely affected by the dredge. Suckers increased below the dredge.

Reviewer's Comments: An example of a "worst case" scenario involving a large gold dredge.

Cordone, A.J. and D. W. Kelley. 1961. The influences of inorganic sediment on the aquatic life of streams. Cal. Fish & Game 47: 189-228.

Authors' Abstract: None

Reviewer's Comments: The authors state that "This report is essentially a review of investigations made of the effects of inorganic sediment on the aquatic life of streams. It is not a complete literature review but rather a summary of most of the pertinent investigations that we believe will assist the fisheries worker faced with sediment problems." This is another report often cited in the literature.

Fudge, R.J.P. and R.A. Bodaly. 1984. Postimpoundment winter sedimentation and survival of lake whitefish (**Coregonus clupeaformis**) eggs in Southern Indian Lake, Manitoba. Can. J. Fish. Aquat. Sci. 41: 701-705.

Authors' Abstract: Flooding of Southern Indian Lake for hydroelectric power development has resulted in extensive wave erosion of glacio-lacustrine clay shore material and greatly increased suspended sediment levels. Winter sedimentation on spawning grounds of lake whitefish (**Coregonus clupeaformis**) ranged from 0.03 to 0.14 g dry wt sediment/cm-2. This deposited a layer 1-4 mm in depth. The sediment, low in organic content, was categorized as silty clay. The effect of this winter sedimentation on survival of whitefish eggs was tested at four sites over a range of winter sedimentation rates. Three of the sites were whitefish spawning areas. Egg survival was significantly higher for eggs incubated in cages designed to minimize exposure to sedimentation compared with survival in cages allowing full exposure to sedimentation. Winter sedimentation rates and whitefish egg survival were negatively correlated for cages designed to minimize exposure to sedimentation, while egg survival in the exposed cages was uniformly low.

Reviewer's Comments: As noted by Harvey et al, 1995 (p. 13), the impacts of fine sediment deposition may be more severe on fish species such as whitefish that deposit eggs on top of the gravel as opposed to fish species such as trout and salmon that deposit eggs within stream gravels.

Griffith, J.S. and D.A. Andrews. 1981. Effects of a small suction dredge on fishes and aquatic invertebrates in Idaho streams. North Amer. J. Fish. Mgmt. 1: 21-28.

Authors' Abstract: A typical dredge (intake diameter 7.6 cm) was operated on four small Idaho streams during July-September 1980 to evaluate some of the effects on aquatic organisms that may result from the use of small suction gold-dredges. Mortality of eggs, sac-fry, and fingerlings of several species of trout was monitored, as was that of benthic invertebrates that were entrained through the dredge. The ability of invertebrates to recolonize a dredged area was assessed, and the performance of the dredge was evaluated.

Un-eyed cutthroat trout (**Salmo clarki**) eggs experienced 100% mortality within 1 hour after entrainment. Eyed cutthroat trout eggs showed means of 29% and 35% for 1-hour and 36-hour mortalities, respectively. The 19% mortality of eyed eggs of hatchery rainbow trout (**Salmo gairdneri**) after 10 days was similar to that of the control group. Hatchery rainbow trout sac fry experienced 83% mortality after 20 days as compared with 9% for the controls. Yolk sacs were detached from approximately 40% of the fry during entrainment. Fewer than 1% of the 3,623 invertebrates entrained showed injury or died within 24 hours. Most of the dead were **Centroptilum** mayflies that were undergoing emergence at the time of dredging.

Most of the recolonization of dredged plots by benthic invertebrates was completed after 38 days. The unmodified dredge moved the equivalent of 0.043-0.055 cubic meters of substrate per hour, about 2% of the manufacturers maximum rating. In the study areas, approximately 0.76 cubic meters of sediment less than 0.5 mm in diameter could be moved in 100 hours of dredging operation.

Reviewer's Comments: As pointed out by Hall (1988) the authors "made no attempt to investigate survival of viable eggs and larvae removed from the habitat in which they naturally occurred and subsequently scattered downstream from the dredge." The authors also noted that suction dredging could impact aquatic systems in other ways, including the trampling of aquatic organisms by dredge operators and consequences of altering stream channel configuration by moving boulders. Other considerations included more substantial sediment plumes below dredges operating in streams where sediment levels are higher and the impacts of using larger-sized dredges.

Hall, D.N. 1988. Effects of eductor dredging of gold tailings on aquatic environments in Victoria. Proceedings of the Royal Society of Victoria, Vol. 100, 53-59.

Author's Abstract: Information on the effects of eductor (suction) dredging on Victoria's [Australia] aquatic habitats and organisms is reviewed and discussed. The paucity of information makes a rational assessment impossible and highlights the need for relevant studies in Victoria. Evidence from North American studies suggests that the rate at which benthic invertebrate communities recover depends on the distance between the dredge site and an undisturbed source of invertebrates upstream. In only one North American study has the effect of passage of fish eggs and fry through an eductor dredge been examined. Alteration of benthic habitat by deposition of sediment downstream from eductor dredging can influence the species composition, diversity and biomass of aquatic communities.

Reviewer's Comments: In reference to the work of Griffith and Andrews, the author states that "No comparable studies on the effects of dredging have been conducted on Victorian species of fish at different stages of their life cycle, but disturbance of the substrate would probably affect the survival of species that utilise this habitat at early stages of their life cycle. Larval short-headed lampreys (**Mordacia mordax**) burrow into the sediment for the early part of their life (Potter 1970), and the river blackfish, Australian grayling (**Prototroctes maraena**), native **Galaxias**, gudgeons and other fish species deposit eggs over the substrate (Table 1)." He also notes that "Whilst it is most probable that the nature and extent of the present eductor dredge practices in Victorian streams are causing relatively localised disruptions to stream ecosystems, the short- and long-term effects of eductor dredging will be elucidated only from well-designed studies."

Harvey, Bret C. 1986. Effects of suction gold dredging on fish and invertebrates in two California streams. North Amer. J. Fish. Mgmt. 6: 401-409.

Author's Abstract: I examined the impact of small suction dredges (hose diameter, <16 cm) on fish and invertebrates in two California streams (North Fork of the American River and Butte Creek) in a 2-year study. I studied both the effect of one dredge (1980) and the effects of an average of six dredges in a 2-km section of stream (1981). Ten replicate Surber samples per station were taken monthly to compare macroinvertebrate abundances at control and dredged stations before, during, and after dredging in both years. Dredging significantly affected some insect taxa when substrate was altered. A recolonization experiment showed that numerical recovery of insects at dredged sites was rapid. Mask-and-snorkel censuses and observations of tagged fish indicated that major changes in available habitat caused local decreases in fish density. Dredging affected riffle sculpins (**Cottus gulosus**) more severely than rainbow trout (**Salmo gairdneri**), probably because of differences in microhabitat requirements. Local turbidity increases below active dredging probably did not affect invertebrates and fish.

Reviewer's Comments: The author stated that "Factors that effect the impact of dredging include dredge size and density, stream size, the fineness of the sediments, and flow regime. The dredge density at BC in 1981, although characteristic of many streams, was not as high as in some streams in California. Qualitative observations on large streams such as the North Fork of the Feather River and North Fork of the Yuba River indicated dredging was a highly localized disturbance on those streams. In contrast, 15 m of a tributary of Butte Creek were completely channelized and riffles were transformed into exposed gravel bars by the 10-d operation of one dredge. In streams with a relatively large proportion of fine sediments, the effects of dredging are probably more severe than those I observed." He also noted that "The microhabitats of riffle sculpins, and possibly those of other bottom-oriented stream fishes such as speckled dace (**Rhinichthys osculus**) and young-of-the year rainbow trout, are altered more readily by dredging than those of less benthic species (and age-classes). [Cobbles utilized by sculpins were partially buried by dredge spoils; increased bedload transport of fine sediment may also have negatively affected sculpins at that site because fewer remained beneath cobbles and boulders which remained unembedded downstream of the dredge (see Harvey et al, 1995, p. 7)]. Overall, however, Harvey's results suggested that "suction dredging effects can be short-lived on streams where high seasonal flows occur."

Harvey, B.C., T.E. Lisle, T. Vallier and D.C. Fredley. 1995. Effects of suction dredging on streams: a review and evaluation strategy. USDA Forest Service, unpublished MS, 38 pp.

Authors' Abstract: None

Reviewer's Comments: Stated purposes of this report are: 1) briefly describes the practice of suction dredging; 2) provides a summary of potential effects of suction dredging in river channels on: stream biota, river recreation, water quality, and channel stability and morphology; 3) outlines questions (associated with each of the above issues) which would be helpful in evaluating the impacts of particular suction dredging operations; 4) identifies high priority research questions; 5) suggests a general strategy for evaluating the effects of suction dredging; and 6) summarizes suction dredging regulations (Federal, California, Idaho, Oregon, and Washington). The authors concluded "that management of suction dredging requires a large-scale approach similar to that used in watershed analysis" (p. 2). They also state: "It appears that non-salmonid fishes have not been considered in the determination of dredging seasons" (p. 5); "Similar to benthic fishes, older amphibian larvae and adults could be negatively affected by dredging if it results in loss of unembedded cobble substrate" (p. 9); and "These animals (referring to mollusks) may be influenced strongly by local events such as suction dredging" (p. 11).

Hassler, T.J., W.L. Somer, and G.R. Stern. 1986. Final Report on Impacts of Suction Dredge Mining on Anadromous Fish, Invertebrates and Habitat in Canyon Creek, California. California Cooperative Fishery Research Unit, U.S. Fish & Wildlife Service, Humboldt State U., Cooperative Agreement No. 14-16-0009-1547, Work Order No. 2, 134 pp.

Authors' Abstract: The popularity of the suction dredge for gold mining has greatly increased in recent years. The effect of dredge mining on anadromous fish and habitat is poorly understood and there is a need to assess its impacts. This study evaluated impacts of suction dredge mining on anadromous fish, invertebrates, and habitat in Canyon Creek, Trinity River Basin, California. Suction dredge mining in the lower 18 km of Canyon Creek is permitted from June 1 to September 15. Dredging is permitted until October 15 on tributary streams. The maximum permitted dredge intake hose size is 15.24 cm. Seventeen suction dredges operated yearly in Canyon Creek from 1980 through 1985. Dredging occurs in the wetted perimeter of the stream and a cone shaped hole is dredged. In 1984-1985, mean dredge hole depth was 1.3 meters, mean surface area disturbed by a dredge was 42 m2 and total area disturbed was 1140 m2. Canyon Creek has about 855 m2 of suitable spawning gravel. About 6% of the area disturbed by dredging was visible the following year. Dredging activity did not appear to affect spawning site selection by chinook salmon and steelhead or the distribution of spring-run chinook salmon or summer-run steelhead holding in Canyon Creek. Salmon and steelhead were observed spawning in the vicinity of recent dredge activity, but fish did not spawn on dredge tailing piles. The effects on benthic invertebrate functional feeding groups were variable. Grazers and shredders were significantly more abundant above dredging and gatherers more abundant below. No significant impacts were noted for filterers. Some damage to the habitat occurred. Twelve percent of the dredgers channelized portions of the stream, 20% damaged some riparian habitat and 30% impacted a limited area of spawning gravel. The studies demonstrated that the impacts of suction dredge mining on fish and habitat were moderate at the current level of suction dredge activity. The impacts were seasonal and site specific. The current regulations controlling dredge aperature size and season appear adequate to protect habitat, but careful monitoring of mining activity is advised.

Reviewer's Comments: The author's noted that dredges operating within 0.5 km of another did infrequently result in cumulative impacts upon water quality. Cumulative impacts of 2 or 3 dredges in the same reach of stream did not compound geomorphic impacts upon the channel bottom, but may have contributed to heightened channel instability if stream bank areas were undercut, sluiced or altered (p. 101). This paper also has an extensive discussion of the effects of dredging on aquatic invertebrates.

As a point of interest, a general year-round closure to suction dredging is proposed for Canyon Creek in the amended California regulations (p. III.6).

Kondolf, G.M., G.F. Cada, M.J. Sale, and T. Felando. 1991. Distribution and stability of potential salmonid spawning gravels in steep boulder-bed streams of the eastern Sierra Nevada. Trans. Amer. Fish. Soc. 120: 177-186.

Authors' Abstract: High-gradient boulder-bed streams have been the sites of relatively few studies of salmonid spawning habitat, although they have geomorphic and hydraulic characteristics - and therefore gravel distributions - that are quite different from the more commonly described lower-gradient channels. We documented gravel distribution in seven high-gradient stream reaches in the eastern Sierra Nevada. Gravels occurred only in locations characterized by relatively low shear stress; they formed small pockets in sites of flow divergence and larger deposits upstream of natural hydraulic controls. In 1986 (a wet year), all tracer gravels placed in gravel pockets at nine sites on four streams were completely swept away, and substantial scour, fill, and other channel changes occurred at many sites. In 1987 (a dry year), tracer gravels and the channel cross sections were generally stable. Periodic mobility of gravel may explain why brown trout **Salmo trutta** are more abundant than rainbow trout **Oncorhynchus mykiss** in the study reaches, where high flows occur every May and June during snowmelt. Brown trout are fall spawners, and their fry emerge long before the high snowmelt flows, whereas rainbow trout are spring spawners whose eggs are in the gravel, and thus vulnerable to scour, during snowmelt flows.

Reviewer's Comments: This paper discusses the important role of large boulders and other stable hydraulic controls in creating and maintaining spawning areas for salmonids in high-gradient streams.

Lewis, R. 1962. Results of gold dredge investigation. California Dept. of Fish & Game, Memorandum, Sept. 17, 1962, 7 pp. Cited in: Hassler, Somer & Stern (1986), Cal. Fish & Game (1997).

Reviewer's Comments: A 12.7 cm aperature dredge was operated in Clear Creek, Shasta County, CA, to examine its effects on gravel. Results indicated that dredging could improve the gravel environment for both fish eggs and aquatic insects, especially if the operator mined uniformily in one direction as opposed to a pocket and pile method. Dredge entrained benthos suffered a 7.4% mortality which may have been extreme due to the method of collection.

McLeay, D.J., I.K. Birtwell, G.F. Hartman, and G.L. Ennis. 1987. Responses of Arctic grayling (**Thymallus articus**) to acute and prolonged exposure to Yukon placer mining sediment. Can. J. Fish. Aquat. Sci. 44: 658-673.

Authors' Abstract: Underyearling Arctic grayling (**Thymallus arcticus**) from the Yukon River system were exposed for 4 d to suspensions of fine inorganic ($\leq$250 g/L) and organic ($\leq$50 g/L) sediment and for 6 wk to inorganic sediment ($\leq$1000 mg/L) under laboratory conditions. The test sediments were collected from an active placer mining area near Mayo, Yukon Territory. The exposures evoked sublethal responses but did not cause gill damage. Mortalities (10 and 20%) occurred only in experiments at 5 degrees C with inorganic sediment concentrations $\geq$20 g/L. Six weeks of exposure to sediment concentrations >100 mg/L impaired feeding activity, reduced growth rates, caused downstream displacement, colour changes, and decreased resistance to the reference toxicant pentachlorophenol, but did not impair respiratory capabilities. Stress response (elevated and/or more varied blood sugar levels, depressed leucocrit values) were recorded after short exposure (1-4 d) to organic sediment concentrations as low as 50 mg/L. Inorganic sediment strengths $\geq$10 g/L caused fish to surface. The lethal and sublethal responses of Arctic grayling to pentachlorophenol were similar to those determined for other healthy salmonid fishes.

Reviewer's Comments: This laboratory study indicated that underyearling Arctic grayling could survive short-term exposure to very high levels of suspended inorganic or organic sediment and prolonged (6 week) exposure to lesser inorganic sediment concentrations. However, the study also indicated that concentrations of suspended placer mining sediment as low as 100 mg/L could effect fish growth and feeding responses. The authors also stated that: "These and other studies indicate that a number of sediment characteristics besides concentration in suspension (i.e. particle size, shape, hardness, organic content) can modify their ability to harm salmonid or other fish species" (p. 671).

McLeay, D.J., A.J. Knox, J.C. Malick, I.K. Birtwell, G. Hartman and G.L. Ennis. 1983. Effects on Arctic grayling (**Thymallus arcticus**) of short-term exposure to Yukon placer mining sediments: laboratory and field studies. Can. Tech. Rep. Fish. Aquatic Sci. No. 1171: xvii + 134 pp.

Authors' Abstract: A program of controlled laboratory and in-situ field bioassays was conducted during 1982/83 to examine the acute effects of suspensions of Yukon placer mining sediment on underyearling Arctic grayling (Thymallus arcticus). Wild grayling, captured as swimup fry or young fingerlings, were acclimated to warmwater (15 degrees C) or coldwater (5 degrees C) conditions for 7-12 weeks, and subjected to a range of concentrations of organic sediment (overburden) and/or inorganic sediment (paydirt) suspensions in recirculating test tanks. On two occasions (August and September 1982), grayling fingerlings were captured from central Yukon clearwater streams and held for 4 or 5 days in cages within turbid creekwater (Highet Creek) downstream of placer mining activities, and at a nearby clearwater site (Minto Creek upstream of its junction with Highet Creek).

Laboratory-reared grayling acclimated to 15C survived a 4-day exposure to inorganic sediment suspensions ≤250,000 mg/L, and a 16-day exposure to 50,000 mg/L. These fish also survived acute (4-day) exposure to all strengths of organic sediment examined (≤50,000 mg/L). All fish acclimated to 5C and held in paydirt suspensions ≤10,000 mg/L survived for 4 days, whereas 10-20% mortalities occurred in the higher strengths examined.

Inorganic sediment strengths ≥10,000 mg/L caused fish to surface, a direct response to elevated sediment levels. No other behavioural anomalies were evident. Other signs of fish distress or damage were not observed for any grayling surviving exposure to either sediment type. The gill histology of fish surviving these 4-day exposures was normal.

The tolerance of laboratory-reared grayling to temperature extremes (critical thermal maxima) was not impaired appreciably by either sediment type. Slight but consistent declines in critical thermal maxima were noted for warmwater-acclimated fish held in inorganic or organic sediment strengths ≥500 mg/L and ≥5,000 mg/L, respectively, whereas changes in thermal tolerance were not found for fish acclimated to cold water and held in high strengths of inorganic sediment.

The acute tolerance of warmwater- or coldwater-acclimated fish to hypoxic conditions (oxygen deficiency) in sealed jar bioassays was not impaired by suspended sediment. Tests with overburden suspensions showed a decreased time to death in these bioassays, which was attributed to the sediment's oxygen demand. High concentrations of paydirt increased time to death (decreased

respiratory rate) in sealed jar bioassays for the warmwater-acclimated fish only.

Suspensions of inorganic and organic sediment caused acute stress responses (elevated and/or more varied blood sugar levels, depressed leucocrit levels) for grayling acclimated to either temperature. Responses were noted for sediment strengths as low as 50 mg/L (overburden), although confirmation of threshold effect levels requires further studies. Hematocrit values for these fish were not affected by sediment.

Acute (short-term) effects toward Arctic grayling of the reference toxicant pentachlorophenol were examined in laboratory bioassays. Median lethal concentrations were similar to those found previously with this aquatic contaminant and other species of salmonid fish, and were not affected by acclimation temperatures. The effects on grayling of sublethal strengths of pentachlorophenol noted for temperature tolerance tests, sealed jar bioassays and acute stress bioassays were also similar to those determined before with other juvenile salmonids.

During the August field bioassays, all grayling held in Highet Creek (suspended solids $\leq$100 mg/L) or Minto Creek (suspended solids $\leq$20 mg/L) for 4 days survived, with no overt signs of distress or physical damage. In September, all fish captured from Minto Creek and held in cages within Highet Creek (suspended solids $\leq$1,210 mg/L) or Minto Creek (suspended solids $\leq$34 mg/L) for 5 days also survived. Gill tissues of fish sampled in September from cages at each site showed moderate-to-marked hypertrophy and hyperplasia of lamellar epithelium, together with a proliferative number of gill ectoparasites. No histopathological differences were found between sites. The gill histology of uncaged grayling sampled directly from Minto Creek upstream of Highet Creek was normal, although occasional ectoparasites were observed.

All grayling captured from Mud Creek (a clearwater tributary of Minto Creek) and held for the same 5-day period during September in cages within Minto Creek survived; whereas 16% (5 of 32 fish) of the Mud Creek fish held at this time in Highet Creek, died within 96 h. The cause of these deaths was attributed to an intolerable stress loading imposed by the combined effects of fish capture, transport, confinement and exposure to suspended sediment and temperature fluctuations within Highet Creek.

Although hematocrit values measured for fish caged at either site were similar, mean plasma glucose values for fish held for 4 days within Highet Creek during August were elevated 30% from values for fish caged in Minto Creek at this time. During September, grayling captured from either Minto Creek or Mud Creek and caged in Highet Creek showed a 100% increase in mean plasma glucose levels, relative to values for corresponding groups held in Minto Creek. These differences were thought to be caused by the more stressful water quality conditions (suspended sediment loadings and/or more extreme temperature differences) within Highet Creek, compared with the Minto Creek site.

It was concluded that the short-term exposure of Arctic grayling to sublethal concentrations of suspended inorganic or organic sediment can cause a number of effects including acute stress responses. In light of these findings, the environmental impact of placer mining sediments on the immediate and long-term adaptive capabilities (including feeding and other behavioural responses, disease resistance, growth and chronic well-being) of this sensitive fish species needs to be more fully understood.

Reviewer's Comments: This study indicated that Arctic grayling could survive short-term exposure to very high concentrations of suspended inorganic or organic sediment under controlled laboratory conditions, despite changes in season and temperature (p. 22). In regards to gill damage from exposure to sediment the authors also stated: "The gill histopathologies attributable to exposure of fish to suspended sediment suggest that factors such as particle type (shape, size), sediment concentrations, and duration of fish exposure likely determine whether or not direct damage to gill tissue will occur" (p. 33).

McCleneghan, K. and R.E. Johnson. 1983. Suction Dredge Gold Mining in the Mother Lode Region of California, California Dept. of Fish & Game, Environmental Services Branch Administrative Report 83-1, Sacramento, CA, 16 pp.

(on order through State library)

Mc Neil, W. J. and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish & Wildlife Service, Spec. Sci. Rep. - Fish. No. 469, 15 pp.

Authors' Abstract: The potential of a salmon spawning bed to produce fry is directly related to its permeability. The relationship between the coefficient of permeability and the fraction of bottom materials consisting of fine particles is inverse.

Field methods for measuring size composition of bottom materials in salmon spawning beds are described, and an empirical relationship between the fraction (by volume) of solids less than 0.833 mm minimum dimension and the coefficient of permeability of stream bottom materials is given. Size of bottom materials in streams utilized for spawning by pink salmon (Oncorhynchus gorbuscha) varied considerably. The more productive spawning streams had the more permeable spawning beds. Adult pink salmon caused the removal of finer particles from bottom materials during spawning. The evidence indicates that the fine particles removed consist largely of organic matter. Logging caused the fine sands and silts to accrue to spawning beds. Flooding caused the removal of fine particles from spawning beds.

Reviewer's Comments: The authors found that low permeability occurs where streambed materials contain more than 15 percent by volume of sands and silts passing through an 0.833-mm sieve. Methods described in this report were utilized by the Washington

Dept. of Fisheries in its evaluation of salmon spawning habitat.

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North Amer. J. Fish. Mgmt. 11: 72-82.

Authors' Abstract: Resource managers need to predict effects of pollution episodes on aquatic biota, and suspended sediment is an important variable in considerations of freshwater quality. Despite considerable research, there is little agreement on environmental effects of suspended sediment as a function of concentration and duration of exposure. More than 70 papers on the effects of inorganic suspended sediments on freshwater and marine fish and other organisms were reviewed to compile a data base on such effects. Regression analysis indicates that concentration alone is a relatively poor indicator of suspended sediment effects ($r2 = 0.14$, NS). The product of sediment concentration (mg/L) and duration of exposure (h) is a better indicator of effects ($r2 = 0.64$, $P < 0.01$). An index of pollution intensity (stress index) is calculated by taking the natural logarithm of the product of concentration and duration. The stress index provides a convenient tool for predicting effects for a pollution episode of known intensity. Aquatic biota respond to both the concentration of suspended sediments and duration of exposure, much as they do for other environmental contaminants. Researchers should, therefore, not only report concentration of suspended sediment but also duration of exposure of aquatic biota to suspended sediments.

Reviewer's Comments: Table 2 in this report summarizes published data on exposures to suspended sediment that resulted in lethal responses in salmonid fishes, Table 3 summarizes data on sublethal responses, and Table 4 describes behavioral responses to suspended sediment.

North, A. Phillip. 1993. A Review of the Regulations and Literature Regarding the Environmental Impacts of Suction Gold Dredges. U.S. Environmental Protection Agency, Region 10, Alaska Operations Office.

(On order from State library)

Oregon Water Resources Research Institute. 1995. Gravel disturbance impacts on salmon habitat and stream health. Vol. I: summary report. Oregon State U., Corvallis, 52 pp.

Authors' Abstract: None.

Reviewer's Comments: This report primarily focuses on gravel mining activities but contains some material related to gold dredging. The authors' state: "Mining of the streambed for precious and semi-precious minerals represents activities having a wide range of potential impacts. Recreational gold mining with a pan or small dredge can locally disturb streambeds and associated habitat" (p. 11).

Perkinson, R. Douglas. 1993. Suction Dredging. White paper prepared for the District Ranger, Kootenai National Forest, Libby, MT, May 27, 1993. 11 pp.

Reviewer's Comments: The author notes that operation of a small dredge can potentially affect the stream hydraulics, water quality, foodchain, fishery habitat value, and the fish population. In regards to individual fish species, he expresses particular concern for juvenile bull trout and sculpins which are strongly dependent on the streambed for hiding cover. He also lists 10 best management practices (BMP's) for avoiding or minimizing adverse impacts on streams.

Prokopovich, Nikola P. and Nitzberg, Katherine A. 1982. Placer mining and salmon spawning in American River Basin, California. Bull. Assoc. Eng. Geol. 19 (1): 67-76.

Authors' Abstract: Mining operations, rightfully blamed for many environmental problems, may also have some beneficial environmental impacts. A good example of such an impact appears to be the channel gravel of the American River in California. A petrographic study of gravels in the American River Basin with a hand lens indicates that present channel gravels within the Central Valley section originated mostly from dredge tailings composed of older alluvial deposits which were washed and sorted by mining operations. Hence, present gravels which are considered to provide good spawning conditions are derived from goldmine dredging operations. Similar conditions could be expected in other streams in the Central Valley.

Reviewer's Comments: The authors noted that the identified beneficial effect of mining in this paper "is restricted to the impact of tailings on the salmon spawning habitat" and that they had no intent to compare total values of beneficial and degrading effects of dredging operations.

Simmons, Rodney C. 1984. Effects of placer mining sedimentation on Arctic grayling of interior Alaska. Master's Thesis, Univ. of Alaska, Fairbanks. 75 pp.

Author's Abstract: During summer 1982 and 1983, I assessed the effects of placer mining sedimentation on Arctic grayling, *Thymallus arcticus*, in the headwaters of the Birch Creek and Chatanika River drainages, northeast of Fairbanks, Alaska. In each drainage I compared the differences between two streams near their confluence, one that was undisturbed and one with mining activity upstream. Although many age-0 and adult grayling used unmined streams for summer habitat, I found no grayling in the mined streams except during periods of migration. Apparently, grayling consistently chose clearwater streams for summer residence. Caged fish studies demonstrated that if grayling could not escape from streams carrying mining sediments, they would suffer direct, chronic effects, including gill damage, dietary deficiencies, and slowed maturation. The indirect effects of sedimentation on grayling populations, through loss of summer habitat for feeding and reproduction, are more severe than the direct ones.

Reviewer's Comments: Noted indirect adverse effects on young salmonids included loss of pool regions utilized during daylight hours to avoid predation by larger fishes and birds, and loss of small crevices beneath rocks, also used as hiding places. (These microhabitats could be disturbed or lost through the dredging process, as well as by sedimentation accumulations.) Gill damage from sedimentation occurs as sediment particles pass through the fish's open mouth and across the gill filaments during respiration, thus abrading sensitive gill tissue. Damaged gill tissue responds by secreting a mucus layer for protection, but if the sediment load is high enough or lasts for an extended period of time, the mucus layer will become clogged with sediment particles.

Smith, Osgood R. 1940. Placer mining silt and its relation to salmon and trout on the Pacific Coast. Trans. Amer. Fish. Soc. 69: 225-230. Cited in: Cordone and Kelley (1961).

(on order from State library)

Somer, William L. And Thomas J. Hassler. 1992. Effects of suction-dredge gold mining on benthic invertebrates in a northern California stream. North Amer. J. Fish. Mgmt. 12: 244-252.

Author's Abstract: The effects on benthic invertebrates of mining with two suction dredges were investigated in 1983 by using artificial-substrate samplers in Big East Fork Creek, a tributary to Canyon Creek in northern California. The samplers were placed in Big East Fork Creek above and below the dredge site and in Canyon Creek above and below the confluence of Big East Fork Creek. The effects of dredging on invertebrates varied with taxa and were site-specific at the level of dredging during the study. Total numbers of invertebrates that colonized samplers and their diversity indices did not differ significantly between Big East Fork and Canyon creeks or above and below dredges in either creek. Numbers of invertebrates peaked earlier in samplers below the dredges. In Big East Fork Creek, shredders were more abundant above than below dredges, whereas gatherers were more abundant below dredges. Filterers rapidly colonized samplers below dredges and were later displaced by siltation. Shredders were more abundant above dredges in Big East Fork Creek and less abundant above dredges in Canyon Creek. Sediment and organic matter fractions in samplers were higher below than above the dredges. Habitat variables (water depth and velocity, organic matter, sediment) accounted for 17-75% of the variation observed in abundance of common taxa. In drift samples, numbers of gatherers were higher below than above dredging sites; numbers of other functional feeding groups were similar. Sedimentation rates in Big East Fork Creek were higher below than above the dredging sites. Sedimentation rates in Canyon Creek were similar above and below Big East Fork Creek. High water flows and bed-load movement in winter filled dredge holes and flushed sediment from the study site.

Reviewer's Comments: The authors' stated that "California regulations for dredge aperture size and season appeared adequate to protect fish and habitat at the level of dredging we observed during the study in the Canyon Creek basin. However, dredge activity was low during the study because of high streamflow. During low-flow years, increased activity could disturb spring chinook salmon and summer steelhead that hold in the basin, possibly causing mortality. Further studies on dredging in small streams should be conducted to determine (1) the extent and effects of bank undercutting, bank sluicing, and removal of instream woody debris and riparian vegetation on aquatic organisms and their habitat; (2) the influence of dredging on downstream sedimentation in regulated rivers such as the Trinity River; (3) the cumulative effects of dredging, especially during low-flow years; and (4) the long-term effect on species composition of aquatic insects in heavily dredged areas."

Stern, G.R. 1988. Effects of suction dredge mining on anadromous salmonid habitat in Canyon Creek, Trinity County, California. M.S. Thesis, Humboldt State U., Arcata, CA, 80 pp.

Author's Abstract: The effects of suction dredge gold mining on the stream habitat of chinook salmon (<u>Oncorhynchus tshawytscha</u>), coho salmon (<u>O. kisutch</u>), and steelhead trout (<u>Salmo gairdneri</u>) were investigated at Canyon Creek, Trinity County, California during 1984 and 1985. In 1984, a total of 1136 m2 of streambed was disturbed by 20 suction dredge operations. In 1985, 1075 m2 of streambed were disturbed by 15 dredge operations. Increased levels of stream turbidity and total suspended solids were detected 100 m below active dredges. Gravel and fine sediment deposited 10 to 50 m downstream of dredge outflows aggraded the channel, reduced substrate particle size, and increased substrate embeddedness. Other adverse effects on stream habitat included bank undercutting, bank sluicing, channelization, and riparian vegetation damage. A stream flow of approximately 24 cms during Water Year 1985 (October 1984 through September 1985) effectively obliterated instream mining disturbance from the previous season. At the onset of the 1985 dredge season less than ten percent of the area disturbed by 1984 dredging was visible. Direct observation of anadromous fish indicated that young-of-the-year steelhead abundance and the holding locations of adult spring-run chinook salmon and adult summer-run steelhead were not affected by dredge mining operations. Current California regulations limit suction dredge impacts by requiring permits, seasonal closures, aperture size restrictions, and exclusion from designated areas. Adverse dredging effects could be additionally reduced by establishing procedural guidelines, educating miners to the habitat needs of salmonids, and an increased presence of Department of Fish & Game and U.S. Forest Service personnel.

Reviewer's Comments: The author found that, in 1984, 50 % of the dredgers classified themselves as professional miners; 25 % undercut stream banks; 15 % channelized waters of the creek; and 25 % caused some damage to riparian vegetation. In 1985, 47 % of the dredgers classified themselves as professional miners; 47 % undercut stream banks; 13 % channelized waters of the creek; 13 % damaged the riparian zone; and 7 % sluiced material from upper stream banks. He stated that: "Bank undercutting, bank sluicing, removal of instream woody debris, and riparian vegetation damage during dredging has greater and longer-term adverse effects upon the channel and fish habitat than dredge holes or tailing piles" (p. 71). He also classified dredge tailing piles as undesirable fish spawning substrate because these gravels are deposited on top of the streambed during summer low flows and are easily transported by fall and winter peak streamflows. However, in general he found that adverse effects on anadromous fish habitat in the stream were minimal to moderate, despite a high level of suction dredging (p. 71).

Thomas, Virginia G. 1985. Experimentally determined impacts of a small, suction gold dredge on a Montana stream. North Amer. J. Fish. Mgmt. 5: 480-488.

Author's Abstract: A small suction dredge was operated experimentally on Gold Creek in Missoula County, Montana to determine the effects of dredging on aquatic insects and the bottom habitat. A 10-m section was dredged from bank to bank. Sampling was conducted before dredging and at upstream and downstream stations for control. The experiments were replicated at an upstream site. Significant changes ($P < 0.01$) in aquatic insect abundance were restricted to the area dredged; downstream areas were not affected ($P > 0.05$). Recolonization was substantially complete 1 month after dredging. Intergravel permeability was not significantly changed by dredging ($P > 0.05$). Suspended sediment concentrations during dredging were highly variable. Suspended sediment discharge averaged a maximum of 340 mg/liter at the outflow and returned to background levels within 11 m. Impacts of suction dredging on the bottom fauna appeared to be highly localized. No immediate downstream impacts were recorded other than fine sediment deposition and movement of unstable gravel beds downstream during the next year's peak flows, filling a downstream pool.

Reviewer's Comments: Stated purpose of the study was to assess the impact of one small (6.4 cm or 2.5 in) dredge operated for a relatively short period of time. While the effects seemed to be small, very localized habitat modifications that had a minimal effect on the stream community, the author also noted that "small modifications occurring over time and/or in a number of places within a watershed can often reach levels resulting in major biological and ecological change". She also noted that suction dredges pose a very difficult management problem due to their portability, a 6.4 cm dredge is one of the smallest made, and Gold Creek had a small proportion of fines in the substrate.

Ward, Henry B. 1938. Placer Mining on the Rogue River, Oregon, in its relation to the fish and fishing in that stream. Oregon Dept. of Geology and Mineral Industries. 31 pp.

Author's Abstract: None

Reviewer's Comments: This paper reports results of an ecological survey conducted for Oregon in response to a 1937 controversy concerning placer mining effects on fish life in the Rogue River. A principal objective of the study was to determine potential adverse effects of releasing muddy mine water into the river. Ward concluded that placer mining discharges were not adversely effecting fish in the river and cited evidence that he thought proved silt did not damage fish gills. He also presented results of "Experiments on tolerance of young trout and salmon for suspended sediment in water" conducted by Dr. L.E. Griffin of Reed College, which further substantiated his conclusions.

Ward's conclusions, including his interpretation of the Griffin experiments, were disputed by other investigators, including Smith (1940) and Cordone and Kelley (1961). The latter paper states: "**First**, there has been sufficient work done to establish the fact that sediment is harmful to trout and salmon streams; the only references found to the contrary (Ward 1938a and 1938b) have been adequately critized" (p. 223). Criticism of the Griffin experiment is also presented (p. 193).