A Review of the Regulations and Literature Regarding the Environmental Impacts of Suction Gold Dredges

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Abstract

Few studies have been published to guide resource managers who are attemping to mitigate the impacts associated with suction dredging in streams. This reveiw summarizes and comments on four articles from peer review journals and four agency reports. Studies done to date have been limited to low intensity operations. Both the size of dredge and density on the stream was low in these studies. Impacts to stream fish were severe for early life stages, eggs and sacfry, while free swimming fish were not directly affected. The effect of habitat disturbance has been poorly studied, but may be of short duration under most circumstances. Changes in stream morphometry was typically of short duration lasting until the next high flow. Invertebrates were displaced but recolonized the disturbed site within the same season. Water quality was typically temporaly and spatially restricted to the time and immediate vicinity of the dredge. Thought more persistant problems may occur under some circumstances. There is little data in this area. Areas for future research include impacts in cold climates, long term affects where mining occurs repeatedly, the impacts of dredges with large intake diameter.

Introduction

The deregulation of gold prices in the early 1970's and the following extraordinary rise in the price of gold in the latter part of that decade resulted in a boom in placer gold mining in the western states and Alaska. In some areas, such as the gold bearing regions of California, suction dredging was the predominant method for extracting gold from stream gravels for professional miners as well as hobbyists. To better understand the impacts associated with this particular type of stream disturbance a number of studies have been completed over the last ten years. These studies have investigated the impacts on stream biota as well as physical and chemical changes that result from mining gold from streams with suction dredges.

Suction dredges, most simply, consist of a floating platform on which a pump and sluice box are mounted, with a suction hose that reaches to the bottom of the stream. The pump is used to lift gravels from the stream bottom through the hose onto the sluice box for gold recovery. The intake size of the hose and the horse power of the engine driving the pump determine the volume of gravel that a dredge can potentially move. The amount of material actually moved depends of the skill of the operator and the conditions in which the operator is working. Intake size typically ranges from two inches to eleven inches in diameter. A Few larger dredges, up to 40 cm (16 inches) diameter, are operated in Alaska. Dredges of 11 and 12 inches are not unusual on some streams in Alaska. Dredges less than 4 inches are most common. Dredges with intake nozzle and hose diameters of 6 or less inches are considered recreational by some governmental bodies (Alaska Department of Fish and Game); others (many federal agencies) draw the line at 3 or 4 inches. A recent phone survey of suction dredge permitting offices of the Alaska Department of Fish and Game (ADFG) and the U.S. Bureau of Land Management established an estimate of the number of suction dredges typically mining on all Alaska streams in the late 1980's and early 1990's (Table 1). There may be many more of the smaller classes of dredge that are operated on a casual basis and are not reported to ADFG.

Table 1. Estimated number of dredges permitted for Alaska streams by the Alaska Department of Fish and Game and the U.S. Bureau of Land Management (personal communication).

Number of Dredges	Intake Diameter (inches)
500+	≤4
40 to 60	>4 and <8
30	≥8

Review of the Literature

The effective action of suction dredges is to excavate stream bed sediments, often down to bedrock, by lifting them completely out of the stream and then dropping them back. The rate that materials settle to the stream bottom depends on particle size. Operation of these machines has the potential to damage stream ecosystems. The four studies that I reviewed from journals subject to peer review consistently found that when certain limitations are placed on suction dredge activity the impacts on the stream ecosystem are local and of short duration. These papers investigated the effects on water quality, channel morphology, invertebrate abundance and composition, and on the abundance and distribution of salmonids and sculpins (Griffith and Andrews 1981, Thomas 1985, Harvey 1986, Somer and Hassler 1992). Four additional studies not subject to formal peer review, investigated the impacts of suction dredges on water quality, channel morphology, invertebrates and fish (McCleneghan and Johnson 1983, U.S. Army Corp of Engineers 1985, Hassler et al. 1986, Huber and Blanchet 1992). All of the above studies were limited to small dredges, the largest being 15 cm (6 inches).

Impacts on Fish

Incubating eggs and very young fish are subject to entrainment in a suction dredge if mining occurs during the egg incubation period or when the young fish are still in the gravel. These life stages have been shown to be sensitive to mechanical damage when entrained in a suction dredge (Griffith and Andrews 1981). In a test of sensitivity, un-eyed eggs of cutthroat trout (<u>Oncorhynchus clarki</u>) were run through an operating dredge. One hundred percent of these eggs were killed. Eyed eggs of cutthroat and rainbow trout (<u>Oncorhynchus mykiss</u>) also had severe mortality, 35% and 19% respectively. Similarly, 83% of rainbow trout sacfry were killed after being run through a suction dredge. The cause of death in all of these cases was mechanical damage. The egg membrane was ruptured in the case of both eyed and un-eyed eggs, and yolk sac was detached in sacfry. Free swimming stages of these fish showed no mortality when passed through a running dredge.

While adult fish did not show a sensitivity to entrainment it is unlikely that they would be sucked into a dredge in the first place. They have the ability to avoid entrainment in a suction dredge by moving to a safer location. All of the investigators who examined the impacts of suction dredges on adult fish concluded that this life stage was not acutely affected (Harvey 1986, Hassler et al. 1986, Summer and Hassler 1992). Harvey (1986) found this to be the case for rainbow trout on streams he studied in California. However, he observed that the abundance of riffle sculpin (<u>Cottus gulosus</u>), a bottom dwelling fish, was reduced in dredged stream sections due to a reduction in suitable habitat. Habitat value was decreased by increased sedimentation during mining causing a loss of refuge sites under boulders. Harvey also observed that trout moved between locations to find suitable habitat as dredging progressed. The fish chose were dredge holes as suitable sites. The fish moved between natural pools in the stream and dredge holes, presumably choosing the site that provided the best habitat characteristics. Thomas (1985) noted that during high flows, following dredging, dredged material moved downstream filling a pool. Any habitat value the pool might have provided to fish was lost until suitable flows could again wash the pool clean of dredged sediments. While adult fish are not acutely affected by dredging, locally reduced habitat quality may result in stress to fish until stream habitat recovers.

Aquatic Invertebrates

The existing literature on the effects of suction dredges on aquatic invertebrates consistently concluded that impacts were very local and of relatively short duration. Dredging probably resulted in a displacement of invertebrates rather than elimination of invertebrates from the ecosystem. However, investigators witnessed fish feeding on invertebrates discharged from a dredge (Hassler et al. 1985, Harvey 1986), so obviously some did not settle back to the stream bottom. Entrainment studies by Griffith and Andrews (1981) showed that juvenile life stages of insects were not sensitive to entrainment. One hundred percent of juvenile insects survived entrainment in Griffith and Andrews' tests. The few insects that happened to be emerging from the juvenile stage at the time of the test were all killed by passage through the active dredge. All were noted to have visible injuries. Undoubtedly developing body parts that are adapted for mobility in the much thinner medium of air are subject to greater stress in the relatively dense and turbulent water conveyed by a suction dredge.

Both Thomas (1985) and Harvey (1986) compared the abundance of invertebrates in gravels being mined with those above and below the mined site. Thomas sampled immediately before and after dredging. She found that the abundance of invertebrates was significantly decreased due to dredging. Harvey sampled once per month for a period that included the dredge season. He found mixed results from dredging, but when there was a difference between dredged and control sites the dredged site had a lower abundance of invertebrates. Harvey attributed the general decrease in abundance of invertebrates at mined sites to changes in substrate. He noted that cobbles were more embedded in fine sediments after mining than before.

The difference between Thomas' and Harvey's results may have been due to difference in study design, specifically the timing and location of sampling. Thomas' sampling target was the actual dredged site. Her timing and choice of location were sure to reflect any disturbance that may have occurred, however locally. Whereas, Harvey's sampling target was the stream reach. His timing and location were not juxtaposed to a specific dredging period or specific location. Some samples that Harvey collected may have been from sites that remained undisturbed for a long enough period of time to allow recolonization, or, the site may never have been dredged, as some of the samples showed no difference from control sites while others did show a difference. Given the nature and degree of disturbance, it seems unlikely that a dredged site will have near normal abundance of invertebrates immediately after dredging.

Downstream of the mined site neither the abundance (Thomas 1985, Harvey 1986, Somer and Hassler 1992) nor the measure of diversity of invertebrates appeared to be altered (Harvey 1986, Somer and Hassler 1992). However, Somer and Hassler using artificial substrate baskets, found that trophic structure of the invertebrate community had changed below the dredge. Shredders, those organisms that consume course particulate organic matter such as leaves on the stream bottom, were more abundant in the undisturbed stream bed immediately upstream of the dredge. Filtering invertebrates, those organisms that filter small organic particles out of the flowing water column were more abundant below the dredge outfall where detrital material, after being removed from the substrate, was suspended in the water column.

In apparent contradiction of these results, they noted that organic matter measured during sedimentation sampling was greater down stream of the dredges. While this greater mass could be explained by the displacement of organic material by the dredges to down stream locations, it does not explain the reduced number of shredders below the mined sites.

Probably the most significant concern in regard to the impacts on aquatic invertebrates is the rate at which mined sites recover the invertebrate fauna. The primary mode of recovery of the invertebrate fauna in streams is drift from upstream sites. Rates of recolonization appear to be a function of the length of stream channel that has been void of invertebrates (Minshall 1983). The longer the affected stream section the more time is required for complete recovery. If recolonization is slow the cumulative impacts of suction dredge mining could be significant over a period of seasons. However, in each of the studies on suction dredges that investigated this question, the length of disturbed stream reach was relatively short (on the order of a few tens of meters) and recolonization proved to be rapid. Griffith and Andrews (1981) found that the dredged site was "substantially recolonized" after 38 days. The abundance within orders of invertebrates were the same before and after dredging and "key" taxa were also the same. Harvey (1986) found that recolonization was complete in terms of numbers of insects within 45 days of dredging. Thomas (1985) sampled the site 30 days after dredging and found, again, that colonization was "substantially complete" for most groups. The number of invertebrates colonizing the artificial substrates used by Somer and Hassler (1992) did not increase two weeks after the first sampling. None of these investigators sampled their study site earlier than the reported time of recolonization. Recolonization may have occurred sooner than the time reported. It should also be noted that the artificial substrates used were, as Somer and Hassler noted, biased because they offer a relatively silt free substrate for invertebrates to colonize. They therefore should not be used as an indication of the time for invertebrate recolonization of the stream substrate.

While, these studies indicate relatively rapid recovery of aquatic invertebrates from disturbance associated with suction dredging, the length of times recorded are a substantial part of the growing season in cold climates. The cumulative impact by disturbance of successive stream bottom reaches year after year could deplete the invertebrate fauna in small streams. In many cases these small headwater streams are the preferred summer habitat for larger arctic grayling (<u>Thymallus</u> <u>arcticus</u>). Reduced invertebrate abundance could impact these fish populations.

Water Quality

Most water quality studies of the effects of suction gold dredges on streams focused on turbidity and suspended sediments. These studies, with some exceptions, largely found that water quality is impacted for a distance downstream of the dredge ranging from a few meters to 30 meters (Griffith and Andrews 1981, Thomas 1985, Harvey 1986), after which distance, turbidity and suspended solids return to background levels. In all of these studies, background turbidity is described as low, typically less than 1 NTU (nephelometric turbidity unit). One study found elevated turbidity 123 meters downstream of the dredge (Somer and Hassler 1992). They reported peak turbidity of 15 NTU and measured the distance downstream was to the point where turbidity was no longer visible. It would seem that turbidity in this case was elevated only a few NTU above background for most of the distance surveyed. The authors attributed the elevated turbidity to greater content of silt and clay in the sediments of the mined stream. Five samples taken by a miner and one by Alaska Department of Environmental Conservation personnel on the Bluestone River, in western Alaska, found slightly elevated turbidity 152 meters (500 feet) downstream of a 25.4 cm (10 inch) dredge. Elevated turbidity at this distance from the dredge ranged from less than 1 NTU to 4.5

NTU. It would seem that in most cases water quality recovers rapidly below a dredge as sediments quickly settle to the stream bottom. If a miner encountered silts or clay in the stream substrate water quality problems could be more persistent.

Somer and Hassler (1992) suggested that salmon were not affected by the elevated turbidity and cited studies that found salmonid growth was reduced at 25 NTU but not below. However there is evidence that fish feeding, angling, and fishery management practices can be hampered at turbidity as low as 5 NTU (Lloyd et al. 1987, Scannell 1988). The cumulative effect of several dredges in relatively close proximity (150 meters) could reduce visibility in a stream reach such that fish productivity would be reduced and human activities hampered.

Hassler et al. (1986) stated that dredges operating within 0.5 km of each other resulted in cumulative impacts on water quality. However, Huber and Blanchet (1992) found no evidence of cumulative impacts of mining on water quality in streams of the Chugach National Forest in Alaska. They monitored streams in the Forest over a period of three years and found no noticeable impact to water quality associated with suction dredges.

A study by the U.S. Army Corps of Engineers (1985) on the Arkansas River of Colorado investigated the fate of metals suspended and dissolved to the water column by suction gold dredging. They found that metals largely follow the pattern observed for sediments. High concentrations of metals are found at the dredge outfall but they quickly decrease as the sediments, with which they are bound, settle back to the stream bottom. They found that zinc and lead continued to exceed Colorado water quality standards (0.135 mg/l and 0.008 mg/l respectively) 15 meters (50 ft) below the dredge and that zinc persisted in excess of state water quality standards 30.5 meters (100 ft) below the dredge outfall. While the authors of this study conclude that suction gold dredge operations on the Arkansas River pose "no imminent environmental problem", they also suggest that suction dredging may cause changes in stream chemistry that could cause an increased risk to stream biota from elevated metal concentrations. Deposition of discharged sediments and associated metals may make these substances more available to stream biota.

It should be noted that the Arkansas River flows through an area where tailings from hardrock mining continually leach metals into the stream. So care must be taken when extrapolating the results from this study to other streams. However, an investigation of the water quality associated with mining placer deposits with heavy machinery also found elevated levels of total and dissolved metals in water discharged from mines (Bjerklie and LaPerriere 1985). These studies were conducted in streams where there were no other upstream sources of contamination. A comparison between the impacts associated with these two mining methods is complicated by the difference in scale between the two types of operation. Suction dredges typically move much less material than do placer mining operations that use heavy machinery. Suction dredges may ordinarily only be able to move relatively well sorted material which may not have the fine grained sediments with which metals are often associated. This may not be a limitation for dredges with a large intake nozzle. More study is clearly needed.

Changes in Channel Morphometry and Sedimentation

In the process of moving stream bottom sediments to extract gold, suction dredges change the stream channel morphometry. Channel form, or morphometry, is one element that determines habitat quality for stream organisms. Suction dredging typically creates a hole and pile pattern on the stream bottom as the miner using a dredge, digs to bedrock, piling sediments behind the dredge. Use of a suction dredge can channelize a stream as the miner works the dredge along bedrock, deepening and narrowing a natural channel. Channelization can eliminate fish habitat by physically decreasing the area available to fish, by increasing water velocity, removing cover and by changing riffles and runs into pool type habitat thereby eliminating areas highly productive for invertebrates.

Hassler et al. (1986) reported all of these types of channel change, but they observed that fish move among sites, including dredge holes. Harvey (1986) made similar observations for trout. He attributed a reduced abundance of sculpin in the study reach to loss of suitable habitat due to substrate changes. Hassler et al. (1986) and Thomas (1985) found that changes in channel morphometry were typically relatively short in duration. Changes usually lasted for the season in which dredging occurred. High flows following dredging redistributed disturbed gravels, though some dredge holes persisted for more than one season (Hassler et al. 1986). They also noted that salmon and steelhead spawned on a site that had been mined the year before, suggesting that as long as gravels are redistributed fish spawning may not be affected. As mentioned in the section on the effects on fish, Thomas noted that gravels disturbed by dredging were washed by high flows into a downstream pool, eliminating any fish habitat that may have existed there until sufficiently high flows recreated the pool.

Dredged sediments may not be redistributed until the following spring when the ice melts in locations where mining continues until winter freeze-up, and where winters are very cold. The impacts of this have not been investigated.

Another possible threat to the stream channel and therefore to fish and invertebrate habitat, is using a suction dredge to mine into the stream bank or by hydraulicly mining the bank. Hassler et al. (1986) and McCleneghan and Johnson (1983) surveyed a combined total of 287 suction gold dredges. They reported that approximately 7% of these dredges were being operated in such a way that they were either undercutting the bank or hydraulicly mining the bank. In all cases the activity observed was illegal. The impacts associated with this activity are loss of riparian vegetation and cover, and discharge of silty sediments into the stream. These impacts have not been quantified for suction dredges, but mining the area above the active stream channel creates a condition similar to placer mining with heavy machinery. These impacts involve sedimentation of the stream channel and reduced water quality associated with suspended sediments and elevated levels of metals. Fish and invertebrates have been found to be reduced in numbers where wastewater with a high sediment load is discharged into streams (Bjerklie and LaPerriere 1985, LaPerriere et al. 1985, Wagener and LaPerriere 1985, Van Nieuwnhuyse and LaPerriere 1986).

Existing Regulations

Regulations of Australia, Canada and most of the western gold bearing states of the United States were surveyed for regulation of suction gold dredges. Where suction dredging is permitted, restrictions are primarily directed toward the practices used in operating the dredge as opposed to controlling the discharge (Table 2). Most of the states and provinces surveyed had similar regulations. The primary control measures are size of intake, restriction of the dredge to the active stream channel, and time windows and stream closures to protect fish. Additional requirements varied according to management unit. Canada and Australia had more restrictive regulations than the United States, with no suction dredging allowed in stream channels under most circumstances. In Australia suction gold dredging is not permitted in an active stream channels (personal communication). In Canada suction gold dredging is permit only streams where water quality is already severely degraded (personal communication).

Table 2. Summary of suction gold dredge regulations in gold-bearing states of the western United States, Canada and Australia.

State (authority)	Intake Size Limit	Closures	Restriction to Active Channel?	Plan Required	Spill Prevent	Chemical Recovery Prohibited?	Water Quality Limit	Special Considerations
United States								
Oregon (Dept. of Env. Qual.)	4" in state scenic waterways.	Window for fish egg incubation.	Yes. Special permit required for out-of-stream mining.	No.	Take "care" not to spill. No disposal allowed on site.	Yes.	"Minimize" turbidity, discharge to quiet pool if practical.	Noise Control. Special permit for scenic waterways. Special permit if moving over 50 cubic yards.
Alaska (Dept. of Fish and Game)	<= 6" no need to file APMA if off claim.	Windows for spawning, egg incubation and specific stream closures.	Yes.	If >6" or off claim.	Not specifically mentioned, but covered under other laws.	Not specifically mentioned, but covered under NPDES.	No.	Fish Habitat permit required if in anadromous fish stream or special site.
Arizona (Dept. of Env. Qual.)	No limit.	No closures.	No.	No.	Not specifically mentioned, but covered under other laws.	Not specifically mentioned.	No.	Can only discharge those substances that are already present in the gravels/soil.
South Dakota (Dept. of Env. and Natrl. Resrs.)	"Recreational, hobby, amateur" exempt from regulation. <25,000 tons moved requires "small scale mining permit".	No closures, but "critical areas" may require special consideration.	No.	Thorough reclamation plan required.	Not specifically mentioned, but covered under other laws.	Prohibition designated for "small scale mines".	No.	
Wyoming <u>Guideline only</u> (Dept. of Env. Qual.)	<=3" requires letter of authorization. >3" requires a "dozing permit".	Window for spawning trout.	Yes.	Permit required if over 3".	Spills prohibited.	Not specifically mentioned.	No.	No dredging in silt or clay. No dredging in beaver ponds.

Montana (Dept. of Health and Env. Sci.)	<=4" requires general permit. >4" requires individual permit (conditions the same for both).	Windows for spawning.	Yes.	No.	Refers to Clean Water Act. "Precautionary measures" must be taken.	Yes.	<=5NTU over background 500' down-stream	Monitoring requirements are different between the GP and individual permit.
California (Dept of Fish and Game)	8" limit.	Windows for migration and spawning specific stream closures.	Yes.	Plan required if one wants to deviate from standard conditions.	Not specifically mentioned, but covered under other laws.	Not specifically mentioned.	No.	Special permit required for variance from standard conditions.
Utah (Dept. of Natrl. Resrs)	In the process of developing regulations.							
Idaho	5" limit.	Windows for migration and spawning. Specific stream closures.	Yes.	No.	Spill prevention included in permit conditions.	Yes, but allowed out of channel	Permit conditions for turbidity	Prohibited near campgrounds.
Colorado	No regulations in place.							
Canada Regulations in Canada are determined by federal law, so all provinces and territories have the same regulations.								
Yukon and British Columbia	No instream suction dredging is allowed unless stream is designated as Type 4 (highly impacted by mining) and water quality limits for the stream are not violated.							
Australia								
Victoria, New South Wales, Queensland and Northern Territory	No instream suction dredging is allowed. Large scale operations have are subject to individual environmental review.							

Summary of Impacts and Discussion

All of the studies I reviewed came to the same conclusion: suction gold dredging had localized and short term impacts. Caveats must be taken into account when coming to this conclusion:

1. All of these studies, except one involved small dredges, 6 inches or less. The one study that involved a larger dredge reported only a small amount of data. Five water samples were taken 500 feet below a six inch dredge and one sample was taken 500 feet below an 11 inch dredge.

2. All of the studies were done on dredges that were operating within the restrictions outlined in Table 2 for Idaho (Griffith and Andrews), California (Harvey, Summer and Hassler, Hassler et al., McCleneghan and Johnson,), Montana (Thomas) or Colorado (U.S. Army Corp of Engineers).

These investigators also offered the suggestion that suction dredge mining could have more severe effects if: the dredge intake size was larger than those they studied; the density of dredges was greater; and/or if small tributary or headwater streams were the target of mining, where the stream did not have flows large enough to redistribute disturbed gravels.

It appears clear that the eggs and young stages of fish are susceptible to damage by suction dredging. Periods when dredging is not allowed, that permit dredging only when eggs and juvenile fish are not in the gravel, appear to be effective for protection of these life stages from direct damage by dredges. While adult fish do not appear at risk to direct mortality, loss of stream habitat necessary for the survival of fish populations may pose a more insidious risk. Dredged sites typically appeared to have recovered over the period of the off season, however, there still exists some question about quality of rearing habitat that remains. Carefully thought out permit conditions could prevent loss of stream habitat that would affect fish populations, but they will have to be monitored for a more conclusive finding. Based on the investigations reviewed here, a restriction to mining only in the active stream channel (wetted perimeter at the time of mining) and limits on the density of dredges on a given stream could prevent cumulative or long term loss of habitat.

Aquatic invertebrates appear to be impacted only temporarily at the immediate location of the dredge. As long as the distances over which recolonizing individual must travel is relatively short, recovery of the site is likely to be rapid. If a large section of stream is dredged over a short period of time impacts could be more persistent. Many dredges focused on consecutive sections of a stream could create this type of situation.

Stream morphometry and water quality also appeared to be impacted only temporarily. Most sediments settle out of the water column quickly, but changes in turbidity have been noted up to 152 meters downstream of a dredge. Redistribution of displaced gravel was observed to occur over the high flow season following mining.

Impacts associated with disturbance to streams in very cold climates have not been addressed. Recolonization of disturbed sites by invertebrates may be prolonged if dredging occurs just before freeze up. Generations of invertebrates may be eliminated from a stream reach if the timing of dredging coincides with egg laying in a given invertebrate species and where there is not enough time for recolonization before freeze up. If upstream populations exist from which recolonization can occur then the local populations will likely return but may be depressed for a period into the growing season.

In turn this may affect over wintering and the spring time feeding by fish. Juvenile grayling (*Thymallus arcticus*) are known to over winter in water under the ice cover of streams. Disturbed portions of the stream may not be recolonized sufficiently to produce the invertebrate biomass necessary to sustain these fish through the winter. Fish may also be affected downstream of the site because invertebrate drift may be reduced from upstream disturbances. In the situation where invertebrate populations are depressed during the spring then fish may not have an adequate food base in disturbed and adjacent downstream waters.

Opportunities exist for additional research. Specifically information is limited or lacking in the following areas: 1. the timing and implications of the redistribution of invertebrates, fish and displaced gravels in stream subject to very cold climates; 2. the long term effects on the species and functional feeding group composition of aquatic insects in heavily mined streams; 3. the long term impacts on the growth of fish in areas repeatedly suction dredged; 4. the long term impacts of elevated levels of metals in stream sediments on benthic biota and fish.

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