Position Paper and AFS Policy Statement on Mining and Fossil Fuel Extraction

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EXECUTIVE SUMMARY AND POLICY STATEMENT

Mining (hard-rock, aggregate, deep & surface) and fossil fuel (coal, oil, gas) extraction have the potential to significantly alter aquatic ecosystem structure and function. Adverse impacts on water quality, hydromorphology (physical habitat structure), aquatic biota, and fisheries include elimination and contamination of receiving waters; significantly altered algal, macroinvertebrate, and fish assemblages; impairments of aquatic-dependent wildlife; and climate change. For example, even at low concentrations, mining-associated contaminants, such as copper, impair salmonid olfactory function, thereby increasing predation susceptibility, altering migratory behavior, increasing disease susceptibility, and reducing productivity. Despite predicted compliance of permit conditions, many operating metal mines have violated water quality criteria. Those permit conditions, or applicable regulations, are minimum requirements and typically do not represent best management practices. Also, the applicable regulations rarely account for the cumulative effects of pollution from multiple mines. In the USA, federal law transfers metal wealth from the public to mining companies, and shifts clean-up liability from those companies to taxpayers. The half million abandoned hard-rock mines in the USA could cost $72-240 billion to clean-up; the majority of those costs will fall on taxpayers. In addition, those costs do not include clean-ups of the newer, larger mines being developed in more inhospitable environments, nor the costs of spills, failures and accidents, such as that occurring in the August 2015 Animas River spill. The Mt. Polley disaster, alone, has been estimated to cost at least $500 million to clean up. Because of various economic factors, the numbers of serious and very serious tailings dam failures have increased since 1960. Surface mining temporarily eliminates surface vegetation and permanently changes topography, as with mountain-top-removal-valley-fill (MTRVF) coal mines. Reclaimed surface mines create a leach bed for ions producing toxic conductivity concentrations, whereas altered hydrology produces flashy flows similar to urban areas. Underground mines produce acid mine drainage that can eliminate most aquatic life across extensive regions or alkaline mine drainage that alters ionic balance of freshwater ecosystems. Oil and gas wells and product transport can cause devastating spills in freshwater and marine ecosystems. Hydraulic fracturing to extract residual oil and gas can contaminate groundwater and alter surface water ecosystems, and a wide range of health effects have been documented as a result of exposure to fracking fluids and gases. The casings and grouting of abandoned oil and gas wells should be expected to eventually leak and contaminate surface and ground water In addition, fossil fuel combustion is fundamentally altering the global climate, sea levels, and ocean chemistry. Instream and gravel bar aggregate mining can alter channel morphology and increase bed and bank erosion, which can reduce riparian vegetation and impair downstream aquatic habitats. Catastrophic mine tailings failures have killed hundreds of thousands of fish and hundreds of people, and contaminated tens to thousands of river kilometers. Oil and gas wells are exempted from regulation by several USA laws, despite growing evidence of their detrimental effects on surface and ground water. Mines and wells should only be developed where, after weighing multiple costs, benefits, beneficiaries and liabilities, they are considered the most appropriate use of land and water by affected publics, can be developed in an environmentally responsible manner, benefit workers and affected communities, and are appropriately regulated. Because of substantial widespread adverse effects of mining and wells on aquatic ecosystems and related human communities, fossil fuel combustion effects on global climate, and enormous unfunded reclamation costs for abandoned extraction sites, the American Fisheries Society (AFS) recommends substantive changes in how North American governments conduct environmental assessments and permit, monitor, and regulate mine and fossil fuel development. In particular, AFS recommends that:

1. Following a formal environmental impact assessment, the affected public should be involved in deciding whether a mine or well is the most appropriate use of land and water, particularly relative to the need to preserve ecologically and culturally significant areas.

2. Mine or well development should be environmentally responsible with regulation, treatment, monitoring, and sureties sufficient for protecting the environment in perpetuity.

3. Baseline ecological and environmental research and monitoring should be conducted in areas slated for mining and fossil fuel extraction before, during, and after development so that the effects of those industries can be assessed in an ecologically and statistically rigorous manner, and the resulting data should be made publicly available.

4. This policy and related research should help inform the process of responsible resource development for mining and fossil fuel extraction, and should guide the implementation of the precautionary principle for those sectors.

5. A formal risk assessment of the cumulative atmospheric, aquatic, and oceanic effects of continued fossil fuel extraction and combustion should be conducted and reported to the public.

6. A formal risk assessment of the cumulative aquatic and oceanic effects of continued hard rock and aggregate extraction and metals smelting should be conducted and reported to the public.

ABBREVIATIONS AND ACRONYMS

ACOE: U.S. Army Corps of Engineers
AFS: American Fisheries Society
AMD: Acid mine drainage
CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CWA: Clean Water Act of 1972
EA: Environmental Assessments
EIS: Environmental Impact Statement
IBI: Index of Biotic Integrity
ICOLD: International Commission on Large Dams
IUCN: International Union for the Conservation of Nature
MTRVF: mountain-top-removal-valley-fill mining
NEB: National Energy Board
NRC: National Response Center
OSM: Office of Surface Mining
PAH: Polycyclic Aromatic Hydrocarbons
RCRA: Resource Conservation and Recovery Act
SDWA: Safe Drinking Water Act
SMCRA: Surface Mining Control and Reclamation Act of 1977
TDS: Total Dissolved Solids
TRI: Toxics Release Inventory
USEPA: United State Environmental Protection Agency
USFS: United States Forest Service
WISE: World Information Service on Energy

INTRODUCTION

This policy is written to supersede American Fisheries Society (AFS) Policy Statement #13: Effects of Surface Mining on Aquatic Resources in North America (Starnes and Gasper 1995). That policy was focused on coal strip mining in the eastern USA. The policy developed herein includes hard rock (metals) mining, fossil fuel extraction (including coal, oil, and gas), and aggregate (sand and gravel) mining. Extraction of metals, fossil fuels, and aggregate has been, and remains, an economically and socially important land use in the USA (Figure 1) and elsewhere in North America, and North American mining and drilling companies exploit minerals and fuels globally. However, they can, and do, have substantial negative impacts on surface and ground water, hydromorphology, water quality, and aquatic biota (Daniel et al. 2014; Figure 2), aquatic-dependent wildlife, and human health. Thornton (1996) considered soil pollution by potentially toxic metals and metalloids from abandoned mines an environmental hazard in countries with historic mining industries. Because many North American firms mine and drill globally and because strengthened regulations in North America may only worsen mining and drilling conditions on other continents, we take a global perspective but focus on the USA and North America in this policy. In the issue definition section, we outline major environmental and socioeconomic concerns with mining. In the technical background section, we first discuss metals mining, then fossil fuel extraction and aggregate mining, including the major existing federal law regulating each type of activity. Background materials are followed by suggested AFS policy intended to support mining in a context that: 1) is the most appropriate use of land and water, 2) is environmentally responsible, and 3) is appropriately regulated.

ISSUES DEFINITION

Mining and fossil fuel extraction practices are diverse, and have varied potential to affect aquatic ecosystems and resources. Hard rock mining can eliminate extensive aquatic habitat, degrade water quality and quantity, result in perpetual water treatment needs, and reduce aquatic biodiversity and carrying capacity. Certain types of coal mining can lead to releases of acidic materials into waterways, causing acute and chronic effects. Kim et al. (1982) estimated over 7,000 stream kilometers in the eastern

USA are contaminated by acid drainage from coal mines. Failures of coal slurry ponds worldwide killed hundreds of thousands of fish and hundreds of people (Wise 2011). Mountain-top-removal-valley-fill mining (MTRVF), also used for coal extraction, can increase stream conductivity (USEPA 2009) and eliminate waterways. Oil and gas drilling, extraction, and transport increase the probability of direct water pollution, sometimes resulting in acute fish mortality and persistent chronic toxic effects on aquatic and marine biota (Rice et al. 1996; Upton 2011). Hydraulic fracturing ("fracking") creates the potential for serious persistent contamination of ground water as a result of intentional rock fracturing, introduction of toxic fracking fluids, and the inability to permanently seal abandoned well casings (Weltman-Fahs and Taylor 2013). Nordstrom and Alpers (1999) estimated potentially billions of fish were killed by mining activities in the USA during the past century. Aggregate is the most commonly mined resource. Aggregate mining within floodplains alters channel morphology, increases erosion and turbidity, reduces riparian vegetation, and impairs downstream water and habitat quality, all of which can stress fish and other aquatic assemblages (Hartfield 1993; Meador and Layher 1998).

These risks to aquatic biota are created and compounded, in part, by inadequate protective measures and regulation. There are approximately 500,000 abandoned hard-rock mines in the USA, with associated clean-up costs estimated at up to $72 billion (USEPA 2000). Many of those abandoned mines will require perpetual water treatment to address water quality concerns (USEPA 2004). Although accurate remediation estimates are unavailable, The U.S. Environmental Protection Agency has identified 156 mine sites with $24 billion of potential clean-up costs, of which 30% lacked a viable payer (USEPA 2004). Acid mine drainage (AMD) and mine failures potentially increase those estimates by 1000% (NRC 2005). Most of these expenses, including all of those associated with abandoned mines, will fall to taxpayers because of bonding (security) shortfalls and underfunding of the federal "Superfund Program" for toxic waste site clean-up under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)[1] (Woody et al. 2010; Chambers et al. 2012). For example, Montana taxpayers face estimated reclamation costs of tens to hundreds of millions of dollars (Levit and Kuipers 2000). WISE (2011) listed 85 major mine tailings dam failures between 1960 and 2006, most at operating mines. Existing USA law allows coal mining in potentially acidic coal seams if the coal company agrees to treat the acid to meet water quality standards for as long as necessary. However, this has resulted in a growing liability, with large river systems now depending on perpetual treatment to maintain pH within acceptable limits. In Appalachian coal fields, existing law fails to adequately regulate, with permitted MTRVF eliminating over 2,000 stream km in a 10-year period (USEPA 2000).

TECHNICAL BACKGROUND

Metal Mining & Processing

Physical and Chemical Effects on Aquatic Habitat

Exploration and development of metal mines follows a standard sequence. Helicopters are used, or access roads developed, for exploratory drilling to assess ore geochemistry and deposit size. Note that in many USA states, subsurface rights to minerals, fossil fuels, or aggregate are not owned by the surface land owner —and those subsurface rights have legal primacy. If exploratory drilling indicates the deposit is large and rich enough to be economically viable, shafts or open pits are developed. The subsequent metal mining and processing produce large volumes of waste rock because only about 0.2-0.6% of the ore is recoverable metal (Dudka and Adriano 1997). Major types of disturbance associated with mining include roads; utility lines; pipelines; and housing. The mines themselves produce massive displacement of earth and rock and waste rock piles. Ore processing yields tailings (fine sediments) left over after ore crushing, chemical treatments, concentration, and metal removal. Dumple and heap leach piles (crushed rock) are treated with acid or cyanide, which must be collected and safely stored. Other toxic products include metal dusts, processing chemicals (e.g.,

[1] The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) authorized the Environmental Protection Agency (EPA) to identify sites contaminated with hazardous materials, and to identify and compel those responsible to clean up the sites. Failing identification of a responsible party, USEPA is authorized to use resources in a special trust fund, known as the Superfund, to clean up the site.

xanthates), radionuclides, acid mine drainage (AMD), and tailings ponds (and potential tailings pond failures) (Woody et al. 2010). Water that seeps into mines must be pumped out to facilitate mining, and mines require large amounts of process water—which is a potentially serious threat to aquatic taxa in arid and semi-arid regions. Such changes can contaminate water, air, and soil; alter stream flows and ground water levels; and increase stream sedimentation. In addition, smelting produces atmospheric gaseous and particulate emissions, wastewater, and slag (melted and rehardened rock). All releases of these waste products can be toxic to aquatic biota to varying degrees. When mine water is removed to facilitate mining, the pumping lowers the immediate water table, dewaters adjacent headwaters and hyporheic zones (ground water immediately under stream beds), and introduces mine-contaminated waters elsewhere (Dudka and Adriano 1997; Hancock 2002). As a result, mine contaminants threaten fisheries and aquatic ecosystems, wildlife, agriculture, recreation, tourism, drinking water supplies, human health, and industries that rely on clean water.

AMD is a serious common toxic problem associated with sulfide ore mining (USFS 1993; USEPA 1994; Sherlock et al.1995; Chambers et al. 2012), typically requiring perpetual treatment or isolation (similar to the need to isolate radionuclides). Often headwater receiving streams are extremely acid sensitive (acid neutralizing capacity, ANC < 50 μeq/L) or acidification sensitive (ANC <200 μeq/L; Kaufmann et al. 1991), and great volumes or distances are required to neutralize even small mine flows that may carry 1,000 mg/L or 2,000 mg/L of acid. Acid introduction causes direct harm by decreasing water pH and buffering capacity, and can leach metals (e.g., cadmium, copper, zinc) from mine wastes, causing more environmental damage than the acid alone. Literature and field observations indicate that mining sulfide ores creates a substantial, unquantifiable risk to fisheries (Jennings et al. 2008), both through direct toxicity to fish and toxicity to their prey. The United States Forest Service (USFS) (1993) estimated that 8,000 to 16,000 km of western streams are compromised by AMD (USFS 1993). Iron hydroxide precipitates from AMD can coat streambeds, eliminating benthic macroinvertebrates and fish and degrading spawning substrates.

Flow and channel alterations from mining reduce available fish habitat and biotic diversity at the watershed scale (Frissell 1993; Smith and Jones 2005; Schindler et al. 2010). Increased fine sediment levels alter fish and macroinvertebrate assemblages and affect sensitive species (Crouse et al. 1981; Waters 1995; Birtwell et al. 1999; Berry et al. 2003; Bryce et al. 2008; 2010). A comprehensive study of 25 modern USA mines indicated that 76% exceeded water quality criteria despite 100% predicted compliance (Maest et al. 2005; Kuipers et al. 2006). The cumulative effects of such landscape-scale changes have a negative feedback effect on long-term fish genetic diversity, production, and fisheries (Nehlsen et al. 1991; Frissell 1993; Spence et al. 1996; Gresh et al. 2000; Hilborn et al. 2003; Schindler et al. 2010).

Biological Effects

In many areas, mining-related activities changed trophic status of receiving waters as a result of increased nutrient concentrations (Carpenter et al. 1998). Use of nitrogen-based explosives can release ammonia, nitrite, and nitrate into surface waters. These substances can be directly toxic to fish and/or result in eutrophication. Mining in phosphorus-rich areas (e.g., apatite deposits) can release phosphate, an essential plant nutrient. Such releases can also result in eutrophication or other changes in primary productivity that can adversely affect fish. Freshwater algae are highly sensitive to increased metal concentration that can occur from mining (Hollibaugh et al. 1980; Thomas et al. 1980; French and Evans 1988; Enserink et al. 1991; Balczon and Pratt 1994; Blanck 2002; Nayar et al. 2004; Morin et al. 2008; Lavoie et al. 2012). The increased incidence of deformed diatoms indicate detrimental genetic effects (Lavoie et al. 2012; Morin et al. 2012). However, algal assemblages may persist as sensitive taxa are replaced by tolerant taxa (Blanck 2002; Lavoie et al. 2012; Morin et al. 2012). For example, discharge from metal mines led to increased percentages of very tolerant and polysaprobic (capable of photosynthesis and consumption of dissolved organics) species and reduced percentages of sensitive species of diatoms in large Idaho rivers (Fore and Grafe 2002).

Toxic chemicals from mines have fundamentally negative effects on aquatic macroinvertebrates. Mine chemicals altered the assemblage structure of benthic macroinvertebrates in streams in Idaho (Hoiland et al. 1994; Maret et al. 2003), Colorado (Beltman et al. 1999; Clements et al. 2000; Griffith et al. 2004), Washington (Johnson et al. 1997), and Bolivia, including complete eradication of invertebrates as a result of AMD (Moya et al. 2011). In southeastern Missouri's current Viburnum Trend Mining District, in situ bioassays indicated significantly lower crayfish biomass and survival in mine sites than in reference sites (Allert et al. 2009), and field surveys revealed significantly lower crayfish densities in mine sites than in a reference site (Allert et al. 2008). In the old Tri-State Mining District of southwest Missouri, riffle crayfish densities were significantly lower in mining sites than in reference sites and crayfish metals concentrations exceeded levels toxic to wildlife (Allert et al. 2012). Allert et al. (2013) reported significantly lower crayfish and fish densities and caged crayfish survival in mine sites than in reference sites in the Old Lead Belt of southeastern Missouri. Invertebrate and fish assemblages of western Montana streams were severely altered by copper and gold mines, two of which had been abandoned (Hughes 1985). Twenty-eight kilometers of Middle Creek, downstream of the Formosa Mine, Oregon, have been destroyed by AMD, eliminating once productive salmon spawning habitat and reducing macroinvertebrate abundance by more than 96% (USEPA 2009). In the aforementioned cases, mines were not necessarily operating within relevant regulations, however, negative effects on aquatic macroinvertebrate assemblages have even been observed at cadmium, copper, and zinc concentrations below water quality criteria (Griffith et al. 2004; Buchwalter et al. 2008; Schmidt et al. 2010). Recent studies have shown that freshwater mussels may be among the most sensitive taxa to ammonia and certain metals (such as copper) that are released by metal mines (Besser et al 2009). Possible reasons that the criteria were non-protective include the absence of sensitive species or life stages, less-than-life-cycle exposures, failure to assess behaviors and species interactions, and the absence of dietary exposures from standard toxicity tests (USEPA 2010).

Fish assemblages also can be altered directly and indirectly by mining activities. In the early 1990s, zinc levels in streams draining the Red Dog Mine, Alaska, killed fish for 40 km in the Wulik River and few fish remain in Ikalukrok Creek (Ott 2004). Fish assemblages also were altered by AMD and metals from mines in Colorado (McCormick et al. 1994), Idaho (Maret and MacCoy 2002), and Quebec (Dube et al. 2005). Farag et al. (2003) reported that Boulder River tributaries in Montana were devoid of all fish near abandoned mine sources of AMD. Significantly fewer Chum Salmon *Oncorhynchus keta* fry were observed in waters located downstream of an abandoned copper mine in British Columbia (pH <6 and dissolved copper >1 mg/L) than in the reference area. Caged Chinook Salmon *O. tshawytscha* smolts exposed to this water were all dead within two days (Barry et al. 2000). The Ok Tedi mine, Papua New Guinea, released waste rock, tailings, and an average of 16-20 µg/L dissolved copper to the upper Fly River, resulting in fish biomass reductions of 65% to 96% in the upper and middle river reaches and decimation of fish species in the upper river (Swales et al. 2000). Castro (unpublished data, Federal University of Lavras, Minas Gerais) reported significantly lower fish Index of Biotic Integrity (IBI) scores in Brazilian streams receiving iron mine effluent than in a neighboring reference stream. Esselman et al. (in Chambers et al. 2012) reported <15% intolerant fish in an assemblage, once catchment mine density exceeded one mine per 5 km^2.

Low copper concentrations can have far-reaching behavioral and pathological effects on fish, especially in low ionic strength waters. Dilute copper concentrations (5 µg/L) impair salmonid olfactory function (Giattina et al. 1982; Hansen et al. 1999a; 1999b; Baldwin et al. 2003; Sandahl et al. 2006; Hecht et al. 2007; McIntyre et al. 2008), making them more susceptible to predation (McIntyre et al. 2012). In laboratory studies, Hansen et al. (1999c) found that Rainbow Trout *O. mykiss* and Brown Trout *Salmo trutta* actively avoided metal concentrations characteristic of those in the Clark Fork River, Montana. Similarly, Woodward et al. (1997) reported that Cutthroat Trout *O. clarkii* avoided metal concentrations simulating those found in the Coeur d'Alene River basin, Idaho. The migratory behavior of Atlantic Salmon *S. salar* was altered by releases from a New Brunswick copper-zinc mine (Elton 1974). DeCicco (1990) found that Dolly Varden *Salvelinus malma* migrations were altered by an Alaskan copper mine and Goldstein et al. (1999) observed altered Chinook Salmon migration associated with Idaho metal mines. Wang et al. (2014) reported adverse effects on the survival and growth of White Sturgeon *Acipenser transmontanus* at copper concentrations below ambient water quality criteria and that sturgeon were substantially more sensitive than rainbow trout.

Toxic metals also bioaccumulate in fish tissues (Swales et al. 1998; Peterson et al. 2007; Harper 2009) causing increased disease susceptibility (Hetrick et al. 1979; Baker et al. 1983; Arkoosh et al. 1998a; 1998b), reduced growth and population size (Mebane and Arthaud 2010), or death (National Academy of Sciences 1999). Hansen et al. (2002) observed increased mortality in Bull Trout *S. confluentus* juveniles at copper concentrations of 179 µg/L. In Mexico, tailings frequently are deposited in creeks and accumulate in areas close to mines (Soto-Jiménez et al. 2001). Several species of commercially exploited fish and crustaceans have been found to contain elevated concentrations of cadmium, chromium, mercury, and lead as a result of exposure to mining waste (Ruelas-Inzunza et al. 2011). Thus there are potential impacts not only to the fish and crustacean populations, but also to human consumers of those aquatic products.

Mining Districts

Mining districts are especially problematic to rehabilitate because they are defined by the presence of multiple mines, covarying natural and anthropogenic disturbances, and tangled liabilities. For example, the Coeur d'Alene mining Area (CDA), Idaho, covers over 180 km^2 with millions of tons of metals-contaminated sediment and soils. The area was mined by American Smelting and Refining Company (ASARCO), a subsidiary of ASARCO Incorporated, a subsidiary of Americas Mining Corporation, a subsidiary of Grupo Mexico. The CDA was listed as a Superfund site in 1983, and USEPA sought $2.3 billion for clean-up costs but only received a $436 million bankruptcy settlement for the Bunker Hill complex (multiple sites and sources) in 2009. Partly because of the funding shortfall, NRC (2005) reported that the USEPA clean-up 1) failed to adequately address metal contamination of groundwater (the major source of surface water contamination; 2) failed to rehabilitate physical habitat structure (precluding fishery recovery); 3) failed to locate adequate repositories for contaminated sediments and soil; 4) developed treatment models based on mean flows (despite flood flows that periodically re-contaminate reclaimed areas); and 5) inadequately assessed rehabilitation effectiveness on fish and macroinvertebrate assemblage structure (NRC 2005).

Another mining district, Clark Fork Basin (CFB), Montana, has impaired 186 km of the Clark Fork River. The floodplain contains nearly 4 million cubic meters of contaminated tailings, covering an area of over 5 km^2, and produced the largest Superfund site in the USA. It was deemed technically impossible to treat all contaminated ground water in the area, some of which contaminates surface waters. The mine pit (160 m deep, 1000 m wide) contains about 900 million L^3 of AMD and metals and continues to fill with ground and surface water seepage, requiring perpetual water treatment via a 30 million liters per day plant costing $75 million to build and $10 million per year to maintain and operate (NRC 2005; Chambers et al. 2012). Treatment of the ground water at the city of Butte requires a $20 million plant and annual operating and maintenance costs of $500,000. Capping the tailings pile and transporting the dusts are additional costs. The USEPA sued the mining company, Atlantic Richfield Company (ARCO), a subsidiary of British Petroleum, for $680 million for water treatment, culminating in a $187 million settlement for Clark Fork River cleanup after 5 years of litigation.

Mine Spills

Fish kills resulting from hard rock mine spills have occurred worldwide. ICOLD (2001) listed 72 tailings dam failures in the U.S. and 11 in Canada between 1960 and 2000. WISE (2011) listed 33 major mine tailings dam failures between 1960 and 2006 in the U.S. and USEPA (1995) described 66 such incidents. Davies (2002) considered these as underestimates because of the number of unreported failures, and calculated an annual failure rate of 0.06-0.1%. Because of various economic factors, the numbers of serious and very serious tailings dam failures have increased markedly since 1960 (Bowker and Chambers 2015). Nordstrom et al. (1977) reported that since 1963, California's Sacramento River experienced more than 20 fish kills as a result of AMD spills; in a 1967 spill, at least 47,000 fish died. In 1989, 5,000 salmonids died in Montana's Clark Fork River when AMD and copper tailings were flushed into the river during a thunderstorm (Munshower et al. 1997). The Brewer Mine, South Carolina, tailings dam failed in 1990, spilling 38 million liters of sodium cyanide solution and killing all fish in the Lynches River for 80 km (USEPA 2005). AMD from a small British Columbia copper mine destroyed 29 km of the Tsolum River, eliminating a once productive salmon river (BCME 2011). In 1998, a tailings dam failure at the Los Frailes Mine, Spain, released over 6 million m^3 of acidic tailings that traveled 40 km and covered an area of 2.6 million ha (ICOLD 2001). A 1985 failure of two tailings dams in Italy released 190,000 m^3 of tailings, which traveled to a village 4 km downriver in 6 minutes killing 269 people (ICOLD 2001). The tailings dam at the Aurul S.A. Mine, Romania, failed in 2000, releasing 100,000 m^3 of cyanide and heavy metal contaminated water into the Somes, Tisza, and Danube Rivers, eventually reaching the Black Sea and destroying aquatic biota for 1,900 km (ICOLD 2001). In 2014, tailings dams failed at Imperial Metals Mount Polley Mine in British Columbia and Grupo Mexico's Buena Vista del Cobre Mine in Sonora. The Mount Polley spill released 15 million cubic meters of water and tailings into Hazeltine Creek changing its 2-m wide channel into a 50-m wide toxic mudflat, and eventually contaminating part of once-pristine Quesnel Lake. Rehabilitation costs are estimated at $600 million; an amount Imperial Metals cannot afford. The Buena Vista del Cobre spill sent 40 thousand cubic meters of copper sulfate and sulfuric acid into the Rio Sonora causing over $130 million in damages.

Federal Laws and Regulations for Hard Rock Mining

The primary USA law governing hard rock mining, the General Mining Law of 1872, makes mining a priority use on most federal lands in the Western USA, and was originally intended to encourage economic growth. Despite deleterious impacts on other resources, applications to mine public lands usually cannot be denied unless there is clear potential for the degradation of nationally important waters. Even if millions of dollars worth of minerals are extracted from federal lands, no royalties are required in return (Bakken 2008), resulting in an estimated annual loss of $160 million to the USA government (Pew Foundation 2009). The law remains in effect despite serious environmental and economic issues caused by hard rock mining practices (Woody et al. 2010). For example, the law makes mining the *de facto* best use of federal lands, unless otherwise designated by Congress. The 1872 law shifts mineral wealth from the USA public to mining companies, whereas the exploitation of all other natural resources on federal land (e.g. oil and gas, aggregates, coal, timber, and even grazing for livestock) returns a royalty to the federal government.

Before passage of the Clean Water Act in 1972, mining companies frequently dumped their tailings in the nearest lake or river, often with catastrophic consequences for those water bodies, for fish, and for human health. The Clean Water Act effectively prohibited these practices from 1972 until 2002. However, as the result of a regulatory change in May, 2002, mine tailings and overburden were added to the list of material that could be deposited as fill material into waters of the USA under a U.S. Army Corps of Engineers (ACOE) §404 permit. See 40 CFR 232.2; 30 CFR 232.2(f). Previously fill was defined as any material used for the primary purpose of replacing an aquatic area with dry land or of changing the bottom elevation of a water body. The 2002 change allows dumping of mine waste into any lake, river, stream, or the ocean, at the discretion of the ACOE. So far this practice has been allowed at only one site, the Kensington mine is Alaska, but the practice is potentially applicable anywhere in the USA.

In Canada, the deposit of tailings and other mining wastes into fish-bearing water bodies is regulated by the Metal Mining Effluent Regulations (MMER), which were developed under the Fisheries Act. If a natural fish-bearing water body will be used to store mining waste, an equivalent amount of fish habitat must be created elsewhere as compensation. For impacts from mines other than tailings storage, the Fisheries Act applies. The Fisheries Act was revised in 2012, with the following prohibitions: "No person shall carry on any work, undertaking or activity that results in serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or to fish that support such a fishery." In the Fisheries Act, "serious harm to fish" is defined as "the death of fish or any permanent alteration to, or destruction of, fish habitat" (Section 2). If a mining project will result in serious harm to fish, the proponents must apply for an authorization under section 35 (2) to proceed with the project, and must state how they will mitigate and offset the serious harm to fish that are part of, or support, a commercial, recreational or Aboriginal fishery. While such regulations may appear to be adequate, they apply only to waters that support a fishery. Therefore, waters that are not frequented by fish or that do not support a fishery are not covered under the Act and will not be protected. These waters were covered by the Fisheries Act prior to the 2012 revision (Post and Hutchings 2013). However, under Schedule Two, even lakes with valuable fisheries can be deemed tailings impoundment areas; such has occurred with Sandy Pond, Labrador/Newfoundland, and 24 other lakes have been classified as tailings impoundment areas (Nelson 2014).

In Mexico, there is no explicit mining law; however, the Norma Oficial Mexicana Nom. 001 Ecol of 1996 (Mexican Official Norm Number 001 Ecology) extends to mining. This law specifies maximum permissible limits of pollutants that can be incorporated into federal waters (lakes, rivers, reservoirs, coastal lagoons, swamps, creeks, marshes, flood plains, sea, etc.) and national assets (forests, deserts, lands in general). If a water body must be used to store waste of any kind, the entity must contact the Comisión Nacional del Agua (National Commission for Water Bodies) to assess the case and to establish conditions under which the activity could be permitted. The regulations do not consider fishing activity per se, but establish that all water bodies must be preserved. Although this regulation seems to be adequate, it is rarely followed or enforced.

In summary, the present legal frameworks in the USA Canada, and Mexico allow the elimination of fisheries habitat by the direct disposal of mine waste. Because there are economic incentives for mines to use lakes instead of constructed waste impoundments, proposals to use natural water bodies for mine waste disposal are expected to continue (Chambers et al. 2008).

Fossil Fuel Extraction

Physical and Chemical Effects on Aquatic Habitat

Coal mining follows a predictable sequence of events, whether it involves shaft mines or surface mines. Roads or railroads are built to access areas of known deposits, and to move the coal to processing facilities and distribution centers. Sometimes pipelines are used for transporting coal slurry. Typically these activities are conducted in or around water, and can negatively affect fish and fish habitat with different degrees of severity. Mountain-top-removal-valley-fill (MTRVF) mining involves removing all or part of a mountaintop to mine and then disposing of that overburden into small valleys near the mine. This process leads to: (1) the permanent loss of springs and headwater streams, (2) persistently altered water chemistry downstream, (3) chemical concentrations that are acutely lethal to test organisms, and (4) significantly degraded macroinvertebrate and fish assemblages (Wiley et al. 2001; USEPA 2009).

Although the effects are at a much smaller scale, surface mining temporarily eliminates surface vegetation and permanently changes topography in a manner similar to MTRVF mining. It also permanently and drastically alters soil and subsurface geologic structure and disrupts surface and subsurface hydrologic regimes thereby altering stream processes (Fritz et al. 2010). Altered patterns and rhythms of water delivery can be expected, as well as changes in water quality. The backfilled, reclaimed surface mine site constitutes a manmade, porous geological recharge area, where water percolates through the fill to emerge as a seep or a spring. The sulphate concentrations (>250 µeq/L; Kaufmann et al. 1991) and conductivities (>1000 µS/cm; Pond et al. 2008) of these leach waters can be an order of magnitude above background (Green et al. 2000; Pond et al. 2008; USEPA 2009b), and they may flow even when drought conditions dry up natural waters. Messinger and Paybins (2003) and Wiley and Brogan (2003) found that peak stream discharges after intense rains were markedly greater downstream of valley fills than in un-mined watersheds. USEPA (2005) and Ferrari et al. (2009) found that MTRVF storm flows were similar to those of urban areas with large areas of impervious surface; infiltration rates in reclaimed sites were 1-2 orders of magnitude less than those of the original forest (Negley and Eshleman 2006). Green et al. (2000) and Wiley et al. (2001) reported elevated percentages of sands and fines in stream sites downstream from MTRVF compared to streams draining unmined areas.

The surface subsidence following longwall mining (where multiple parallel shafts are drilled into mountainsides) can dewater stream reaches and divert flows into different surface stream channels that are not adjusted to such increased flows. Many longwall mines in the eastern USA produce alkaline mine drainage and greatly increase chlorides and dissolved salts in the streams receiving mine effluent.

Fossil fuel combustion is fundamentally altering the global climate, sea levels, and ocean chemistry (Orr et al. 2005; Dai 2013), as well as fish distributions (Bigford et al. 2010; Comte and Grenouillet 2013). In addition to climate change impacts, fossil fuel combustion and atmospheric transport are associated with elevated and widespread levels of mercury in fish tissue at concentrations of concern for both human and non-human piscivores. Stoddard et al. (2005) found that elevated levels of fish tissue mercury were associated with poor IBI scores throughout the western USA. Peterson et al. (2007) reported that mercury in piscivorous fish exceeded mammalian piscivore and human health consumption criteria in 93% and 57%, respectively, of the length of western USA rivers. Landers et al. (2008) determined that fish in 86% and 42% of the lakes in 14 western USA national parks exceeded mammalian piscivore and human health consumption criteria, respectively. Eagles-Smith et al. (2014) found tissue mercury levels of concern for avian and human piscivores in 35% and 68%, respectively, of fish sampled from 21 western USA national parks from California to Alaska.

Biological Effects

High selenium and ion concentrations (HCO_3−, Ca^{2+}, $SO_4$2−, Mg2+, K+, Na+, Cl−), especially as measured by conductivity below MTRVF sites, produce strong negative correlations with macroinvertebrate metrics (Stauffer and Ferreri 2002; Palace et al. 2004; Pond et al. 2008; USEPA 2009; 2010). Coal mining via MTRVF had subtle to extreme effects on stream macroinvertebrate assemblages, including the loss of most or all Ephemeroptera (mayflies), depending on the degree of mining disturbance in Kentucky (Howard et al. 2001), and West Virginia streams (USEPA 2005; Merricks et al. 2007; Pond et al. 2008; Pond 2010). AMD contaminated streams often contain elevated heavy metals, and can be devoid of most life (Cooper and Wagner 1973; Kimmel 1983). Warner (1971) and Menendez (1978) found fewer macroinvertebrate taxa and individuals in West Virginia streams polluted by AMD from coal mines than in reference streams. All benthic macroinvertebrates were eliminated by AMD for 10 km below a coal mine on a Virginia stream (Hoehn and Sizemore 1977). Soucek et al. (2000) reported significant decreases in Ephemeroptera-Plecoptera-Trichoptera (mayfly, stonefly, caddis fly) taxa richness and percent Ephemeroptera individuals in a Virginia stream receiving continuous AMD from coal mines. Using water from Ohio surface and underground coal mines and the mayfly *Isonychia bicolor* (rather than standard toxicity test organisms) in 7-day toxicity tests, Kennedy et al. (2004) found that mayfly survival significantly decreased relative to controls at conductivities of 1,562, 966, and 987 µS/cm. Pond et al. (2008) recorded an average of 10 µg/L selenium at stream sites below valley fills, which exceed the 5 µg/L chronic criterion. In streams draining Canadian coal mines, DeBruyn and Chapman (2007) found >50% abundance declines in some invertebrate taxa at selenium concentrations of 5–100 µg/L.

Despite standard MTRVF reclamation practices (slope stabilization, flood control, rehabilitation of soils/vegetation), the deleterious effects on aquatic biota of dissolved ions associated with MTMVF effluent remain. In addition, the thousands of kilometers of buried headwater streams have not been mitigated (Palmer et al. 2010). Consequently, USEPA (2010) set a conductivity criterion of 300 µS/cm, which was intended to prevent extirpation of 95% of the aquatic macroinvertebrate genera in the central Appalachians. The effectiveness of that criterion has not yet been fully assessed.

Streams contaminated with AMD have low fish taxa richness and abundance (Kimmel 1983). Cooper and Wagner (1973) reported fish severely affected at pH 4.5 to 5.5; 68 species were found only at pH levels greater than 6.4. Baldigo and Lawrence (2000) observed reduced fish species richness and densities at a highly acidified site in the Neversink River Basin of New York. Kaeser and Sharpe (2001) found that Slimy Sculpin *Cottus cognatus* mortality increased, and normal spring spawning did not occur in a Pennsylvania stream receiving episodically acidified spring flows. Holm et al. (2003) found increased incidences of edema and spinal deformities in Rainbow Trout fry and increased frequency of craniofacial deformities in Brook Trout *S. fontinalis* fry at sites downstream of a coal mine with elevated selenium concentrations. Palace et al. (2004) found that Bull Trout captured downstream from the same area had selenium concentrations that would be expected to impair recruitment. Total and benthic fish species richness were reduced by MTRVF in Kentucky and West Virginia streams (USEPA 2005). In the upper Kentucky River watershed, Kentucky, Hopkins and Roush (2013) found a negative association between MTRVF mean patch size and the occurrence probability for four of the six taxa they evaluated. Hitt and Chambers (2014) reported that compared to reference sites, West Virginia MTRVF sites had reduced fish functional and taxonomic diversity, richness, abundance, and biomass, and increased abundance of tolerant species. As with macroinvertebrates, high conductivities can be directly or indirectly toxic to fish. For example, a longwall mine on the Pennsylvania-West Virginia border altered Dunkard Creek total dissolved solids (TDS) producing a golden algae bloom that killed fish, salamanders, mussels, and other macroinvertebrates for 25 miles (Reynolds 2009).

Fish kills from coal mine infrastructure failures occur worldwide and not infrequently. Recently, three such spills occurred: 40,000 L of coal processing chemical spilled into Elk River, West Virginia from a Freedom Industries plant; 400,000 L of coal slurry spilled into Fields Creek, West Virginia from a Patriot Coal facility; and 100 million L of coal ash contaminated water spilled into the Dan River, North Carolina from a Duke Energy plant. An October 2013 Sherritt International spill released 1 million m^3 of coal slurry into Apetuwon Creek, a tributary of the Athabasca River, and home to native Bull Trout and Rainbow Trout (Klinkenberg and Pratt 2013). In 2008, the Tennessee Valley Authority's coal ash pond spilled over one billion gallons of fly ash contaminating the Emory River and killing hundreds of fish (Sourcewatch 2010). The Black Mesa, Arizona, coal slurry pipeline ruptured seven times between 1997 and 1999 and eight times in 2001–2002, including a 500-ton spill covering Willow Creek with 20 cm of sludge (Ghioto 2002). In 2005, over 1 million liters of coal sludge spilled from the Century Mine, Ohio, pipeline, killing most fish in Captina Creek (OEPA 2010). In 2000, the Martin County Coal Corporation's tailings dam failed, releasing over 100,000 m^3 of coal waste, turning 120 km of rivers and streams black, killing at least 395,000 fish, and forcing towns along the Tug River, Kentucky to turn off their drinking water intakes (WISE 2008). In 1972, a coal waste impoundment above Buffalo Creek, West Virginia, failed, killing 125 people, destroying 500 homes, and degrading water quality (ASDO No Date).

Federal Laws and Regulations for Fossil Fuel Extraction

The Surface Mining Control and Reclamation Act of 1977 (SMCRA, 25 U.S.C. § 1201), which is administered by the Office of Surface Mining (OSM), governs coal mining in the USA. In addition, the Clean Water Act (CWA), administered by the USEPA and the ACOE, regulates fill or pollutants that enter surface and ground waters. SMCRA sets national standards regulating surface coal mining and exploration activities and regulates surface impacts of underground mining and required land reclamation. The Act's goals are to ensure prompt and adequate reclamation of coal-mined lands and to provide a means of prohibiting surface mining where it would cause irreparable damage to the environment. The CWA sets national standards for water quality with the objective of restoring the physical, chemical and biological integrity of the Nation's waters. However, each state may acquire primacy and administer its own programs, which must be no less stringent in environmental protection than the federal programs. States with reclamation plans approved by the OSM also may administer their own reclamation funds to ameliorate the health, safety, and environmental impacts from coal mines abandoned prior to 1977.

Most mining in the eastern USA occurs on private lands and is regulated by state and local laws. In the western USA, where there is more public land, much mining is administered by federal agencies. The Clean Water Act Section 404 directs the USEPA to set environmental standards for mining permits issued by the ACOE, and, gives the USEPA the right to veto a permit. In 2011, the USEPA used this authority and vetoed a permit for a mountain top mine that would bury >11 km of streams and degrade water quality further downstream, citing "unacceptable adverse impacts to wildlife and fishery resources" (Copeland 2013). That veto was overturned in a federal district court but supported in a federal appeals court; similarly, various bills in the U.S. Congress have sought recently to either strengthen or weaken USEPA regulation of MTRVF.

As with metal mining in Canada, the deposit of coal mining wastes into fish-bearing water bodies is regulated under the Fisheries Act Section 2 and Section 35 (2) and apply only to waters that support a fishery; those that are not will not be protected.

Similarly in Mexico, the Norma Oficial Mexicana Nom. 001 Ecol of 1996 (Mexican Official Norm Number 001 Ecology) extends to coal mining. The regulations do not consider fishing activity per se, and the law is rarely followed or enforced.

Oil and Gas Exploration and Development

Physical and Chemical Effects on Aquatic Habitat

Traditional oil and gas exploration and development generally follows a predictable sequence of events. First, roads or trails are built to access the exploration area in order to conduct the seismic surveys that are required to locate the oil and gas reserves. After a reserve is located, an exploration well is drilled to evaluate the quality and quantity of the oil or gas deposit. If the oil or gas deposit is large enough to be economically viable, then production wells are drilled (INAC 2007). Pipelines are then constructed to move the hydrocarbons to processing facilities and distribution centers (Bott 1999; Schnoor 2013). Because these activities are often conducted in or around water, they have the potential to negatively affect fish and fish habitat with different degrees of severity. One of the main stressors resulting from oil and gas development activities is sedimentation. The effects of suspended sediment on fish include clogging and abrasion of gills (Goldes et al. 1988; Reynolds et al. 1989), impaired feeding and growth (Sigler et al. 1984; McLeay1984), altered blood chemistry (Servizi and Martens 1987), reduced resistance to disease (Singleton 1985), altered territorial and foraging behavior (Berg and Northcote 1985), and decreased survival and/or reproduction (CCME 2002). Suspended sediments can indirectly affect fish by reducing plant photosynthesis and primary productivity (due to decreased light penetration; Robertson et al. 2006). Excess fine sediments on streambeds smother some benthic invertebrates (Singleton 1985) and reduce macroinvertebrate assemblage condition (Bryce et al. 2010), leading to a reduced food supply for fish.

There are several other effects of oil and gas development on fish and fish habitat. One is the restriction of fish passage by building roads and stream crossings. If fish cannot reach their normal spawning grounds, they may spawn in inappropriate areas, re-absorb their eggs (Auer 1996), or suffer from increased predation while waiting to reach their spawning grounds (Brown et al. 2003). In addition, instantaneous pressure changes (IPCs) caused by seismic surveys can kill fish or injure internal organs, such as the swimbladder, liver, kidney, and pancreas (Govoni et al. 2003). Furthermore, equipment leaks, pipeline ruptures, and fuel truck spills can all result in hydrocarbons contaminating the environment. A substantial contribution to climate change results from methane leakage in areas of coal, gas, and coalbed methane production and processing. For example, approximately 10% of total USA methane emissions occurs in a methane cloud over the Four Corners region of the Southwest USA (Kort et al. 2014).

Horizontal drilling with hydraulic fracturing ("fracking") is increasingly employed to extract oil and gas from rock throughout the USA. Major gas deposits occur and are being fracked in the northern Appalachians, North Dakota, and in a wide band from the western Gulf of Mexico Coast to Wyoming. As with the injection of hot water into the Alberta tar sands, this technique for extracting oil and gas in the USA is relatively new, under-studied, and to date only nominally regulated in the USA. Fracking for oil and gas has resulted in instances of increased stream sediment loads, reduced water quality from toxic chemicals and salts, increased water temperatures, increased migration barriers at road-stream crossings, and reduced stream flows (Entrekin et al. 2011; Weltman-Fahs and Taylor 2013). Fracking wells and oil sands mines use considerable amounts of surface or ground water (Weltman-Fahs and Taylor 2013). Water recycling is practiced but inevitably some becomes unusable and must be stored in tailings ponds or injected underground, both of which increase the risk of surface and ground water contamination. Shipment of oil and gas by pipeline, barge, tanker, and truck mean increased probability of small, large, and catastrophic spills. For example, recent pipeline failures (e.g., Kalamazoo River, July 2010, 3,400,000 L; Yellowstone River, July 2011, 250,000 L and January 2015, 200,000 L) have called attention to the network of oil pipelines buried under rivers and streams across the USA (AP 2012). Hazards from gas pipelines are evidenced by the explosion of a Pacific Gas and Electric (PG&E) pipeline in San Bruno, California. In that case, a federal grand jury charged PG&E with lying to National Transportation Safety Board investigators regarding its pipeline testing, maintenance, and safety procedures, and failing to act on threats identified by its own inspectors (http://www.cbsnews.com/news/pacific-gas-electric-accused-of-lying-over-fatal-2010-gas-explosion/; Accessed 23 March 2015). Because of the enormous pressures of underground oil and gas deposits, 'blow-outs' are part of the industry. As with abandoned metal and coal mines, the casings of abandoned oil and gas wells are likely to eventually leak and contaminate surface and ground water (Dusseault et al. 2000). In parts of the Appalachians, hydraulic fracturing for gas coincides with longwall coal mining, increasing the risk of casing failure as the longwall advances through the gas field (Soraghan 2011).

Biological Effects

Small oil-spills occur frequently (García-Cuellar et al. 2004). When early life stages of fish have been exposed to oil, and the polycyclic aromatic hydrocarbons (PAHs) within it, mortality and blue-sac disease (craniofacial and spinal deformities, hemorrhaging, pericardial and yolk sac edema, and induction of P450 [CYP1A] enzymes) have resulted (Hose et al. 1996; Carls et al. 1999; Colavecchia et al. 2004; Schein et al. 2009). PAHs reduce salmonid growth rates (Meador et al. 2006) and are carcinogenic and immunotoxic to fish (Reynaud and Deschaux 2006). Sublethal PAH exposure can lead to fish lesions (Myers et al. 2003); abnormal larval development and reduced spawning success (Incardona et al. 2011); and reproductive impairment, altered respiratory and heart rates, eroded fins, enlarged livers, and reduced growth (NOAA 2012). The dispersants used in oil spills also facilitate dispersal of PAH across membranes, thereby increasing exposure (Wolfe et al. 1997; 2001). In total, PAH exposure leads to reduced fish health and fish populations (Di Giuilo and Hinton 2008). Because of the cumulative catchment-scale effects of shale gas fracking, Smith et al. (2012) used existing empirical models describing Brook Trout responses to landscape disturbance to estimate responses to gas development. They concluded that fewer than one well pad per 3 km^2 and 3 ha per pad were needed to minimize damage to trout populations. Bamberger and Oswald (2012) and Webb et al. (2014) have documented a wide range of health effects, ranging from dermatological, reproductive and developmental to death, as a result of exposure to fracking fluids and gases. Stacey et al. (2015) and Cil (2015) both found small but statistically significant lower birth rates of infants in association with fracking wells. However, because of inadequate study designs and pre- and post-monitoring, Bowen et al. (2015) and USEPA (2015) were unable to detect consistent trends in fracking areas from nationally collected data.

The Ixtoc I spill in the Gulf of Mexico had adverse effects on marine organisms (Blumer and Sass 1972a, 1972b; Mironov 1972; Anderson et al. 1978; 1979). Different studies in the region demonstrated that this spill adversely affected zooplankton (Teal and Howarth 1984; Guzmán del Próo et al. 1986), benthos and infauna (Teal and Howarth 1984), shrimps and crabs (Jernelöv and Linden 1981), and turtles and birds (Garmon 1980; Teal and Howarth 1984). Oil spills also effect fish larvae and eggs (Teal and Howarth 1984), which can affect or disrupt recruitment, and therefore have long-term impacts on the fisheries and the ecosystem in general (Teal and Howarth 1984; Hjermann et al. 2007).

In fact, this spill affected fish landings in the State of Campeche, where the accident occurred, 3 years after the incident: a decrease of 30 tons/per boat was observed, and the catch composition also changed from before to after the spill, reflecting an increase in more tolerant taxa and smaller and shorter-lived individuals. These diminished returns affected the economy, especially of Campeche (Amezcua-Linares et al, 2013). Also the diversity, biomass and abundance of finfish species decreased drastically immediately after the spill in the area surrounding the oil well (Amezcua Linares et al., 2013).

Despite 30 years of tar sands mining near Fort McMurray, Alberta, little measureable impact has been observed on biota or water quality. However, there is evidence of increased PAH concentrations in river water (Gosselin et al. 2010) and lake sediments (Kurek et al. 2013) coincident with oil sands development. Nonetheless *Daphnia* have not been affected by increased PAH deposition. Kelly et al. (2010) found that 13 priority pollutants were higher near oil sands development than they were upwind or upstream. Ross (2012) demonstrated that toxic naphthenic acids originate from oil sands process water, but also occur naturally in regional ground waters and may enter surface waters from anthropogenic or natural sources. Analyzing data for 24-31 years, Evans and Talbot (2012) reported reduced, or no change in, fish tissue mercury concentrations in oil sands area fish when analyses were calibrated by fish weight and sample type (whole body versus filet; Peterson et al. 2005). However, the aquatic biological monitoring programs may be insufficiently rigorous to detect other than substantial effects (Gosselin et al. 2010).

Major Spills

In recent years, oil trains have derailed, spilled oil or burned explosively in Aliceville, Alabama; Casselton, North Dakota; Denver, Colorado; Gainford, Alberta; Gogama, Ontario; Lac-Megantic, Quebec; Lynchburg, Virginia; Mount Carbon, West Virginia; Philadelphia, Pennsylvania; Plaster Rock, New Brunswick; Timmins, Ontario; and Vandergrift, Pennsylvania. Oil trains are projected to derail at a rate of about 10 per year, resulting in estimated damages of $4 billion over the next 20 years (Brown and

Funk 2015). Although the total amount of PAHs released into the environment from daily transporting and use of oil and gas exceeds that of major spills, those major spills help us see the effects of PAHs on aquatic life. The Deepwater Horizon explosion and spill in 2010 was the largest in US history, spilling an estimated 670,000 tons of oil into the Gulf of Mexico. Its effects are still being studied, but fish deformities and fisheries closures cost the industry an estimated $2.5 billion. British Petroleum (BP) was fined $18.7 billion for civil settlements in addition to its $4 billion in criminal fines (USDJ 2012), much of which can be written off as business expenses from its taxes (Keller 2015). The Exxon Valdez ran aground on a reef in Prince William Sound, Alaska, in 1989 and spilled 38,500 tons; despite cleanup efforts fisheries were markedly reduced and much of the oil remains in sediments. Exxon settled for $1.03 billion in criminal and civil penalties, but is still in court regarding additional penalties (USGAO 1993). The PEMEX IXTOC 1 well off the coast of Mexico exploded and spilled 480,000 tons of oil in 1979. Fisheries were closed and estuarine and lagoon species were reduced dramatically (see *Biological Effects* above). As a national company PEMEX declared immunity and paid no fines because governments do not fine themselves. A blowout on Union Oil Platform A in 1969 spilled 14,000 tons of oil in the Santa Barbara Channel, California. Although fish populations showed initial declines, the long-term effects probably were minimized by microbial decomposition of the oil. Union Oil paid a total of $21.3 million in damages (Wikipedia 2013). In most spills the lack of a statistically and scientifically rigorous pre- and post-spill monitoring program with standard methods and indicators hinder quantitative assessment of fishery effects. Such programs should be implemented wherever—and before--mining and fossil fuel developments (and spills) occur (Hughes 2014b; Lapointe et al. 2014; Bowen et al. 2015).

Federal Laws & Regulations

The U.S. Energy Policy Act of 2005 exempts oil and gas production from regulation under the CWA, Safe Drinking Water Act (SDWA)[2], the Resource Conservation and Recovery Act (RCRA)[3], CERCLA, and the Toxic Release Inventory (TRI)[4].

In Canada, the federal government is responsible for control of oil and gas exploration in Nunavut, and Sable Island, as well as offshore. Using the Canada Oil and Gas Operations Act, the federal government attempts to promote safety, environmental protection, conservation of oil and gas resources, joint production arrangements, and economically efficient infrastructure during the oil and gas exploration and development process. Elsewhere, each province, as well as Yukon territory, has jurisdiction, except where federal lands and First Nations are involved. Therefore, primary responsibility for regulating surface mining development and associated impacts lies with the provinces, which, as with U.S. states, tend to be more lenient than the federal government.

The National Energy Board (NEB), an independent Canadian federal agency, regulates oil and gas exploration, development, and production in Frontier lands and offshore areas that are not covered by provincial or federal management agreements. In addition, the NEB must approve all interprovincial and international oil and gas pipelines before they are built. The NEB takes economic, technical, and financial feasibility, as well as the environmental and socio-economic impact of the project, into account when deciding whether a pipeline project should be allowed. If a pipeline lies entirely within one province then it is regulated by the appropriate provincial regulatory agency.

[2] The Safe Drinking Water Act (SDWA), enacted in 1974, is the principal federal law in the USA intended to ensure safe drinking water for the public.
[3] The Resource Conservation and Recovery Act (RCRA), enacted in 1976, is the principal federal law in the USA governing the disposal of solid waste and hazardous waste.
[4] The Toxics Release Inventory (TRI) is a publicly available database containing information on toxic chemical releases and other waste management activities in the USA.

As with mining, the pollution of water bodies by oil and gas in Mexico is also regulated by the Mexican Official Norm Number 001 Ecology.

Aggregate Mining

Aggregate is used in the construction and transportation industries. Aggregate is the most commonly mined resource, and is also the least regulated form of mining. In the USA, 80% of aggregate is extracted under the jurisdiction of state and local laws only (Swanson 1982). The most important sources of sand and gravel are river channels, floodplains, and previously glaciated terrain.

Physical Effects on Aquatic Habitat

Instream mining alters local channel morphology (gradient, width-to-depth ratios) and gravel bar mining effectively straightens the river during bank-full flows. The resulting increase in stream power can incise beds upstream or downstream from a mine (Kondolf 1994; Meador and Layher 1998; NOAA-Fisheries 2004). Although prohibited in much of Canada, dredging is widely employed in U.S. rivers and can increase fine-sediment bed load through resuspension, alter channel morphology, physically eliminate benthic organisms, and destroy fish spawning and nursery areas, all of which change aquatic community composition (OWRRI 1995; IMST 2002; NOAA-Fisheries 2004). Instream gravel mining in three Arkansas rivers was associated with increased bankful widths and turbidity, longer pools, and fewer riffles (Brown et al. 1998). Dry bar scalping in the Fraser River, British Columbia, reduced high-flow fish habitat by 25% (Rempel and Church 2009). Instream aggregate mining also ignores natural bed load requirements for channel maintenance (Meador and Layher 1998). Where potential bedload is lost upstream to mined gravel bars, rivers erode gravel downstream from river banks, beds, gravel bars, and bridge pilings (Dunne et al. 1981; Kondolf 1997). Gravel extraction rates have exceeded replenishment rates by more than 10 fold in Washington (Collins and Dunne 1989) and 50 fold in California (Kondolf and Swanson 1993) rivers, causing bed incision and lateral migration in the mined reaches and downstream. Channel incision, bank erosion, and altered channel stability can reduce riparian vegetation (Kondolf 1994). Floodplain aggregate mines become part of the active channel when viewed on a multi-decadal time scale (Kondolf 1994). Aquatic habitats may be lost during floods when mine pits in flood plains capture the river channel (Kondolf 1997; Dunne and Leopold 1978; Woodward-Clyde Consultants 1980; USFWS 2006).

Biological Effects

The biological effects of aggregate mining have been little studied. Brown et al. (1998) reported reduced densities of macroinvertebrates and fish at gravel mined sites. Gravel dredging in the Allegheny River, Pennsylvania, USA, decreased benthic fish abundance and altered food webs (Freedman et al. 2013). However, Bayley and Baker (2002) demonstrated how proper rehabilitation projects can convert gravel mines into regularly inundated floodplains and appropriately graded floodplain lakes with restored riverine connectivity and habitats that are highly productive for fish (DOGAMI 2001).

PROPOSED AFS POLICY

(Adapted from ICMM 2003; International Labor Organization Convention 169 1989; Miranda et al. 2005; NMFS 1996; USFWS 2004; Nushagak-Mulchatna Watershed Council 2011; O'Neal and Hughes 2012; Woody et al. 2010; Wood 2014)

Increasingly, people have begun to recognize the social and environmental costs of irresponsible behavior and the inability of current state/provincial and national laws and regulations to protect vulnerable environments and human societies, especially in regards to extractive industries (Wood 2014). International agreements have led to common principles for development: precautionary principle, sustainable economies, equity, participatory decision making, accountability, and transparency, efficiency, and polluter pays. Additional human rights principles include: existence as self-determining societies with territorial control, cultural integrity, a healthy and productive environment, political organization and expression, and prior and informed consent to development activities that affect territories and livelihoods. Sustainable natural resource management incorporates obligations to future generations because degraded resources are transferred to future generations (Hughes 2014a; Wood 2014), and obligations to future generations are incorporated in USA federal law (e.g., NEPA 1969; FWPCA 2002). Boulding (1970) argued that a society's long-term welfare is governed by the degree to which its citizens identify with their society in space and time (including the future). Thus, AFS recommends that four overarching issues should be considered:

Involve the affected public in deciding whether a mine or well is the most appropriate use of land and water. The concept and application of free, prior, and informed consent (FPIC) is the basis for public involvement/community engagement. There is no universally accepted definition of FPIC, and as fashioned FPIC itself applies only to indigenous communities. The IFC (2012) has attempted to provide guidance for its clients in the application of FPIC (IFC, 2012, Guidance Note 7), and there are numerous efforts today to apply the FPIC principles in a similar manner to include all affected communities and, where appropriate, to include other stakeholders as well (e.g. IFC, 2012, Guidance Note 1; Wood 2014).

The International Union for the Conservation of Nature (IUCN) and the Convention of Wetlands (Ramsar) provides an internationally accepted means of prioritizing lands designated as environmentally and socially significant for protection. Mining and oil/gas drilling should not occur in or bordering IUCN I–IV protected areas, marine protected areas (categories I–VI), Ramsar sites that are categorized as IUCN I–IV protected areas, national parks, monuments or wilderness areas, areas of high conservation value (scenic, drinking water, productive agricultural, fisheries & wildlife areas, aquatic diversity areas, sensitive, threatened & endangered species habitats, regionally important wetlands and estuaries), or where projects imperil the ecological resources on which local communities depend. For an example of the potential effects of a proposed copper mining district on aboriginal, sport, and commercial fisheries see USEPA (2014).

Minimize risk before mining or drilling. No mine should be permitted that will require mixing zones or perpetual active management to avoid environmental contamination or to maintain flows in receiving waters. No mine should be permitted that could result in acid mine drainage during operation or post-closure unless the risk of such drainage can be eliminated by methods proven to be effective at mines of comparable size and location. Financial sureties for mines should be disclosed and analyzed as a part of the public review process, for example in an Environmental Impacts Statement/Analysis. In political jurisdictions where mixing zones or perpetual water treatments are allowed, the affected public should be directly engaged in approving mixing zones or perpetual water treatment since they bear the ultimate environmental and/or financial responsibility for the impacts of these practices. There should be no presumption in favor of mineral exploration or development as the most appropriate land use. Where there is scientific uncertainty regarding the impacts of proposed mineral exploration or a mine or oil/gas field on the water quality and subsistence resources of the community, such activities should not proceed until there is clear and convincing scientific evidence that they can be conducted in a safe manner. In other words, the burden of proof of no impact should be on the company versus the local citizens as is true for the pharmaceutical and biocide industries that purposely produce or release toxic compounds (for a mining example, see USEPA 2014).

Ensure environmentally responsible mine development. The proposed mineral exploration project and its potential impacts should be made publicly available to area residents in an appropriate language and format at least 6 months before exploration begins. Companies should be required to provide adequate financial guarantees to pay for prompt cleanup, reclamation, and long-term monitoring and maintenance of exploratory wells, borings or excavations. Stakeholders should be given adequate notification, time, financial support for independent technical resources, and access to supporting information, to ensure effective environmental impact assessment (EIA) review. Companies should be required to collect adequate baseline data before the EIA and make it publicly available on easily accessible computer databases. Potential resource impacts of the mining or oil/gas facility (including the sizes and types of mines and tailings storage facilities, oil/gas field extent, surface and ground water, hydromorphological changes, fugitive dust, fish and wildlife, power, road and pipeline access, road/rail/pipeline stream crossings/proximity, worker infrastructure, and expansion potentials) should be fully evaluated in the EIA. Companies should be required to conduct adequate pre-mining and operational mine sampling and analysis for acid-producing minerals, based on accepted practices and appropriately documented, site-specific professional judgment. Sampling and analysis should be conducted in accordance with the best available practices and techniques by professionally certified geologists. Companies should be required to evaluate environmental costs (including regulatory oversight, reclamation and mitigation, closure, post-closure monitoring and maintenance, and spills and catastrophic failures) in the EIA. The assessment should include worst-case scenarios, analyses and plans for potential off-site social and environmental impacts, including those resulting from cyanide transport, storage and use; emergency spill responses and facilities; tailings dam and pipeline failures, and river channel erosion. Importantly, affected communities must be provided with opportunities to meaningfully participate in the reviews of Environmental Impact Statement (EIS)/Environmental Assessments (EA) (Wood 2014). Companies should be required to work with potentially affected communities to identify potential worst-case emergency scenarios and develop appropriate response strategies. Companies proposing developments should consider any affected First Nations and tribal treaty rights and respect First Nation and tribal traditional use areas whether on or off reserve lands.

Regarding air and water contamination and use, companies should make reports of fracking chemicals and contaminant discharges to surface and ground waters publicly available as collected. Companies also should be required to monitor and publicly report atmospheric emissions (particularly toxics, metals and sulphates). A professionally certified expert should certify that water treatment, or groundwater pumping, will not be required in perpetuity to meet surface or groundwater quality standards beyond the boundary of the mine. Water and power usage and mine dewatering should be minimized to reduce undesirable impacts on ground and surface waters, including seeps and springs. When permit violations occur, companies should rapidly implement corrective actions to limit damages and fines. The environmental performance of mines and oil/gas companies and the effectiveness of the regulatory agencies responsible for regulating mines and oil/gas fields should be audited annually, and the results made publicly available. Communities should have the right to independent monitoring and oversight of the environmental performance of a mine or well field. Tailings impoundments and waste rock dumps should be constructed to minimize threats to public and worker safety, and to decrease the costs of long-term maintenance. If groundwater contamination is possible, liners should be installed and facilities should have adequate monitoring and seepage collection systems to detect, collect, and treat any contaminants released in the immediate vicinity. Acid-generating and radioactive material should be isolated in waste facilities and hazardous material minimization, disposal, and emergency response plans should be made publicly available. Rivers, floodplains, lakes, estuarine, and marine systems should not be used for oil/gas, mining, or mine waste disposal. Mines, wells, pipelines, roads, and disposal areas should be distant from surface and ground waters to avoid their contamination. Mine operators should adopt the International Cyanide Management Code, and third-party certification should be used to ensure safe cyanide management is implemented.

Companies should be required to develop a reclamation plan before operations begin that includes detailed cost estimates. The plan should be periodically revised to update changes in mining and reclamation practices and costs. All disturbed areas should be rehabilitated consistent with desirable future uses, including re-contouring, stabilizing, and re-vegetating disturbed areas. This should include the salvage, storage, and replacement of topsoil or other acceptable growth media. Aggregate mines should be designed to improve and increase off-channel and wetland habitat along rivers. Quantitative standards should be established for re-vegetation in the reclamation plan, and clear mitigation measures should be defined and implemented if the standards are not met. Where acid-generating or radioactive materials are exposed in the mine wall, companies should backfill the mine pit if it would minimize the likelihood and environmental impact of acid generation or radiation. Backfilling options must include reclamation practices and design to ensure that contaminated or acid-generating materials are not disposed of in a manner that will degrade surface or groundwater. Companies should be required to backfill underground mines where subsidence is likely and to minimize the size of waste and tailings disposal facilities. Reclamation plans should include plans and funding for post-closure monitoring and maintenance of all mine facilities and oil and gas wells, including surface and underground mine workings, tailings, and waste disposal facilities.

Adaptive management plans at the basin scale should exist and be followed rigorously for mines and wells (e.g., ISP 2000, NOAA 2004; NRC 2004; Goodman et al. 2011). Those plans should include clear goals, objectives, expectations, research questions, alternatives, conceptual models, and simulation models. The plans should include appropriate study designs (BACI, probability) and standard sets of quantitative and socially and ecologically informative indicators that are monitored through the use of standard methods to assess the ecological effectiveness of management practices (i.e., performance-based standards; e.g., Roni 2005; Hughes and Peck 2008; Roni et al. 2008). Monitoring indicators should include ground and surface water quality, and sediment quality, tissue chemistry, flow regime, physical habitat structure, and biological assemblages (fish, benthic macroinvertebrates, algae, riparian vegetation, human health). For many indicators both intensive (e.g., five water samples in a 30-d period during high- and low-flow periods) and extensive (e.g., monthly water samples) monitoring is required to evaluate mining-related effects. Fish sampling should be conducted during base flows and during major migratory periods; for other variables (e.g., benthic macroinvertebrate and algal assemblage structure), annual base flow sampling is required. Environmental monitoring must be included as a pre-condition of the mine permit and paid for by the company. All data, including quality assurance/quality control data, should be collected by an independent entity, and stored in a computer database that is easily accessible by the public. Funding for the monitoring should be stable before, during, and after the term of the mine. There should be a single lead agency with a single lead scientist responsible for implementing the monitoring, research, data management and analyses, and reporting of the monitoring team. The data analyses should lead to defensible, science-based decisions regarding management alternatives, and those decisions should be fully documented and defensible with data and underlying rationale. Regarding aggregate mines, the lead agency should develop a sediment budget, including removal and transport rates, at a basin scale. In all mining and fossil fuel extraction cases, long-term BACI monitoring of reference and altered sites needs to be conducted to support effects assessment and management decisions (Irvine et al. 2014; Bowen et al. 2015).

Financial sureties (bonds, trust funds, insurance) should be reviewed and upgraded on a regular basis by the permitting agency, and the results of the review should be publicly disclosed. The public should have the right to comment on the adequacy of the reclamation and closure plan, the adequacy of the financial surety, and completion of reclamation activities prior to release of the financial surety. Financial surety instruments should be independently guaranteed, reliable, and readily liquid to cover all possible costs of mine, oil/gas field, and post-closure failures—including litigation. Sureties should be regularly evaluated by independent analysts using accepted accounting methods. Self-bonding or corporate guarantees should be prohibited. Financial sureties should not be released until reclamation and closure are complete, all impacts have been mitigated, and cleanup and rehabilitation have been shown to be effective for decades after mine or oil/gas field closure.

Ensure that appropriate governance structures are in place. Corporate governance policies should be made public, implemented, and independently evaluated. Companies should report their progress toward achieving concrete stated environmental and social goals through specific and measurable biological and environmental indicators that can be independently monitored and verified. That information should be disaggregated to site-specific levels. Companies should report money paid to political parties, central governments, state or regional governments, and local governments. These payments should be compared against revenues governments receive and government budgets.

To ensure the above rights and practices, strong and honest central and local governments must exist, including laws, regulations, monitoring funds and staff, and the will and capacity to enforce the laws and regulations (Wood 2014). In that regard, several weaknesses of the U.S. General Mining Law of 1872 need strengthening. Necessary fiscal reforms include: ending patenting (which extends ownership for far less than land values), establishing royalty fees (similar to the 8%--12.5% paid by the fossil fuel industry for use in land and water rehabilitation), ensuring adequate reclamation bonding, establishing regulatory fees (to cover permitting, rigorous effectiveness monitoring, enforcement infrastructure, and research), and creating funds to clean up abandoned mines (currently estimated at $32–72 billion) (Woody et al. 2010). Likewise, the regulatory exemptions for the oil and gas industry (Halliburton loopholes) in the U.S. Energy Policy Act of 2005 should be rescinded. Needed mine and oil and gas field oversight improvements include independent peer review from exploration to closure, and rigorous effectiveness monitoring and reporting by independent consultants. The peer review and monitoring results should be released directly to the public and oversight agencies for review (Woody et al. 2010). Unannounced inspections should be mandatory. Failure to address mining and drilling violations successfully should result in the cessation of operations until they are appropriately corrected. New or renewed permits by the company should not be considered until reclamation at other sites has been deemed successful by the regulatory agencies and stakeholders involved. Mining and oil and gas companies and persons with a history of serious violations nationally or internationally should be ineligible for new or renewed permits and liable for criminal proceedings. Citizens should have the right to sue in federal and state courts when companies or agencies fail to implement best management practices. Mine permitting and reclamation sureties should include the risks of tailings dam failures resulting from human error, meteorological events, landslides, and earthquakes. An aggressive and coordinated research program regarding mining and oil and gas fracking practices and the environmental impacts of mining and oil and gas fracking are needed (National Academy of Sciences 1999; USEPA 2004; Entrekin et al. 2011; Weltman-Fahs and Taylor 2013; Bowen et al. 2015).

CONCLUSIONS

Because of the substantial and widespread effects of mining and oil/gas extraction on hydromorphology, water quality, fisheries, and regional socioeconomics; and the enormous unfunded costs of abandoned mine and oil/gas field reclamation; the AFS recommends that governments develop immediate and substantive changes in permitting, monitoring, and regulating mines and oil/gas fields. In addition, firms that mine and drill in North America should be held to the same mining and drilling standards on other continents to reduce the likelihood of simply shifting their activities to other areas of the ecosphere where regulatory standards are weaker. Companies and governments that follow the recommended AFS mining policy should be actively and openly commended, whereas those that do not should be made open to public scrutiny.

REFERENCES

Allert, A.L., J.F. Fairchild, R.J. DiStefano, C.J. Schmitt, J.M. Besser, W.G. Brumbaugh, and B.C. Poulton. 2008. Effects of lead-zinc mining on crayfish (*Orconectes hylas*) in the Black River Watershed, Missouri, USA. Freshwater Crayfish 16:97-111.

Allert, A.L., J.F. Fairchild, R.J. DiStefano, C.J. Schmitt, W.G. Brumbaugh, and J.M. Besser. 2009. Effects of lead mining on Ozark streams: in-situ toxicity to woodland crayfish (*Orconectes hylas*). Ecotoxicology and Environmental Safety 72:1207-1219.

Allert, A.L., R.J. DiStefano, C.J. Schmitt, J.F. Fairchild, and W.G. Brumbaugh. 2012. Effects of mining-derived metals on riffle-dwelling crayfish in southwestern Missouri and southeastern Kansas, USA. Archives of Environmental Contamination and Toxicology 63:563-573.

Allert, A.L., R.J. DiStefano, J.F. Fairchild, C.J. Schmitt, M.J. McKee, J.A. Girondo, W.G. Brumbaugh, and T.W. May. 2013. Effects of historical lead-zinc mining on riffle-dwelling fish and crayfish in the Big River of southeastern Missouri. Ecotoxicology 22:506-521.

Amezcua-Linares, F., F. Amezcua, and B. Gil. 2013. Effects of the Ixtoc I oil spill on fish assemblages in the Southern Gulf of Mexico. In: B. Alford, M. Peterson, and C. Green (Editors) Impacts of oil spill disasters on marine fisheries in North America. American Fisheries Society Symposium. Taylor & Francis, New York.

Anderson, J. W., G. Roesijadi and E. A. Crecelius. 1978. Bioavailability of hydrocarbons and heavy metals to marine detritivores from oil-impacted sediments. Pages 130-148 in D. A. Wolfe (editor) Marine biological effects of OCS petroleum development. National Oceanic and Atmospheric Administration, Washington, DC.

Anderson, J. W., S. L. Kiesser and J. W. Blaylock. 1979. Comparative uptake of naphthalenes from water and oiled sediment in benthic amphipods. Pages 579-584 in Proceedings of the 1979 oil spill conference, Publication 4308, American Petroleum Institute, Washington, DC.

AP (Associated Press). 2012. Exxon increases estimate of Yellowstone River oil spill by 50%. Website. Available at: http://billingsgazette.com/news/local/exxon-increases-estimate-of-yellowstone-river-oil-spill-by/article_e3f0de2e-f931-50e8-9678-c5f230c9e00d.html. Accessed 14 June 2013.

Arkoosh, M. R., E. Casillas, E. Clemons, A. N. Kagley. 1998a. Effect of pollution on fish diseases: potential impacts on salmonid populations. Journal of Aquatic Animal Health 10: 182–190.

Arkoosh, M. R., E. Casillas, P. Huffman, E. Clemons, J. Evered, J.E. Stein, U. Varanasi. 1998b. Increased susceptibility of juvenile Chinook salmon from a contaminated estuary to *Vibrio anguillarum*. Transactions of the American Fisheries Society 127:360–374.

Auer, N.A. 1996. Importance of habitat and migration to sturgeons with emphasis on lake sturgeon. Canadian Journal of Fisheries and Aquatic Sciiences 53(Suppl. 1): 152–160.

Baker, R., M. Knittel, and J. Fryer. 1983. Susceptibility of Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), and rainbow trout, *Salmo gairdneri* Richardson, to infection with *Vibrio anguillarum* following sublethal copper exposure. Journal of Fish Diseases 6:267–275.

Bakken, G. M. 2008. The mining law of 1872: past politics, and prospects. University of New Mexico Press, Albuquerque.

Balczon, J., and J. Pratt. 1994. A comparison of the responses of two microcosm designs to a toxic input of copper. Hydrobiologia 281:101–114.

Baldigo, B. P., and G. B. Lawrence 2000. Composition of fish communities in relation to stream acidification and habitat in the Neversink River, New York. Transactions of the American Fisheries Society 129: 60-76.

Baldwin, D.H., J.F. Sandahl, J.S. Labenia and N.L. Scholz. 2003. Sublethal effects of copper on coho salmon: impacts on nonoverlapping receptor pathways in the peripheral olfactory nervous system. Environmental Toxicology and Chemistry 22: 2266-2274.

Bamberger, M. and R.E. Oswald. 2012. Impacts of gas drilling on human and animal health. New Solutions 22:51-77.

Barry, K. L., J. A. Grout, C. D. Levings, B. H. Nidle, and G. E. Piercey. 2000. Impacts of acid mine drainage on juvenile salmonids in an estuary near Britannia Beach in Howe Sound British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 57: 2031-

2043.

Bayley, P.B., and C. Baker. 2002. Fish population observations in Endicott and Truax floodplain areas under restoration following aggregate mining in the Willamette River Basin, Oregon (1998-01). 1998/01 Report to Willamette River Gravel Removal Restoration Fund Program. Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.

BCME (British Columbia Ministry of Environment). 2011. Analysis of effects of mine site remediation on total copper concentrations in the Tsolum River and some of its tributaries. BWP Consulting Inc. http://www.env.gov.bc.ca/wat/wq/pdf/minesite-rem-effects-on-tsolum.pdf . (November 2011).

Beltman, D. J., W. H. Clements, J. Lipton, and D. Cacela. 1999. Benthic invertebrate metals exposure, accumulation, and community level effects downstream from a hard rock mine site. Environmental Toxicology and Chemistry 18: 299-307.

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. Canad ian Journal of Fisheries and Aquatic Sciences 42:1410–1417.

Berry, W., N. Rubenstein, and B. Melzian. 2003. The biological effects of suspended and bedded sediment (SABS) in aquatic systems: a review. U. S. Environmental Protection Agency, Washington, D. C. Available: http://www.epa.gov/sites/production/files/2015-10/documents/sediment-appendix1.pdf .(August 2010).

Besser, J.M. W.G. Brumbaugh, D.K. Hardesty, J.P. Hughes, and C.G. Ingersoll. 2009. Assessment of metal-contaminated sediments from the Southeast Missouri (SEMO) mining district using sediment toxicity tests with amphipods and freshwater mussels. Administrative Report 08-NRDAR-02. Prepared for U.S. Fish and Wildlife Service. Columbia Ecological Services Office.

Bigford, T., C.A. Caldwell, D. Fluharty, R.E. Gresswell, K. Hyatt, D. Inkley, D. MacDonald, A. Mullan, A. Todd, C. Deacon Williams, A. Rosenberger, and R. Valley. 2010. Climate change. AFS Policy Statement 33. Available at: http://fisheries.org/docs/policy_statements/policy_33f.pdf

Birtwell, I. 1999. The effects of sediment on fish and their habitat. Fisheries and Oceans Canada, Pacific Scientific Advice Review Committee, Canadian Stock Assessment Secretariat Research Document 99/139, Ottawa,Ontario.

Blanck, H. 2002. A critical review of procedures and approaches used for assessing pollution-induced community tolerance (PICT) in biotic communities. Human and Ecological Risk Assessment: an International Journal 8:1003-1034.

Blumer, M. and J. Sass. 1972a. Oil pollution: persistence and degradation of spilled fuel oil. Science 176:1120-1122.

Blumer, M. and J. Sass. 1972b. Indigenous and petroleum-derived hydrocarbons in a polluted sediment. Marine Pollution Bulletin 3:92-94.

Bott, R. 1999. Our petroleum challenge: exploring Canada's oil and gas industry. Petroleum Communications Foundation. Calgary, AB.

Boulding, K. 1970. The economics of the coming spaceship Earth. Pages 96-101 in Garret deBell (editor). The environmental handbook. Ballentine, New York.

Bowen, Z.H., G.P. Oelsner, B.S. Cade, T.J. Gallegos, A.M. Farag, D.N. Mott, C.J. Potter, P.J. Cinotto, M.L. Clark, W.M. Kappel, T.M. Kresse, C.P. Melcher, S.S. Paschke, D.D. Susong, and B.A. Varela. 2015. Assessment of surface water chloride and conductivity trends in areas of unconventional oil and gas development—why existing national data sets cannot tell us what we would like to know. Water Resources Research 51:704-715.

Bowker, L.N., and D.M. Chambers. 2015. The risk, public liability, & economics of tailings storage facility failures. Available at: https://www.earthworksaction.org/files/pubs-others/BowkerChambers-RiskPublicLiability_EconomicsOfTailingsStorageFacility%20Failures-23Jul15.pdf

Brown, A.V., M.M. Lyttle, and K.B. Brown. 1998. Impacts of gravel mining on gravel bed streams. Transactions of the American Fisheries Society 127:979-994.

Brown, M., and J. Funk. 2015. Feds: fuel-hauling trains could derail at a rate of 10 a year. The Columbian. http://www.columbian.com/news/2015/feb/23/feds-fuel-hauling-trains-derail-10-year/. (Accessed August 2015).

Brown, T.G., Munro, B., Beggs, C., Lochbaum, E., and Winchell, P. 2003. Courtenay River seal fence. Canadian Techncial Report of Fisheries and Aquatic Sciences 2459: 55 p.

Bryce, S.A., G.A. Lomnicky, P.R. Kaufmann, L.S. McAllister, and T.L. Ernst. 2008. Development of biologically-based sediment criteria in mountain streams of the western United States. North American Journal of Fisheries Management 28:1714-1724.

Bryce, S.A., S.G. Lomnicky, and P.R. Kaufmann. 2010. Protecting sediment-sensitive aquatic species in mountain streams through the application of biologically-based streambed sediment criteria. Journal of the North American Benthological Society 29:657-672.

Buchwalter, D.B., D.J. Cain, W.H. Clements, and S.N. Luoma. 2008. Using biodynamic models to reconcile differences between laboratory toxicity tests and field biomonitoring with aquatic insects. Environmental Science & Technology 42:3117-3117.

Carls, M.G., S.D. Rice, and J.E. Hose. 1999. Sensitivity of fish embryos to weathered crude oil. I. Low-level exposure during incubation causes malformations, genetic damage, and mortality in larval pacific herring (Clupea pallasi). Environmental Toxicology and Chemistry 18: 481–493.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8:559-568.

CCME (Canadian Council of Ministers of the Environment). 2002. Canadian water quality guidelines for the protection of aquatic life: Total particulate matter. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg, MB.

Chambers, D., C. Coumans, and C.A. Woody, C.A. 2008. Brief of amici curiae in support of Southeast Alaska Conservation Council v. Coeur Alaska and the State of Alaska, in the Supreme Court of the United States, Nos. 07-984, 07-990.

Chambers, D., R. Moran, L. Trasky, S. Bryce, L. Danielson, L. Fulkerson, J. Goin, R.M. Hughes, J. Konigsberg, R. Spies, G. Thomas, M. Trenholm, and T. Wigington. 2012.

Bristol Bay's wild salmon ecosystems and the Pebble Mine: key considerations for a large-scale mine proposal. Wild Salmon Center and Trout Unlimited, Portland, Oregon.

Cil, G. 2015. Effects of behavioral and environmental factors on infant health. Ph.D. Dissertation. Department of Economics, University of Oregon, Eugene, Oregon.

Clements, W. H., D. M. Carlisle, J. M. Lazorchak, and P. C. Johnson. 2000. Heavy metals structure benthic communities in Colorado mountain streams. Ecological Applications 10:626-638.

Colavecchia, M.V., S.M. Backus, P.V. Hodson, and J.L. Parrott. 2004. Toxicity of oil sands to early life stages of fathead minnows (Pimephales promelas). Environmental Toxicology and Chemistry 23: 1709–1718.

Collins, B.D., and T. Dunne. 1989. Gravel transport, gravel harvesting, and channel-bed degradation in rivers draining the southern Olympic Mountains, Washington, USA. Environmental Geology and Water Sciences 13:213-224.

Comte, L., and G. Grenouillet. 2013. Do stream fish track climate change? Assessing distribution shifts in recent decades. Ecography 36:1236-1246.

Cooper, E.L., and C.C. Wagner. 1973. The effects of acid mine drainage on fish populations. Page 114 in: Fish and food organisms in acid mine waters of Pennsylvania. EPA-R-73-032: 114. U.S. Environmental Protection Agency, Washington, DC.

Copeland, C. 2013. Mountaintop mining: background on current controversies. 7-5700. Congressional Research Service, Washington, DC.

Crouse, M., C. Callahan, K. Malueg, and S. Dominguez.1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. Transactions of the American Fisheries Society 110(2):281–286.

Dai, A. 2013. Increasing drought under global warming in observations and models. Nature Climate Change 3:52-58.

Daniel, W.M., D.M. Infante, R.M. Hughes, P.C. Esselman, Y.-P. Tsang, D. Wieferich , K. Herreman, A.R. Cooper, L. Wang, and W.W. Taylor. 2014. Characterizing coal and mineral mines as a regional source of stress to stream fish assemblages. Ecological Indicators 50:50-61.

Davies, M.P. 2002. Tailings impoundment failures: are geotechnical engineers listening? Geotechnical News, September: 31-36.

DeBruyn, A.M.H., and P.M. Chapman. 2007. Selenium toxicity to invertebrates: will proposed thresholds for toxicity to fish and birds also protect their prey? Environmental Science and Technology 41:1766−1770.

DeCicco, A. L. 1990. Northwest Alaska Dolly Varden studies. Fishery Data Series 90-08. Alaska Department of Fish and Game, Fairbanks.

Di Giuilo, R.T. and D.E. Hinton. 2008. The toxicology of fishes. Taylor and Francis, New York, New York.

Dube, M., D. MacLatchy, J. Kieffer, N. Glozier, J. Culp, and K. Cash. 2005. Effects of metal mining effluent on Atlantic salmon (Salmo salar) and slimy sculpin (Cottus cognatus): using artificial streams to assess existing effects and predict future consequences. The Science of the Total Environment 343:135–154.

Dudka, S., and D.C. Adriano. 1997. Environmental impacts of metal ore mining and processing: a review. Journal of Environmental Quality 26:590-692.

Dunne T., W.E. Dietrich, N.F. Humphrey, and D.W. Tubbs. 1981. Geologic and geomorphic implications for gravel supply. pp. 38–74 in Proceedings from the conference: salmon-spawning gravel: a renewable resource in the Pacific Northwest? October 6–8, 1980. Report no. 39, State of Washington Research Center, Pullman, Washington.

Dunne, T., and L.B. Leopold. 1978. Water in environmental planning. W.H. Freeman and Co., San Francisco, California.

Dusseault, M.B., M.N. Gray, and P.A. Nawrocki. 2000. Why oil wells leak: cement behavior and long-term consequences. International Oil and Gas Conference and Exhibition in China. ISBN 978-1-55563-907-5. Society of Petroleum Engineers.

Eagles-Smith, C.A., J.J. Willacker, and C.M. Flanagan Pritz. 2014, Mercury in fishes from 21 national parks in the Western United States—Inter and intra-park variation in concentrations and ecological risk: U.S. Geological Survey Open-File Report 2014-1051.

Elton, P.F. 1974. Impact of recent economic growth and industrial development on the ecology of northwest Miramichi Atlantic salmon (*Salmo salar*). Journal of the Fisheries Research Board of Canada 31:521-544.

Enserink, E., J. Maas-Diepeveen, and C. van Leeuwen. 1991. Combined toxicity of metals: an ecotoxicological evaluation. Water Research 25:679–687.

Entrekin, S., M. Evans-White, B. Johnson, and E. Hagenbuch. 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and the Environment 9:503-511.

Evans, M.S., and A. Talbot. 2012. Investigations of mercury concentrations in walleye and other fish in the Athabasca River ecosystem with increasing oil sands developments. Journal of Environmental Monitoring 14:1989-2003.

Farag, A.M., D. Skaar, D.A. Nimick, E. MacConnell, and C. Hogstrand. 2003. Characterizing aquatic health using salmonid mortality, physiology, and biomass estimates in streams with elevated concentrations of arsenic, cadmium, copper, lead, and zinc in the Boulder River Watershed, Montana. Transactions of the American Fisheries Society 132:450-457.

Ferrari, J.R., T.R. Lookingbill, B. McCormick, P.A. Townsend, and K. Eshleman. 2009. Surface mining and reclamation effects on flood response of watersheds in the central Appalachian Plateau region. Water Resources Research 45(4):DOI: 19.1029/2008WR007109.

Fore, L.S., and C. Grafe. 2002. Using diatoms to assess the biological condition of large rivers in Idaho (U.S.A.). Freshwater Biology 47:2015-2037.

Freedman, J.A., R.F. Carline, and J.R. Stauffer Jr. 2013. Gravel dredging alters diversity and structure of riverine fish assemblages. Freshwater Biology 58:261-274.

French, M., and L. Evans. 1988. The effects of copper and zinc on the growth of the fouling diatoms Amphora and Amphiprora. Biofouling 1:3–18.

Frissell, C. 1993. Topology of extinction and endangerment of native fishes in the Pacific Northwest and California (U.S.A.). Conservation Biology 7(2):342–354.

Fritz, K.M., S. Fulton, B.R. Johnson, C.D. Barton, J.D. Jack, D.A. Word, and R.A. Burke. 2010. Structural and functional characteristics of natural and constructed channels draining a reclaimed mountaintop removal and valley fill coal mine. Journal of the North American Benthological Society 29:673-689.

FWPCA (Federal Water Pollution Control Act). 2002. Available at http://www.epw.senate.gov/water.pdf (accessed March 2014)

García-Cuellar, J. A., F. Arreguín–Sánchez, S. Hernández-Vázquez, and D. Lluch-Cota. 2004. Impacto ecológico de la industria petrolera en la sonda de Campeche, México, tras tres décadas de actividades: una revisión. Interciencia 29(6):311-319.

Garmon, L. 1980. Autopsy of an oil spill. Science News 118(17):267–270.

Ghioto, G. 2002. Pipeline faces fines for spills. Arizona Daily Sun. http://azdailysun.com/pipeline-faces-fines-for-spills/article_65bf9770-e3ae-592b-b379-f3ae1f97f12e.html

Giattina, J.D., R.R. Garton, and D.G. Stevens. 1982. Avoidance of copper and nickel by rainbow trout as monitored by a computer-based data acquisition system. Transactions of the American Fisheries Society 111:491-504.

Goldes, S.A., H.W. Ferguson, R.D. Moccia, and P.Y, Daoust. 1988. Histological effects of the inert suspended clay kaolin on the gills of juvenile rainbow trout, Salmo gairdneri Richardson. Journal of Fish Disease 11:23–33.

Goldstein, J. N., D. F. Woodward, and A. M. Farag. 1999. Movements of adult Chinook salmon during spawning migration in a metals-contaminated system, Coeur d'Alene River, Idaho. Transactions of the American Fisheries Society128:121–129.

Goodman, D., M. Harvey, R. Hughes, W. Kimmerer, K. Rose, and G. Ruggerone. 2011. Klamath River expert panel final report: scientific assessment of two dam removal alternatives on Chinook salmon. U.S. Fish and Wildlife Service. http://klamathrestoration.gov/sites/klamathrestoration.gov/files/FINAL%20Report_Chinook%20Salmon_Klamath%20Expert%20Panels_06%2013%2011.pdf

Gosselin, P., S.E. Hrudey, M.A. Naeth, A. Plourde, R. Therrien, G. Van Der Kraak, and Z. Xu. 2010. The Royal Society of Canada Expert Panel: Environmental and health impacts of Canada's oil sands industry, Ottawa, Ontario.

Govoni J.J., L.A. Settle, and M.A. West. 2003. Trauma to juvenile pinfish and spot inflicted by submarine detonations. Journal of Aquatic Animal Health 15: 111-119.

Grabarkiewicz, J.D., and W.S. Davis. 2008. An introduction to freshwater fishes as biological indicators. EPA-260-R-08-016. U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC.

Green, J. M. Passmore, and H. Childers. 2000. A survey of the conditions of streams in the primary region of mountaintop mining/valley fill coal mining. Mountaintop mining/valley fills in Appalachia. Final programmatic environmental impact statement. Appendix D. U.S. Environmental Protection Agency, Philadelphia, PA. http://www.cet.edu/pdf/mtmvfbenthics.pdf

Gresh, T., J. Lichatowich, and P. Schoonmaker. 2000. An estimation of historic and current levels of salmon production in the Northeast Pacific ecosystem: evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest. Fisheries 25:15–21.

Griffith, M.B., J.M. Lazorchak, and A.T. Herlihy. 2004. Relationships among exceedences of metals criteria, the results of ambient bioassays, and community metrics in mining-impacted streams. Environmental Toxicology and Chemistry 23:1786-1795.

Guzmán del Próo, S. A., E.A. Chávez, F.M. Alatriste, S. de la Campa, G. De la Cruz, L. Gómez, R. Guadarrama, A. Guerra, S. Mille, and D. Torruco. 1986. The impact of the Ixtoc-1 oil spill on zooplankton. Journal of Plankton Research 8:557-581.

Hancock, P.J. 2002. Human impacts on the stream-groundwater exchange zone. Environmental Management 29:763-781.

Hansen, J. A., D. F. Woodward, E. E. Little, A. J. DeLonay, and H. L. Bergman. 1999c. Behavioral avoidance: possible mechanism for explaining abundance and distribution of trout in a metals-impacted river. Environmental Toxicology and Chemistry 18: 313- 17.

Hansen, J. A., P. G. Welsh, J. Lipton, and D. Cacela. 2002. Effects of copper exposure on growth and survival of juvenile bull trout. Transactions of the American Fisheries Society 131: 690-697.

Hansen, J.A., J.C.A. Marr, J. Lipton, D. Cacela, and H.L. Bergman. 1999a. Differences in neurobehavioral responses of Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss)* exposed to copper and cobalt: behavioral avoidance. Environmental Toxicology and Chemistry 18:1972-1978.

Hansen, J.A., J.D Rose, R.A. Jenkins, K.G. Gerow, and H.L. Bergman. 1999b. Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss)* exposed to copper: neurophysiological and histological effects on the olfactory system. Environmental Toxicology and Chemistry 18:1979-1991.

Harper, D. H., A. M. Farag, C. Hogstrand, and E. MacConnell. 2009. Trout density and health in a stream with variable water temperatures and trace element concentrations: does a cold-water source attract trout to increased metal exposure? Environmental Toxicology and Chemistry 28:800-808.

Hartfield, P. D. 1993. Headcuts and their effect on freshwater mussels. Pages 131-141 in K.S. Cummings, A. C. Buchanan, and L. M. Koch (editors). Conservation and management of freshwater mussels. Proceedings of a Upper Mississippi River Conservation Committee Symposium, 12–14 October 1992. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Hecht, S.A., D.H. Baldwin, C.A. Mebane, T. Hawkes, S.J. Gross, and N.L. Scholz. 2007. An overview of sensory effects on juvenile salmonids exposed to dissolved copper: applying a benchmark concentration approach to evaluate sublethal neurobehavioral toxicity. NOAA Technical Memorandum NMFS-NWFSC-83. Seattle, Washington.

Hetrick, F., M. Knittel, and J. Fryer. 1979. Increased susceptibility of rainbow trout to infectious hematopoietic necrosis virus after exposure to copper. Applied and Environmental Microbiology 37:198–201.

Hilborn, R., T. Quinn, D. Schindler, and D. Rogers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences of the United States of America 100:6564–6568.

Hitt, N.P., and D.B. Chambers. 2014. Temporal changes in taxonomic and functional diversity of fish assemblages downstream from mountaintop mining. Freshwater Science 33: 915-926.

Hjermann, D.O., A. Melsom, G. E. Dingsør, J. M. Durant, A. M. Eikeset, L. P. Røed, G. Ottersen, G. Storvik and N. C. Stenseth. 2007. Fish and oil in the Lofoten–Barents Sea system: synoptic review of the effect of oil spills on fish populations. Marine Ecology Progress Series 339:283–299.

Hoehn, R., and D. Sizemore. 1977. Acid mine drainage and its impact on a small Virginia stream. Journal of the American Water Resources Association 13:153–160.

Hoiland, W. K., F. W. Rabe, and R. C. Biggam. 1994. Recovery of macroinvertebrate communities from metal pollution in the South Fork and mainstem of the Coeur d'Alene River, Idaho. Water Environment Research 66:84–88.

Hollibaugh, J., D. Seibert, and W. Thomas. 1980. A comparison of the acute toxicity of ten heavy metals to phytoplankton from Saanich Inlet, B.C., Canada. Estuarine and Coastal Marine Science 10:93–105.

Holm, J., V.P. Palace, K. Wautier, R.E. Evans, C.L. Baron, C. Podemski, P. Siwik and G. Sterling. 2003. Pages 257-274 in H.I. Browman and A. Berit Skiftesvik (editors) The big fish bang. Proceedings of the 26th Annual Larval Fish Conference. 2003. Institute of Marine Research, Postboks 1870 Nordnes, N-5817, Bergen, Norway. ISBN 82-7461-059-8.

Hopkins, R.L. II, and J.C. Roush. 2013. Effects of mountaintop mining on fish distributions in central Appalachia. Ecology of Freshwater Fish doi: 10.1111/eff.12061

Hose, J.E., M.D. McGurk, G.D. Marty, D.E. Hinton, E.D. Brown, and T.T. Baker. 1996. Sublethal effects of the Exxon Valdez oil spill on herring embryos and larvae: morphological, cytogenetic, and histopathological assessments, 1989–1991. Canadian Journal of Fisheries and Aquatic Sciences 53: 2355–2365.

Howard, H.S., B. Berrang, M. Flexner, G. Pond, and S. Call. 2001. Kentucky mountaintop mining benthic macroinvertebrate survey. In: Mountaintop mining/valley fills in Appalachia. Final programmatic environmental impact statement. Appendix D. U.S. Environmental Protection Agency, Philadelphia, Pennsylvania. http://nepis.epa.gov/Exe/ZyNET.exe/20005XA6.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2000+Thru+2005&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C00thru05%5CTxt%5C00000008%5C20005XA6.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

Hughes, R.M. 1985. Use of watershed characteristics to select control streams for estimating effects of metal mining wastes on extensively disturbed streams. Environmental Management 9:253-262.

Hughes, R.M. 2014a. Fisheries ethics, or what do you want to do with your scientific knowledge in addition to earning a living? Fisheries 39:195.

Hughes, R.M. 2014b. Monitoring: garbage in yields garbage out. Fisheries 39: 243.

Hughes, R.M., and D.V. Peck. 2008. Acquiring data for large aquatic resource surveys: the art of compromise among science, logistics, and reality. Journal of the North American Benthological Society 27:837-859.

ICMM (International Council on Mining and Minerals). 2003. Ten principles of sustainable development framework. http://www.icmm.com/our-work/sustainable-development-framework/10-principles.

ICOLD (International Commission on Large Dams). 2001. Tailings dams—risk of dangerous occurrences: lessons learnt from practical experiences. Bulletin 121. Paris, France.

IFC (International Finance Corporation) 2012. International Finance Corporation's Guidance Notes: Performance Standards on Environmental and Social Sustainability. Available at: http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/ifc+sustainability/our+approach/risk+management/performance+standards/environmental+and+social+performance+standards+and+guidance+notes ; Accessed June 2014.

IMST (Independent Multidisciplinary Science Team). 2002. Technical review of Oregon Water Resources Research Institute. 1995. Gravel disturbance impacts on salmon habitat and stream health. Corvallis, Oregon.

INAC (Indian and Northern Affairs Canada). 2007. Oil and gas exploration and production in the Northwest Territories. Petroleum and Development Division, Yellowknife, NT. Catalogue No.R2-464/2007. ISBN 978-0-662-49966-4. Available from http://www.aadnc-aandc.gc.ca/eng/1100100023703/1100100023705 [Accessed 27 May 2013].

Incardona, J., T.K. Collier, and N.L. Scholz. 2011. Oil spills and fish health: exposing the heart of the matter. Journal of Exposure Science and Environmental Epidemiology. 21: 3-4.

International Labor Organization Convention 169 1989. Indigenous and tribal peoples. http://www.ilo.org/indigenous/Conventions/no169/lang--en/index.htm (Accessed August 2015).

Irvine, K.M., S.W. Miller, R.K. Al-Chokhachy, E.K. Archer, B.B. Roper, B.B., and J.L. Kershner. 2014. Empirical evaluation of the conceptual model underpinning a regional aquatic long-term monitoring program using causal modeling. Ecological Indicators 50: 8-23.

ISP (Independent Science Panel). 2000. Recommendations for monitoring salmonid recovery in Washington State. Report 2000-2. Olympia, Washington.

Jennings, S.R., D.R. Neuman, and P.S. Blicker. 2008. Acid mine drainage and effects on fish health and ecology: a review. Reclamation Research Group Publication, Bozeman, Montana.

Jernelöv, A and O. Linden. 1981. Ixtoc I: a case study of the world's largest oil spill. Ambio 10(6):299-306.

Johnson, A., J. White, and D. Huntamer. 1997. Effects of Holden Mine on the water, sediment, and benthic invertebrates of Railroad Creek (Lake Chelan). Publication 97-330. Washington Department of Ecology, Olympia.

Kaeser, A. J., and W. E. Sharpe. 2001. The influence of acidic runoff episodes on slimy sculpin reproduction in Stone Run. Transactions of the American Fisheries Society 130: 1106-1115.

Kaufmann, P.R, A.T. Herlihy, M.E. Mitch, J.J. Messer, and W.S. Overton. 1991. Stream chemistry in the eastern United States: synoptic survey design, acid-base status, and regional patterns. Water Resources Research 27:611-627.

Keller, J. 2015. The maddening silver lining to BP’s $18.7 billion penalty. Pacific Standard. http://www.psmag.com/politics-and-law/how-come-bp-gets-to-treat-fines-like-business-expenses-but-i-cant-even-get-out-of-this-parking-ticket.

Kelly, E.N., D.W. Schindler, P.V. Hodson, J.W. Short, R. Radmanovich, and C.C. Nielsen. 2010. Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries. 2010. Proceedings of the National Academy of Sciences of the United States of America 107:15178-16183.

Kennedy, A.J., D.S. Cherry, and R.J. Currie. 2004. Evaluation of ecologically relevant bioassays for a lotic system impacted by a coal-mine effluent, using Isonychia. Environmental Monitoring and Assessment 95:37−55.

Kim, A.G., B. Heisey, R. Kleinmann, and M. Duel. 1982. Acid mine drainage: control and abatement research. Information Circular 8905, U.S. Bureau of Mines, Washington, DC

Kimmel, W.G. 1983. The impact of acid mine drainage on the stream ecosystem. Pages 424-437 in S. K. Majumdar and W. W. Miller (editors), Pennsylvania coal: resources, technology, and utilization. Pennsylvania Academic Science Publications.

Klinkenberg, M., and S. Pratt. 2013. Massive coal mine leak damaged fisheries, habitat. Edmonton Journal. November 12, 2013.

Kondolf, G.M. 1994. Geomorphic and environmental effects of instream gravel mining. Landscape and Urban Planning 28:225–243.

Kondolf, G.M. 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21:533–551.

Kondolf, G.M. and M.L. Swanson. 1993. Channel adjustments to reservoir construction and gravel extraction along Stony Creek, California. Environmental Geology 21:256-269.

Kort, E.A., C. Frankenberg, K.R. Costigan, R. Lindenmaier, M.K. Dubey, and D. Wunch. 2014. Four corners: the largest US methane anomaly viewed from space. Geophysical Research Letters 41:6898-6903.

Kuipers, J. R., A. S. Maest, K. A. MacHardy, and G. Lawson. 2006. Comparison of predicted and actual water quality at hardrock mines: the reliability of predictions in environmental impact statements. Kuipers and Associates, Butte, Montana.

Kurek, J., J.L. Kirk, D.C.G. Muir, X. Wang, M.S. Evans, and J.P. Smol. 2013. Legacy of a half century of Athabasca oil sands development recorded by lake ecosystems. Proceedings of the National Academy of Sciences of the United States of America 110: doi/10.1073/pnas.1217675110

Landers, D.H., S.L. Simonich, D.A. Jaffe, L.H. Geiser, D.H. Campbell, D.H., A.R. Schwindt, C.B. Schreck, M.L. Kent, W.D. Hafner, H.E. Taylor, K.J. Hagman, S. Usenko, L.K. Ackerman, J.E. Schrlau, NL. Rose, T.F. Blett, and M.M. Erway. 2008, The fate, transport, and ecological impacts of airborne contaminants in western national parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Corvallis, Oregon.

Lapointe, N.W.R., S.J. Cooke, J.G. Imhof, D. Boisclair, J.M. Casselman, R.A. Curry, O.E. Langer, R.L. McLaughlin, C.K. Minns, J.R. Post, M. Power, J.B. Rasmussen, J.D. Reynolds, J.S. Richardson, and W.M. Tonn. 2014. Principles for ensuring healthy and productive freshwater ecosystems that support sustainable fisheries. Environmental Review 22:110-134.

Lavoie, I., M. Lavoie, and C. Fortin. 2012. A mine of information: benthic algal communities as biomonitors of metal contamination from abandoned tailings. Science of the Total Environment 425:231-241.

Levit, S.M., and J.R. Kuipers. 2000. Reclamation bonding in Montana. Center for Science in Public Participation. Polson, Montana.

Maest, A. S., J. R. Kuipers, C. L. Travers, and D.A. Atkins. 2005. Predicting water quality at hardrock mines: methods and models, uncertainties, and state-of-the-art. Kuipers and Associates, Butte, Montana.

Maret, T. R., and D. E. MacCoy. 2002. Fish assemblages and environmental variables associated with hard-rock mining in the Coeur d’Alene River Basin, Idaho. Transactions of the American Fisheries Society 131:865–884.

Maret, T. R., D. J. Cain, D. E. MacCoy, and T. M. Short. 2003. Response of benthic invertebrate assemblages to metal exposure and bioaccumulation associated with hard-rock mining in northwestern streams, USA. Journal of the North American Benthological Society 22:598-620.

McCormick, F.H., B.H. Hill, L.P. Parrish, and W.T. Willingham. 1994. Mining impacts on fish assemblages in the Eagle and Arkansas Rivers, Colorado. Journal of Freshwater Ecology 9:175-179.

McIntyre, J.K., D.H. Baldwin, D.A. Beauchamp, and N.L. Scholz. 2012. Low-level copper exposures increase visibility and vulnerability of juvenile coho salmon to cutthroat trout predators. Ecological Applications 22:1460-1471.

McIntyre, J.K., D.H. Baldwin, J.P. Meador, and N.L. Scholz. 2008. Chemosensory deprivation in juvenile coho salmon exposed to dissolved copper under varying water chemistry conditions. Environmental Science and Technology 42:1352-1358.

McLeay, D.J., G.L. Ennis, I.K. Birtwell, and G.F. Hartman. 1984. Effects on arctic grayling (Thymallus arcticus) of prolonged exposure to Yukon placer mining sediment: a laboratory study. Canadian Technical Report of Fisheries and Aquatic Sciences 1241:30–34.

Meador, J. P., F. C. Sommers, G. M. Ylitalo, and C. A. Sloan. 2006. Altered growth and related physiological responses in juvenile Chinook salmon (*Oncorhynchus tshawytscha*) from dietary exposure to polycyclic aromatic hydrocarbons (PAHs). Canadian Journal of Fisheries and Aquatic Sciences 63:2364–2376.

Meador, M.R., and A.O. Layher. 1998. Instream sand and gravel mining: environmental issues and regulatory process in the United States. Fisheries 23(11):6-13.

Mebane, C. A., and D.L. Arthaud. 2010. Extrapolating growth reductions in fish to changes in population extinction risks: copper and Chinook salmon. Human and Ecological Risk Assessment: An International Journal 16:1026--1065

Menendez, R. 1978. Effects of acid water on Shavers Fork – a case history. Surface mining and fish/wildlife needs in the Eastern United States., U.S. Fish and Wildlife Service. FWS/OBS 78/81: 160-169.

Merricks, T.C., D.S. Cherry, C.E. Zipper, R.J. Currie, and T.W. Valenti. 2007. Coal-mine hollow fill and settling pond influences on headwater streams in southern West Virginia, USA. Environmental Monitoring and Assessment 129:359−378.

Messinger, T., and K.S. Paybins. 2003. Relations between precipitation and daily and monthly mean flows in gaged, unmined and valley-filled watersheds, Ballard Fork, West Virginia, 1999–2001. Water-Resources Investigations Report 03-4113, U.S. Geological Survey, Charleston, West Virginia.

Miranda, M., D. Chambers, and C. Coumans. 2005. Framework for responsible mining: a guide to evolving standards. Center for Science in Public Participation and World Wildlife Fund. www.frameworkforresponsiblemining.org.

Mironov, O.G. 1972. Effect of oil pollution on flora and fauna of the Black Sea. Pages 222-224 in M. Ruivo (editor) Marine pollution and sea life: fish. Fishing Books Limited, London, England.

Morin, S., A. Cordonier, I. Lavoie, A Arini, S. Blanco, T.T. Duong, E. Tomés, B. Bonet, N. Corcoll, L. Faggiano, M. Laviale, F. Pérès, E. Becares, M. Coste, A Feurtet-Mazel, C. Fortin, H. Guasch, S. Sabater. 2012. Consistency in diatom response to metal-contaminated environments. Pages 117-146 in Emerging and priority pollutants in rivers: bringing science into river management plans, H. Guasch, A. Ginebreda, and A. Geiszinger (editors). Springer-Verlag, Berlin.

Morin, S., T.T. Duong, A. Dabrin, A. Coynel, O. Herlory, M. Baudrimont, F. Delmas, G. Durrieu, J. Schafer, P. Winterton, G. Blanc, and M. Coste. 2008. Long-term survey of heavy-metal pollution, biofilm contamination and diatom community structure in the Riou Mort watershed, southwest France. Environmental Pollution 151:532-542.

Moya, N., R.M. Hughes, E. Dominguez, F-M Gibon, E Goita, and T. Oberdorff. 2011. Macroinvertebrate-based multimetric predictive models for measuring the biotic condition of Bolivian streams. Ecological Indicators 11:840-847.

Munshower, F.F., D.R. Neuman, S.R. Jennings, and G.R. Phillips. 1997. Effects of land reclamation techniques on runoff water quality from the Clark Fork River floodplain, Montana. Office of Research and Development, U.S. Environmental Protection Agency, 199-208. Washington, DC,

Myers, M.S., L.L. Johnson, and T.K. Collier. 2003. Establishing the causal relationship between polycyclic aromatic hydrocarbon (PAH) exposure and hepatic neoplasms and neoplasia-related liver lesions in English sole (Pleuronectes vetulus). Human and Ecological Risk Assessment 9: 67–94.

National Academy of Sciences. 1999. Hardrock mining on federal lands. National Research Council. National Academy Press, Washington, DC.

______. 2005. Superfund and mining megasites—lessons from the Coeur d’Alene River Basin. National Academies Press, Washington, D.C.

Nayar, S., B. Goh, and L. Chou. 2004. Environmental impact of heavy metals from dredged and resuspended sediments on phytoplankton and bacteria assessed in situ mesocosms. Ecotoxicology and Environmental Safety 59:349–369.

Negley, T.L., and K.N. Eshleman. 2006. Comparison of stormflow responses of surface-mined and forested watersheds in the Appalachian Mountains, USA. Hydrological Processes 20(16):3467−3483.

Nehlsen, W., J. Williams, and J. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries. 16(2): 4-21.

Nelson, J. 2014. Loophole lets healthy lakes be converted into waste dumps. CCPA Monitor 20 (7):18 – 20.

NEPA (National Environmental Policy Act). 1969. (Available at: http://energy.gov/sites/prod/files/nepapub/nepa_documents/RedDont/Req-NEPA.pdf. Accessed February 2014).

NMFS (National Marine Fisheries Service). 1996. NMFS National gravel extraction policy. National Oceanic and Atmospheric Administration (available at http://www.nmfs.noaa.gov/op/pds/documents/03/401/03-401-11.pdf).

NOAA (National Oceanic and Atmospheric Administration). 2004. Coastal restoration: innovative and successful monitoring and adaptive management approaches http://www.csc.noaa.gov/coastal/management/monitor.htm. Accessed August 2015).

______. 2012. Natural resource damage assessment: April 2012 status update for the Deepwater Horizon oil spill. http://www.gulfspillrestoration.noaa.gov/wp-content/uploads/FINAL_NRDA_StatusUpdate_April2012.pdf (accessed 8 June 2013).

NOAA-Fisheries. 2004. Sediment removal from freshwater salmonid habitat: guidelines to NOAA Fisheries staff for the evaluation of sediment removal actions from California streams. National Oceanic and Atmospheric Administration, Southwest Region, Long Beach, California.

Nordstrom, D.K., and C.N. Alpers. 1999. Negative pH, efflorescent mineralogy, and consequences for environmental restoration at the Iron Mountain Superfund site, California. Proceedings of the National Academy of Science of the United States of America 96:3455-3462.

Nordstrom, D.K., E.A. Jenne, and R.C. Averett. 1977. Heavy metal discharges into Shasta Lake and Keswick Reservoir on the Sacramento River, California – a reconnaissance during low flow. Open-File Report 76-49. U.S. Geological Survey.

NRC (National Research Council). 2004. Endangered and threatened fishes in the Klamath River basin: causes of decline and strategies for recovery. The National Academies Press, Washington, D.C.

_____. 2005. Superfund and mining megasites: lessons from the Coeur d’Alene River Basin. National Academies Press, Washington, DC.

Nushagak-Mulchatna Watershed Council. 2011. Standards and practices for environmentally responsible mining in the Nushagak River Watershed. http://takshanuk.org/sites/default/files/FINAL%20-%20A%20Framework%20for%20Responsible%20Mining%20in%20the%20Nushagak%20River%20Watershed%20.pdf (Accessed August 2015).

OEPA (Ohio Environmental Protection Agency). 2010. Biological and water quality study of the Captina Creek Watershed 2009. Division of Surface Water. http://www.epa.state.oh.us/portals/35/documents/CaptinaCreekTSD2009.pdf (January 2016).

O’Neal, S., and R.M. Hughes. 2012. Fisheries and hard rock mining: AFS symposium synopsis. Fisheries 37:54-55.

OWRRI (Oregon Water Resources Research Institute). 1995. Gravel disturbance impacts on salmon habitat and stream health. Volumes 1 and 2. Oregon Water Resources Research Institute, Oregon State University, Corvallis.

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key K. Lindsey, E. Maier-Reimer, R. Matear, P. Monfrey, A. Mouchet, R.G. Najjar, G.-K. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schiltzer, R.D. Slater, I.J. Totterdell, M.-F. Weirig, Y. Yamanaka, and A. Yoo. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437:681-686.

Ott, A. 2004. Aquatic biomonitoring at Red Dog Mine, 2003. Resources Technical

Palace, V.P., C. Baron, R.E. Evans, J. Holm, S. Kollar, K. Wautier, J. Werner, P. Siwik, G. Sterling and C.F. Johnson. 2004. An assessment of the potential for selenium to impair reproduction in bull trout, Salvelinus confluentus, from an area of active coal mining. Environmental Biology of Fishes 70:169-174.

Palmer, M.A., E.S. Bernhardt, W.H. Schlesinger, K.N. Eshleman, E. Foufoula-Georgiou, M.S. Hendryx, A.D. Lemly, G.E. Likens, O.L. Loucks, M.E. Power, P.S. White, and P.R. Wilcock. 2010. Mountaintop mining consequences. Science 327:148-149.

Peterson, S.A., J. Van Sickle, A.T. Herlihy, and R.M. Hughes. 2007. Mercury concentration in fish from streams and rivers throughout the western United States. Environmental Science and Technology 41:58-65.

Peterson, S.A., J. Van Sickle, R.M. Hughes, J.A. Schacher, and S.F. Echols. 2005. A biopsy procedure for determining filet and predicting whole fish mercury concentration. Archives of Environmental Contamination and Toxicology 48:99-107.

Pew Foundation. 2009. Reforming the U.S. hardrock mining law of 1872: the price of inaction. Pew Campaign for Responsible Mining, Washington, D.C. Available at: http://www.pewtrusts.org/en/research-and-analysis/reports/2009/01/27/reforming-the-us-hardrock-mining-law-of-1872-the-price-of-inaction.

Pond, G.J. 2010. Patterns of Ephemeroptera taxa loss in Appalachian headwater streams (Kentucky, USA). Hydrobiologia 641:185−201.

Pond, G.J., M.E. Passmore, F.A. Borsuk, L. Reynolds, and C.J. Rose. 2008. Downstream effects of mountaintop coal mining: comparing biological conditions using family- and genus-level macroinvertebrate bioassessment tools. Journal of the North American Benthological Society 27:717–737.

Post, J.A., and J.R. Hutchings. 2013. Gutting Canada's Fisheries Act: no fishery, no fish habitat protection. Fisheries 38:497-501.

Rempel, L.L., and M. Church. 2009. Physical and ecological response to disturbance by gravel mining in a large alluvial river. Canadian Journal of Fisheries and Aquatic Sciences 66:52-71.

Reynaud, S., and P. Deschaux. 2006. The effects of polycyclic aromatic hydrocarbons on the immune system of fish: a review. Aquatic Toxicology 77:229–238.

Reynolds, J.B., R.C. Simons, and A.R. Burkholder. 1989. Effects of placer mining discharge on health and food for Arctic grayling. Water Resources Bulletin 25: 625-635.

Reynolds, L. 2009. Update on Dunkard Creek. Website. Available at: http://www.energyindepth.org/wp-content/uploads/2009/12/EPA_dunkard_creek.pdf. Accessed 14 June 2013.

Rice, S.D., R.B. Spies, D.A. Wolfe, and B.A. Wright (editors). 1996. Proceedings of the Exxon Valdez Oil Spill Symposium. Symposium 18. American Fisheries Society, Bethesda, Maryland.

Robertson, M.J., D.A. Scruton, R.S. Gregory, and K.D. Clarke. 2006. Effect of suspended sediment on freshwater fish and fish habitat. Canadian Technical Report of Fisheries and Aquatic Sciences 2644: v + 37p.

Roni, P. (editor). 2005. Monitoring stream and watershed restoration. American Fisheries Society, Bethesda, Maryland.

Roni, P., K. Hanson, and T. Beechie. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management 28:856–890.

Ross, M.S., A. dos Santos Pereira, J. Fennell, M. Davies, J. Johnson, L. Sliva, and J.W. Martin. 2012. Quantitative and qualitative analysis of naphthenic acids in natural waters surrounding the Canadian oil sands industry. Environmental Science and Technology 46:12796-12805

Ruelas-Inzunza J., C. Green-Ruiz , M. Zavala-Nevárez, M. Soto-Jiménez. 2011. Biomonitoring of Cd, Cr, Hg and Pb in the Baluarte River basin associated to a mining area (NW Mexico). Science of the Total Environment 409:3527–3536

Sandahl, J.F., G. Miyasaka, N. Koide, and H. Ueda. 2006. Olfactory inhibition and recovery in chum salmon (*Oncorhynchus keta*) following copper exposure. Canadian Journal of Fisheries and Aquatic Sciences 63:1840–1847.

Schein, A., J.A. Scott, L. Mos, and P.V. Hodson. 2009. Oil dispersion increases the apparent bioavailability and toxicity of diesel to rainbow trout (Oncorhynchus mykiss). Environmental Toxicology and Chemistry 28: 595-602.

Schindler, D., R. Hilborn, B. Chasco, C. Boatright, T. Quinn, L. Rogers, and M. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465:609–612.

Schmidt, T.S., W.H. Clements, K.A. Mitchell, S.E. Church, R.B. Wanty, D.L. Fey, P.L. Verplanck, and C.A. San Juan. 2010. Development of a new toxic-unit model for the bioassessment of metals in streams. Environmental Toxicology and Chemistry 29:2432-2442.

Schnoor, J.L. 2013. Keystone XL: pipeline to nowhere. Environmental Science and Technology 47:3943-3943.

Servizi, J.A. and D.W. Martens. 1987. Some effects of suspended Fraser River sediments on sockeye salmon (Oncorhynchus nerka). Canadian Special Publication of Fisheries and Aquatic Sciences 96:254–264.

Sherlock, E. J., R. W. Lawrence, and R. Poulin. 1995. On the neutralization of acid rock drainage by carbonate and silicate minerals. Environmental Geology 25: 43-54.

Sigler, J.W., T.C. Bjornn, and F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelhead and coho salmon. Transactions of the American Fisheries Society 113:142–150.

Singleton, H.J. 1985. Water quality criteria for particulate matter: Technical appendix. British Columbia Ministry of the Environment Lands and Parks, Victoria, BC.

Smith, K.L., and M.L. Jones. 2005. Watershed-level sampling effort requirements for determining riverine fish species composition. Canadian Journal of Fisheries and Aquatic Sciences 62:1580-1588.

Smith, D.R., C.D. Snyder, N.P. Hitt, J.A. Young, and S.P. Faulkner. 2012. Shale gas development and brook trout: scaling best management practices to anticipate cumulative effects. Environmental Practice 14:1-16.

Soraghan, M. 2011. In fish-kill mystery, EPA scientist points at shale drilling. Website. Available at: http://www.nytimes.com/gwire/2011/10/12/12greenwire-in-fish-kill-mystery-epa-scientist-points-at-s-86563.html?pagewanted=all. Accessed 14 June 2013.

Soto-Jiménez M,, F. Páez-Osuna, and F. Morales-Hernández. 2001. Selected trace metals in oyster (Crassostrea iridescens) and sediments from the discharge zone of the submarine sewage outfall in Mazatlán Bay (southeast Gulf of California): chemical fractions and bioaccumulation factors. Environmental Pollution 114:357–70.

Soucek, D. J., D. S. Cherry, R. J. Currie, H. A. Latimer, and G. C. Trent. 2000. Laboratory and field validation in an integrative assessment of an acid mine drainage-impacted watershed. Environmental Toxicology and Chemistry 19: 1036-1043.

Sourcewatch. 2010. TVA Kingston fossil plant coal ash spill. http://www.sourcewatch.org/index.php/TVA_Kingston_Fossil_Plant_coal_ash_spill (Accessed August 2015).

Spence, B., G. Lomnicky, R. Hughes, and R. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. National Marine Fisheries Service, Portland, Oregon.

Stacey, S.L., L.L. Brink, J.C. Larkin, Y. Sadovsky, B.D. Goldstein, B.R. Pitt, and E.O. Talbott. 2015. Perinatal outcomes and unconventional natural gas operations in Southwest Pennsylvania. PLOS One DOI: 10.1371/journal.pone.0126425

Starnes L.B., and D.C. Gasper. 1995. Effects of surface mining on aquatic resources in North America. AFS Policy Statement # 13: Available at: http://fisheries.org/docs/policy_statements/policy_13f.pdf

Stoddard, J. L., D. V. Peck, S. G. Paulsen, J. Van Sickle, C. P. Hawkins, A. T. Herlihy, R. M. Hughes, P. R. Kaufmann, D. P. Larsen, G. Lomnicky, A. R. Olsen, S. A. Peterson, P. L. Ringold, and T. R. Whittier. 2005. An ecological assessment of western streams and rivers. EPA 620/R-05/005, U.S. Environmental Protection Agency, Washington, DC.

Swales, S., A.W. Storey, and K.A. Bakowa. 2000. Temporal and spatial variations in fish catches in the Fly River system in Papua New Guinea and the possible effects of the Ok Tedi copper mine. Environmental Biology of Fishes 57:75–95.

Swales, S., A.W. Storey, I.D. Roderick, B.S. Figa, K.A. Bakowa, and C.D. Tenakanai. 1998. Biological monitoring of the impacts of the Ok Tedi copper mine on fish populations in the Fly River system, Papua New Guinea. The Science of the Total Environment 214:99-111.

Swanson, G. A. 1982. Summary of wildlife values of gravel pits symposium. Pages 1-5 in W. D. Svedarsky and R. O. Crawford, editors. Wildlife values of gravel pits. University of Minnesota Miscellaneous Publication 17, Minneapolis.

Teal, J. M., and R. W. Howarth. 1984. Oil spill studies: a review of ecological effects. Environmental Management 8:27-44.

Thomas, W., J. Hollibaugh, D. Seibert, and G. Wallace Jr. 1980. Toxicity of a mixture of ten metals to phytoplankton. Marine Ecology Progress Series 2:213–220.

Thornton, I. 1996. Impacts of mining on the environment: some local, regional and global issues. Applied Geochemistry 11:355–61.

Upton, H.E. 2011. The Deepwater Horizon oil spill and the Gulf of Mexico fishing industry. Congressional Research Service, Washington, DC.

USDJ (U.S. Department of Justice). 2012. BP Exploration and Production Inc. agrees to plead guilty to felony manslaughter, environmental crimes, and obstruction of Congress surrounding Deepwater Horizon incident. Justice News: 15 November.

USEPA (U.S. Environmental Protection Agency). 1994. Acid mine drainage prediction. EPA530-R-94-036. Washington, DC. Available at: www.epa.gov/osw/nonhaz/industrial/special/mining/techdocs/amd.pdf

_____. 1995. Human health and environmental damages from mining and mineral processing wastes. Office of Solid Waste, Washington DC.

USEPA. 2000. Liquid assets: America’s water resources at a turning point. EPA-840, Washington, DC.

_____. 2004. Nationwide identification of hardrock mining sites. Evaluation report. Report 2004-P-00005. Office of Inspector General, Washington, DC.

_____. 2005. Mountaintop mining/valley fills in Appalachia. Final programmatic environmental impact statement. U.S. Environmental Protection Agency, Philadelphia, Pennsylvania. Available online at http://nepis.epa.gov/Exe/ZyNET.exe/20005XA6.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2000+Thru+2005&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C00thru05%5CTxt%5C00000008%5C20005XA6.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL.

_____. 2009. The effects of mountaintop mines and valley fills on aquatic ecosystems of the central Appalachian coalfields. EPA/600/R-09/138A. Washington, DC.

_____. 2010. A field-based aquatic life benchmark for conductivity in central Appalachian streams. EPA/600/R-10/023A. Office of Research and Development, Washington, DC.

_____. 2014. An assessment of potential mining impacts on salmon ecosystems of Bristol Bay, Alaska. EPA 910-R-14-001A-C, ES. Washington, D.C.

_____. 2015. Assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources. EPA/600/R-15/047c. Office of Research & Development. Washington, DC.

USFS (U.S. Forest Service). 1993. Acid mine drainage from impact of hardrock mining on the National Forests: a management challenge. Program Aid 1505. USFS, Washington, DC.

USFWS (U.S. Fish and Wildlife Service). 2004. Interim endangered and threatened species recovery planning guidance Version 1.3. Silver Spring, Maryland.

_______. 2006. Sediment removal from active stream channels in Oregon: considerations for the evaluation of sediment removal actions from Oregon streams. Version 1.0. U.S. Fish and Wildlife Service, National Marinde Fisheries Service, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency. http://www.fws.gov/oregonfwo/ExternalAffairs/Topics/Documents/GravelMining-SedimentRemovalFromActiveStreamChannels.pdf

USGAO (U.S. General Accounting Office). 1993. Natural resources restoration: use of Exxon Valdez oil spill settlement funds. GAO/RCED-93-206BR. Washington, DC.

USGS (U.S. Geological Survey). 2009. Mineral resources program http://tin.er.usgs.gov/metadata/mineplant.faq.html. (August 2009).

_____. 2012. National coal resources data system ustratigraphic (USTRAT) database, http://energy.usgs.gov/Tools/NationalCoalResourcesDataSystem.aspx.(September 2012).

Wang, N., C.G. Ingersoll, R.A. Consbrock, J.L. Kunz, D.K. Hardesty, W.G. Brumbaugh, and C.A. Mebane. 2014. Chronic sensitivity of white sturgeon (*Acipenser transmontanus)* and rainbow trout (*Oncorhynchus mykiss*) to cadmium, copper, lead, or zinc in water-only laboratory exposures. Pages 35-70 in C.G. Ingersoll and C.A. Mebane (editors) Acute and chronic sensitivity of white sturgeon (*Acipenser transmontanus)* and rainbow trout (*Oncorhynchus mykiss*) to cadmium, copper, lead, or zinc in laboratory water-only exposures. Scientific Investigations Report 2013–5204, U.S. Geological Survey, http://dx.doi.org/10.3133/sir20135204.

Warner, R.W. 1971. Distribution of biota in a stream polluted by acid mine drainage. Ohio Journal of Science 71: 202-215.

Waters, T. 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society, Bethesda, Maryland.

Webb, E., S. Bushkin-Bedient, A. Chang, C.D. Kassotis, V. Balise, and S.C. Nagel. 2014. Developmental and reproductive effects of chemicals associated with unconventional oil and natural gas operations. Reviews on Environmental Health 29:307-318.

Weltman-Fahs, M., and J.M. Taylor. 2013. Hydraulic fracturing and brook trout habitat in the Marcellus Shale region: potential impacts and research needs. Fisheries 38:4-15.

Whittier, T.R., R.M. Hughes, G.A. Lomnicky, and D.V. Peck. 2007. Fish and amphibian tolerance values and an assemblage tolerance index for streams and rivers in the western USA. Transactions of the American Fisheries Society 136:254-271.

Wikipedia. 2013. 1969 Santa Barbara oil spill.

Wiley, J.B., and F.D. Brogan. 2003. Comparison of peak discharges among sites with and without valley fills for the July 8–9, 2001, flood in the headwaters of Clear Fork, Coal River basin, mountaintop coal-mining region, southern West Virginia. Report 03-133, U.S. Geological Survey, Charleston, West Virginia. http://pubs.usgs.gov/of/2003/ofr03-133/pdf/ofr03133.pdf.

Wiley, J.B., R.D. Evaldi, J.H. Eychaner, and D.B. Chambers. 2001. Reconnaissance of stream geomorphology, low streamflow, and stream temperature in the mountaintop coal-mining region, southern West Virginia, 1999-2000. U.S. Geological Survey, Charleston, West Virginia. http://pubs.usgs.gov/wri/wri014092/pdf/wri01-4092.book_new.pdf.

WISE (World Information Service on Energy). 2008. The Inez coal tailings dam failure (Kentucky, USA). WISE Uranium Project. http://www.wise-uranium.org/mdafin.html. (June 2011).

_____ . 2011. Chronology of major tailings dam failures. WISE Uranium Project. http://www.wise-uranium.org/mdaf.html. (April 2011).

Wolfe M.F., J.A. Schlosser, G.L.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema, and M.L. Sowby. 2001. Influence of dispersants on the bioavailability and trophic transfer of petroleum hydrocarbons to larval topsmelt (Antherinops affinis). Aquatic Toxicology 52:49-60.

Wolfe, M.F., J.A. Schlosser, G.L.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema, and M.L. Sowby. 1997. Influence of dispersants on the bioavailability and trophic transfer of petroleum hydrocarbons to primary levels of a marine food chain. Aquatic Toxicology 42: 211-227.

Wood, M.C. 2014. Nature’s trust: environmental law for a new ecological age. Cambridge University Press. New York, NY.

Woodward, D. F., J. K. Goldstein, A. M. Farag, and W. G. Brunbaugh. 1997. Cutthroat trout avoidance of metals and conditions characteristic of a mining waste site: Coeur d’Alene River, Idaho. Transactions of the American Fisheries Society 126: 699-706.

Woody, C.A., R.M. Hughes, E.J. Wagner, T.P. Quinn, L.H. Roulsen, L.M. Martin, and K. Griswold. 2010. The U.S. General Mining Law of 1872: change is overdue. Fisheries 35:321-33.

Woodward–Clyde Consultants, Inc. 1980. Gravel removal guidelines manual for arctic and subarctic floodplains: report to U.S. Fish and Wildlife Service. Contract FWS-14-16-0008-970, WWS/OBS-80/09.

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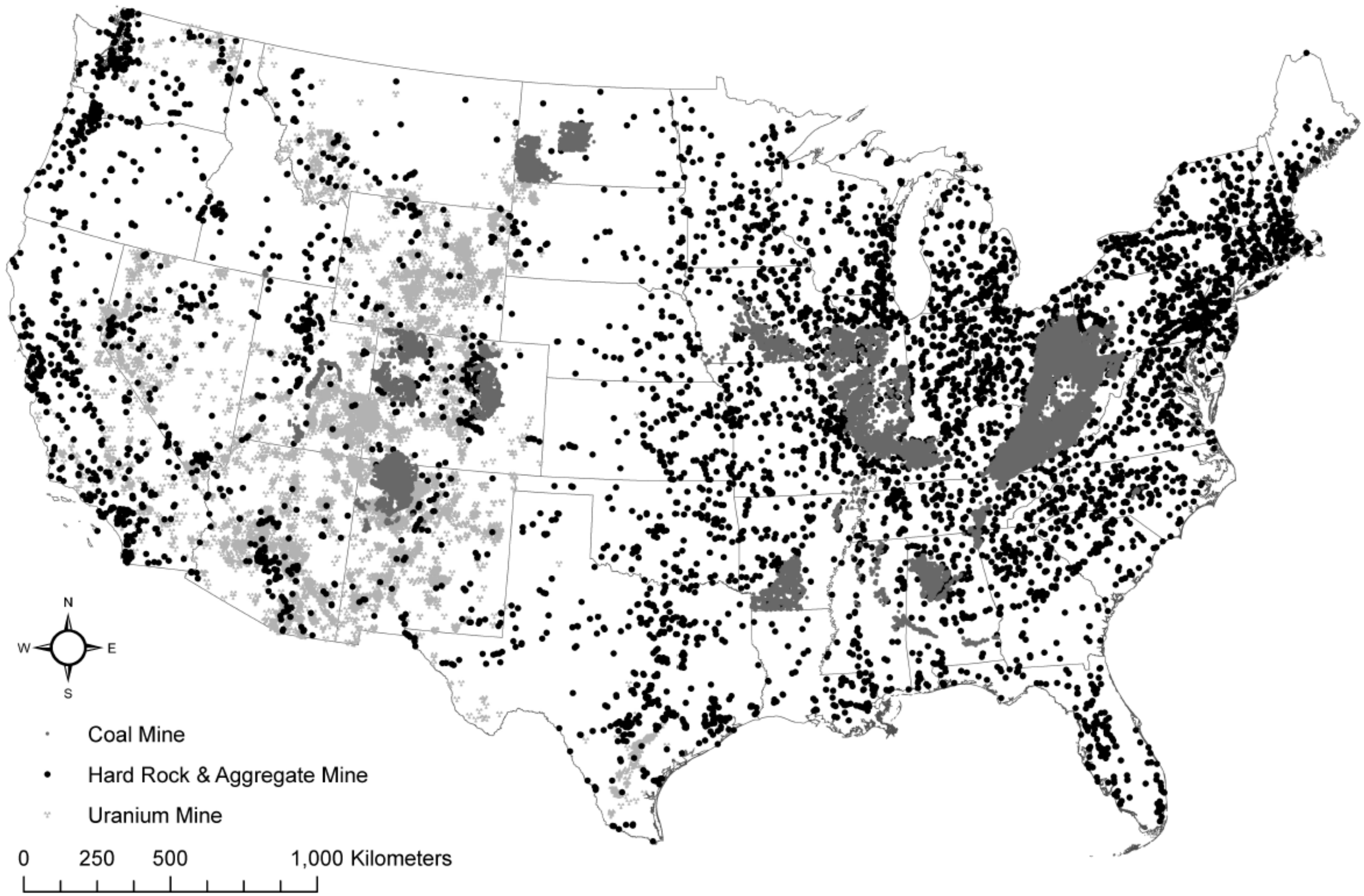

Figure 1. Mines in the conterminous US (n=93,674). Coal mine data points include coal mines (n=64,541) and support mining activities (n=96,710; not included in total for U.S. (USGS 2012). Hard rock and aggregate mine data points (n=6,785) comprise non-energy mining actives including ferrous, gravel, precious, and non-precious mineral mining and processing (USGS 2009). Uranium mine data points (n=22,348) are from USEPA (2006).

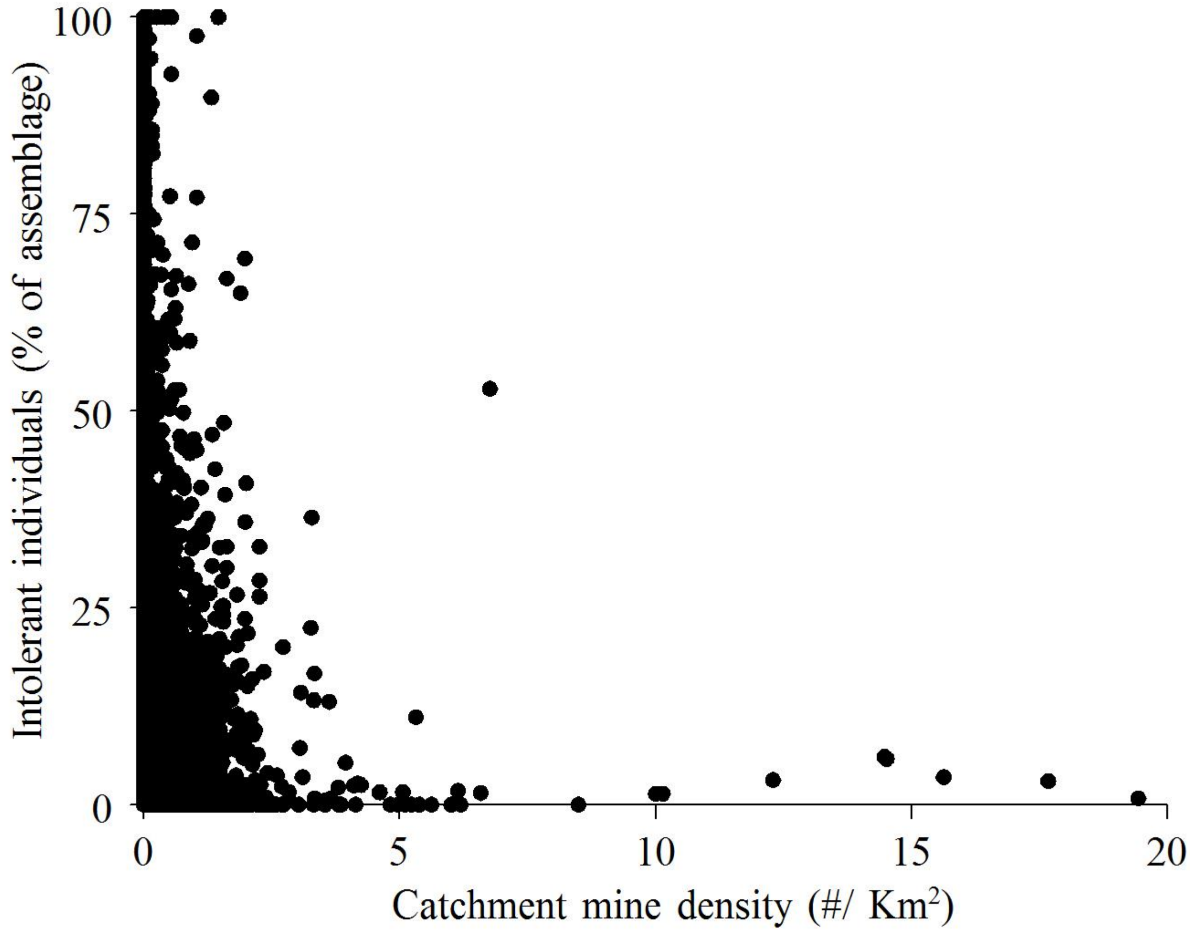

Figure 2. Percent generally intolerant fish individuals as a function of mine density for the conterminous US (n=33,538). Mines include coal mine and support mining activities (USGS 2012), hard rock and aggregate mine data points (USGS 2009), and uranium mines (USEPA 2006). Intolerant fish species are from Whittier et al. (2007) and Grabarkiewicz and Davis (2008). Fish data provided by National Fish Habitat Partnership (W.M. Daniel, D.M., Infante, K., Herreman, D., Wieferich, A. Cooper, P.C., Esselman, and D. Thornbrugh, Michigan State University, unpublished data)