Some Effects of Natural Gas Operations on Fishes & Their Habitats on Canada's Rocky Mountain East Slopes

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Rocky Mountain Ecosystem Coalition
Technical Report 95/1

March 1995
Reprinted with minor changes March 1998

Abstract

This paper summarizes the effects of the natural gas industry on fishes and their habitats in the Rocky Mountain East Slopes in Alberta and British Columbia primarily by inferring effects from data in the general fisheries and aquatic sciences literature, given a basic knowledge of how gas exploration and development is conducted. The account emphasizes the effects of surface disturbance from natural gas exploration and development on salmonid habitat.

On the Rocky Mountain East Slopes, threatened, vulnerable or rare fishes include bull trout, rare remnant populations of westslope cutthroat trout, the endemic and genetically-unique Athabasca rainbow trout, rare mountain stocks of lake trout, endemic subspecies of minnow and sucker, unique or unusual whitefish stocks and perhaps other as-yet undetected unique fishes. Many fishes appear in the area in habitat near the limits of their ecological ranges, and for that reason are likely to be disproportionately important to the continued existence of the larger species population as a whole. Refugial populations of a variety of rare aquatic invertebrates are unusually common in the area, probably related to its Pleistocene history as virtually the only Late Wisconsinan unglaciated area in southern Canada.

The natural gas industry threatens these and other fishes and their habitats during all stages of exploration, development and production. Seismic lines, roads and pipeline rights-of-way can transform drainage basin hydrology, especially in small headwater basins. In effect a new artificial drainage net is imposed on the natural channel system, delivering water and sediment to streams in ways that damage critical fish habitats, and destroying critical streamside vegetation. Spawning, rearing and overwintering areas frequently are damaged or destroyed, and migrations may be impeded or blocked entirely. These effects are both chronic and episodic, and significant damage from these sources is inevitable no matter how careful are the attempts at mitigation. Increased access leads to increased poaching problems and heavier fishing pressure. Given the high levels of activity, contamination from produced groundwater and drilling fluids, for example, are certainties. The most important single threat to habitat arises from vastly increased sediment loadings to streams. Reliance by government and industry on regulation and mitigation to protect aquatic ecosystems from damage is naive at best. Regulations are rarely enforced, and mitigation techniques always are far from perfect. As a result, the cumulative effects of unmitigable damage are rapidly destroying the integrity of aquatic ecosystems in the region.

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Introduction

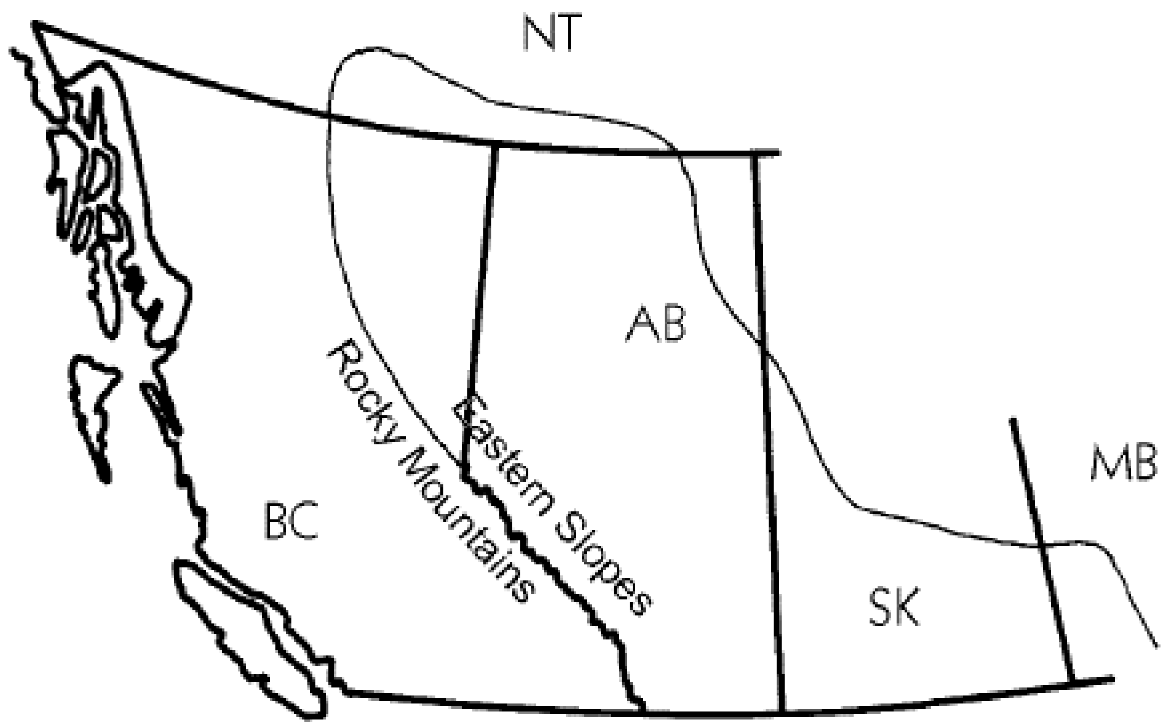
Few adequate independent studies exist specifically examining the effects of natural gas industry activities on fishes and their habitats in Canada. Most documents are industry-funded mitigation plans designed to win approvals for projects from government agencies. Typically, the agencies are too overburdened to properly assess the claims or to monitor the outcomes after the projects are approved. As a consequence, there are exceedingly few published scientific reports (as opposed to guideline and regulation documents) from government agencies or independent researchers on the environmental impacts of oil and gas operations in western Canada. A recent industry-sponsored proposal for environmental protection strategies in northeastern British Columbia (Antoniuk 1994) contains 26 pages of cited references listing well over 300 documents in total. The list includes just three scientific reports from Canadian government agencies or independent investigators dealing with the environmental effects of the oil and gas industry on aquatic resources.

Nevertheless there is nothing especially unusual about the way the gas industry uses land other than its extent and pervasiveness. It is possible, therefore, to infer effects from data in the general fisheries and aquatic sciences literature, given a basic knowledge of how gas exploration and development is conducted. That is the approach I have taken here.

The sole significant source of Canadian production of natural gas is the Western Canada Sedimentary Basin (WCSB) (Cleland and Stewart 1994:1), an area east of the Rocky Mountains incorporating northeastern British Columbia (BC), most of Alberta, southern Saskatchewan, southeastern Manitoba and the western Northwest Territories (Figure 1). At present 95% of Canadian production is derived from Alberta and northeastern BC (Cleland and Stewart 1994:3). Nearly one-quarter of discovered natural gas reserves (produced and remaining) in the WCSB have been found in the Rocky Mountain Foothills regions of these provinces alone (Anonymous 1993:5).

Indeed, the Rocky Mountain Foothills / Deep Basin areas are believed to hold the single largest volume of “undiscovered” gas reserves in western Canada (39 percent of undiscovered reserves; Anonymous 1993:5). These areas on the eastern slopes of the Rocky Mountains recently have been the focus of unusually high interest for oil and gas exploration, with many leases being sold in ecologically sensitive areas (M. Sawyer, RMEC, unpublished data; Boras 1993; Barnett 1994a, 1994b). Furthermore, the National Energy Board (NEB) has overestimated gas reserves elsewhere in the WCSB, specifically the crucial central Alberta region, by over 45 percent (Boras 1995), so even more future production than previously expected will have to come from elsewhere.

Figure 1. The study area location, showing the approximate boundary of the Western Canada Sedimentary Basin.



For these reasons it is reasonable to expect that increasing pressure from gas exploration and development will be placed on the Rocky Mountain East Slopes, which will undoubtedly be a major centre of gas-related industrial activity for the foreseeable future. Streams and rivers are the principal aquatic ecosystems subject to damage from gas exploration and development in the region, and salmonids (salmons, trouts, charrs, whitefishes and graylings) are the principal aquatic organisms of direct and most obvious economic interest. This paper is limited to a consideration of industry effects on these fishes and their habitats, which is not to imply that damage to other elements of aquatic ecosystems is of no consequence. The much larger problem of the degradation of whole drainage basin ecosystems — often initiated by the natural gas industry, but by no means limited to it — will be dealt with elsewhere.

The Study Area

The study area comprises the Canadian Rocky Mountains and foothills east of the Continental Divide (Figure 1). The region is drained by two great river systems. Northeastern BC and northwestern Alberta drain to the Arctic Ocean through the Mackenzie River via its major tributaries, the Liard, Hay, Peace and Athabasca rivers. Southwestern Alberta drains to Hudson Bay through the Saskatchewan River via its major tributaries, the North Saskatchewan and South Saskatchewan (Red Deer, Bow and Oldman) rivers. Virtually the entire region was completely covered by Cordilleran and/or Laurentide ice sheets one or more times during the Pleistocene. Recent geological interpretations argue for a variable Late Wisconsinan unglaciated area over much of the East Slopes. This “Ice-free Corridor” is postulated to have existed between the maximum extent of the Cordilleran and Laurentide ice sheets during the late Wisconsinan, the last major advance (Reeves 1973, Rutter 1984, Prest 1984, Gadd 1986). The possible significance of the Ice-free Corridor as a Late Wisconsinan refugium for several known endemic, relict or otherwise unusual aquatic organisms has been treated elsewhere (Crossman and McAllister 1986, Mayhood 1992), and is touched upon below.

The terrain of the Rocky Mountain East Slopes is hilly to mountainous, covered in the south primarily by subalpine forest of (in approximate order of descending elevation) subalpine fir, Engelmann and/or white spruce, lodgepole pine and aspen. In the north similar forests predominate in the most westerly high-elevation areas, giving way to boreal forests of lodgepole pine, white and black spruce, trembling aspen, balsam poplar, with some white birch and tamarack at lower elevations to the east. Interior Douglas fir montane savannah and grasslands occupy isolated major valleys and slopes southward from the Athabasca River, becoming more frequent with decreasing latitude. The highest points throughout the region are treeless alpine tundra and rock (Rowe 1972, North 1976).

The climate of the region is classified as Dc in the Köppen system, with long, cold, snowy winters and short, cool summers. The highest elevations, however, have Arctic-alpine climates. Mean annual precipitation over the region ranges from approximately 41 to 107 cm, perhaps about half of which, on average, falls as snow (Longley 1972). Peak streamflows are produced by spring snowmelt in most years; minimum flows occur in late winter.

Fishes of the Region

Sixty-five species of fish have been reported from waters in or near the Canadian Rocky Mountains and foothills east of the Continental Divide (Table 1). Of these, 9 species are known only from sites immediately adjacent to the region in connected waters, but not from within the region itself. Seventeen species have been introduced, only ten successfully. Many non-native stocks of native species have been introduced; this is especially true of major sportfishes. Some stocks of native fishes, mainly sportfish and baitfish species, have been transplanted within the region into drainages to which they are not native. Only eight species are native to all major drainage systems in the region.

Table 1. Fishes of the Rocky Mountains and foothills east of the Continental Divide, Alberta and BC. Interpretation primarily of distribution data in McPhail and Lindsey (1970), Paetz and Nelson (1970), Scott and Crossman (1973), Ward (1974), Lee et al. (1980), McLeod and O'Neil (1983), Lindsey and McPhail (1986), Roberts (1988, 1989a, 1989b) Haas and McPhail (1991), Behnke (1992) and Nelson and Paetz (1992). Details of many interpretations are provided elsewhere (Mayhood 1991, 1992, 1995). Nomenclature follows Robins et al. (1991a, 1991b). The spelling "charr" follows Morton (1980). ● - native; ❍ - adjacent; i - introduced; f - failed intro; ? questionable.

		Major drainage basin						
Common name	**Scientific name**	**Liard**	**Peace**	**Athabasca**	**North Sask.**	**Red Deer**	**Bow**	**Oldman**
lake sturgeon	*Acipenser fulvescens*				❍			❍
goldeye	*Hiodon alosoides*	❍	❍	?	❍	❍		❍
mooneye	*Hiodon tergisus*					❍		❍
lake chub	*Couesius plumbeus*	●	●	●	●	●	●	●
brassy minnow	*Hybognathus hankinsoni*		●					
pearl dace	*Margariscus margarita*		●	●	●	●	●	●
peamouth	*Mylocheilus caurinus*		●					
emerald shiner	*Notropis atherinoides*	❍			❍			❍
river shiner	*Notropis blennius*							●
spottail shiner	*Notropis hudsonius*			●				❍
n. redbelly dace	*Phoxinus eos*		●		●			●
finescale dace	*Phoxinus neogaeus*	❍	●	●	●	❍		●
fathead minnow	*Pimephales promelas*		i?	●	●	●	❍	●
flathead chub	*Platygobio gracilis*		●	?				
northern squawfish	*Ptychocheilus oregonensis*		●					
longnose dace	*Rhinichthys cataractae*	●	●	●	●	●	●	●
redside shiner	*Richardsonius balteatus*		●					i
longnose sucker	*Catostomus catostomus*	●	●	●	●	●	●	●
white sucker	*Catostomus commersoni*	●	●	●	●	●	●	●
largescale sucker	*Catostomus macrocheilus*		●					
mountain sucker	*Catostomus platyrhynchus*				●	●	●	●
shorthead redhorse	*Moxostoma macrolepidotum*							❍
northern pike	*Esox lucius*	●	●	●	●	●	❍	●

continued…

Table 1. (concluded)

Common name	Scientific name	Liard	Peace	Atha-basca	North Sask.	Red Deer	Bow	Oldman
cisco	*Coregonus artedi*						i	
Arctic cisco	*Coregonus autumnalis*	●						
lake whitefish	*Coregonus clupeaformis*	●	●	●	❍		i?	●
pygmy whitefish	*Prosopium coulteri*	❍	●	●				●
round whitefish	*Prosopium cylindraceum*	●						
mountain whitefish	*Prosopium williamsoni*	●	●	●	●	●	●	●
inconnu	*Stenodus leucichthys*	❍						
Arctic grayling	*Thymallus arcticus*	●	●	●				i
golden trout	*Oncorhynchus aguabonita*			i	i	f	f	i
cutthroat trout	*Oncorhynchus clarki*		i	i	i	i	●	●
rainbow trout	*Oncorhynchus mykiss*	●	●	●	i	i	i	i
chum salmon	*Oncorhynchus keta*	●						
kokanee	*Oncorhynchus nerka*							f
Atlantic salmon	*Salmo salar*			f			f	
brown trout	*Salmo trutta*			i	i	i	i	i
bull trout	*Salvelinus confluentus*	●	●	●	●	●	●	●
Dolly Varden	*Salvelinus malma*						i	
brook trout	*Salvelinus fontinalis*		i	i	i	i	i	i
lake trout	*Salvelinus namaycush*	●	●	●	●		●	●
Arctic charr	*Salvelinus alpinus*						f	
splake	*S. fontinalis* × *S. namaycush*			f	f		i	
trout-perch	*Percopsis omiscomaycus*	●	●	●	❍	●	●	●
burbot	*Lota lota*	●	●	●	●	●	●	●
western mosquitofish	*Gambusia affinis*						i	
sailfin molly	*Poecilia latipinna*						i	
guppy	*Poecilia reticulatus*						f	
green swordtail	*Xiphophorus helleri*						f	
brook stickleback	*Culaea inconstans*		●	●	●	❍	●	●
ninespine stickleback	*Pungitius pungitius*	❍		❍				
prickly sculpin	*Cottus asper*		●					
slimy sculpin	*Cottus cognatus*	●	●					
shorthead sculpin	*Cottus confusus*							●
spoonhead sculpin	*Cottus ricei*	●	●	●	●	●	❍	●
deepwater sculpin	*Myoxocephalus thompsoni*							●
Iowa darter	*Etheostoma exile*			❍	❍			●
yellow perch	*Perca flavescens*			●	❍			
walleye	*Stizostedion vitreum*	❍	❍	❍	❍	❍		❍
sauger	*Stizostedion canadense*				❍	❍		❍
smallmouth bass	*Micropterus dolomieu*						f	
African jewelfish	*Hemichromis bimaculatus*						i	
convict cichlid	*Cichlasoma nigrofasciatum*						f	
freshwater angelfish	*Pterophyllum scalare*						f	

The region holds many unusual stocks of fish, several of which are of special concern for conservation. The following unique stocks have been reported, many considered distinct at the subspecies level: Liard Hotsprings lake chub (Wells 1978, cited in Nelson and Paetz 1992:127), Jasper pearl dace (Bajkov 1927, Mayhood 1992), Banff longnose dace (Nichol 1916, Renaud and McAllister 1988), Jasper longnose sucker (Bajkov 1927, McAllister and Camus 1984, Mayhood 1992), some genetically unique or morphologically unusual lake whitefish stocks in Jasper National Park (Bajkov 1927, Franzin and Clayton 1977, Foote et al. 1992), morphologically distinct stocks of pygmy whitefish in Waterton Lake and the Snake Indian River (Lindsey and Franzin 1977, Mayhood 1992), Athabasca rainbow trout (Bajkov 1927, Mayhood 1992, Carl et al. 1994) and St. Mary shorthead sculpin (Roberts 1988, 1989a, personal communication 1994; Peden et al. 1989:2717). Native westslope cutthroat trout stocks in the South Saskatchewan River basin are the most genetically divergent in the subspecies, both among themselves and in comparison to those elsewhere within the native range (Leary et al. 1985). There are also disjunct or otherwise distributionally unusual populations of brassy minnow, Arctic cisco, chum salmon, lake trout and deepwater sculpin. An introduced assemblage of tropical fishes in a hotspring in the Bow drainage may represent the northernmost distribution of self-sustaining populations of these species (McAllister 1969, Nelson 1983). The study area also holds numerous other rare, relict, endemic or otherwise unusual aquatic invertebrates.

All such occurrences may be related to the putative Late Wisconsinan “ice-free corridor” noted in the Study Area, above. Whatever the explanation for their existence here, the rarity and isolation of many of these populations renders them especially susceptible to extinction. All such populations have unusually high scientific value, and are important to regional biodiversity. Furthermore, these and many of the other fish stocks listed in Table 1 exist in the region near their ecological limits. Such stocks have high adaptive significance to the species as a whole, and are especially valuable for conservation purposes (Scudder 1989). These matters have been discussed at considerable length elsewhere (Mayhood 1989, 1991, 1992, 1995).

Native populations of most salmonid sportfishes in the region are in serious trouble. None of these animals is protected by any form of endangered species legislation; indeed, the serious nature of the conservation problems are not generally recognized for most species.

Arctic grayling, native to the northern two-thirds of the study area, are notoriously susceptible to overfishing wherever they become readily accessible (Falk and Gilman 1974, and references therein; Tripp and Tsui 1980:126). Several populations in the region already are of concern for this reason (C. Hunt, personal communication; L. Carl, personal communication). Once lost from a locale, grayling have proven exceedingly difficult to reintroduce from elsewhere, a problem likely attributable to subtle differences in behaviour among stocks (Mayhood 1992).

The cutthroat trout subspecies native to Alberta, the westslope cutthroat trout, is highly differentiated genetically from other cutthroat subspecies and may deserve to be recognized as a full species in its own right (Leary et al. 1987, Allendorf and Leary 1988). Most indigenous stocks of westslope cutthroat trout in Alberta and elsewhere have been destroyed by various combinations of overexploitation, genetic introgression from introduced rainbow and non-native subspecies of cutthroat trouts, displacement by non-native species, and habitat damage. In Alberta there are perhaps no more than a half-dozen indigenous populations left in their native waters (Mayhood and Anderson 1976:69-70; McAllister et al. 1981; Mayhood 1986, 1989, 1991, 1995; Carl and Stelfox 1989). Meanwhile, one Alberta native but genetically-depauperate stock has been widely transplanted into dozens of previously fishless mountain lakes within and beyond its native drainage, where it threatens to contaminate any of the few native stocks downstream that may remain there.

The distinctive Athabasca rainbow trout (Bajkov 1927, Carl et al. 1994) is often quite abundant where it is found, but it is highly endemic, being restricted to a few headwater drainages of the Athabasca River. It is endangered, possibly extirpated, in Jasper National Park (Mayhood 1992), the only so-called "protected area" of significant size in which it occurs. Throughout most of its range it has been exposed to genetic introgression from introduced western black-spotted trouts, including non-native stocks of its own species. It is also threatened by overexploitation and especially by habitat damage as its small range continues to be opened up by extractive resource industries. Native stocks of rainbow trout in the headwater drainages of the Peace (Finlay, Parsnip) and Liard (Kechika) rivers are likewise vulnerable to the same problems because of their restricted range in these basins.

Indigenous populations of lake trout are rare and widely scattered on the East Slopes south of the Peace River drainage: there once were perhaps 11, including a rare riverine stock (Ward 1974, Mayhood 1992, Nelson and Paetz 1992, Donald and Alger 1993). One of these was deliberately destroyed by poisoning, five others have been exposed to genetic introgression from introduced non-native stocks, and these latter plus four more have been exposed to other non-native species or are significantly fished, or both (Ward 1974; Bradford 1990; Mayhood 1992; Donald and Alger 1993; S. Herman, personal communication). Just one is likely to be a relatively unexploited, uncontaminated native stock associated with a completely indigenous community of fishes. Introduced brown trout in the upper Clearwater River (T. Hurd, personal communication) may soon contact this last remaining relatively pristine population.

Although still widespread in the study area, bull trout have declined markedly throughout, and some local populations have been lost (Allan 1980; Nelson and Paetz 1982, 1992; Carl 1985; Roberts 1987, 1991; Mayhood 1992, 1995; Donald and Alger 1993; Mayhood and Paczkowski 1993). This species is listed internationally as of special concern (vulnerable) throughout its range (Johnson 1987, Williams et al. 1989) because of "present or threatened destruction, modification, or curtailment of its habitat or range", and because of "other natural or man-made factors affecting its continued existence", including hybridization, introduction of exotic or transplanted species, predation and competition (Williams et al. 1989:3-4). A Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report in preparation is considering a listing of "vulnerable" (Campbell 1993:398).

The bull trout is unusually vulnerable to overexploitation because of its ease of capture, the large size of adults in many populations (which attracts angler attention), and its late age at maturity (Radford 1975, 1977; Allan 1980; Carl 1985; Roberts 1987). It is also highly vulnerable to habitat disturbance as a result of its rather specific habitat requirements, especially for stable flows and clean, coarse substrates for spawning, early rearing and overwintering (reviewed by Rieman and McIntyre 1993). Bull trout are also susceptible to displacement by introduced charrs (brook trout, Leary et al. 1993; lake trout, Donald and Alger 1993).

Despite repeated assertions by the Alberta Government that this species will be protected and where possible restored (Alberta Fish and Wildlife 1984, Carl 1985, Berry 1994, Evans 1994), the need for sufficient protection has been, and continues to be, routinely ignored: bull trout stocks are being destroyed by increments (e.g., Mayhood 1986, 1988a, 1988b, 1991; Roberts 1987, 1991; see also discussion below). Even the national parks have been ineffective in adequately protecting bull trout stocks under their care (Mayhood 1992, 1995; Donald and Alger 1993; Mayhood and Paczkowski 1993), a situation that will likely continue.

The loss of many local populations of native Alberta salmonids is serious. The remaining few small, isolated populations of some species are highly vulnerable to extinction from chance occurrences simply because they are small and isolated (MacArthur and Wilson 1967). Furthermore, it is important to maintain the genetic integrity and diversity of species and populations to conserve them in both the short (Leberg 1990) and the long term (Frankel and Soulé 1981, Schonewald-Cox et al. 1983, Meffe 1987, Ferguson 1990, Meffe and Carroll 1994). For example, much of the genetic variation in the westslope cutthroat trout subspecies is represented in many individual, highly-isolated populations each of which possesses one or two unique alleles, often at high frequencies. To conserve this fish and maintain its genetic integrity, it is critical to save as many individual local populations as possible (Leary et al. 1985, Allendorf and Leary 1988). The same is true of bull trout where the species has been adequately studied (Leary et al. 1993).

Critical Habitats for Salmonids

To understand how salmonids can be affected by gas exploration and development, it is necessary to understand how they use streams throughout their lives. Although there are differences in specific habitat needs among the species, and even among separate stocks within a species, some useful generalizations are possible (Bisson 1991, Bjornn and Reiser 1991, Schlosser 1991).

All salmonids require certain key habitats to complete their life cycle. These *critical habitats* include places for spawning, egg incubation, rearing, feeding, refuge (from predators and extreme events such as floods), and overwintering. Since critical habitats are seldom in a single location in a drainage basin, safe and passable migratory routes between them also are critical.

Some salmonids bury their eggs in gravel, while others simply broadcast their eggs over the substrate, where they lodge in the crevices among stones on the bottom. Whichever method is used, the incubating eggs must be safe from drying or severe streambed scour, and have free circulation of water to irrigate them, bringing them oxygen and carrying away waste products. For trout, beds of well-sorted gravels at the tails of pools are often favoured, especially where springs and other areas of groundwater discharge maintain reasonably stable flows. Such a combination of habitat characteristics tends to be rare in any drainage basin, but is generally more common in the upper reaches and headwaters.

When the eggs hatch, the larvae (alevins) remain buried in the gravel or among the crevices while they resorb their yolk sacs. To emerge from the gravel or crevices, the pore spaces must be large enough to allow them to pass. Once they emerge the fry move or are swept into slackwater areas along the banks, in side channels or behind obstructions in the current, often in very shallow water. They may continue to use crevices among stones for shelter, especially in winter. The juveniles use such refuges and shallow water to avoid predation from larger fishes. They also use overhead cover afforded by overhanging riparian vegetation, undercut banks and large woody debris (e.g., stranded logs, logjams, rootwads, brushpiles) to avoid terrestrial and avian predators.

As the fish grow, they can withstand increasingly stronger currents, become increasingly less vulnerable to predatory fish and outgrow the small spaces available to them among stones and in shallow water. At the same time they become more vulnerable to terrestrial and larger avian predators. These factors cause them increasingly to use larger spaces and deeper water found more frequently toward midchannel and downstream areas, and among larger pieces of cover material (e.g., among unembedded boulders in areas of stronger current, or in the deep pools excavated by currents under logjams).

Growth in the size of juveniles typically is accompanied by a shift to increasingly larger items of food. In some species and stocks, juveniles shift from a diet of invertebrates to one of fish as they grow. These shifts may require the fish to move within a drainage basin to locate suitable food during the open-water period. Once salmonids mature, they again often must undertake migrations to reach suitable spawning habitat. Because spawning habitat is more frequently found in the upper reaches of a drainage basin while larger adult habitat is generally more common in middle and lower reaches, adults typically must undergo an upstream migration to spawn.

Peak flows during spring runoff, especially when warm spring rains melt the snowpack very rapidly, and to some extent during severe summer rainstorms, scour the channel and change its morphology, rendering much of the habitat unuseable for any purpose. At such times fish must take refuge in side channels, backwaters, small intermittent tributaries and other off-channel habitats that hold water only during high flows. Lakes or beaver ponds may be important refuge habitat where these are available.

Winter can pose severe problems for fishes in the study area. In our cold climate, even large streams commonly freeze to the bottom over large areas and long distances for two to three months in winter. Small streams usually have very low winter flows and extensive ice cover. Fishes need areas of unfrozen water to survive. In midwinter such habitat usually is found only in the deepest pools or in areas of substantial, relatively warm groundwater discharge. Both features typically have a very restricted distribution in a drainage basin. Suitable pools for overwintering large fish in particular are more commonly found in middle reaches and downstream areas than in the upper reaches and headwaters simply because there is more water in mainstems than in tributaries.

In summary, salmonids require a wide variety of habitat types — some with rather specific characteristics — throughout their lives. Some of these critical habitats are rare and vulnerable to damage, and are often scattered widely throughout a drainage basin, necessitating migrations among them seasonally. Any human activity that damages or destroys critical habitats, or that impedes or blocks fish movements among critical habitats, may damage or destroy the fish populations themselves.

Damage to Fishes and Their Habitats

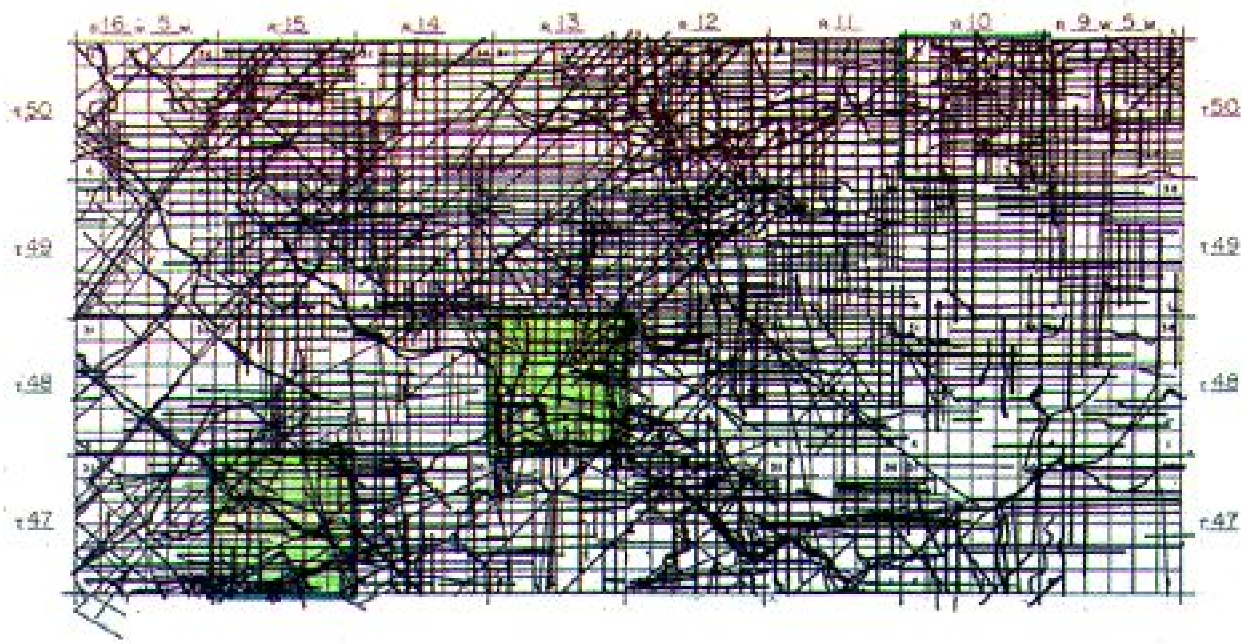
There are three general types of impact that may arise from natural gas exploration and development: surface disturbance from roads, seismic lines pipelines, wellsites, camp sites and gas plants; contamination from leaks, spills and emissions of all kinds; and increases in resource use arising from greater knowledge and accessibility of formerly remote areas. Of these, roads and other linear developments (seismic lines, pipelines and transmission lines) produce the most obvious negative effects on salmonids and their habitats. They do this in two principal ways: first, by damaging stream habitat, and second, by providing increased access for both legitimate anglers and poachers, thereby increasing exploitation. Because they make contaminants accessible to watercourses, roads and pipelines also contribute to contamination problems. This account, however, focuses on habitat damage due to surface disturbance from natural gas exploration and development.

Roads, Seismic Lines, Pipelines: The Magnitude of the Problem

Exploring for and developing a gas field entails extensive development of roads, seismic lines and pipelines. There are some relatively minor variations in the details of how these facilities are built from field to field and from operator to operator, but the overall approach is consistent. The following describes a typical scenario in areas of low initial road density such as that found throughout most of the study area.

During initial exploration work, arrow-straight seismic lines are cut through the forest along which crews move in all-terrain vehicles (ATVs) mapping subsurface geological structures. The process involves drilling along the line, setting small explosive charges in the holes, and recording the resulting echoes from subsurface geologic structures with sensitive recording devices. These lines are extremely extensive throughout the study area, forming a dense “pick-up sticks” pattern of intersecting trails over the landscape (Figure 2). Companies have certain rights to seismic lines, and frequently exercise them to prevent their use by other exploration companies. In consequence, new seismic crews cut new lines to explore the same areas that have already been explored by others, unnecessarily increasing the amount of disturbance. The density becomes even greater where the new three-dimensional seismic technology is used, because this technique requires shots along a grid of seismic lines.

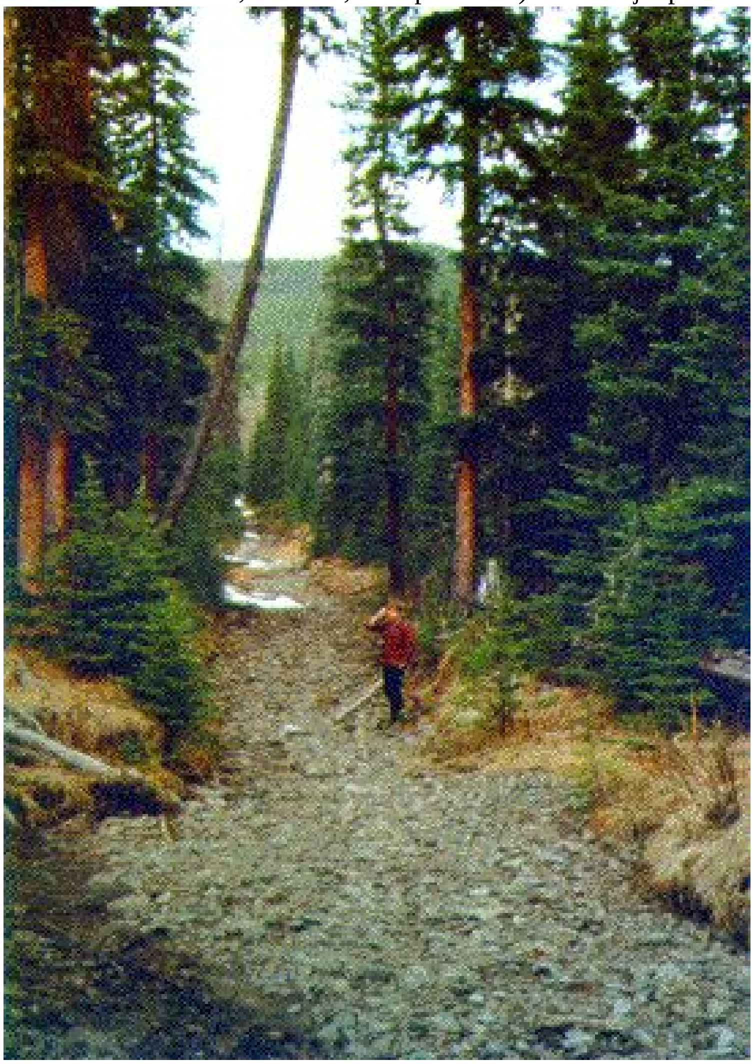
Figure 2. Roads and seismic trails west of Drayton Valley, Alberta, 1989. Ranges and townships as shown.



Although narrow lines are sometimes used, most existing seismic trails are wide enough to accommodate such large vehicles as mobile drilling rigs. Most lines are used extensively by hunters in trucks, ATV recreationists, power bikers and snowmobilers, and have frequently been adapted for use in logging operations (Alberta Fish and Wildlife 1977, Sadler 1978, RMEC file data). Since the trails were intended only for brief use they are unsurfaced, unimproved and commonly suffer serious erosion problems even on gentle to moderate slopes, yet direct vertical lines up exceedingly steep slopes are common. Stream crossing points are rarely well-planned, usually unbridged and frequently become serious point sources of sediment (Figure 3). Damage is often progressive and long-term.

If seismic results justify it, exploratory drilling begins. Drilling rigs are large and transported by several big flatbed trucks that require substantial roads to travel. Occasionally rigs are moved into position on improved seismic lines over frozen ground in winter, but more frequently new roads are built that use little or none of the seismic trail network. If drilling results are favourable, further exploratory drilling is undertaken to delimit the reservoir. This ordinarily requires more road to be built, despite new directional-drilling techniques that allow several holes to be drilled in various directions from a single wellpad.

Figure 3. Once a forest, this seismic trail is now a streambed. A creek took over the right-of-way at a poorly-designed crossing. The former forest floor has been wending its way down Jumpingpound Creek for several years (Moose Mountain field, Alberta, 20 April 1994). B. Horejsi photo.



In the developmental stage an entire network of medium- to high-grade roads is completed to allow production drilling, regular maintenance and servicing of all the wells in the field. In addition a central processing plant is built (in many fields) to remove sulphur from the raw gas. A gas-gathering network of buried pipelines is installed to transport the raw product to the gas plant for processing (for high-sulphur content "sour" gas), or directly to the long-distance trunk transmission pipeline (for low-sulphur content "sweet" gas). Both the development roads and the gas-gathering system pipelines typically require substantial lengths of yet more cleared rights-of-way, although they may use already-disturbed land from time to time. Like seismic lines, pipeline rights-of-way are used by off-road vehicles of all kinds, and suffer the same kinds of damage, although they tend to be better maintained to protect the buried pipe and access to it.

The extent of linear developments attributable exclusively to the oil and gas industry is massive by any standard. For example, for the three-year period fiscal 1990-92, over 400 seismic surveys cut more than 15,000 km of seismic lines on the Alberta East Slopes, nearly half of which were new cuts (Alberta Forest Service data). Since the lines may be anywhere from 3 m to as much as 8 m in width (Alberta Forest Service 1984:1), something between 45 and 120 km^2 of forest was cut or re-cut for oil and gas exploration just in the Alberta portion of the study area during this brief period, which was not an especially active one. Substantial seismic exploration has been going on in most of the region since the 1940s, so the total amount of forest lost to seismic line cuts alone must be on the order of several hundred square kilometres. More significantly for aquatic resources, on the order of hundreds of thousands of kilometres of substandard roads in the form of seismic lines have been created in the region during the same period.

The total length of standard roads produced by the oil and gas industry likewise is prodigious. Highly conservative measures of 462 wellsite access roads (Mayhood and Horejsi, in preparation) range from 1.7 km per wellsite in a developed field (South Wapiti) to 3.6 km per wellsite in a sparsely-drilled area (Grande Cache). An industry source estimates access road lengths as 1.6 and 5.3 km per well in the Grizzly and Sukunka areas, respectively, of northwestern BC (Antoniuk 1994). Individual access roads tens of kilometres long have been built to some exploration wells. There are several thousand existing wellsites in the study area, and thousands of new wells are being drilled annually. Thus, tens of thousands of kilometres of road already have been built solely for oil and gas exploitation in the region. In terms of surface area, in the order of 500 km^2 of forest already has been cut just to accommodate roads for oil and gas development in the Canadian Rocky Mountains and foothills, approximately half of it attributable to natural gas activity alone (Mayhood and Horejsi, in preparation).

As yet, we do not have good estimates of the amount of pipeline length and right-of-way cleared by the industry. The order of magnitude is likely to be similar to that for the road system. While there is some overlap of seismic trails, roads and pipelines, these quantities are largely additive. There clearly have been thousands of kilometres of linear rights-of-way of all classes cut in the region. Because gas exploration and development are projected to exceed that existing by two to three times over the next two decades (Carlson et al. 1992, Cleland and Stewart 1994), we should expect at least a doubling of these forest clearance figures in future.

Fine and Coarse Sediments

Most of the damage to fish habitat from linear developments arises from greatly increased sediment loadings to streams. It is therefore worth summarizing the general effects of sediments on critical fish habitats.

Many of the critical habitats of fishes are especially sensitive to damage by fine sediments (particles smaller than about 4-6 mm in diameter; i.e., from coarse sand to clay: Hynes 1970:24, Platts et al. 1983:15-16, Shepard et al. 1984:149, 151). The porous gravels required by salmonids for spawning, egg incubation and alevin rearing may be covered by fine sediments, blocking the pores, suffocating incubating eggs and preventing alevins from emerging. Trout and charr are exceedingly sensitive to such damage. Similarly, fine sediments can block the pores in rifflebeds, substantially reducing the habitat available for invertebrates. Stony riffles typically are the most productive areas of streams for invertebrates (Hynes 1970:207-211), upon which most stream salmonids rely for food, especially as young juveniles.

Juvenile bull trout shelter year-round in the large pore spaces among cobbles and boulders, actually penetrating deep into the stream floor (Nelson 1965:736; Allan 1980:20; Pratt 1984, 1985). Westslope cutthroat trout do likewise when water temperatures drop to 4-5 °C (Bjornn and Liknes 1986:60, Liknes and Graham 1988:55). Filling of these interstices even by relatively large particles reduces the quality and amount of habitat for these fishes (Furniss et al. 1991:302-303, Shepard et al. 1984:151, Fraley and Shepard 1989:141). This a serious loss of critical habitat, especially in mid-winter when suitable overwintering sites are in extremely short supply in our area.

Most streams have large natural sources of fine sediment. To the extent that critical fish habitat is limited by fine sediments, these help to define the natural carrying capacity of the stream for salmonids. Artificial sources of fines can reduce the carrying capacity still further.

It is seldom recognized that additions of even relatively large sediment particles, such as sand and gravel normally carried as bedload, also can destroy fish habitat. East Slopes streams freeze over for months in mid-winter, often to the bottom over much of their length. As noted above, unfrozen water capable of supporting fishes may be available only in the deepest pools even in relatively large streams. Increased bedload deposited in these critical areas can fill them in, reducing their carrying capacity or even rendering them unusable by overwintering fishes (Furniss et al. 1991:302-303).

Roads

The literature on the effects of road construction and maintenance on streams recently has been reviewed by Furniss et al. (1991).

Road networks can greatly increase erosion in drainage basins: in fact, roads alone commonly contribute more sediment to watercourses per unit area than all other land-use activities combined (see also Leathe and Enk 1985:69). Erosion from mass soil movements (slides) and surface erosion are both important. Roads often create unstable slopes that then fail, or trigger movements on slopes that were already unstable. Roadfill itself fails in steep terrain or at stream crossings during high flows. Culverts and other constrictions of flow increase the erosive power of streams, which then erode their banks and scour their beds immediately below the constriction. Bedload often is stored above the constriction, causing the channel below the crossing to suffer a net loss of gravel as it fails to be replaced from upstream. Road surfaces, ditches and cut- and fillslopes are chronic producers of sediment. The sediment ultimately finds its way into streams where roads cross or closely parallel the watercourses (Figure 4).

Figure 4. The clay from this seemingly-innocuous roadcut (note the concavity) has literally paved about 50 m of cobbled Whitney Creek streambed (left, out of picture) some 100-200 m below the road. The author first drew attention to this problem at an ERCB hearing in 1988 (Waterton field, Alberta). D. Mayhood photos.

1 August 1988

10 September 1991

18 October 1994

Sediment from roads has often been shown to damage fish habitat. One study, for example, detected increased fine sediment content in spawning gravels when roads comprised as little as 2.5 percent of the drainage basin area (Cederholm et al. 1981, cited by Furniss et al. 1991:298). Relating roads directly to damage to fish populations, however, has proven more complicated because of inherently difficult methodological problems. In a compilation of existing data from previous studies, Nip (1991) asserted that roads did not adversely affect aquatic biota in the Tri-Creeks experimental watershed in western Alberta, despite the fact that road construction greatly elevated suspended sediment loading. This study was fraught with serious design and methodological inadequacies acknowledged by the author that "do not provide the necessary data to address relationships between the physical, chemical and biological regimes" (Nip 1991:ii). Benthic invertebrates "did not appear to to be negatively affected by sediment" (Nip 1991:iv) "because the sample size was not sufficient to detect any statistically significant changes" (Nip 1991:41). Beaver dams removed from the experimental treatment streams during the postharvest period "resulted in a significant increase" in the population density of rainbow trout (Nip 1991:46), which would have made it impossible to detect any effects of road construction and logging.

Other studies provide strong evidence of the negative effects of roads on fish. Perhaps the most compelling of these were conducted on bull trout in the Flathead River basin of northwestern Montana (Shepard et al. 1984, Leathe and Enk 1985). Field observations and sediment modelling studies demonstrated that sediment loading from roads was positively correlated with the amount of fines (particles ≤6.4 mm in diameter) on the streambed: roads increased sediment loads to the streams in their basins by as much as 114 percent above natural loadings (Leathe and Enk 1985:69). Other findings showed that elevated sediment loadings from roads were directly related to effects on fish. Juvenile bull trout population densities were negatively correlated with the percentage of fine sediment in the streambed, and positively correlated with substrate score, a measure of streambed condition — the larger and less embedded the bottom materials, the more juvenile bull trout a reach supported. In field experiments, bull trout embryo survival to fry emergence was highly negatively correlated with the percentage of fine sediments in the substrate (Shepard et al. 1984). This effect was noted when the percentage of fines exceeded 30 percent. Above that proportion, the embryos were exceedingly sensitive: every five percent increase in fine sediments caused a decrease of more than 25 percent in egg survival to emergence. Survival was zero when the proportion of fines in the substrate reached approximately 44 percent.

These observations are consistent with expectations based upon known requirements of salmonids (discussed above) for unsilted gravels for spawning, egg incubation and alevin emergence; and for crevices among rocks within which young juveniles may hide. They also help to explain why trout population densities in general — not just those of bull trout — have been negatively correlated with density of road crossings in at least one other study (Eaglin and Hubert 1993).

Other road-related changes can damage fish habitat. Poorly-designed, poorly-maintained or damaged culverts can block fish movements into tributaries and upstream reaches. Even well-designed culverts can become blocked by stream-transported debris or beaver activity.

Road ditches in effect are extensions of the natural drainage network. By increasing the drainage density of a basin, intercepting shallow subsurface flow and forcing it to the surface, roads can change streamflows. Streamflows may be measurably changed when road densities are less than 2 km/km^2, and occupy less than 4 percent of the area of the drainage basin (King and Tennyson 1984). When roads change the peak flows or amount of sediment entering streams, the streams must adjust their shape to accommodate the new conditions, frequently with negative effects on fish habitat.

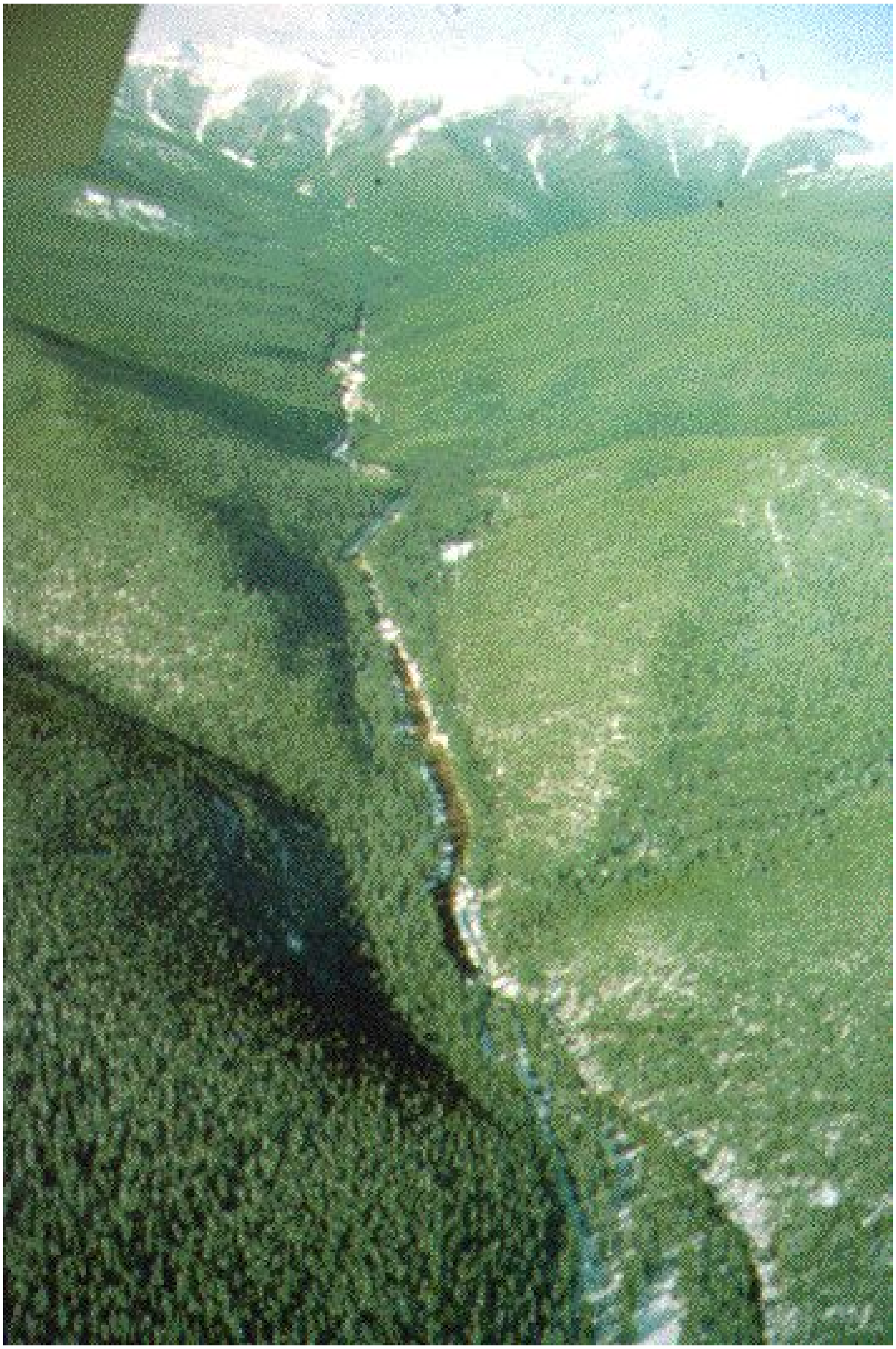
In our area with its steep slopes and narrow valleys, roads ordinarily are designed to follow the lowest gradients and flattest topography. This usually means that they are routed along valley bottoms, closely paralleling watercourses for long distances. Well access roads are no exception (Figures 5 & 6). Besides maximizing the amount of road-related sediment added to streams, much riparian vegetation inevitably is removed. While removal or thinning of the canopy can improve fish rearing habitat in some cases (E.g., Murphy and Meehan 1991), it also destroys one of the crucial structural elements holding banks together and protecting them from erosion. It also removes the source (trees) of large woody debris that is important in controlling flows, storing sediment and providing cover for fishes.

Routing roads beside streams interferes with surface and shallow subsurface flows on the floodplain, and leads to frequent efforts to channelize the stream to protect the roadbed. As a consequence, channel morphology is simplified and fish habitat is lost. Critical groundwater discharge and springbrooks important for spawning, egg and alevin incubation, juvenile rearing and overwintering is cut off or diverted. Sidechannel habitat important for fish rearing and refuge from spates is often permanently cut off from the main channel. Side channel and springbrook habitats are generally more stable than those in the mainstem, and are thought to be “hotspots” of bioproduction, disproportionately important to the ecology of many rivers and streams (Stanford and Ward 1992).

Riparian zones in general are far more important to the ecological integrity of drainage basins than their small proportion of the land base would suggest (Gregory et al. 1991). Not only does water and the materials transported by it move through and out of the basin via the riparian zone, but everything from air masses to animals and plant propagules — terrestrial and aquatic — move in, out and within the basin primarily along the valley floor. The interactions between land and water by definition happen in the riparian zone. Moreover, this zone tends to be the most biologically productive, as well as the most diverse and dynamic in the basin in terms of habitat structure and community composition. Consequently, damaging the riparian zone by routing roads through it has a disproportionately strong negative effect on basin ecology.

Roads greatly increase fishing pressure by making streams and lakes more accessible to legal fishermen and poachers alike. Several salmonid species, especially bull trout, cutthroat trout and grayling, are notoriously vulnerable to overfishing even in waters where meticulous control is possible. Where it is not, overexploitation is virtually certain. To be effective, the necessary restrictive regulations require substantial manpower to enforce effectively. Sufficient manpower for this purpose is never available, even at the best of times, and certainly not during periods of massive government cutbacks such as Alberta is experiencing at present.

Figure 5. Coxhill Creek and this well access road battle for the riparian zone. The creek is losing (Husky 10-22, Moose Mountain field, Alberta, 27 April 1994). B. Horejsi photo.



In these circumstances, the only reasonable approach is to prevent easy road access, as recommended long ago by the public and Alberta Government staff (e.g., Radford 1975:44, 1977:56-58). Unfortunately gates and other barriers on existing roads are readily circumvented by all-terrain vehicles, including mountain bicycles. Even foot travel is made easier by roads. Not building roads into new country in the first place, and removing roads that presently make vulnerable stocks accessible, is a far more effective response to the overexploitation problem.

Figure 6. A construction crew building a well access road has pushed road fill and debris into a tributary of Jumpingpound Creek. (Moose Mountain field, 20 April 1994). B. Horejsi photo.

Seismic Lines and Pipelines

To the extent that seismic lines and pipelines are cleared of vegetation and used by vehicles, the effects of these differ from those of roads only in detail. Routing is used only to a very limited extent to minimize problems of seismic lines. Instead they are routed in straight lines to optimize the quality of seismic data collected from subsurface formations. Short detours are made only where serious problems in moving equipment along the line are encountered, and occasionally where regulations requiring bridge crossings at streams and detours to less sensitive sites are strictly enforced. As a result of this Russian roulette approach to surface protection, serious damage is inevitable: erosion and slope failures are common problems (Figures 7 & 8).

Figure 7. Chronic erosion on a seismic trail. Jumpingpound Creek (foreground), once an important trout stream, is the beneficiary of the sedimentary largesse (Moose Mountain field, Alberta, summer 1989). D. Mayhood photo.

Figure 8. This gully is displayed by the Alberta Forest Service (AFS) on its Jumpingpound Demonstration Forest loop road. It was caused by runoff from the road ditch directed down a highly erodible bank on a seismic trail. The gully was approaching 2 m in depth when photographed. Its former contents are progressing down Jumpingpound Creek. The AFS regulates the design, construction and maintenance of well access roads in the Alberta portion of the study area (Moose Mountain field, Alberta, summer 1989). D. Mayhood photo.

Pipelines take the most direct cross-country routes allowed by the terrain, but are more subject to limitation by topography than are seismic lines. As a result, pipeline problems commonly are due to chronic erosion and mass wasting on the right-of-way (Figure 9), and to direct dumping of fill or dirty ditchwater in streams during construction (Tripp et al. 1992). Instream construction at water crossings is a major source of damage to aquatic habitats from pipelines.

Figure 9. This pipeline right-of-way was selectively eroded during an extreme flood event, exposing the pipe. (Savanna Creek field, Highwood River drainage, September 1995). D. Mayhood photo.

Regulation, Mitigation and the Myth of Protection

Government regulators and industry rely heavily on government guidelines and mitigation procedures to protect fishes and their habitats while allowing unstinted oil and gas development in the study area. There is regrettably little reason for faith in this approach. For example Alberta government agencies regulate virtually all road and seismic trail design, routing, construction and maintenance, as well as pipeline routing, stream crossings and right-of-way maintenance, throughout the Alberta portion of the study area to protect fish habitat, among other purposes (Alberta Forest Service 1984, Fisher 1985, Fisher et al. 1985, Alberta Fish and Wildlife 1982-1992). But these agencies consistently fail to enforce their regulations and guidelines; in fact, often deliberately avoid it (e.g., Shaw and Thompson 1986, Nip 1991, Sheppard 1994, RMEC file correspondence; see also personal communication from W. E. Roberts, below). Even though mitigative techniques are capable of substantially reducing environmental impacts, the facts are that (1) there is residual unmitigable damage from any project of significant size that cumulatively has insupportably high environmental costs, and (2) mitigative actions commonly are poorly implemented, ignored, or don't work in practice (e.g., Tripp et al. 1992).

Here are some examples of existing problems.

Most pipeline stream crossings in Alberta are made using unprotected open cuts. A backhoe simply trenches across the stream or river, a weighted length of pipe is installed in the trench, and the trench is then backfilled, burying the pipe. In nearly all cases this procedure mobilizes enormous quantities of fine sediments, especially during backfilling (Mayhood 1982), that are swept downstream to be deposited on the stream bottom. They will eventually be transported away from the immediate area by high flows, but they do not disappear. They are just redeposited further downstream in the system, damaging stream substrate there (e.g., Leathe and Enk 1985:72). In small streams unprotected open cuts temporarily reduce the flow drastically, often to the point of dewatering the watercourse for long distances downstream (and even upstream, where the gradient is slight; Mayhood 1982). Needless to say, the potential for damage to fishes and their habitats in such streams is very high.

A great deal of the damage from construction of open-cut pipeline crossings is avoidable with the aid of construction techniques that isolate the work area from streamflow. Flumes and coffer dams have been used successfully to install pipelines across rivers as large as the Coquihalla and the upper Fraser, respectively, in British Columbia (D. B. Tripp, Tripp Biological Consultants, Nanaimo, BC, personal communication, and personal observation). Pipeline crossings can be bored for distances greater than 1 km, resulting in virtually no direct impact on rivers (Anonymous 1994). These and other techniques such as pumping water around the work area or bridging are standard procedure in BC. For example, only three of over 300 stream crossings on the recently-completed Vancouver Island Gas Pipeline were made in open cuts (Tripp et al. 1992) As a result there were relatively few problems from water crossings on this major project.

Most Alberta pipeliners and biologists alike generally dismiss these same isolation and protection procedures as too expensive, unnecessary or technically impossible (e.g., T. Lawrence 1982, personal communication; Shell Canada Ltd. 1992; Townsend and Allan

1994). Unlike their federal counterparts in BC, Alberta regulators seldom require that isolation procedures be used. At a November 1994 conference on pipeline water crossings, the Alberta Government's biologist in charge of fish habitat protection asserted that his agency makes no attempt to enforce regulations under the Fisheries Act designed to protect fish habitat, nor would it do so in future, because in his opinion Alberta guidelines offered superior protection. Yet in a recent case an Alberta Fish and Wildlife biologist stood by watching while pipeline construction at an unprotected open cut crossing silted over a trout spawning area in which eggs were incubating, even after the problem was drawn to his attention by an independent fish biologist (W. E. Roberts, University of Alberta, personal communication).

In another recent case where road fill from constructing a well access road was deliberately pushed into a small creek tributary to a stream inhabited by bull trout, Alberta authorities refused to lay charges. The Alberta Minister of Environmental Protection defended the action as an example of "how our regulations are working to maintain" the Alberta bull trout fishery (Evans 1994). Enforcement of the habitat protection provisions of the federal Fisheries Act by Alberta authorities is so feeble that in summer 1990 a provincial court judge made a point of imposing a fine more than twice that requested by the Crown prosecutor for a not unusually egregious violation (Kambeitz 1991). Incredibly, the federal Department of Fisheries and Oceans is in the process of formally delegating authority for fish habitat protection under the Fisheries Act to the province of Alberta (Swanson 1994).

Conclusions

The Canadian Rocky Mountains and foothills east of the Continental Divide are undergoing intense exploration and development for natural gas. The region holds numerous unique, rare, relict or otherwise unusual fishes and other aquatic organisms. Many of its fish stocks already are in serious trouble. The roads, seismic lines and pipelines that accompany gas exploration and development pose serious threats to these aquatic resources directly by damaging their habitats, and indirectly by increasing use through greatly increased public access. The most important single threat to habitat arises from vastly increased sediment loadings to streams. Reliance by government and industry on regulation and mitigation to protect aquatic ecosystems from damage is naive at best. Regulations are rarely enforced, and mitigation techniques always are far from perfect. As a result, the cumulative effects of unmitigable damage are rapidly destroying the integrity of aquatic ecosystems in the region.

Acknowledgements

A number of the ideas in this paper grew out of innumerable discussions with Mike Sawyer and Brian Horejsi on the ecological effects of the petroleum industry. I am grateful to Derek Tripp, of D. Tripp Biological Consultants, Nanaimo, B. C., and an anonymous reviewer, who provided many useful comments on various drafts, and to Brian Horejsi for providing several of the photographs. Dave Good provided the scans of the figures for this reprint.

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