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On Assessing Risks to Fish Habitats and Populations Associated with a Transportation Corridor for Proposed Mine Operations in a Salmon-rich Watershed

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Abstract

Natural resource extraction in large undeveloped areas – such as the Bristol Bay watershed in Southwest Alaska – often necessitates construction of roads that contribute substantial environmental risks. Herein, we attempt to address risks from a proposed mine transportation corridor in a virtually roadless watershed that crosses important salmon streams and rivers. The Bristol Bay watershed supports the largest sockeye salmon fishery in the world. A proposed 138 km permanent access road would connect a porphyry copper/gold deposit to a deep-water port. Of 64 potential stream crossings, salmonid spawning migrations may be impeded by culverts at 36 crossings, 32 of which contain restricted upstream habitat. After cessation of mine operations, assuming typical maintenance practices, 10 or more of the 32 streams with restricted upstream habitat would likely be entirely or partly blocked at any time. Consequently, salmon passage – and ultimately production – would be reduced in these streams, and they would likely not be able to support long-term populations of resident species. Additional long-term risks associated with operation of the road include filling or alteration of National Wetland Inventory aquatic habitats; spills of highly toxic xanthate or cyanide due to truck accidents; and reduced habitat quality due to dust production from traffic. We discuss our methodology, and information needs, in the context of Environmental Impact Statements that set the stage for decisions regarding future mining projects.

Keywords

Access road; Mining; Salmonids; Fish habitats; Risks; Stream crossings

Introduction

Natural resource extraction (mining, timber, oil, and gas) in large undeveloped areas often necessitates construction of roads to haul materials to the area during development and

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operations, and extracted resources from the area for transport to markets. Road construction and use can have a wide variety of immediate and long-term impacts on water quality and fish habitat (Furniss et al. 1991, Jones et al. 2000, Angermeier et al. 2004).

Herein, we address the problem of assessing risks from a potential mine transportation corridor that crosses important salmon streams. The mining scenarios upon which this assessment is based are in the Bristol Bay watershed, Alaska, one of the largest remaining virtually roadless areas in the United States. The Bristol Bay watershed supports the largest sockeye salmon (*Oncorhynchus nerka*) fishery in the world and provides substantial benefits to wildlife, commercial, subsistence and recreational fishers, hunters, and consumers. A proposed 138 km two-lane gravel surface, all-weather permanent access road (Fig. 1) would connect a porphyry copper/gold deposit, the Pebble deposit, to a new deep-water port on Cook Inlet from which extracted minerals would be shipped elsewhere for final processing (Ghaffari et al. 2011). Approximately 113 km of this corridor would fall within the Bristol Bay watershed. This assessment does not include the many kilometers of roads associated with extracting and processing resources at the deposit itself.

The above-mentioned scenarios describe a range of operations during mineral extraction. They were developed by USEPA (2014), but draw heavily on specifics put forth in Ghaffari et al. (2011). One scenario would mine 2.0 billion tons (1.8 billion metric tons) of ore over 25 years, while the second scenario would mine 6.5 billion tons (5.9 billion metric tons) of ore over 78 years. An access road is required for both scenarios, the difference being the length of time the road would be used for transport of materials to and from the mine.

The transportation corridor area (Fig. 1) considered in the assessment comprises 32 subwatersheds draining to Iliamna Lake. These subwatersheds, located within the Kvichak River watershed, encompass ~ 2,340 km^2 and contain nearly 1900 km of perennial streams. The seven largest subwatersheds are, from west to east, the headwaters of Upper Talarik Creek, the headwaters of the Newhalen River, Chekok Creek, Canyon Creek, Knutson Creek, Pile River, and Iliamna River. The Newhalen River is the largest river that would be crossed by the corridor, draining Sixmile Lake and Lake Clark. The transportation corridor would cross the Newhalen River and parallel the north shore of Iliamna Lake (Fig. 1). From there the corridor would traverse the following: rolling, glaciated terrain for ~ 60 km of roadway; steeper hillsides along the shoreline of Knutson Bay northwest of the village of Pedro Bay; gentler terrain around the northeast end of Iliamna Lake (Pedro Bay and Pile Bay); the Pile River; and the Iliamna River. From that point the corridor would cross the Chigmit Mountains (the highest source of runoff in the Bristol Bay watershed) along the route of the existing Pile Bay Road to tidewater at Williamsport, and then crosses Iliamna Bay and follows the coastline to the port site on Iniskin Bay, off Cook Inlet. Highly variable terrain and variable subsurface conditions, including areas requiring rock excavation in steep mountainous terrain, would be expected over this proposed route (Ghaffari et al. 2011).

Although this route is not necessarily the only option for corridor placement, the assessment of potential environmental risks would not be expected to change substantially with minor shifts in road alignment. Along most feasible routes, the proposed transportation corridor would cross many streams (including unmapped tributaries), rivers, wetlands, and extensive areas with shallow groundwater, draining to Iliamna Lake (Figs. 1 and 2).

In this paper, we consider the risks to fish habitats and salmonid populations associated with waterbodies intersected by the transportation corridor, and discuss our findings and information needs in the context of Environmental Impact Statements that set the stage for decisions regarding future mining projects. Risks to habitat components and effects on populations are illustrated in a conceptual model showing potential linkages among the corridor-associated sources and stressors, and assessment endpoints (Fig. 3). We begin with a discussion of fish habitats and populations along the corridor. We then consider potential impacts on these habitats and populations resulting from its construction and operation. Although the transportation corridor would include adjacent pipelines to supply fuel to the deposit and pipe copper concentrate to the port, we focus on the road component of the corridor. The risks considered in this paper assume the use of referenced best management practices (BMPs) to minimize potential risks to salmonids and the ecosystems that support them.

Study Area - Fish Habitats and Populations

The Kvichak River watershed, the location of the proposed transportation corridor, produces about 34% of Bristol Bay sockeye salmon (USEPA 2014: Appendix A Table 5). Small and large rivers ($\geq 2.8\ m^3/s$ mean annual streamflow) that would be crossed by the corridor provide spawning and rearing habitat, and are important routes for adult salmonid migration to upstream spawning areas and juvenile salmonid migration downstream to Iliamna Lake. Streams with low to moderate gradients (< 3%) provide important high-quality spawning habitats, primarily for sockeye salmon. These streams also provide high-quality seasonal and year-round habitats for resident Dolly Varden (*Salvelinus malma*) and rainbow trout (*Oncorhynchus mykiss*). A majority (62%) of stream length in the Kvichak River subwatersheds crossed by the corridor is classified as low to moderate gradient. However, streams in subwatersheds crossed by the corridor are generally steeper than the regional average (38 versus 15% of length ≥ 3%). (Regional refers to Nushagak and Kvichak River watersheds as a whole.) They also have higher proportions of stream length without floodplain potential (< 5% of flatland in lowland adjacent to stream) (69 versus 40% without floodplain potential) (USEPA 2014: Tables 3-3 and 10-1). All streams crossed by the corridor flow into Iliamna Lake, which provides the majority of sockeye rearing habitat in the Kvichak River watershed (Fair et al. 2012).

Sockeye salmon spawn across diverse habitats, including small tributary streams, small and large rivers, mainland beaches, island beaches, and spring-fed ponds. The spatial separation and diverse spawning habitat features within the watershed have influenced genetic divergence among spawning populations of sockeye salmon at multiple spatial scales (Gomez-Uchida et al. 2011). These distinct populations can occur at very fine spatial scales. For example, sockeye salmon that use spring-fed ponds and streams ~ 1 km apart exhibit differences in traits such as spawn timing, spawn site fidelity, and productivity that are consistent with discrete populations (Quinn et al. 2012).

Most sockeye spawning locations are in the eastern portion of Iliamna Lake. Sockeye spawning has been documented at 30 locations along the transportation corridor (Table 1, Fig. 4, Demory et al. 1964). Annual sockeye index counts are highest in the Iliamna River (averaging over 100,000 spawners), the Newhalen River (averaging over 80,000 spawners), and on beaches in Knutson Bay (averaging over 70,000 spawners) (Table 1, Fig. 4). In some years, these counts can be very large, as illustrated by the 1960 survey for Knutson Bay that reported 1 million adults (Demory et al. 1964). In Knutson Bay, sockeye spawning is associated with upwelling groundwater areas on beaches along the north and east shores, adjacent to the transportation corridor.

Less is known about the occurrence or abundance of other salmon species in streams and rivers crossing or adjacent to the transportation corridor. Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), pink (*O. gorbuscha*), and chum (*O. keta*) salmon are present in the Kvichak River watershed, but data for their spatial occurrences are for isolated points in the system (Johnson and Litchfield 2016). Moving from west to east along the corridor, streams with documented occurrence of salmon species other than sockeye are: Upper Talarik Creek (Chinook, coho, chum, and pink salmon), the Newhalen River (Chinook and coho salmon), Youngs Creek (East and West Branches), Chekok and Tomkok Creeks (coho salmon), Swamp Creek (a tributary to Pile Bay) (Chinook salmon), and the Iliamna River (Chinook, coho, chum, and pink salmon).

Dolly Varden and rainbow trout distributions are not as well documented as salmon distributions along the transportation corridor (Fig. 5). Dolly Varden have been documented in nearly every sockeye salmon-bearing stream that would be crossed by or adjacent to the corridor, as well as in locations upstream of sites with reported anadromous salmon use (ADF&G 2017). Rainbow trout presence along the corridor is reported for only a few streams, including Upper Talarik Creek, the Newhalen River, an unnamed tributary to Eagle Bay, Youngs Creek, Tomkok Creek, Swamp Creek, Iliamna River, and Chinkelyes Creek (ADF&G 2017).

Methods

We used the National Hydrography Dataset (NHD) (USGS 2012), the National Wetlands Inventory (NWI) (USFWS 2012), the Alaska Anadromous Waters Catalog (AWC) (Johnson and Litchfield 2016), and the Alaska Freshwater Fish Inventory (AFFI) (ADF&G 2017) to evaluate potential effects of the transportation corridor on hydrologic features and fish populations.

The length of stream downstream of each crossing was estimated from NHD flowlines. Stream length by subwatershed, based on 12-digit hydrologic unit codes, was calculated as the total distance from each crossing to Iliamna Lake. In the multiple instances where stream crossings were tributaries to a single main channel, the mainstem length was only counted once. However, where downstream lengths were summarized by crossings, the lengths at each crossing represent contiguous lengths, and a portion of stream may be included in more than one crossing.

Mean annual streamflow was estimated using regression equations for the prediction of mean annual streamflow, based on drainage area and historical mean annual precipitation in southwestern Alaska (Parks and Madison 1985, USEPA 2014: Box 3-2). We defined four classes of stream size based on these mean annual streamflow calculations: small headwater streams (< 0.15 m^3/s), medium streams (0.15-2.8 m^3/s), small rivers (2.8-28 m^3/s), and large rivers (> 28 m^3/s). The mean annual streamflow threshold for separating small headwater streams from medium streams was also used to designate stream crossings that would be bridged (i.e. > 0.15 m^3/s) (USEPA 2014: Section 6.1.3.1).

The channel gradient of NHD stream segments intersected by and upstream of the corridor was estimated using a 30 m National Elevation Dataset digital elevation model (DEM) (Gesch 2007, Gesch et al. 2002, USGS 2013) as described in USEPA (2014: Box 3-1). A 12% maximum slope was used to calculate stream length likely to support salmonids (i.e., salmon, rainbow trout, or Dolly Varden). This criterion is used as an upstream limit for salmonid habitat, as Dolly Varden have been observed in higher-gradient reaches (average 12.9% gradient) throughout the year in southeastern Alaska (Bryant et al. 2004). Stream length upstream of the corridor with < 12% slope was based on the NHD stream length to the first reach segment with a slope > 12%.

Information on sockeye salmon spawning abundance at locations along the potential transportation corridor was based on aerial index counts conducted by the Alaska Department of Fish and Game (ADF&G) since 1955 (Morstad 2003).

For the analysis of road length intersecting or near a stream or wetland, each stream (NHD) or pond, small lake and wetland (NWI) was buffered to a distance of 100 m and 200 m and the lengths of corridor within these ranges were summed. For the area of wetlands, ponds, and small lakes directly filled by the road corridor, we assumed a road width of 9.1 m (from Ghaffari et al. 2011).

To estimate overall truck traffic required by the mine scenarios, we extrapolated from vehicle use at a smaller gold mine (Pogo Mine) based on the rate of ore production at Pogo relative to the mine scenarios. Estimated production rate at Pogo is 3000 tons per day (USEPA 2003a), versus 200,000 tons per day in the mine scenarios (Ghaffari et al. 2011). Overall mine-related vehicle use at Pogo averages between 10 and 20 round trips per day (USEPA 2003a). Approximately 175 truck trips per year (0.5 round trip per day) are required at Pogo to transport reagents, leaving 19.5 round trips per day for other purposes. The number of truck trips required for transport of reagents is assumed to be roughly proportional to ore production, resulting in an estimate of 33 round trips per day to transport reagents in the assessment mine scenarios. The number of daily round trips for purposes other than reagent transport was estimated at 19.5 round trips per day, for a total daily traffic estimate of 52.5 round trips in the mine scenarios. This value is likely an underestimate, as it does not account for potential effects of size differences between Pogo Mine and the mine scenarios on the number of trips for purposes other than reagent transport.

To estimate the amount of dust generated from the transportation corridor we used an Iowa Highway Research Board project (Hoover et al. 1973) that quantified dust sources and emissions created by traffic on unpaved roads. According to that study, one vehicle, traveling 1 mile of unpaved road once a day every day for 1 year, would result in the deposition of 1 ton of dust within a 1,000-foot corridor centered on the road (i.e., traffic would annually deposit 1 ton of dust per mile per vehicle).

To estimate how much reagent and thus how many transport trucks would be needed for the mine scenarios, we extrapolated from the number of trucks required to transport reagents at a smaller gold mine (175 trucks per year at Pogo Mine) to the mine scenarios, based on the relative annual ore production at the two mines. Assuming 20 tons of reagent per truck and expected annual production rates of 3000 tons per day at Pogo Mine (USEPA 2003a) and 200,000 tons per day in the mine scenarios (Ghaffari et al. 2011), we estimate that transport of reagents would require ~ 11,725 truck trips per year.

Potential Risks to Fish Habitats and Populations

Roads modify natural drainage networks and accelerate erosion processes, which can lead to changes in streamflow regimes, sediment transport and storage, channel bank and bed configurations, substrate composition, and the stability of slopes adjacent to streams (Furniss et al. 1991). These changes may occur long distances from the road, both down- and up-gradient of the road crossing (Richardson et al. 2001). Road construction can increase the frequency of slope failures by orders of magnitude, depending on variables such as soil type, slope steepness, bedrock type and structure, and presence of subsurface water. These slope failures can result in episodic sediment delivery to streams and rivers, potentially for decades after roads are built (Furniss et al. 1991, Trombulak and Frissell 2000). All of these potential changes can have important biological consequences for anadromous and resident fishes by negatively affecting food, refugia, spawning habitat, water quality, and access for upstream and downstream migration (Furniss et al. 1991).

In the Bristol Bay region, risks to fish from construction and operation of the transportation corridor would be complex and potentially significant, largely because of hydrological issues. Field observations in the mine area (Hamilton 2007, Woody and O’Neal 2010) indicate terrain with abundant near-surface groundwater and a high incidence of seeps and springs associated with complex glaciolacustrine, alluvial, and slope till deposits. The abundance of mapped wetlands (Figs. 1 and 2) further demonstrates the pervasiveness of shallow subsurface flows and high connectivity between groundwater and surface-water systems in the areas traversed by the transportation corridor. The strong connection between groundwater and surface waters helps to moderate water temperatures and streamflows, and this moderation can be critical for fish populations. For example, groundwater contributions that maintain water temperature above 0 °C are very important for maintaining in-stream refugia that would otherwise freeze (Power et al. 1999). The construction and operation of the transportation corridor could fundamentally alter connections between shallow aquifers and surface channels and ponds by intercepting shallow groundwater flowpaths, leading to impacts on surface water hydrology, water quality, and fish habitat (Darnell et al. 1976, Stanford and Ward 1993, Forman and Alexander 1998, Hancock 2002).

In the following sections, we consider potential risks to fish habitats and populations resulting from construction and operation of the transportation corridor. We focus on risks related to stream crossings, filling and alteration of wetlands, fine sediments, dust deposition, and runoff contaminants.

Stream Crossings

Free access to spawning and early rearing habitat in headwater streams is critical for salmonids, and culverts are common migration barriers (Bates et al. 2003, Sheer et al. 2006). Culverts are deemed to have failed if fish passage is blocked (e.g., by debris, ice, beaver activity, or culvert perching) or if streamflow exceeds culvert capacity and results in overtopping and road washout. The potential ecological impacts of culverts are summarized in Table 2.

Standards for culvert installation on fish-bearing streams in Alaska mainly consider fish passage (ADF&G and ADOT 2001). Additional factors unrelated to fish passage, such as the physical structure of the stream or habitat quality, are addressed on a project-specific basis during preparation of the Alaska Department of Transportation and Public Facilities environmental document. Culvert capacities are allowed to be less than channel capacity (ADF&G and ADOT 2001). In most cases culvert width must be > 90% of the ordinary high-water channel width, but where channel slope is < 1.0%, culverts may be installed at slopes < 0.5% with culvert width greater than only 75% of the ordinary high-water channel width. During flood flows, this reduced channel width results in slower than normal velocities upstream of the culvert and higher water velocities exiting the culvert, reducing the capacity of downstream reaches to support salmonids. Downstream erosion and channel entrenchment could result in perched culverts that, if they were not inspected and maintained, would inhibit and ultimately block fish passage. Floodplain habitat and floodplain/channel ecosystem processes could also be disrupted (Table 2).

Culverts and other road crossings that do not provide free passage between upstream and downstream reaches can fragment populations into small population isolates vulnerable to extinction (Hilderbrand and Kershner 2000, Young et al. 2005). In a study of natural long-term isolates of coastal cutthroat trout and Dolly Varden in southeastern Alaska, Hastings (2005) found that about 5.5 km of perennial headwater stream habitat, supporting a census population size of > 2000 adults, is required for a high likelihood of long-term population persistence.

Bridges would generally have fewer impacts on salmon than culverts, but could result in the loss or shortening of long riparian side channels if they did not span the entire floodplain. Approximately 500,000 bridges listed in the National Bridge Inventory are built over streams, and many of these, especially those on more active streams, experience problems with aggradation, degradation, bank erosion, and lateral channel shift during their useful life (FHWA 2012).

Filling and Alteration of Wetlands, Ponds, and Small Lakes

Filling and alteration of wetlands, ponds and small lakes from construction and operation of a mining road can result in loss of resting, spawning and rearing habitat for salmonids and loss of foraging opportunities (see Table 3).

Chemical Contaminants

Four sources of potentially toxic chemicals are related to the transportation corridor: traffic residues, road construction, chemical cargos, and road treatment.

During runoff events, traffic residues (metals, oil, grease) can wash into streams and accumulate in sediments or disperse into groundwater (Van Bohemen and Van de Laak 2003). Road construction involves the crushing of minerals for the road fill and bed and the exposure of rock surfaces at road cuts, which leads to leaching of minerals and increased dissolved solids.

Chemical reagents used to process ore would be transported by road to the mine site. Truck accidents along the transportation route could spill reagents into wetlands and streams.

Roads are treated with salts and other materials to reduce dust and improve winter traction. In Alaska, calcium chloride is commonly used for dust control and is mixed with sand for winter application. During periods of rain and snowmelt, these materials are washed off roads and into streams, rivers, and wetlands, where fish and their invertebrate prey can be directly exposed.

Fine Sediment

During rain and snowmelt, soil eroded from road cuts, borrow areas, road surfaces, shoulders, cut-and-fill surfaces, and drainage ditches (as well as road dust deposited on vegetation; see the “Dust” section), would be washed into streams and other water bodies. Erosion and siltation are likely to be greatest during road construction. The State of Alaska has recognized erosion problems along the road between Iliamna and Nondalton, specifically, badly eroded road embankments depositing sediment into two streams. The State has proposed improvements to alleviate these concerns (ADOT 2001).

Sediment loading from roads would likely diminish habitat quality, particularly for spawning salmonids, in the streams below road crossings. The potential ecological impacts of fine sediment are summarized in Table 4.

BMPs for control of stormwater runoff, erosion, and sedimentation can be found in ADEC 2016: pp 22–27 (stormwater general permit for construction activities), ADEC 2011, USEPA 2003b: Appendix H Section 6.0 (hardrock mining), and USEPA 2006: first row of Table 2 (metal mining haul and/or access roads).

Dust

Dust results from traffic operating on unpaved roads in dry weather, grinding and breaking down road materials into fine particles (Reid and Dunne 1984). The amount of dust derived from a road surface is a function of many variables, including composition and moisture state of the surface, amount and type of vehicle traffic, and speed. Dust particles are either transported aerially in the dry season or mobilized by water in the wet season. These fines may also include trace contaminants, including de-icing salts, hydrocarbons, and metals. Following initial suspension by vehicle traffic, aerial transport by wind spreads dust over long distances, so that it can reach surface waters that are otherwise buffered from sediment delivery via aqueous overland flow. Dust control agents such as calcium chloride have been shown to reduce the generation of road dust by 50 to 70% (Bader 1997), but these agents may cause toxic effects when they run off and enter surface waters (see “Chemical Contaminants” in the “Results” section below).

Walker and Everett (1987) evaluated the effects of road dust generated by traffic on the Dalton Highway and Prudhoe Bay Spine Road in northern Alaska. Dust deposition altered the albedo of snow cover, causing earlier (and presumably more rapid) snowmelt up to 100 m from the road margin and increased depth of thaw in roadside soils. Dust was also associated with loss of lichens, sphagnum, and other mosses and reduced plant cover (Walker and Everett 1987). Loss of near-roadway vegetation has important implications for water quality, as that vegetation helps to filter sediment from road runoff. Thus, dust deposition can contribute to stored sediment that can mobilize in wet weather, and deposition can reduce the capacity of roadside landscapes to filter that sediment.

In a study of road effects in Arctic tundra at acidic (soil pH < 5.0) and less acidic (soil pH at least 5.0) sites, Auerbach et al. (1997) found that vegetation effects were more pronounced at the acidic site. Permafrost thaw was deeper next to than away from the road at both sites, and could affect road structure detrimentally. Vegetation biomass of most taxa was reduced near the road at both sites. Species richness in acidic tundra next to the road was less than half the richness at 100 m away from the road. Sphagnum mosses, dominant in acidic low arctic tussock tundra, were virtually eliminated near the road.

Results

The lengths of the transportation corridor proximate to National Hydrography Dataset (NHD) streams (USGS 2012) and National Wetlands Inventory (NWI) wetlands, ponds, and small lakes (USFWS 2012) are shown in Table 5. The length of the road within 200 m of NHD streams would be ~ 31 km; the length of road within 200 m of NWI aquatic habitats would be ~ 58 km (Table 5). In sum, the length of road within 200 m of NHD streams *or* NWI aquatic habitats would be ~ 67 km (not shown). These lengths do not encompass the section of corridor outside of the Kvichak River watershed (i.e., the watersheds flowing into Cook Inlet). The 200 m road buffer was derived from an estimate of the road-effect zone for secondary roads (Forman 2000). The largest impact on sockeye salmon would likely occur where the road would run parallel to the Iliamna River and Chinkelyes Creek, sites at which many sockeye salmon spawn (Fig. 2: Inset C). Other high-impact areas include where the road would run parallel to Knutson Bay, intersecting many small streams and where groundwater upwelling supports spawning for hundreds of thousands of salmon (Fig. 2, Inset B), and where the road crosses wetlands north of Iliamna Lake (Fig. 2: Inset A).

Stream Crossings

The transportation corridor would cross ~ 64 streams in the Kvichak River watershed. Of these streams, 20 are listed as supporting anadromous fish in the AWC (Johnson and Litchfield 2016) at the crossing (Table 6, Online Resource 1). An additional 35 are likely to support salmonids (Table 6), and a number of these are anadromous downstream of the crossing. In total, the transportation corridor would cross 55 streams known or likely to support salmonids.

Potential risks from the transportation corridor could affect 272 km of stream between its road crossings and Iliamna Lake (Online Resource 2). Spawning may also be affected in the ~ 780 km of streams upstream of the transportation corridor that are likely to support salmonids (based on surveys and stream gradients < 12%, Online Resource 3).

Based on a mean annual streamflow threshold of > 0.15 m^3/s (see the “Methods” section), the transportation corridor would include 19 bridges, 12 over known anadromous streams and 7 over streams likely to support salmonids (Table 6). Culverts would be placed at all other stream crossings. Given that the transportation corridor would cross a total of 55 streams and rivers known or likely to support migrating or resident salmonids, culverts would be constructed on 36 presumed salmonid streams.

The transportation corridor would traverse varied terrain and subsurface conditions, including areas requiring rock excavation in steep, mountainous terrain where storm runoff can rapidly accumulate and result in intense local runoff conditions (Ghaffari et al. 2011). Although the road design, including placement and sizing of culverts, would account for seasonal drainage and spring runoff requirements, culvert failures would still be expected. For example, heavy rains in late September 2003 washed out sections of the Williamsport–Pile Bay Road (Lake and Peninsula Borough 2015), and culverts on this road have been washed out on numerous occasions (PLP 2011: Appendix 7.3A).

Blockage of a culvert by debris or downstream erosion would inhibit the upstream and downstream migration of salmon and the movement of other fish among seasonal habitats. The effects of a blockage would depend on its timing and duration. A blockage would result in the loss of spawning and rearing habitat if it occurred during adult migration periods and persisted for several days. It could cause the loss of a year class of salmon from a stream if it occurred during juvenile migration periods and persisted for several days or more.

Culvert blockages could persist for as long as the intervals between culvert inspections. We assume that the transportation corridor would receive daily inspection and maintenance during operation of the mine, or at least that would be the intent of the owners. The level of surveillance along the corridor can be expected to affect the frequency of culvert failure detection. Some failures that would reduce or block fish passage (e.g., gradual downstream channel erosion resulting in a perched culvert) might not be noticed by a driving inspection. Thus, blockage of migration could persist for an extended period.

After mine operations end, traffic would decrease to that which is necessary to maintain any residual operations on the site, and inspections and maintenance would decrease. If the road was adopted by the state or local government, the frequency of inspections and quality of maintenance would decline to those provided for other roads. Either of these possibilities could result in a proportion of failed culverts similar to those described in the literature.

Culvert failure frequencies reported in the literature are 30% (Price et al. 2010), 53% (Gibson et al. 2005), and 58% (Langill and Zamora 2002). That is, culvert surveys indicate that at least 30% block or inhibit fish passage at any given time. These surveys were on modern roads and included various design types.

As noted previously, Hastings (2005) found that about 5.5 km of perennial headwater stream habitat, supporting a census population size of > 2,000 adults, is required for a high likelihood of long-term population persistence. Table 6 shows that, of the 55 known or likely salmonid-supporting streams that would be crossed by the transportation corridor, 39 contain < 5.5 km of habitat (stream length) upstream of the proposed road crossings. These 39 stream crossings contain a total of 68 km of upstream habitat and 493 km of downstream habitat. Seven of these crossings would be bridged, leaving 32 with culverts. Assuming typical maintenance practices after the cessation of mine operations, 30% or more of these streams, i.e., at least 10 streams, would be entirely or partially blocked at any one time. As a result, these streams would likely not be able to support long-term populations of resident species such as rainbow trout or Dolly Varden.

Filling and Alteration of Wetlands, Ponds, and Small Lakes

Approximately 11% (12 km) of the transportation corridor would intersect mapped wetlands, ponds, and small lakes (Table 5). An additional 24% (27 km) would be located within 100 m of these habitats, and another 16% (19 km) would be located within 100–200 m (Table 5). In total, ~ 51% (58 km) of the corridor length would fill or otherwise alter wetlands, ponds, and small lakes. These habitats encompass 2.3 km^2 (1.6, 0.1, and 0.6 km^2 of wetlands, ponds, and small lakes, respectively), or nearly 11% of the total area within 100 m of the transportation corridor. The area of NWI-mapped aquatic habitats within 200 m of the corridor would be 4.7 km^2 (3.3, 0.2, and 1.2 km^2 of wetlands, ponds, and small lakes, respectively). The area of these habitats filled by the roadbed would be 0.11 km^2 (i.e., ~ 12 km of road, assuming a road width of 9.1 m).

The distribution of salmonids in wetlands, ponds, and small lakes along the transportation corridor is not known, but these aquatic habitat losses can result in the loss of resting habitat for adult salmonids and of spawning and rearing habitat in ponds and riparian side channels. Sockeye use of spring-fed ponds has been observed at several locations along the corridor (Table 1). The potential ecological impacts of filling and alteration of wetlands, ponds, and small lakes are summarized in Table 3.

Chemical Contaminants

As noted previously, four sources of potentially toxic chemicals are related to the transportation corridor: traffic residues, road construction, chemical cargos, and road treatment.

With respect to traffic residues, it is unclear if the transportation corridor would have sufficient traffic for this to be a problem. With respect to road construction, it is not clear where materials for the road will come from or their composition. Hence, this risk is not considered further.

Many chemical reagents would be used to process ore (USEPA 2014: Box 4-5), and these chemicals would be transported by road to the mine site. Truck accidents along the transportation corridor could spill reagents into wetlands or streams. The transport of reagents would require ~ 11,725 truck trips per year (see the "Methods" section). The length of the transportation corridor within the Kvichak River watershed would be 113 km. The probability of truck accidents and releases was reported as 1.9 × 10-7 spills per mile of travel for a rural two-lane road (Harwood and Russell 1990). Based on this rate, the number of spills over the 25-year mining scenario would be 3.9—that is, ~ 4 spills from truck accidents would be expected during mine operations. Over the roughly 78-year life of the second scenario, 12 spills would be expected. Only one-way travel is considered, because return trips from the mine would be with empty trucks or with a load other than process reagents. Because conditions on the mine road would be different from those for which the statistics were developed (e.g., more difficult driving and road conditions), this calculation provides an order of magnitude estimate. The reasonableness of these estimates is suggested by an assessment of the Cowal Gold Project in Australia, which estimated that a truck wreck would occur every 1 to 2 years, resulting in a spill every 3 to 6 years (NICNAS 2000).

For 14% of its length (15 km), the transportation corridor would be within 100 m of a stream or river, and for 24% of its length it would be within 100 m of a mapped wetland (Table 5). If the probability of a chemical spill is independent of location, and if it is assumed that liquid spills within 100 m of a stream could flow to that stream, a spill would have a 14% probability of entering a stream within the Kvichak River watershed. This would result in roughly 0.5 stream-contaminating spills over the 25-year mining scenario or up to 2 stream-contaminating spills over the 78-year life of the second scenario. Similarly, a spill would have a 24% probability of entering a wetland, resulting in an estimate of 1 wetland-contaminating spill in the 25-year scenario or 3 wetland-contaminating spills in the 78-year scenario. A portion of those wetlands would be ponds or backwaters that support fish. It should be noted that the risk of spills could be somewhat mitigated by using spill-resistant containers.

A principle processing chemical of concern that would be transported by truck to the mine site is sodium ethyl xanthate. This chemical would be transported as a liquid and would enter the environment as a result of truck accidents. It is representative of the process reagents estimated to result in roughly two stream-contaminating spills over the 78-year mining scenario.

A risk assessment by Environment Australia for sodium ethyl xanthate generated a predicted no effect concentration of 1 μg/L, and estimated that a spill of as little as 10% of a 25 metric-ton-capacity truck carrying sodium ethyl xanthate into a stream would require a "650000:1 dilution before the potential hazard is considered acceptable" and that the spill could not be mitigated (NICNAS 2000).

Given the liquid form and toxicity of sodium ethyl xanthate, it is expected that a spill of this compound into a stream along the transportation corridor would cause a fish kill. Runoff or groundwater transport from a more distant spill would cause effects that would depend on the amount of dilution or degradation occurring before the spilled material entered a stream.

Cyanide for gold processing would be transported as a solid. We assume containment equivalent to that at the Pogo mine (i.e., dry sodium cyanide pellets inside plastic bags inside wooden boxes inside metal shipping containers). Hence, even in a truck wreck, a cyanide spill is an unquantifiable but low probability occurrence. Spills on land would be collected unless they occurred during rain or snowmelt, in which case spilled pellets would dissolve and flow to surface or groundwater. Cyanide pellets spilled by a truck wreck into a stream would be carried by the current but would rapidly dissolve into a cyanide solution and would ultimately disperse, volatilize, and degrade in Iliamna Lake. Spills into a wetland would dissolve in place.

Cyanide has acute and chronic U.S. ambient water quality criteria for freshwater of 22 and 5.2 μg free cyanide per liter. The geometric mean of 30 median lethal concentration (LC50) values from acute tests of rainbow trout is 55.7 μg/L (USEPA 1985, 2013). In a 2-H exposure to 10 μg/L cyanide, swimming speed of coho salmon was reduced (USEPA 1985). Standard acute endpoints for invertebrates range from 17 to 210,000 μg/L (USEPA 1985, 2013). Data needed to derive a cyanide spill scenario and quantify risks are unavailable, but given the toxicity of cyanide and its rapid action, effects on invertebrates and fish, including death, would be likely if a substantial spill into a stream or wetland occurred.

Molybdenum concentrate (primarily molybdenum sulfide) is a product of the mine and would also be transported by truck. The concentrate would be a dewatered fine granular material contained in bags packed in shipping containers. Thus, as with cyanide, a spill of molybdenum concentrate is an unquantifiable but low probability occurrence. A spill on land could be collected, but a spill into water would be transported downstream. Settled concentrate would oxidize, forming acidic pore water with dissolved molybdenum to which benthic invertebrates and fish eggs and larvae could be exposed.

Molybdenum's aquatic toxicity is relatively poorly characterized. The most directly relevant values are 28-day LC50 values for rainbow trout eggs of 730 and 790 μg/L (Birge 1978, Birge et al. 1979). The mean of two acute lethality tests with rainbow trout is 1,060,000 μg/L (USEPA 2013). Acute and chronic values for *Daphnia* are 206,800 and 4500 μg/L (USEPA 2013). Hence, molybdenum appears to be much less toxic than xanthate or cyanide. However, the small body of test data and lack of information on the influence of water chemistry on toxicity make judgments about the effects of aqueous molybdenum uncertain.

Roads are treated with salts and other materials to reduce dust and improve winter traction. In Alaska, calcium chloride is commonly used for dust control and is mixed with sand for winter application. Compounds used to control ice and dust (Hoover 1981) have been shown to cause toxic effects when they run off and enter surface waters. Rainwater tends to leach out the highly soluble chlorides (Withycombe and Dulla 2006), which can degrade nearby vegetation, surface water, groundwater, and aquatic species (Environment Canada 2005).

Salmonids are sensitive to salinity, particularly at fertilization (Weber-Scannell and Duffy 2007). According to Bolander and Yamada (1999), application of chloride salts should be avoided within at least 8 m of water bodies (including shallow groundwater, if significant migration of chloride would reach the groundwater table), and restricted if low salt-tolerant vegetation occurs within 8 m of the treated area. On a total molarity basis, calcium chloride – commonly used in Alaska – is more toxic than sodium chloride (Mount et al 2016). Alaska acute and chronic water quality standards for chloride (associated with sodium) are 860 and 230 mg/L, respectively (ADEC 2003). However, these values may not provide adequate protection from calcium salts. In addition, exceedances of the acute criterion could affect many species, because freshwater biota have a narrow range of acute susceptibilities to chloride (ADEC 2003). Adverse biological effects are likely to be particularly discernible in naturally low-conductivity waters such as those of the Bristol Bay watershed, but modeling is needed to substantiate this. In summary, risks to salmonids from de-icing salts and dust suppressants could be locally significant, but would depend on the amount and frequency of application.

Fine Sediment

The magnitude of effects from fine sediment loading are highly location-specific and are not quantifiable given available data. However, published studies of the influence of silt on salmonid streams indicate that even relatively small amounts of additional sediment could have locally significant effects on reproductive success of salmonids and production of aquatic invertebrates. For example, Bryce et al. (2010) found that for each 10% increase in fines (≤ 0.06 mm), the predicted maximum vertebrate Index of Biotic Integrity (IBI) and macroinvertebrate IBI declined 4.4 and 4.0 points, respectively.

Dust

The length of the transportation corridor within the Kvichak River watershed would be 113 km. Based on the estimate from Hoover et al. (1973), the average amount of dust (in tons) generated per mile of road per year along the transportation corridor within the Kvichak River watershed would be equivalent to the daily average number of vehicles passing along the corridor (one vehicle making a round-trip constituting two passages). Using this method, the mine scenarios would generate ~ 105 tons of dust per mile (59 metric tons per km) annually or ~ 6700 metric tons annually for the entire length of road within the Kvichak River watershed. This value may be an underestimate because smaller vehicles typically use rural roads in Iowa, or an overestimate if roads in Iowa are drier or if dust suppression is effective. Regardless, it indicates that dust production along the transportation corridor would be substantial.

As noted earlier, the effects of road dust on near-roadway vegetation may be more pronounced at acidic sites. According to PLP (2011: Chapter 5), ~ 34% of the transportation corridor is composed of well-drained acidic soils (3.5% strongly acidic).

The main impact of dust from the transportation corridor on salmonids likely would be reduced habitat quality due to a reduction in riparian vegetation and subsequent increase in suspended sediment and fine bed sediment, especially during road construction. Potential effects of increased sediment loading are discussed in the “Fine Sediment” section under “Potential Risks to Fish Habitats and Populations”.

Discussion

Uncertainties

The risk of culvert failures is somewhat uncertain due to the paucity of literature on culvert failures both in Alaskan taiga and tundra and for modern mining roads crossing salmonid habitat. The most relevant studies on potential effects of roads, particularly as they relate to salmon, are from forest and rangeland roads. These roads may differ in important ways from mining roads. Forested streams inevitably carry more woody debris that could block culverts. However, forested vegetation types represent 68% of the mapped potential transportation corridor area (PLP 2011: Chapter 13). Mine roads carry much heavier loads than logging roads, but would likely be better engineered. For example, the transportation corridor in this assessment would be designed to support 190-ton haul truck travel on the road surface (Ghaffari et al. 2011), compared to an average gross legal weight limit of ~ 44 tons per log truck (Mason et al. 2008). In any case, the culvert failure frequencies cited in this assessment are from modern roads and not restricted to forest roads, and represent the most relevant data available.

The characterization of both stream length and wetland, pond, and small lake area affected is likely a conservative estimate. The NHD may not capture all stream courses and may underestimate channel sinuosity, resulting in underestimates of affected stream length. Additionally, the AWC and the AFFI do not necessarily characterize all potential fish-bearing streams due to limited sampling along the corridor (Johnson and Litchfield 2016). The characterization of wetland, pond, and small lake area is limited by the resolution of the available NWI data product. In this analysis, the transportation corridor often bisects wetland features and the wetland area falling outside the 200 m boundary was assumed to maintain its functionality. We were also unable to determine the effect that the transportation corridor may have on wetlands that have no direct surface water connection but may be hydrologically connected via groundwater pathways. Together, these limitations likely result in an underestimate of the effect that transportation corridor development would have on hydrologic features in this region. These estimates could be improved with enhanced, higher-resolution mapping, increased sampling of possible fish-bearing waters, and ground-truthing of surface-water and groundwater connections.

Aerial index surveys that were used by ADF&G to estimate sockeye salmon spawning abundance tend to underestimate true abundance for many reasons (Bue et al. 1988, Jones et al. 2007). Nonetheless, aerial index survey counts are a useful relative measure of sockeye abundance within subwatersheds that would be crossed by the transportation corridor.

Observations on the State of Practice

We compared the methodology of our case study with road-relevant information in Environmental Impact Statements (EISs) for two mining projects in Alaska: Pogo mine (active) and Donlin Gold (proposed) (USEPA 2003a and USACE 2018, respectively).

Quantitative information for acreage of wetlands affected, and estimates of spill frequency and impacts from traffic accidents were provided for both mines (gross estimates in the case of Donlin), as well as our case study. All three study types acknowledge the effects of fugitive dust from road traffic. Estimates of dust quantities generated specifically from traffic, however, are provided only in our study. With respect to suspended sediment loads, we did not report baseline data from the study area. EISs for Pogo and Donlin contain baseline suspended sediment concentrations prior to the start of mine development. But these EISs are limited in value because they do not contain information on suspended sediment loads expected to result from construction and operation of the transportation corridor. These loads can diminish habitat quality, particularly for spawning salmonids, in the streams below road crossings. Best management practices to control or mitigate erosion are covered only in a general sense in these EISs. Specific elements of mitigation and monitoring practices are not developed until the final design and permitting phase of each project (e.g., within an Erosion and Sediment Control Plan (ESCP) and Sediment Water Discharge Pollution Prevention Plan (SWPPP)). For the Pogo mine preferred access road, “fish distribution and habitat use in the drainage, with the possible exception of grayling, are largely unknown” (EPA 2003a). In the case of Donlin, data are presented from intermittent fish surveys conducted in streams crossed by the proposed mine access road. Potential culvert failures were not factored into these EISs. In both cases, all (Pogo) or most (Donlin) fish-containing streams were crossed by bridges, suggesting that these crossings are unlikely to have a severe environmental impact. However, this will not be the case in the present study, where the transportation corridor would cross 55 streams (36 crossings with culverts) known or likely to support salmonids. Importantly, state-of-the-art culverts sometimes fail and this should be acknowledged in any EIS.

Best management practices (BMPs) are used in the development and operation of a mine road to minimize environmental impacts, and these are taken into account in environmental assessments. EISs often contain statements such as Mitigation, reclamation and monitoring measures proposed by the Applicant to reduce environmental impacts would be used to ensure that (1) there would be no unreasonable impacts from project development, operation, and closure, or that (2) the project would comply with applicable regulations. However, even with continued technological improvements in BMPs, attempted compliance with state and federal requirements does not equate with actual compliance or acceptable risk. Continued monitoring – often in perpetuity if a road persists after mine closure – of habitats and fish populations that may be affected by a mining road is of utmost importance. We were not able to present information on fish population dynamics in this study. However, estimating fish population changes through modeling should be a part of any EIS where roads potentially affect major fisheries used for subsistence purposes (see the “Information Needs” section below).

Information Needs

We present the direction of risks from projected exposures associated with the road development scenarios, and their relative likelihood, but were unable to quantify population-level effects to salmon and other resident fish. Translating exposures to population-level risks to salmon and other fish populations for this case study entails significant challenges.

Given that the development has not yet occurred, and the timing, location, frequency, and magnitude of the assessed impacts cannot truly be known, exposures are best characterized as probabilities and cannot be ascribed to specific locations or populations with certainty. In addition, though the occurrence of salmonid species in rivers and major streams is known, we currently lack complete quantitative information on salmon population status and population dynamics in many of the streams potentially impacted by the proposed road. Estimating fish population changes would require population modeling, which requires knowledge of life-stage-specific survival and production and limiting factors and processes. Further, it requires knowledge of how temperature, habitat structure, prey availability, density dependence, and sublethal toxicity would respond to road construction, maintenance, and transportation activities, and how these changes in turn would influence life-stage-specific survival and production of fish populations. Obtaining this information would require more detailed monitoring and experimentation. At present, data are insufficient to establish reliable salmon population estimates, and obtaining such data would take many years. Estimated effects of a mining road on fish habitat thus become the best available surrogate for estimated effects on fish populations.

Conclusions

The scenario examined here, potential development of a mine-associated transportation corridor in a watershed that supports the largest sockeye salmon fishery in the world, is unlike any other in terms of size, hydrological complexity and potential societal ramifications (due to importance of salmon to the economy and diets of numerous people). The corridor would cross 55 streams known or likely to support salmonids in an area characterized by an abundance of mapped wetlands. Risks to salmonids from filling of wetlands, hydrologic modifications, spillage or runoff of contaminants and fine sediment, and dust deposition are likely to diminish the production of anadromous and resident salmonids in many of these streams.

To provide the most accurate predictions, EISs for mining projects in Alaska need to contain more detailed information relative to the potential ecological effects of the proposed mining road(s) on fish populations. They also need to contain more detailed management practices designed to mitigate these effects. Soon, important decisions will be made regarding mineral resource extraction in the Bristol Bay watershed. The sustainability of an important, generations-old, wild salmon fishery depends upon getting them right.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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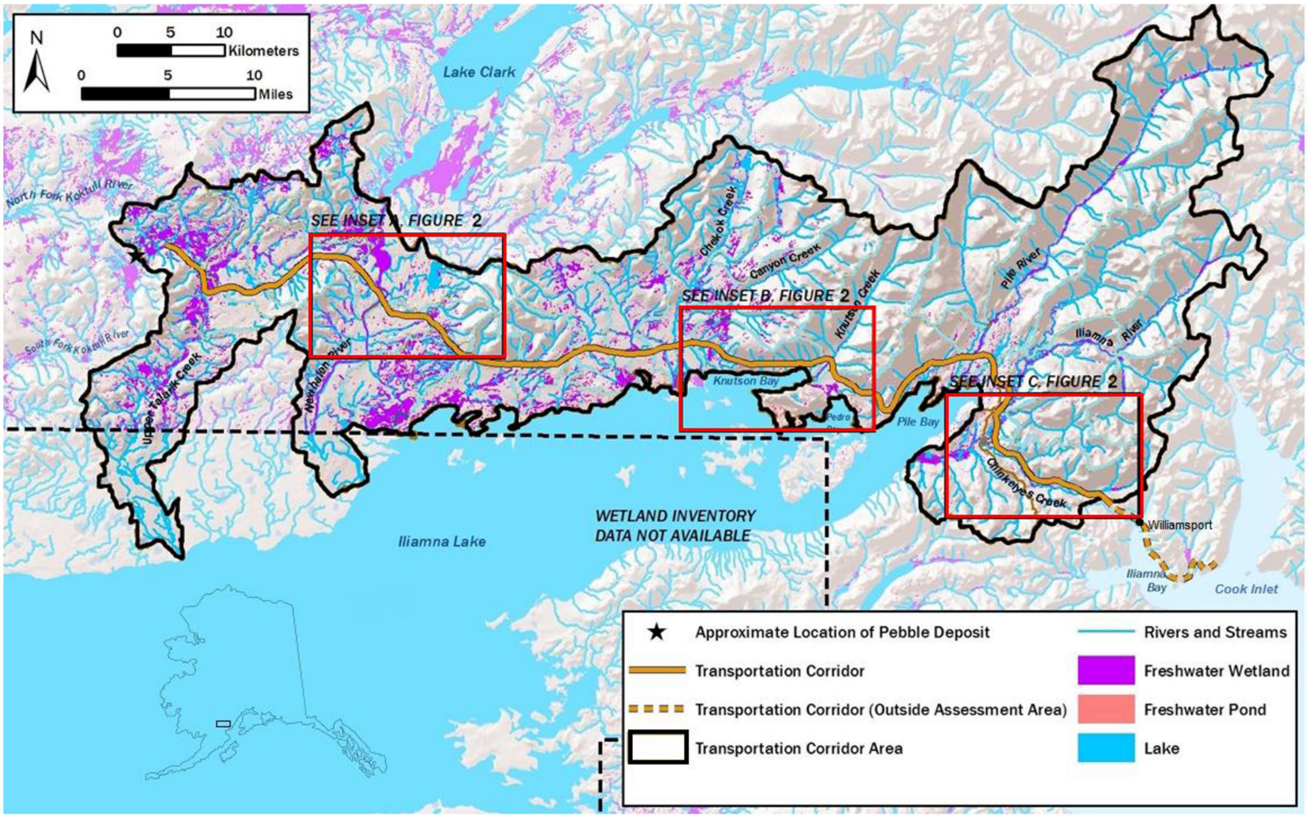

Fig. 1.

The transportation corridor area. Streams and rivers are from the National Hydrography Dataset (USGS 2012); wetlands, lakes, and ponds are from the National Wetlands Inventory (USFWS 2012)

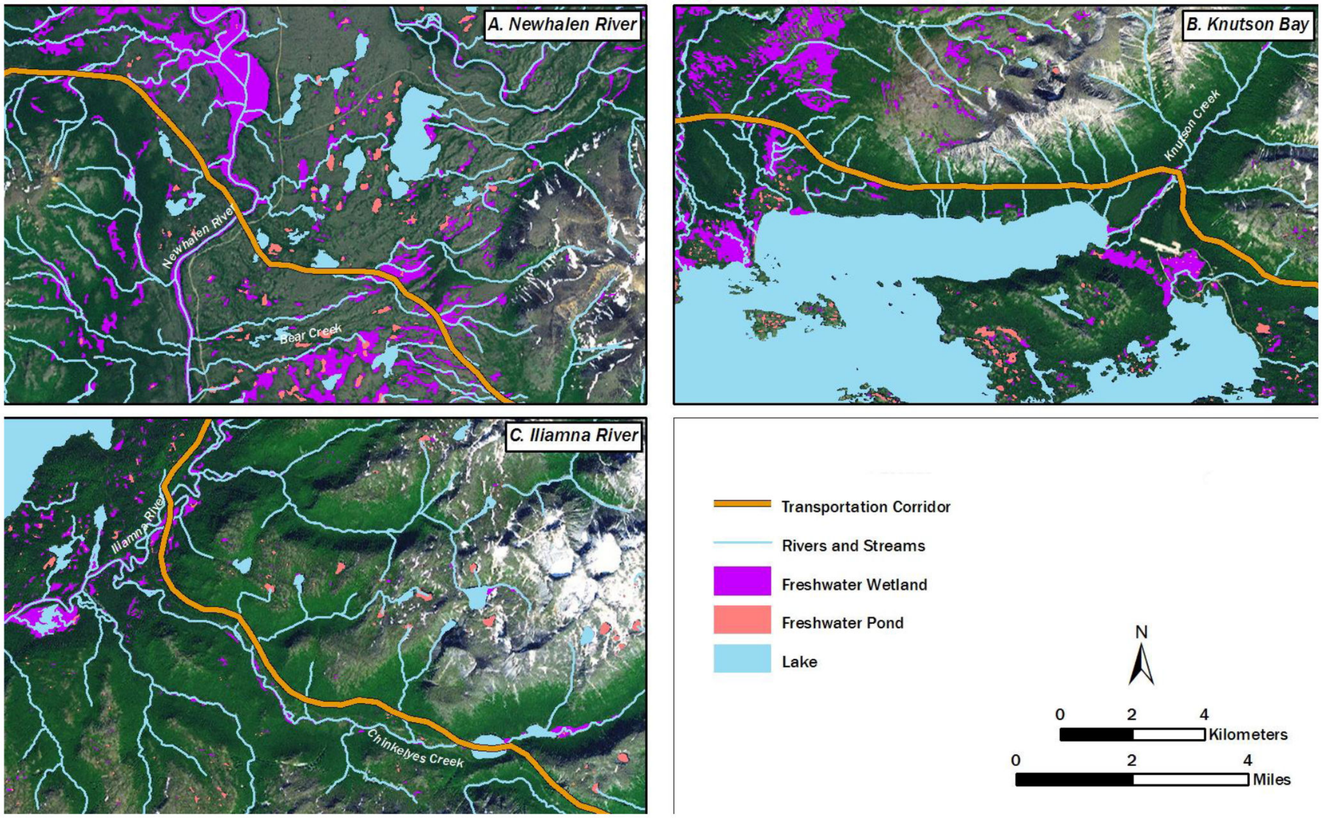

Fig. 2.

High-impact areas along the transportation corridor. Streams and rivers are from the National Hydrography Dataset (USGS 2012); wetlands, lakes, and ponds are from the National Wetlands Inventory (USFWS 2012). Image source: ESRI 2013. See Fig. 1 for location of these areas along the transportation corridor

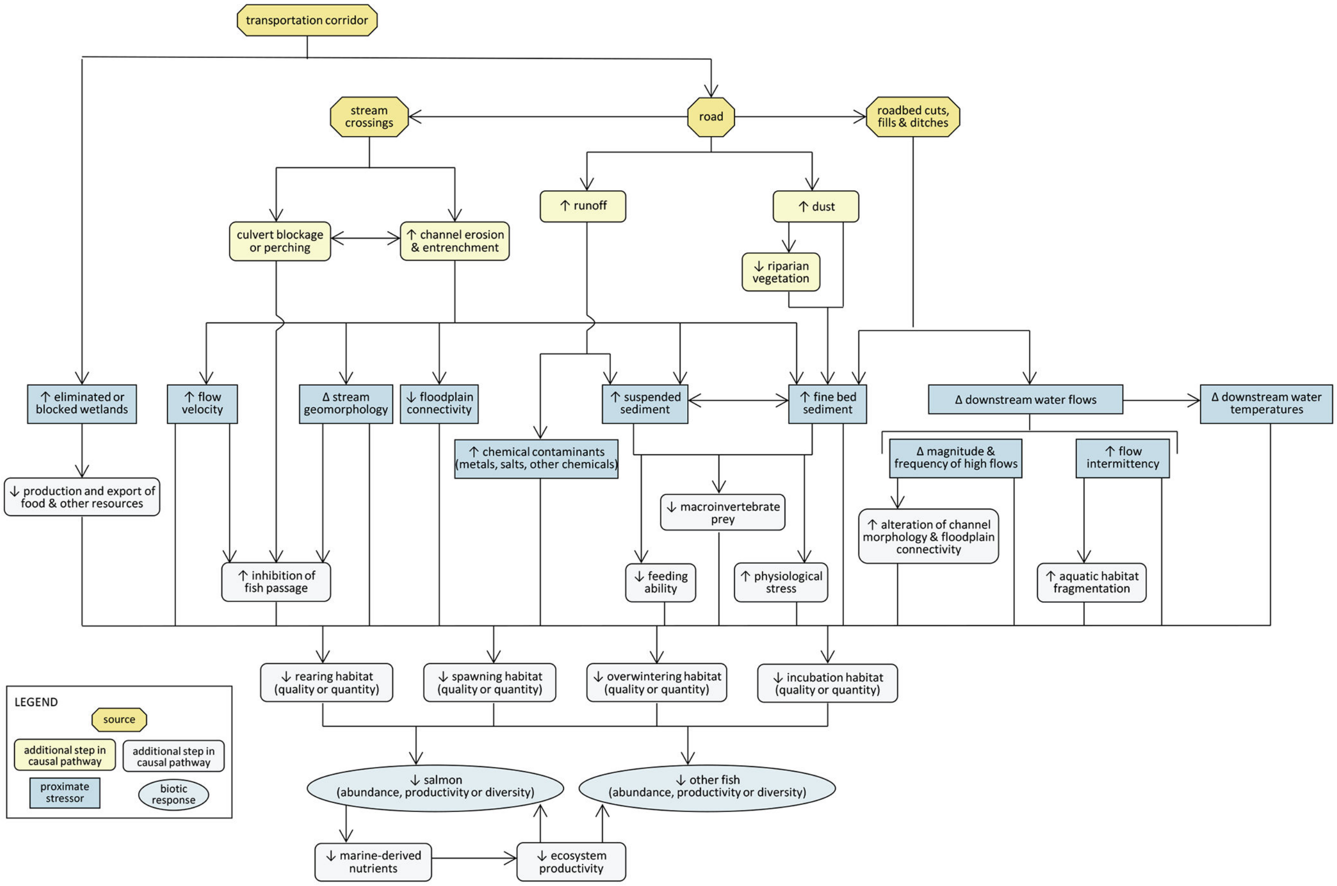

Fig. 3.

Conceptual model showing potential pathways linking the transportation corridor and related sources to stressors and assessment endpoints

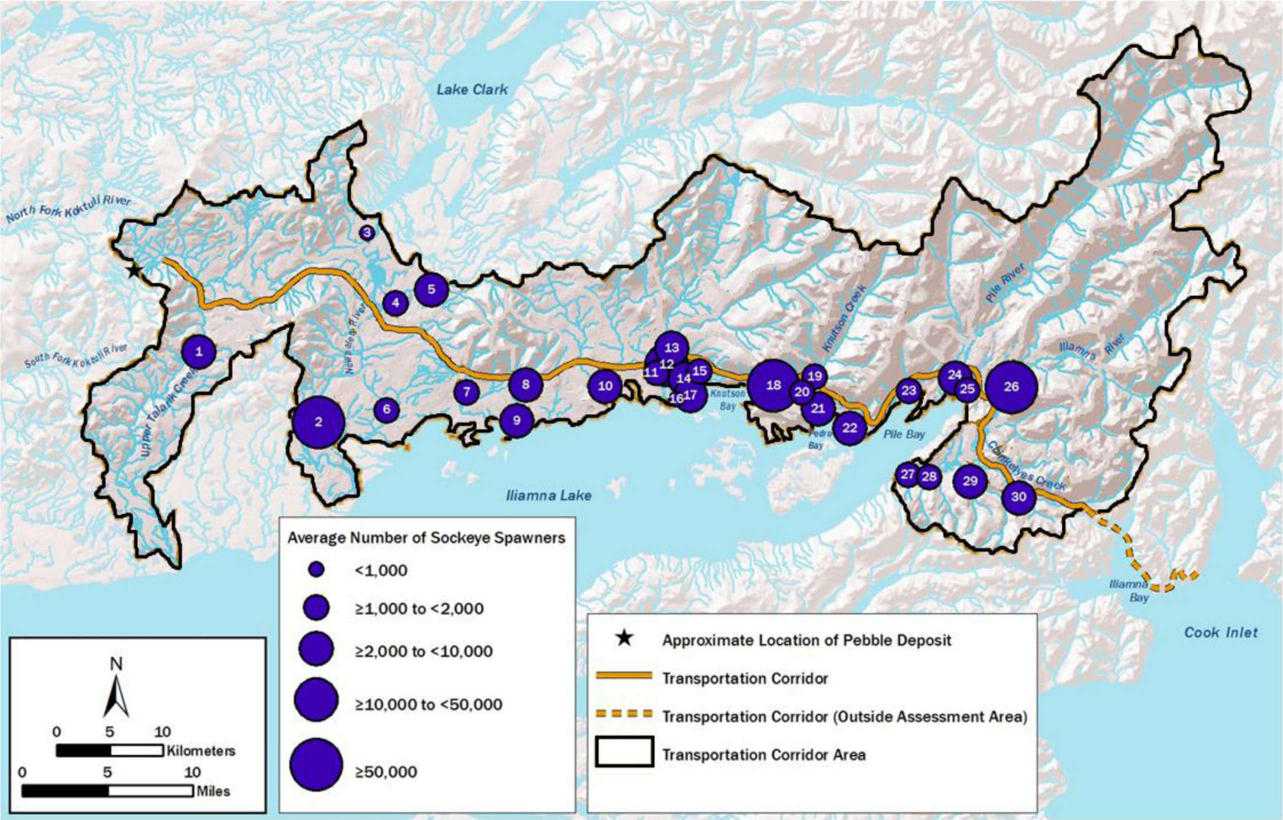

Fig. 4.

Location of sockeye salmon surveys and number of spawners observed along the transportation corridor. Numbers within circles refer to map points listed in Table 1

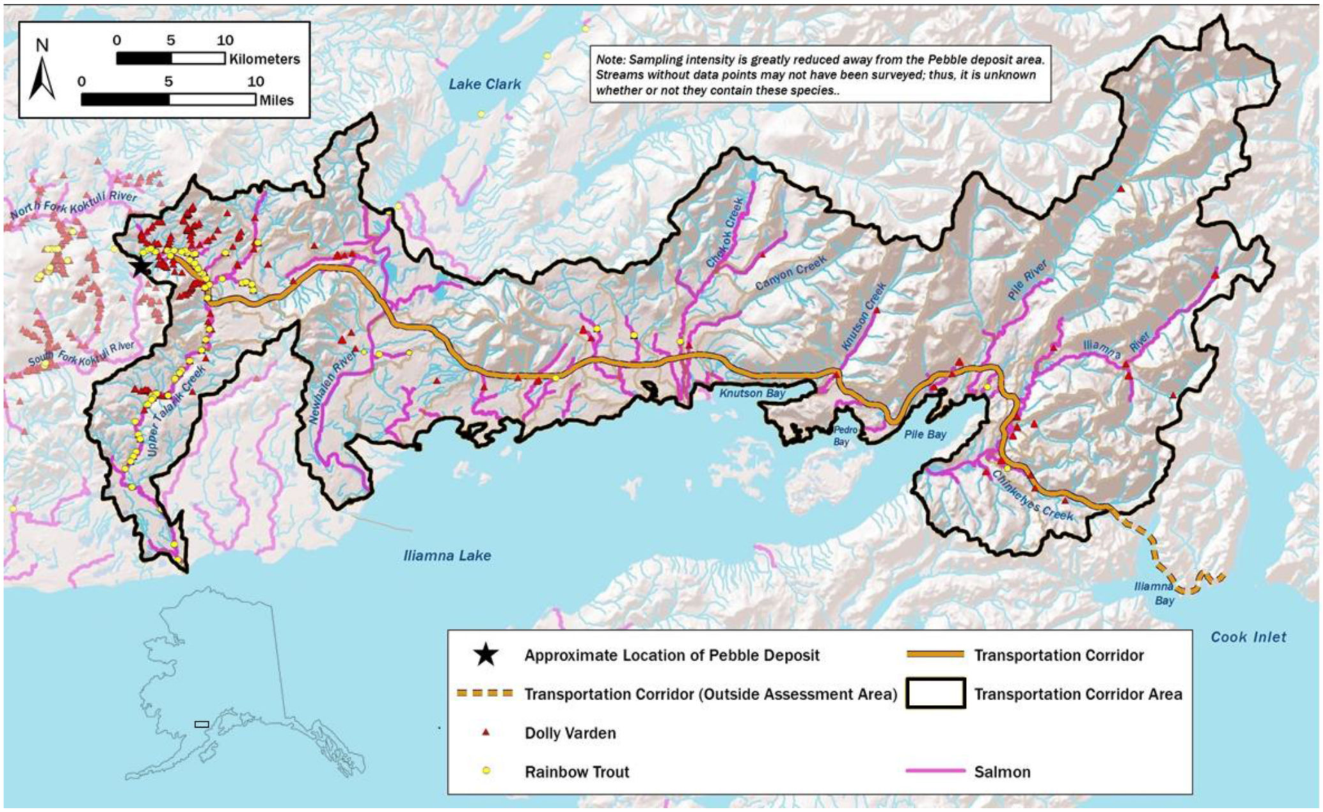

Fig. 5.

Reported salmon, Dolly Varden, and rainbow trout distributions along the transportation corridor. Salmon presence data are from the Anadromous Waters Catalog (Johnson and Litchfield 2016); Dolly Varden and rainbow trout presence data are from the Alaska Freshwater Fish Inventory (ADF&G 2017). Though not indicated on this map, rainbow trout have also been documented in the Iliamna River (Russell 1977)

Table 1

Average number of spawning adult sockeye salmon at locations near the transportation corridor. See Fig. 4 for the locations of these areas

Map Point	Area Name	Type	Average Number of Sockeye Salmon Spawners (1955–2011)	Number of Years Spawners were Counted (Max = 57)	Range
1	Upper Talarik Creek	Stream	7,021	49	0–70,600
2	Newhalen River	River	84,933	34	97–730,900
3	Little Bear Creek/Ponds	Ponds	527	20	0–1,860
4	Alexi Creek	Stream	1,176	27	0–13,200
5	Alexi Lakes	Lake	7,121	33	11–38,000
6	Roadhouse Creek	Stream	1,052	28	0–4,950
7	N.W. Eagle Bay Creek	Stream	1,649	32	0–17,562
8	N.E. Eagle Bay Creek/Ponds	Stream	3,416	38	0–18,175
9	NE Eagle Bay Cr. Ponds	Ponds	4,766	5	200–11,700
10	Youngs Creek	Stream	3,532	38	0–26,500
11	Chekok Creek/Ponds	Stream	1,840	32	0–8,700
12	Tomkok Creek	Stream	10,882	38	300–56,600
13	Canyon Creek	Stream	8,015	38	200–48,000
14	Wolf Creek Ponds	Ponds	4,469	26	0–28,000
15	Mink Creek	Stream	1,144	35	0–6,000
16	Canyon Springs	Ponds	884	20	0–5,000
17	Prince Creek Ponds	Ponds	3,797	34	5–34,800
18	Knutson Bay	Lake	72,845	47	1,000–1,000,000
19	Knutson Creek	Stream	1,548	41	1–6,600
20	Knutson Ponds	Ponds	1,200	39	0–6,350
21	Pedro Creek & Ponds	Ponds	4,259	48	0–38,150
22	Russian Creek	Stream	2,263	17	0–20,000
23	Lonesome Bay Creek	Stream	1,026	6	32–2,675
24	Pile River	River	6,431	38	0–39,200
25	Swamp Creek	Stream	1,091	18	25–7,700
26	Iliamna River	River	101,306	53	3,000–399,300

Map Point	Area Name	Type	Average Number of Sockeye Salmon Spawners (1955–2011)	Number of Years Spawners were Counted (Max = 57)	Range
27	Bear Creek & Ponds	Ponds	1,748	30	40–10,300
28	False Creek	Stream	1,317	21	0–13,300
29	Old Williams Creek	Stream	3,726	27	0–38,000
30	Chinkelyes Creek	Stream	9,128	46	50–44,905

Notes: Locations are organized from west to east along the corridor

Sources: Morstad 2003, Morstad pers. comm. (Morstad S. Fishery Biologist III, ADF&G. September 2011—email of unpublished data to Rebecca Shaftel)

Table 2

Potential ecological impacts of culverts

Cause	Impact	Reference(s)
Flow restrictions	By funneling flow from entire floodplain into main channel, culverts may serve to increase water velocities in the channel, and reduce flow into seasonal floodplain wetlands and small valley floor tributaries that serve as important salmonid habitat. Resulting downstream erosion and channel entrenchment can result in perched culverts and barriers to fish migration, inability of fish to reach slow-water refugia during high flow events, reduction of nutrient and sediment cycling between stream channel and floodplain, and a change in the water table and extent of the hyporheic zone, with consequences for water-body connectivity and floodplain water temperatures	Bunn and Arthington 2002, Forman and Alexander 1998, Bates et al. 2003
Aufeis[a] that fills culverts	Water runs over roadway unless flow is initiated through the culvert	Kane and Wellen 1985
Culverts plugged by debris or overtopped by high flows	Fish-passage barrier. Road damage, channel realignment, severe sedimentation; habitat value diminished as channel becomes wider and shallower. Increased downstream deposition of fine sediment decreases abundance and production of fish and benthic invertebrates	Bates et al, 2003, Furniss et al. 1991; Wood and Armitage 1997

[a] Ice feature that forms when water in or adjacent to a stream channel rises above the level of an existing ice cover and gradually freezes to produce a thickened ice cover

Table 3

Potential ecological impacts of filling and alteration of wetlands, ponds, and small lakes

Service Provided	Impact	References
Resting, spawning and rearing habitat provided by hydraulically and thermally diverse conditions	Loss of resting, spawning and rearing habitat. By damming and diverting surface flow and inhibiting subsurface flow, could block or limit access by fish to important habitats, including beaver ponds	Brown and Hartman 1988, Nickelson et al. 1992, Cunjak 1996, Collen and Gibson 2001, Lang et al. 2006
Floodplain wetlands and ponds can be important contributor to abundance and diversity of food (and foodwebs) upon which salmon depend	Loss of foraging opportunities	Sommer et al. 2001, Opperman et al. 2010
Biogeochemical processes necessary for vegetation, and affecting the contribution of nutrients, organic material and macroinvertebrates from headland wetlands to higher order streams receiving wetland drainage. Invertebrates and detritus provide an important energy subsidy for juvenile salmonids	Changes in subsurface flow paths and extent of hyporheic zone caused by the road bed can alter rates or types of biogeochemical processes, leading to loss of vegetation, and affecting the food supply of juvenile salmonids	Wondzell and Swanson 1999, Wipfli and Baxter 2010, Wipfli and Gregovich 2002

Table 4

Potential ecological impacts of fine sediment

Cause	Impact	Reference(s)
Sediment loading from roads leading to increased concentrations or durations of fine sediment downstream	Decreased survival and growth of salmonids; decreased fry emergence, decreased juvenile densities, loss of winter carrying capacity, increased predation on fish, and reduced benthic organism populations and algal production; reduced quality and quantity of spawning habitat through channel braiding, increased width-depth ratios, increased bank erosion, and reduced pool volume and frequency of occurrence	Newcombe and Jensen 1996, Gucinski et al. 2001, Angermeier et al. 2004, Furniss et al. 1991
During high discharge events, accumulated sediment tends to be flushed out and redeposited in larger water bodies	Impact on clarity and chemistry of downstream waterbodies, especially Iliamna Lake, would affect the photic zone and thereby primary production and zooplankton abundance which are critical to concentrated sockeye spawning populations in these areas	Forman and Alexander 1998
Increased deposition of fine sediment	Decreased survival and growth of salmonids, and reduced spawning habitat: can completely cover suitable spawning gravel rendering it useless for spawning, or smother eggs and alevins after spawning; decreased abundance and production of fish and benthic invertebrates	Suttle et al. 2004, Wood and Armitage 1997, Bryce et al. 2010

Table 5

Proximity of the transportation corridor to National Hydrography Dataset streams (USGS 2012) and National Wetlands Inventory wetlands, ponds, and small lakes (USFWS 2012)

		Proximity to Streams			**Proximity to Wetlands**		
HUC-12 Name or Description	**HUC-12 Digit**	**<100 m (km)**	**100–200 m (km)**	**Total Corridor Length (km)**	**Intersects (km)**	**<100 m (km)**	**100-200 m (km)**
Headwater, Upper Talarik Creek	190302060702	0.8	1.2	7.4	1.9	4.0	1.2
Upper tributary stream to Upper Talarik Creek	190302060701	0.2	0.1	4.6	0.3	1.4	1.2
Tributary to Newhalen River portion of corridor	190302051404	1.9	1.2	10.9	0.4	3.9	2.6
Headwaters, Newhalen River	190302051405	0.4	0.4	3.4	0.1	0.4	0.5
Outlet, Newhalen River	190302051406	1.5	0.8	6.5	2.4	1.7	1.4
Roadhouse Creek	190302060907	1.2	1.3	3.3	0.3	1.8	0.5
Iliamna Lake	190302060914	4.3	4.1	37.7	1.8	3.9	3.7
Eagle Bay Creek	190302060905	0.5	0.8	4.4	0.7	1.7	0.8
Youngs Creek Mainstem (Roadhouse Mountain HUC)	190302060903	0.1	0.2	3.4	0.2	1.1	1.2
Youngs Creek East Branch	190302060904	1.0	0.6	3.0	0.5	0.8	1.5
Chekok Creek	190302060302	0.3	0.3	2.5	0.2	0.3	0.2
Canyon Creek	190302060902	0.1	0.2	1.4	0.0	0.2	0.3
Knutson Creek	190302060901	0.3	0.4	2.0	0.1	0.6	0.3
Outlet, Pile River	190302060104	0.6	0.7	3.4	1.2	1.5	0.5
Middle Iliamna River	190302060205	1.1	0.7	6.4	0.6	1.7	1.3
Chinkelyes Creek	190302060206	0.8	2.1	12.5	1.4	1.9	1.5
Total length across all HUCs		**15.3**	**15.2**	**113**	**12.2**	**27.0**	**18.5**
Percentage across all HUCs		14%	13%	100%	11%	24%	16%

HUC = hydrologic unit code

Table 6

Summary of road-stream crossings along the transportation corridor, upstream lengths of streams of different sizes likely to support salmonids (based on stream gradients of < 12%), and downstream lengths to Iliamna Lake. Information on individual road-stream crossings is contained in Online Resource 1

HUC-12 Name or Description	Stream Crossings (Bridges[a])	Anadromous-designated Streams at Crossings [AWC] (AWC + other Streams with Upstream Salmonid Potential)	Upstream Fish Habitat Length (km)					Salmonid Streams with Restricted[c] Upstream Habitat (# of these with Culverts)	Downstream Length to Iliamna Lake (km)
			Small Headwater Streams[b]	Medium Streams[b]	Small Rivers[b]	Large Rivers[b]	Total (Salmonid Streams with Restricted[c] Upstream Habitat)		Total (Salmonid Streams with Restricted[c] Upstream Habitat)
Headwaters Upper Talarik Creek	3 (1)	3 (3)	102.3	37.6	0.0	0.0	139.9 (4.9)	2 (2)	170.2 (113.2)
Upper Tributary to Upper Talarik Creek	1 (0)	0 (1)	3.7	0.0	0.0	0.0	3.7 (3.7)	1 (1)	66.0 (66.0)
Tributary to Newhalen River	5 (0)	2 (5)	22.7	0.0	0.0	0.0	22.7 (10.2)	3 (3)	204.1 (121.0)
Headwaters, Newhalen River	2 (1)	1 (2)	70.8	45.2	0.0	13.1	129.1 (3.1)	1 (1)	55.8 (29.4)
Outlet, Newhalen River	4 (1[d])	0 (3)	11.2	2.6	0.0	0.0	13.8 (5.0)	2 (2)	9.8 (7.4)
Roadhouse Creek	4 (0)	0 (3)	1.8	0.0	0.0	0.0	1.8 (1.8)	3 (3)	23.9 (8.2)
Iliamna Lake–Eagle Bay	3 (1)	1 (2)	2.5	1.5	0.0	0.0	4.0 (4.0)	2 (1)	31.0 (20.7)
Eagle Bay Creek	3 (2[e])	2 (3)	15.7	5.5	0.0	0.0	21.2 (4.0)	1 (1)	19.1 (6.4)
Youngs Creek Mainstem (Roadhouse Mountain HUC)	1 (1)	1 (1)	25.7	16.3	0.0	0.0	42.0 (0.0)	0	10.4 (0.0)
Youngs Creek East Branch	1 (1)	1 (1)	32.9	12.4	0.0	0.0	45.3 (0.0)	0	9.0 (0.0)
Chekok Creek	2 (1)	2 (2)	41.9	42.5	7.9	0.0	92.3 (0.0)	0	13.4 (0.0)
Canyon Creek	1 (1)	1 (1)	0.0	1.2	8.6	0.0	9.80 (0.0)	0	12.1 (0.0)
Iliamna Lake–Knutson Bay	16 (0)	0 (13)	11.0	0.0	0.0	0.0	11.0 (11.0)	13 (13)	30.1 (28.3)
Knutson Creek	2 (1)	1 (2)	0.5	3.2	1.9	0.0	5.6 (5.6)	2 (1)	8.8 (8.8)
Iliamna Lake–Pedro Bay	2 (0)	0 (1)	0.3	0.0	0.0	0.0	0.3 (0.3)	1 (1)	7.2 (4.7)
Iliamna Lake–Pile Bay	4 (2[e])	1 (2)	0.0	1.2	0.0	0.0	1.2 (1.2)	2 (0)	5.5 (4.5)
Outlet, Pile River	4 (2[e])	3 (4)	38.3	28.3	50.0	0.0	116.6 (7.6)	2 (1)	13.9 (7.2)
Middle Iliamna River	1 (1)	1 (1)	27.9	36.5	40.6	0.0	104.9 (0.0)	0	10.2 (0.0)
Chinkelyes Creek	5 (3[f])	0 (5)	1.9	12.2	0.0	0.0	14.1 (5.6)	4 (2)	89.6 (67.5)

Notes: Values (lengths) are arranged by 12-digit HUC from west (top) to east (bottom) along the transportation corridor. Each upstream value is a sum of NHD stream segment lengths in the respective HUC between the crossing and upper extent of salmonid habitat potential based on 12% gradient. Each downstream value is a sum of stream segment lengths in the respective HUC between the crossing and Iliamna Lake. Because the lengths at each crossing represent contiguous lengths, a portion of stream may be included in more than one crossing

[a] Based on annual streamflow threshold of > 0.15 m^3/s; bridges are over anadromous streams unless otherwise noted

[b] Small headwater streams = 0–0.15 m^3/s; medium streams = 0.15–2.8 m^3/s; small rivers = 2.8–28 m^3/s; large rivers = > 28 m^3/s

[c] < 5.5 km

[d] Bridge over non-anadromous stream with upstream salmonid potential

[e] One bridge over non-anadromous stream with upstream salmonid potential

[f] Bridges over non-anadromous streams with upstream salmonid potential

NHD = National Hydrography Dataset; AWC = Anadromous Waters Catalog; HUC = hydrologic unit code