# Potential Impact of Road-Stream Crossings (Culverts) on the Upstream Passage of Aquatic Macroinvertebrates

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## 1. Purpose

The purpose of this report is to document the potential impact of various culvert (i.e., road-stream crossing) characteristics on the upstream passage of aquatic macroinvertebrates.


## 2. Executive Summary

**A.** To minimize the impact of culverts (Figure 1) on upstream dispersal, as well as their overall effect on the hydro-geomorphology of a stream:

**i.** culverts should be as wide as possible to allow for lateral movement of the stream (in fact, if possible, bridges should be built instead); and

**ii.** the bottom of culverts should be set at least 20 cm below the surface of a stream's substrate.

**B.** Although we provide several examples of species that *could* be affected – adversely or otherwise – by culverts, we must stress that the actual culvert-crossing ability of many of the species discussed is unknown. We do know that any barrier to host-fishes for mussels will impede their upstream colonization and we have genetic data suggesting that certain freshwater snails (i.e., *Goniobasis proxima*) do not move upstream if the culvert outflow is above the downstream water level. However, we have little real data on which species can and cannot cross such a barrier and, thus, for each culvert placement the species impacted should be closely examined. For example:

**i.** The aquatic stages (nymphs and larvae) of a *few* stream insects may move a significant distance upstream, as much as two or more kilometers in some cases. However, most will move only short distances upstream. This movement is a measurable, but not critical, portion of the insects' stream-colonization cycle. The ability of most adult aquatic insects to fly upstream will greatly reduce the impact of culvert-obstacles on stream insect communities. Furthermore, at least one species known to migrate long distances has been observed climbing up short waterfalls and, likely, will not find most culverts to be an barrier.

**ii.** Although there is little direct evidence (see Dillon (1988) for an exception), culverts, depending upon their design, may pose a variety of barriers to the upstream passage and dispersal of some non-insects, namely mollusks and some crustaceans.

**1.** The parasitic larval stage (glochidia) of freshwater mussels depend upon the movement of host organisms (mostly fish) in order to disperse upstream. Any culvert that blocks the upstream passage of these hosts also will prevent mussels from colonizing habitat.

**2.** Some crustaceans (e.g. amphipods) are obligate stream species and, like mussels, may be prevented from dispersing by some culverts.

**C.** The home range of several species of endangered stream invertebrates, especially mussels and some freshwater snails (Dillon, 1988), may be limited by culverts. However, the actual effect of culverts on upstream passage of species needing conservation attention will need to be addressed on a case-by-case basis.


Figure 1. Example of a culvert that may not allow upstream passage of some macroinvertebrates. The outflow of this culvert is above the downstream water level because either (1) it was designed and installed this way or (2) downstream erosion has cut the stream's substrate out from underneath the outfall.

**D.** In a very limited number of cases, culverts may block the spread of invasive predators (e.g. brown trout) or possible competitors (e.g. the Asian clam) and, thus, protect some populations of stream invertebrates. However, if true barriers are desired, culverts should *not* be relied upon and appropriate barriers should be designed with the target organism in mind.

**E.** Although upstream passage of macroinvertebrates is the subject of this report, many reviewers of this document believe that the channelization and subsequent erosion and sedimentation associated with culverts will have a much greater, negative impact upon stream macroinvertebrates (see Appendix A). One expert also expressed the concern that, over the long term, even well-designed culverts will experience erosion at their outflows. Over time, this erosion may leave the culvert outflow suspended above the downstream water level and, thus, create a future barrier to upstream passage. In addition, two other reviewers thought that, as microscopic aquatic invertebrates (meiofauna) are also important components of stream ecosystems, especially in the food webs supporting macroinvertebrates, the potential impact of culverts on these organisms should be assessed as well (see Appendix A).

## 3. Introduction

Recent attention has been focused on protecting and rehabilitating anadromous fish runs in the Pacific northwest and elsewhere. A critical part of this effort is to identify barriers that interrupt the upstream passage of these fish. Historically, and for good reason, most attention has been given to dams on large rivers. However, other barriers, such as poorly designed road-stream crossings (i.e., culverts), have been recognized as posing a threat to fish migration in lower order streams.

Besides blocking the upstream passage of fish, some culverts could disrupt the normal, within-stream movements of some macroinvertebrates. Aquatic macroinvertebrates are key components of these stream ecosystems. They are an important food source for anadromous and resident fish, as well as amphibians, birds, bats, and other mammals. They also are important herbivores, detritivores, as well as predators of other invertebrates and, therefore, play a critical role in the cycling of energy and nutrients through stream ecosystems.

Disruptions to the movement and dispersal of stream macroinvertebrates could reduce available habitat and lead to genetic isolation of some populations. The range size of most stream macroinvertebrates (e.g. insects) is unlikely to be affected, but certain culvert characteristics could pose problems for some mollusks and crustaceans. The separation of populations and subsequent reduction in genetic diversity may be especially important for relatively long-lived and highly threatened taxa such as the freshwater mussels.

If designed without regard for all stream organisms, culverts may pose barriers to the upstream movement and dispersal of invertebrates by disrupting the stream flow or structure in one or more of the following ways.

A. A culvert may break the continuity of water in a stream if its outflow is lifted above the water level downstream of the culvert.
B. The water velocity in a culvert may be higher than in the natural stream because the culvert is straight and constricts the stream into a narrower channel. Also, if the culvert contains little or no substrate (e.g. gravel, rocks, or cobbles), then the smoother bottom and sides will offer less resistance to the flowing water.
C. A culvert may break the continuity of the stream's substrate. It may have less, if any, substrate along its stream bottom and, presumably, the ground underneath the culvert would be compacted as a result of construction.

Culverts cause other problems in addition to obstructing upstream movement. These problems likely will affect many more streams and their macroinvertebrate communities and will have a much greater cumulative effect than barrier-culverts alone. While these impacts are beyond the scope of this report, we briefly mention them here.

A. Culverts channelize the stream and do not allow it to migrate laterally across its floodplain. This channelization may cause increased erosion and sedimentation.
B. Culverts serve as an entry point of pollutants (e.g., salt, silt, or soot) that accumulate from water that runs off of roads into roadside ditches.
C. Culverts may change the temperature of the stream water. If the area around the

B. Culverts serve as an entry point of pollutants (e.g., salt, silt, or soot) that accumulate from water that runs off of roads into roadside ditches.
C. Culverts may change the temperature of the stream water. If the area around the culvert and road receives more energy from the sun because the tree canopy was removed, water temperatures may be elevated. However, if the stream is slow relative to the length of the culvert (i.e., if the stream in the culvert is very shallow, slow-moving, and has to travel over a long distance), then the water may be cooled.

A few scientists have documented specific effects these changes in stream structure have on the diversity of adjacent invertebrate communities. For example, King, et al. (2000) found that removing the tree canopy in the area around a highway stream crossing led to an increase in the water temperature and the amount of algae and macrophytes found in the wetland near the crossing. These changes were associated with an increase in the number of invertebrate herbivores (i.e., grazers). In addition, these grazers were species with higher tolerances for warm water environments.

In another example, current research efforts at Tennessee Technological University (TTU), Cookesville, suggest that culverts cause measurable changes to stream invertebrate communities. Early results suggest that the species composition changes downstream from culverts, but that the overall species richness is not significantly different. Furthermore, organisms more tolerant of degraded water quality (i.e., less oxygen, greater temperature fluctuations, etc), as well as filterers and scrapers (i.e., herbivores) tended to be more abundant below culverts (Bradford Cook, TTU, pers. comm.). However, data on the specific effects of various culvert designs on stream invertebrate communities are not yet available.

Because so little research effort has been focused specifically on how culverts impact *upstream migration* or *passage* of invertebrates, this report will highlight data gleaned from the literature reflecting the physical or behavioral characteristics of macroinvertebrates that may prevent them from bypassing culverts. We will address, at various times, the four ways (mentioned above) in which culverts may disrupt stream flow. Then, we will use this data, as well as the opinions of experts in the field, to speculate about the potential impacts these disruptions may have on the upstream passage of macroinvertebrates.

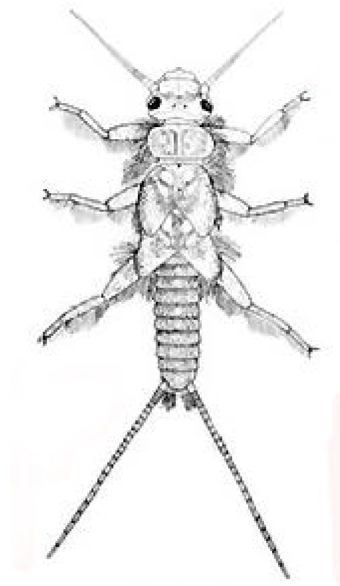

Figure 2. Line drawing of a stonefly nymph (Order: Plecoptera).

# 4. Insects

## 4.0. Summary

Because the adults of most species of aquatic insects can fly, their upstream dispersal is much less affected by culverts than the upstream movement of organisms confined to the water for all life stages (e. g. mussels or amphipods). However, aquatic insects spend most of their lives as immature nymphs (Figure 2) or larvae within the stream. These nymphs and larvae colonize new habitat by drifting downstream with the current, by moving vertically within the substrate, or by crawling along or under the substrate. Some downstream drift is compensated by upstream movement along the substrate, but much of this crawling is random in its direction. Neverthemuch greater, adverse impact upon the stream insect communities near culverts than the potential obstacle culverts may pose to upstream passage of immature insects.

## 4.1. Drift

Several studies support the hypothesis that drift is a dispersal mechanism for aquatic nymphs and larvae (e.g. Benson and Pearson, 1987). McLay (1970) found that macroinvertebrates drifted 0.5 to 19.5 m downstream and Elliott (1967) recorded a maximum distance of 10 m. Townsend and Hildrew (1976) demonstrated that 85% of drifting invertebrates traveled only 2 m downstream.

There also is evidence indicating that drift occurs more often with seasonal higher water levels (Bishop and Hynes, 1969; Ciborowski, 1983, Williams and Williams, 1993). The increased volume and rate of stream flow during these periods may have a higher scouring effect on the stream bottom, decrease the ability of drifting invertebrates to reattach to the substrate, and, in addition, open up new area along the stream banks for colonization. Gore (1977) provides evidence to the contrary, however. In this study, lower flow volumes may decrease the available foraging habitat, increase the density of macroinvertebrates, and, thus, lead to an *increase* in the number of drifting invertebrates as a means of redistributing the population.

## 4.2. Compensation for drift

Whatever the mechanism causing drift, there often is a positive correlation between drift and upstream movement (Williams and Williams, 1993; Turner and Williams, 2000). These findings indicate that, to some degree, the drifting of benthic invertebrates is compensated by upstream movement (summarized in Söderström, 1987). Furthermore, this phenomenon could be part of a dispersal mechanism, whereby larvae or nymphs drift relatively short distances downstream and crawl back upstream, or in some other random direction, in search of suitable habitat or resources.

Many authors have recorded data on the percentage of drifting invertebrates that are compensated by upstream movement. To illustrate, in the case of a 30% compensation for drift, for every hundred individuals that drifted downstream during the study, 30 moved back upstream along the substrate. For example, some studies report compensation rates of 6% (Bishop and Hynes, 1969), 7% to 30% (Elliott, 1971) and 19% to 80% (Williams and Williams, 1993). Williams and Hynes (1976) found that 18.2% and 19.1% of invertebrate colonists to a stream came from upstream migration and vertical movement in the substrate, respectively.

Bergey and Ward (1989) collected data on specific orders of insects and found a wide range in the percentage of drifting insects that were replaced by upstream movement. Upstream movement of Ephemeroptera, Plecoptera, and Coleoptera compensated for 24.6%, 18.7%, and 18.0% of drift. However, the Trichoptera and Diptera moved upstream in relatively much larger numbers, compensating for 284% and 62% of drifting individuals, respectively. Thus, for every caddisfly that drifted downstream, almost three moved upstream.

Benson and Pearson (1987) found differences based on season, with upstream movement compensating for 27% of drift during the dry season, and 2% during the wet season (the mean over 14 months was 8.2%). Gray and Fisher (1981) found differences based on water volume: 3.8% of drifting individuals were compensated by upstream movement of immature insects during non-flood periods, and 17.9% to 40% after periods of flooding.

The examples above present summarized data on communities and orders. Within these broad groups, however, there may be unique examples of a single species or family that demonstrates a greater tendency than others to move upstream within or along the stream's substrate. For example, in one study, upstream movement of riffle beetle larvae (Elmidae) compensated for 180% to 300% of the number of drifting larvae (Bird and Hynes, 1981) and, as mentioned previously, more than 2.8 times the number of drifting caddisflies (comprised of four species) moving upstream in another study (Bergey and Ward, 1989).

## 4.3. Distance and direction

The movement of invertebrates within a stream's substrate is not always directed upstream, and is not always purposeful. Elliot (1971) and Peckarsky (1979) found that downstream movement within the substrate was actually higher than the rate of upstream movement (from Delucchi 1989). Freilich (1991) found that marked *Pteronarcys* nymphs (Plecoptera) moved between zones of attraction, both up and downstream. Bird and Hynes (1981) provide evidence that the direction of movement within the substrate is random.

However, random or not, upstream movement does occur. It often involves short distances of 1 to 10 meters over 24 hours (Elliott, 1971). Yet, over the course of many days, these invertebrates may move as much as 40 to 300 meters (Ball and Hooper, 1963 (reported in Bird and Hynes, 1981); Freilich, 1991; Erman, 1986). A few stream insects will migrate up a stream, moving long distances, through several types of habitat (e.g., riffles, pools, sunny, shady, etc). For example, nymphs of some mayfly species (Ephemeroptera) have been documented moving distances of more than two kilometers upstream to colonize newly opened reaches of temporary streams (Neave, 1930; Hayden and Clifford, 1974). Hayden and Clifford (1974) also documented that the mayflies in their study, *Leptophlebia cupida*, were able to crawl up the ice and plants hanging over a 1.5 m tall waterfall that was in their way. This behavior implies that, in some cases, immature aquatic insects may be able to pass up through culverts that break the continuity of the stream.

### 4.4. Location of upstream movement

Evidence suggests that fast currents and/or high water levels decrease upstream migration along stream bottoms (Turner and Williams, 2000). Perhaps for this reason, most stream invertebrates move upstream closer to shore (Neave, 1930; Elliott, 1971). Presumably, this area is chosen because of its lower water velocity, although a decrease in the number of predators or an increase in available food resources also may play a role. If some invertebrates move upstream in this area because of the slower currents, even culverts that maintain the continuity of water in the stream may pose a barrier if the water velocity is significantly higher or if there is no substrate through the length of the culvert.

The data presented in the previous four sections (4.1. to 4.4.) demonstrate that immature insects do move upstream along the substrate, sometimes for great distances. However, it is important to acknowledge that most insect species depend upon flight rather than in-stream migration to colonize upstream habitat.

### 4.5. Potential threats and advantages to endangered insects

Several insect species listed on state and federal endangered species lists may be affected, both positively and negatively, by the construction or cleaning of culverts. Here we list two case studies to highlight upstream passage concerns.

**4.5.1. Hungerford's crawling water beetle (*Brychius hungerfordi* Spangler)** This federally listed endangered species is found at only five locations in Michigan and Ontario and inhabits the riffles that are created downstream from beaver dams, wing dams, and culverts (Wilsmann and Strand, 1990 (reported in Hyde and Smar, 2000)). The identified threats to this species include siltation, stream modification (e.g., dredging, pollution, logging, channelization, beaver control, bank stabilization, and impoundment), and possibly the introduction of brown trout (Hyde and Smar, 2000). In streams containing brown trout, culverts with outflows above the downstream water level actually may protect beetle populations by preventing the spread of the trout. However, this fish barrier also may limit the dispersal of the beetle, which appears reluctant to fly.

**4.5.2. Endemic damselflies (suborder Zygoptera) of Hawaii** Several at-risk species of damselflies in Hawaii are protected in some stream reaches by culverts or waterfalls which keep out mosquitofish in the family Poeciliidae (Polhemus, 2001).

## 5. Non-Insect Macroinvertebrates

Unlike insects, other aquatic macroinvertebrate species have no aerial life stage. When these non-insect macroinvertebrates move up or down a stream, they usually stay within the wetted limits of the stream and, therefore, are more likely than insects to be impacted by the design and placement of culverts. These non-insect species include some mollusks, crustaceans, worms, mites, and other benthic organisms.

## 6. Mollusks

### 6.0. Summary

The dispersal of mollusks, especially bivalves in the order Unionoida, may be impaired by certain culvert characteristics. For the most part, mussels disperse within a watershed as larvae (called glochidia) attached to the gills of various host species, usually fish. If the fish cannot pass upstream through a culvert, then the mussel is unable to colonize or recolonize new, suitable habitat. This barrier has significant implications for the mussels in these streams, especially if they already are endangered or coping with the degradation or loss of their habitat. Many species of freshwater snails also will be affected by culverts. Representatives of this group are the only stream macroinvertebrates with published evidence implicating *culverts* as a barrier to their upstream dispersal (Dillon, 1988). Other gastropods (e.g. limpets in Hawaii) are known to migrate long distances, but whether culverts block their passage remains unknown.

## 6.1. Mussels (Bivalves)

Freshwater mussels primarily disperse upstream in two ways. An adult mussel may crawl slowly along the stream bottom, changing its position by a few hundred yards during its lifetime unless it is dislodged and carried away by the current (Parmalee and Bogan, 1998). More significantly, however, the glochidia of almost all species of freshwater mussels in North America attach themselves to the gills or fins of fish and, in one case, an amphibian. In this way, these mussels are dispersed throughout a stream. Culverts may pose a significant barrier to both of these dispersal strategies.

Figure 3. Fawnsfoot mussel (*Truncilla donaciformis*). Photo courtesy of Kevin Cummings, Illinois Natural History Survey.

The glochidia of nearly all of the 297 mussels native to the U.S. parasitize fish. One exception is *Simpsonaias ambigua*, which parasitizes the gills of the mudpuppy, *Necturus maculosus* (Watters, 1996). Interestingly, in laboratory experiments conducted by Watters and O'Dee (1998) the mussels *Lampsilis cardium* and *Utterbackia imbecillis* were able to parasitize and metamorphose on larval tiger salamanders, as well as fish. However, this increase in potential hosts would do little to move larval mussels around a barrier culvert.

Looking closely at two species of unionoid mussel, the fragile papershell (*Leptodea fragilis*) and the pink heelsplitter (*Potamilus alatus*), Watters (1996) found that even low dams of 1 m in height were enough to prevent the upstream movement of these mussels' host fish, the freshwater drum, *Aplodinotus grunniens*. He concludes that dams (and, based on anecdotal evidence, improperly constructed culverts as well) may artificially restrict the distribution and dispersal capabilities of these mussels and also may isolate populations from one another. These barriers could be particularly problematic for endangered mussels.

Currently, research on mussels and culverts is being conducted by scientists at North Carolina State University (NCSU). They are assessing the impacts of road crossings and road runoff on freshwater mussels (Chris Eads, NCSU, pers. comm.). However, this research is still in its early stages and has not yielded any results.

In addition to the barrier culverts present to the dispersal of freshwater mussels, building or cleaning culverts may pose another threat: siltation of downstream reaches. Siltation often is cited as one of several reasons for endangerment of mollusks listed on the ESA (Williams et al., 1993). Another major threat to native mussels is competition by invasive exotic species. The Asiatic clam (*Corbicula fluminea*) is the most widespread example found in small streams (Williams, et al., 1993). This species will be discussed in more detail in the section on invasive species.

## 6.2. Snails and limpets (Gastropods)

Unlike mussels, freshwater snails do not produce glochidia in order to disperse. Instead, they lay eggs that hatch directly into small snails (Thorp and Covich, 1991) and rely on a simple crawling motion to spread and colonize new habitats (Robert Dillon, pers. comm.). Downstream dispersal may be facilitated by dislodgement during peak stream flows. Rare overland dispersal via birds is also documented (Rees, 1965).

Freshwater snails have limited abilities to crawl out of water. The pulmonates, which have lungs and lighter shells, are better adapted to leave the water than the prosobranchs, which have gills and thick shells (Robert Dillon, pers. comm.). In either case, culverts are expected to block dispersal of many, if not most, freshwater snails (Dillon, 1988). In fact, Dillon (1988) provides some of the only direct evidence that culverts block upstream dispersal of macroinvertebrates – in this case, the freshwater snail *Goniobasis proxima*. In addition, Bovbjerg (1952) showed that the upstream movement of the snail *Campeloma decisum* was obstructed by the logs in the stream.

Two specific cases in Hawaii highlight the need to understand the biology of each species in order to

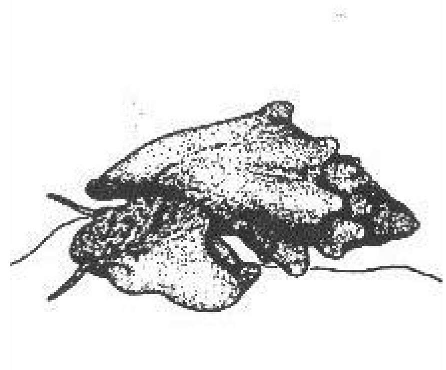

Figure 4. Line drawing of the freshwater snail, *Io fluvialis*, a threatened freshwater gastropod endemic to the upper Tennessee River system. Line drawing provided by the Freshwater Mollusk Conservation Society.

know whether they will be affected adversely by culverts. In Hawaii, two neritid limpets, *Neritina ganosa* and *N. vespertina*, complete a life cycle in which adults lay eggs in the streams, the eggs hatch and the larvae drift to the ocean where they complete their larval stage, migrating back into the streams as miniature adults (Ford and Kinzie, 1982). According to Richard Merritt and Eric Benbow (pers. comm.), the migratory stage of *N. granosa* (as well as the fully developed adults) can spend quite a long time out of the water during migration, and is known to ascend waterfalls greater than 300 m high, although they typically have a thin film of water pulsing over them. *N. vespertina* on the other hand, is unable to climb past the first substantial waterfall (less than 1 m high) and remains near the stream mouth or in the estuary (if there is one). Some culverts could block the upstream movement of the latter species, whereas the former probably would not be impacted. As an additional point, because these larvae typically survive the plunge from falls greater than 300 m, falling over a culvert outflow raised above the stream below is unlikely to harm these species (Richard Merritt and Eric Benbow, pers. comm.).

### 6.3. Potential threats and advantages to endangered mollusks

Seventy mussels and clams, and thirty-one snails are listed as threatened or endangered by the US Fish and Wildlife Service. Williams et al. (1993) found that of the 297 mussels native to the U.S. and Canada, 213 (71.7%) are considered endangered, threatened, or of special concern. According to the work of Watters (1996), all of these species and their host fish may find it difficult to pass through some culverts, although many of these species occur in larger rivers and streams, which usually are crossed by bridges, not culverts.

The two main threats to mussels are habitat destruction (e.g. caused by impoundments, channel modification, and siltation) and the introduction of non-indigenous mollusks (Williams et al., 1993; Parmalee and Bogan, 1998). Interestingly, culverts may help prevent the Asiatic clam (*C. fluminea*) – one of the two most problematic and widespread introduced mollusks – from spreading into the habitat of native endangered mussels (see section on invasive species). Unfortunately, while keeping this introduced species at bay, culverts may restrict the available habitat for native mussels. Any barrier to the upstream movement of mussel host fishes will prevent mussels from colonizing new or previously occupied habitat.

The greatest threats to endangered snails come from loss of habitat (especially dam construction) and water pollution (Neves et al., 1997). Culverts may pose an additional challenge to some species and would have to be examined on a case-by-case basis.

## 7. Crustaceans

### 7.0. Summary

Many species of amphipods, and a few crayfish, are confined to streams as they disperse and, like mussels, their upstream passage also may be blocked by culverts. Some species have been shown to travel significant distances upstream and, therefore, a barrier to this movement could limit available habitat. This reduction in range is especially detrimental to species that already are suffering from degraded or lost habitat, or the pressures imposed by invasive species. In certain streams, however, culverts may act as a obstacles to the spread of invasive species (e.g. the rusty crayfish) that compete with native species. However, this potential barrier should not be depended upon.

### 7.1. Crayfish

One of the major threats faced by crayfish populations (esp. endangered species) is limitations on their ranges (Taylor, et al., 1996). Studies have demonstrated that several factors–such as density pressures, reproductive condition, and sediment types (Gherardi et al., 1998)–determine the distribution of crayfish in streams and, therefore, their need to move within a stream. In response to these factors, various crayfish species have been shown to move from 25 m to over 300 m along a stream reach (Hazlett, et al., 1974; Guan and Wiles, 1997; Gherardi et al., 1998).

Many species of crayfish migrate upstream or across land to colonize new habitat. For those that are obligate stream species, however, barriers such as dry streambeds may block this migration (Momot, 1966). These obligate stream species typically are found in high-gradient, well-oxygenated streams (John Cooper, pers. comm.) and their upstream movement is likely to be obstructed by some culvert designs (i.e., culverts with an outflow above the downstream water level).

Besides breaking the continuity of a stream, culverts also may increase stream velocity through their length. This is unlikely to pose a barrier to most crayfish species. However, Maude and Williams (1983) demonstrated that certain species of crayfish (e.g. *O. rusticus*) are better adapted than others for holding their position in fast-flowing streams or rivers. Therefore, the invasive *O. rusticus* may be better able than the native species to cross this type of barrier and, thus, continue to spread through a stream while the range of a native species is limited. However, many experts think that this scenario is unlikely to occur (John E. Cooper, Horton H. Hobbs, Melvin L. Warren, pers. comm.)

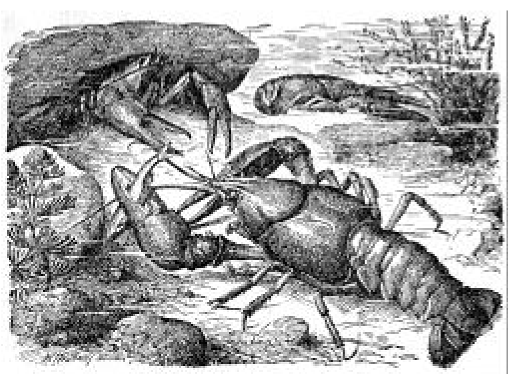

Figure 5. Diagram of generalized crayfish.

Several experts in this field, however, note that many of the crayfish species they have observed are capable of traveling across land, over roads (Cooper and Braswell, 1995), or up and over the sides of dams (John Cooper, Horton Hobbs, and Kate Schofield, pers. comm.) These observations further illustrates the importance of understanding the biology of the organisms found in each stream in order to accurately assess the full impact of a culvert. For example, although they are not crayfish, some species of diadromous shrimp and prawns on the Hawaiian islands are capable of climbing from the ocean to stream reaches 1000 m above sea level. The upstream passage of organisms like these is unlikely to be blocked by culverts.

## 7.2. Amphipods

The experts we contacted generally agreed that culverts are much more likely to impact amphipods than crayfish (John Cooper, Horton Hobbs, pers. comm.). Minckley (1964) reports on the work of Hynes (1960) that small dams prevented the upstream migration of *Crangonyx pseudogracilis* and *Gammarus pulex* in England. Also in England, *G. pulex* was found to have moved two miles upstream from its point of introduction, after four years. Thus, it is apparent that at least Gammarid amphipods (scuds) move upstream, sometimes for significant distances, and because they cannot leave the water their range would be limited by culvert outflows above the downstream water level or and by culverts that increase the velocity of stream flow, especially if there is no substrate or hyporheos through the length of the culvert (Horton Hobbs, pers. comm.).

## 7.3. Potential threats and advantages to endangered crustaceans

Taylor et al. (1996) write that 162 of the 338 crayfish native to the United States are in need of conservation recognition. For many of these species, little is known regarding their ecology (Kate Schofield, pers. comm.) and, therefore, the impact of culverts on each species' upstream passage is unknown and would have to be investigated.

The California freshwater shrimp (*Syncaris pacifica*) provides one example of a federally listed endangered species. It was listed under the endangered species act in 1988 and is found in streams along the California coast. This species primarily stays in the pools around undercut root systems. According to the ruling in the Federal Registrar (53 CFR 43889) the primary threats faced by this species are urban development, highway construction, gravel dams, pollution, and fire control. It is unknown whether culverts would be an obstacle to their upstream passage, thus limiting this species ability to disperse into new, available habitat.

As previously mentioned, culverts may act as selective barriers, allowing the passage of stronger swimmers like *O. rusticus* or species that are able to leave the water. Therefore, endangered species that are weak swimmers and those that are obligate stream species may be affected adversely by the additional limits to their range and by the continued spread of invasive species.

## 8. Other groups of stream macroinvertebrates

The species groups described above are by no means exhaustive, but they do represent the bulk of the stream invertebrate populations in streams about which one can find data on upstream movement. Less attention has been given to other stream invertebrates, such as flatworms, mites, worms, and leeches. However, Dumnicka (1996) reports that oligochaetes seem to move very little in the streams below a reservoir. Steve Fend (pers. comm.) further suggests that discontinuities created by most culvert designs would restrict passage of worms, but migration rates are so slow that other problems, like downstream sediment starvation, are much more important to consider.

Leeches have been documented moving 4 m upstream over a twelve hour period (Elliott, 1971). And, mites have been shown to compensate for 23.3% of their drift by moving upstream along the substrate (Bergey and Ward, 1989). Based on these data, we can conclude that at least some of these organisms move upstream and that this might be an important form of dispersal within a watershed. For those species that do move upstream, certain culvert designs might pose a barrier, but, again, the upstream passage of each species will be affected differently.

## 9. Impact on invasive species

### 9.0. Summary

Although culverts may impede the upstream dispersal of some native macroinvertebrate species, these same barriers also may help slow or prevent the spread of noxious invasive species. However, the degree to which culverts will impede their dispersal remains unknown and experts agree that, to block the movement of an invasive species, barriers need to be designed especially for this purpose. In this section, I examine the literature regarding four invasive species.

### 9.1. Zebra mussel (*Dreissena polymorpha*)

Unlike native mussels, zebra mussel larvae do not attach themselves to fish in order to disperse. Instead, their larvae become part of the plankton in a body of water and disperse passively (Carlton, 1993). Thus, Horvath et al. (1996) note that to colonize a small stream (less than 30 meters wide), zebra mussels must have established a population in an upstream lake. Culverts will do little to prevent this passive dispersal into downstream habitat.

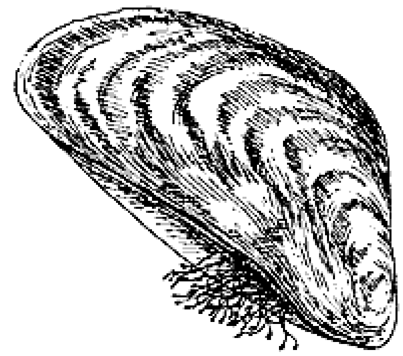

Figure 6. The Zebra mussel (*Dreissena polymorpha*). Line drawing from http://www.extension.umn.edu.

However, Carlton (1993) mentions that zebra mussels are known to colonize crayfish. Further evidence for this phenomenon is provided by Brazner and Jensen (2000). Of the rusty crayfish (*O. rusticus*) they collected in southern Green Bay, Lake Michigan, 12% to 24% were colonized by zebra mussels. The number of mussels on each crayfish ranged from 16 to 431 individuals. However unlikely, if these crayfish then move up a small stream, they could bring the zebra mussels with them and colonize a new stream habitat without the need of an upstream lake source.

### 9.2. Asian clam (*Corbicula fluminea*)

Voelz et al. (1998) argue that, based on the circumstances around their study site, the Asian clam is able to move upstream without the help of humans or waterfowl. Juvenile Asian clams are incapable of swimming and they lack glochidia unlike native freshwater (Unionoid) mussels. However, a juvenile

*C. fluminea* can crawl along the substrate with its foot and securely hold itself against downstream currents using a byssal thread (McMahon, 1983). Furthermore, its eggs may be eaten by fish, passing unharmed through the digestive system (Richard Neves, pers. comm.). In at least one case, this clam appears to have moved upstream, unaided (except, maybe, by fish), at a rate of 1.2 km per year and was stopped by the placement of a culvert outflow that was above the downstream water level (Voelz et al., 1998).

### 9.3. Rusty crayfish (*Orconectes rusticus*)

The rusty crayfish (*O. rusticus*) is native to the Ohio river basin, but when introduced to other watersheds by people it is an invasive species. *O. rusticus* can live in lakes, ponds, and streams. When introduced to a new stream reach, they displace native crayfish by forcing them out of their daytime refugia, which increase their vulnerability to predation. Rusty crayfish also prey upon benthic macroinvertebrates (e.g. mayfly, stonefly, and caddisfly nymphs) and reduce plant cover for other crayfish species (Gunderson, 1999).

If culverts break the continuity of a stream, they may prevent upstream passage of this invasive crayfish. However, if set in the stream flow, culverts may selectively allow this species to pass upstream because of its greater ability to maintain a position in fast currents.

Culverts also may keep several other invasive crayfish species out of upstream reaches. These include *O. juvenilis*, the noble crayfish (*Pacifastacus leniusculus*), as well as other species introduced into aquatic habitats for commercial culture (Taylor, et al., 1996). However, again, it is important to note that no one has specifically addressed this question in the literature and, if a barrier to invasive species is desired, it should be designed and tested with a particular species in mind.

### 9.4. Mosquito fish (*Gambusia spp.*)

In addition to the above listed invasive invertebrate species, it is important to consider some vertebrates that may threaten populations of native stream invertebrates. For example, it is thought that the relatively rare orangeblack Hawaiian damselfly (*Megalagrion xanthomelas*) is protected in suburban Honolulu because culverts are keeping *Gambusia* out of its breeding streams. In other areas where this damselfly occurs, *Gambusia* have been aggressive predators on these damselfly nymphs (Polhemus, 2001).

## 10. Conclusions

### 10.1. Insects

The studies that we reviewed on the in-stream movement of immature aquatic insects, as well as feedback from experts in the field, indicate that the effects of culverts on upstream passage of stream insect populations would be localized. Most upstream movement of nymphs and larvae occurs over relatively short distances (less than 300 m). Immature insects inhabiting stream reaches immediately above hanging culverts may drift into the culvert and be unable to move back upstream. In other words, a culvert may act like a one-way valve for insect nymphs and larvae. However, if upstream movement is blocked by a culvert, upstream reaches will likely be colonized by aerially dispersing adults.

### 10.2. Non-insects

The studies we reviewed on mollusks, crustaceans, and other macroinvertebrates indicate that these organisms may travel long distances within a stream, either attached to the gills of fish in the case of mussels or by their own power in the case of snails, amphipods, crayfish and other crustaceans. Because many of these species are confined to the water, any barrier to their dispersal impacts their populations more than insects. It will be important to know which fish are used as hosts by different mussel species and to make sure that culverts accommodate the upstream passage of these fish. If host fish are unknown, then culverts will need to be designed such that all fish within a stream may pass through.

### 10.3. Endangered and invasive species

It is important to address each culvert design and placement on a case by case basis and to assess what endangered or invasive species are located in a watershed and how they might be affected by a culvert design. In most cases, making sure all organisms can pass through a culvert is the best policy. Additionally, it is advised that surveys of aquatic organisms be made to predict how culverts affect these species, and the management goals for that stream. In other words, does a stream contain mussels that need to be able to disperse, or is there a very special circumstance in which it would be beneficial to maintain a barrier to try to keep out an invasive species?

### 10.4. Recommendations

Overall, we recommend that culverts be designed to allow upstream movement of almost all macroinvertebrates, including those inhabiting the hyporheos (i.e., the rocks, gravel, and sand that makes up the stream bed), as well as all fish living in a stream. Culverts also should be designed to protect the hydro-geology of the stream as much as possible. Thus, if feasible, small bridges should be built and they should be as wide as possible. However, if a culvert must be placed for financial or practical reasons, then the bottom of the culvert should be at least 20 cm below the surface of the substrate. Culverts should be built as wide as possible in order to reduce the negative impacts of increased stream velocity on upstream passage, as well as the effects of the erosion and sedimentation caused by channelization. In addition, culverts should be designed so that twenty years from now, erosion hasn't cut away the substrate at the downstream end, leaving the outflow hanging above the downstream water level.

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# Appendix A. Other issues raised by experts

The experts we contacted to review this report raised many other issues besides the possible impact of culverts on upstream passage of macroinvertebrates. We will briefly relate these issues here as a starting point for future analysis.

## A.1. Effects of Channelization

Most reviewers were concerned about the effect of channelization upon the structure of the stream. According to these experts, streams that are forced into a rigid channel, like a culvert, will experience increased erosion (both up and downstream). Essentially, the stream banks upstream and downstream from the culvert have to dissipate the energy in the stream flow and, in doing so, the resulting erosion leads to sedimentation around and downstream from the channelized reach. This erosion and sedimentation will disrupt the quality of the available stream habitat. For example, sedimentation is one of the threats faced by many endangered mussel species. In another example, the area immediately downstream from the culvert will be scoured and starved of sediment, resulting in loss of habitat for most worms.

These same reviewers believe that if the channel is protected, the species in the channel also will be protected. These comments led us to conclude that, if a culvert must be used, it should be as wide as possible. Barbara Peckarsky (Department of Entomology, Cornell University) generously contributed the list of references on road and bridge construction, channelization, and sedimentation that follows at the end of this section.

## A.2. Point source pollutants from road run-off.

Reviewers also expressed concern that culverts would act as an entry point for silt, salt, soot, hydrocarbons, and other stream pollutants running off of nearby roads.

## A.3. Impact of construction on burrowing species.

When constructing a culvert it may be important to know what burrowing species might be living along the stream banks where a culvert is being placed. For example, some species of crayfish are limited most of the year to burrows that they construct in the stream bank. Other species build burrows connected to the stream bed, which are entered periodically (e. g. for protection from predators, periods of high water, or cold weather).

## A.4. Other downstream effects of culverts

Reviewers also raised concerns about our relatively short mention of culvert effects on the invertebrate food quality or quantity downstream. They wondered if changes in water temperature or increases in sedimentation associated with culverts influence growth and reproduction in downstream communities. For example, changes in stream temperature may lead to increases or decreases in the growth of stream plants, microscopic invertebrates (i.e., meiofauna), and, subsequently, macroinvertebrate communities. If these downstream communities are negatively impacted, then an overall decrease in fecundity could reduce the ability of aerial adults (in the case of insects) to recolonize upstream reaches.

## A.5. References on impacts of channel alterations on stream invertebrates

These references were provided by Dr. Barbara Peckarsky, Department of Entomology, Cornell University, Ithaca, N.Y.


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