INTRODUCTION

The dwarf wedge mussel (*Alasmidonta heterodon*) is a small freshwater mussel that was Federally listed as Endangered in 1990 (50 CFR 944)7), due to a severe decline in documented occurrences. Although the Recovery Plan for this species is in the process of being developed, successful restoration will undoubtably require a greater understanding of the species' life requisites and the reasons for its decline.

The dwarf wedge mussel is a member of the Family Unionidae. It is small in size, rarely exceeding 1.5 inches in length, and lives on muddy sand and gravel bottoms in streams and rivers of slow to moderate current, with little silt deposition. A host fish is required for the development of the larvae, or glochidia, of most freshwater mussels. The host fish for the dwarf wedge mussel has not yet been identified. The dwarf wedge mussel is usually found in association with the common elliptio (*Elliptio complanata*), a larger fresh water mussel, throughout its range (Clarke 1981). In New England, the triangle floater (*A. undulata*), the alewife floater (*Anodonta undulata*), and the eastern lamp mussel (*Lampsilis radiata*) are also often found with the dwarf wedge mussel.

According to Master (1986), the dwarf wedge mussel was discovered in the 1800's, and has always been considered rare. The species was found solely in Atlantic slope drainages from North Carolina to New Brunswick. Originally the mussel was known to exist in 70 localities in 15 major drainages. In recent years, it has only been found at 14 sites. Only two viable populations are presently known to exist in New England; one in the Ashuelot River in Keene, New Hampshire, and one in the Connecticut River through an approximately 16 mile stretch that runs from North Hartland (Sumners Falls), Vermont to just south of Weathersfield, Vermont. The Ashuelot River population appears to be declining. The status of the Connecticut River population is presently under study (S. von Oettingen, USFWS, pers. commun.).

Few rivers in New England have not been dramatically altered by human activities, including damming, channelization, industrial and municipal discharges, as well as non-point runoff. Freshwater mussels have been reported to be adversely impacted by poor water quality. Specific factors that have been implicated include: low dissolved oxygen, low pH, siltation, low alkalinity and hardness, and pollutants including potassium, copper, chlorine, cadmium, and arsenic (Fuller 1974). Master (1986) discusses evidence that the dwarf wedge mussel is intolerant of poor water quality. Dwarf wedge mussels may also have been displaced from some locations by construction activities such as bridges, and riprap for bank stabilization.

The Ashuelot River is a small tributary to the Connecticut River that traverses a rural area of southwestern New Hampshire. However, the Ashuelot River has been dramatically altered by the construction of an Army Corps of Engineers flood control dam, the Surry Mountain Dam, just upstream of the dwarf wedge mussel population. Also, along the banks of the Ashuelot, in the vicinity of the dwarf wedge mussel population, a golf course and agricultural land potentially provide opportunities for pesticide and fertilizer runoff into the river. The Connecticut River has been severely altered by numerous hydroelectric dams, which have created a series of unnatural impoundments, which have highly fluctuating water levels. The water quality of the Connecticut River has also historically received industrial and sewage effluents, and has experienced siltation and shoreline devegetation.

The purpose of this study was to provide a cursory screening for heavy metals, pesticides, and organochlorine compounds in the locations of the Connecticut and Ashuelot populations as a means of exploring potential pressures that may be affecting the mussels. A third location, in the Mill River just below Northampton, Massachusetts, was investigated because a population of dwarf wedge mussels existed there as recently as 1973, and is now believed to be extirpated (Master 1986). This location could be considered as a candidate for population reestablishment should this strategy be deemed feasible and necessary for recovery of the species.

STUDY AREA

The Connecticut River is the largest and longest river in New England, draining a watershed of 11,265 square miles from the Connecticut Lakes in northern New Hampshire to Long Island Sound in Saybrook, Connecticut (Merriman and Thorpe 1976). The Connecticut River was the natural route for commerce for interior New England before the development of railroads (McNary et al. 1913). Through the construction of dams, locks, and canals, the Connecticut River became the first river in North America to be developed for navigation (Martin 1951). Later, the river provided power for industry. At present, five dams provide for hydroelectric facilities along the mainstem of the Connecticut River.

The section of the Connecticut River where the mussels are known to exist traverses primarily rural countryside, so the banks of the river are either vegetated by native trees and shrubs, or by farm crops. The river is mostly deep and slow moving, with the dwarf wedge mussels inhabiting gravelly shallows in locations along the edge of the river. It should be noted that the Connecticut River exists within the State of New Hampshire to the high water mark on the west bank. However, dwarf wedge mussel occurrences along the west bank of the Connecticut River are usually described as being located in the State of Vermont.

The Ashuelot River drains an area of 71.1 square miles (USGS 1972), and flows into the Connecticut River near the southwest corner of the State of New Hampshire (Fig. 1). North of the City of Keene, the Ashuelot River traverses a mostly rural area which has historically been farmed. Much of the area is now forested, with some home development. The dwarf wedge mussel is known to exist primarily throughout an approximately three mile stretch of the river below the Surry Mountain Dam and above the City of Keene. The Bretwood Golf Course exists along the east bank and a portion of the west bank in this stretch, and farmland planted to corn comprises much of the rest of the west bank. Presently, there are plans to convert the farmland to additional golf course (City of Keene Conserv. Comm., pers. commun.).

The Mill River flows from the northwest into the Connecticut River at Northampton, Massachusetts, after draining an area of 52.8 square miles (USGS 1972) (Fig. 1). The river is mostly quick-flowing and shallow with a sandy gravel substrate. Except for passing through Northampton, the river is rural, with forest and farmland bordering its banks.

METHODS

In the Connecticut River, two sampling stations were chosen; one in each of the two dwarf wedge mussel occurrences known in 1990. During the summer of 1991, mussels were found scattered throughout the reach. Figure 1 shows the two locations, CT1 in North Hartland, Vermont, and CT2 in Weathersfield, Vermont. Connecticut River samples were collected in July of 1990. One sediment sample was collected from each station. Sediments from an area near dwarf wedge mussels were collected with a stainless steal spoon, and placed in a acid-rinsed, solvent-rinsed glass jar. Sediments were stored by freezing before shipping. Twenty of the largest *Elliptio complanata* were collected from around dwarf wedge mussels at each station. *Elliptio* was selected as a surrogate for *A. heterodon* because of its usual co-occurrence. The ten mussels collected for organochlorine analyses were wrapped in aluminum foil, placed in plastic bags, and frozen. The ten mussels collected for metal analyses were placed in acid-rinsed, solvent-rinsed jars and frozen before shipping. Water samples were collected from each station by emersing a cubitainer. Water samples were also frozen before shipping.

Six locations were chosen for sampling in the Ashuelot River (Fig. 2). ASH5 was located above the Surry Mountain Dam Reservoir. ASH6 was located just below the dam, ASH 4, 3, and 2 were located along the golf course, and ASH 1 was located below the golf course. Sediments were collected from the stations in June and September, (high and low water events), in a similar manner as for the Connecticut River. In June, *Elliptio complanata* and water samples were also collected from each station in a similar manner as for the Connecticut River. Mussels were not collected from ASH5 as none were located.

Only one sample was collected from the Mill River. MIL1 was located just below the Route 10 bridge in Northampton (Fig. 1). Sediments, water, and *Elliptio complanata* were collected in August of 1990. Since no dwarf wedge mussel are presently known to exist in the Mill River, *Elliptio* were collected from an area considered to be suitable habitat for *Alasmidonta heterodon*.

Organophosphate and carbamate pesticide analyses were conducted by the Patuxent Analytical Control Facility. Organochlorine analyses were conducted by the Environmental Trace Substance Laboratory. Mussels were analyzed, by site, as a composite of soft body parts. Sediments were analyzed for grain size. Mussel tissues and sediments were analyzed for organochlorine, organophosphate, and carbamate pesticides, and heavy metals. Water samples were analyzed for heavy metals only. Sediments were analyzed for twenty-one metals. Tissue and water samples were analyzed for 12 metals. Mercury was detected using cold vapor atomic absorption. The other metals were quantified by ICP (inductively coupled plasma) analyses. All metals reported by the laboratory as "not detected" are reported here as half the detection limit.

RESULTS

Sediments

The sediment characteristics at each of the sample stations are provided in table 1, including percent sand, silt, clay, and moisture, and the total weight of the samples. All of the samples were over 90% sand except ASH5, CT1, and CT2, which ranged from 57% sand (ASH5 in September) to 76.5% sand (ASH5 in June)(Fig. 3). The percent silt in the sediment collected from the Ashuelot River was generally higher in September samples than in the June samples (Fig. 4).

Organochlorine compounds were not detected in any of the sediment samples, with the exception of a trace amount of chlordane at ASH1 and p,p'-DDE at ASH5 (Appendix 1). Organophosphates and carbamates also were not detected at any of the stations (Appendix 2).

Table 2 displays the metals found in the sediment samples. Levels of arsenic, chromium, cadmium, copper, lead, mercury, nickel, and zinc were compared to criteria developed by Bahnick *et al*. (1981) for Great Lakes harbors sediments. Arsenic exceeded the Bahnick *et al.'s* criterion for unpolluted sediment (<3 ppm) at all of the stations. Levels ranged from 3.5 to 5.0 ppm. Chromium and nickel levels exceeded the unpolluted level reported by Bahnick *et al.* of <25 and <20 ppm, respectively, at stations ASH5 and CT1. CT2 also exceeded the unpolluted level for nickel. ASH5 exceeded the unpolluted level of copper (<25 ppm) and zinc (<90 ppm). Mercury, lead, and cadmium were detected in all of the sediment samples below concentrations considered polluted by Bahnick *et al.*, <1.0, <40.0, and <6.0, respectively. Figures 5, 6, and 7 illustrate the levels of copper, lead, and zinc in the sediments.

Long and Morgan (1990) provide a literature review for silver and concluded that effects to aquatic biota have generally been observed when sediment levels are greater than 1.7 ppm. Sediments from all of the sample stations in the Ashuelot River exceeded this level. The concentrations of silver in sediments from the stations in the Connecticut and Mill Rivers were found to be below the 2.0 ppm detection limit for this study. Figure 8 illustrates the levels of silver in the river sediments.

Little literature exists regarding toxicity or sediment quality criteria for the other metals. However, in reviewing the data it appears that metal concentrations in the sediments in general, were higher at stations ASH5, and CT1 and CT2 than at the other stations. Also, levels tended to be higher in the samples collected in September from the Ashuelot River than in June. These trends may be explained by the higher silt content in these samples (Fig. 3).

Water

Results for the metal concentrations in water are displayed in table 3.

According to EPA's Quality Criteria for Water (1986), freshwater biota should not be affected unacceptably if the 4-day concentration of mercury does not exceed 0.012 ug/L more than once every three years on average, and if the 1-hour average does not exceed 2.4 ug/L more than once every three years on average. This study did not detect mercury in the water, however, the detection limit was 0.3 ug/L, which is above the 4-day limit recommended by EPA.

Hardness has been demonstrated to have an antagonistic effect on the acute toxicity of cadmium and copper on aquatic organisms (USEPA 1986). Therefore, criteria for these metals is dependent, in part, on water hardness. Water in the Connecticut, Ashuelot, and Mill Rivers is relatively soft (< 50 mg/L as $CaCO^3$)(USGS 1972). The 4-day average criteria for cadmium for a hardness of 50 mg/L is 0.66 ug/L, and the 1-hour average is 1.8 ug/L (USEPA 1986). Cadmium concentrations in this study ranged from 0 to 0.99 ug/L, with the highest concentrations found in the Ashuelot River samples. For copper, the 4-day average criterion for a hardness of 50 mg/L, is 6.5 ug/L, and the 1-hour average is 9.2 ug/L (USEPA 1986). In this study, copper levels remained below the recommended levels, and ranged from 0 to 3.6 ug/L, with the highest concentration found in the Mill River.

Due to the number of chemical forms of nickel and aluminum, and the relative lack of information regarding the toxicity of these metals, no clear definitive guidance has been provided for the protection of aquatic biota (USEPA 1986b and 1988). However, the little toxicity information that does exist can serve for comparisons with our study. For nickel, it has been predicted that 5 ug/L would affect the productivity of *Daphnia magna* (Lazareva 1985). In this study, concentrations of nickel ranged from 0.5 to 2.0 ug/L. For aluminum, the lowest acute values for invertebrates are for ceriodaphnids and range from 1,900 ug/L (McCauley *et al.* 1986) to 3,690 ug/L (USEPA 1988). The concentrations of aluminum in this study are well below these values, ranging from 13 to 250 ug/L.

The water quality criteria recommended for iron by the EPA (1986) for the protection of aquatic biota, is 1.0 mg/L. This was exceeded at one sample station in our study, ASH5, with a level of 1.4 mg/L. The concentrations at the other stations ranged from 81 to 753 ug/L. Concentrations of beryllium, chromium, lead, thallium, and zinc found in this study were all well below the recommended criteria for the protection of aquatic life (USEPA 1986). Manganese is considered by EPA (1986) to be an essential nutrient that is rarely found in concentrations above 1 mg/L, therefore, it is not considered a problem in fresh waters. In this study, manganese levels were found to range from 1.7 to 138.0 ug/L, with the highest concentration at ASH5.

Mussel Tissue

Metal concentrations in mussel tissue are displayed in table 4. No clear trends were evident in the data.

Table 5 compares concentrations of metals found in mussel tissue in this study to concentrations found in the literature. Levels found in our study were generally either similar to, or lower than, levels published in the literature. No literature was found that provided concentrations of beryllium or thallium in mussel tissue.

Organochlorines, organophosphates, and carbamates were not detected in any of the mussel tissue samples (Appendix 1 and 2).

DISCUSSION

Freshwater mussels are relatively long-lived, are sedentary, and come into contact with both sediment and water during feeding and respiration. They have also been found to accumulate trace metals and other persistent pollutants, and have, therefore, been studied extensively as potential biological indicators of pollution. Havlik and Marking (1987) provide an extensive literature review on this topic. However, relatively little information is available on the toxicity of the various pollutants on freshwater mussels.

Freshwater mussels have been found to be vulnerable to some pesticides, including Thimet and Satox (Salanki and Varanka 1978), and some fish toxicants such as antimycin (Antonioni 1974), TFM lampricide (Maki *et al.* 1975), and rotenone (Heard 1970). It has also been reported that insecticides are readily taken up and eliminated by freshwater mussels (Godsil and Johnson 1968). In this study, little or no evidence of organochlorines or pesticides were found in any of the samples collected. This suggests that these compounds have not made a contribution to the population declines of mussels in these areas. However, the sediments collected were predominantly large grained sand, since this is the substrate preferred by the dwarf wedge mussel. Since contaminants are known to bind most easily to fine grained sediments and organic matter, the sediments collected may serve as good examples of the sediments ingested by the mussels, but perhaps not of the persistent pollutants absorbed by the rivers over time. Further, most of the pesticides in common use are "non-persistent", and are, therefore, unlikely to be detected in significant amounts in the river sediments after a few days or weeks after application. The water samples, similarly, only represent one moment in time. It is plausible that pesticides could be washed into the river in a pulse soon after application. Several weeks later there would be little or no residue of the pesticide in the water, and any biota killed would have already decomposed, leaving no evidence in sediments.

The literature review by Havlik and Marking (1987) reported that zinc, manganese, copper, cadmium, and lead are the metals in mussels that have been studied the most. They reported that cadmium has been found to be the most toxic of the metals, with toxicity reported at a concentration of 2 mg/L (no hardness reported), and an acute exposure of As_2O_3 at 16 mg/L (12 ppm as As) was also found to be toxic to mussels. Imlay (1973) reported that 11 mg/L of potassium was lethal to mussels within two months of exposure, and 7 mg/L was lethal within eight months of exposure. Imlay (1980) also reported that chronic exposures of freshwater mussels to a copper concentration of 0.025 mg/L was lethal. Zinc has not been found to be highly toxic, but effects in mussels have been reported with concentrations of 20 mg/L and greater (Millington and Walker 1983).

In this study, the highest concentration of cadmium in water was found to be 0.99 ug/L at station ASH4, which is well below the reported lethal level. Zinc was also well below the reported effect level at all stations, and potassium, and arsenic were not tested in the water in this study. Arsenic was found to be slightly elevated at all stations in the sediments relative to criteria designed for the Great Lakes. However, a study conducted jointly by NH Division of Public Health Services and the US Fish and Wildlife Service in 1989 tested **soils** at 129 public school yards across the State for selected metals. The mean arsenic level was 5.5 ppm, which is slightly higher than the levels found in the river sediments of this study. This suggests that these levels of arsenic represent background levels for the region rather than evidence of contamination.

Some studies have found that the concentration of metals in the bodies of freshwater mussels correlate with the concentrations in the sediments (Mathis and Cummings 1973; Anderson 1977). However, Tessier *et al.* (1984) found that the metal concentrations in *Elliptio complanata* were related to the easily extracted fraction of the metal in the sediment. In this study, the levels of metals in the mussel tissue were much lower than in the sediments, which suggests either a low availability, or selective excretion of the metals by the mussels. The fact that all the metal concentrations found in mussels in this study are similar to or lower than those found in other studies suggests that the metals examined are probably not stressing the present mussel population.

Silver was the only metal that differed notably in concentration between the rivers, with elevated levels only in the Ashuelot River. We did not analyze the mussel tissue or water samples for this metal, therefore, no conclusions should be drawn from our data as to whether it may be affecting the mussel population. It should be noted that silver is one of the most toxic metals to aquatic biota, and that it is more toxic in soft water than hard (USEPA 1980). The EC50 for silver reported for *Daphnia magna* is 1.5 ug/L (USEPA 1978).

Although no contaminants were found to be elevated in the tissues of the common elliptio, it should be kept in mind that the common elliptio is a very common mussel that frequents even areas of slightly degraded water quality. Thus, we can perhaps presume that the common elliptio is a relatively tolerant mussel as compared to the rare dwarf wedge mussel. Conclusions regarding affects to the dwarf wedge mussel based on the common elliptio should be drawn with caution.

CONCLUSIONS AND RECOMMENDATIONS

This study did not provide any conclusive evidence that any of the locations sampled have been impacted by pollution. However, the sampling scheme could not account for nonpersistent toxins, or brief but damaging pulses of toxins. Further, not all metals sampled in the sediments, such as silver, were sampled in the water or mussel tissue. It also can not be presumed that our surrogate species, the common elliptio, accurately represented the dwarf wedge mussel.

Although one study attributes the decline of mussels to eutrophication rather than to contaminants (Bauer *et al.* 1980), many authors have suggested that mussel populations are most often damaged by cumulative pressures rather than one specific factor (Havlik and Marking 1987). Future studies should focus on some chronic documentation of the more basic water quality parameters, (dissolved oxygen content, pH, hardness, and temperature), which in themselves could affect aquatic biota, or affect the availability and toxicity of contaminants such as metals. Future, work should also include an investigation of whether pesticides and fertilizers are getting into the rivers in concentrations that could affect mussels. This may require conducting bioassays on mussels to determine their tolerances for contaminants, and perhaps *in situ* bioassays in the rivers near potential sources of pesticides and fertilizers during the times of year that they are usually applied. Lastly, the Ashuelot River should receive further testing for silver and potassium.

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