Keynote presentations

Review of Migration, Research Methods, and Passage for Downstream Migrant Fishes in the Northeast USA

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ABSTRACT

Pre-spawning adults of most northeast diadromous species migrate from the Atlantic Ocean into rivers in March-June. Many adults survive spawning and return downstream to salt water. Thus, for species passed upstream of dams to spawn, both post-spawned adults and early life stages (typically, juveniles) need safe passage when moving downstream past dams and water withdrawals. Many northeast potamodromous fishes (=riverine fish species here) have evolved up- and downstream migrations that occur from March to November. Migrations of the riverine Connecticut River shortnose sturgeon, *Acipenser brevirostrum*, show the river is a busy highway of up- and downstream movement of various life stages during March-November. These migrations may be typical of long-lived riverine fishes that have evolved in a large open river. Researchers study downstream fish migrations using traps, nets, telemetry, and hydroacoustic techniques. When field studies are not possible, scientists study migration of early life stages in artificial streams. Fish passage in the northeast US is directed by agencies at a few diadromous sport fish species that are the subject of restoration programs, and not at the diverse diadromous and riverine migratory fish community. Target species and life stages are typically adult and juvenile alosids (American shad, *Alosa sapidissima*, and blueback herring, *A. aestivalis*), and Atlantic salmon, *Salmo salar*, smolts. These fish are in the upper part of the water column; so surface bypass systems are effective. At Holyoke Dam, Connecticut River, MA efforts are underway to protect two new diadromous target species that are benthic, i.e., the federally endangered shortnose sturgeon and American eel, *Anguilla rostrata*, whose populations have declined. To date, no bypass system for benthic species has been developed. Screens are commonly used in the western US to protect fish with mixed success, but are uncommon in the Northeast because agencies protect surface migrants mainly using bar racks with 25-mm clear spacing that extend from the surface to 3 m deep. While this effort has been successful for a few surface-oriented species, it does not protect small fish of any species or benthic species. Many northeast rivers have been dammed and the riverine fish populations segmented for about 100 years. Migratory riverine fishes are not adapted to a segmented river, so without fish passage to restore natural migrations, their long-term fate is poor. If this situation continues for another 50-100 years, we may discover that the fate of many segmented riverine fish populations was sealed by the 20th Century river damming that failed to provide fish passage. There is a clear need for research to assist resource agencies resolve issues about fish migration and passage for migratory fishes. During the 21st Century, providing passage for the downstream migrant fish community should become a major goal for riverine fisheries in the Northeast.

INTRODUCTION

The information in this paper was from a presentation given in June 2003 at the First Downstream Fish Migration Workshop in Canberra, Australia. The Workshop was sponsored by The Murray-Darling Basin Commission and brought together foreign and Australian experts to explore widely the biological and passage issues with downstream migrating fish. This paper reviews the northeast US experience with downstream migrant fish. It focuses on three areas: migration styles, research methods, and fish passage.

MIGRATION STYLES

Adults of most anadromous fish species in the northeast United States (US) migrate from the Atlantic Ocean during March-June into fresh water streams to spawn (Bigelow & Schroeder 1953; Smith 1985). In rivers that have anadromous fish restoration programs, adults pass upstream of dams using a variety of fishways or by trucking. Many adults of anadromous species survive spawning and return downstream to salt water during June-July, except for adult sea lamprey, *Petromyzon marinus*, which die after spawning (Bigelow & Schroeder 1953; Steir & Kynard 1986a). After rearing in fresh water from several weeks to several years, depending on the species, larvae or juveniles (usually) migrate downstream to salt water. Thus, adults and larvae (or juveniles) need safe passage at dams and water intakes when they migrate downstream.

Many potamodromous fishes (= riverine fish here) migrate up- and downstream during their life history to spawn, forage, rear young, or find refuge. These movements have seasonal and yearly variation and are particularly well documented in Europe (Jungwirth *et al*. 1998). The limited information on northeast US species indicates they are similar to European species (USFWS 1997). Because fish migrations have evolved in natural open-river systems during many generations, they are certain to be critical for long-term survival and health of populations (Fausch & Young 1995). However, the long-term effects on population health and survival are poorly documented.

Unfortunately, many agencies do not appreciate the critical role migrations of northeast riverine fishes have for long-term survival of well-adapted populations. While individuals of a species can remain for many years in segmented groups up- and downstream of dams, the population, which includes all segments, only functions for the long-term when natural up- and downstream movements are possible by migrants. Fish population segmentation by damming has existed for more than 100 years in the Northeast (many fish generations), and would be a good place to examine the long-term effects of population segmentation.

The life-history migrations of Connecticut River shortnose sturgeon, *Acipenser brevirostrum*, an amphidromous species that spends most of its life in freshwater reaches of rivers, is well-studied and may be typical of many long-lived potomadromous species in large rivers. Pre-spawning adults move upstream to rocky spawning areas in April-May, then downstream after spawning to summer feeding areas. Non-spawning adults move up- or downstream to feeding areas in April-June, remain there during the summer, and then move up- or downstream in August-October to wintering areas along with post-spawning adults. Mature adult females that will spawn the next spring migrate upstream during the summer preceding spawning to an upstream foraging area near the spawning area (Kynard *et al*. in press-a). Year 2+ juveniles also participate in spring-fall up- and downstream migrations to foraging areas. Early-life stages have a 2-step downstream migration (a short 3-day migration as larvae from the spawning site; then, a long migration during spring-fall as yearlings that disperse downstream throughout the population; Kynard & Horgan 2002; Kynard *et al*. in press-b). Each month from March through November, various life stages of sturgeon are moving up- and downstream. It is not surprising that a complicated series of migrations has evolved in a long-lived species living in a large open river with diverse habitats. Similar movements of long-lived fishes likely occur in other regions, countries, and continents, including Australia.

RESEARCH METHODS

Researchers in the northeast US study downstream fish migration by capturing fish or monitoring fish movements using telemetry and electronic PIT tags. Common methods for capturing juveniles and adults that are surface-oriented or in shallow water use stream weirs (Hearn & Kynard 1986), an inclined-plane floating trap (McMenemy and Kynard 1988), or an Archimedes screw trap (Nielsen & Johnson 1983). Researchers use drift nets to capture early-life stages in the open river or at water exits at dams, where capture of fish is often easier than in the river (O'Leary & Kynard 1986). Vertical gill nets can also reveal the vertical distribution of migrants (Witherell & Kynard 1990). Telemetry tracking of fish movements has proven valuable for documenting downstream fish migration and ecology in large rivers (Buckley & Kynard 1985; Warner & Kynard 1986; Steir & Kynard 1986b; Kieffer & Kynard 1993; Kynard *et al*. in press-a).

Although documentation of downstream fish migration in the field is preferable, sometimes due to species rarity or the high cost of field sampling, field studies cannot be done. In this

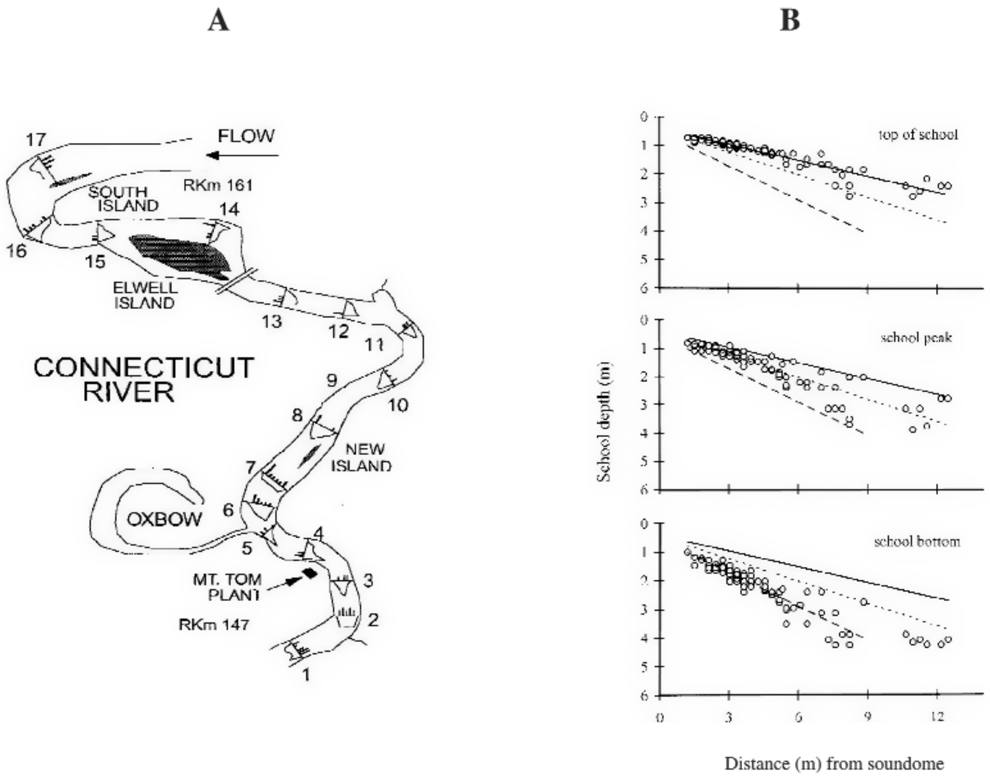

Figure 1. Downstream migration route of juvenile alosids in the Connecticut River as shown by river bottom contour and bar graph of fish abundance at each of 17 transects (A), and the vertical distribution (least squares regression) of juvenile abundance relative to water depth (B).

case, observations of fish in artificial streams can provide information on migration of early-life stages. These migrations are innate and observations in a stream channel can reveal many basic features of migration. This method has been used to determine migration timing, swimming height above the bottom, and habitat preference of early-life stages of sturgeons (Kynard & Horgan 2002; Kynard *et al*. 2002). This information contributes to a conceptual model of migration useful for resource managers concerned about the impact of water withdrawals and dams on downstream migrants.

Hydroacoustics is a useful technique for determining migration route and vertical distribution of migrant adults and juveniles in large rivers. Downstream migration of juvenile alsoids (American shad and blueback herring) in the Connecticut River was studied using a mobile boat-mounted hydroacoustic system. The study discovered that the migration route followed the channel and fish were in schools near the surface (**Figure 1**; Kynard *et al*. in press-c). Migration route was studied for 2 years, vertical distribution was studied for 1 year during a longitudinal transect of the channel. Information on migration route and vertical distribution is useful for selecting the location for bypass facilities and to locate water diversions and withdrawal pipes.

Odeh & Orvis (1998) state in their review of protection for downstream migrant fish in the Northeast that "most downstream migrant fish in the north-east USA are found in the upper (3-4 m) of the water column". This statement was likely meant to address the situation for Atlantic salmon and American shad (the only references cited to support this statement are for these two species). Unfortunately, many people believe this is the situation for downstream migrants of most species. This common perception may cause resource agencies to believe that surface-oriented structures and bypasses are more effective at guiding a wide range of migratory species than is actually the case. The few non-target species guided by surface bypass systems and the benthic body adaptations of many species that migrate suggest that most migrant species are mid-water or benthic. This situation can only be understood after research examines riverine species for passage in surface bypasses and the vertical distribution of diadromous and riverine migrants. Adult American shad moving downstream are not schooled and are near the bottom (Witherell & Kynard 1990), but after they enter the confusing area around dams and canals, they form schools and are surface-oriented (Kynard & O'Leary 1993), a change likely due to stress (Kynard 1993). For schooling species, vertical orientation needs to be determined at a passage site or in a similar situation.

DOWNSTREAM FISH PASSAGE

In the US, federal and state resource agencies decide which fish species (and life stages) need passage. This is done selectively, focusing not on the migratory fish community, but on target species important for accomplishing specific program goals, like sport fish restoration or protection of endangered species. The Fish & Wildlife Coordination Act (FWCA) directs federal agencies to protect and increase fish and wildlife resources and to coordinate with US Fish & Wildlife Service, National Marine Fisheries Service, and state agencies on water development projects authorized by Congress or requiring a federal permit. This direction by the FWCA provides the mandate to protect migratory fishes. In practice, passage for migratory fishes is a function of agency will, funding, traditional program emphasis, and acceptance by licensees. State resource agencies vary widely on practices for riverine fish passage. The result of this situation is that most northeast diadromous and riverine species are given little consideration for safe passage.

Development of downstream fish passage at Holyoke Dam on the Connecticut River illustrates the approach of resource agencies for fish passage. Federal and state agencies manage an anadromous fish restoration program for the river, with emphasis on the sport fishes, American shad and Atlantic salmon. Initially in the 1950s, restoration goals focused on developing upstream passage. Hundreds of thousands of American shad began passing upstream of the dam in the mid-1970s, and research showed a high level of turbine-related mortality for migrants (Steir & Kynard 1986b; Bell & Kynard 1985). Thus during relicensing of the hydropower facility, agencies required downstream passage for these target species. When downstream migrants approach the dam, they have three possible routes, i.e., pass in spillage over the dam (if river discharge is high), enter a turbine at Hadley Falls Station (34 MW), or enter the canal system with many small turbine intakes (**Figure 2**). Adult and juvenile American shad and Atlantic salmon smolts are surface-oriented, so some protection was provided by surface spillage at the dam near the intake for Hadley Falls Station, and protection in the canal was provided by a bypass. The initial

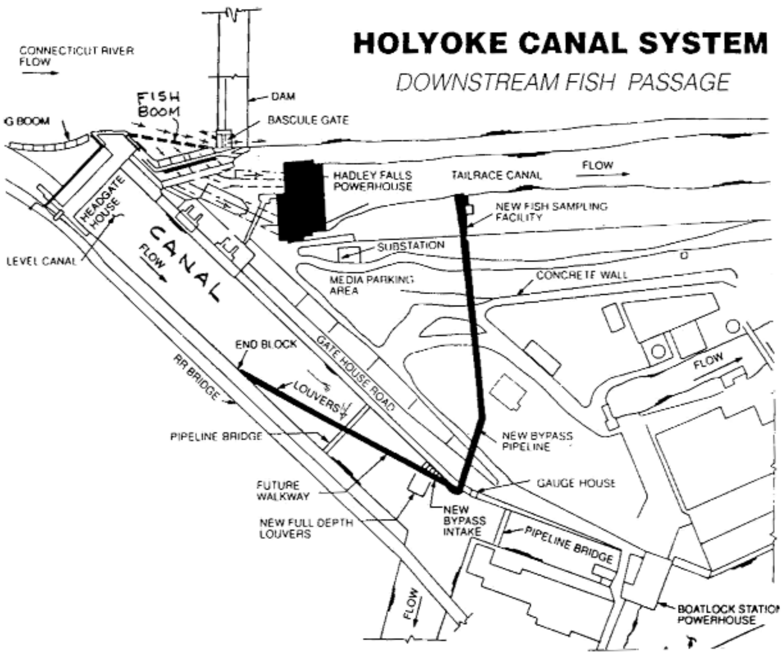

Figure 2. Plan view of Holyoke Dam and the First Level Canal showing the louver array in the canal to guide downstream migrant American shad and Atlantic salmon to a bypass.

trash rack bypass for American shad in the canal was the first bypass developed for the species. It relied on the accumulation of adults at a trash rack, immobilization of fish with DC electricity, and collecting and passing fish through a bypass system (Kynard & O'Leary 1993). Behavioral guidance using electricity, sound, and light, which are successful in some cases (Kynard 1993), was not successful at Holyoke (Kynard & O'Leary 1991). Behavioral guidance is still used at a few sites, but behavioral guidance not been reliable and only physical guidance (bar racks and louvers) is used now. The trash rack bypass worked for adults, but provided no protection for juvenile shad or Atlantic salmon smolts, so it was replaced in the early 1990s by a louver array bypass on the first level canal. The louver array was 174 m long at 15° to approach flow, 3 m deep, with louver slats spaced 7.5 cm apart (**Figure 2**). Exit of the 1 m diameter bypass pipe had a wedgewire screen to separate fish from water and capture and evaluate guidance efficiency. Tests showed about 90% of the target life stages were guided successfully.

In 1999 during the relicensing period for Hadley Falls Station, fish protection at Holyoke expanded to include two new species. Based on new research information that the federally endangered shortnose sturgeon migrates downstream past the dam during yearling to adult life stages from March-November (Kynard *et al*. 1999; Kynard & Horgan 2002; Kynard *et al*. in press-b), and that adult American eels, *Anguilla rostrata*, are killed passing the dam, agencies required that new fish passage must include these species. Both species are benthic, not surface-oriented like previous target species. Research shows physical barriers like louvers and bar racks guide sturgeons (Kynard & Horgan 2001). However, no research information is currently available on the best design or attraction water for a bottom bypass entrance. Research studies at Conte AFRC in a flume (6.1 m x 6.1 m x 36 m) will test sturgeon and eels to determine the best structural configuration to guide and bypass these fish. In an attempt to protect these benthic fishes at Holyoke with the existing canal louver array, in 2003 resource agencies have required an extension of the louver to full depth and installed an inclined ramp leading to the bypass entrance. It is uncertain that fish guided to the surface bypass entrance will remain there long enough to find the entrance before they swim through the louver slats and avoid passage. Research is needed to protect sturgeon and eels at Holyoke. This research could provide the guidance for passing many benthic migrants.

Fish protection at Minetto Dam, Oswego River, NY is another example of using relicensing to secure protection for downstream migrant fishes (Kleinsmidt Assoc. unpubl. Report, USFWS 1997). The facility has a generation capacity of 15 MW and has six Francis turbines. A fish entrainment study used three full draft tube nets with live boxes to capture 35 fish species from 10 families (diadromous and riverine species) that moved downstream and entered the turbines for 9 months of the year (March-November). Peak captures occurred in March and May. This pattern was similar to the migration pattern of shortnose sturgeon cited earlier, and may be typical of northeast species. Species from the most common riverine families were captured moving downstream, i.e., Catostomidae, Centrarchidae, Clupeidae, Cyprinidae, Cyprinodontidae, Esocidae, Ictaluridae, Osmeridae, and Percidae.

Survival of fish by size that passed through the Minetto turbines depended on the species, i.e.,

Table 1. Survival of fish by body type and size that passed through the Francis turbines at Minetto Dam, Oswego R., NY. Small = <100 mm TL, Medium = 100-250 mm TL, and Large = >250 mm TL.

Family and Body Size	% Spring Survival	% Fall Survival
Small Sunfish	91	
Medium Sunfish	89	74
Large Sunfish	84	83
Small Perch	80	89
Medium Perch	91	89
Large Perch	92	
Small Sucker/Minnow	81	82
Medium Sucker/Minnow	97	89
Large Sucker/Minnow	80	87

small sunfish survived better than large sunfish, but small perch survived poorer than large perch (**Table 1**). Survival also depended on season, with spring survival slightly higher (80-92%) than fall survival (74-89%). The species seemed similar for survival. An estimated 722,472 fish were killed. The fish had a monetary value (replacement cost, American Fisheries Society Monetary Value Book) of $196,122.

To protect fish at Minetto Dam, state and federal resource agencies recommended a full-depth, angled bar rack placed at 45° to approach flow, with 25 mm slat spacing, and a maximum approach flow of 0.8 m/s. Bypass attraction water was 5% of the capacity of the turbine units (2-5% is the standard for resource agencies in the northeast US). Although there were bottom and surface entrances required, passage effectiveness was not evaluated. Questions also remain about the effectiveness of the bar rack, particularly regarding protection of riverine species. Only research can resolve these questions.

Although the technology of screening fish has greatly improved in recent years (Clay 1995), use of screens to protect diadromous migrants is rare in northeast rivers. In a few streams with small dams where juvenile Atlantic salmon need protection, movable flat plate wedgewire screens of 5-mm-clear spacing are placed over trash racks at the dam to protect fish from entrainment. For old dams, many experts consider the cost of full screening is prohibitive. For new water withdrawals from eastern rivers with diadromous fishes, many agencies require low velocity, end-of-pipe, drum screen cylinders (capacity, <1-1.5 m^3s). These cylinders, which are cleaned by a water jet or airburst, are capable of successfully screening striped bass, *Morone saxatilis*, larvae 10 mm TL (Hanson 1981).

The best test of screening to protect northeast diadromous and riverine species was done in the mid-1990s on the Hudson River at the Green Island Project (Taft *et al*. 1992; Winchell *et al*. 1996). A flat-plate wedgewire screen with 2 mm spacing was tested for guiding fish as small as 60 mm TL to a bypass. Guidance and passage survival at 1.2 m/s approach velocity to the screen was high (>99%) for all families except for Clupeidae (68%); and at 2.4 m/s velocity, survival of most families was still high (>91%), except for Percidae (55%) and Clupeidae (22%; **Table 2**). Most of the Clupeidae were juvenile river herring, which like Atlantic salmon smolts, are sensitive to handling just before they enter salt water.

In the western US, screens are the common method to protect fish (Clay 1995). Protecting fish that are diverted from the mainstem into water irrigation channels is commonly done by using a rotary barrel screen, which is located at the diversion site or in the diversion channel, to separate fish from irrigation water and return the fish to the river (**Figure 3**). Barrel screens operate over a wide range of flow (0.08-84 m^3s), and operational guidelines usually require 12 cm/s approach velocity and a 65-85% submerged barrel. Under these conditions, the barrel is self-cleaning and has high fish diversion and high fish survival.

Concern for the survival of several small, native, potamodromous, fishes in the Sacramento River, CA, that were entrained for years and that were recently listed as federally protected has resulted in screening of water diversions and turbine intakes that could impact the fishes. Commonly, V- and inclined wedgewire-type screens with 2 mm clear openings are being used. The regulation responsible for this action is the Endangered Species Act. This is the greatest effort in North America to protect native non-game riverine fishes from losses at water diversions and dams. This action in California has implications in the Northeast for protecting the migratory fish community. The problems

Table 2. Survival of fish from six families guided and bypassed using a modular inclined wedgewire screen at Green Island Dam, Hudson River.

Family	TL (mm)	% Survival @1.2 m/s approach velocity	% Survival @ 2.4 m/s approach velocity
Salmonidae	95	100	99
Centrarchidae	69	99	98
Cyprinidae	70	99	91
Perchidae	58	99	55
Clupeidae	60	68	22
Ictaluridae	88	100	100

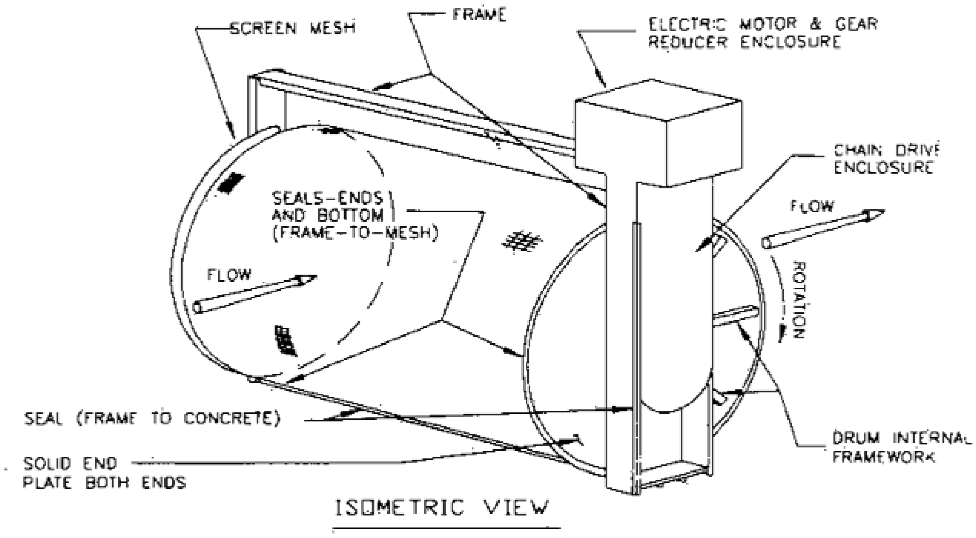

Figure 3. Drawing of a rotary barrel screen typically used in irrigation diversions to separate fish from irrigation water and return fish back to the river.

created for migratory fish in the Sacramento River are not unique. Hopefully, agencies throughout the US are seeing the future and learning from this situation.

Passage of downstream migrant fish in the northeast US has been ongoing since the late 1970s. This effort has been mostly successful for a few diadromous, surface-oriented alosids and Atlantic salmon, but until the Oswego River projects in New York, has provided no passage for riverine fishes. Thus, after more than 20 years, passage for most diadromous and riverine fish species is still not available in most northeast rivers. In the Connecticut River, resource agencies hope that a full-depth bar rack with 25 mm bar spacing will guide and pass juvenile and adult sturgeon and eels. If the full-depth bar rack successfully excludes 15 cm long yearling sturgeon, it will also give some protection to many fish species that presently have no passage. Even if a bar rack successfully passes sturgeon and eels, it will not protect small life stages of any species or any of the life stages of small species. Small life stages and small species have greater survival than large fishes when passed through turbines (Stone & Webster Env. Service. 1992), and may survive turbine passage better than bypass screens.

Many years of ignoring the impacts of damming, water withdrawals, and population segmentation on riverine migratory fishes in the Sacramento River has now created the situation where intake screening is widespread to protect species that declined to endangered species status. Are segmented populations of migratory riverine fishes slowly declining in the Northeast (or Australia)? No one knows, and no one is seriously looking in the Northeast. However, without a population decline or evidence of high mortality to trigger resource agency concern, an increased level of passage for the migratory fish community will not likely occur. Protecting migratory fish in the Northeast during the 21st Century will continue to be a major conservation issue. Hopefully, this effort will expand to include the entire migratory fish community before a dire situation like that in the Sacramento River occurs.

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