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Proceedings of a Workshop on American Eel Passage Technologies

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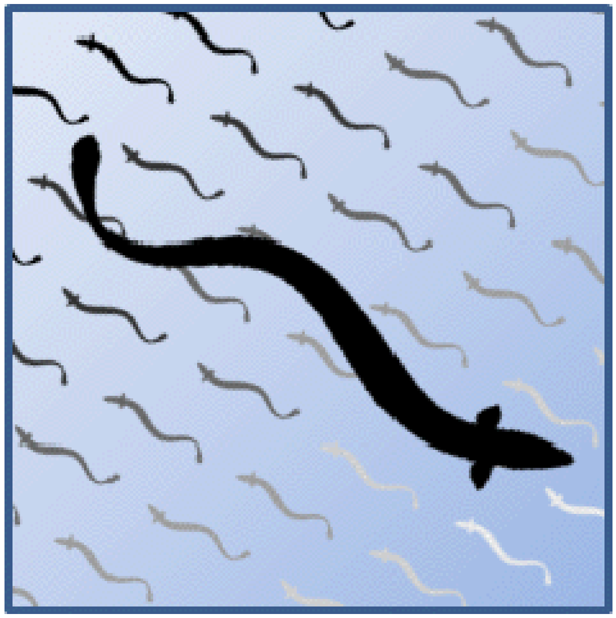

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Preface

This document was prepared in cooperation with the Atlantic States Marine Fisheries Commission's (ASMFC) American Eel Management Board, American Eel Technical Committee, and Fish Passage Working Group. *Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.*

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Acknowledgements

This report is the result of a Workshop on Eel Passage Technologies held on March 30 and 31, 2011, in Gloucester, Massachusetts (NOAA National Marine Fisheries Service Northeast Regional Office). The workshop was convened and organized by a Workshop Steering Committee composed of: Brad Chase (Massachusetts Division of Marine Fisheries), Timothy Wildman (Connecticut DEEP Inland Fisheries Division), and Skip Zink (Maine Department of Marine Fisheries).

Essential funding for the workshop was provided by ASMFC, the Massachusetts Division of Marine Fisheries, and the NOAA National Marine Fisheries Service Northeast Region Habitat Conservation Restoration Center.

Special thanks are extended to the session moderators, speakers, and participants whose commitment of valuable time and effort helped make the workshop a success. In particular, the Steering Committee would like to acknowledge Jeanne Shaw (Massachusetts Division of Marine Fisheries), Helena Torres (NOAA National Marine Fisheries Service), Jim Turek (NOAA National Marine Fisheries Service), John Catena (NOAA National Marine Fisheries Service), and Don Pugh (Trout Unlimited). Thanks are also due to Pat Campfield (ASMFC) and Jeff Kipp (ASMFC) for facilitating the workshop and production of the report.

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1. Introduction/Background

Recent concerns regarding a decline in recruitment of American eels (*Anguilla rostrata*) have prompted efforts to restore this species to historic habitats by providing passage for both upstream migrant juveniles and downstream migrant adults at riverine barriers, including low-head and hydroelectric dams (Castonguay et al. 1994, Haro et al. 2000). These efforts include development of management plans and stock assessment reviews in both the US and Canada (COSEWIC 2006, Canadian Eel Working Group 2009, DFO 2010, MacGregor et al. 2010, ASMFC 2000, ASMFC 2006, ASMFC 2008, Williams and Threader 2007), which target improvement of upstream and downstream passage for eels, as well as identification and prioritization of research needs for development of new and more effective passage technologies for American eels.

Traditional upstream fish passage structures, such as fishways and fish lifts, are often ineffective passing juvenile eels, and specialized passage structures for this species are needed. Although designs for such passage structures are available and diverse (Knights and White 1998, Porcher 2002, FAO/DVWK 2002, Solomon and Beach 2004a,b, Environment Agency UK 2011), many biologists, managers, and engineers are unfamiliar with eel pass design and operation, or unaware of the technical options available for upstream eel passage. Better coordination is needed to account for eel passage requirements during restoration efforts for other diadromous fish species. Also, appropriately siting eel passes at hydropower projects is critical, and siting can be difficult and complex due to physical restrictions in access to points of natural concentrations of eels, dynamic hydraulics of tailrace areas, and presence of significant competing flows from turbine outfalls or spill. As a result, some constructed eel passes are sited poorly and may pass only a fraction of the number of eels attempting to pass the barrier. When sited and constructed appropriately, however, eel passes can effectively pass thousands of individuals in a season (Appendix D).

Technologies for preventing impingement and entrainment mortality and injury of downstream migrant eels at hydropower projects are not well developed. Traditional downstream fish passage mitigative techniques originally developed for salmonids and other species are frequently ineffective passing eels (Richkus and Dixon 2003, EPRI 2001, Bruijs and Durif 2009). Large hydropower projects, with high project flows or intake openings that cannot be fitted with racks or screens with openings small enough to exclude eels, pose significant passage problems for this species, and turbine impingement and entrainment mortality of eels can be as high as 100%. Spill mortality and injury may also be significant for eels, given their tendency to move during high flow events when projects typically spill large amounts of flow. Delays in migration of eels that have difficulty locating and utilizing bypass entrances can also be significant. Therefore, downstream passage technologies are at a much more nebulous state of development than upstream passage technologies, and require further evaluation and improvement before rigorous design guidelines can be established.

There have been few studies conducted to evaluate effectiveness of current mitigative measures for both upstream and downstream passage of eels. Research is needed to determine eel migratory timing, behavior, and appropriate mitigation technologies for specific sites and eel life history stages. Both upstream and downstream eel passage structures can be difficult to evaluate in terms of performance, and examples of how evaluation and monitoring can be accomplished were reviewed at the workshop.

2. Workshop Goals

This workshop was intended to serve as an educational tool for biologists, engineers, and managers wishing to learn more about upstream and downstream eel passage technologies, methodologies, and evaluation. The workshop also served as a vehicle for information sharing, exposition of new or experimental technologies, and discussion of management strategies for eel protection at riverine migratory barriers.

Three primary goals of the workshop were:

- For upstream eel passage: define specific guidelines for design and operation of upstream eel passage structures.

- For downstream eel passage structures: review current technologies and experiences, identify successful and unsuccessful technologies, and identify priority areas for future research.

- Review evaluation and monitoring techniques and methodologies for both upstream and downstream eel passage projects.

The workshop concluded with an exercise to identify areas of research needs or information/technology transfer, within the following classifications:

Research Needs: formal research necessary to address basic biological or ecological questions on eel migrations and life history (**Table 1**).

Technical Information Needs: develop specific criteria for design of eel passage technologies, monitoring protocols, or management strategies (**Table 2**).

Evaluations: refine methodologies for evaluating eel passage structure performance or overall effectiveness of management programs (e.g., stocking) (**Table 3**).

Tough Questions: areas that were identified as difficult to address at present using available techniques, or serious gaps in knowledge with no clear methodology to approach them (**Table 4**).

Because of the variety and number of research, technical information, and evaluation needs, these topic areas were initially listed and not ranked or prioritized, in an effort to capture the variety of topic areas identified. It was also evident from discussions that the priority of these areas varied between agencies, stakeholder groups, and regions. However, the comprehensive listing was considered useful in identifying the breadth and variety of needs, and as a starting point for future or alternative prioritization of needs by stakeholders.

Similar research needs relevant to eel passage were summarized in the ASMFC 2012 American Eel Benchmark Stock Assessment (ASMFC 2012). These research needs were secondarily classified into short- or long-term research needs and prioritized as high, low, or moderate priority (**Table 5)**. Research needs identified in the stock assessment focus on general research to improve American eel stock condition, inform future stock assessments, and improve management of the stock. Research, technical information, and evaluation needs identified during the workshop complement these general research needs and focus on more specific needs for eel passage.

3. Venue, Agenda, and Attendance

The workshop was held March 30-31, 2011 at the NOAA National Marine Fisheries Service Northeast Regional Office, Gloucester, Massachusetts, USA. The workshop agenda is provided in **Appendix B**. Over 120 participants attended the workshop; attendees represented federal and state agencies, NGOs, and the private sector (primarily hydroelectric companies and their consultants). Most attendees were from the northeastern US; other represented countries included Canada (11), France (1), and New Zealand (1) (**Appendix C**).

4. General Review of Workshop Themes and State of Science/Technology

4.1 Synopsis: General Guidelines for Design and Operation of Upstream Eel Passes (Day 1)

Although performed for centuries, provision of upstream passage for eels at migratory barriers (usually dams) is highly varied, and historical techniques have primarily been developed in Europe. Many technical designs seen today in the US and Canada are derived from European designs, although a few truly innovative designs exist. Presentations during the workshop covered the general status and performance of upstream eel pass design in Europe, New Zealand, and coastal river systems in the eastern US and Canada from Quebec to North Carolina. Excellent reviews of eel pass design options are found in Solomon and Beach (2004a & b), and of eel passability at dams by Tremblay et al. (2011).

4.1.1 Upstream Passage Structure Design

Many of the designs, although somewhat refined, are generally small-scale and are implemented and maintained on a low budget, often using general materials on hand. Most sites have temporary passes that can be removed and stored for protection during the nonmigratory season. Sites in the southern US where American eel migrations occur from March through November tend to have permanent pass structures. Operation period of passes varies; typically they run from early spring, when glass eel and elvers first appear at coastal sites, through spring and early summer. Some passes on larger river systems operate throughout the summer and into the fall; often these are at larger hydroelectric dams where continuous operation from spring to fall is mandated by agency regulations. General design guidelines for North American eel traps and passes and several examples of the variety of existing upstream eel passage structure designs are given in **Appendix D**.

Upstream eel passage structures may either take the form of **passes** which convey fish past a barrier passively (i.e., eels are permitted to volitionally swim or climb the pass structure over the full height or length of the barrier before passing volitionally upstream into a headpond; Appendix D.11), or **traps** which pass eels from a climbing ramp, pipe, or other collecting conduit to a collection tank (often a box or bucket; Appendix D.2-D.10). Eels must then be manually removed from the tank and physically transported past the barrier and released. Passage structures may extend the full height of the barrier (**full-height;** Appendix D.2, D.5-D.11) or only a short vertical distance less than the full height of the barrier (**partial height;** Appendix D.3-D.5). Passage structures at higher or larger barriers typically employ shorter ramps with large capacity traps to avoid forcing eels to climb long distances, or lift devices. Thus, passes are usually full-height, while traps may be either full-height or partial-height.

Passes are usually more highly engineered and require more specialized materials and structural design than traps, especially if they are designed to be permanent structures. Smaller, lightweight portable traps are frequently employed to determine optimal siting of passes at new sites, size distribution of eels available to pass, and selection of appropriate attraction flow and climbing substrate material. Manually-tended full-height traps may also be converted to full-height passes by providing a mechanism for eels entering the collection tank to exit the tank (escape hole or overflow) into the headpond, or bypass the collection tank altogether. Frequently, passes are initially designed as traps so that catch can be monitored to evaluate attraction, passage rates, escapement, and passage performance, and then later modified as a pass to permit fully volitional passage of eels without monitoring.

4.1.2 Design Variants

Although typical upstream passage structures for eels take the form of open channels fitted with specialized climbing substrate, variants on this design can be effective at locations where a technical design is not required or is impractical. The simplest form of a pass consists of a **passive climbing substrate** placed on the barrier itself to assist eels in climbing past obstructions, dry areas, or vertical faces. The substrate may consist of netting, frayed rope, matting, or even simple roughening of the climbing face. These types of structures, however, require addition of flow to keep surfaces wetted and make them climbable; they are also susceptible to fluctuations in river flow which may dewater the substrate or overwhelm the substrate with too much flow. Some flow control structures may be added to passive climbing substrates (i.e., netting stuffed into pipes through flashboards at a dam crest; **"Delaware"-type pass;** Appendix D.11) or other structures that regulate flow down the substrate under varying headpond conditions.

Other variations include **open-conduit passes** that exchange an open, flat channel for a closed pipe or flexible hose fitted with climbing substrate; typically these structures still operate with open-channel hydraulics (air-filled with small amounts of flow provided to wet the substrate). Conduits filled with water (closed conduits) tend to create water velocities that are too high for most smaller eels to swim against, and are typically not used except at locations where barrier water level differentials are extremely low (< 10 cm).

Eel lifts have been developed at several sites; usually they are effective where site conditions preclude construction of a traditional ramp pass (i.e., limited footprint, fluctuating water level, or risk of damage). Most lifts consist of a short ramp pass and trap box that can be hoisted and emptied at the top of the barrier structure (Appendix D.10). Lifts also can be an efficient solution at very high dams, obviating the need for very long and expensive ramps that can also be stressful to climbing eels. Lifts usually require more complexity and cost in design, but smaller lifts can have costs comparable to a ramp pass.

4.1.3 Flows

Water flow is the primary means to attract eels into passes and to assist their passage through structures, either by climbing or swimming. Flows to eel passage structures are usually provided by large **pumps, siphons, or gravity flow**; some of the total flow supplied to a structure can be distributed from a pump or siphon inlet to **attraction flow**, **ramp flow**, and **trap flow** (flow supplied to the trap box or other structure to keep trapped eels with adequate dissolved oxygen and at ambient water temperature). Supplemental attraction flow is usually essential for larger passage structures, or structures in larger rivers. Attraction flows directed to the vicinity of a pass entrance tend to attract more eels, although there are no set guidelines for either absolute attraction flows or flows relative to passage structure size or scale of the site. The general rule of "more is always better" seems to be effective, but care must be taken not to overwhelm entrances with too much flow, which can prevent eels from orienting to the entrance and entering the structure. Typically, pumps or siphons which deliver 100 to 200 l/min are required for most passes supplied with attraction flow. Attraction and ramp flows that include odors of conspecifics (i.e., eels already trapped within the trap box) may add an additional component of attraction into eel traps and passes (Briand et al. 2002).

Ramp flows are usually relatively small with respect to attraction flows. The particular type of climbing substrate used will dictate appropriate flows, but, in general, adequate flow must be provided to keep climbing surfaces wetted, and give eels a rheotactic cue to orient to the flow and motivation to continue climbing. For flat technical substrates (i.e., Enkamat®, vertical brush, vertical cylinders), only a few millimeters of depth over the substrate are required. Ramps that are angled laterally can accommodate more flows, as long as a wetted margin along the substrate is provided that enables eels to select a wetted region that is climbable. Closed conduits stuffed with climbing netting may similarly require minimum flows to adequately wet the substrate.

Trap flows need to maintain adequate water turnover within a trap to keep temperatures near ambient and oxygen levels high. Trap flows should accommodate anticipated maximum capacity of eels and associated oxygen demand; a large pulse of eels entering a trap can deplete dissolved oxygen rapidly.

4.1.4 Operation and Evaluation

Much of the discussion period following the presentations focused on not only pass design but also operation criteria and evaluation of performance of passes and other mitigation techniques. Knowledge of passage performance of traditional fishways and culverts for eels was also noted to be limited. Identified research, technical information, and evaluation needs are listed in **Tables 1, 2**, and **3, respectively**.

Accurate evaluation of eel pass performance was noted to be particularly difficult to achieve at many sites, especially larger sites where recapture probability is low, and is also compounded by technical difficulties in individually marking eels for the short- and long- term. Juvenile eels are relatively small and difficult to mark, either individually or in batches. Batch marking (i.e., dye baths, radioactive tracers) holds promise for marking large numbers of juvenile eels (glass eels or elvers) rapidly, which may benefit studies by increasing recapture rates when the probability of recapture is low (i.e., large systems). However, most batch marks have a limited retention time; tetracycline marks and other dyes typically fade within several months (although tetracycline marks in bony tissues may be retained much longer, but must be examined microscopically or require tissue sampling).

Other viable marking techniques include visible implant elastomer (VIE) tags and coded wire tags, which have been used with some success on larger (>100 mm TL) elvers. However, marking large numbers of eels (again, potentially required under low recapture rates) with these methods is laborious and time-consuming. Recently, passive integrated transponder (PIT) tags have been used to mark larger juvenile eels, but generally cannot be used for the smallest juveniles. Typically, conventional 12 mm PIT tags can only be used to mark eels >200 mm TL, although 8 mm PIT tags may be viable for eels as small as 100 mm TL. Tagging mortality and tag retention of PIT tags in eels requires additional study, especially given the long lifespan of eels. PIT tags may also significantly affect growth and behavior of eels.

Conventional radio and acoustic telemetry is also frequently used with eels, but transmitters usually must be implanted internally to prevent self-removal of externally attached tags. Long-term telemetry requires that the transmitter (including antenna) be completely enclosed within the body cavity, and some rejection of tags may occur for eels tagged more than 6 months.

Most population evaluations (i.e., dispersal, growth, population estimation) require recapture methods, which are varied for eels. Fyke nets, pots, and other nets are typically used, but mesh size selection should be taken into account with these methods. Electrofishing is also frequently used, but can be less efficient for eels, which tend to actively avoid electric fields more strongly than other fishes. Eels stunned by electrofishing may also hide under bottom substrate, making them more difficult to recover, especially in deep or swiftly flowing streams. A general trend was noted by workshop participants that recapture rates of eels in many past field studies tended to be exceptionally low, even when very large numbers of eels were marked in mark-recapture studies, thus complicating population, dispersal, or passage estimates. The causes of low recapture rates are not well understood; rapid dispersal (i.e., upstream movement), trap-shyness, low mobility, or inefficiency of capture methods are all potential causes.

The ecological implications of programs that employ stocking of eels upstream of a barrier were also identified as a major gap in knowledge. Although advantages of stocking eels, collected at a first barrier, above other consecutive barriers upstream seems intuitively efficient, survival, sex determination, and disease issues of stocked eels all may influence the overall production and effectiveness of stocking in upstream habitats (i.e., measured in terms of number of adult eels able to emigrate to the ocean). It was noted that the significant ecological role that eels may play in upstream habitats (e.g., as mussel hosts, prey for other species, or dominant fish predator) may outweigh any disadvantages to stocking in terms of survival to reproduction. Conversely, the concern of stocking eels with exotic parasites to upstream habitat with no or limited exotic parasite presence was discussed. These questions will require long-term studies of eel populations and ecology in both dammed and undammed river habitats.

4.2 Synopsis: Issues for Investigation and Mitigation of Downstream Eel Passage (Day 2)

Downstream eel passage was quickly identified by workshop participants as the “more difficult” problem to address, as knowledge of downstream migration and methods of protection for downstream migrants is poorly developed, and lags behind those for upstream passage. The potential impacts of downstream passage mortality for eels are significant, given that large-bodied eels are more susceptible to turbine blade strike and resultant mortality and injury, and that these are all pre-reproductive losses of large eels nearing maturity. Past efforts to provide protection for downstream migrant eels have met with mixed success, and traditional methods used for juvenile salmonids and clupeids have generally been ineffective for eels.

The “Best Available Technology” for protecting downstream migrant eels at present appears to be screening or narrow trash rack spacing which excludes eels from entrainment (but does not cause impingement from high approach velocities), or suspension of generation at hydroelectric projects. However, these methodologies are often expensive or technically difficult to implement, or result in reduced generation. Even if such protective measures are established, questions remain about location and operation of bypasses that eels must be guided to if they cannot pass through turbine units, potential for spill mortality of “turbine excluded” eels, and the impact of potential delays in passage while excluded eels search for a passage route. More novel techniques of “behavioral barriers” that have been used for other species (e.g., light, sound, flow inducers) to either exclude individuals from intakes or guide them to safe passage routes have generally not been successful for eels. However, most behavioral barriers have not been exhaustively evaluated for American eels. A noted general trend was that larger projects tended to have more complex and intractable downstream passage issues for eels, based on their scale and operation criteria. In at least one system (St. Lawrence River), capturing silver or near-silver eels and moving them downstream past barriers before they can experience turbine mortality is being investigated as a mitigation measure.

Identified research, technical information, and evaluation needs for downstream eel passage are listed in **Tables 1**, **2**, and **3, respectively**. Identified research needs included addressing the issues mentioned above, as well as approaching larger issues relevant to downstream passage including movements and migration rates in undammed systems, effect of swimbladder nematode infestation on migration and survival, impacts of non-hydropower structures (i.e., culverts, tide gates), tradeoffs of provision of upstream passage versus survival of adults to the ocean, and effects of delays on successful migration. Technical information needs included development of techniques for intercepting and sampling downstream migrants and effectiveness evaluation tools for proposed trap-and-transport mitigation. A need was also seen for databases of mortality estimates for various turbine designs, as well as for passage efficiency relevant to bar rack design, and estimation of O&M costs for implementing various mitigation schemes. Evaluation needs were identified as development of turbine strike probability models and desktop analyses for site-specific studies, and systematic definitions and protocols for quantifying mortality, morbidity, and injury.

4.3 Synopsis: "Tough Questions" (Days 1 & 2)

More difficult "tough questions" for upstream passage focused mainly on appropriateness of out-of-basin transfers of eels, either as a passage mitigation technique or as a stocking technique to reintroduce eels to historic habitat to restore their ecological function (**Table 4**). Many uncertainties exist regarding how juvenile eels should be reintroduced (apportioned) to upstream habitats, either to maximize production or ecological function, without knowledge of habitat value or historic distribution. Some concern existed that upstream passage at some sites might not provide any significant benefit over not passing eels upstream, given significant downstream passage mortality, lack of suitable habitat, etc., but there were little basic data or models on which to judge these decisions.

Downstream passage issues presented a significant number of "tough questions" (**Table 4**). The lack of development of effective downstream passage technologies predominated, but additional new downstream passage threats, such as hydrokinetic turbines, may prove equally difficult to evaluate and mitigate. More "holistic" metrics of management strategies relevant to downstream passage were sought; i.e., could some model or decision support system be developed to weigh the costs and benefits of provision of downstream passage (and perhaps logic of promoting upstream passage) so that informed decisions could be made with respect to the need for downstream passage, degree of protection required, and ultimate benefit of restoration of eels to upstream habitats?

5. Summary

The past 10 years have seen an increase in the application and provision of eel passes at low-head dams in New England that have relied mainly on European designs and trial-and-error experiences. Designs are being continually improved; at present roughly 50-60 passes have been built at low-head barriers in the northeastern US, with an equivalent number in Canada, and the number of new passes is likely to increase at an accelerated rate in the foreseeable future. Improvements are also advancing in upstream eel passage at larger hydropower dams in the US and Canada. This movement is viewed as a success because managers working on sea-run fish passage are giving more attention to eel passage needs when designing passage goals at obstructions. Another sign of success is the growing number of pump-supply eel ramps in New England that are recording annual census counts in the tens of thousands. Despite recent gains, there are outstanding questions over how to improve downstream passage at large dams and evaluations for both upstream and downstream passage.

An additional list of ASMFC eel passage research recommendations was developed during 2011 and 2012 through interactions with the ASMFC American Eel Technical Committee and ASMFC American Eel Stock Assessment Subcommittee and was reported in the 2012 ASMFC American Eel Benchmark Stock Assessment (ASMFC 2012; **Table 5**). The recommendations from the 2011 workshop came from a brief "brainstorming" session and were submitted independently of the ASMFC stock assessment process; however, the large attendance of fish passage professionals and participation of ASMFC committee members and staff in the workshop naturally resulted in many common themes and recommendations.

The two sets of recommendations differ in that the ASMFC recommendations are larger, broad-scale concepts that have relevance and receive support throughout the range of American eel, while many of the workshop recommendations fall under the same categories as the ASMFC recommendations but address more specific, technical questions. Readers are encouraged to consider these origins while scanning the recommendations for ideas that are applicable to their locations and research interests.

Both sets of recommendations will assist the ASMFC management process to update the American Eel Fishery Management Plan. A Plan Development Team is preparing an Addendum (No. 3) for the American Eel Fishery Management Plan in 2013. This Addendum will further highlight and consider eel passage and habitat improvements that can assist the population recovery of American eel.

The workshop met its primary goals of reviewing the status of eel passage applications and sharing these practices among the wide range of practitioners. The workshop report can assist the coordination of this practice and the recommendations can provide guidance and motivation for future advances in eel passage.

Table 1: Research Needs

Upstream Passage	Downstream Passage
Determine the fate of eels unable to migrate above a dam	Study attraction to downstream bypass entrances
Evaluate effects of temperature on attraction upstream	Evaluate electrical guidance
Evaluate effects of chemical attractants	Determine effect of *A. crassus* on downstream migrations
Assess eel ability to negotiate "traditional" fishways	Develop methods of monitoring natural populations to determine baseline densities by habitat type and life stages
Identify eel searching behaviors (i.e., lateral movement) at barriers and evaluate effect on upstream migration (also Evaluation Need)	Evaluate passage efficiencies at existing barriers without upstream and downstream passage
Evaluate benefits of below-dam refugia	Develop spill mortality estimates
Study movement of larger eels to and from the estuary	Evaluate existing downstream passage facilities
Evaluate effects of PIT tags and other telemetry tags on eel behavior	Determine bypass entrance specifications (e.g., location, flow, depth, size, shape)
Assess the impact of *Anguillicoloides crassus* introductions to previously "clean" ecosystems	Determine efficacy of passing eels upstream if downstream passage is unknown or poor and evaluate resultant population effects
Identify anticipated changes to aquatic communities from American eel introductions	Determine optimal bar spacing of vertically angled bar racks
Assess ecological effects of eels as a host species for mussels	Identify debris management methods for reduced bar rack spacing
Determine the effect of year class variability (leptocephali, glass eels) and environmental influences on passage numbers and evaluations of passageway efficiencies	Evaluate efficiencies of culverts and tide gates for downstream passage
	Evaluate migratory delays attributed to barriers and the effect of delays on reproductive function/success; Determine how long of a delay will stop migration entirely
	Evaluate effects of trap and transport on behavior, survival, and physiology

Table 2: Technical Information Needs

Upstream Passage	Downstream Passage	General Passage
Develop protocols for siting upstream passes	Develop appropriate techniques for sampling downstream migrants	Develop implementation strategies for upstream and downstream passage
Develop eel passage design matrix with size, style, size of eels requiring passage, ramp flow rate, slope (horizontal and traverse), design of substrate, power supply options, barrier type, watershed characteristics, and cost/maintenance		
Determine attraction flow standards and the effects of attraction flow vs. project and total flows	Develop matrix of passage efficiency for bar rack spacing, angle, and approach velocity (guidance vs. exclusion)	
Identify passage solutions for perched culverts		
Develop and evaluate nontraditional structures/passes		
Evaluate climbing ramp exit design	Complete assessment of state of knowledge for bypass efficiencies	
Develop predator exclusion/control modifications		
Develop guidance on culvert passage design specifically for eel passage (also Research Need)		
Evaluate effectiveness of trap and transport		
Determine effects of release point	Develop and evaluate innovative technologies	
Provide cost and maintenance/personnel estimates		
Identify and evaluate power supply options		
Develop spec sheet for portable trap design		
Develop "Eel Watch" website for live (video) monitoring of passes	Develop fish friendlier turbine designs for eels and generation efficiency consequences	Evaluate holistic passage of all relevant species
Develop ramp and trap box capacity criteria		
Develop guidelines for upstream stocking density estimation	Identify general O&M costs for existing protection technologies	
Develop techniques for PIT tagging		
Monitor distribution of *A. crassus*		
Assemble compilation of US and international regulatory strategies	Develop a database of mortality estimates for various turbine designs and types at existing facilities	
Develop methods to identify and quantify the most essential fish habitat and identify the correct authority for protection		
Standardized survey/density methods and metrics	Determine effect of trap and transport on subsequent migration/settlement	
Develop a matrix of appropriate technologies for large, medium, and small hydro projects & specific site characteristics		

Table 3: Evaluation Needs

Upstream Passage	Downstream Passage
Determine how to estimate true passage efficiency (including attraction)	Validate turbine strike probability models and determine appropriate application to other sites (also Research Need)
Identify the design or target efficiency at a site	Determine appropriateness of desktop analyses (e.g., EPRI database) to site-specific studies
	Develop definitions of mortality (immediate and latent), morbidity, and injury
	Conduct field evaluations of bypass efficiencies

Table 4: Tough Questions

Upstream Passage	Downstream Passage	General Passage
Are out-of-basin transfers of eels appropriate?	What are the effects of hydrokinetic turbines?	How to establish criteria for passage evaluation? Is percent passage sufficient? (also Evaluation Need)
When is a structural eel pass needed and when should eels be allowed to pass an obstruction under existing conditions?	How to define "holistic" measures of passage success (i.e., on an ecosystem scale)?	Is it appropriate to provide upstream passage when downstream passage is poor?
		What are the pros and cons of provision of passage?

Table 5: Passage Research Recommendations - 2012 ASMFC American Eel Stock Assessment

<table>
<tr><th>Research Recommendation</th><th>Time Period</th><th>Priority</th><th>Review Panel Comments</th></tr>
<tr><td>Develop design standards for upstream passage devices for eels; this will be a product (at least partial design guidelines) from the ASMFC 2011 Eel Passage Workshop; i.e., the research need may be partially met in the near term.</td><td>Short term</td><td>High</td><td rowspan="2">These are all high priority recommendations but the Panel would like to emphasize the need to separate upstream and downstream passage. Upstream passage contributes primarily to habitat availability of yellow stage eels while downstream has a more direct and readily measured mortality effect on migrating silver stage eels.</td></tr>
<tr><td>Investigate, develop, and improve technologies for American eel passage upstream and downstream at various barriers for each life stage; in particular, investigate low-cost alternatives to traditional fishway designs for passage of eel.</td><td>Long term</td><td>High</td></tr>
<tr><td>Evaluate the impact, both upstream and downstream, of barriers to eel movement with respect to population and distribution effects; determine relative contribution of historic loss of habitat to potential eel population and reproductive capacity.</td><td>Long term</td><td>High</td><td rowspan="2">As noted above, it may be more effective to focus on upstream passage and the effects on movement and habitat losses of yellow phase eels. Silver eel downstream access is not significantly reduced but rather impacted by factors such as turbine mortality.</td></tr>
<tr><td>Recommend monitoring of upstream and downstream movement at migratory barriers that are efficient at passing eels (e.g., fish ladder/lift counts); data that should be collected include presence/absence, abundance, and biological information; provide standardized protocols for monitoring eels at passage facilities; coordinate compilation of these data; provide guidance on the need and purpose of site-specific monitoring.</td><td>Long term</td><td>Moderate</td></tr>
<tr><td>Monitor non-harvest losses such as impingement, entrainment, spill, and hydropower turbine mortality.</td><td>Short term</td><td>High</td><td rowspan="2">In river systems with hydropower, it is essential to have these data; as it is a substantial source of mortality that must be accounted for.</td></tr>
<tr><td>Evaluate eel impingement and entrainment at facilities with NPDES authorization for large water withdrawals; quantify regional mortality and determine if indices of abundance could be established at specific facilities.</td><td>Long term</td><td>Moderate</td></tr>
</table>

Improve understanding of within-drainage behavior and movement and the exchange between freshwater and estuarine systems.	Long term	Moderate	Allows for better understanding of habitat use and movement between habitats. May also provide needed data for regions where fisheries are either estuarine or freshwater based.
Assess available drainage area over time to account for temporal changes in carrying capacity; develop GIS of major passage barriers.	Long term	Low-moderate	Tracking changes in carrying capacity could also provide an understanding of sex ratio and size and age composition changes.

Appendix A: Bibliography

Web Resources

Atlantic States Marine Fisheries Commission: *American Eel*. http://www.asmfc.org/americanEel.htm

Electric Power Research Institute: *Review and Documentation of Research and Technologies on Passage and Protection of Downstream Migrating Catadromous Eels at Hydroelectric Facilities*. http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001000730

Environment Agency UK: *Eel Passes and Eel Screens - Safe Passage for Eel*. http://www.environment-agency.gov.uk/business/topics/water/146448.aspx

Gulf of Maine Council*: American Eels: Restoring a Vanishing Resource in the Gulf of Maine*. http://www.gulfofmaine.org/2/resources/reports/

USFWS Newsroom: The American Eel. http://www.fws.gov/northeast/newsroom/eels.html

Department of Fisheries and Oceans Canada: The American Eel – A Species at Risk. http://www.dfo-mpo.gc.ca/species-especes/species-especes/eel-anguille-eng.htm

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Appendix B: Workshop Agenda

Wednesday, March 30, 2011

8:00	*Arrivals, Registration, Setup*	
9:00	Welcome and Introductions; Overview of Upstream Eel Migratory Behavior and Pass Design	Steering Committee, Alex Haro
9:15	Presentation: Upstream Eel Passage Structures and Projects in Europe	Antoine Legault
9:50	Presentation: Upstream Eel Passage Structures and Projects in New Zealand	Jacques Boubee
10:30	*Break*	
10:50	Presentation: *Upstream Eel Passage in Inland Massachusetts*	Steve Leach, Don Pugh
11:30	Presentation: *American Eel Restoration in the Susquehanna River Basin*	Ian Park
11:50	*Lunch/Demonstrations*	
12:30	Presentation: *American Eel Passage Improvements in Massachusetts' Coastal Rivers*	Brad Chase
12:50	Presentation: Upstream Eel Passage Structures in the U.S.: Connecticut	Tim Wildman
13:10	Presentation: *State of Maine Upstream Eel Passage: Passage Designs and What We Have Learned*	Skip Zink
13:30	Presentation: *American eel upstream passage on the Roanoke River, North Carolina*	Wilson Laney, Fritz Rhode
13:50	Presentation: Upstream Eel Passage Structures in the U.S.: St. Lawrence River	Ben Lenz
14:10	Presentation: Upstream Eel Passage Structures in the U.S.	TBA
14:30	*Break*	
14:50	Presentation: *Upstream eel passage structures in Québec : eel ladders and fishways use*	Pierre Dumont et al.
15:10	Group Discussion: Development of Guidelines for Upstream Eel Pass Design and Monitoring	Group
17:00	*Adjourn*	

Thursday, March 31, 2011

8:00	*Arrivals, Registration, Setup*	
8:30	Presentation: *Aspects of Eel Downstream Migratory Behavior*	Alex Haro
8:50	Presentation: Overview of Downstream Eel Pass Structure Design	Paul Jacobsen
9:10	Presentation: *Downstream eel passage structures in Québec*	Pierre Dumont et al.
9:30	Presentation: Downstream Eel Passage Structures and Projects in Europe	Antoine Legault
10:10	*Break*	
10:30	Presentation: Downstream Eel Passage Structures and Projects in New Zealand	Jacques Boubee
11:10	Presentation: *Turbine Passage Survival/Injury of European Eels at Hydro-Power Stations in France*	Paul Heisey
11:30	Presentation: *Downstream Eel Passage at Hydropower Projects in New England - an Agency Perspective*	Melissa Grader
11:50	*Lunch/Demonstrations*	
12:30	Presentation: *Infrasound as a silver eel guiding mechanism*	Jean Caumartin et al.
12:50	Presentation: *Hydroacoustics technologies for detection of outmigrating eel*	Brandon Kulik
13:10	Group Discussion: Review of Mitigation Techniques for Eel Downstream Passage and Their Effectiveness	Group
14:10	*Break*	
14:30	Group Discussion: Development of Guidelines for Upstream Eel Pass Design and Monitoring	Group
15:10	Group Discussion: Identification of Data Gaps and Future Research Priorities	Group
15:50	Closing Comments	Steering Committee
16:00	*Adjourn*	

Also presented: **Poster:** *Silver eel migration and mortality associated with five hydroelectric dams on the Shenandoah River*. Sheila Eyler, U.S. Fish and Wildlife Service, Maryland Fishery Resources Office. Sheila_Eyler@fws.gov

Appendix C: Workshop Attendee List

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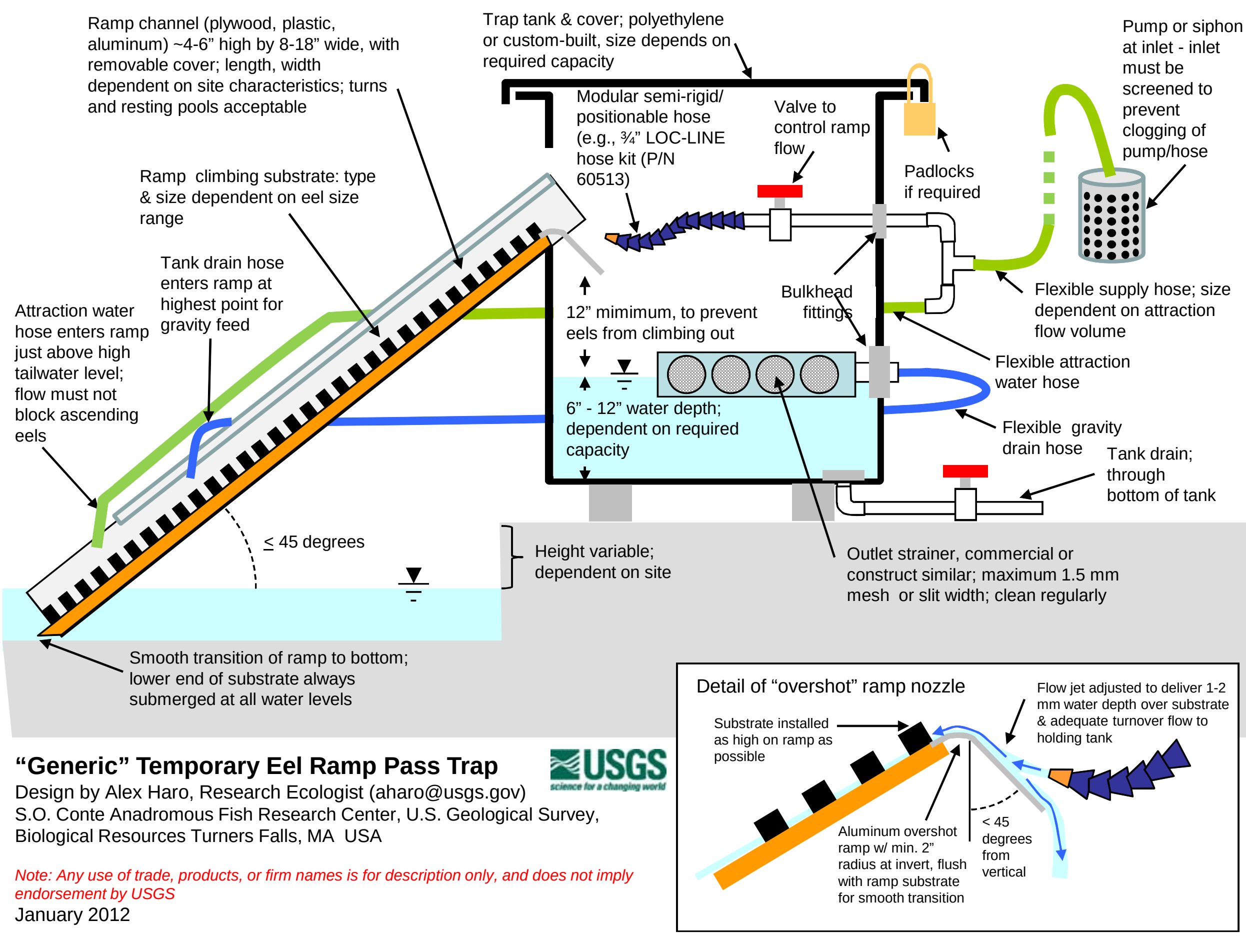
*(2) Proxy for Mike Hendricks

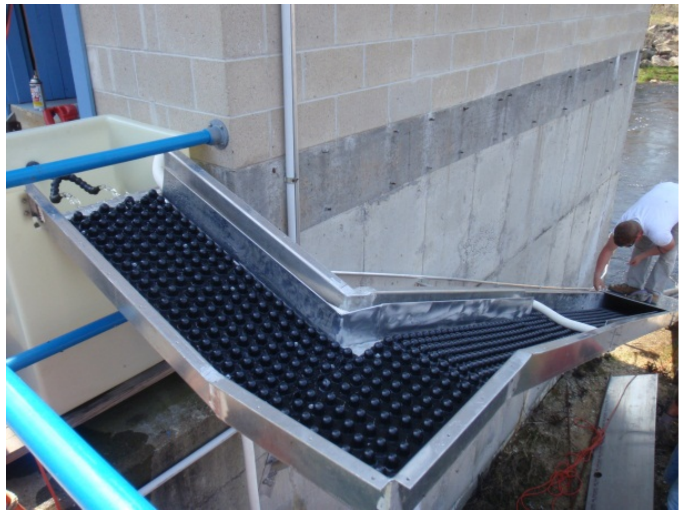
Appendix D: Technical Specifications and Examples (Photographs) of Upstream Eel Passage Devices

D.1 - Generic Eel Ramp Pass Design

This diagram illustrates generalized design aspects of generic upstream eel passage ramp and trap passes used in the northeastern US (A. Haro, USGS, pers. comm.). The simple ramp pass design is used at many sites, both as an experimental or portable temporary pass to identify optimal pass siting and operation, or as a longer-term semi-permanent pass. Some aspects of the design are variable (i.e., attraction flows, substrate type and sizing, source of supply flow, etc.) and largely dependent on site characteristics, but the general design and operation follows this plan.



D.2 - New Home Dam Ramp Trap (Millers River, Orange, Massachusetts)



This semi-permanent ramp pass was constructed in 2010 at a tributary of the Connecticut River, approximately 360 km from the mouth of the Connecticut River.

Type: full-height ramp trap, pumped supply
River Kilometer: 364
Dam Height: 5 m
Ramp Length: 14 m
Substrate: molded ABS (FishPass); vertical brush
Trap flow: approximately 10 l/min
Ramp flow: approximately 10 l/min
Attraction flow: approximately 100 l/min
Flow source/Power: 190 l/min submersible pump/110 VAC
Trap: polyethylene box; approximately 150 l water volume

Dam Status: Run-of-river mill dam converted to hydropower; continual spill and significant leakage from dam.

Performance: Design follows that of the USGS Generic Ramp Pass Design. Eels at this site are generally larger than 150 mm; the ABS substrate was initially chosen to accommodate these larger eels, but later replaced with vertical brush. No eels have been passed at this site; low eel density and difficulty in locating ramp entrance due to poor siting and significant "distraction" spill are thought to be factors.

Installation/Contact: Alex Haro, U. S. Geological Survey

D.3 - Maine DMR Portable Ramp Trap (various locations)

This "portable trap" was designed by the Maine Department of Marine Resources in the 1990s primarily to intercept small elvers and glass eels at small- to modest-sized coastal dams, and as a tool to explore possible locations for future permanent passes. Construction is usually of wood, but follows the generic ramp pass design; it is lightweight and portable, allowing placement at multiple sites. Attraction flow is via a small pump or siphon from the headpond. The pass is somewhat "sacrificial"; if damaged or blown out by high flows, it can usually be repaired or replaced at modest cost.

Type: partial height ramp trap, pumped or gravity supply
Dam Height: variable
Ramp Length: variable; usually < 3 m
Substrate: variable; usually Enkamat®
Trap flow: approximately 1-2 l/min
Ramp flow: approximately 1-2 l/min
Attraction flow: variable; usually ~10 l/min
Flow source/Power: submersible pump, siphon, or gravity
Trap: plastic bucket, cooler or other enclosure; usually 5-20 l water volume

Performance: A variety of substrates may be used; this trap has the capacity to pass glass eels. Low volume of the trap box necessitates frequent inspection and emptying to prevent overcrowding of eels.

Installation/Contact: Gail Wippelhauser, Maine Department of Marine Fisheries

D.4 - Webber Pond Box Trap (Seven Mile Brook, Augusta, Maine)

This is another portable/temporary trap developed by the Maine Department of Marine Resources for small, specialized sites where space is restricted, but the box can be protected from flows and tailwater levels. It is designed primarily for small elvers and glass eels. Construction consists of a sealed plastic box which receives flow from a hose (gravity supply), which is directed to the top of the climbing pipe. The box fills with water to the level of a screened overflow outlet. Eels enter via the climbing pipe, which is lined with plastic bird netting, and climb up the pipe and drop into the box. Eels are prevented from climbing back down the pipe from the box via a specialized collar around the top of the climbing pipe.

This design can only be employed at specialized sites where eels can climb to the level of the box, although the climbing pipe could be extended to a lower elevation. The box and all associated hardware need to be completely sealed to prevent escape of eels, and the outlet screen needs to be kept free of debris to prevent overflow. As designed, the trap has no supplemental attraction flow, which can be added.

Type: Partial height ramp trap, gravity supply
River Kilometer: 45
Dam Height: 1.5 m
Ramp Length: < 1 m
Substrate: bird netting
Trap flow: approximately 1-2 l/min
Ramp flow: approximately 1-2 l/min
Attraction flow: none; can be added
Flow source/Power: 2-3 l/min; gravity or submersible pump
Trap: polyethylene or other plastic box; volume variable; usually 50-75 l

Dam Status: Low-head non-hydro dam with stoplogged spill bays.

Performance: This trap works well in flashy water flows. It caught 1,237 eels (4,879.4 grams) ranging from 9 to 15 cm TL between July 12 and August 24. The trap box should be checked frequently to avoid overcrowding.

Installation/Contact: Gail Wippelhauser, Maine Department of Marine Fisheries

D.5 - Mary Steube Dam Bucket Trap (Mill Brook, Old Lyme, Connecticut)

This is a variant of the Webber Pond box trap. The ramp is constructed from 1.5 inch schedule 40 PVC pipe lined with Enkamat®. The entrance of the ramp is a horizontal section of pipe with a ¼" gap to allow the substrate to hang vertically down to the mill race, attached to wooden weir boards. The ramp exit is located in the center of the trap and also serves to control water level. Eels are able to exit (escape from) the trap downstream via the pipe and therefore this eel pass needs to be checked each morning. This eel pass is located close to the head-of-tide and is appropriate for YOY and elvers < 100 mm in length.

Type: partial-height ramp trap, pumped supply
River Kilometer: 5
Dam Height: 2.5 m
Ramp Length: 1.5 m (PVC pipe)
Substrate: Enkamat®
Trap flow: approximately 1-2 l/min
Ramp flow: approximately 1-2 l/min
Attraction flow: none; can be added
Flow source/Power: 2-3 l/min; gravity or submersible pump
Trap: plastic bucket; volume variable; usually 5-8 l

Dam Status: Out of service mill dam with continual spill located adjacent to eel pass. Not considered a census as eel can scale roughened rock spillway.

Performance: 30 to 40 thousand eels passed during April-July for 2009-2012. Mixed age-1+ and YOY.

Installation/Contact: Tributary Mill Conservancy, Old Lyme, Connecticut

D.6 - Saugus River Ramp Trap (Saugus River, Massachusetts)

Type: full height ramp trap, pumped supply
River Kilometer: 15
Dam Height: 2.1 m
Ramp Length: 3 m
Substrate: Enkamat®
Trap flow: approximately 1-2 l/min
Ramp flow: approximately 1-2 l/min
Attraction flow: approximately 100 l/min
Flow source/Power: 190 l/min; 110 VAC submersible pump
Trap: 450 l polyethylene box; water volume approximately 100 l

Dam Status: The eel trap records a census of eel passage as flow over the dam crest is rare due to a bottom opening sluice gate in the dam.

Performance: 6 to 12 thousand eels passed during April-July for 2007-2012. All age-1+ juvenile eels with a few YOY exceptions.

Installation/Contact: Brad Chase, Massachusetts Division of Marine Fisheries

D.7 - Pilgrim Lake, Gravity Fed Floating Trap (Orleans, Massachusetts)

Type: full height ramp trap, gravity supply
River Kilometer: 1
Dam Height: 0.5 m
Ramp Length: 2 m (PVC pipe)
Substrate: Enkamat®
Trap flow: approximately 1-2 l/min
Ramp flow: approximately 1-2 l/min
Attraction flow: none; can be added
Flow source/Power: 2-3 l/min; gravity
Trap: floating plastic bucket; volume variable; usually 5-8 l

Dam Status: A board controlled sluice maintains the headpond elevation. The eel pass pipe runs through the lower board.

Performance: Approximately 40 thousand YOY eels passed during April-July in both 2011 and 2012. Site selected as pilot for new gravity fed design for low-head dams.

Installation/Contact: Brad Chase, Massachusetts Division of Marine Fisheries

D.8 - Grass Pond, Ramp Trap (Harwich, Massachusetts)

Type: full height ramp trap, pumped supply
River Kilometer: 0 (head of tide)
Dam Height: 1.5 m
Ramp Length: 5 m plywood, later replaced with sheet aluminum in 2009
Substrate: Enkamat®
Trap flow: approximately 1-2 l/min
Ramp flow: approximately 1-2 l/min
Attraction flow: approximately 20 l/min
Flow source/Power: 23 l/min; 12VDC Rule bilge pump; powered by battery/solar panel
Trap: plastic trash bin (replaced with custom 3/8 in sheet aluminum box in 2009; water volume approximately 5-8 l

Dam Status: The dam is a cranberry bog water control. The tank records a census of eel passage as eels cannot scale the vertical steel flume wall.

Ramp Performance: 5 to 10 thousand eels passed during April-July for 2008-2012 except >25 thousand in 2009. Mixed age-1+ and YOY.

Installation/Contact: Brad Chase, Massachusetts Division of Marine Fisheries

D.9 - Amoskeag Dam Ramp Trap (Amoskeag Dam, Merrimack River, New Hampshire)

This pass is a traditional ramp pass but is more highly engineered than most; it is constructed as a permanent pass. The midsection of the ramp has an articulating joint, and is constructed to allow the lower end of the ramp to be hoisted out of the tailwater below the dam under high flow conditions. The pass is strategically sited at the foot of the dam in an area where eels naturally congregate. Attraction flow is supplied from a pump in an adjacent power canal. Vandalism at this site requires extra security measures (e.g., locked trap box).

Type: full height ramp trap, pumped supply
River Kilometer: 118
Dam Height: 8.8 m
Ramp Length: 14.3 m
Substrate: Akwadrain® and 3.8 cm diameter PVC pegs
Trap flow: 4-8 l/min
Ramp flow: 20-40 l/min
Attraction flow: 190 l/min
Flow source/Power: 225 l/min; 1/2 hp, 120 VAC, 10 A well pump
Trap: polyethylene box; water volume approximately 560 l

Dam Status: Large mainstem hydropower dam; minimum spill flows in spillway reach to provide attraction of eels to the base of the pass.

Ramp Performance: Operational only since 2013; passed 123 eels of varying sizes; improvements planned for entrance geometry and attraction flow.

Installation/Contact: Curt Mooney, Public Service of New Hampshire/Northeast Utilities, Manchester, New Hampshire

D.10 - Eel Lift (Greeneville Dam, Shetucket River, Norwich, CT)

This is a custom-built trap box with two entry ramps that is modified as a lift, as it is attached to a 1-ton electric hoist and vertical guide rails anchored to a vertical concrete wall of an existing fish lift structure. Although the dam is not high, high tailwater levels and damaging flows exist at this location during flood events; a previous flood event destroyed a traditional partial ramp trap at this site. The lift is hoisted to an upper walkway for emptying/inspection, or during high water events. The trap box is removed from the site and stored during winter months.

Type: full-height lift with ramp trap, pumped supply
River Kilometer: 3.2
Dam Height: 10 m
Ramp Length: 1.5 m
Substrate: ½ Enkamat®; ½ Akwadrain®
Trap flow: 3 l/min
Ramp flow: 5 l/min (2.5 l/min each ramp)
Attraction flow: approximately 200 l/min
Flow source/Power: 230 l/min submersible pump; 110 VAC
Trap: polyethylene box; water volume approximately. 400 l

Dam Status: Moderate-sized hydropower dam; spill flows over dam provide attraction of eels to the base of the pass. Numbers of eels counted are not considered a census as eels are able to scale dam via spillway.

Ramp Performance: 1,500 eels passed May-July 2012; mixed ages.

Installation/Contact: Tim Wildman, Connecticut Department of Energy and Environmental Protection, Inland Fisheries Division, Old Lyme, Connecticut

D.11 – Passive Climbing Structure: “Delaware-type” Pass (Leesville Dam, Salmon River, Leesville, Connecticut)

The eel pass at Leesville Dam consists of simple nylon trawl netting (approximately 7.5 cm bar mesh) draped over existing ledge and formed concrete dam crest that is wetted from leakage and that eels typically attempt to climb. Eels have the most difficulty ascending at the vertical face of the concrete dam crest; the draped netting assists eels in climbing this portion. The netting is stuffed into a 10 cm diameter PVC pipe tube inserted into flashboards at the dam crest, near the end of the flashboards where water from the overflow section provides additional attraction. Eels can pass through the pipe lined with netting and can exit either directly into the headpond or into a trap structure (mesh-lined box) that can be placed on the upstream side of the pipe. Flow through the pipe is dependent on headpond level, which typically varies very little (note that center of pipe is located at about mean headpond level). Debris can accumulate inside the pipe, making it impassable or nonfunctional (no water flow), so the structure needs to be checked frequently.

Type: full-height pass, gravity supply
River Kilometer: 1.1
Dam Height: 4 m
Ramp Length: approximately 4 m
Substrate: nylon trawl netting
Trap flow: n/a
Ramp flow: approximately 10 l/min
Attraction flow: none; pipe in flashboards provides all flow (approximately 10 l/min)
Flow source/Power: gravity, from headpond
Trap: optional mesh-lined box

Dam Status: Small, low-head non-hydropower dam; equipped with Denil fishway. Eels naturally congregate at the location of the pass, attracted to spill flow over the semi-climbable rock ledge.

Ramp Performance: Passes about 5,000 eels per year; average size approximately 120mm TL.

Installation/Contact: Tim Wildman, Connecticut Department of Energy and Environmental Protection, Inland Fisheries Division, Old Lyme, Connecticut

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