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MEMORANDUM

Diadromous Fish Passage Guidelines

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Purpose. The Massachusetts Division of Marine Fisheries (DMF) Diadromous Fish Project and Habitat Program have independent roles in commenting on projects that could impact diadromous fish migrations and habitats. The Diadromous Fish Project has a direct regulatory role based on state fish passage statutes and the Habitat Program makes recommendations to regulatory agencies within the context of permitting under the Wetlands Protection Act, Clean Water Act, and other processes. However, a common interest under DMF's overall mission to protect marine resources requires coordination on fish passage project review. This framework was discussed at a January 23, 2020 meeting with the Diadromous Fish Project and Habitat Program. The goal is to integrate DMF's environmental permit review with diadromous fish management and species life history requirements. To assist this goal, this memorandum was prepared to give guidance to present and future DMF staff for evaluating environmental permit applications involving passageways for diadromous fish.

Background. Until recently, there was sparse documentation on design guidelines for diadromous fish passageways. The DMF has been the primary regulatory authority for diadromous fish passage and population management in Massachusetts coastal rivers since the 1930s and has accumulated much experience in this field since then. However, this has been conveyed mainly as institutional knowledge with few written policies or guidelines that relate species life history to physical passageways. Two recent Federal resource agency publications provide the best available summaries on this topic (Turek et al. 2016; and USFWS 2019). Diadromous Fish project staff should be familiar with the two reports. The criteria in these reports will be the basis for DMF's guidelines and the standards that all fish passage projects should strive for. It is important to note, that while the Federal guidelines used the best available science to set design criteria for fish passage, for some species and criteria, information is incomplete and professional judgement is necessary. Secondly, streamflow in many Massachusetts coastal rivers is modified and limited, resulting in conditions that will not meet the optimized passage thresholds. Finally, given DMF's diadromous fish management authority, case-by-case conditions may cause DMF to make recommendations or legal determinations that differ from the Federal guidelines.

Both Federal fish passage guidelines discuss the importance of providing *Safe*, *Timely* and *Effective* passage through a *Zone of Passage*. These terms are defined in the Federal guidelines and have a basis within Federal statutes. The terms are generally qualitative, although it is a goal to develop quantified *Performance Standards* that will become thresholds or measures of success for passageways. DMF has long supported these principals and will endeavor to use this language and approach in our evaluation of fish passage projects.

The following are physical standards that rely heavily on the Federal guidelines but are customized to account for typical conditions in Massachusetts where fish runs can be challenged with low discharge and cases where technical data on hydraulic and hydrologic conditions may be lacking. These are not regulatory standards, but guidelines to assist DMF technical review of fish passage projects and related permits. The guidelines can become regulatory requirements for specific projects if declared in a written determination or in a DMF Fishway Construction Permit from the DMF Director citing MGL c. 130, §19.

A large majority of fish passage projects in Massachusetts focus on river herring. The five species that most often require passage and management considerations are river herring (alewife and blueback herring), American shad, American eel and rainbow smelt. Relatively few shad spawning runs occur in Massachusetts: for shad projects the Federal guidelines should be followed directly. The following guidelines will focus on river herring requirements, with comments where appropriate for smelt and eel.

Physical Standards

It should be recognized that fishway type and river discharge will influence the relationship between fish passage performance and the above thresholds. DMF's guidelines below are focused on river herring passage during the spring migration in stream channels, and structural and nature-like pool and weir fishways. Generally, these guidelines are directed to small, fishways in flow-limited watersheds (migratory season mean discharge < 20 cfs), although they can apply to any weir-based structures in larger watersheds. Larger designs such as Alaskan Steeppass or Denil fishways should directly follow the Federal guidelines and always be derived from site specific hydrologic and hydraulic analyses.

Fishway Pool Depth. The Federal recommendation for minimum pool depth = 1 ft + 4*body depth (BD) of target species. Pool depth can be independent of river discharge. For this reason, all new fishway construction should use the Federal threshold and rely on calculations of Energy Dissipation Factor (EDF). For fishway reconstruction in small watersheds with physical limitations, a minimum pool depth of 2 ft should be evaluated. The DMF Fishway Operation and Maintenance Plan for each fishway should include direction on maintaining pool depth.

Fishway Elevation Change. Diadromous fish generally favor elevation changes at fishway weirs with low turbulence and air entrainment, and vertical transitions of < 1 ft. DMF has long used a target elevation change between fishway weirs of 6". This can be modified based on pool length and depth.

Fishway Weir Velocity. Haro et al. (2004) recommended 1.0 m/s as the upper limit for channel restrictions. Turek et al. (2016) recommended 6 ft/s (1.8 m/s) as the maximum weir opening velocity for river herring. In practice we view 1.0 m/s as the upper end of rainbow smelt swimming ability through restricted passageways, and 2.0 m/s as a similar metric for river herring. Depending on slope and characteristics of the run leading up to the restriction, smelt and herring may be able to pass higher velocities. However, 1-2 m/s is a suitable range to consider based on species presence.

Fishway Weir Width. The Federal recommendation for Fishway Weir Width = 2 * maximum total length (TL). This won't be practical for rivers with low discharge. Hydrologic and hydraulic analyses should be used to size weir width when available. Otherwise, DMF recommends a minimum of 6" surface notches for flow-limited watersheds and to prevent excessive drawdown of impoundments.

Fishway Weir Depth. The Federal recommendation for Fishway Weir Depth = 3* BD of largest species. This should be the optimal target; however, by necessity, DMF targets a minimum of 6" in flow-limited watersheds and to prevent excessive drawdown of impoundments. Submergence depth (difference in elevation from pool water surface to upstream weir notch) is a critical factor related to weir depth. In all cases, there should be some level of positive submergence at the weir notch and designs should not allow the lack of submergence.

Channel Depth. The Federal recommendation for channel depth = 2 x BD of target species. For river herring, this is similar to the 6" minimum channel depth long used by DMF for spring migrations.

Channel Slope. Determining channel slope for species is a highly quantified process requiring measures for channel geometry, substrate friction and species swimming performance. For nature-like fishways, Turek et al. (2016) recommended a maximum 1:20 (5%) slope for river herring and 1:30 (3.3%) for shad and smelt. In practice, DMF has found that these maximum slopes can impede passage, especially under straight "raceway" conditions. Therefore, DMF recommends a maximum 3% slope for river herring and 1% or less for smelt for channels and nature-like fishways with no weirs to grade elevation changes.

Channel/Culvert Velocity. Channel restrictions and culverts in river herring runs should be designed to not exceed 1.0 m/s (for flows > 5% exceedance). To the extent practical and feasible, culvert replacements in coastal rivers should adopt the Massachusetts Stream Crossing Guidelines.

Culvert Slope. A near zero or slightly positive slope is preferred. To the extent practical and feasible, culvert replacements in coastal rivers should adopt the Massachusetts Stream Crossing Guidelines.

American Eel. Prolonged swimming speeds of juvenile American eel (age-0 and age-1) has been estimated at 0.25 m/s with burst speeds of 0.40 m/s (Barbin and Krueger 1994). This life stage of eel may be limited by the above fishway weir conditions. When these weir conditions are unavoidable, alternative means will be needed for juvenile eel passage: increased channel roughness, low-flow channel dimensions, or eel ramps.

Rainbow Smelt. The swimming performance of rainbow smelt has not been investigated. Field observations at smelt spawning habitat indicate that most egg deposition occurs in water velocity of 0.3 to 0.8 m/s with velocity barriers potentially occurring at in the range of 1.0 to 1.2 m/s (Chase 2006). Combining water velocity of 1.0 m/s with a 1% slope may limit smelt passage. Refer to Chase (2006) for locations of smelt spawning habitat in coastal rivers north of Cape Cod. Improvements to smelt spawning habitat are possible by including channel daylighting, low-flow channels, low-slope riffles (0.5%), and adding 3-6" native cracked stone to substrate to enhance smelt spawning habitat.

Fish Passage Design Guidelines

Passage Parameter	Interagency	USFWS	MA DMF
Fishway Pool Depth	1 ft + 4 x max. BD		min. 2 ft
Fishway Weir Width	2 x max. TL		min. 6 in
Fishway Weir Depth	3 x max. BD	2 x max. BD	min. 6 in
Fishway Weir Velocity (herring)	Vmax = 6 ft/s		2 m/s (6.56 ft/s)
Fishway Weir Velocity (smelt)	Vmax = 3.25 ft/s		1 m/s (3.28 ft/s)
Fishway Elevation Change		1 ft	6 in
Channel Depth (all species)		2 x max. BD	min. 6 in
Channel Slope (herring)	5% max.		3% max.
Channel Slope (smelt)	3.3% max.		1% max.
Culvert Slope (all species)			0%
Energy Dissipation Factor (EDF)		max. 4.0 ft-lb/s/ft^3	

Notes

Interagency: Turek et al. (2016) **USFWS:** USFWS (2019)

Vmax: Vmax is calculated from sprint swimming data for each species. If no data are available, use Umax = 5 x TL for each species.Turek et al. (2016) applies Vmax and Umax to each species.

EDF: EDF is a measure of the volumetric power dissipation in a fishway or stream reach.

Citations

Barbin, G.P., and W.H. Krueger. 1994. Behavior and swimming performance of elvers of the American eel, *Anguilla rostrata*, in an experimental flume. J. Fish Bio. 45: 111-121.

Castro-Santos, T. 2004. Quantifying the combined effects of attempt rate and swimming capacity on passage through velocity barriers. Can. J. Fish. Aquat. Sci. 61: 1602-1615.

Castros-Santos, T. 2005. Optimal swim speeds for traversing velocity barriers: an analysis of volitional high-speed swimming behavior of migratory fishes. J. Exp. Bio. 208: 421-432.

Chase, B.C. 2006. Rainbow smelt (*Osmerus mordax*) spawning habitat on the Gulf of Maine coast of Massachusetts. Mass. Div. Mar. Fish. Tech. Rep. TR-30.

Haro, A., T. Castro-Santos, J. Norelka, and M. Odeh. 2004. Swimming performance of upstream migrant fishes in open-channel flow: a new approach to predicting passage through velocity barriers. Can. J. Fish. Aquat. Sci. 61: 1590-1601.

Turek, J., A. Haro, and B. Towler. 2016. Federal Interagency Nature-Like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fish. Interagency Technical Memorandum. 47 pp.
USFWS (U.S. Fish and Wildlife Service). 2017. Fish Passage Engineering Design Criteria. USFWS, Northeast Region R5, Hadley, Massachusetts.

USFWS (U.S. Fish and Wildlife Service). 2019. Fish Passage Engineering Design Criteria. USFWS, Northeast Region R5, Hadley, Massachusetts.