The Maine Tidal Restriction Database

A desktop assessment of tidal restrictions in Maine to facilitate community resilience and habitat restoration

July 2020

Maine Coastal Program
Maine Department of Marine Resources

Authors:
Ellen Bartow-Gillies
Slade Moore
Claire Enterline

Contents

Acknowledgements

The Maine Tidal Restriction Database was prepared by Maine Coastal Program with help from many partners. We would like to extend our gratitude to the organizations and individuals listed in Appendix A that contributed to the project. Special thanks to Alex Abbott and William Bennett with USFWS Gulf of Maine Coastal Program, Matthew Craig with Casco Bay Estuary Partnership, and Charles Hebson with Maine Department of Transportation.

I. Introduction

Roads, dams, and other structures crossing through estuaries often restrict tidal flow. Sufficiently restrictive conditions can alter and impair the physical, chemical, and biological conditions necessary for these systems to persist and thrive. For example, tidal restrictions that reduce sediment deposition can impact a marsh's ability to keep pace with sea level rise and sustain the structure and function of ecological communities. Knowing the locations and condition of tidal restrictions provides an opportunity to reverse or alleviate these impacts and is a key element in efforts to apply the most effective allocation of restoration resources to affected sites.

Several sources of data are available to provide the locations of road crossings and dams in Maine or to assess the impact of known tidal restrictions. These include Conservation Law Foundation's (CLF) Return the Tides (RTT) project (Bonebakker et al. 1999); the statewide crossing database maintained by the United States Fish and Wildlife Service's (USFWS) Gulf of Maine Coastal Program; and regional projects commissioned or executed by Maine Department of Transportation (Army Corps of Engineers 2004), Maine Coastal Program (Northern Ecological Associates 2005*a*), Casco Bay Estuary Partnership (Northern Ecological Associates 2005*b*; Bohlen et al. 2012), and several unreported efforts. Of these, RTT was the sole product developed specifically to identify tidal restrictions throughout all of Maine's coast.

In 2014, Maine Coastal Program (MCP) began exploring the feasibility of providing a tidal restriction database that would reflect current conditions, sea level rise considerations, and knowledge gained since RTT was initiated over 20 years ago. The database would be a resource for communities, restoration practitioners, land trusts, and others to sequence crossing replacements, screen potential wetland restoration projects, and integrate sea level rise into infrastructure planning. After convening several meetings to discuss the needs and preferences of our statewide group of project partners, we set out to develop a desktop assessment method allowing rapid identification of tidal restrictions along Maine's coast by using readily available data. That method is described in this document.

II. The Tidal Crossing Database

A. Estimating Tidal Extent

After identifying all crossing data sources available, the next step in creating an updated tidal restriction database was to define the landward extent of Maine's intertidal zone. MCP used the Highest Astronomical Tide (HAT) line from Maine Geological Survey (MGS) as a starting point to finding crossings in intertidal areas (Slovinsky et al. 2018). MGS created HAT inundation and sea level rise (SLR) data for Maine using highest observed tide data and predictions from the NOAA Center for Operational Oceanographic Products and Services (CO-OPS). Using a Python-based tool, MGS adjusted HAT predictions from NOAA CO-OPs tidal stations in Maine using NOAA's VDATUM tool, which converts mean lower low water (MLLW) tidal prediction elevations to NAVD88 elevations. MGS also incorporated bare-earth lidar digital elevation models of Maine's coastal zone areas that were collected in 2006, 2010, and 2011. This work resulted in the State of Maine HAT and SLR layers that we used in the database.

We found that for the purposes of this project, relying on HAT alone was not sufficient. In many instances, the GIS-based HAT line did not extend over wider roads and trails (Figure 1). To solve this issue, MCP experimented with elevation data to create a vertical buffer around HAT. Inconsistencies in the resolution of elevation data along Maine's coast prevented the success of that effort.

MCP then explored horizontal buffer options using the 2018 MGS HAT layer. A 10-meter buffer was too small for the width of larger roads (Figure 2). A 40-meter buffer was too large, clearly including nontidal areas. We ultimately concluded that a 20-meter horizontal buffer beyond the HAT line (Figure 3) adequately addressed different road widths.

Figure 1. Highest Astronomical Tide (blue) from 2018 MGS release without any horizontal buffer in Trescott Township, Maine. Culvert (red circle) is not covered by HAT polygons.

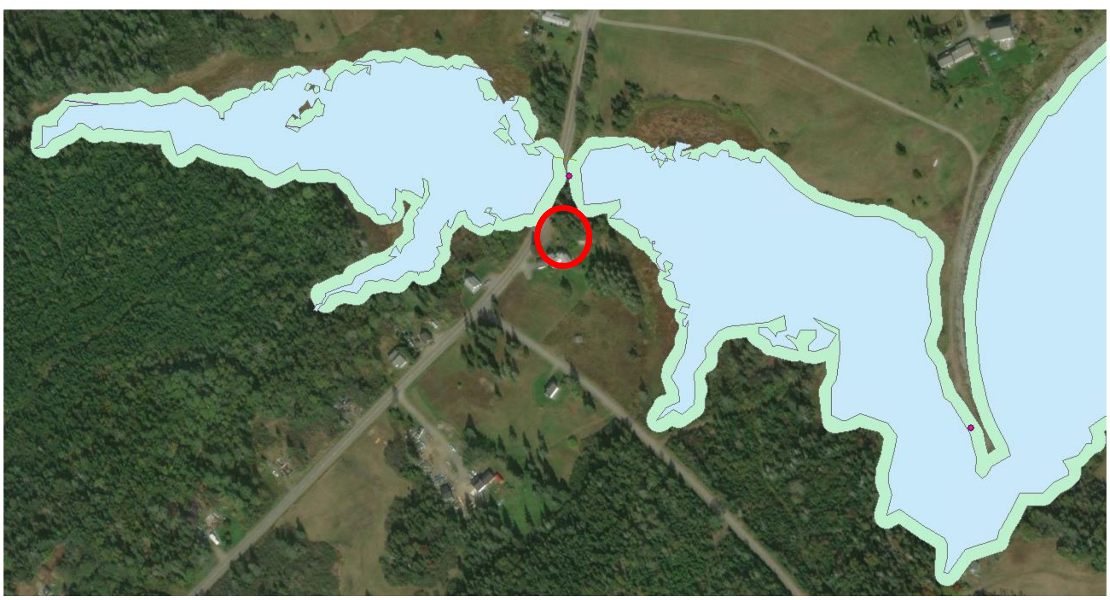

Figure 2. Highest Astronomical Tide (blue) from 2018 MGS release with a 10m horizontal buffer (green) in Trescott Township, Maine. Culvert (red circle) is minimally covered by the 10m HAT buffer.

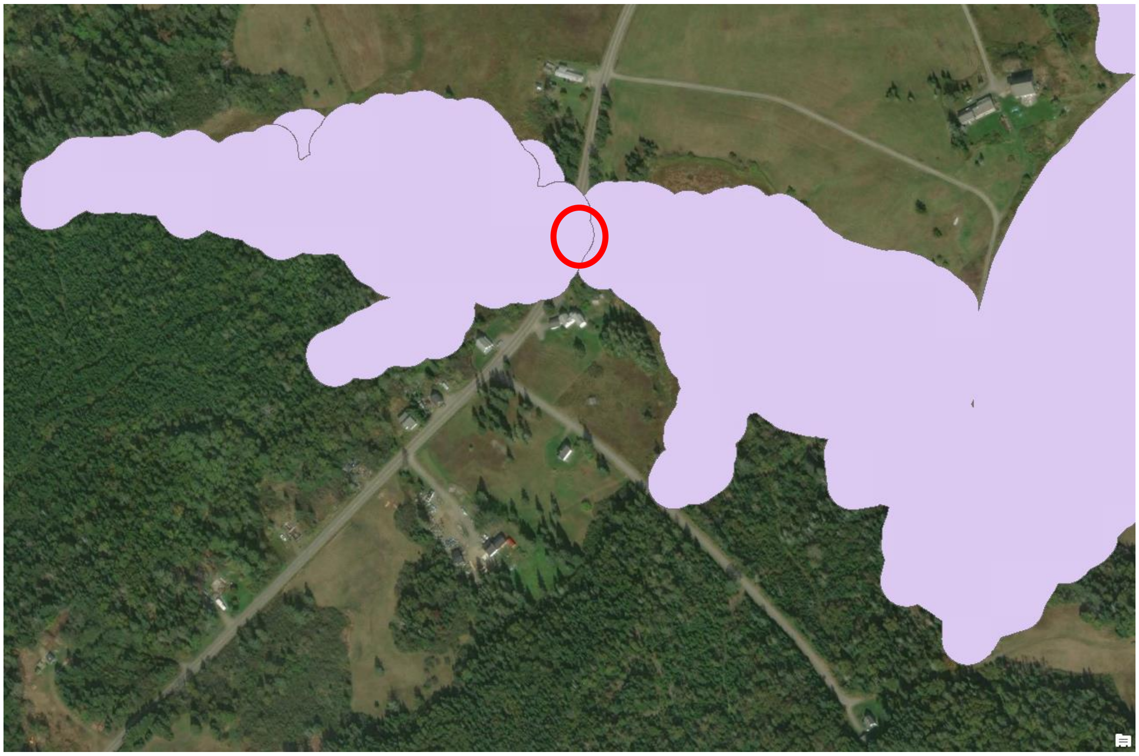

Figure 3. A 20m horizontal buffer (pink) from the Highest Astronomical Tide 2018 MGS release in Trescott Township, Maine. Culvert is clearly covered by the 20m HAT buffer.

B. Merging Existing Data and Adding to the Dataset

To create MCP's tidal restriction database, we began with three versions of the Return the Tides (RTT) dataset, US Fish and Wildlife's (USFWS) Maine crossing survey dataset, Maine Department of Transportation's (DOT) crossing structural condition survey dataset, and USFWS's enhanced dams dataset. The method of determining tidal extent from Section I above was used on each contributing dataset to identify crossings in the tidal zone.

RTT is a dataset of tidal restrictions created in 1999 by CLF. Hardcopy data from RTT is housed at MCP offices in the Boothbay Harbor Department of Marine Resources Lab. Over several years, three iterations of this dataset were created, with 144, 1084, and 1197 records, respectively. Many of the same sites appear in all three records. Each overlapping data field (e.g. structure type, acreage upstream, location) has the same value in each RTT version. We compiled and merged the databases and deleted redundant fields. We also added a column in the compiled file to identify the dataset/s to which each record corresponds. Occasionally, crossings in the RTT dataset would appear where no structure was apparent. We used topographic maps, USGS historic maps, orthoimagery, and Google Earth to locate as many structures as possible. Our revised RTT database has 976 records, with 710 records falling within the 20m HAT tidal buffer.

The USFWS road crossing survey dataset identified 160 of the 21,450 records as "tidal." When we applied the 20m HAT buffer to the USFWS surveyed crossings the number of tidal sites increased to 506. We also incorporated the Enhanced Dams shapefile from USFWS. Using the 20m HAT tidal buffer zone, we identified 57 of the 942 dams as tidal.

The Maine DOT dataset has survey data for 10,305 bridges and culverts throughout the state of Maine. There is no field to represent the presence of tidal conditions. Using the 20m HAT buffer, we identified 473 tidal crossings.

To identify other potential tidal crossings not contained within existing datasets, MCP created five new point feature classes where different roads layers intersect flowlines from the National Hydrography Dataset (NHD). The road layers include (1) OSMap; (2) DEProads; (3) MEDOT pubroads; (4) E911Roads; and (5) RailRoutes. These are not limited to the coast, so we applied the same 20m buffer from the 2018 HAT to identify which road-stream crossings were tidal. This method was used to add 28 previously unidentified tidal crossings after a manual, systematic scan to ensure accuracy of results in GIS.

Records from these different data sources were joined in a GIS merge on the basis of location. Overlapping crossings from different sources were combined into one comprehensive record. For each point, the entirety of the data from each source was carried over to the compiled database. A field was added to the database to denote the source(s) of the point.

<u>Data Sources for Road Crossings</u>

We compiled all crossing data sources listed below in Table 1 to create a database with 468 fields. MCP maintains a master database that includes all fields from all source data for each point. However, there was a need to pare-down the number of fields to only those providing the most actionable information. Based on conversations with the various data custodians and internal MCP discussions, we assessed the extent to which each field provided reliable information on crossing size, condition, or restriction status. Comment fields from each data source were generally carried through as they were found to sometimes provide useful information not adequately captured in existing fields.

Table 1. Data sources merged and included in the tidal crossing database.

Data Source	Description
USFWS Gulf of Maine Coastal Program Crossing Survey Database	From roughly 2007-2020, organizations worked with USFWS to inventory road crossings over perennial streams throughout Maine to identify barriers to aquatic organisms.
CLF Return the Tides (RTT)	In 1999, CLF used volunteer field surveys to create the RTT database documenting tidal restrictions in Casco Bay. Several organizations developed subsequent versions of the database and restriction assessments through 2004.
Maine DOT Large Culverts, Bridges, and Cross Culverts	Maine DOT conducted surveys to inventory the condition of road crossings they owned and maintained.
Enhanced Dams	The USFWS and partners inventoried and surveyed dam condition and aquatic organism barrier status.
MCP Crossing Intersects	The MCP GIS layer identified current and future locations of crossings over tidal waters to facilitate desktop restriction assessments using newly developed criteria.

C. Identifying Crossings with Tidal Marsh Upstream

MCP and its partners have a particular interest in opportunities for tidal marsh conservation, restoration, and long-term resilience. Consequently, we attempted to add value to the Tidal Restriction Database by calling attention to crossings potentially influencing marshes. The mapped marsh data used in the database include the Maine Natural Areas Program (MNAP) tidal marsh polygon shapefile and the National Wetlands Inventory (NWI) coded wetland polygons.

Identifying and Merging Mapped Marsh Data

The MNAP salt and brackish marsh mapping layer has the advantage of field verification but does not include most tidal marshes less than 5 acres in area. Using the steps below, we incorporated the full NWI dataset to identify and map tidal wetland polygons falling below MNAP's minimum area threshold and to arrive at an updated calculation for total tidal marsh area in Maine:

1. For the first layer, we selected all "salt or brackish" habitat type polygons from MNAP's tidal marsh layer. This layer represents 18,096 acres of salt or brackish marsh. It does not include solitary marshes smaller than 5 acres.

2. We then selected from the NWI database all marsh polygons with the E2EM code, which denotes an estuarine intertidal wetland system with emergent vegetation. This layer yielded 19,140 acres of salt marsh.
3. A third version of salt and brackish marsh acreage was created by merging the MNAP and NWI layers listed above. Boundaries between the two layers were dissolved, and overlaps removed. This merged layer yielded 22,823 acres, which we calculated by subtracting 13,456 overlapping acres from the 36,280 total combined acres.

All marsh polygons designated as "freshwater tidal" habitat from MNAP's tidal marsh layer were selected to create the first version of a tidal freshwater marsh layer. From these, we selected polygons containing NWI codes REM, PEM, and LEM with hydrology modifiers Q, R, S, T, and V. These denoted riverine, palustrine, and lacustrine communities supporting emergent vegetation subject to tidal influence, were selected from NWI database for a second freshwater tidal marsh layer.

Determining the Presence and Type of Upstream Marsh

Rapid screening of key attributes can assist in determining the sequence of action among potential tidal restriction sites. We added the field "Presence of Upstream Marsh" to specify if any tidal marsh, either freshwater tidal or salt or brackish, is present upstream of each tidal crossing.

A first query was completed by locating all tidal crossings within a 50m radius of salt marsh using MNAP and NWI wetland data. We then conducted a manual analysis using satellite imagery to verify those results and to identify crossings at the upstream extent of marshes with no marsh upstream, signifying that the crossing was impacting upstream tidal hydrology. Another query involved locating all tidal crossings within a 50m radius of tidal freshwater marsh, followed by a manual validation as with the salt marshes.

Our analyses indicated that 397 crossings have salt marsh and tidal freshwater marsh upstream and 167 crossings have only freshwater tidal marsh upstream. This field helped us create the Restricted Salt Marsh Acreage Layer described below.

Calculating Upstream Marsh Acreage

To estimate the area of tidal marsh affected by the tidal crossing, MCP added a field for current tidal marsh acreage upstream of the crossing. We calculated both salt or brackish marsh and freshwater tidal marsh acreages.

This metric was calculated by measuring the total area of MNAP or NWI tidal marsh polygons upstream of the crossing. If available, MNAP polygon data were used to compute upstream salt marsh or freshwater tidal marsh acreage. If MNAP data were unavailable, such as in marsh systems smaller than 5 acres, NWI-mapped acreage was used to calculate upstream totals of salt marsh (E2EM).

Separate fields in the database are labeled salt marsh upstream acreages and tidal freshwater marsh upstream acreages. When marshes on both sides of the crossing had associated open tidal water, it was sometimes difficult to determine the pattern of tidal flooding and acreage of marsh impacted. In those instances, we left the "Upstream Marsh Acreage" field blank. Finally, if the wetland data were unclear or upstream acreages were not connected to each other (e.g. in the case of fringing marshes or multiple separate marsh areas), we left the field blank. However, the "Presence of Upstream Marsh" reflects the presence and type of upstream marsh in all cases, even if the area was not calculated.

Creating the Restricted Salt Marsh Acreage Layer

To calculate an estimate of restricted salt marsh statewide, MCP created a layer of mapped marsh polygons upstream of crossings we designated as tidal restrictions based on the protocol in Section III below. The NWI and MNAP combined salt marsh layer was used to create the restricted salt and brackish marsh layer. We cross-referenced this polygon layer with MCP's in-house restriction assessment of all tidal crossing structures in Maine using remotely-sensed data and previously acquired crossing survey data.

This spatial analysis resulted in a selection of tidal restrictions with salt or brackish marsh mapped upstream. These upstream salt marsh polygons were selected and used to create the restricted salt marsh layer. MCP conducted a manual verification of the results, and any mapped polygons not associated with tidal restrictions were removed from the layer. A second MCP member reviewed locations with unclear upstream marsh directions in order to decide on the acreage included. However, most atypical upstream situations described above exist upstream of clearly defined tidal restrictions and this issue was minimal. The restricted salt and brackish marsh layer yields 9,649 acres in total.

Identifying Crossings with Tidal Marsh Habitat Discontinuity Immediately Upstream

MCP created the marsh habitat discontinuity field to identify sites where the crossing structure is likely responsible for altered natural community conditions upstream. We did this by finding sites that had any type of tidal marsh downstream and an altered or altogether different (e.g. non-marsh, non-tidal) community type immediately upstream.

D. Incorporating Sea Level Rise Scenarios and Marsh Migration Scenarios

We created fields calculating marsh migration potential and sea level rise scenarios to help users plan for which crossings could become tidal under 6 different scenarios of SLR and the potential for marsh resilience under those conditions.

Adding Sea Level Rise Scenarios

In 2018, MGS released 6 new sea level rise (SLR) scenarios for Maine along with the updated HAT. These scenarios include 1.2, 1.6, 3.9, 6.1, 8.8, and 10.9 feet of sea level rise or storm surge by 2100 along the Maine coastline from the baseline HAT layer. MGS developed these SLR scenarios using available long-term sea level rise data from Portland, Bar Harbor, and Eastport tide gauges as well as the US Army Corps of Engineers Sea-Level Change Curve Calculator (v. 2017.55) and NOAA SLR scenarios included in the US National Climate Assessment (2017). SLR scenarios include low, intermediate low, intermediate, intermediate high, high, and extreme sea level rise (1.2 to 10.9 ft) at the 50% confidence interval using a static “bathtub” inundation model. This model is based on a lidar-informed DEM adjusted for HAT tidal predictions that take into account variations in elevation datums throughout the Maine coast. SLR and storm surge scenarios are then added to the initial calculated starting elevation.

We added the “SLR Status field” in MCP’s Tidal Restriction Database by conducting a spatial analysis with each SLR scenario and crossings within a 10m radius. We used a smaller buffer for the SLR scenarios than HAT because of the spatial proximity of the SLR scenarios to each other. This analysis was followed by a manual validation of the results to ensure accuracy of results. This field reveals the lowest SLR scenario at which a currently nontidal crossing will become tidal.

Adding Marsh Migration Scenarios

MCP added marsh migration scenarios to the database to identify crossing sites that may influence tidal marsh migration upstream. As of July 2020, three datasets mapped nontidal lands adjacent to estuary systems that could support development of new tidal marsh if sea level rises by 1.2, 1.6, or 3.9 ft above highest astronomical tide by 2100 (MNAP 2020). MNAP developed these layers in response to the Maine Climate Council Science and Technical Committee’s report indicating the most probable scenarios given current rates of sea level rise (Maine Climate Council STS 2020).

MCP conducted a spatial analysis to locate crossings from the tidal restriction database within 50 meters of the maximum (3.9 ft SLR) mapped marsh migration scenario. All resulting crossings were cross-referenced with the “Presence of Upstream Tidal Marsh” field for values “No” to ensure that these crossings do not currently have tidal marsh upstream. The same processes were used to evaluate the 1.6 and 1.2 ft marsh migration scenarios. MCP conducted a complete manual validation of the resulting 394 crossings for each of the three scenarios. The crossings associated with each marsh migration scenario therefore represent both currently tidal and future tidal crossings without existing mapped tidal marsh upstream, but with tidal marsh mapped upstream of the site according to one or multiple marsh migration scenarios.

E. Incorporating Additional Ecological Data

We added ecological data to the database to incorporate information about several Species of Greatest Conservation Need (SGCN) that can be affected by aquatic passage within a crossing or tidal marsh habitat upstream or downstream of a crossing. Each crossing includes updated information about Atlantic salmon spawning and rearing habitat, alewife streams, rainbow smelt spawning streams, and brook trout habitat. We anticipate expanding the list beyond fully aquatic species, such as marsh-nesting SGCN birds. We also included information on crossings located in Beginning with Habitat focus areas, crossings within 75 meters of Tidal and Inland Waterfowl and Wading Bird Habitat, and locations on undeveloped land parcels. The data types and sources are listed in Table 2.

Table 2. Auxiliary data sources included in the tidal crossing database.

Data Type	**Source**
Highest Astronomical Tide	Maine Geological Survey, 2018
Sea Level Rise Scenarios	Maine Geological Survey, 2018
Marsh Migration Scenarios	Maine Natural Areas Program, 2020
Mapped Marsh	Maine Natural Areas Program, 2015 National Wetlands Inventory
Rainbow Smelt	USFWS Crossing Survey Database, Downeast Salmon Federation, Wells NERR
Brook Trout	Eastern Brook Trout Joint Venture
Atlantic Salmon	Maine Department of Marine Resources and USFWS, 2019
Alewife	USFWS and Maine Habitat Stream Viewer
Beginning with Habitat focus areas	Maine Department of Inland Fisheries and Wildlife
Tidal Waterfowl and Wading Bird Habitat	Maine Department of Inland Fisheries and Wildlife
Inland Waterfowl and Wading Bird Habitat	Maine Department of Inland Fisheries and Wildlife
Undeveloped Blocks	Maine Department of Inland Fisheries and Wildlife

III. Tidal Restriction Assessment

A. Identifying Tidal Restrictions

Several factors contribute to restrictive conditions at a tidal crossing, including local geomorphic conditions, tidal range, crossing elevations, span of the crossing orifice (e.g. bridge or culvert) relative to the length of the tidal system crossed, and cross section of the crossing's primary orifice as compared to the channel cross section. In some combinations and levels of magnitude, these influencing factors interact in ways that result in ecological and physical responses that are readily observable using remote data in a desktop setting. Examples of observable responses include abrupt shifts in community type, channel dimensions, and water quality up and downstream of the crossing. Another response is prominent, localized scour in the immediate area of the crossing. At times, the type or quality of data available for desktop assessments prevented conclusive observations of responses to restrictive conditions. In those instances, access to field data and onsite photos from previous field surveys allowed us to determine the presence of crossing characteristics, such as culvert perch, that predispose restrictive conditions.

This approach allowed us to rapidly assess crossings based on the presence of primary criteria associated with observed responses of the system to restrictive conditions and secondary criteria based on crossing structure characteristics known to predispose restrictive conditions. The type of data used in this desktop assessment did not equitably lend itself to classification of restrictions based on level of severity. Some of the most dramatic restrictions, such as ponds immediately upstream of tidal areas) were readily identifiable. However, other types of high magnitude community shift due to restrictive conditions (e.g. upstream subsiding marsh plain) were less obvious. Consequently, classification of severity seemed a more appropriate objective for on-site studies that can observe system responses too subtle for a desktop method. Likewise, we were unable to find a rule of thumb or well-accepted consensus on what minimum degree of tidal restriction is "actionable." For all these reasons, we envision that the Tidal Restriction Database will be used as a screening tool prompting users to initiate further investigations and enabling them to learn more about individual sites for which supplementary data are already available.

It should be noted that characteristics of crossings that restrict tidal flow (e.g., undersized or perched culverts), even if apparently minor, can also signal the presence of a barriers to the movement of some species. Aquatic organism passage (AOP) is an important factor that should be considered when investigating the potential impacts of tidal restrictions. Determining AOP impairments was not necessary for us to identify restrictions to tidal flow. For more information on tidal crossings assessments performed in the context of impacts to tidal AOP, see Becker et al. (2018).

Source Data for Assessments

We used a variety of data sources to evaluate if tidal crossings and adjacent areas showed signs of a tidal restriction (Table 3). We used high resolution satellite and aerial imagery as the primary data sources; when imagery was not sufficiently informative, we relied on other data types. Additionally, we anticipate that the quality of our data and assessments will improve with contributions of local knowledge from our partners.

Table 3. Data sources used for tidal restriction assessments.

Source	**Description**
Google Earth satellite imagery	The latest imagery provides adequate resolution. Timing and seasonality of imagery varies, sometimes allowing visualization of low-tide and leaf-off conditions, which is important in wooded settings.
Maine low-tide aerial imagery	Extremely useful for detecting scour patterns and other features, such as dam remnants and natural bedrock restrictions.
Historical Aerials Viewer	The imagery and topographic maps can provide important insights demonstrating changes in conditions. Onscreen watermarks in the free version sometimes obscure the area of interest.
Google Street View	Occasionally useful when other data sources are not available.
NWI and MNAP marsh polygons	These sources can help determine the presence of impounded or other dramatically different conditions upstream.
USFWS crossing survey photos	Site photos can show scour, perching, structural damage, and other problems associated with crossings. Not all crossings have photos. Site photos for public crossings and owner-approved private crossings can also be accessed using the Maine Stream Habitat Viewer.
USFWS crossing survey database	Fields with crossing measurement data helped provide evidence of undersized or perched crossing conditions.

Primary Restriction Criteria

Abrupt differences in physical or community characteristics upstream and downstream of the crossing and the presence of scour at the crossing site were chosen as our two primary restriction criteria because they provided observable evidence of system responses to tidal restrictions. Descriptions of the primary criteria follow below:

1. Upstream/Downstream Habitat Discontinuity: A restriction of tidal flow was indicated by observed differences immediately upstream and downstream of a crossing that were abrupt and dramatic. Unless existing evidence suggested otherwise, we assumed these differences were largely driven by hydrology or hydraulics altered by a tidal restriction at the crossing and that the restrictive conditions remained present. Differences we observed during assessments tended to fall into several categories: vegetation community type (Figure 4), channel morphology (Figure 5), surface water level/extent of flooding, and visible water quality characteristics. These factors are all influenced by hydrology, and several may be observed at a single site. The timing of imagery was key; if during spring tide conditions, flooding could obscure notable differences, and other data sources were consulted or different criteria used. We also note that each of the conditions described below in Table 4 could be caused by natural bedrock features that restrict flow, so additional data are sometimes necessary for a confident assessment that the crossing is the cause of the restriction or contributes to a natural constriction.

Figure 4. Mismatched upstream and downstream vegetation communities signals a tidal restriction response.

Figure 5. Clear differences in channel width and geomorphology on either side of this road signal a response to a tidal restriction.

Table 4. Examples up/downstream conditions discontinuity associated with tidal restrictions. Some require additional evidence to support a restriction determination.

Indicator	Restriction probability	Comments
Higher upstream surface water level than downstream	Likely	Differences in surface water levels can be recognized by the lateral extent of flooding and water color.
Shallow basin upstream with a weakly defined or no visible channel	Likely	More apt to be observed during lower tide levels.
Water color and/or transparency differs from downstream	Likely	Examples include the upstream channel water being “tannin-stained” (dark, reddish-brown).
Lower-salinity communities upstream	Likely	Highly variable but often distinguishable using imagery and/or MNAP and NWI wetland mapping.
Marsh upstream, beach or open water downstream	Possible	Natural dunes, berms, or levees can impede or block flow. Conclusive determinations may require additional data sources.
“Soggy marsh” with many or expansive pools	Possible	Marsh surface alterations, not just primary tidal restrictions, can result in this pattern. Conclusive determinations may require additional data sources.

2. Scour pools: Scour indicates over-pressurized, misaligned, and/or plunging flow caused by restrictions but does not signify the timing of when the conditions causing scour were present. If no indications to the contrary were present, we assumed scour was an ongoing condition associated with, if not primarily resulting from, the present crossing. The classic pattern of scour is an obvious bulge in the channel wall (Figure 6). This can be observed at one or both ends of the crossing. The scour pool is often deeper than the channel outside of the immediate influence of the crossing. When flooded, this section of the channel can appear darker than other areas. If high water conditions prevented observations of scour, the next step in the assessment was to review low tide imagery. This is sometimes available in Google Earth or Google Maps when zooming-in but is more reliably accessed through Maine's low tide aerial imagery sets. In addition to the classic pattern described above, intrusion of the crossing structure and fill material associated with bridges on larger streams can also signal scour is present even if not immediately evident. In these cases, the channel width appears "pinched." A review of low-tide imagery often provides evidence of scour caused by narrowing of the channel and deflection of currents at these sites.

Figure 6. Scour pool clearly indicating restrictive conditions.

Secondary Restriction Criteria

The two primary restriction criteria described above are not always clearly observable due to imagery quality, woodland cover, or other factors. In those instances, we used secondary criteria focused on crossing characteristics that predispose crossings to restrictive conditions.

1. Perched crossing: When the ocean side of a culvert is perched above the channel bottom (Figure 7), the upstream flowing tide is blocked until it rises sufficiently to spill over and into the perched culvert. Perching delays the onset of upstream flow and as a result, shortens the upstream tidal cycle. This limits the volume, extent, depth, and duration of tidal flooding upstream of the perch. Not surprisingly, these changes to upstream hydrology can cause a range of shifts in the system's chemical, physical, and biological conditions. These conditions can limit or completely block aquatic organism passage, depending on the characteristics of the perch and the species. The most profound changes can be observed where the culvert is perched above the maximum tide elevation, in which case conditions are functionally non-tidal and often pond-like immediately upstream of the crossing. Less pronounced perched conditions also have consequences, but we found no studies or rules of thumb that might identify the minimum perch height likely to cause impairment to upstream habitat. Lacking that information, we chose not to set an arbitrary threshold for the minimum perch height warranting a "restriction" classification. As a result, we classified all crossings with visible or measured perches in existing data as restrictions. This field was unassessed where there was no crossing survey data to confirm a perch.

Figure 7. A perched culvert high above downstream channel substrate and water level. Image from Maine Stream Habitat Viewer.

2. Undersized crossing: When a crossing orifice is too small to allow unhindered exchange of the entire volume of the tide and freshwater inflow (Figure 8) across the full range of tides, restrictive conditions are present. By this assertion, crossings that integrate barriers to sheet flow, such as causeways, would represent some of the most obvious restrictions. However, we were unable to determine what combination of causeway length versus tidal system distance crossed would cause a significant restriction. As a result, we chose to not use the presence of a causeway as grounds for applying a restriction classification. Instead, we had more confidence in using characteristics of the primary crossing orifice (e.g., culvert or bridge span compared to tidal stream channel width) to assess a predisposition for restrictive conditions, because of its influence on flow directly at the stream channel. When the culvert cross section or span appeared clearly smaller than that of the channel, we classified the crossing as a restriction. This approach for classifying restrictions would likely underrepresent the number of undersized crossings. However, being that the primary criteria were more often used to classify restrictions, we don't believe the possible shortcomings in this secondary criterion impacted the quality of our assessment.

Figure 8. An undersized culvert and causeway clearly contribute to restrictive conditions at this site. Image from Maine Stream Habitat Viewer.

Literature Cited

Army Corps of Engineers. 2004. Planning assistance to states: Maine Department of Transportation coastal wetland tidal restriction study. Department of the Army Corps of Engineers, New England District Concord, Massachusetts.

Becker, S., Jackson, S., Jordaan, A. and Roy, A. 2018. Impacts of tidal road-stream crossings on aquatic organism passage. U.S. Department of Interior, Fish and Wildlife Service, Cooperator Science Series FWS/CSS-131-2018, Washington, D.C.

Bohlen, C., Stelk, M., Craig, M., Redmond, L., and C. Gerber. 2012. Geomorphology and the effects of sea level rise on tidal marshes in Casco Bay. Casco Bay Estuary Partnership, Portland, Maine.

Bonebakker, E., P. Shelley, and K. Spectre. 1999. Return the Tides. Conservation Law Foundation, Portland, Maine.

Maine Climate Council Scientific and Technical Subcommittee (STS). 2020. Scientific Assessment of Climate Change and Its Effects in Maine: Phase I Working Document. Available at: https://www.maine.gov/future/sites/maine.gov.future/files/inline-files/MCC_STS_PhaseI_FINALWORKINGDOCUMENT_2.18.20.pdf.

Maine Natural Areas Program. 2020. Model and Report for the Blue Carbon Strategy of the Maine Climate Council's Coastal and Marine Working Group. Available at: https://www.maine.gov/future/initiatives/climate/climate-council/coastal.

Northern Ecological Associates. 2005a. Habitat restoration inventory summary report for the Royal River, Spruce Creek, and Lower Kennebec River Estuary. Volume I. Maine Coastal Program, Augusta, Maine.

Northern Ecological Associates. 2005*b*. Final Habitat Restoration Inventory Summary Report for the Lower Presumpscot River Watershed: Volume I. Casco Bay Estuary Partnership.

Slovinsky,P., Rickerich, S., and C. H. Halsted. 2018 Maine Highest Astronomical Tide and Sea Level Rise Scenarios. Maine Geological Survey, Augusta, Maine.

US Geological Survey, TopoView. 2019. National Geospatial Program, National Geological Map Database.

Appendix A

Maine Coastal Program would like to express our gratitude to the following organizations and individuals that contributed to the success of this project.

Alex Abbott
US Fish and Wildlife Service, Gulf of Maine Coastal Program

Charles Hebson
Maine Department of Transportation

Briana Fischella
Great Bay National Estuarine Research Reserve

Eric Hutchins
NOAA Restoration Center

Jacob Aman
Wells National Estuarine Research Reserve

Jamie Carter
NOAA Office for Coastal Management

Jeremy Bell
The Nature Conservancy in Maine

Jeremy Gabrielson
Maine Coast Heritage Trust

Kirstin Underwood
US Fish and Wildlife Service, Gulf of Maine Coastal Program

Kristen Puryear
Maine Natural Areas Program

Matthew Craig
Casco Bay Estuary Partnership

Rachel Stevens
Great Bay National Estuarine Research Reserve

Ruth Indrick
Kennebec Estuary Land Trust

Shri Verrill
Midcoast Conservancy

William Bennett
US Fish and Wildlife Service, Gulf of Maine Coastal Program