TRANSCANADA HYDRO NORTHEAST INC.

ILP Study 24

DWARF WEDGEMUSSEL AND CO-OCCURRING MUSSEL STUDY

Development of Habitat Suitability Criteria for Co-Occurring Mussels

In support of Federal Energy Regulatory Commission Relicensing of:

Wilder Hydroelectric Project (FERC Project No. 1892-026)
Bellows Falls Hydroelectric Project (FERC Project No. 1855-045)
Vernon Hydroelectric Project (FERC Project No. 1904-073)

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List of Abbreviations

1D	One-Dimensional Hydraulic Model (e.g., PHABSIM)
2D	Two-Dimensional Hydraulic Model (e.g., River2D)
BSS	Bed Shear Stress
BV	Benthic Water Velocity
DEP	Water Depth
DWM	Dwarf Wedgemussel (*Alasmidonta heterodon*)
ELCO	Eastern Elliptio (*Elliptio complanata*)
FERC	Federal Energy Regulatory Commission
FWS	U.S. Department of the Interior-Fish and Wildlife Service
HSC	Habitat Suitability Criteria
ILP	Integrated Licensing Process
ISR	Initial Study Report
MCV	Mean Column Water Velocity
RSP	Revised Study Plan
RSS	Relative Shear Stress
SUB	Substrate Composition
TransCanada	TransCanada Hydro Northeast Inc.
TNC	The Nature Conservancy

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1.0 INTRODUCTION

This report presents the results of part of the Dwarf Wedgemussel and Co-occurring Mussel Survey (ILP Study 24) conducted in support of Federal Energy Regulatory Commission (FERC) relicensing of the TransCanada Hydro Northeast Inc. (TransCanada) Wilder Hydroelectric Project (FERC Project No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855), and Vernon Hydroelectric Project (FERC No. 1904). TransCanada has initiated the Integrated Licensing Process (ILP) for these projects in order to renew their operating licenses beyond the current expiration date of April 30, 2019 for each project. Dwarf Wedgemussel (*Alasmidonta heterodon*, DWM) is a federally endangered species that currently inhabits select reaches of the Connecticut River within the project-affected areas of the Wilder and Bellows Falls projects.

Phase 1 fieldwork for Study 24 was completed in September 2013, in accordance with the study's Revised Study Plan (RSP) and the Phase 1 Study Report was prepared. The public version of the report was shared with the aquatics working group (Volume IV of the Initial Study Report [ISR] filed September 15, 2014). The privileged version of the report containing specific DWM locations was filed as Volume V of the ISR and provided to specific agency staff in August 2014, as requested.

A Phase 2 Study Plan was developed, distributed, and discussed with the working group at a May 23, 2014, consultation meeting and following comments received via email from The Nature Conservancy (TNC) in June 2014, a working group conference call was held on July 1, 2014. The proposed Phase 2 Study Plan was subsequently revised in response to those comments (revised plan filed as Volume VI of the ISR); however, it was not distributed prior to the 2014 field study because there was an indication that further comments were being prepared by US Fish and Wildlife Service (FWS), and the study plan might need to be revised again. Based upon all initial comments received previously, it was anticipated that further comments would be slight modifications on the previous discussions and draft study plan. Because the study field work time table was at risk, TransCanada initiated field work based upon its undistributed Revised Phase 2 Study Plan (filed as Volume VI of the ISR), presuming that any issues remaining could be addressed rather easily, and while field work was in progress. However, FWS provided substantial new comments in the form of a "counter proposal" on September 4, 2014.

Fieldwork for Phase 2 relied on the Revised Phase 2 Study Plan and consisted of establishing twenty 50x1 m monitoring transects distributed among six general locations in the Wilder impoundment, riverine reach, and upper Bellows Falls impoundment. Most were surveyed in the period from August 20-29, 2014 and one pair (Cornish Covered Bridge – North) was surveyed on October 1. Data collection followed the methods outlined in the Revised Phase 2 Study Plan. The 2014 fieldwork also included quadrat surveys in the 2,400-meter reach that included Cornish Covered Bridge and Chase Island, as described in the Revised Phase 2 Study Plan. This work was completed under low-flow conditions and warm temperatures in September. A total of 405 2.25-m^2 quadrats were sampled in this reach; 385 were distributed in a systematic random pattern across the channel (bank to bank) and 20 additional quadrats were distributed in areas where mussel densities were higher. Counts for all mussel species, and several habitat parameters, were recorded for each quadrat as described in the Revised Phase 2 Study Plan.

A consultation meeting was held on October 9, 2014 to discuss the FWS counter proposal. FWS subsequently provided a revised counter proposal along with that agency's comments on the Initial Study Report (ISR). TNC also provided comments on the ISR. TransCanada provided a response to ISR comments filed with FERC on December 15, 2014 which included responses to the numerous comments on Study 24, and reported that the revised FWS counter proposal was under internal review, and that additional stakeholder consultation would occur once that review was completed. The Phase 2 Study Progress Report (public version and privileged version with supporting privileged geodata) was filed on March 2, 2015 in accordance with FERC's September 2013 SPD. The FWS revised counter proposal was included as Appendix A, and TransCanada's proposed habitat suitability methodology was included as Appendix B of that report.

On January 22, 2015, FERC issued a Determination on Requests for Study Modifications and New Studies in which the requested study modifications in the FWS' revised counter proposal were not adopted at that time. FERC acknowledged that consultation on this study remained ongoing, and that specific methodologies for development of habitat suitability criteria for DWM and/or other study methodologies would be the subject of this consultation. FERC also noted on page 3 of its determination, "[i]f agreement cannot be reached on the phase 2 study methods, we recommend that TransCanada seek a determination from the Commission and file the comments received, a response to comments, and any updates to the phase 2 study plan at least 30 days prior to commencing any additional field work."

A consultation conference call was held on March 5, 2015 to review TransCanada's proposed habitat suitability methodology which had been provided to the working group in advance (and filed on March 2, 2015 as part of the study report). On the conference call, the working group agreed on an approach to developing habitat suitability criteria (HSC) for DWM and co-occurring mussel species. HSC would be hybrids of Category I (qualitative) and Category II (quantitative, using empirical data), depending on the amount of data available for each parameter. Criteria for DWM would be developed by reviewing and synthesizing existing data, and by soliciting input from regional experts using a Delphi approach. Criteria for co-occurring species would be developed primarily using existing data collected in the prior field studies.

2.0 STUDY GOALS AND OBJECTIVES

As stated in the RSP, one of the goals of Study 24 was to assess the influence of flow regime (which includes water-level fluctuations) on DWM, co-occurring mussel species, and mussel habitat. This report specifically addresses the development of

HSC for co-occurring mussel species. Details regarding the development of Delphi-based HSC for DWM are presented in the report filed May 16, 2016 (Normandeau, 2016). HSC represent a critical and influential factor in 1D and 2D modeling of the flow:habitat relationship for any given species.

3.0 METHODOLOGY

3.1 Approach to Development of HSC

Assessing flow effects on co-occurring mussel habitat was conducted using several tools, including 1Dimensional (1D) and 2Dimensional (2D) hydraulic modeling as part of the Instream Flow Study (ILP Study 9). Both 1D and 2D modeling requires descriptions of the microhabitat selectivity of target species, including DWM and co-occurring mussels. The indices describing habitat selectivity are termed Habitat Suitability Criteria (HSC), which are microhabitat variables believed to influence the position choice and health of the target organism. Most HSC variables used in instream flow studies are those that directly interact with streamflow, such as water depth and velocity (and derivatives thereof), but may also include variables such as substrate composition or instream cover. For non-motile benthic species such as mussels, variables related to near-bottom shear stresses are also considered to be critical parameters, due to their influence on scour of substrate particles and subsequent bedload movement.

HSC are defined as “graphical or statistical models that depict the relative utility of increments or classes of macro- or microhabitat variables (e.g., depth, velocity, cover type) to a life stage of a target species” (Bovee et al., 1998). The relative utility of the variables ranges from zero (unsuitable) to 1.0 (fully suitable) for any increment or class of the variable. HSC are used within the hydraulic habitat modeling component of computer software (e.g., PHABSIM, River2D) associated with the Instream Flow Incremental Methodology (IFIM) to evaluate potential habitat impacts of flow alterations or flow regime alternatives.

The shape of an HSC for any specific variable can either be binary (suitable/unsuitable), categorical (stepped functions), or continuous, but all HSC range from a value of 0.0 to 1.0. Binary HSC are typically developed from presence/absence studies, and stepped HSC are typically used to describe suitability for categorical variables arranged in non-continuous classes (e.g., substrate types). Continuous HSC typically show smooth transitions from unsuitable habitat to suitable habitat, and are often defined by equations and/or adjusted by professional judgment. HSC can also be multivariate and incorporate interactions between variables such as velocity and depth, where for example, the suitability of a specific velocity is dependent on the associated depth. HSC can even be conditional, where a velocity or depth for a sample point is suitable only if suitable cover occurs within a specified distance from the sample point. Binary HSC are the easiest to create, but are inconsistent with normal biological responses, while many higher-level HSC require observational data.

HSC can be developed in several ways, ranging from intensive field measurements of habitat use and habitat availability, to professional judgment, such as the Delphi-based HSC developed for DWM (Normandeau, 2016). In general, site-specific HSC developed at the project location is preferable due to its potential ability to account for local characteristics of aquatic habitat and other environmental conditions, but development of site-specific HSC is only an option if the target species are present in sufficient numbers. Due to the rarity of DWM in the project reaches, the Delphi-based approach was used for that species. However, Eastern Elliptio (*Elliptio complanata*, or ELCO) were relatively abundant in the project area, and are the subject of this report.

3.2 Selection of Candidate Species for Co-Occurring Mussels

The quantitative mussel studies conducted as part of the 2014 Phase 2 efforts involved random selection and assessment of 402 quadrats (each 2.25m^2) in the vicinity of the Wilder riverine reach 2D study site at Chase Island. Quadrat sampling in the Chase Island study are occurred in September 2014. Additional mussel counts were made within strip transects; however, those data were not used to develop HSC since the sample size obtained from the quadrat sampling was adequate and because transect sampling protocols differed from the quadrat sampling.

Of the 402 Chase Island quadrats, 300 of the quadrats were located within the actual boundaries of the hydraulically modeled 2D site (Figure 3-1). Overall, 215 mussels were counted within those 300 quadrats, of which 186 (87%) were Elliptio, 27 (13%) were Eastern Lampmussel (*Lampsilis radiata*), and 1 each (<1%) were DWM and Triangle Floater (*Alasmidonta undulata*). Because Elliptio were by far the dominant species encountered at Chase Island, and because sample sizes for the remaining species were too low to develop species-specific HSC, Elliptio was selected for developing site-specific HSC to represent co-occurring mussels in the project area. In most northeastern rivers and lakes, Eastern Elliptio are usually far more abundant than other mussel species; the cause(s) for this dominance are unknown but may be related to fecundity, number and availability of suitable fish hosts, larval and juvenile survivorship, adult longevity, broad tolerance to different and variable environmental conditions, etc. Although they are typically far more abundant than other species, they do tend to occupy the same types of habitats as co-occurring species (i.e., their “success” seems to be related more to reaching a higher density within suitable habitats that they share with co-occurring species, rather than in occupying habitat niches that co-occurring species cannot tolerate). However, empirical data to support this assertion are lacking.

3.3 Selection of Chase Island for Development of Co-Occurring Mussel HSC

The Chase Island 2D site was selected to develop site-specific HSC for co-occurring mussels due to the availability of a large dataset of mussel counts and due to the ability to simulate habitat parameters at various flows using the 2D hydrodynamic model (Figure 3-1). Site-specific HSC data is often collected at a single point in time, which was the case with the quadrat mussel data collected between September 3 and October 1, 2014 (TransCanada, 2015). Each of the riverine reaches (including Chase Island in the Wilder riverine reach) typically exhibits a

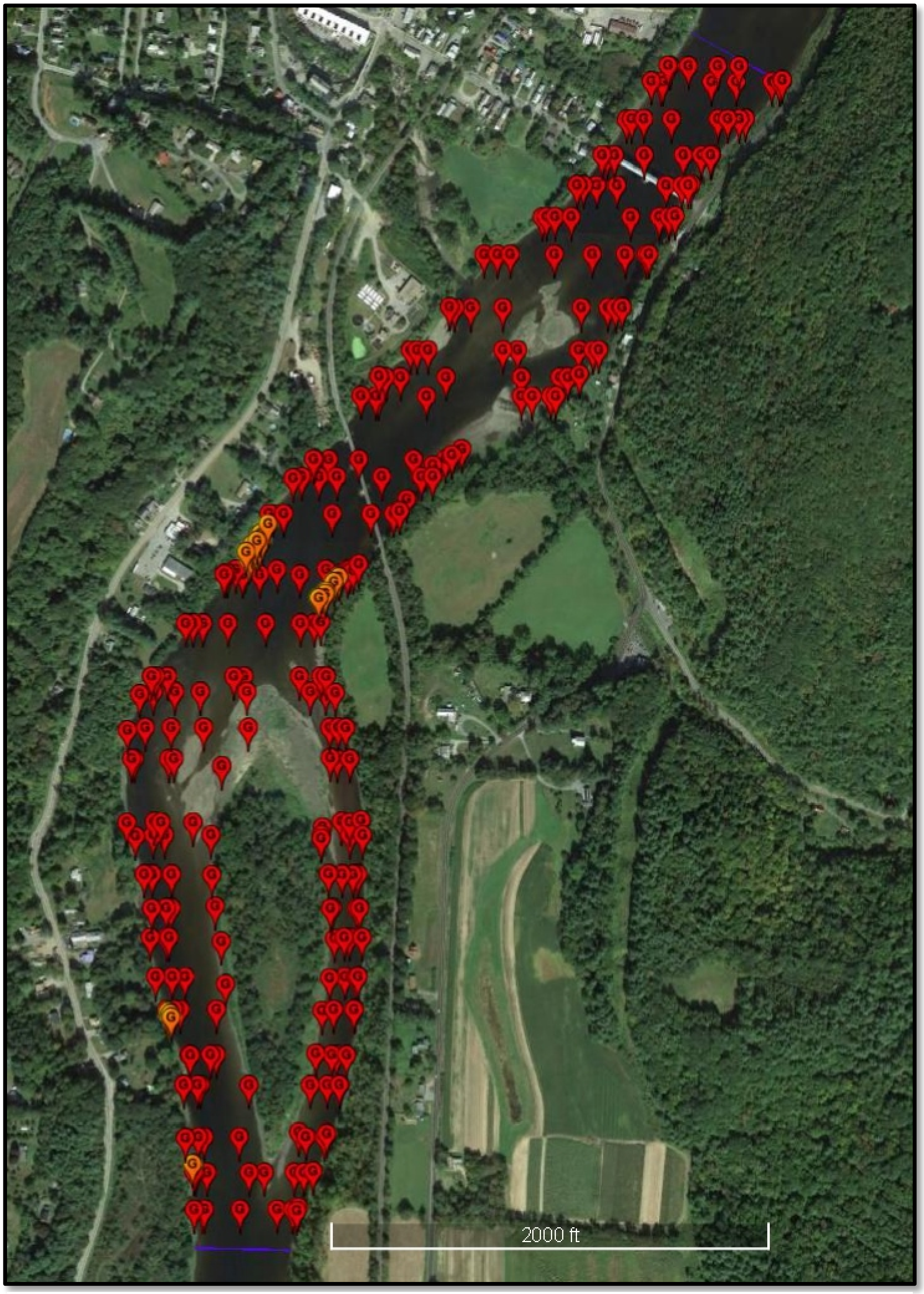

Figure 3-1. Chase Island 2D study site showing approximate location of mussel quadrats.

daily (and seasonally) range of fluctuating flows, with associated changes in depths, velocities, and shear characteristics. Consequently, the relatively non-motile and long-lived mussel species observed at Chase Island quadrat sites were subject to a wide range of conditions prior to being counted. For these reasons, developing HSC from the habitat parameters measured only at the time of sampling would not be expected to be fully representative of conditions experienced by the mussels, and may not be highly correlated with the observed distribution. This is in contrast to mobile species such as fish, which can move to new habitat when conditions become unsuitable at their present location, thus potentially displaying their selectivity at any given time.

The DWM Delphi panelists each emphasized that DWM distributions were likely highly influenced by physical habitat conditions experienced during high flow events, which suggested that intermediate conditions at a single point in time would not be a reliable predictor of mussel distributions or suitability (Normandeau, 2016). Therefore it was necessary to use quadrat count data from a hydraulically modeled study site in order to estimate the range of habitat variables experienced by the mussels; variables which were believed to have influenced the counts of mussels at the time of sampling. The Chase Island 2D site was the only location that had both quantitative counts of mussels as well as a detailed flow:habitat model that could be used to estimate historical habitat parameters at specific quadrat locations.

3.4 Selection of Candidate Variables and HSC Curves

The Delphi-based approach used to develop HSC for DWM resulted in the selection of 7 variables thought to be influential to the distribution and abundance of mussels in the project area (Normandeau, 2016). One of the 7 variables (shear velocity), is an integral component of the other two shear variables (bed shear stress and relative shear stress), and was recommended to be dropped from the analysis due to redundancy. This resulted in a total of six HSC variables for inclusion in the proposed flow modeling process:

1. Water depth (DEP),
2. Mean column water velocity (MCV),
3. Benthic water velocity (BV),
4. Substrate composition (SUB),
5. Bed shear stress (BSS),
6. Relative (dimensionless) shear stress (RSS).

See Appendix A for calculation of BV and the shear variables BSS and RSS.

3.5 Selection of Modeled Flows

Because most mussel species are relatively non-motile and long-lived, and mussels in the project area are subject to potentially large daily (and seasonal) fluctuations in flow-related habitat, it was necessary to select a set of flows over a period of time to assess the range in habitat conditions experienced by the mussels within the sampled quadrats. An assumption in the process of selecting flows is that environmental (flow-related) conditions exceeding the capacity for persistence of mussels would be defined as unsuitable habitat. Suitable habitat is therefore the range of flow conditions that allow for continued persistence of the species in question, and can range in quality from poor to optimal. Optimal habitat is defined by flow conditions where growth, reproduction, and resistance from displacement are ideal, given the additional limitations of non-flow related parameters. It is further assumed, consistent with general assumptions regarding HSC, that highly suitable habitat allows for higher densities of the target organism. In the context of this study, quadrats with higher counts of Elliptio are assumed to represent flow-related conditions closer to optimal, whereas quadrats with low counts represent suitable, but sub-optimal habitat (e.g., where mussels may persist but growth or reproduction is less successful than in optimal habitat).

The next step was to select what range of flows might be assumed to define those extreme conditions which would result in unsuitable habitat conditions and therefore prevent colonization and persistence of mussels in a particular location. Examples of extreme conditions include dewatering at one end and high, substrate scouring flows at the other end. It was also necessary to determine what period of time should be assessed to evaluate flows in its relationship to the 2014 mussel counts. The three panelists involved in the DWM Delphi process were contacted to enquire what length of time prior to sampling should flows be assessed, i.e., how long would those mussel species present (with emphasis on Elliptio) in the project area on September 2014 likely to have been at that same location prior to sampling? The panelists were also asked what range of flows should be assessed to define extreme conditions that might be expected to determine the presence or absence of mussels. Finally, it was necessary to estimate what range of flows occurred with enough frequency to influence the relative densities of Elliptio in quadrat sites, i.e., flows that could be used to define the range of optimal habitat.

Two of the panelists responded to the inquiries, suggesting that flows should be assessed for 3-5 years prior to sampling. The panelists also suggested that the 1% and the 99% exceedance flows might adequately represent extreme or limiting conditions to the mussels, i.e., flows that would define suitable vs. unsuitable habitat. In addition, the Study 8 - Channel Morphology and Benthic Habitat report (Stantec and Normandeau, 2016) was reviewed to assess what flows were predicted to mobilize substrate materials in the vicinity of Chase Island. Lastly, it was decided to use the 25% and 75% exceedance flows to define those conditions that would allow mussels to occupy quadrat locations without flow-related limitations, i.e., to define optimal habitat based on mussel densities in quadrat samples.

Based on the above recommendations, flow duration curves for the 3 years prior to the mussel sampling events were developed from Connecticut River flow data at West Lebanon (USGS gage #01144500), resulting in the exceedance flows listed in Table 3.1. Flows used to define suitable vs. unsuitable habitat conditions were 1,000 cfs and 33,000 cfs, and flows to define optimal vs. suboptimal habitat conditions were 2,300 cfs and 11,000 cfs. The Study 8 data assessed shear forces at three HEC-RAS transects in their 08-M12 study site at the head of or just upstream of Chase Island. Figure 7 in the Study 8 supplemental information provided in response to comments on the study report (TransCanada, 2016) showed that shear stresses reached critical levels to begin mobilizing medium gravel (8-16mm diameter) over a short range of flows near 2,000 to 3,000 cfs, but then subcritical shear forces existed at higher flows until critical values were exceeded at ~11,000 cfs for transect 710, ~33,000 cfs for transect 708, and ~100,000 cfs for transect 709. Coarse gravels (16-32mm) were not mobilized at any of the transects until flows exceeded 75,000 cfs.

Table 3-1. Flow exceedance values based on USGS gage #01144500 from Sept 2011 to Sept 2014 and flows selected for modeling.

Exceedance Value (%)	**Flow cfs**	**Modeled Flow cfs**
0 (max)	60,200	
1	33,000	33,000
5	19,700	
10	15,300	
26	11,000	11,000
75	2,230	2,300
90	1,300	
95	1,120	
99	1,010	1,000
100 (min)	920	

The Study 8 results generally supported the use of 33,000 cfs to define bed scouring flows and unsuitable conditions, and the use of flows >11,000 cfs to define potentially suboptimal habitat conditions. Additional support is based on the 25% and 75% exceedance criteria that bracket the central 50% of flows, which is consistent with a common protocol for developing HSC that utilizes the central 50% of habitat measurements to define optimal habitat (Bovee, 1986). The 11,000 cfs criteria is also roughly equivalent to the Wilder maximum generating capacity of 10,700 cfs. Given the above analysis, the Chase Island 2D site was used to estimate depths, velocities, and shear variables at 1,000 cfs, 2,300 cfs, 11,000 cfs, and at 33,000 cfs.

3.6 Estimating HSC Variables at Mussel Quadrats

The River2D model used for the extraction of HSC variables at mussel quadrat locations was developed for the instream flow modeling portion of Study 9 (Normandeau, 2017) and is described in that study report, consequently this section only describes specific methods associated with the development of HSC for co-occurring mussel species. The GPS coordinates for the 300 quadrat samples were used to identify the locations for estimating HSC variables within the River2D model (Figure 3-1). Inflow to the top of the 2D site (1,000 cfs, 2,300 cfs, 11,000 cfs, and 33,000 cfs) and water surface elevation (WSE) for each flow at HEC-RAS transect #702 near the downstream end of the 2D site was input into the 2D model. WSEs for each flow were based on an assumed Bellows Falls dam WSE of 289.2 ft (NAVD88), the minimum WSE under normal project operations.

Total depth (DEP), mean column velocity (MCV), and shear velocity were calculated at each quadrat location at each of the four modeled flows using River2D. Bottom velocity (BV), bed shear stress (BSS), and relative shear stress (RSS) were then calculated in a spreadsheet at each quadrat location based on existing formulas (Appendix A). Dominant substrate type at each quadrat was taken from the original quadrat sampling data; it was assumed that substrate composition is relatively constant within the range of modeled flows.

HSC variables were estimated or calculated for all in-water quadrats at each modeled flow. Estimated depths were zero (i.e., out of water) at 78 quadrat locations at the 1,000 cfs flow (including 7 quadrats with a total of 13 Elliptio) and at 39 quadrats (with a total of 2 Elliptio) at 2,300 cfs. These occupied yet presumably exposed quadrats suggest either some level of tolerance of exposure by Elliptio or uncertainties in WSE simulation (or both). Boundary conditions at the bottom of the 2D reach at 33,000 cfs resulted in a persistent eddy which required excluding the lowest 8 quadrats (with a total of 1 Elliptio). Such anomalies are not uncommon in boundary regions at extreme ranges of simulated flows.

3.7 Developing HSC for Co-Occurring Mussels

Site-specific HSC for the six habitat variables were developed for Elliptio to represent co-occurring mussels in the project riverine reaches by first plotting the counts of surface and buried Elliptio from each 2.25m^2 quadrat against each habitat variable at the four modeled flows. Because individual counts in a few quadrats could overestimate perceived suitability at a specific location, the general tendency of relative suitability was better assessed by calculating mean counts of Elliptio within specified bins for each habitat variable. For example, mean counts of Elliptio were calculated at each modeled flow for depths of <1.0 ft, 1.0-2.0 ft, 2.0-3.0 ft, etc. These mean values were then used to visually guide hand-drawn HSC curves.

As previously described, it was expected that habitat attributes at the lowest flow (1,000 cfs) would help to define the minimum range of suitability for most habitat parameters, whereas estimated habitat values at the highest flow (33,000 cfs) would define the maximum range of suitability for those parameters. Attributes at the two intermediate flows (2,300 cfs and 11,000 cfs) were used to define the range of optimal habitat for each parameter. A composite HSC curve was developed by “borrowing” the selected HSC value from each flow to define the shape of the final HSC curve, as seen in Figure 3-2.

4.0 RESULTS

Site-specific HSC curves were developed for Elliptio in the Wilder Chase Island 2D study site to represent habitat requirements of co-occurring mussels in the three project riverine reaches for each of the following six habitat parameters: depth (DEP), mean column velocity (MCV), benthic velocity (BV), substrate (SUB), bed shear stress (BSS), and relative shear stress (RSS).

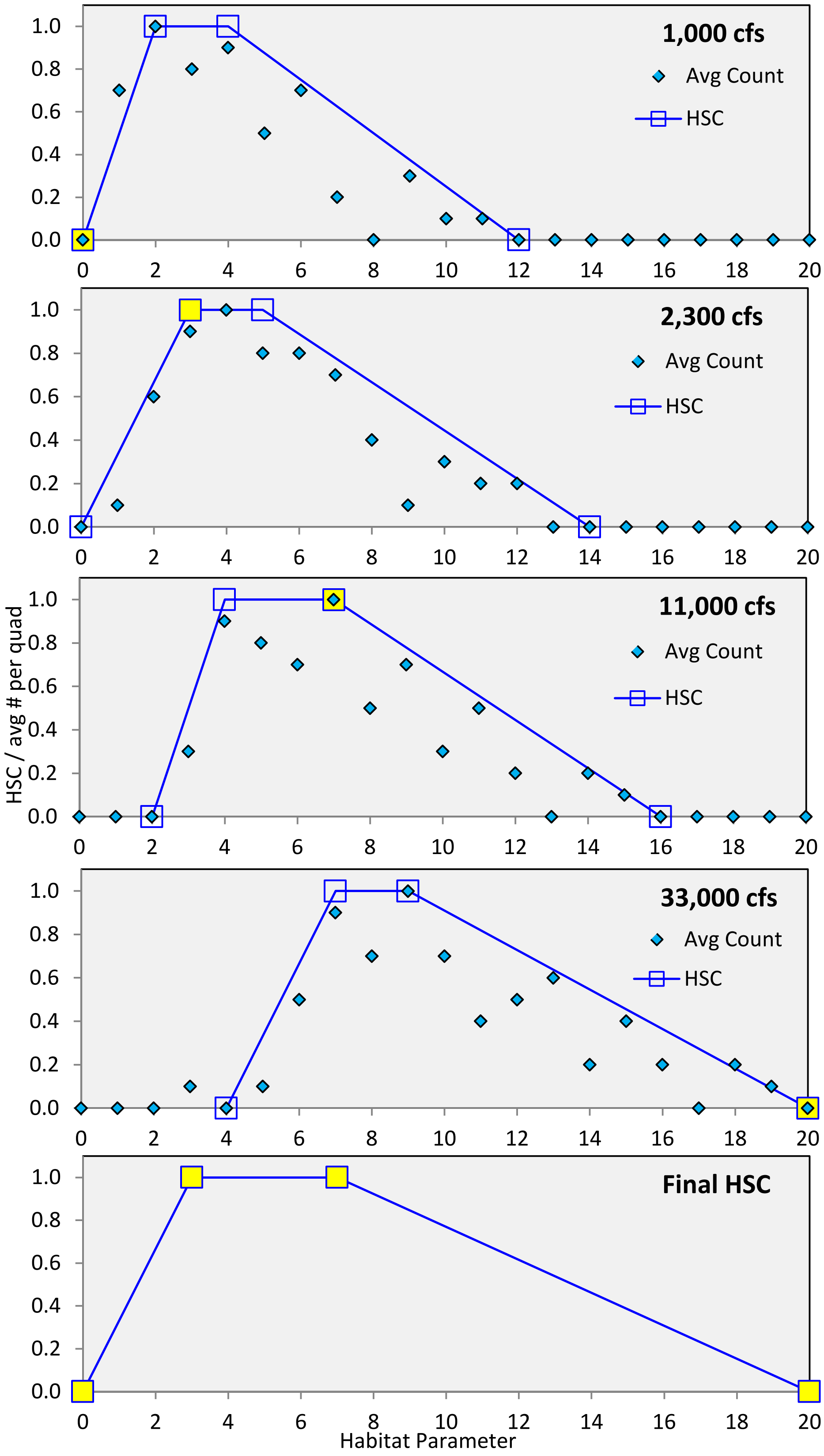

Figure 3-2. Hypothetical example of HSC development process. Yellow-filled symbols were taken from each flow curve to construct final HSC curve (bottom).

4.1 Depth

The estimated depths at quadrat locations ranged from zero ft at 1,000 cfs (as noted above) to almost 30 ft at 33,000 cfs. Figure 4-1 shows the relationship between counts of Elliptio in quadrat samples with estimated depths at both flow simulations. In addition to raw quadrat counts, relative mean counts at depths arranged in one foot bins are also shown, after normalizing the means to a maximum of 1.0. Hand-drawn curves bracketing the quadrat data, with emphasis on the average count values, suggest that Elliptio tolerated depths ranging from <0.5 ft to depths exceeding 20 ft. In contrast to the DWM Delphi HSC, co-occurring mussel depth curves were subjectively dropped down to give intermediate suitability (0.5) in deeper water, due to the site-specific quadrat data that consistently showed zero counts in the deepest quadrats (Table 4-1). It is unknown if the lack of deep water Elliptio observations is due to excessive depth, or potentially due to differences in substrate characteristics. However, evaluation of the 2D substrate polygons suggests that all but the shallowest areas were dominated by gravel (82-96%), with a slight increase (2-11%) in cobble in the deepest areas.

The combined curve to represent co-occurring mussels (based on Elliptio) brackets the four simulated flow datasets and is almost identical to the DWM Delphi curve, except for the subjective decrease in suitability in deeper water. The broadness of the depth curve, with maximum suitability from 1.5-13.5 ft, will result in a flow:habitat relationship that is minimally influenced by depth, except in the deepest pools and where the stream bottom is dewatered or nearly exposed.

4.2 Mean Column Velocity

Estimated mean column velocities at in-water quadrat locations under a simulated flow of 1,000 cfs ranged from 0.0 fps (at five quadrats) to 5.25 fps (Figure 4-2). At 33,000 cfs, estimated velocities ranged from 0.25 to 6.18 fps. The highest mean densities of Elliptio at flows from 2,300 cfs to 11,000 cfs occurred at mean column velocities from <0.1 fps to 2.5 fps, resulting in a relatively broad combined HSC curve (Table 4-1). This combined HSC curve was highly similar to the DWM Delphi curve, except the latter gave lower suitability for velocities <0.5 fps and a somewhat narrower range of optimal suitability.

4.3 Benthic Velocity

Calculated benthic velocities, as expected, were well below mean column velocities at all simulated flows. Estimated benthic velocities ranged from 0.0-2.68 fps at 1,000 cfs and 0.07-1.76 fps at 33,000 cfs. The relationship between benthic velocities and mean counts of Elliptio in quadrat samples showed maximum counts at intermediate flows for velocities between 0.05 and 0.7 fps (Figure 4-3). The combined HSC curve then declined to zero suitability at 1.5 fps (Table 4-1). The co-occurring mussels HSC curve was similar to the DWM Delphi curve, except the DWM curve maintained a tail of low suitability into velocities faster than were estimated to occur at high flows in occupied quadrats at the Chase Island 2D site.

4.4 Substrate Particle Size

Substrate composition is typically assumed to remain constant over the range of flows typically modeled for assessing flow:habitat relationships, although movement and sorting of bed materials clearly occurs at very high flows. As noted in Section 3.5, some movement of fine gravels or smaller particles may be expected to occur within the range of flows assessed in this analysis, however because of the assumption of bed stability the substrate HSC derived for co-occurring mussels was not based on modeled or estimated substrate data, but instead was based on the actual substrate composition measured at each quadrat site at the time of mussel sampling in 2014. Because of slight differences in substrate classifications in the Study 24 field surveys and the Study 9 flow assessments, the substrate data collected at quadrats was converted into the classification scheme used for the Study 9 modeling, or:

Code	Description
1	Submerged Aquatic Vegetation (25 mm)
2	Clay/Silt (0.01 mm)
3	Sand (1 mm)
4	Fine Gravel (5 mm)
5	Gravel (36 mm)
6	Cobble (160 mm)
7	Boulder (256 mm)
8	Bedrock

The dominant substrate types measured in each quadrat and the corresponding count of Elliptio in those quadrats is shown in Figure 4-4. The co-occurring mussel HSC, based on the normalized mean relative count of Elliptio by dominant substrate type, showed highest counts in silt substrates, intermediate counts in gravel and cobble substrates, and lowest counts in vegetation, sand, boulder, and bedrock dominated substrates (Table 4-1). In comparison to the DWM Delphi HSC, the co-occurring HSC gives much lower suitability for sand and vegetation dominated substrates, but somewhat higher suitability for cobble and boulder substrates. Although silt-dominated substrates contained the highest mean counts of Elliptio, 88% of all quadrats with one or more Elliptio present also contained larger substrate particles as either dominant or subdominant components.

4.5 Bed Shear Stress

Estimated bed shear stresses (BSS) at quadrat locations ranged from a minimum of <0.01 lbs/ft^2 to a maximum of 12.42 lbs/ft^2 at 1,000 cfs. Bed shear stresses were intermediate at 33,000 cfs due to the increased depths, with a maximum value of 7.78 lbs/ft^2. At the more common flows of 2,300 cfs to 11,000 cfs, mean relative quadrat counts of Elliptio were highest at BSS values between zero and 1.5 lbs/ft^2 (Figure 4-5). The resulting combined HSC curve for co-occurring mussels gave positive suitability at BSS from 0.0-6.0 lbs/ft^2, with maximum suitability below 1.5 lbs/ft^2 (Table 4-1). The co-occurring HSC curve was far broader than the DWM Delphi HSC curve, which only extended suitability to a maximum BSS of 1.0 lbs/ft^2.

4.6 Relative Shear Stress

The dimensionless parameter relative shear stress (RSS) is calculated as the ratio of estimated bed shear stress to critical shear stress, which is largely based on the size of the substrate at a particular location (i.e., at each quadrat sample). Estimated RSS values ranged from 0.0-10.3 at 1,000 cfs up to a maximum of just over 50 at 33,000 cfs. Almost all RSS values exceeding 20 occurred at quadrats with 80-100% silt or sand substrates, which possess low critical shear stresses and thus a high ratio result. It should be noted, however, that most quadrat locations in the riverine reach that were categorized as silt-dominated were typically not composed of fine, loose silt substrates but rather were more often a firm, packed dirt substrate, which would be much less subject to shear-related scour than would the loose silt deposits more characteristic of the reservoir reaches. Also notable was one quadrat where the maximum relative count of Elliptio was associated with RSS values well outside of the remaining distributions at 1,000 cfs and at 11,000 cfs (Figure 4-6); consequently for the purposes of drawing an HSC curve these values were treated as outliers. The remaining mean RSS values at both extreme flows and at the two intermediate flows resulted in a combined co-occurring mussel HSC curve with maximum suitability for RSS from 0.0 to 3.0, with zero suitability for all RSS exceeding 15.0 (Table 4-1). As for BSS described above, this co-occurring HSC is far broader than the DWM HSC produced by the Delphi process.

4.7 Conclusions

Estimating the relative suitability of different magnitudes of depth, velocity, and shear variables for a stationary aquatic species under conditions of wide and near-daily fluctuations in streamflow is subject to a certain degree of uncertainty. In this assessment, uncertainty is limited based upon the following reasonable assumptions. Channel morphology and substrate composition, which has a large effect on the model-derived estimates of each parameter, was relatively unchanged between the period of mussel quadrat sampling in September 2014 and the Study 9 collection of bathymetry data in October of the same year (Normandeau, 2016). These two assumptions related to habitat stability are clearly supported by the geomorphic study, which suggested that flows of 40,000 to 100,000 cfs would be required at Chase Island transects to mobilize coarse sediments (Stantec and Normandeau 2016). In the interim between the mussel sampling and the bathymetry data collection, flows in the Wilder riverine reach exhibited daily normal operations and never exceeded 14,000 cfs, far below channel-forming flows and highly unlikely to alter bed elevations or substrate composition.

Additional assumptions were required to determine what flow criteria were likely to have influenced the presence/absence of mussels at a particular quadrat location (e.g., limiting flows), as well as what flows were more likely to have influenced the observed density of mussels at those locations (e.g., the flows that allowed mussels to express their relative selectivity for habitat attributes, as represented by their density). The flow criteria employed (1% and 99% exceedance flows to represent maximum and minimum limiting flows, and 25% and 75% exceedance flows to represent the range where habitat suitability could influence densities) were chosen based on professional judgment of mussel experts and instream flow practitioners, but these criteria contain significant uncertainty.

Table 4-1. HSC for co-occurring mussels.

Variable	**Value**	**Co-Occuring HSC**
Depth (ft)	0	0.00
	1.5	1.00
	13.5	1.00
	22	0.50
	30	0.50
Mean Column Velocity (fps)	0	0.50
	0.1	1.00
	2.25	1.00
	5.5	0.00
Benthic Velocity (fps)	0	0.50
	0.05	1.00
	0.7	1.00
	1.5	0.00
Dominant Substrate	Vegetation	0.00
	Silt	1.00
	Sand	0.19
	Fine Gravel	0.72
	Coarse Gravel	0.72
	Cobble	0.57
	Boulder	0.29
	Bedrock	0.17
Bed Shear Stress (lbs/ft2)	0.0	1.00
	1.5	1.00
	6.0	0.00
Relative Shear Stress	0.0	1.00
	3.5	1.00
	15.0	0.00

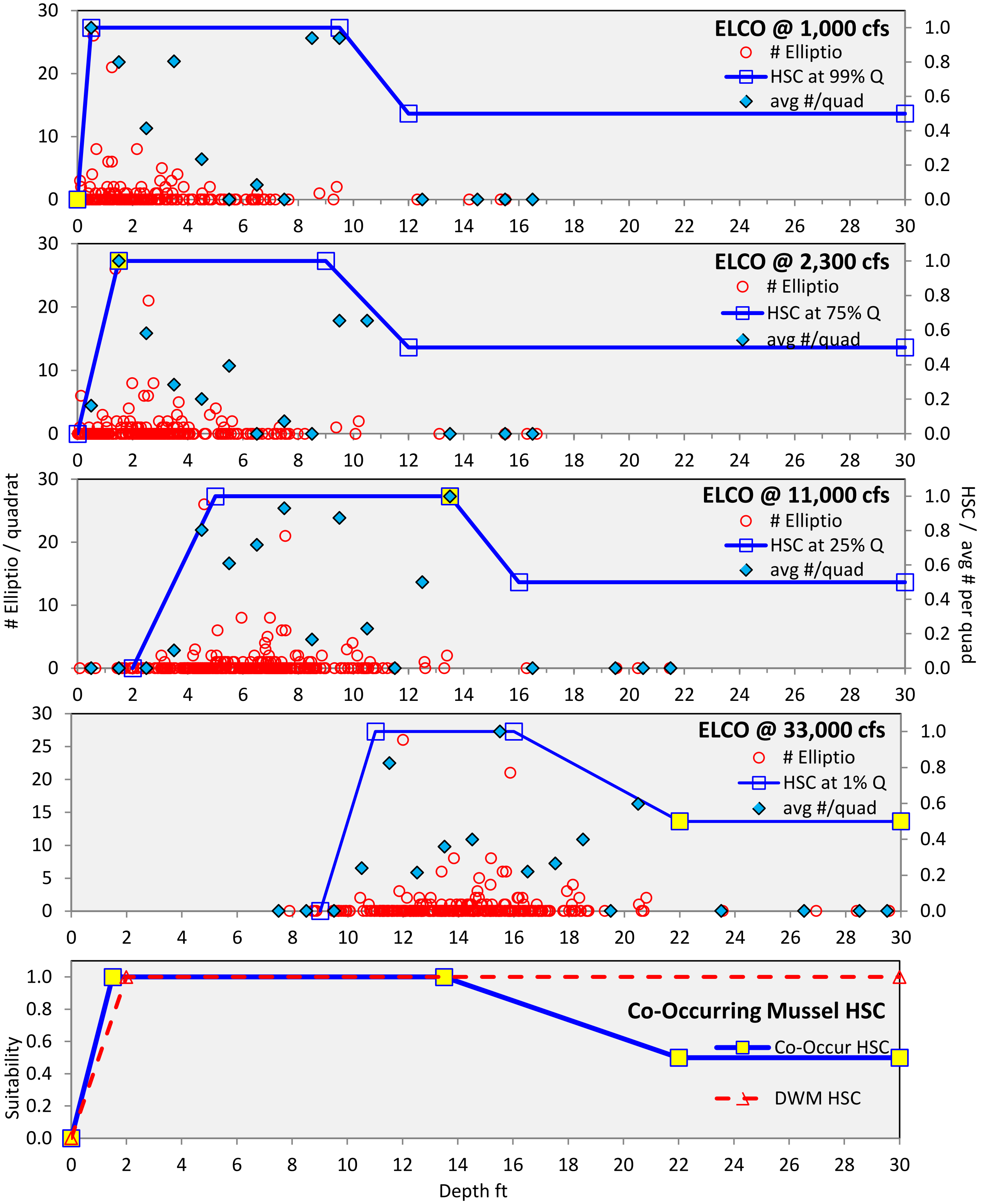

Figure 4-1. Quadrat counts of Elliptio (ELCO) (circles) and relative mean counts (diamonds) according to depth, with HSC curves (lines) at four flows. Final combined HSC curve (yellow squares) and DWM Delphi HSC curve at bottom.

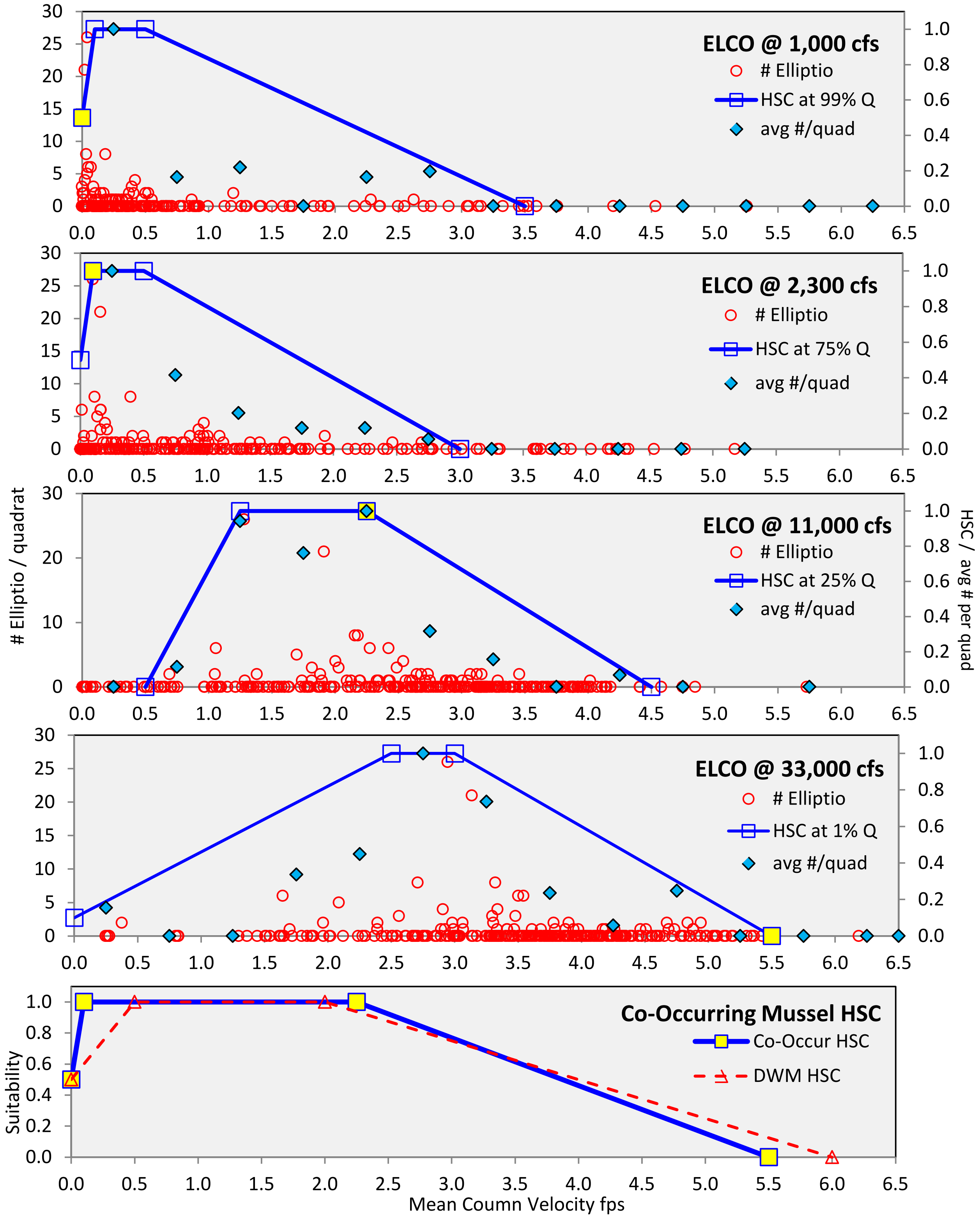

Figure 4-2. Quadrat counts of Elliptio (ELCO) (circles) and relative mean counts (diamonds) according to mean column velocity, with HSC curves (lines) at four flows. Final combined HSC curve (yellow squares) and DWM Delphi HSC curve at bottom.

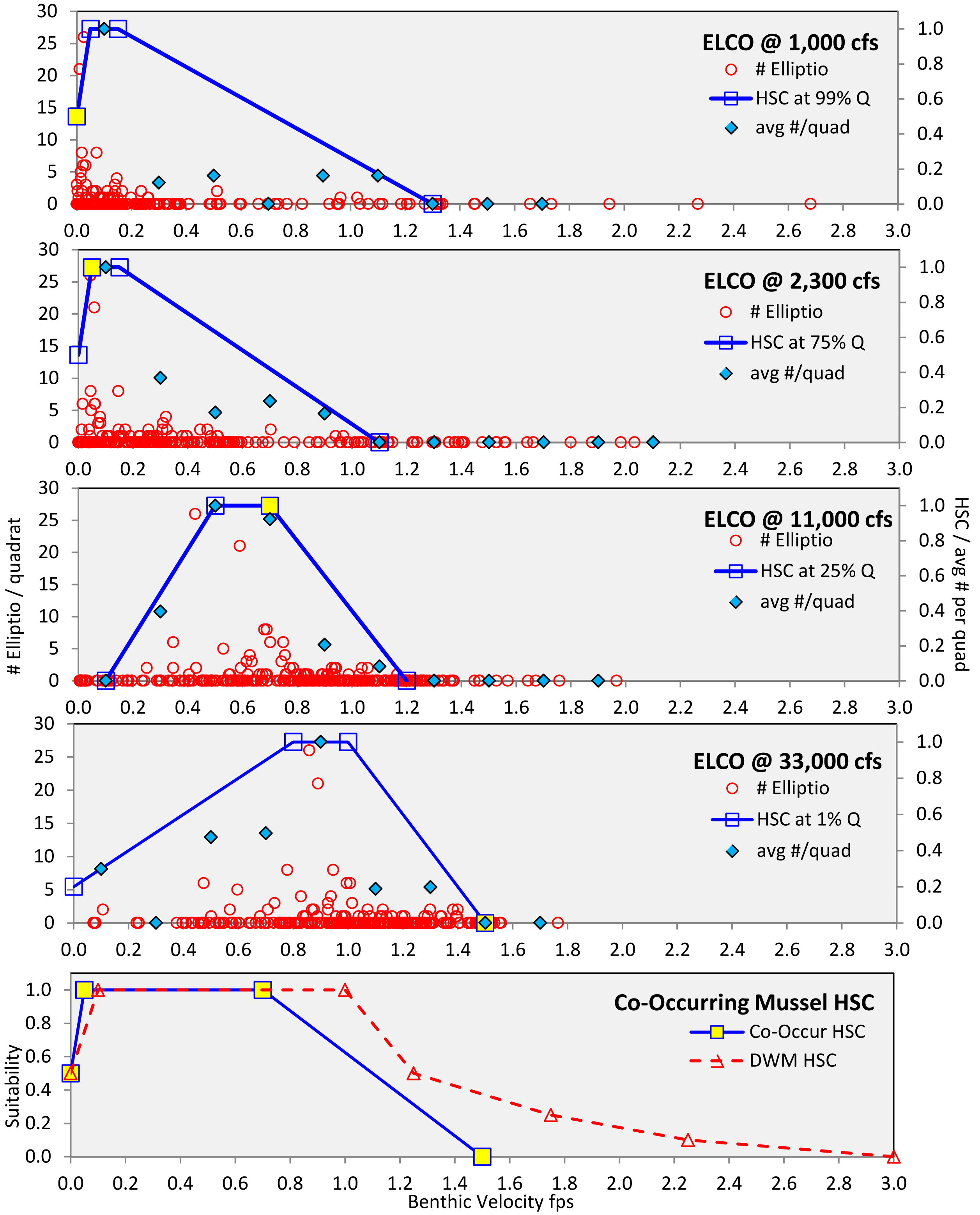

Figure 4-3. Quadrat counts of Elliptio (ELCO) (circles) and relative mean counts (diamonds) according to benthic velocity, with HSC curves (lines) at four flows. Final combined HSC curve (yellow squares) and DWM Delphi HSC curve at bottom.

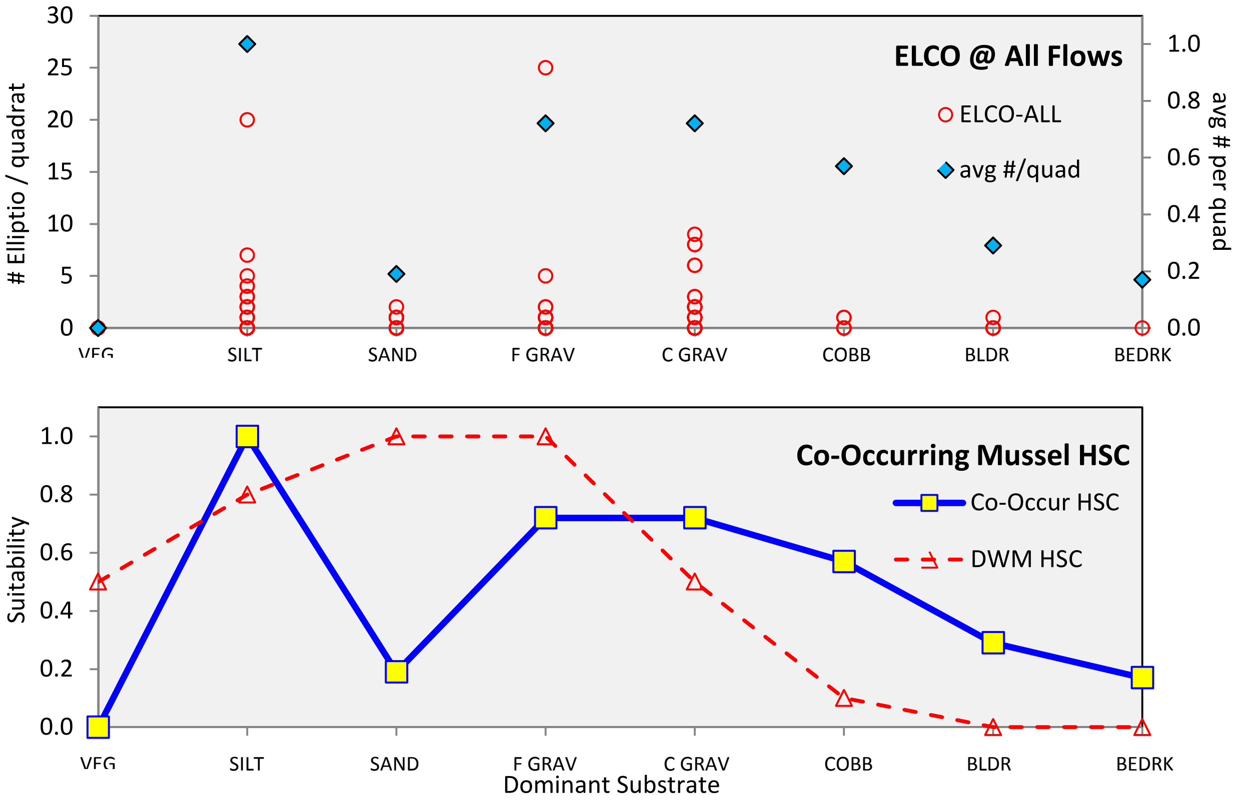

Figure 4-4. Quadrat counts of Elliptio (ELCO) (circles) and relative mean counts (diamonds) according to dominant substrate type (top). Final HSC curve (yellow squares) and DWM Delphi HSC curve at bottom.

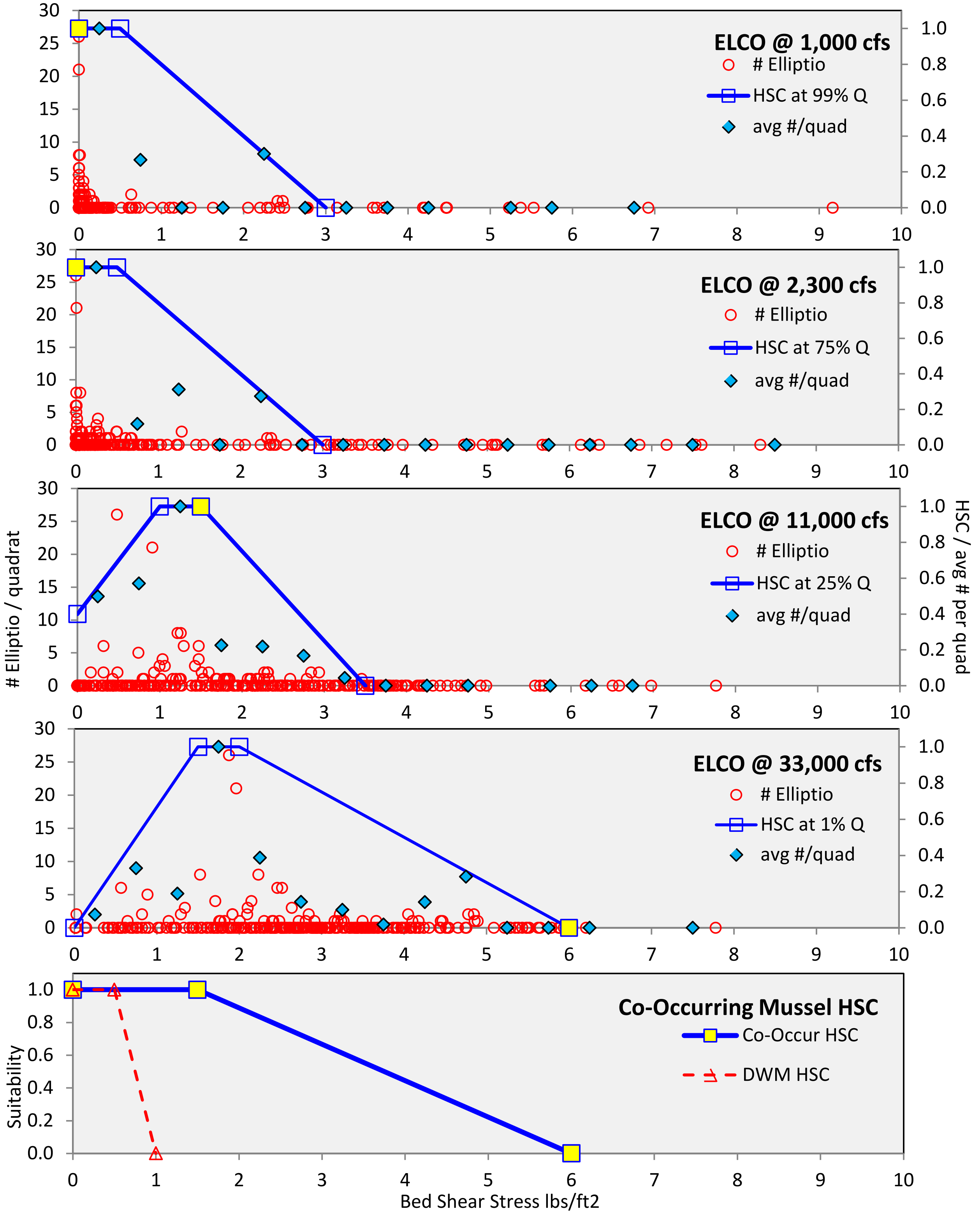

Figure 4-5. Quadrat counts of Elliptio (ELCO) (circles) and relative mean counts (diamonds) according to bed shear stress, with HSC curves (lines) at four flows. Final combined HSC curve (yellow squares) and DWM Delphi HSC curve at bottom.

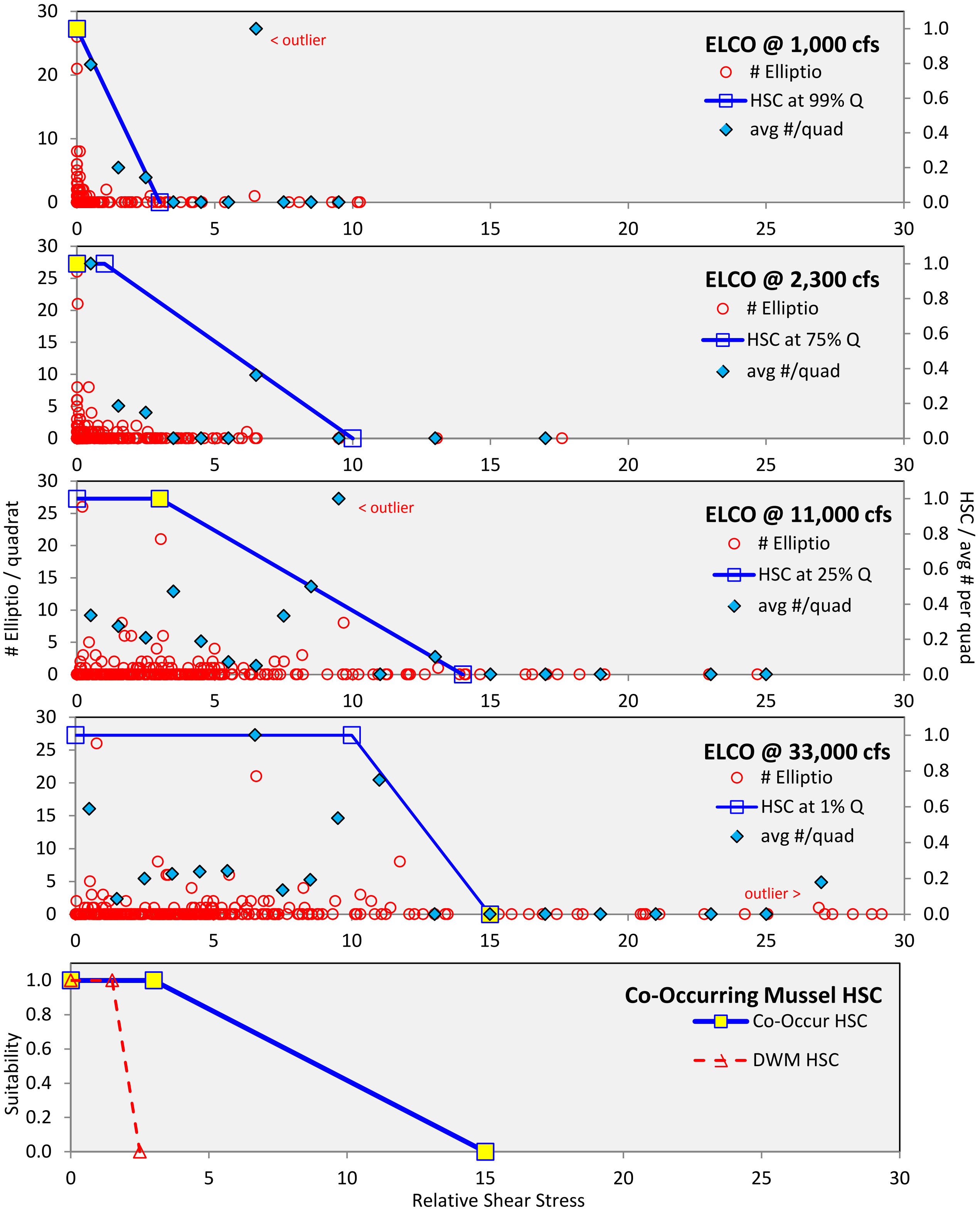

Figure 4-6. Quadrat counts of Elliptio (ELCO) (circles) and relative mean counts (diamonds) according to relative shear stress, with HSC curves (lines) at four flows. Final combined HSC curve (yellow squares) and DWM Delphi HSC curve at bottom.

When comparing the co-occurring mussel HSC developed from the above assumptions with HSC created by a Delphi panel of mussel experts for DWM (Normandeau, 2016), close correspondence was noted for the depth and velocity variables, but not for the shear variables. The former result lends confidence to the methods chosen to develop co-occurring mussel HSC, whereas the latter points to the greater uncertainty in how well shear-related variables are estimated in a hydraulic model, and how these species interact with benthic forces. The assessment of shear forces on mussel habitat is a relatively new field of research with its own suite of uncertainties.

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APPENDIX A – FORMULAS USED TO CALCULATE SHEAR VARIABLES

Benthic Velocity (BV): $A = (0.105/0.05)*DEP^{0.1667}$

$BV = MCV*(1+1/A)*(FOCAL\ HEIGHT/DEP)^{1/A}$

Shear Velocity (SV): U (calculated internally in SEFA and River2D)

Bed Shear Stress (BSS): $\tau = p_w(U)^2$

Critical Shear Stress (CSS): $\tau_c = \theta_c*((p_s-p_w)*D_{50})$

Relative Shear Stress (RSS): τ / τ_c

where:

p_w (water density, lb/ft^3) = 62.3051

p_s (density of substrate, , lb/ft^3) = 165.4395

θ_c (Shields Parameter, dimensionless) = 0.045

D_{50} (average substrate size, ft) = varies by location