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Habitat Modelling in Support of the Recovery of Channel Darter (*Percina copelandi*) Populations along the Trent River, Ontario

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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TABLE OF CONTENTS

ABSTRACT

A habitat modelling study was undertaken to inform the setting of minimum flow levels for the Trent River (Trent-Severn Waterway, Ontario) during the spawning period of the Threatened Channel Darter. Flow recommendations are required for all populations along the Trent River and for tailwater habitat below the Lock 5 dam.

The study included the following components:

(i) habitat suitability curves developed for water depth and water velocity;

(ii) regression relationships between river discharge and water depth and water velocity developed for three Channel Darter populations (Glen Ross, Lock 5 dam, Sonoco);

(iii) a two-dimensional hydrodynamic model (River2D) calibrated to predict local water depths and velocities downstream of the Lock 5 dam; and,

(iv) habitat suitability curves coupled with the River2D model's hydrodynamic predictions used to provide site-specific guidance for releasing flow through dam control gates at Lock 5.

Channel Darter were generally associated with shallow water depths (0.1 - 0.4 m), water velocities greater than 0.2 m/s, and coarse river bed material (gravel, cobble, boulder). River discharge and habitat suitability relationships differed among the three Channel Darter populations. Water depth and velocity were significantly and positively correlated to discharge only at Glen Ross. Predicted improvements to habitat suitability at Sonoco occur at discharges twice as high (> 80 m^3/s) as that expected to be optimal at Glen Ross (30 to 50 m^3/s). Water depth, water velocity, and habitat suitability downstream of the Lock 5 dam were predicted to be strongly influenced by river discharge, the amount of water released through the eastern-most gate (spill discharge) and downstream water elevation. River2D model output predicted that most improvements in habitat suitability would occur with spill discharges between 5 and 7.5 m^3/s.

Modélisation de l'habitat à l'appui du rétablissement des populations de fouille-roche gris (*Percina copelandi*) dans la rivière Trent, en Ontario

RÉSUMÉ

Une étude de modélisation de l'habitat a été entreprise pour guider l'établissement des débits minimaux dans la rivière Trent (voie navigable de Trent-Severn, en Ontario) durant la période de frai du fouille-roche gris, une espèce menacée. Il faut recommander des débits pour toutes les populations dans la rivière Trent ainsi que pour l'habitat dans le lit des rapides, en aval de la vanne de l'écluse 5.

L'étude a porté sur les composantes suivantes :

(i) élaboration de courbes du caractère propice de l'habitat pour la profondeur de l'eau et la vitesse du courant;

(ii) définition de la relation de régression entre le débit de la rivière et la profondeur de l'eau et la vitesse du courant pour les trois populations de fouille-roche gris (Glen Ross, vanne de l'écluse 5, Sonoco);

(iii) étalonnage d'un modèle hydrodynamique bidimensionnel (River2D) pour prévoir localement les profondeurs de l'eau et les vitesses du courant du cours d'eau en aval de la vanne de l'écluse 5;

(iv) utilisation des courbes du caractère propice de l'habitat combinées aux prévisions hydrodynamiques du modèle River2D pour fournir des orientations propres au site sur le débit aux vannes de régulation de l'écluse 5.

Le fouille-roche gris est généralement associé à des eaux peu profondes (de 0,1 à 0,4 mètre), à des vitesses de courant supérieures à 0,2 m/s et à un lit de rivière constitué de matériaux grossiers (gravier, galets, roches). La relation entre le débit et le caractère propice de l'habitat différait entre les trois populations de fouille-roche gris. Au site de Glen Ross seulement, la profondeur de l'eau et la vitesse du courant affichaient une corrélation positive significative avec le débit de la rivière. On peut prévoir des améliorations du caractère propice de l'habitat à Sonoco lorsque le débit est deux fois plus élevé (> 80 m^3/s) que le débit jugé optimal à Glen Ross (de 30 à 50 m^3/s). Selon les prévisions, la profondeur de l'eau, la vitesse du courant et le caractère propice des habitats situés en aval du barrage de l'écluse 5 sont fortement influencés par le débit de la rivière, le volume d'eau rejeté de la vanne située à l'extrémité est du barrage (débit d'évacuation) et la hausse du niveau des eaux en aval. La sortie du modèle produit dans River2D prévoit que les plus grandes améliorations de la qualité des habitats propices se produiront à des débits d'évacuation compris entre 5 et 7,5 m^3/s.

INTRODUCTION

The Channel Darter (*Percina copelandi*) is a small benthic fish, listed as Threatened under the Ontario *Endangered Species Act* (ESA) and Schedule 1 of the Federal *Species at Risk Act* (SARA). Many of the Canadian rivers that support Channel Darter populations are affected by dams, and the species is considered sensitive to altered flow regimes (especially during the spawning period, Winn 1953). In general, dams and associated flow regulation have negatively affected the distribution and abundance of darters in North American rivers (Freeman et al. 2001, Layzer and Scott 2006). Along the Trent River (Ontario), Channel Darter has been collected downstream of five dams between the City of Trenton and the Village of Glen Ross. Critical habitat for Channel Darter has been identified along this 22 km reach (DFO 2013). As part of the Trent-Severn Waterway, Trent River flows are primarily managed for navigation, public safety and flood control; although, water level maintenance also considers other uses such as fish and wildlife habitat, and hydroelectric power generation. Channel Darter populations along the occupied reach are fragmented by a total of seven dams.

Channel Darter utilizes shallow habitats with moderate current along the Trent River (Reid 2006, Boucher et al. 2009). Found along river-edges, riffles or at shoals, the availability of these habitats is strongly affected by changes in river discharge. Areas delineated as Channel Darter critical habitat along the Trent River have been observed to undergo minor to complete dewatering. Shoals used by the Channel Darter have been observed to be temporarily (1-2 hours) de-watered during the spawning period (Reid personal observation), and consistently dry in the fall (Reid 2006). Channel Darter was absent from typically populated shallow gravel/cobble habitats when flow was diverted during the reconstruction of a Trent River hydroelectric generating station (Coker and Portt 2011). There is concern that water flows in this system are not sufficient and suitably stable to support spawning activities. The potential effect of dewatering during the spawning period may be particularly acute given the proportionately large effect year-class strength has on the viability of short-live species and associated resilience to other stressors (e.g., the invasive Round Goby) (Coker and Portt 2011). Channel Darter population viability models indicate that population growth rate is sensitive to perturbations to the reproductive output of spawners (Venturelli et al. 2010).

The establishment of minimum flow regimes has been successful at restoring impoverished warm-water fish assemblages (including darter species) below dams in the southern United States (Higgins and Brock 1999, Layzer and Scott 2006). In response to direction provided by a multi-agency (Parks Canada Agency, Fisheries and Oceans Canada and Ontario Ministry of Natural Resources and Forestry) steering group, an instream flow needs study was initiated to recommend minimum flow levels during the Channel Darter spawning period. The information will be used to inform Parks Canada Agency staff (the agency responsible for managing flow in the Trent-Severn Waterway) of alternative flow management regimes that will minimize impacts on the Channel Darter population. Flow recommendations will enhance operational guidance developed by Coker and Portt (2011) to protect aquatic species at risk and minimize habitat disruption; and, help to ensure that the recovery of Trent River populations is not in jeopardy. Current guidance to date recommends that;

(i) flow reductions are to be done incrementally to allow fish to move from shallow water habitats; and,

(ii) significant flow reductions be avoided during the June spawning period.

Flow recommendations are required at two spatial scales:

(i) for all Channel Darter populations along the Trent River (from Glen Ross to Trenton); and,

(ii) for the tailwater habitat below the Lock 5 dam.

At the largest spatial scale, recommendations can be based on relationships between daily discharge and estimates of Channel Darter habitat suitability over the course of the spawning period. During the low flow period, water at the Lock 5 site is diverted past the Channel Darter shoal through the Frankford Ontario Power Generation hydropower generating station spillway. The beginning of the low period overlaps with the timing of Channel Darter spawning and subsequent egg incubation.

The objectives of the project were to:

(i) characterize Channel Darter habitat use during the spawning period and develop habitat suitability curves for water depth and water velocity;

(ii) develop regression relationships between daily river discharge and water depth and water velocity for Channel Darter habitat at three Trent River locations;

(iii) calibrate a two-dimensional hydrodynamic model (River2D) in order to predict local water depths and velocities downstream of the Lock 5 dam; and,

(iv) use habitat suitability curves coupled with the River2D model's hydrodynamic predictions to provide site-specific guidance for releasing flow through dam control gates at Lock 5.

METHODS

FIELD SAMPLING – HABITAT

To describe the relationship between river discharge and Channel Darter habitat conditions, monitoring stations were established at three sites along the Trent River: Glen Ross, downstream of the Lock 5 dam, and downstream of the Sonoco dam (Figures 1, 2, 3 and 4). Site selection was non-random. Site selection was based on knowledge gained from past Channel Darter collections (Reid 2004, 2006), and the contrasting influence of different flow management practices on downstream water depths and velocities at these locations. Channel Darter have been collected at other Trent River sites, but not in numbers sufficient for habitat suitability studies. At Glen Ross (Figure 2), there is no hydro-electric facility and spillway through which flow could be diverted to one side of the river. During the low flow period, water at the Lock 5 site (Figure 3) is diverted through a hydropower generating station spillway to the side of the river opposite the Channel Darter shoal. At the Sonoco site (Figure 4), the Channel Darter shoal is located downstream of the hydropower generating station spillway. At all sites, there are multiple control gates through which river flow can be released. The Trent River is between 126 and 160 m wide at the three sites.

Systematic point-transect sampling (Simonson 1993) was used to describe habitat availability at each site. At each site, habitat was characterized at 102 points systematically distributed across a grid. Each grid was comprised of six transects (running parallel to the shoreline), with 17 points along each transect. The distance between transects, and points along each transect was 4 m. Transects (and corresponding sample points) were demarcated by anchoring a rope with white floats every 4 m. Placement of the first transect was based on standardized distances from permanent shoreline markers at downstream end, mid-point, and upstream end of the grid. Physical habitat measurements taken at each point included water depth (m), mid-water column water velocity (m/s) and bed material composition. Water depth and water velocity were measured with a top-setting wading rod and a Swoffer™ water velocity meter. Water velocity was measured at 0.6 of the water depth (Bain and Stevenson 1999). Percent composition of bed material was visual assessed using the following modified Wentworth particle size categories: bedrock, boulder (>256 mm diameter), cobble (65-256 mm), and gravel (2-64 mm). Glen Ross and Lock 5 habitat conditions were measured between May 30 to September 19 (2012), and at river discharges between 11.4 and 76.4 m^3/s. Habitat at the Sonoco site was measured between June 26 and October 11, 2013, at river discharges between 18.7 and 100.6 m^3/s.

Over the period of May 31 to June 26, 2012, Channel Darter habitat use was also studied at Glen Ross and below the Lock 5 dam. River discharges were between 38.5 and 75.1 m^3/s. The study period corresponded with observations of spawning readiness from the Trent River and nearby Salmon River (Reid 2004). It is recognized that habitat use observations are not specific to spawning activity or successful egg incubation and hatching. The feasibility of in-situ characterization of spawning activity and habitats in a large system, such as the Trent River, is untested. Therefore, study data are intended to represent microhabitat use during the spawning season, rather than precise spawning measurements.

A 1-m wide swath of habitat to the right of each transect was sampled with a Smith-Root backpack electrofisher (400 V). Mean effort (seconds) along each transect was 444 (Glen Ross) and 456 (Lock 5). Channel Darter collection sites were individually marked. At each collection site, position along the transect was recorded, and physical habitat characteristics were measured. Visual-based (i.e., snorkeling) studies of stream fish microhabitat selection often include estimates of focal point elevation (vertical distance of the fish from the bottom) and focal point water velocity (velocity at the fish's snout) (Leidy 1992). For benthic fishes, focal point water velocities can be expected to be less than mean water column velocity (as measured at 0.6 of depth). Channel Darter focal point elevations could not be estimated using electrofishing-based collections. For this study, mean water column velocity is assumed to be an index of focal point velocity.

Captured Channel Darter were measured for total length (TL). Identification of sex and spawning readiness was based on differences in coloration (Etnier and Starnes 1993) and the release of eggs or milt excluded under slight pressure (gonadal maturity Stage V, Nikolsky 1963).

HABITAT SUITABILITY MODELLING

Habitat suitability curves are used to translate hydraulic and structural elements of rivers into indices of habitat quality. In this study, habitat suitability curves were constructed following the approach described by Hightower et al. (2012). Suitability curves were developed for water depth and water velocity using habitat use and availability data collected at the Glen Ross and Lock 5 sites. Habitat preferences for different bed material (i.e., substrate) compositions have been reported for Channel Darter (Schofield and Ross 2003, Boucher et al. 2009, Proulx 2014) and other darter species (e.g., Freeman et al. 1997). However, substrate suitability curves were not constructed as there were large differences in bed material between the Glen Ross and Lock 5 sites, and the potential transferability of curves was considered poor.

Modeling was conducted using a Bayesian approach to ascertain resource use in proportion to availability at site. A Bayesian modelling approach was selected for the following reasons:

(i) Bayesian models incorporate uncertainty and provide estimates of uncertainty for suitability indexes;

(ii) models can be easily updated when new data is available (using previous parameter estimates as priors); and,

(iii) associated Markov chain Monte Carlo (MCMC) algorithms are well suited for fitting difficult models.

A multinomial distribution was used in the models to account for the possible selection of different habitat types. The probability of using habitat category *i* was modeled as:

$$P_i = \frac{w_i a_i}{\sum_{j=1}^{n}(w_j a_j)}$$

where a_i is the proportion of habitat available in category *i*, and w_i is the unscaled relative probability of using habitat *i* based on the frequency of Channel Darters in habitat *i* if all habitats were equally available. Estimates of w_i would be similar in magnitude if all habitats were used in proportion to their availability. As per Hightower et al. (2012), w_i values were rescaled to a maximum of 1 for all habitat variables, so that the scaled w_i values could be used as habitat suitability estimates. Uninformative priors were used (i.e., existing suitability indexes, HSI, were not incorporated) in order to develop habitat suitability curves based strictly on existing data. Variables were aggregated into bins in order to use the multinomial model. Water depths and velocities available were determined from the transect sites sampled each day. Depths were segmented into 0.1 m bins, ranging from 0 to 1.1 m. Velocities were segmented into 0.2 m^2/s bins, with a range from 0 to 1.2 m^2/s. The proportion of the sampling area (i.e., a_i) available within each velocity or depth bin was calculated based on frequency distributions. Likewise, the frequency where Channel Darter were sampled was calculated from catch data.

Analysis was conducted in OpenBugs (version 3.2.3) using MCMC algorithms (two chains, 100,000 iterations with a 10,000 iteration burn-in period). The numbers of iterations selected removed the influence of initial values on results, and ensured a stable model solution. Model convergence was assessed for each run by plotting the sample value against the iteration number (i.e., history) to ensure there was stationary distribution. In addition, the posterior distribution was assessed for normality (i.e., density) and autocorrelation. Uncertainty for each suitability curve was characterized using the 95% Bayesian credible interval (CI). The probability of no habitat preference (Bayesian *P*-value) for water velocity and water depth was estimated by comparing the observed data to simulated data sets generated under the hypothesis of no preference (Thomas et al. 2004).

DEVELOPMENT OF DISCHARGE-HABITAT MODELS

For the Glen Ross, Lock 5, and Sonoco sites, regression relationships were developed to relate daily river discharge to:

(i) mean water depth;

(ii) mean water velocity; and

(iii) a composite habitat suitability index (CSI) score.

Mean water depth and water velocity were calculated for each sampling date using the point-transect measurements. CSI was calculated as:

$$\frac{\sum(d\mathrm{HSI}_{ij} \times v\mathrm{HSI}_{ij})}{N}$$

where $d\mathrm{HSI}_{ij}$ is the habitat suitability estimate associated with the water depth measurement at point *i* along transect *j*, $v\mathrm{HSI}_{ij}$ is the habitat suitability estimate associated with the water velocity measurement at point *ij*, and *N* = number of points sampled. Water depth and velocity measurements were converted to HSI scores using the Glen Ross, Bayesian-modelled habitat suitability curves.

Discharge-habitat models for water depth and velocity were derived using least-squares regression analysis (Morrison and Smokorowski 2000). Daily Trent River discharge data were provided by Parks Canada and Ontario Power Generation.

RIVER2D MODELLING

A two-dimensional hydrodynamic model was used to predict water depths and velocities at a Channel Darter shoal along the east bank downstream of the Lock 5 dam (Figure 3). Flow complexity at the site precluded the application of a simpler one-dimensional model. Model simulations examined the effects of:

(i) increasing the amount of water released from the eastern-most dam spill gate; and,

(ii) different downstream water surface elevations.

The model used was River2D; a two-dimensional, depth averaged finite element hydrodynamic model developed to model fish habitat evaluation studies in streams and rivers (Steffler and Blackburn 2002). The model can predict water depth and velocity, laterally and longitudinally, throughout a river reach over a range of flows. The hydrodynamic component of River2D is based on the two-dimensional, depth-averaged St. Venant Equations, which represent the conservation of water mass and the lateral and longitudinal momentum vectors (Steffler and Blackburn 2002). The model is able to accommodate supercritical/subcritical flow transitions, wetting and drying of banks, and variable wetted areas. Past studies have used River2D to model the availability of fish habitat at different stream and river flows (Stewart et al. 2005, Gard 2009), investigate the effects of daily hydropeaking on fish habitat (Boavida et al. 2013), and to design and evaluate fish habitat enhancements (Lacey and Millar 2004, Pasternack et al. 2004, Lee et al. 2010).

FIELD DATA COLLECTION – RIVER2D MODELLING

Inputs required by River2D include channel bed topography, equivalent roughness height of the bed material, transverse eddy viscosity distributions, and boundary conditions (Steffler and Blackburn 2002). Of these inputs, channel bed topography, followed by bed roughness, are the most important parameters. Field data collection below the Lock 5 dam required to build, calibrate, and validate the River2D model took place September 16 to 19, 2013, and on June 26, 2014. Field activities included: bathymetric and topographic surveys, collection of low altitude drone aerial imagery, discharge measurements, and water depth and velocity measurements.

Topographical and bathymetric data were collected from September 16 to 19, 2013. A Trimble R8 GNSS Survey System was used to survey points located above the water surface or in depths less than 0.5 m. A SonTek RiverSurveyer™ M9 and a SonTek Real Time Kinematic (RTK) GPS were used to collect channel bathymetric data and measure the channel bed elevation in water depths greater than 0.3 m. Surveying focused on breaks in bed topography, with a greater density of survey points located in areas of complex bed topography. In total, 2,523 topographical measurements were collected using the Trimble R8 system and 31,434 bathometric measurements were collected using the SonTek M9 system. While bathymetric survey data were collected at a relatively high density, it was further supplemented with depths derived from high resolution optical imagery taken at low altitude by a drone (GoPro camera). A nonparametric piecewise regression was used to correlate measured water depths with brightness values in the blue band of a geometrically corrected image to predict water depth at time of survey. Depths were subtracted from a water surface elevation surface to estimate bed elevation. The spatial resolution of the predicted surface is 0.25 m. Predicted water depths have a standard error of 0.08 m (for depths between 0.5 and 4 m).

On September 16, 2013, several discharge measurements were collected using the SonTek RiverSurveyer. Thirty-one spot water depth and velocity measurements were taken with a SonTek Flowtracker™ and wading rod within the study area. A Garmin GPSMap 64ST handheld GPS was used to measure position. Forty additional depth and velocity measurements were taken at a higher discharge level on June 26, 2014.

River discharge during the two sampling periods was estimated to be 22 m^3/s (September 2013) and 87 m^3/s (June 2014). September discharge was based on an estimate of approximately 20 m^3/s through the Frankford Generation Station spillway (data source: Ontario Power Generation), and a field estimate of 2 m^3/s leakage through closed dam stop gates. June discharge was based on an estimate of approximately 60 m^3/s (estimated precision 2 m^3/s) through the Frankford Generation Station spillway (data source: Ontario Power Generation), and a field estimate of 27 m^3/s through the eastern-most stop gate. Estimates of flow through the generating station provided by Ontario Power Generation were based on back-calculations from energy production. The accuracy of these estimates is unknown and maybe poor given the age of the facility (constructed in 1913).

MODEL DEVELOPMENT

A computational mesh developed from bed topography measurements is required for River2D to solve local water depth and velocity conditions. To correctly model flows in the study area, the entire reach between Lock 4 and Lock 5 dams was included, as the Lock 4 dam strongly influences water levels more than 350 m downstream of Lock 5. Due to the distance of nearly 2.5 km between dams, the bed elevation of the channel located beyond 350 m downstream of Lock 5 was approximated using a Digital Elevation Model (DEM). The DEM was provided by the Mapping and Geomatics Services Section, Ontario Ministry of Natural Resources and Forestry. Steps taken to develop the bed mesh were:

(i) merge survey data with DEM and optical imagery data,

(ii) input topographic breakpoints,

(iii) create a Triangulated Irregular Network (TIN),

(iv) after trial runs, increase point densities in problem areas,

(v) rerun and repeat until model converges, and

(vi) validate roughness values (see validation results below).

The bed mesh contained 41,153 nodes and 81,094 elements, and had a Quality Index of 0.38 (within the acceptable range of 0.15 to 0.5 identified in River 2D Mesh manual). Along the study reach, node density was variable; highest in the Channel Darter habitat area (50-75 cm) and within 350 m of the Lock 5 dam (1 m), and lowest along the reach downstream of the dam tailwaters to the Lock 4 dam (>2 m). Variation in node density reflected differences in the complexity of bed topography and flow fields, and a greater interest in modelling depth and velocities in the Channel Darter habitat area.

MODEL CALIBRATION AND VALIDATION

The River2D model was calibrated using June 26, 2014 water depth and velocity measurements, and by modifying three input parameters (bed roughness, spill gate discharge and downstream water surface elevation). Calibration requires matching modelled flows to field-measured water depths and velocities. The roughness value of the bed was set at 10 times the standard deviation in bed elevations from the original survey points. Roughness value selection was based on:

(i) comparisons between modelled and measured depths and velocities using linear regression and Root Mean Square Error (RMSE), and

(ii) the poor performance of the model at higher values.

The value is similar to that applied in gravel-cobble rivers, where the roughness value, *k*, is set to 4 times the largest grain diameter (Steffler and Blackburn 2002). Transverse eddy viscosity distributions were left at default values. It was assumed that:

(i) exact channel depth and shape were not required downstream of the surveyed area to run the model due to the backwater conditions caused by Lock 4,

(ii) groundwater losses or gains were negligible for the time periods modelled, and

(iii) bed topography did not change over the course of the modelling exercise.

The model was validated using water depth and velocity measurements collected on September 15, 2013. Modelled and measured values were compared using linear regression and mean average error (MAE) (Figure 5). The slope of the regression line for water velocity was 0.68 with an intercept of 0.14 m/s and r^2 of 0.67. For depth, the regression line slope was 0.81, an intercept of 0.05 m, and r^2 of 0.59. Perfect agreement would be indicated by a slope of 1, and an intercept of 0. No pattern of over- or underestimation of values was evident (Figure 5). MAE was 13.2% for water depth and 13.4% for velocity. MAE values are comparable or lower than other River 2D values reported in the literature (Hayes et al. 2007, Lacey and Millar 2004, Kozarek et al. 2010). Differences between modelled and measured values could be due to sources of error related to GPS location measurements, estimates of the volume of water released from the dam, and changes to the channel bed topography between September 2013 and June 2014.

The collection of validation data was independent of the collection of mesh data. Consequently, the accuracy of results is very conservative, and is not biased by selecting validation data where the topographic survey density was very high.

MODEL SIMULATIONS

Once calibrated and validated, the model was run for:

(i) river discharges of 20, 30, and 60 m^3/s, and

(ii) downstream boundary water surface elevations of 99.91 m, 100.00 m, and 100.14 m.

The three discharges correspond to the lower quartile, median, and upper quartile of historical flows at Lock 5 for mid-June to mid-July (based on 37 years of Parks Canada monitoring data). Outflow conditions were based on 2013 and 2014 water surface elevation data, measured daily at the Lock 4 dam (provided by Innergex Renewable Energy, Inc). For each combination of river discharge and downstream boundary water surface elevation values (n = 9), the amount of water diverted through the eastern-most gate was incrementally increased between runs; starting with 0 m^3/s being diverted, and then 2.5, 5, 7.5, 10, 12.5, 15, and 20 m^3/s. In total, 72 model simulations were run.

Suitability of Lock 5 habitat at different flow conditions was assessed based on water depth, water velocity, and CSI score. For each simulation, predicted water depths and water velocities were characterized using a 5 cm square grid overlain over the area of Channel Darter habitat.

For each run, depth and velocity at each grid-point was exported (n = 83,410 points) and the percentage of points within individual velocity or depth bins was calculated. As the size of grid-points was constant, model output was not converted to measures of weighted useable area (WUA). Suitability differences were primarily interpreted using the following ranges: water depths between 0.1 and 0.3 m, and water velocities between 0.2 and 0.6 m/s. These ranges were selected based on Channel Darter habitat use information at Glen Ross.

RESULTS

HABITAT USE

Glen Ross

From May 31 to June 26, 121 Channel Darter (mean length: 50.2 mm TL; range: 28 to 69) were collected. Between 10 and 43 individuals were collected during each sampling event. Mean electrofishing catch-per-unit-effort (CPUE) across dates sampled was 0.53 individuals per minute (range: 0.18 to 1.37). CPUE varied with daily river discharge. CPUE was 1.5 to 6 times higher when discharge was between 38.5 and 40.5 m^3/s, compared to sampling dates with greater flows (67.5 and 70.5 m^3/s). Over this period, water temperatures ranged from 19 to 27°C. Spawning ready individuals (7♀ and 12♂) were collected over the sampling time period. The ratio of males and females collected was 1.2:1.

Channel Darter captures were generally associated with shallow water depths (0.1 - 0.3 m), water velocities greater than 0.2 m/s, and gravel and cobble substrates (Figures 6 and 7). There was a weak positive correlation between water depth and water velocity at Channel Darter collection points ($r = 0.22$, $p = 0.01$). Individual captures were largely concentrated along the riverbank, and at the upstream and downstream ends of the sampling area (Figure 6). The pattern of capture reflected the spatial distribution of coarse bed material.

Habitat suitability at Glen Ross was predicted to improve rapidly as water velocities increase from zero, and to be greatest at water depths between 0.1 and 0.4 m (Figure 7). The Bayesian multinomial model produced scaled resource functions for:

(i) water velocity that was relatively flat for 0.4 m/s and above, with a maximum at the highest velocity bin; and,

(ii) water depth with a maximum of 0.2 m.

Estimated suitabilities were relatively precise (narrow 95% CI). Estimated probabilities of no habitat preference were $P < 0.001$.

Lock 5

From June 4 to June 25, 127 Channel Darter (mean length: 51.2 mm TL; range: 42 to 68) were collected. Between 11 and 58 individuals were collected during each sampling event. Mean electrofishing catch-per-unit-effort (CPUE) across dates sampled was 0.34 individuals per minute (range: 0.17 to 0.87). No pattern between CPUE and daily discharge was evident. Over this period, water temperatures ranged from 19 to 26°C. Seven spawning ready individuals (1 ♀ and 6 ♂) were collected from June 11 to 25. The ratio of males and females was 1.4:1.

At Lock 5, Channel Darter captures were generally associated with shallow to moderate water depths (0.1 - 0.4 m), low water velocities (<0.1 m/s), and cobble and boulder substrates (Figures 8 and 9). There was a moderate negative correlation between water depth and water velocity at Channel Darter collection points ($r = 0.34$, $p = 0.002$). Individual captures were relatively widespread across the sampling area (Figure 8).

Channel Darter habitat suitability at Lock 5 was predicted to improve as water velocities increase from zero, and to be greatest at water depths between 0.3 and 0.6 m (Figure 9). The Bayesian multinomial model produced scaled resource functions for:

(i) water velocity that was relatively flat for 0.1 m/s and above, with a maximum at 0.2 m/s; and,

(ii) water depth with a maximum of 0.4 m.

In contrast to Glen Ross resource selection functions, estimated suitabilities were imprecise (wide 95% CI). Estimated probabilities of no habitat preference were $P = 0.027$ for water depth. Data did not provide strong support for a water velocity habitat preference ($P = 0.16$). In contrast to the Glen Ross site, the proportion of available habitat with water velocities greater than 0.2 m/s was very low.

Discharge-Habitat Models

Relationships between river discharge and water depth, water velocity, and habitat suitability differed among the three sites. At Glen Ross, water depth and velocity were significantly and positively correlated to discharge ($r^2 = 0.95$ and 0.98; $p<0.0001$) (regression equations provided in Figure 10). Discharge was not a significant predictor of water depth or water velocity at the Lock 5 site ($p>0.18$). There was a significant positive relationship between discharge and water velocity at the Sonoco site ($r^2 = 0.86$; $p<0.0001$), but not between discharge and water depth ($p>0.65$). For Sonoco, the regression equation was:

$$\text{mean water velocity} = -0.012408+0.0041 \times \text{discharge}.$$

At the Glen Ross site, discharges between 30 and 40 m^3/s were predicted to provide 60-80% of the habitat with water velocities >0.2 m/s, and a mean water velocity between 0.2 and 0.3 m/s. Over these discharges, mean water depth was predicted to range from 0.3 to 0.35 m. At higher discharges, water depths increased and the amount of habitat with preferred water depths decline.

Plots of CSI scores vs river discharge indicate that responses differed in shape and direction among the three sites (Figure 11). At Glen Ross, habitat suitability improved as discharge increased from 10 to 40 m^3/s, but declined above 50 m^3/s. Glen Ross and Lock 5 CSI scores were similar when discharge was ≤ 20 m^3/s. However, there was no change in suitable habitat at Lock 5 as discharge increased. Habitat suitability at Sonoco generally improved in a linear fashion as discharge increased above 20 m^3/s. The highest Sonoco CSI scores were associated with higher river discharges (>80 m^3/s) than present when Glen Ross and Lock 5 were sampled in 2012.

RIVER2D MODELLING

Water depth, water velocity and habitat suitability at the Lock 5 Channel Darter habitat were predicted to be strongly influenced by river discharge, the amount of water released through the eastern-most gate (spill discharge) and downstream water elevation (Figures 12, 13, and 14).

For most simulations, the largest increase in the availability of habitats with water depths between 0.1 and 0.3 m was associated with increasing spill discharge from 0 to 5 m^3/s. At 5 m^3/s, ~45% of area modelled was predicted to be within this depth range (Figure 12). Additional increases resulted in little or no improvement to either the amount of wetted habitat or habitats with the 0.1 to 0.3 m depth range. In contrast to the other simulations, at the highest river discharge (60 m^3/s) and water elevation (100.14 m), a negative relationship between spillage and the percentage of points with depths between 0.1 and 0.3 was predicted. At 20 and 30 m^3/s, increasing spill discharge only resulted in a small improvement when the modelled downstream water elevation was 100.14 m.

At river discharges of 20 and 30 m^3/s, the greatest change in habitat area with water velocities between 0.2 and 0.6 m/s was associated with increasing spill discharge from 0 to 5 m^3/s. At 5 m^3/s, ~35% of area modelled was predicted to be within this velocity range (Figure 13). Releasing more water (i.e., 10 m^3/s) was predicted to have only a small positive effect on the percentage of habitat with these velocities. At 60 m^3/s, releasing more water was predicted to have a greater positive effect on downstream water velocities; with improvements continuing up to a spill discharge of 12.5 m^3/s. The predicted response of water velocities to increased spill discharge varied with downstream water elevation. The rate of increase in water velocity was slower at the lowest downstream water elevation (99.91 m).

Composite habitat suitability increased with greater spill discharge for all combinations of river discharge and downstream water elevation (Figure 14). As previously identified for water depth and velocity, the largest increases in suitability were predicted to occur as spill discharge increases from 0 to 5 m^3/s. Unlike the water depth and velocity ranges previously interpreted, composite habitat suitability scores continued to increase up to 20 m^3/s (although at a much reduced rate). The shape of predicted discharge vs CSI relationships is not surprising given the shape of the resource selection function for water velocity. Variation in composite habitat suitability scores as a result of downstream water levels was less than predicted individually for water depth and velocity.

DISCUSSION

The influence of hydraulic conditions and bed material composition (i.e., microhabitat characteristics) on Channel Darter habitat use in the Trent River was consistent with recent studies undertaken in Quebec rivers (Boucher et al. 2009, Proulx 2014). These relationships were also consistent with the numerous studies of microhabitat use by other darter species (e.g., Paine et al. 1982, Leidy 1992, Chipps et al. 1994, Freeman et al. 1997, Harding et al. 1998, Skyfield and Grossman 2008). The association of Trent River Channel Darter with coarse bed material, and water velocities >0.2 m/s has also been observed in Quebec rivers (Boucher et al. 2009, Proulx 2014). Support for the selection of faster water velocities differed between Glen Ross and Lock 5; reflective of the general lack of water velocities ≥ 0.2 m/s at Lock 5. In the Trent River, Channel Darter depth-suitability relationships were also evident. Similarly, Boucher et al. (2009) reported water depth to influence habitat selection in the Richelieu River, Quebec. Alternatively, studies in Ottawa River tributaries did not find depth to have significant influence on Channel Darter habitat selection (Boucher et al. 2009, Proulx 2014). However, for both Ontario and Quebec rivers, most late-spring and summer Channel Darter collections were from water depths of 0.2 to 0.4 m. Suitable water velocities and depths identified for the Trent River were markedly different than those selected by Giguère et al. (2005) to model the effect of water level fluctuations on the availability of “safe reproduction” habitat along the lower St. Lawrence River. For this much larger river system, spawning and egg development habitat features included water velocities >0.05 m/s and water depths >0.45 m and <1.5 m.

In the Trent River, spawning-ready Channel Darter have been collected from late-May to early July (Reid 2004, this study). This period of capture extended two weeks later (and at warmer water temperatures) than observed by Comtois et al. (2004) in the Gatineau River. However, Winn (1953) observed spawning to occur during July at similar water temperatures in the Cheboygan River, Michigan. Water temperatures ranged from 14 to 19˚C in the Gatineau River during the period of spawning readiness. Additionally, Comtois et al. (2004) did not sample past June 23. By mid-June, Trent River water temperatures are typically higher than 20°C. At these temperatures, the duration of egg incubation for darter species is generally 5 to 10 days (Hubbs et al. 1969, Paine 1984, Simon and Wallus 2005). Therefore, the period of Channel Darter spawning and egg incubation can be expected to extend into the second week of July.

Improved water-level management has been identified as a means to mitigate threats related to dams, and improve and expand the extent of suitable Channel Darter habitat (DFO 2013). Modelling results from this study can be used to inform the setting of flow recommendations during the spawning period. However, results also indicate that a single Trent River flow recommendation will not meet this goal. First, areas of Channel Darter habitat along the Trent River respond differently to increases in river discharge. At Glen Ross and Sonoco, habitat suitability increased with discharge. However, discharge-habitat models indicate that optimum river discharges differ between sites. Predicted improvements to habitat suitability at Sonoco occur at discharges twice as high (> 80 m^3/s) as that expected to be optimal at Glen Ross (30 to 50 m^3/s). Improvements to Channel Darter habitat at Lock 5 require releasing water through the eastern-most dam gate. These improvements will be dependent on: the amount of water released; whether river flows are below-average, average or above-average; and the effect of the Lock 4 dam on water level elevation. River2D model output predicts that most of the improvement in habitat suitability will occur with spill discharges between 5 and 7.5 m^3/s.

Validation and monitoring are important components of model development and application (Aber 1997). Future field surveys may need to be undertaken to evaluate and adjust the River2D model and associated flow recommendations. These could include the following:

1) Measurements of water depth and velocity (and Channel Darter habitat use) during controlled releases from the eastern-most Lock 5 dam gate to further validate River2D model predictions and assess the response of Channel Darter to increased flows;

2) The interpretation of River2D water depth and velocity predictions was based on habitat suitability curves developed from a single site (Glen Ross) and field season (2012). Mean June 2012 river discharge (52.5 m^3/s) was 35 m^3/s less than the June mean over the previous 10 year period. The generality (or transferability) of suitability curves is not known. Habitat use relationships have been found to be transferable among watercourses for some darter species but not others (Bain 1995, Freeman et al. 1997, Leftwich et al. 1997). Further habitat selection studies at Glen Ross and other river sites (where flow is not diverted through hydro-electric generating stations) would permit an assessment of how habitat variation across sites and among years affects flow recommendations (Bozek and Rahel 1992).

3) A key assumption of this study was that habitat preferences inferred from collections of adult Channel Darter are representative of conditions required for successful spawning and egg incubation. Observations on spawning behaviour have only been reported in the literature from one location; a 30 m wide section of the Cheboygan River (Winn 1953). Visual-based studies could be attempted at sites along the Trent River to corroborate electrofishing-based interpretations.

4) Bed topography at the Lock 5 site is very complex, and accordingly has a large influence on local flow patterns and characteristics. Extreme flow events are expected to redistribute coarse bed material, and change the relationship between spill discharge and local water depth and velocity conditions. In this case, River2D model predictions would need to be revised using update bed topography information.

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FIGURES

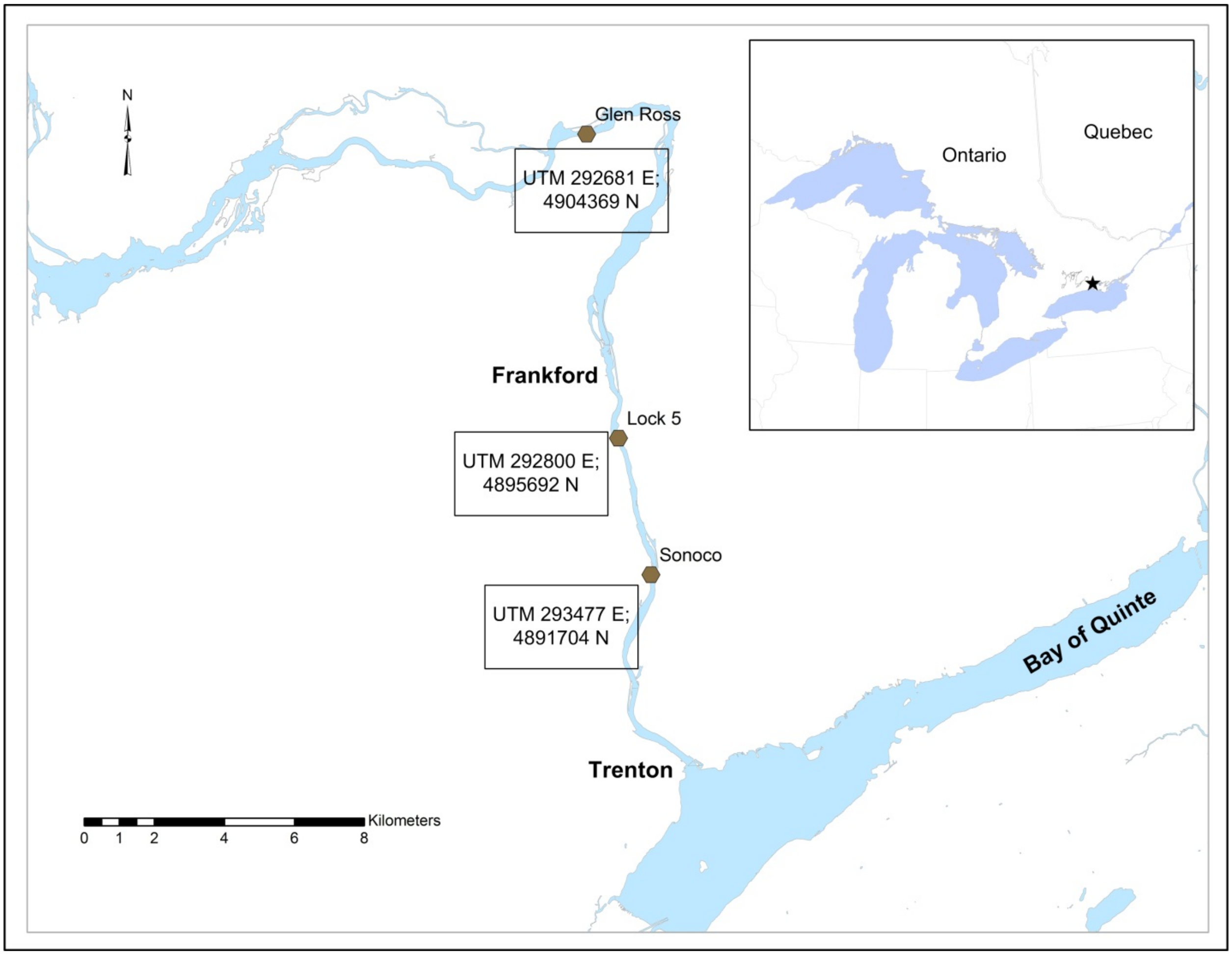

Figure 1. Distribution of Channel Darter study sites along the Trent River. Location of the Trent River in the Great Lakes basin is provided in the inset map.

Figure 2. Aerial photo of the Glen Ross study reach with the dam and Channel Darter habitat study area indicated.

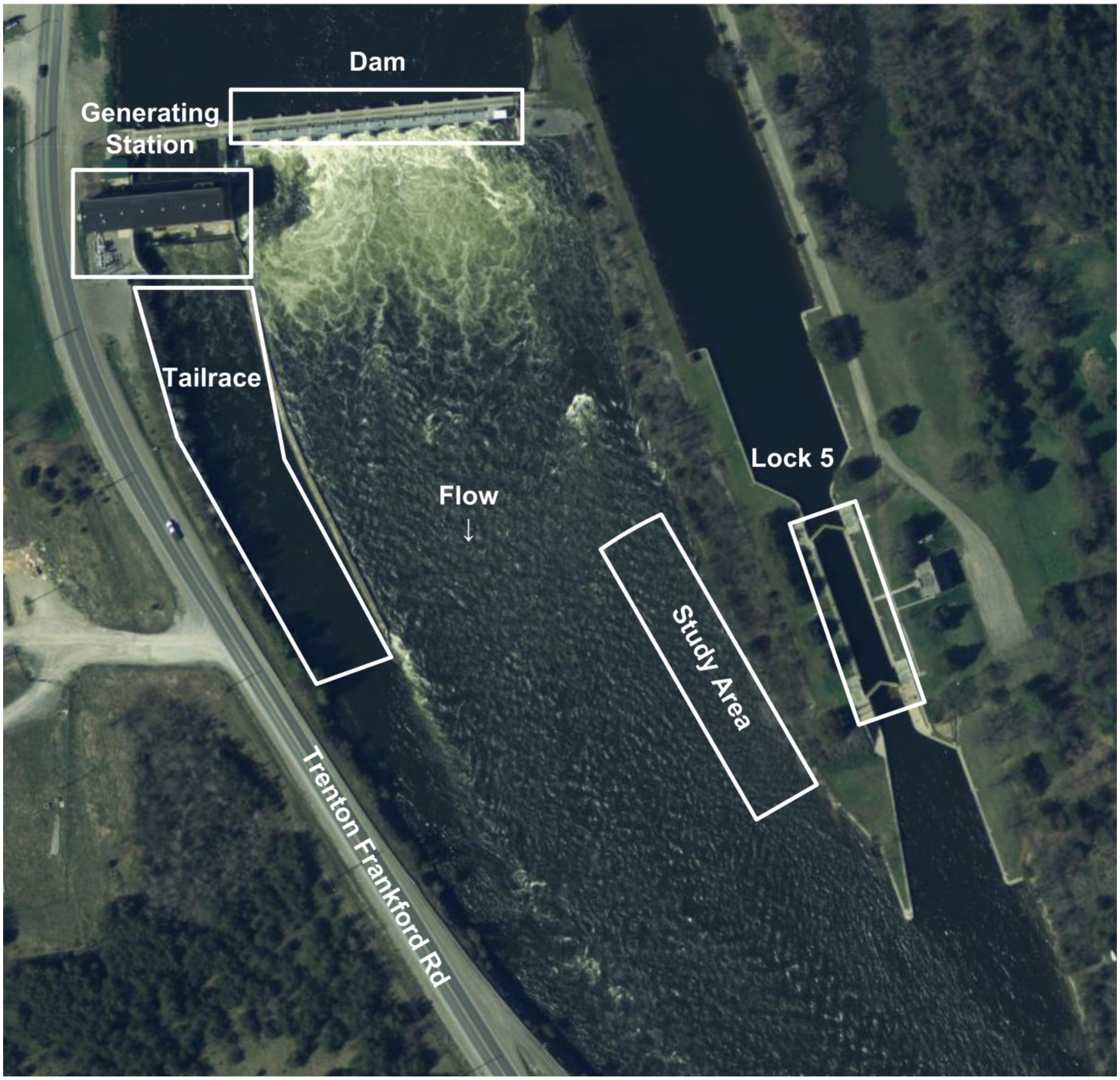

Figure 3. Aerial photo of the Lock 5 study reach with the lock, dam, Ontario Power Generation Station and Channel Darter habitat study area indicated. Lock 4 is located approximately 2.5 km downstream.

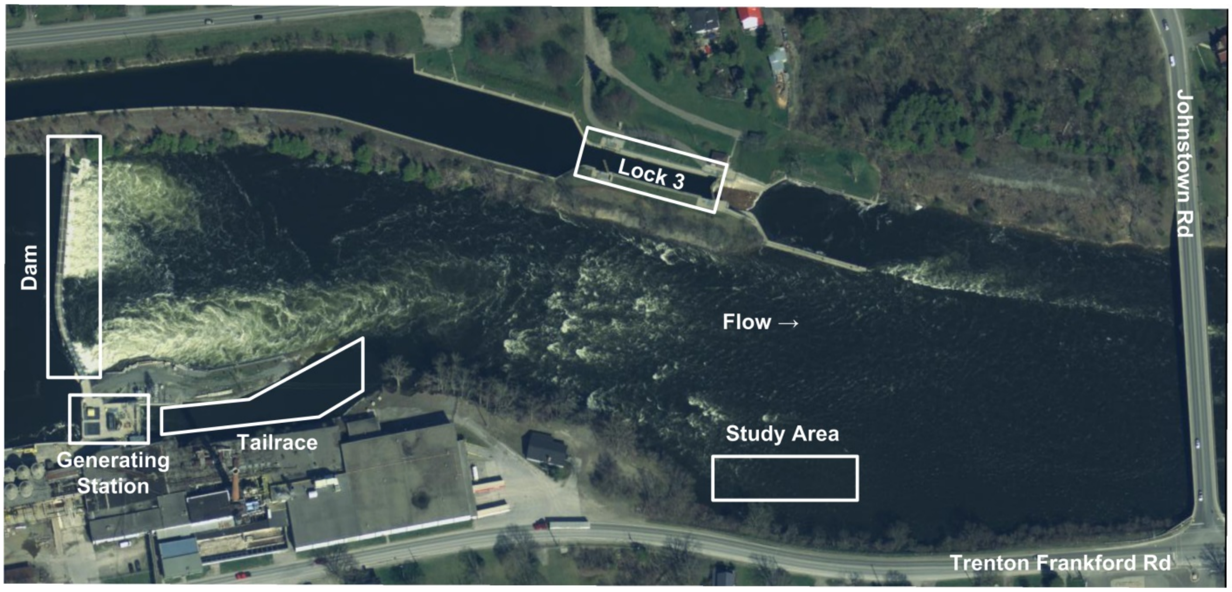

Figure 4. Aerial photo of the Sonoco study reach with the lock, dam, Sonoco Generating Station and Channel Darter habitat study area indicated.

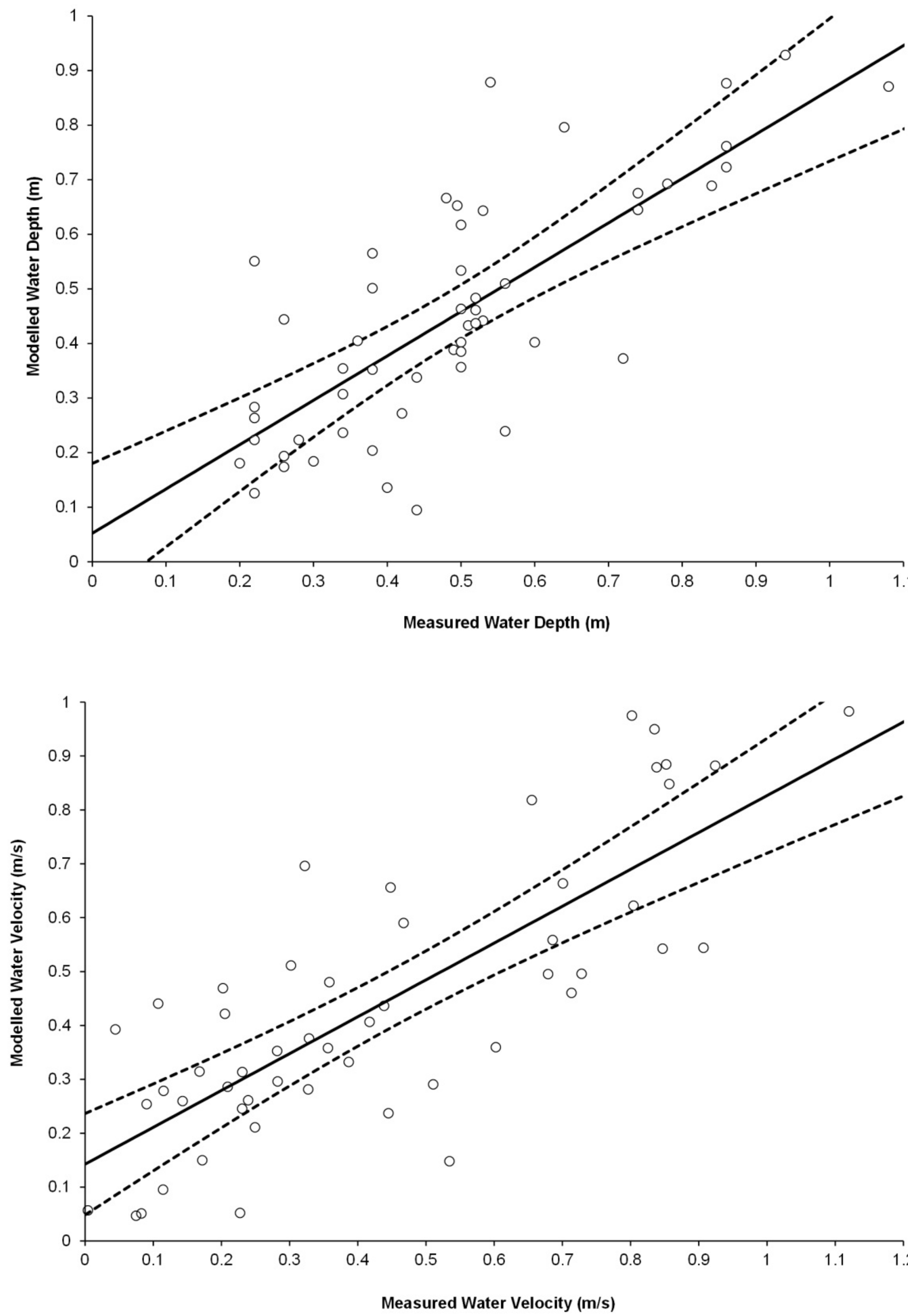

Figure 5. Comparison of River2D model-predicted and field-measured water depths (upper) and water velocities (lower) at the Lock 5 site (September 15, 2013). Regression lines and 95% confidence intervals are provided. Regression equations: (a) modelled depth = 0.0523+0.8124×measured depth; and (b) modelled velocity = 0.1426+0.6839×measured velocity.

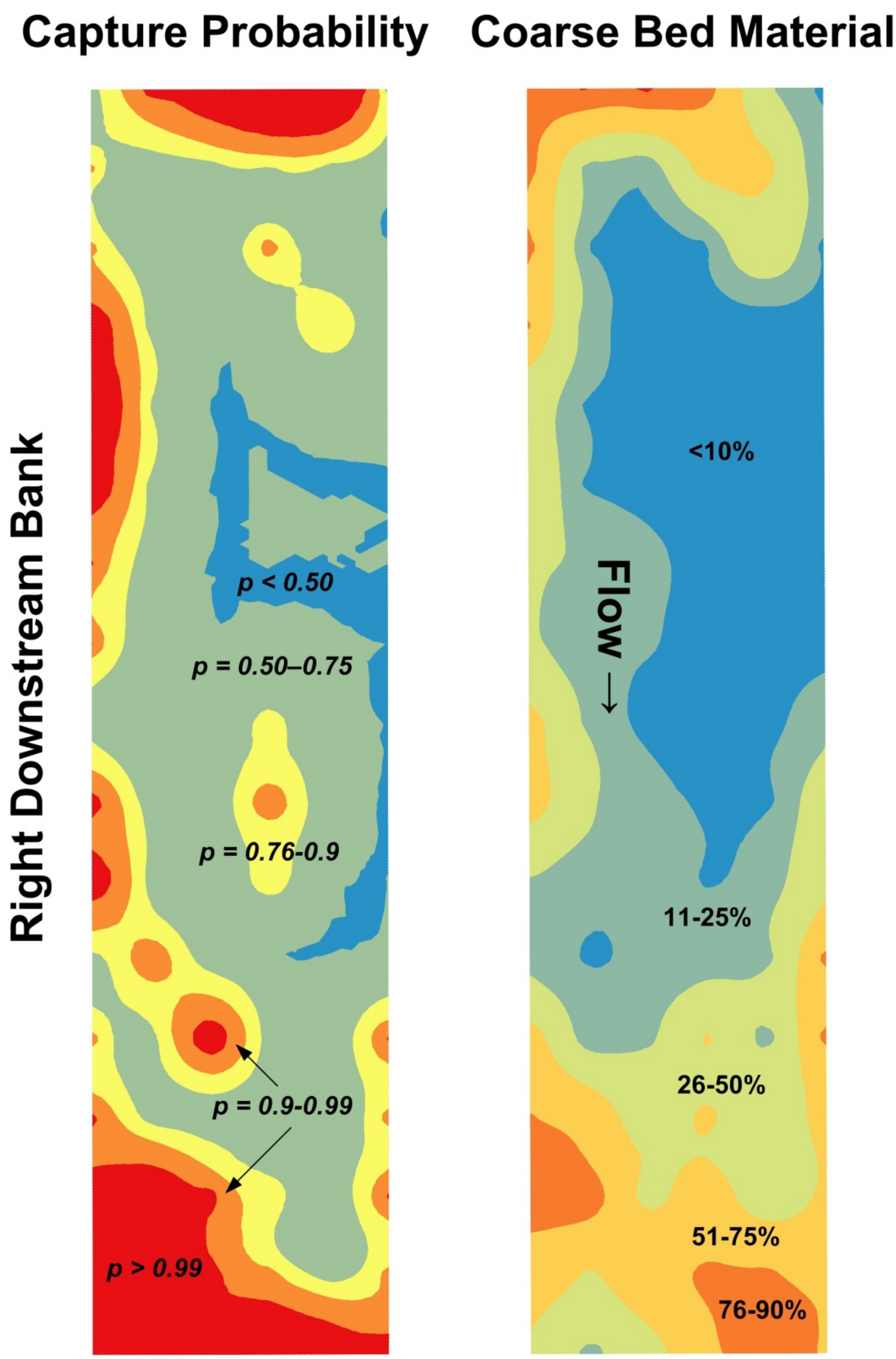

Figure 6. Spatial pattern of Channel Darter capture probability (p) and coarse bed material (% composition) at the Glen Ross site (May 31 – June 26, 2012). Empirical Bayesian Kriging (ArcGIS version 10.1) was used to interpolate the surfaces.

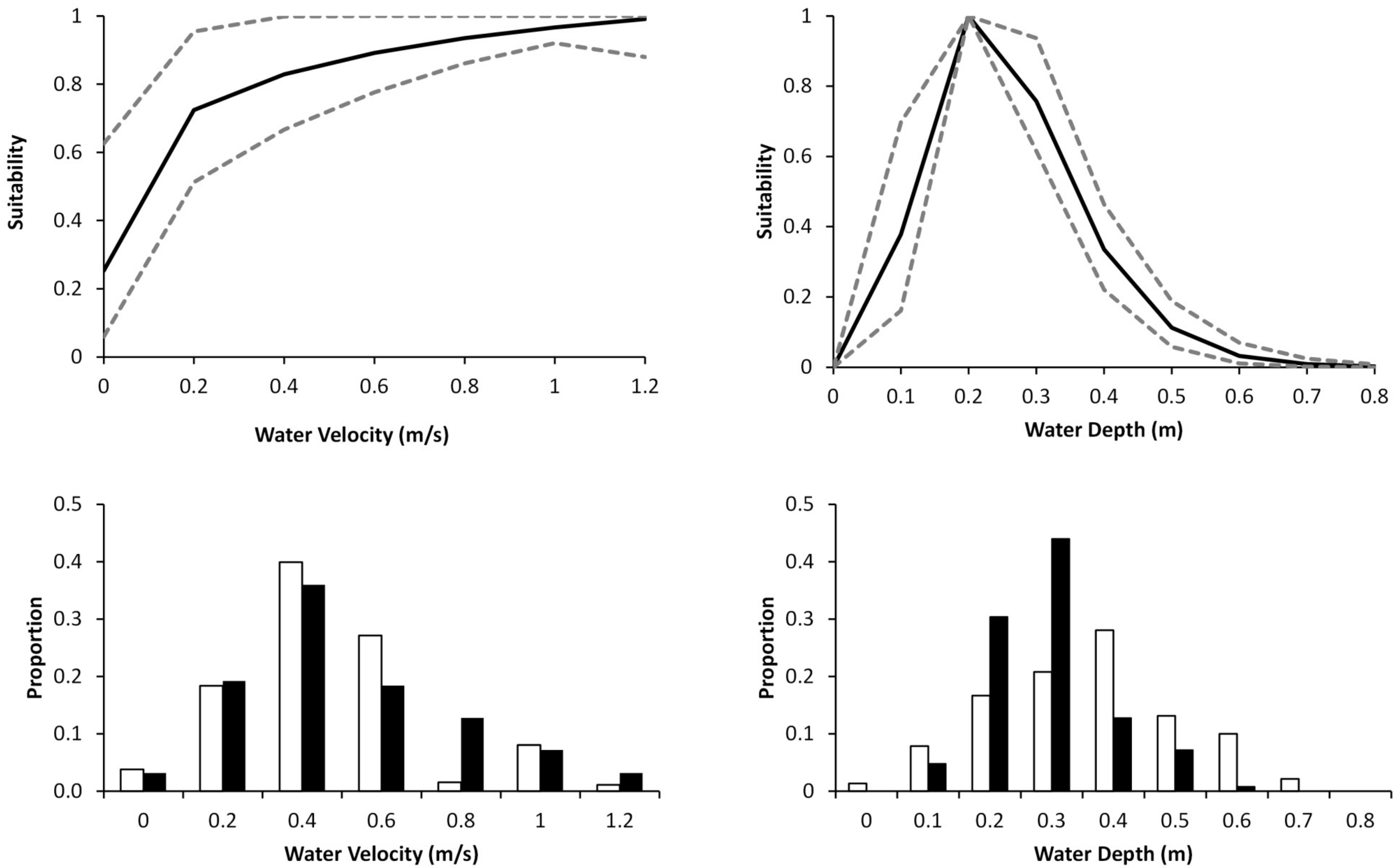

Figure 7. Estimated Channel Darter habitat suitability for water velocity and water depth (median, with dotted lines indicating 95% CI) at Glen Ross, based on a resource selection function fitted to data on habitat use (solid bar) vs availability (open bar).

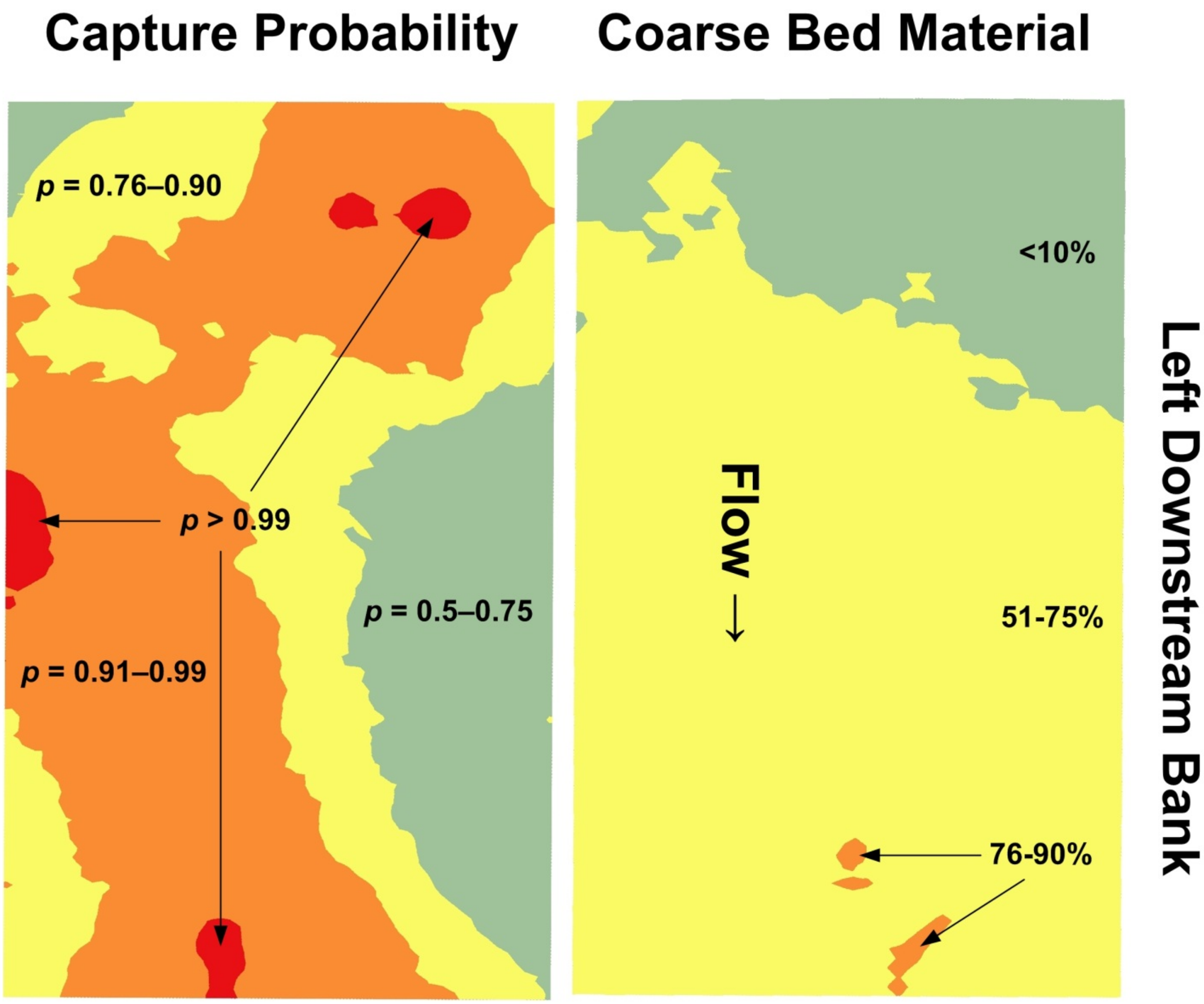

Figure 8. Spatial variation in Channel Darter capture probability (p) and coarse bed material (% composition) at the Lock 5 site (June 4 to 25, 2012). Empirical Bayesian Kriging (ArcGIS version 10.1) was used to interpolate the surfaces.

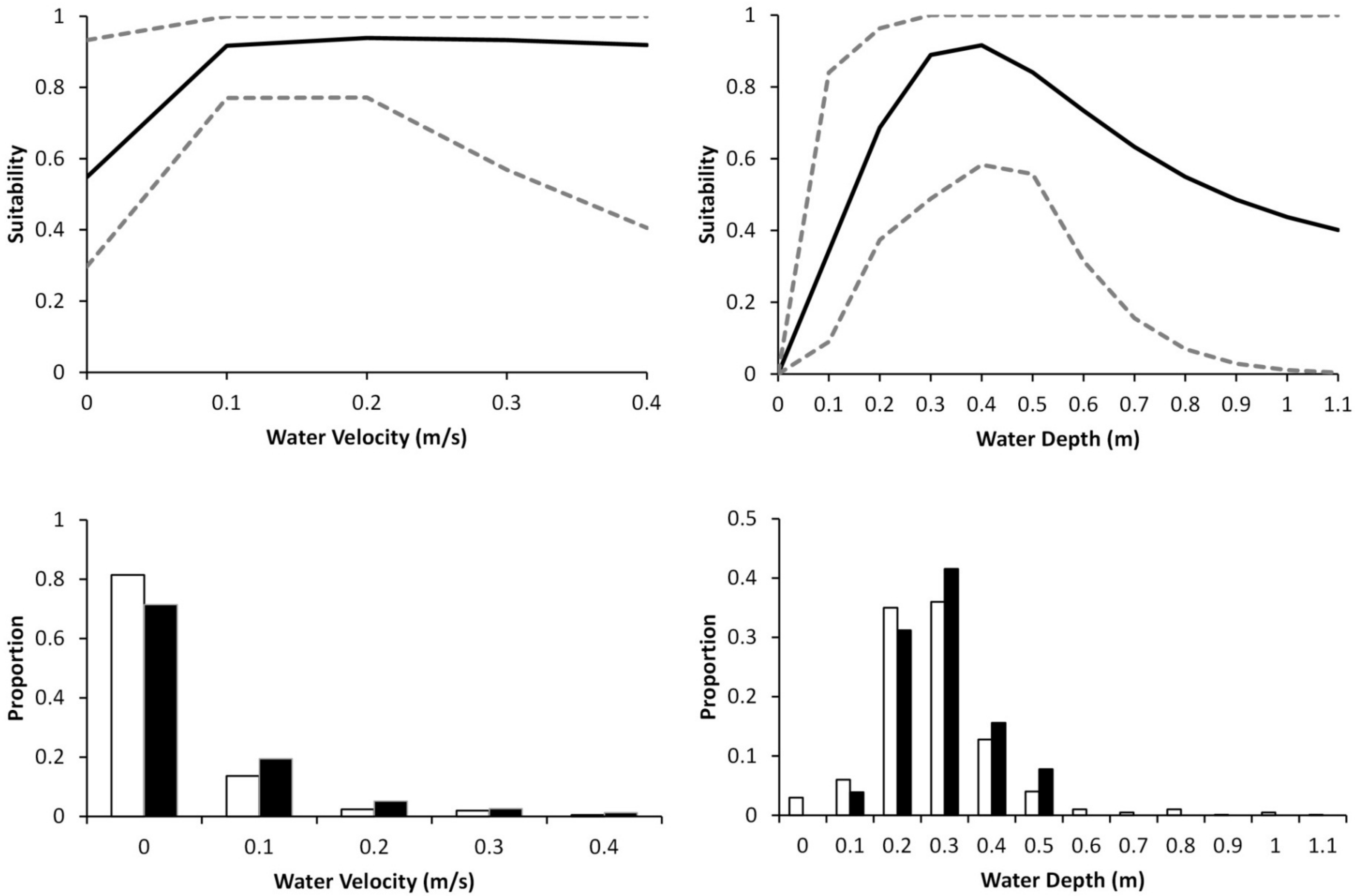

Figure 9. Estimated Channel Darter habitat suitability for water velocity and water depth (median, with dotted lines indicating 95% CI) at Lock 5, based on a resource selection function fitted to data on habitat use (solid bar) vs availability (open bar).

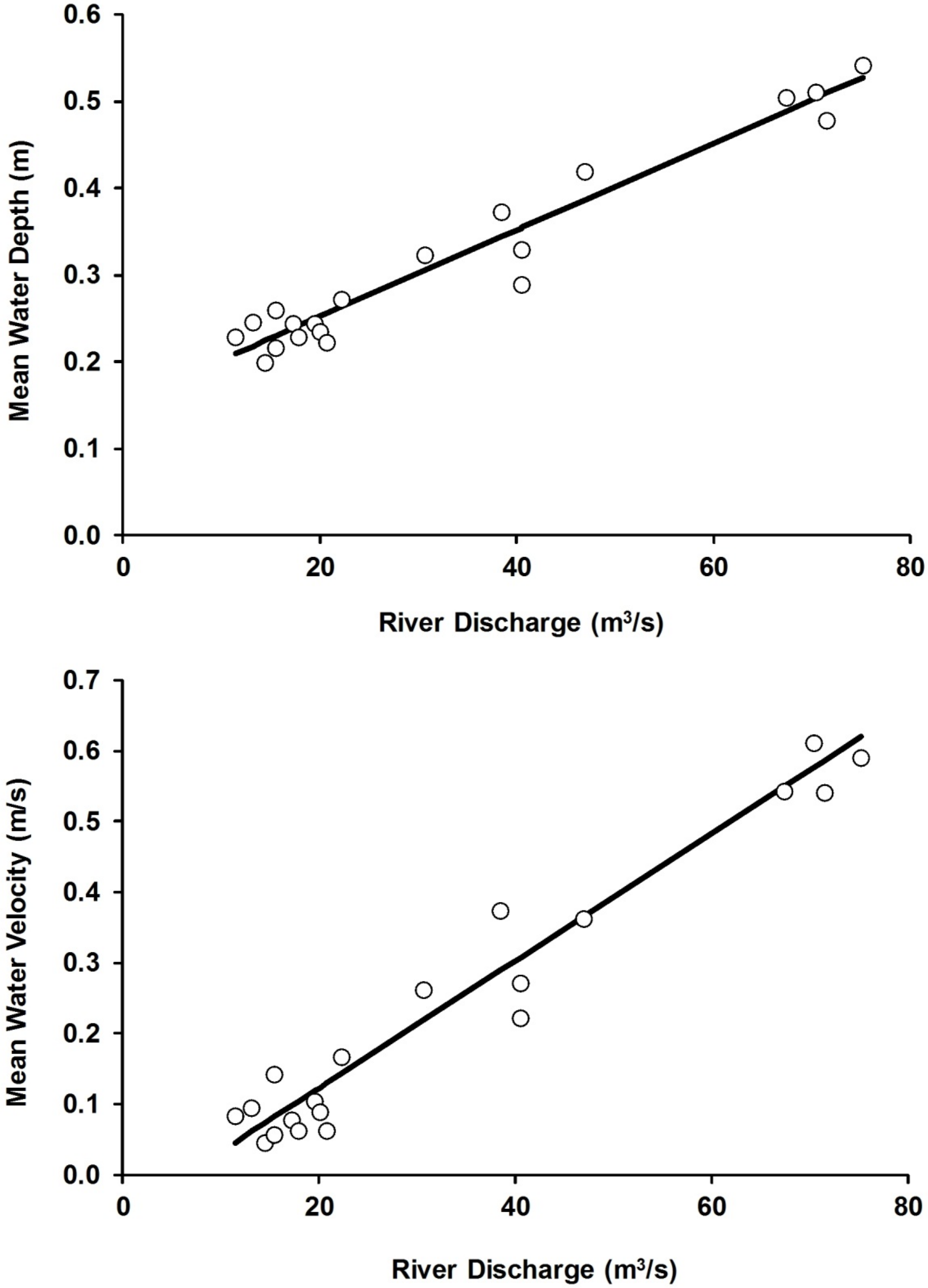

Figure 10. Linear relationships between Trent River daily discharge and mean water depth (upper) and mean water (lower) at Glen Ross in 2012. Regression equations: (a) mean water velocity = -0.064+0.009 × discharge; and (b) mean water depth = 0.147+0.005×discharge.

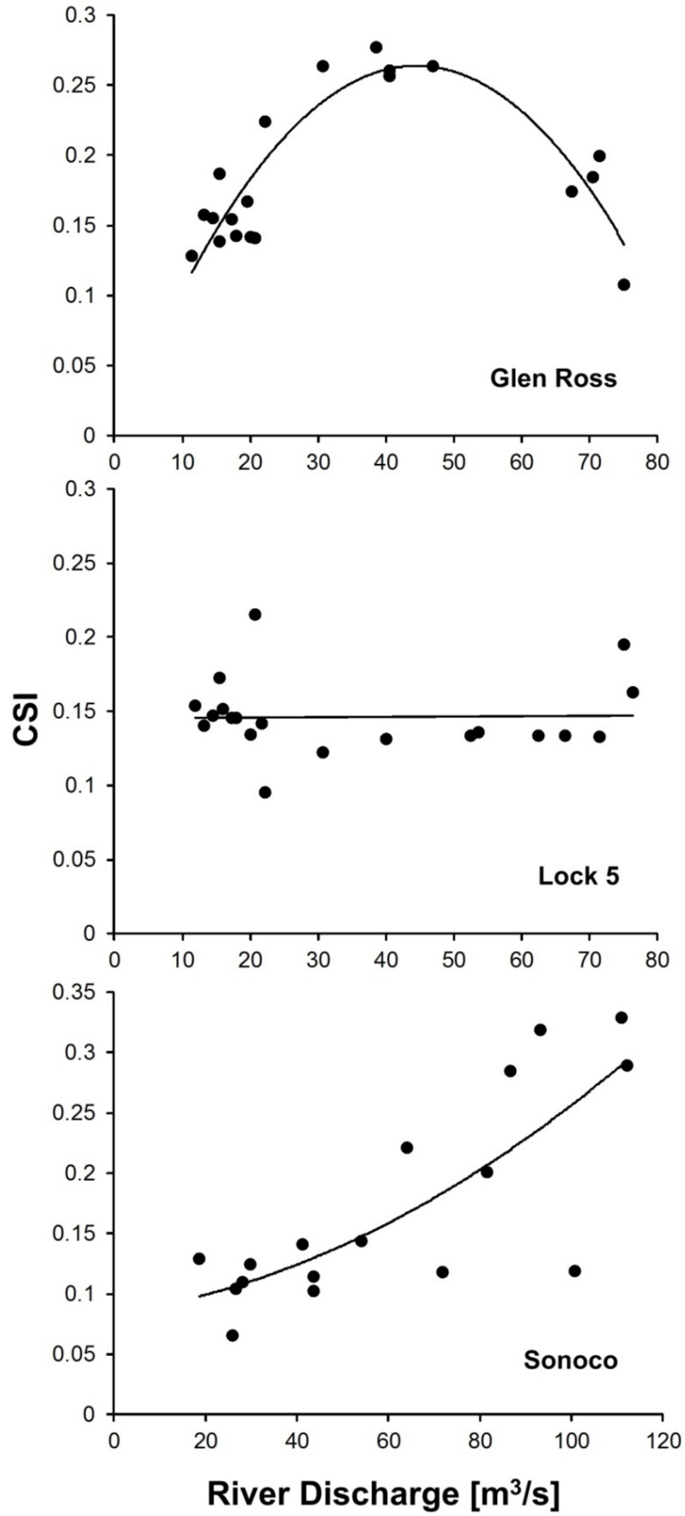

Figure 11. Relationships between Trent River discharge and Channel Darter habitat suitability (based on a composite suitability index, CSI) at three monitoring sites. Trend lines are provided to aid interpretation.

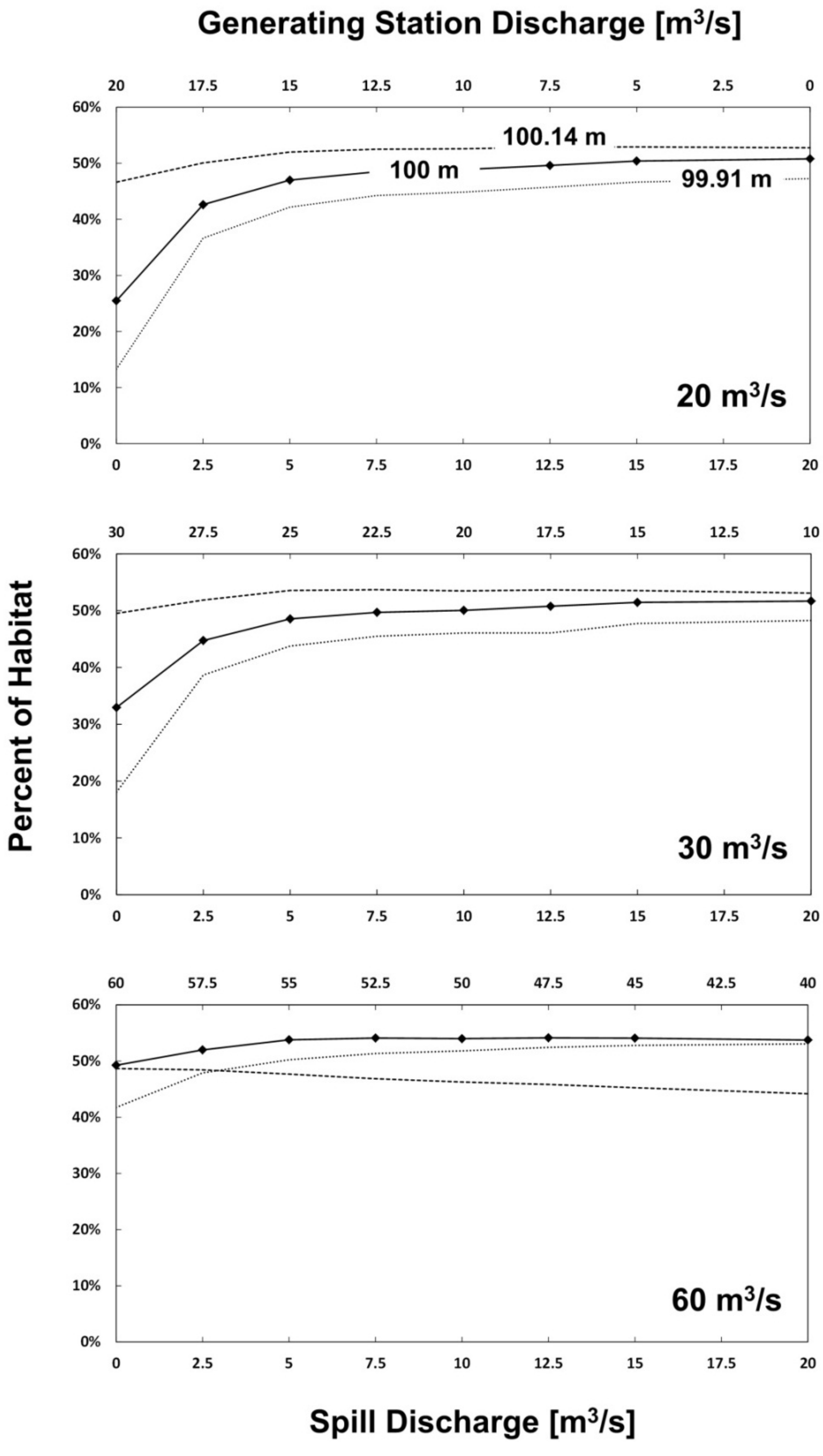

Figure 12. Availability of suitable water depths (0.1 to 0.3 m) at the Lock 5 Channel Darter shoal at different river discharges, gate spill discharges and downstream water elevations. Water depths were predicted using the River2D model.

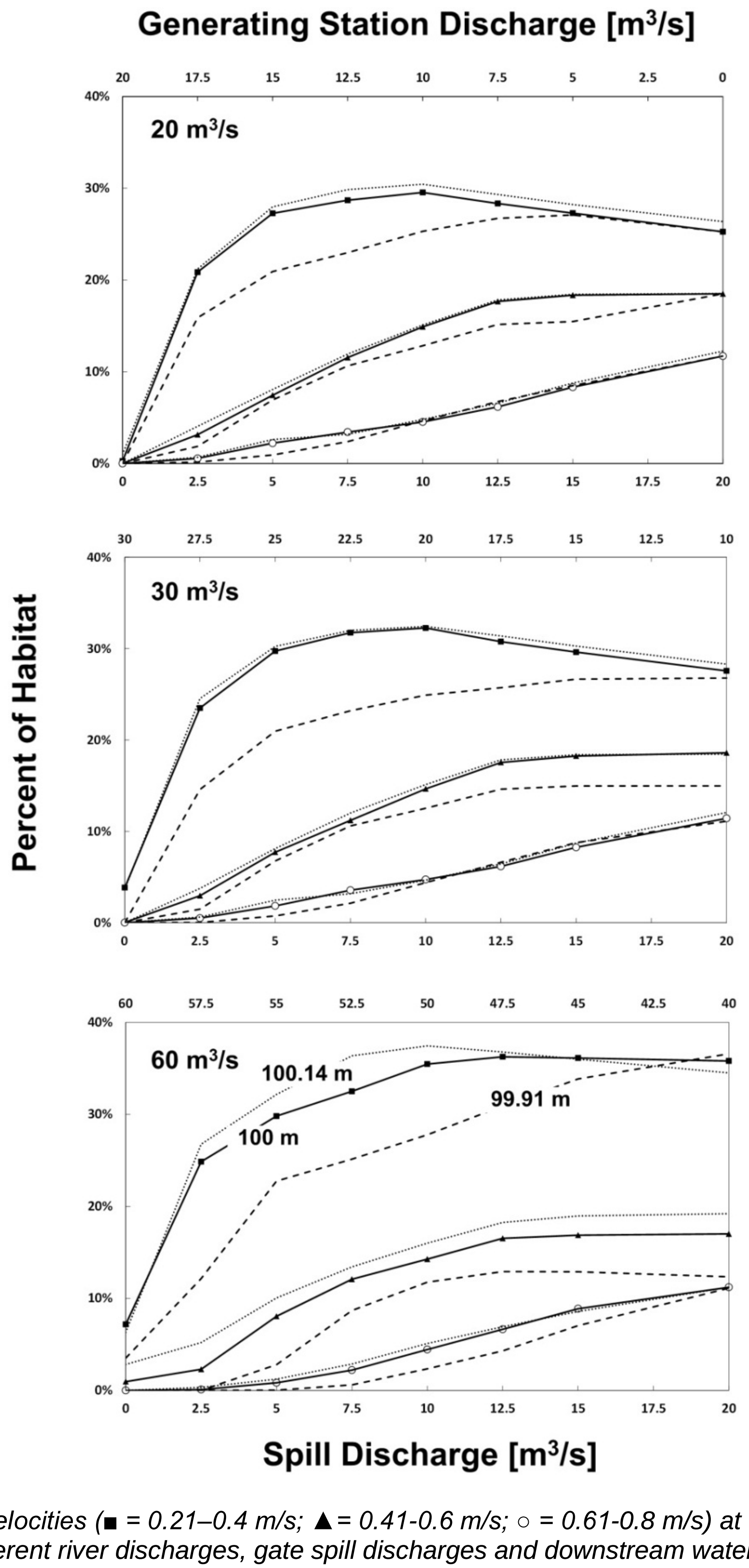

Figure 13. Water velocities (■ = 0.21–0.4 m/s; ▲= 0.41-0.6 m/s; ○ = 0.61-0.8 m/s) at the Lock 5 Channel Darter shoal at different river discharges, gate spill discharges and downstream water elevations. Water velocities were predicted using the River2D model.

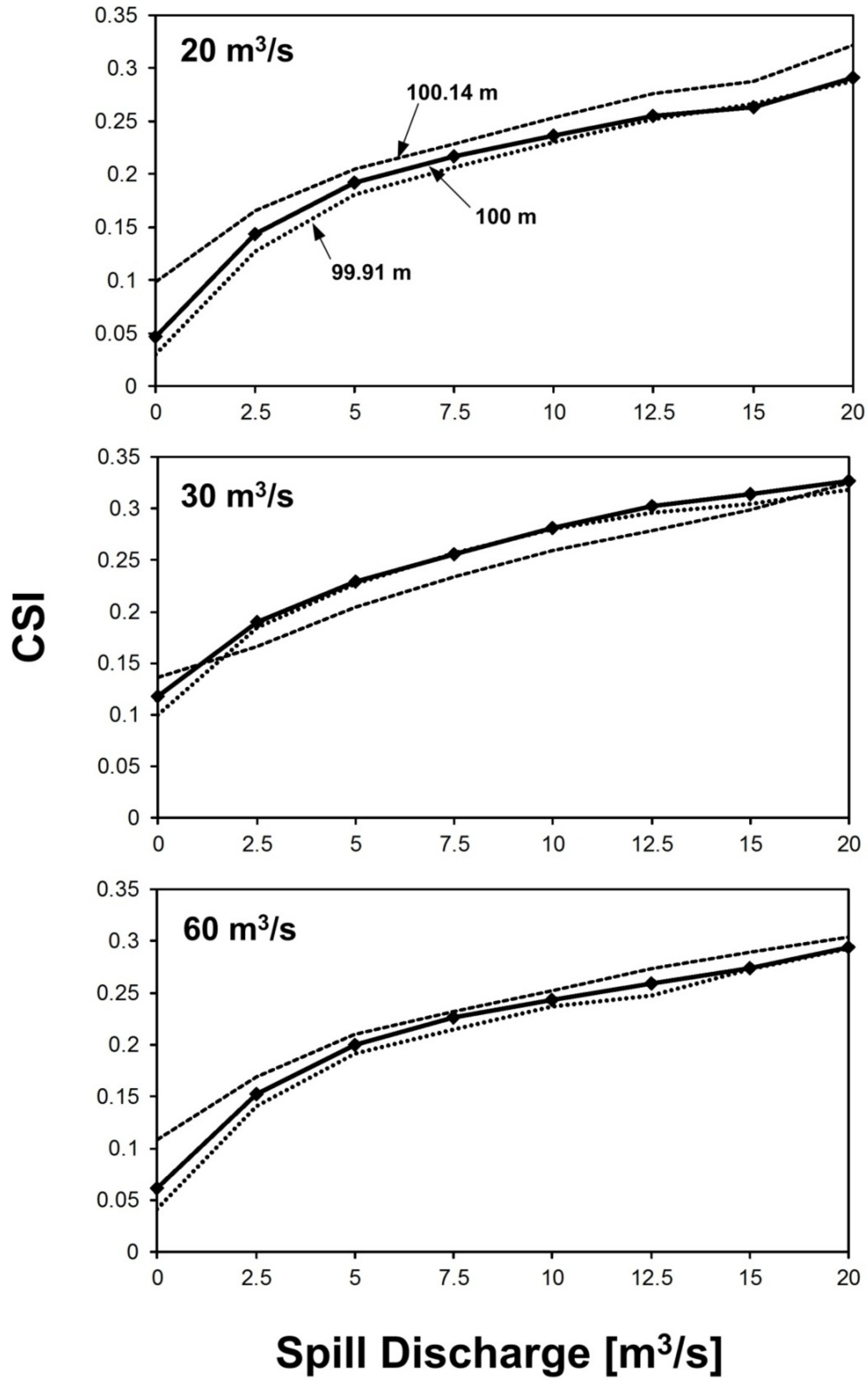

Figure 14. Composite habitat suitability (CSI) at the Lock 5 Channel Darter shoal at different river discharges, gate spill discharges and downstream water elevations. CSI was calculated using water velocities and depths predicted using the River2D model, and habitat suitability curves.