NECHAKO RIVER WHITE STURGEON
2020 SPAWNING SUBSTRATE RESTORATION AND MONITORING

FINAL REPORT

Prepared for:

Ministry of Environment and Climate Change Strategy
2202 Main Mall
Vancouver, BC V6T 1Z4
Attention: **Steve McAdam, Ph.D.**
Hydro Impacts/Sturgeon Specialist

Prepared by:

Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC V7M 3G3
Attention: **André Zimmermann, Ph.D, P.Geo.**
Principal Geomorphologist

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Report Prepared by:

Simon Gauthier-Fauteux, M.Sc.
Project Geomorphologist

Report Reviewed by:

A. E. ZIMMERMANN
34226
March 15th 2021

André Zimmermann, Ph.D, P.Geo.
Principal Geomorphologist

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Steve McAdam	Ministry of Environment and Climate Change Strategy
Zsolt Sary	Ministry of Forests, Lands, Natural Resource Operations and Rural Development

The following NHC personnel participated in the study:

Barry Chilibeck	Project Manager
André Zimmermann	Principal Geomorphologist
Simon Gauthier-Fauteux	Project Geomorphologist

Field support was provided by:

Will Mole	Carrier Sekani Tribal Council
Wayne Salewski	Community of Vanderhoof
Mike Manky	Nechako White Sturgeon Conservation Center
Olin Albertson	Avison Management Services Ltd.

Diver support was provided by:

Bill Stark	Northern Underwater Systems
John Rilkoff	Northern Underwater Systems

EXECUTIVE SUMMARY

The white sturgeon (Acipenser *transmontanus*) population in the Nechako River has undergone recruitment failure since 1967. As part of continued efforts to promote the recovery of this population, this study was commissioned to investigate the feasibility and performance of restoration techniques aimed at restoring the quality of spawning substrate. Specifically, the objectives of this study were to 1) remove fine substrates from an area of 50-150 m^2 within the spawning reach, with the effort being split between the Middle Patch, Lower Patch and Lower Site spawning areas, 2) install four sediment traps to allow quantitative estimation of substrate infilling between the time of substrate cleaning (anticipated early May 2020) and the spawning and early rearing period (approx. May 15 to July 7), and 3) conduct monitoring to determine the extent of substrate cleaning, the resultant condition of river bed substrates and the longer-term spatial/temporal patterns of substrate infilling.

To achieve these objectives, a variety of sediment cleaning techniques were used to restore areas on the Middle Patch, Lower Patch and Lower Site from May 6, 2020 to May 8, 2020, inclusively. These techniques included the use of a hydraulic jet, a suction dredge fitted with a variety of dredge heads and screen sizes, and mechanical raking of the substrate in combination with the suction dredge. Four sediment traps were also installed by the divers within the spawning reach to measure infilling rates within the core spawning area, as determined based on egg detections in 2017 and 2019. Finally, underwater imagery was used during the instream operation to select cleaning sites based on visual inspections of the pre-existing substrate and to conduct pre- and post-operation substrate assessments. Underwater imagery was subsequently used to evaluate the longevity of the treatment by collecting images of the substrate at predetermined monitoring locations following the spawning period on June 22, 2020.

Of the methods used, hydraulic jetting was found to be the most productive and effective, while suction dredging was found to be relatively ineffective due to several key limitations, including: 1) the dredge would rapidly jam with particles due to the wide grainsize distribution on the bed, 2) small adjustments in vertical height would cause the dredge to either provide too much or too little suction on the bed, and 3) that even when used in combination with mechanical raking, the dredge was only partially effective at removing surficial fines and largely ineffective at capturing fine sediment brought into suspension. In comparison, the hydraulic jet was capable of mixing and mobilizing all grainsizes found within the substrate to a considerable depth, resulting in a progressive coarsening of the remaining sediment mixture as fines (silt and sand) were brought into suspension and transported downstream. When applied to an area for a sufficient duration, hydraulic jetting was found to produce a much thicker layer of cleaned gravels (up to approx. 15 cm) containing a comparatively small proportion of sand and silt compared to other substrate treatments.

A total area of approximately 20-25 m^2 of the Lower Patch (production rate of roughly 12-14 m^2/hr) and approximately 30-35 m^2 at the Lower Site (production rate of roughly 8-10 m^2/hr) were restored primarily using hydraulic jetting on May 7 and 8, 2020. Although an attempt was made to clean a portion of the Middle Patch as well (May 6), the operation could not be completed because a

considerable amount of time was required to experiment with the various cleaning methods, and because high flow velocities rendered the operation nearly infeasible using the suction dredge.

Underwater imagery collected after the spawning period on June 22, 2020 suggests that the quality of the restored substrate on the Lower Patch was at least partially maintained over this period, as the substrate within the cleaned area was generally composed of coarse gravel and cobble with a low to moderate degree of embeddedness and infilling with sand. However, these results should be interpreted with a degree of uncertainty because it was not possible to collect accurate substrate photos on the Lower Patch immediately following the cleaning operation due to operational constraints and lack of time.

At the Lower Site, accurate photo locations were collected immediately following the cleaning operation, allowing for reliable change detection between the pre- and post-spawning periods. However, the growth of macrophytes within the entire area rendered detailed observations of the underlying substrate difficult in the June imagery. The condition of the substrate within the offshore portion of the cleaned area appears to have been maintained over this period, as the gravels are still seen to protrude above the bed and are not embedded in sand. Locations nearer to the bankline appear to have undergone greater siltation in the form of a thin veneer of very fine sediment.

All sediment traps embedded within the spawning reach were found to contain a considerable amount of sediment when retrieved on June 22, 2020, with the traps located on and upstream of the Lower Patch containing the greatest amounts (traps were 100% full or nearly so). Interestingly, the least amount of sediment was captured by the trap located approximately 140 m directly upstream of the Lower Site cleaning area (approx. 20-25% full). This trap also contained much finer sediment than the other traps, composed almost entirely of fine sand and silt; this very fine sediment is likely to have settled out of suspension, as opposed to being transported along the bed. These findings are supported by the results of the underwater imagery, suggesting that cleaned area was exposed to a relatively limited amount of bedload sediment transport, but was subject to siltation.

This study demonstrated that diver-operated techniques may be applied to restore the quality of infilled substrate over small- to moderately-sized areas, but that the effectiveness and feasibility of the operations decrease with area, especially in challenging hydraulic conditions. Key limitations of the methodology include: 1) the divers are limited to areas which have a relatively low flow velocity, generally not exceeding about 1.0 m/s, 2) the slow production rate achieved using diver-operated machinery, especially in conditions which approach their operational feasibility (e.g. high velocity, low visibility, etc.), 3) the limited effectiveness of certain techniques (i.e. suction dredging), especially if the objective is to remove fines at-depth, 4) that the biological benefits of the cleaning may be limited given that the treatment can only be applied to relatively small areas with a low flow velocity, which may or may not correspond to spawning locations, and 5) that the condition of the restored substrate is highly dependant on incoming sediment transport.

Acknowledging these limitations, substrate cleaning using a diver-operated procedure may still represent a feasible solution for certain applications, as these methods were shown to successfully create relatively thick deposits of loose, clean gravel at both the Lower Patch and Lower Site locations. For example, these techniques may be useful if the intent of the work is to produce high quality substrate immediately prior to the spawning period at targeted locations, or for specific applications which require intensive, detailed cleaning of small areas. Alternative methods may also be developed based on what produced the best results in this study, such as designing a hydraulic jet that operates from the surface using a mechanical attachment, as opposed to diver-operated tools.

Finally, the results of this study, including the sediment sampling and underwater imagery, may be helpful for siting and planning future restoration activities. Based on the review of this years images and previous image data collection, we recognize that there are some areas where the substrate does not contain a large amount surficial sand, which might potentially support (at least some) larval survival. These areas are small and local in extent and may not correspond to spawning locations in any given year, and the overall quality of the interstitial habitat may be limited at-depth due to embeddedness and/or an underlying layer of sandy gravel. Future studies may be conducted to further investigate innovative sampling methodologies that provide a more quantitative evaluation of biological habitat quality based on specific larval requirements (e.g. substrate composition below the surficial layer of grains).

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1 INTRODUCTION

1.1 Background

The Nechako white sturgeon (*Acipenser transmontanus*) population has undergone recruitment failure since 1967 (McAdam et al., 2005). To promote the recovery of this population, the Nechako White Sturgeon Recovery Initiative (NWSRI) constructed two spawning pads in 2011 within a critical spawning reach of the Nechako River located near Vanderhoof, BC (Figure 1.1). Although the spawning pads may have initially promoted natural recruitment (Steve McAdam, *pers. comm.*), subsequent monitoring has shown that one of the spawning pads ("Lower Patch") began to infill with fine sediment soon after placement, thus decreasing the biological functionality of the substrate over time (NHC, 2012).

DATA SOURCES: ORTHOPHOTO COLLECTED FOR MFLNRORD ON OCT. 3, 2017 AT A DISCHARGE OF 50 M3/S AT VANDERHOOF

Figure 1.1 White sturgeon spawning reach on the Nechako River at Vanderhoof, BC.

In response to the sedimentation of the spawning pad, a series of investigations were commissioned to better understand how sediment transport within the area affects the quality of spawning and incubation habitat (NHC, 2013, 2014, 2015, 2016a, 2018). In addition to these studies, instream works were conducted in 2016 to remediate the quality of the substrate provided by the Lower Patch and to determine the feasibility of using mechanical cleaning as a restorative measure within the spawning reach (NHC, 2016b). The present study was commissioned as part of the continued effort to develop feasible methods to remediate the quality of the spawning substrate and promote natural recruitment on the Nechako River.

1.2 Scope of work

The initial scope of work outlined in RFPGS20JHQ-209 issued by Ministry of Environment and Climate Change Strategy (the "Ministry") on December 24, 2019 was to:

(1) develop a method for cleaning river bed substrates in the Vanderhoof Reach of the Nechako River,

(2) obtain all necessary permits to conduct the work,

(3) implement restoration measures to clean at least 10 m^2 of the Lower Patch spawning pad and 10 m^2 of substrate at the Lower Site (Figure 1.1) prior to the spring 2020 spawning season, and

(4) conduct substrate monitoring to determine the extent of substrate cleaning, the resultant condition of river bed substrates and the longer-term spatial/temporal patterns of substrate infilling using a suction sampler, or other appropriate device in conjunction with video monitoring.

Subsequent discussions with the Ministry expanded the scope to include:

- Removal of fine substrates from an area of 50-150 m^2 within the spawning reach. The substrate cleaning effort was to take place over three days, with the effort split between the Middle Patch, Lower Patch and Lower Site areas (Figure 1.1); and
- Installation of four sediment traps to allow quantitative estimation of substrate infilling between the time of substrate cleaning (anticipated early May 2020) and the spawning and early rearing period (approx. May 15 to July 7).

2 METHODOLOGY

2.1 Spatial data

Spatial positioning was achieved using multi-band Real-Time Kinematic (RTK) Global Navigation Satellite System (GNSS) receivers (EMLID REACH RS2). Two GNSS receivers were used for the fieldwork: one was used as a Base Station positioned near the Vanderhoof boat launch while the other was used to log geographic points during the fieldwork. The survey was post-processed using calculated Base Station coordinates obtained from the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service offered by Natural Resources Canada. All surveying was compared to a previously established control network to ensure consistency between studies (NHC, 2016a); all datasets were in good agreement and no additional shifts were required.

All spatial data in this report are relative to the following coordinate system:

- Horizontal datum: NAD83 CSRS2002.0;
- Projection: UTM 10N;
- Vertical Datum: CGVD28 (HT2.0) orthometric heights.

2.2 Substrate cleaning

Substrate cleaning was conducted from May 6, 2020 to May 8, 2020, inclusively. The provisional discharge at Water Survey of Canada (WSC) gauge 08JC001 NECHAKO RIVER AT VANDERHOOF during the operation averaged 268 m^3/s. This timing was before the onset of white sturgeon spawning and immediately after the peak of the spring freshet, which reached 272 m^3/s on May 1, 2020 (Figure 2.1).

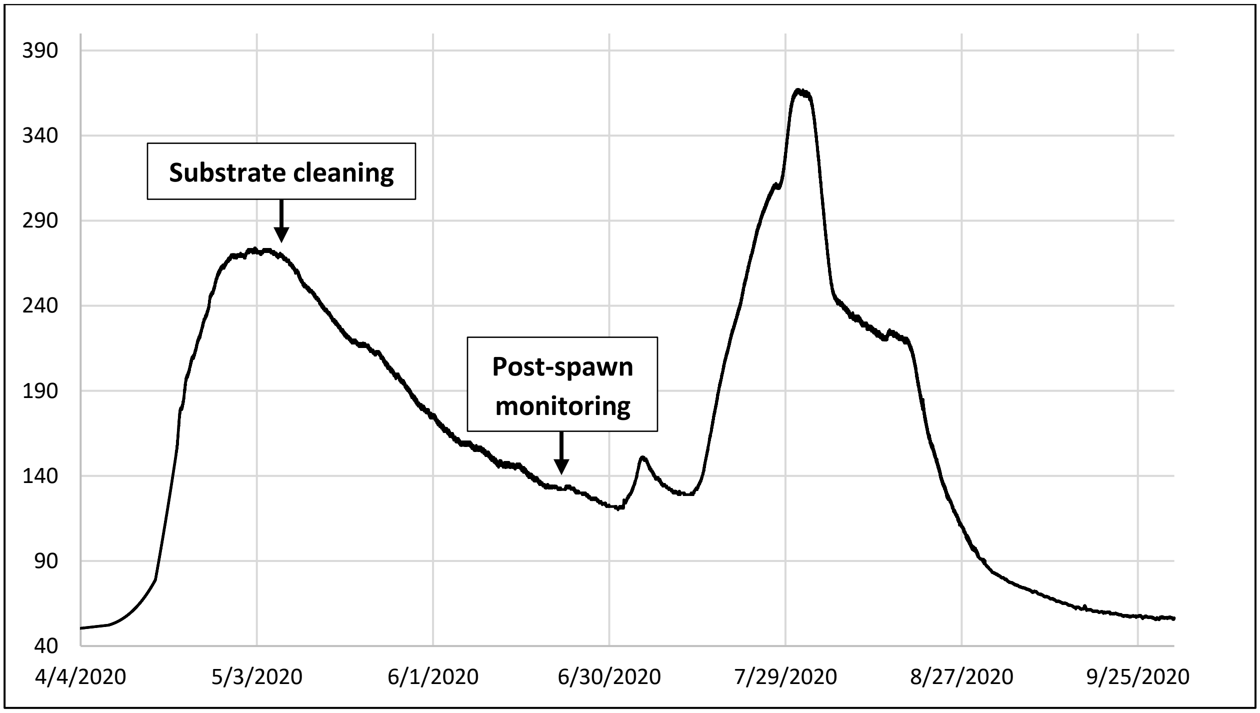

Figure 2.1 Provisional discharge at Vanderhoof (08JC001) showing the timing of the sediment cleaning and subsequent monitoring operations in relation to the 2020 hydrograph.

The substrate cleaning was completed using a team of commercial divers (Northern Underwater Systems). The dive team operated from two boats: one which was used as the main work station, containing the diving equipment, an umbilical system (air/communications line) and a real-time audio/video communication station, while the other housed the pumps and generators (Photo 2.1). A third boat was used by NHC to assist in the operations by selecting cleaning sites based on visual inspections of the pre-existing substrate using underwater imagery, conducting pre- and post-operation substrate assessments and monitoring downstream turbidity during the instream work.

A variety of diver-operated sediment cleaning techniques were used to explore the feasibility and effectiveness of various methods, including:

- A hydraulic jet consisting of a high-pressure firehose-type nozzle (Photo 2.2) fitted to a 4” water line pressurized by a trash pump;
- A suction dredge fitted with a variety of dredge heads and screen sizes (Figure 2.2), which was also used to relocate dredged sediment via an anchored discharge line; and
- Mechanical raking with hand tools used in combination with the suction dredge (Photo 2.3).

Photo 2.1 Divers preparing to perform substrate cleaning at Lower Site on May 7, 2020; note area to be cleaned marked by white buoys, as well as the slurry discharge line used to relocate dredged sediment (black hose trailing downstream).

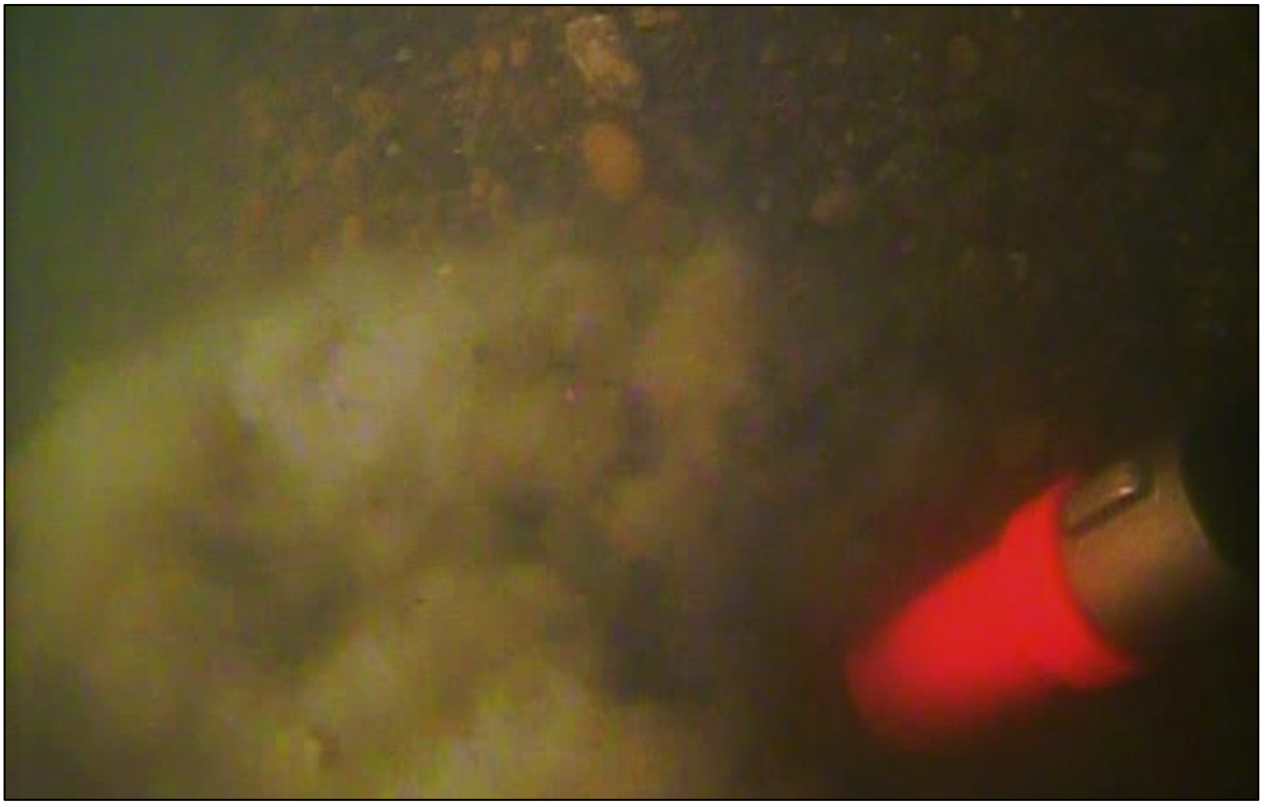

Photo 2.2 Hydraulic jet used for substrate cleaning and embedding sediment traps; image shows jet directed down into substrate, mobilizing the substrate and displacing fines downstream.

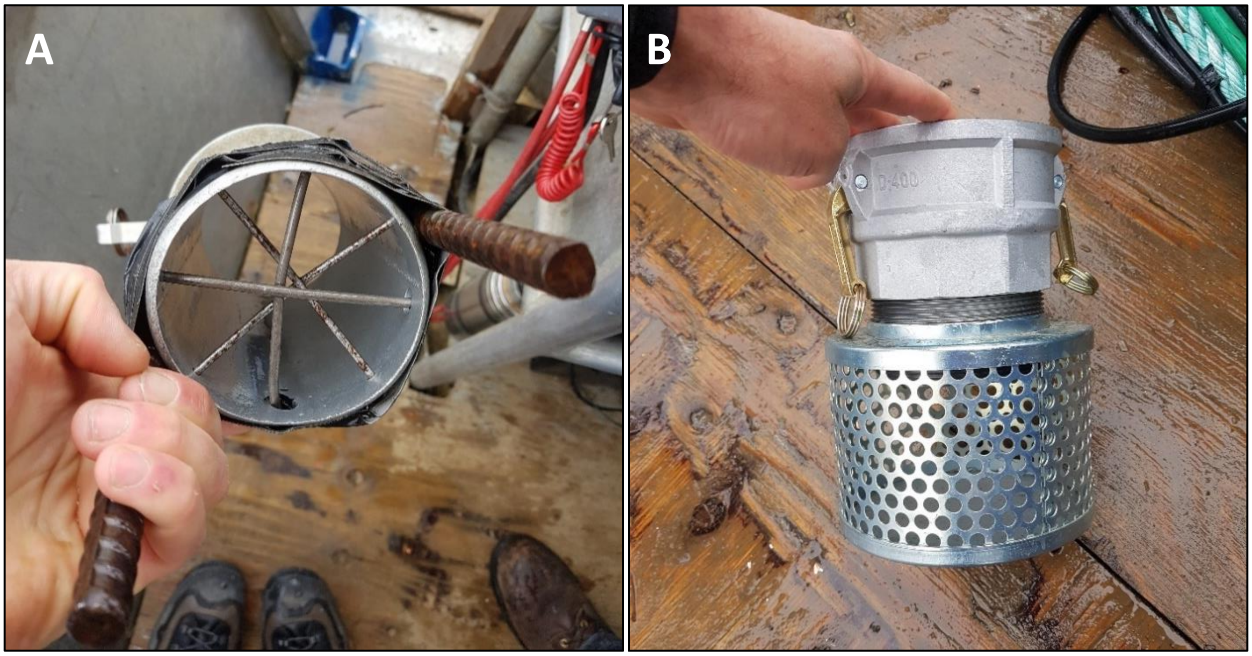

Figure 2.2 Dredge heads used during the cleaning operation; A) cylinder-type dredge head with rebar attachments used to rake the substrate and B) circular screen-type dredge head.

Photo 2.3 Mechanical raking used in combination with the suction dredge to remove infilled fines from the subsurface layers (flow left to right; substrate at top-left of image has been cleaned).

Prior to the instream operation, potential cleaning sites were selected at the Middle Patch, Lower Patch and Lower Site based on substrate mapping completed as part of previous studies (NHC, 2018, 2020). The proposed sites were located away from the dominant lanes of sediment transport (NHC, 2020), in areas where the existing substrate was composed of infilled cobbles and gravels. As shown in Figure 2.3, Figure 2.4 and Figure 2.5, each proposed cleaning site covered an area of 50 m^2, based on the understanding that one site would be selected at the Middle Patch, Lower Patch and Lower Site, for a total cleaned area of 150 m^2 (Section 1.2).

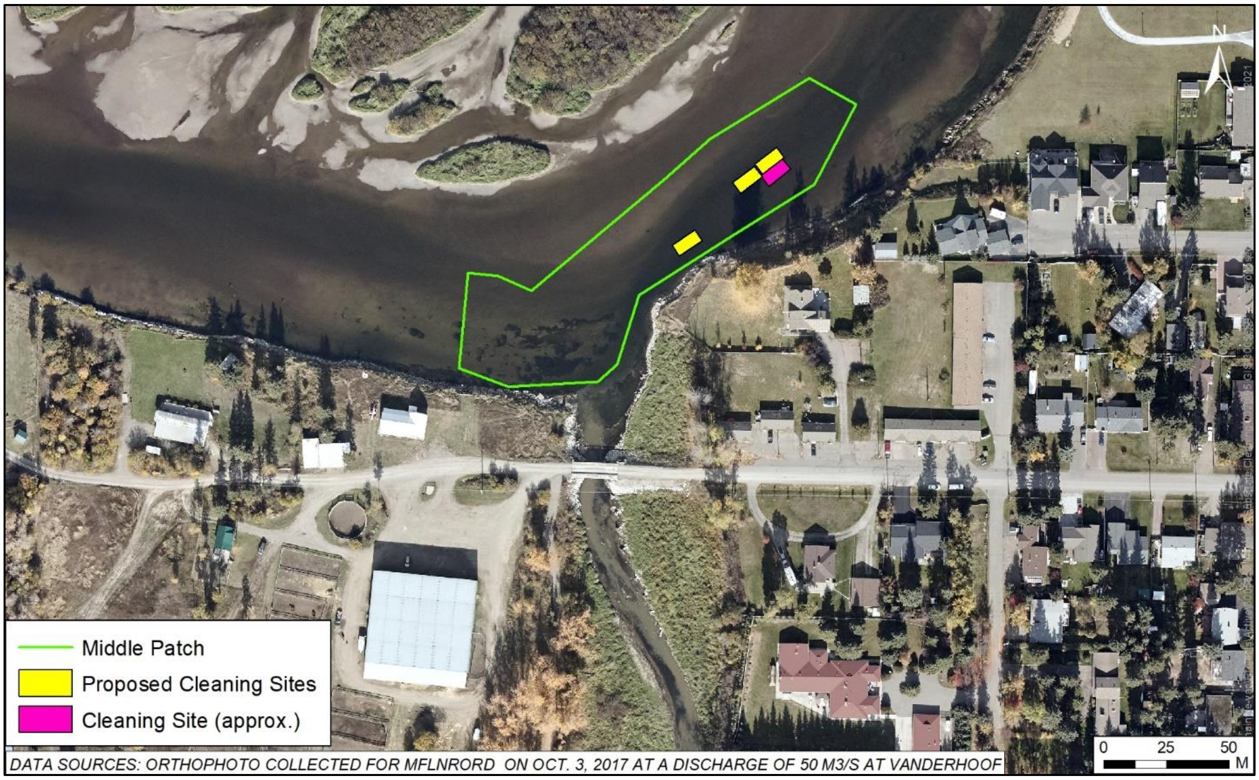

Figure 2.3 Proposed cleaning locations and final cleaning site on the Middle Patch.

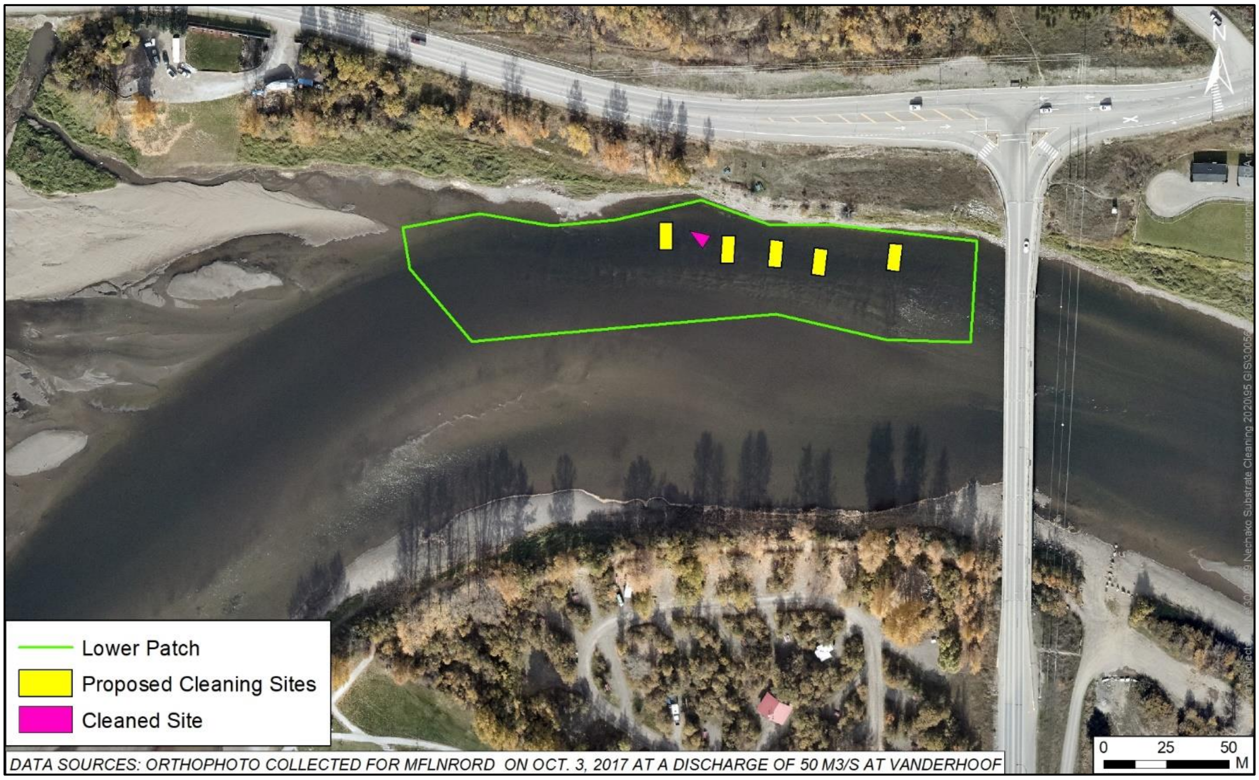

Figure 2.4 Proposed cleaning locations and final cleaning site on the Lower Patch.

Figure 2.5 Proposed cleaning locations and final cleaning site at the Lower Site.

The final locations for the substrate cleaning shown on the figures above were determined on-site based on local hydraulic conditions and the characteristics of the existing substrate, which was observed using an underwater camera (Section 2.4) as part of the prescreening/prioritization process. The selected sites had the following characteristics:

- A maximum flow velocity of 1.5 m/s, with a greater preference attributed to sites having a flow velocity nearer to 1.0 m/s;
- A pre-existing substrate composed of cobbles and gravels with only a minor to moderate degree of infilling;
- Sites which were not visibly exposed to high sediment transport; and
- Sites which did not have large assemblages of mussels on the riverbed.

2.3 Turbidity monitoring

Downstream impacts were monitored throughout the instream operations using an Analite 5000 (ISO 7027) Turbidity Probe installed downstream of each work site. Turbidity measurements from the sensor were processed in real-time using a Campbell Scientific CR300 Datalogger, which was used to calculate the turbidity-based Severity-of-Ill-Effects (SEV) value (Newcombe, 2003) at 5 minute intervals. Instream turbidity was also compared to short-term BC Water Quality Guidelines (BCWQG) during the operations.

2.4 Underwater imagery

Underwater imagery was used during the cleaning operation (May 6-8, 2020) to select cleaning sites based on visual inspections of the pre-existing substrate and to conduct pre- and post-operation substrate assessments. Underwater imagery was also used to evaluate the longevity of the treatment by collecting images of the substrate following the spawning period on June 22, 2020 (Figure 2.1). All underwater imagery was collected in continuous video format using a SeaViewer mobile underwater camera mounted at a fixed distance above the bed on a 3 m pipe. Geographic coordinates at specific photo locations were simultaneously collected using an RTK GPS mounted to the top of the pipe.

The turbidity of the water at the time of the cleaning operation (early May) was approximately 12-15 NTU. The underwater visibility at this level of turbidity was sufficient to observe the substrate composition using the underwater camera. The turbidity did not create any issues for the divers, and the continuous video feed recorded using helmet cameras was also relatively clear, allowing for real-time supervision and input from the communications station located onboard.

2.5 Suction sampling

In addition to the underwater imagery, attempts were made to collect quantitative data on substrate infilling during the cleaning operation using a Venturi-type dredge sampler fabricated for this project (Photo 2.4). The sampler consisted of a 3 m long aluminum pipe (2” diameter) with an adjustable suction intake grate, where the sampler could be used with or without the intake grate (note removable rubber coupling on Photo 2.4). Water was pumped through the sampler using a trash pump connected to a 2” hose leading to the jet hose inlet. The 2” discharge hose was connected to a fabricated plywood sluice box lined with 125 micron mesh to retain sediment and discharge water. The sluice box was fastened across the stern of a jetboat, allowing the sampler to be operated entirely from the vessel.

The sampler was tested in a controlled setting prior to deployment, where it proved to be capable of lifting sand and medium gravels (8-10 mm). The sampler was subsequently used at the Lower Site at the start of the substrate cleaning operation, where it provided enough suction to lift sand, fine and medium gravels off the riverbed and into the sluice box. However, after holding the intake grate on the bed for several seconds to collect a sample, the intake grate would become clogged with gravels and the suction would lose efficiency. Several attempts were made with and without the intake grate; however, the pipe would inevitably become clogged regardless of the opening size because the grainsize distribution on the bed was wide enough to contain some grains which would jam within the cylinder. This issue also proved to be problematic for the larger, diver-operated suction dredge used for the substrate cleaning, as discussed later in this report. Given that this issue could not be resolved in the field with materials at-hand and the tight work schedule, the suction sampler was not used to collect additional samples and is not discussed further in this report.

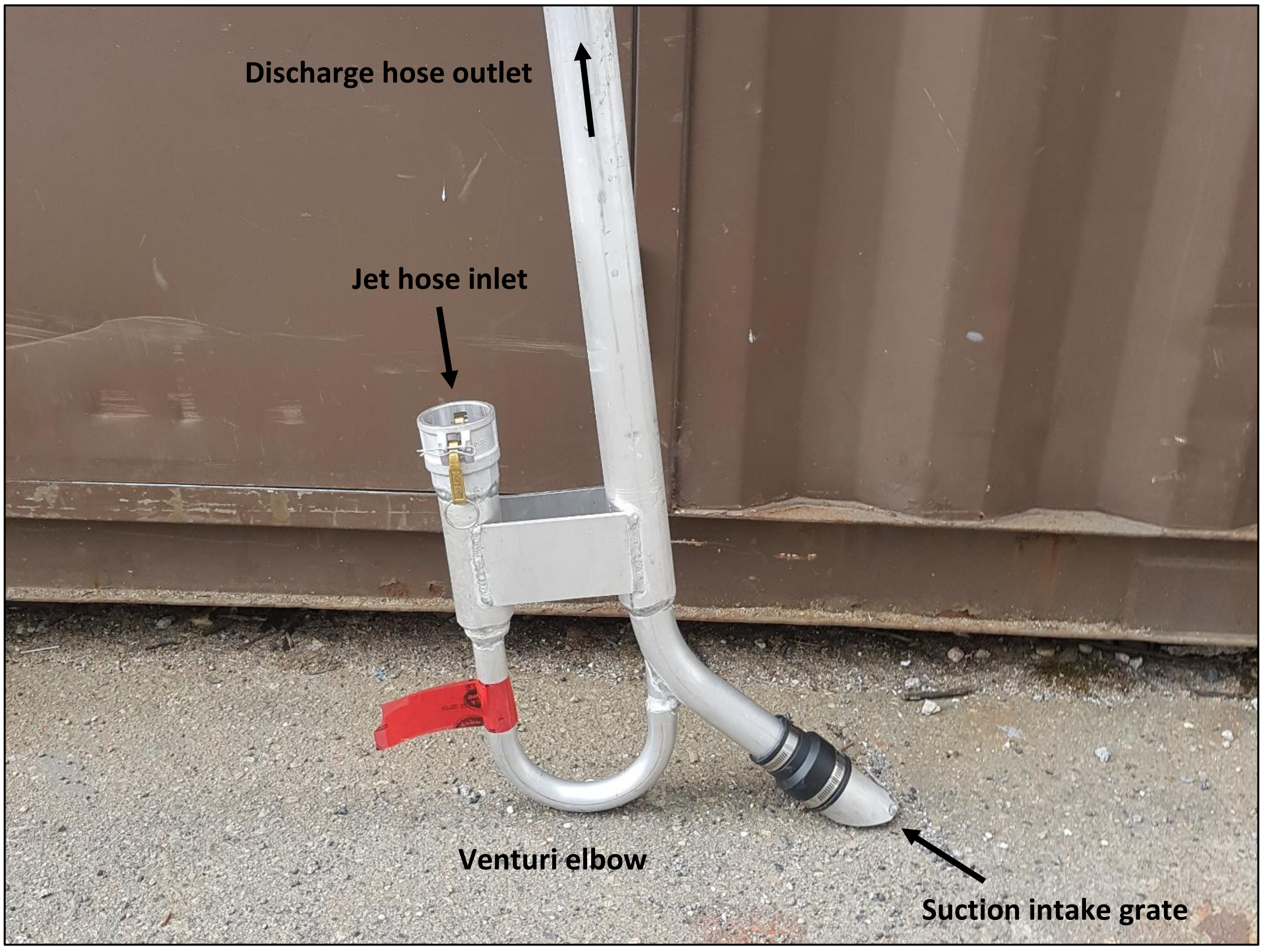

Photo 2.4 Venturi-type sediment sampler fabricated for this project in an attempt to collect quantitative data on sediment infilling.

2.6 Installation of sediment traps

The sediment traps consisted of 50 cm x 50 cm x 20 cm welded aluminum trays with a hinged grate lid (Photo 2.5). Large rounded cobbles sized to replicate the existing cobble substrate of the Lower Patch were fastened to the lid to maintain near-bed hydraulic roughness and sediment transport processes. Sampling bags made from stitched 125 micron mesh were attached to the inside of the aluminum trays and fitted with a drawstring to avoid losing sample contents upon retrieval (Photo 2.6). Finally, plastic fencing was placed inside the sample bag to reduce flow turbulence and velocity within the trap, thus preventing the scour and loss of collected sediment.

As with the proposed substrate cleaning sites, potential sites to install the sediment traps were identified prior to the operations based on results from previous studies (NHC, 2018, 2020). These sites were concentrated between the downstream end of the island complex and the Lower Site spawning area (Figure 2.6) to measure infilling rates within the core spawning area, determined based on egg detections in 2017 and 2019[1]. The sites were intended to sample a range of sediment transport conditions, including high sediment transport immediately downstream of the island complex, as well as lower sediment transport rates where less infilling has been observed (NHC, 2020).

As with the substrate cleaning sites, the final locations for the sediment traps were determined on-site based on local hydraulics and existing substrate conditions, observed using the underwater camera as part of the prescreening/prioritization process. Fewer criteria were required to select the final trap locations compared to the substrate cleaning because the traps were intended to sample a range of sediment transport conditions, while the cleaning was performed only in areas with relatively low sediment transport (Section 2.2). The primary criteria used to select the trap locations was a flow velocity of less than approx. 1.0 m/s and no large assemblages of mussels on the riverbed.

Photo 2.5 Overhead view of sediment trap showing hinged lid with cobbles, 125 micron mesh sampling bag and snow fencing to prevent scour and loss of collected sediment.

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[1] Data provided by the Nechako White Sturgeon Conservation Center (NWSCC).

Photo 2.6 **Front-view of the sediment trap showing the anchor chain attachment and drawstrings used to close the sample bag prior to retrieval.**

Figure 2.6 Proposed sediment trap locations shown in relation to proposed cleaning sites.

3 RESULTS

3.1 Substrate cleaning techniques

As mentioned in Section 2.2, a variety of sediment cleaning techniques were used to explore the feasibility and effectiveness of different tools; these techniques included a diver-operated hydraulic jet (Photo 2.2) and a suction dredge fitted with various dredging heads and screen sizes (Figure 2.2). The suction dredge was also used in combination with hand tools to see whether infilled fines could be extracted from the subsurface layers by manually raking and mechanically disturbing the surficial substrate (Photo 2.3). The following subsections describe the performance of each method.

3.1.1 Suction dredging

The cylinder-type dredge head shown on Photo 2.2 (A) did not prove to be an effective tool to remove fine sediment from native gravel substrates. The main issue encountered with this type of fitting was that the cylinder would rapidly become clogged due to the wide grainsize distribution on the riverbed.

Adjusting the number and spacing of bars[2] which cross the opening of the cylinder did not resolve this issue because regardless of the opening size, the grainsize distribution on the bed was wide enough to contain some grains which would jam within the cylinder. In a final attempt to resolve this issue, rebar was attached to the sides of the dredge head to a) maintain a certain distance from the bed to prevent clogging and b) mechanically rake the substrate while providing enough suction to remove infilled fines. This configuration still did not resolve the issue, as very minor changes in the height above the bed would cause the dredge either to not provide enough suction to remove sediment or provide too much suction and become clogged with gravels.

The dredge head with a circular screen shown on Photo 2.2 (B) did not become clogged with sediment like the cylinder-type dredge, mainly because the suction is distributed over a wider area, reducing the amount suction directed towards the bed. However, the reduced amount of suction acting on the bed in turn reduced the effectiveness of the dredge at removing fine sediment from the surficial layer of substrate, and rendered it incapable of removing fine sediment at-depth. In an attempt to increase the efficiency of the dredge, it was then used in combination with mechanical raking. Even in doing so, however, the dredge was only partially effective at removing surficial fines, and largely ineffective at capturing fine sediment brought into suspension.

In a second attempt to increase the performance of the circular screen-type dredge head, the top half of the screen was covered to increase the amount of suction directed downwards toward the bed (Photo 3.1). This modification increased the ability of the dredge not only to remove larger grains (sand and granules), but also more sediment. Again, the most effective way of to use this type of dredge head was to combine it with mechanical raking of the surrounding substrate.

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[2] It was necessary to maintain a minimum of two cross-cylinder bars inside the suction head to prevent removal of gravels and small cobbles, which are considered to be within the range of grainsizes that provide interstitial habitat.

Photo 3.1 Suction dredge with circular screen-type dredge head partially covered to increase suction overtop of the substrate at the Middle Patch.

3.1.2 Hydraulic jetting

Hydraulic jetting (Photo 2.2) was found to be the most effective method for removing fine sediment from within the surficial layer of substrate, where the high pressure nozzle would be positioned approx. 5-10 cm above the bed and directed into the substrate in a sweeping motion. The jet was capable of mobilizing all grainsizes contained within the substrate simultaneously, including gravels and cobbles, which allowed for a complete mixing of the surface and subsurface material. The constant mixing and mobilization of the substrate resulted in a progressive coarsening of surficial material, as fine sediment (silt and sand) would be brought into suspension and transported downstream, while coarser pebbles and gravels would rapidly settle out of suspension and deposit nearby. When applied to an area for a sufficient duration, hydraulic jetting was found to produce a much thicker layer of cleaned gravels (up to approx. 15 cm) containing a comparatively small proportion of sand and silt compared to other substrate treatments.

Hydraulic jetting was conducted from upstream to downstream to prevent redeposition of fines in treated areas. This method was found to produce a hummocky topography (which was subsequently smoothed out by hand) as the jet would cause a progressive lowering of the bed due to the removal of fines from within the subsurface layer, along with an accumulation of sediment downstream. Although this downstream deposition did not prove to be problematic for this study given the relatively small scale of the operation, it may become problematic while cleaning larger areas, as the cleaning process would become increasingly difficult due to the increasing accumulation of fines in the downstream direction.

3.2 Substrate cleaning during the spawning period

3.2.1 Middle Patch

Cleaning at the Middle Patch took place on May 6, 2020. As shown on Figure 2.3, the selected treatment area was located in the downstream portion of the spawning pad, approximately 20-25 m from the right bank (facing downstream). At the time of the operation, the depth at this site was approximately 3 m and the velocity was estimated to be between 1.0 and 1.5 m/s. The existing substrate was generally composed of cobbles and gravels, with a relatively limited amount of sand deposited between the coarser clasts; however, the amount of surficial sand did vary spatially, from areas with little to no sand to areas with a moderate amount of sand between the cobbles. Generally speaking, however, the existing substrate at the Middle Patch had a relatively minor amount of infilling and deposition overtop of the placed cobble material (Photo 3.2) and interstitial spaces did appear available at a depth of one or two grains thick.

Suction dredging was the primary method used to remove infilled fines, including the use of the cylinder-type and circular screen-type dredge heads, with and without the screen cover modification (Section 3.1.1). Cleaning at this site was very slow and diver mobility was limited by the excessive drag on the suction dredge and discharge hoses. After approximately one hour of dredging with the modified screen-type dredge head, which was achieving fair results (Photo 3.3), albeit at a very slow production rate, the entire operation including two tethered dive boats and an anchored discharge line began to drag anchor and drift downstream. This marked the end of the operations for May 6, 2020, as there was insufficient time to reposition the equipment and crew.

Photo 3.2 Pre-existing substrate observed on the Middle Patch showing coarse bed of placed cobbles and gravels with a minor to moderate amount of infilled sand.

Photo 3.3 Cleaning substrate at the Middle Patch using the modified screen-type dredge (substrate in the image has been cleaned).

3.2.2 Lower Patch

Cleaning at the Lower Patch took place on May 8, 2020. As shown on Figure 2.4, the selected treatment area was located approximately 15 m offshore from the north bank, roughly midway down the Lower Patch (i.e. from upstream to downstream). This site was selected in large part due to the lack of mussels, as other proposed locations were found to have a high density of mussels embedded within the existing cobble substrate (Photo 3.4).

Photo 3.5 shows the typical substrate observed on the Lower Patch prior to the cleaning operation, consisting of a mix of large cobbles and gravels typically overlaying a base of sand. However, the composition of the existing substrate, including the amount of surficial sand, varied spatially over the area. Several sites were found to have a coarse cobble substrate protruding above the bed. These sites appeared to provide large interstitial voids (perhaps too large for larvae to find velocity refuge) between the protruding cobbles, although interstitial space at-depth appeared limited by a base of sand and gravel.

Photo 3.4 **High density of mussels embedded within the cobbles of the Lower Patch upstream of the selected cleaning site.**

Photo 3.5 Typical substrate at the Lower Patch cleaning site prior to hydraulic jetting showing a mix of large cobbles and gravels overlaying a base of sand.

The primary method used to clean the substrate at this location was hydraulic jetting with a high pressure nozzle. The hydraulic jet was able to mobilize the embedded cobble and gravel substrates to a depth of approximately 15 to 30 cm. This method successfully produced a layer of loose, cleaned gravels deposited to a thickness of several times the mean grainsize (total thickness of approx. 5-10 cm) (Figure 3.1). However, the results were not consistent across the treatment area due to several key limitations of the methodology, as discussed below.

One key limitation associated with this technique is that the fine sediment was not being removed from the site, but rather displaced, creating an accumulation of fine sediment immediately downstream of cleaned gravel deposits (Figure 3.2). Higher flow velocity within the river would be required to transport the sand in suspension as it does with silt; however, higher velocities would render the operation infeasible, as existing velocities at the site (1.0-1.5 m/s) were already limiting diver mobility (diver and hoses had to be tied off to additional anchoring systems). This deposition and progressive accumulation of finer material downstream makes it increasingly difficult to clean the substrate, until the jet becomes largely incapable of moving the accumulated sand and small gravel.

Another factor which influenced the quality of the restored substrate was the composition of the pre-existing substrate, where the jetting was most effective in areas that had a relatively high proportion of coarse grains within the surface or subsurface sediment mixture. In areas where the substrate composition was fine-grained, or where the surficial cobbles and gravels were underlain by a thick layer of sand and silt, the hydraulic jet was found to continuously produce a larger and larger hole, without necessarily producing a coarser substrate of cleaned gravels.

Overall, a total area of approximately 20-25 m^2 was cleaned on the Lower Patch using the hydraulic jet in about 1 hour and 45 minutes, resulting in a production rate of roughly 12-14 m^2 per hour once on-site.

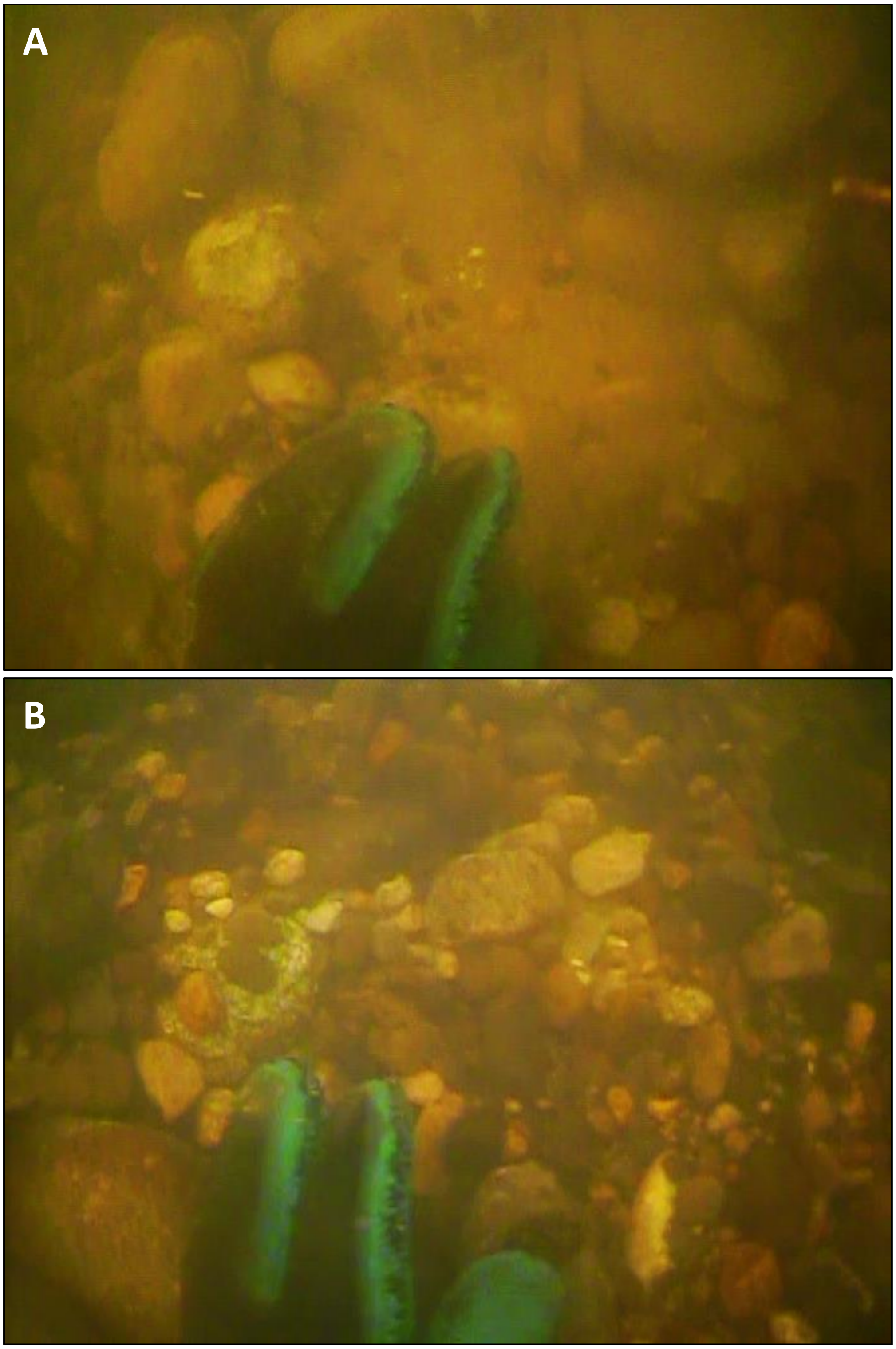

Figure 3.1 Pre- and post-operation substrate condition at the Lower Patch cleaning site; A) pre-existing substrate showing embedded cobbles and gravel with surficial sand deposition and B) cleaned substrate showing recently mobilized gravels.

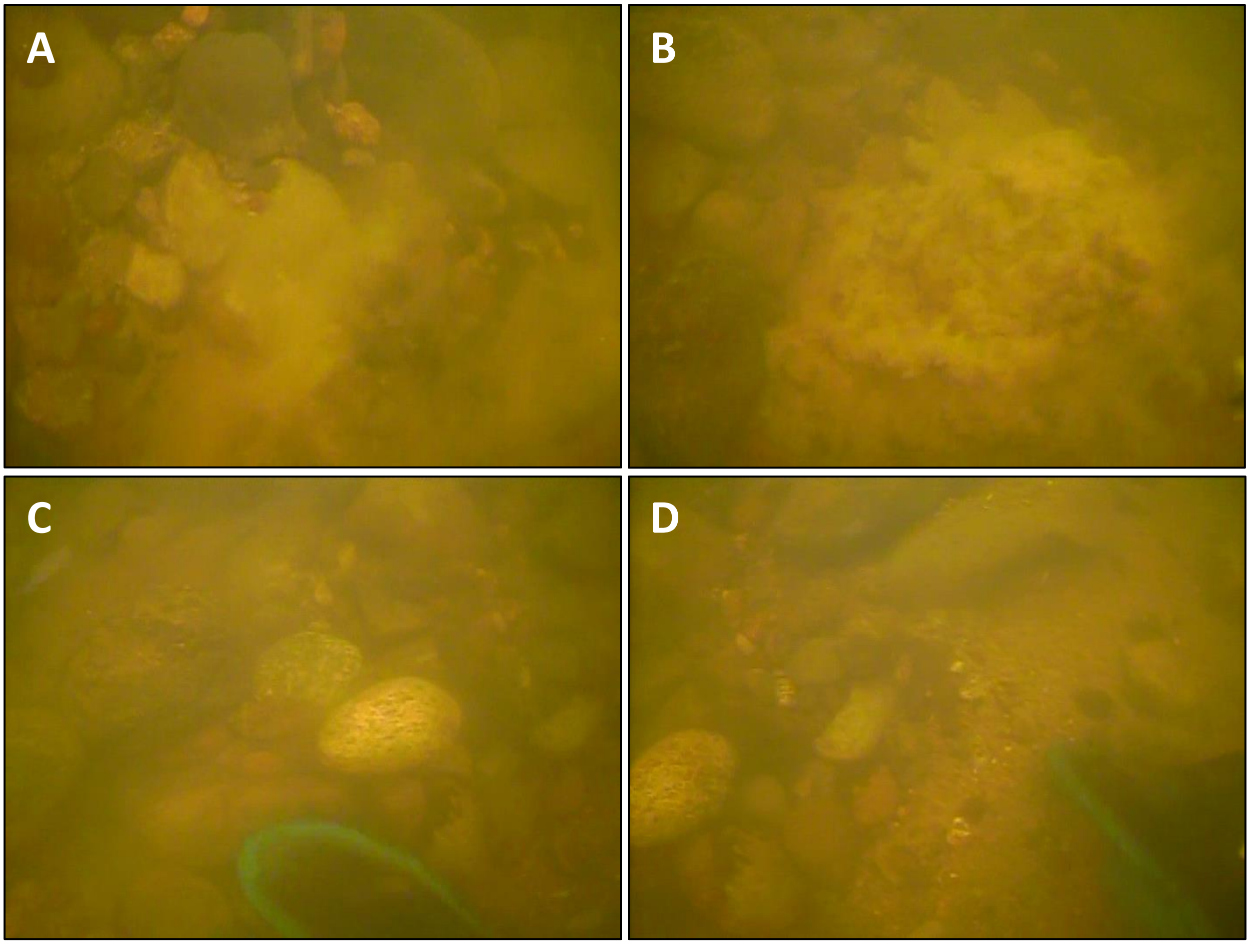

Figure 3.2 Overview of the substrate cleaning process using the hydraulic jet at the Lower Patch; A) pre-existing substrate composed of cobbles and gravels on base of compacted sand, B) hydraulic jet mixing substrate and bringing underlying sand and silt into suspension, C) substrate after jetting showing layer of loosely deposited gravels and cobbles with minimal surficial sand and D) redeposition of sand approximately 0.5 m downstream of cleaned substrate.

3.2.3 Lower Site

Cleaning at the Lower Site took place on May 7, 2020. As shown on Figure 2.5, it was necessary to shift the location of the treatment area downstream relative to the target locations due to high velocities and mussel beds present at the originally planned locations. The estimated depth and velocity at the selected location were approximately 2.5-3.0 m and 0.75-1.25 m/s, respectively. Prescreening of this area using the underwater camera confirmed that the existing substrate was predominantly composed of small to large gravels with granules and scattered cobbles (Photo 3.6). The gravels had a varying degree of embeddedness and appeared to be overlying a base of fine silt and sand, which was considered suitable for experimental cleaning.

Photo 3.6 Pre-existing substrate observed at the Lower Site cleaning area showing infilled gravels with trace cobbles.

Several methods were used to explore the effectiveness of different cleaning techniques at this location, including mechanical raking, suction dredging and hydraulic jetting. Of these methods, hydraulic jetting was found to be the most productive and effective method of removing subsurface fines. Mechanical raking and suction dredging (used in combination and separately) were able to able to produce a surficial layer (5-10 cm thick) of loose, cleaned pebbles and gravels; however, the production rate was excessively slow, the suction dredge was largely ineffective at removing fines at depth or capturing suspended fines, and the thickness to which the substrate could be cleaned was limited by the fine grainsize distribution of the pre-existing substrate and the considerable thickness of the underlying sand and silt. In contrast, the hydraulic jet was able to mobilize all grainsizes contained within the substrate to a considerable depth (approx. 15-30 cm) and break up a unit of compacted fine sediment underlying the substrate in portions of the area (Figure 3.3). Although this compacted sediment is likely to indicate a lack of disturbance of underlying substrates for an extensive period, detailed observations of the material were not collected as part of this project.

The composition of the cleaned substrate using the hydraulic jet consisted of a relatively thick (approx. 15 cm) layer of lag material (Photo 3.7 – Photo 3.9), including pebbles, gravels and trace cobbles, which generally contained only minimal fines, as evidenced by the minimal plume of suspended sediment produced as the diver pushed piles lag materials by hand (Photo 3.10). However, the coarseness of the resulting substrate composition, as well as the proportion of fine sediment contained within it, varied from upstream to downstream, where the downstream portion of the area had a greater proportion of fine gravels, pebbles and sand (Photo 3.11; Photo 3.12). This may have been caused by differences in the pre-existing grainsize distribution, or by the cleaning process itself, which progressively created a larger accumulation of fine sediment downstream.

A total area of approximately 30-35 m^2 was cleaned using the hydraulic jet in 3 hours and 25 minutes, achieving a production rate of roughly 8-10 m^2 per hour. This estimate does not include the time spent experimenting with alternative cleaning methods, but does include all operational time required for hydraulic jetting (e.g. lowering jet hoses, changing divers, etc.).

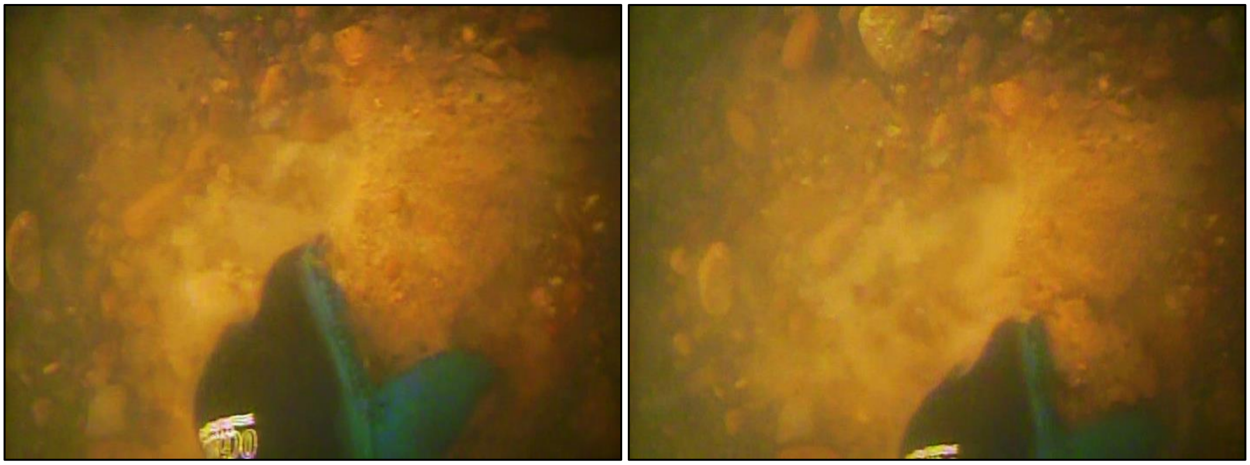

Figure 3.3 Consecutive photos showing the diver breaking off a piece of compacted fine sediment found to underly the substrate in portions of the Lower Site cleaning area.

Photo 3.7 Cleaned substrate near the upstream end of the Lower Site treatment area.

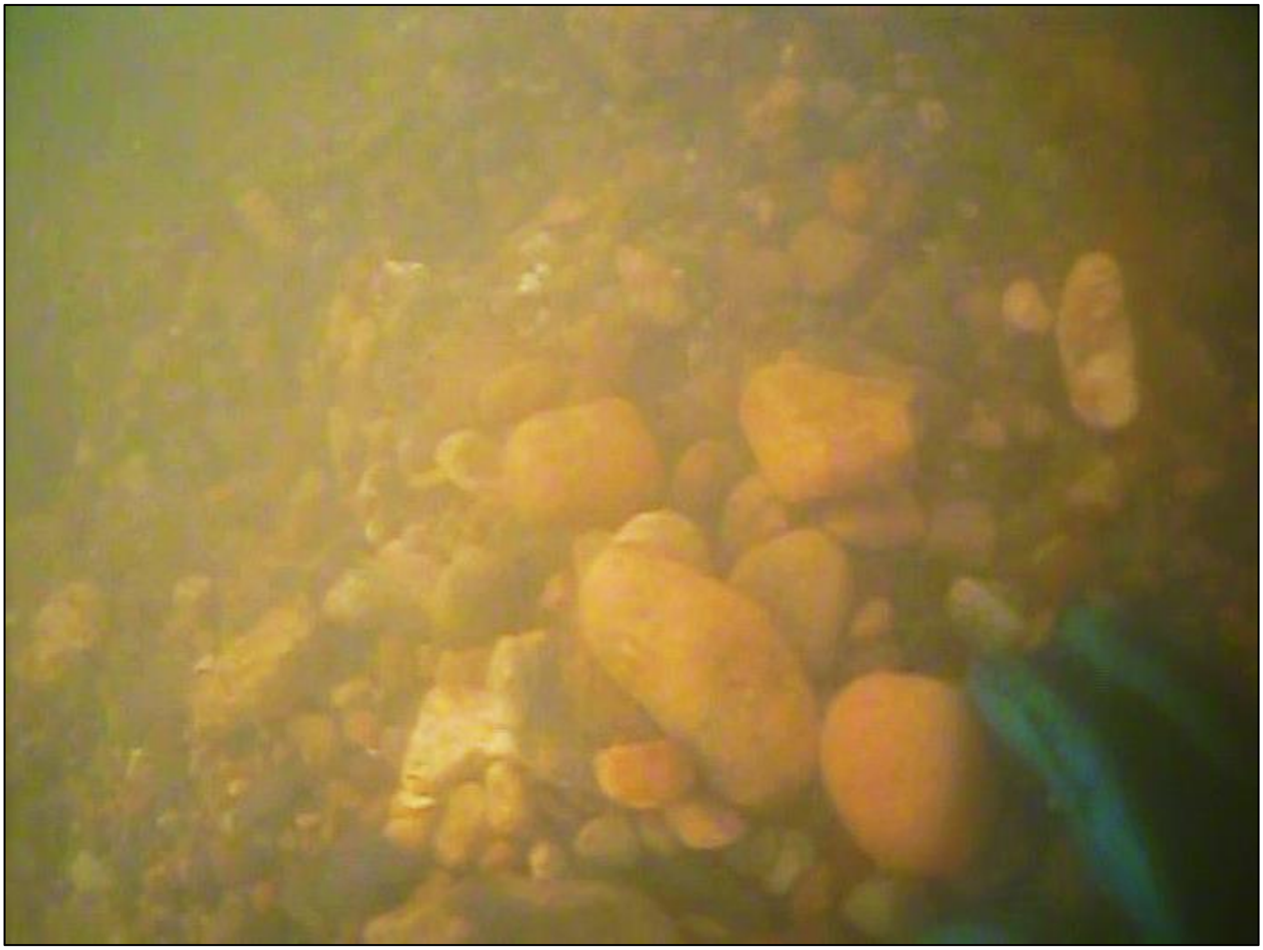

Photo 3.8 Cleaned substrate near the upstream end of the Lower Site treatment area.

Photo 3.9 Cleaned substrate near the upstream end of the Lower Site treatment area.

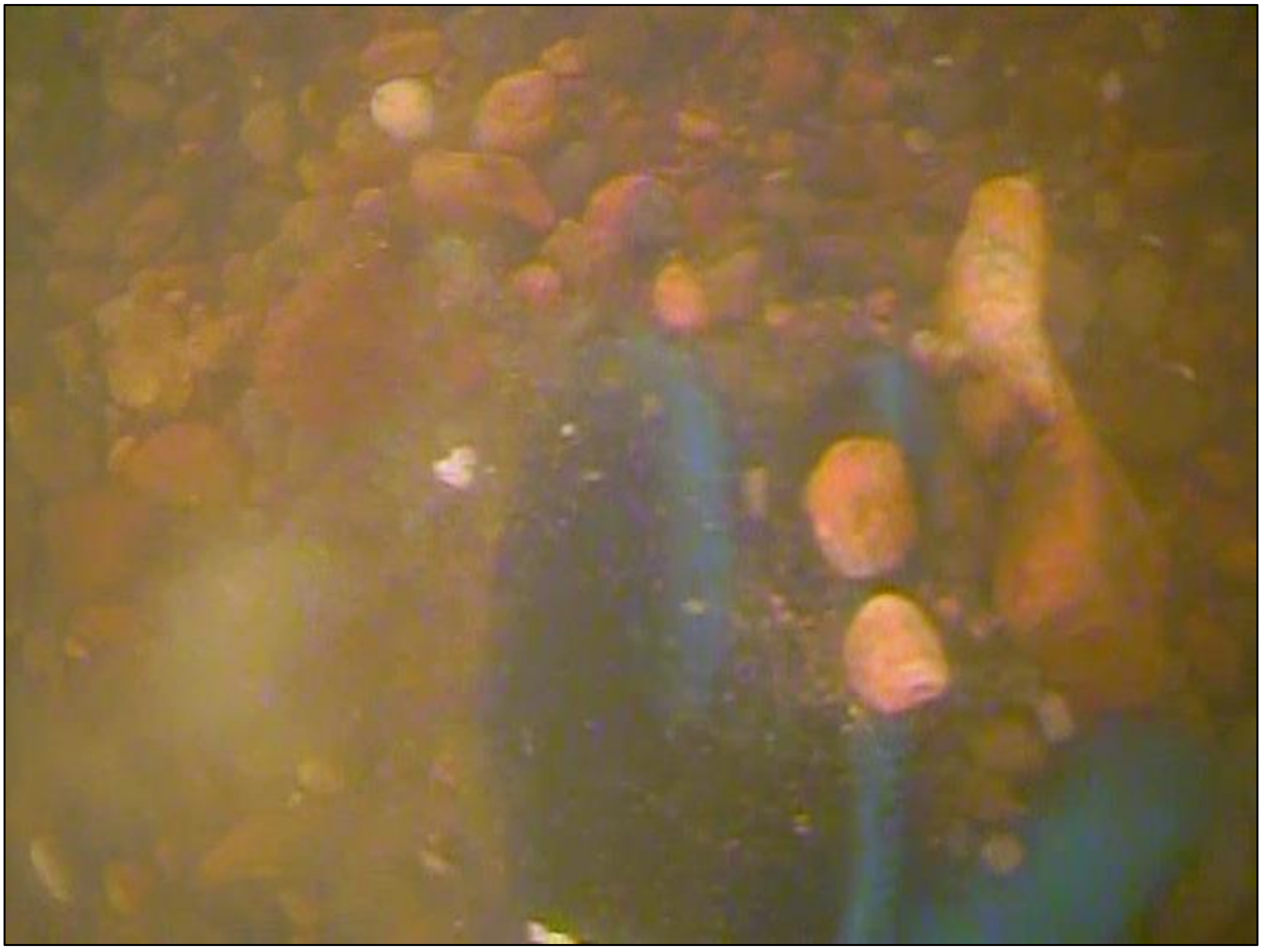

Photo 3.10 **Post-cleaned substrate containing only a small amount of fine sediment, as evidenced by the small plume of suspended sediment (as opposed to a large plume) produced as the diver pushes piles of cleaned gravels.**

Photo 3.11 Cleaned substrate near the downstream end of the Lower Site treatment area showing a greater proportion of finer gravels compared to upstream.

Photo 3.12 Diver showing the composition of the cleaned substrate near the downstream end of the Lower Site treatment area.

3.3 Condition of the substrate over time

As previously mentioned in Section 2.4, additional monitoring was done following the spawning period to assess whether the condition of the cleaned substrate changed over this time. To achieve this, underwater images of the substrate were taken at predetermined monitoring locations immediately after cleaning operation on May 7, 2020 and during the follow-up site visit on June 22, 2020. The photos were georeferenced using an RTK GPS, and therefore the maximum spatial difference between the before and after photos was approximately 1 m, allowing for a fairly reliable comparison. The following sections compare the condition of the cleaned substrate at both the Lower Patch and Lower Site areas; no comparison is made for the Middle Patch because the cleaning was unsuccessful due to the operational issues described in Section 3.2.1.

3.3.1 Lower Patch

It was not possible to collect spatially accurate substrate photos on the Lower Patch immediately following the cleaning operation due to operational constraints and lack of time; photos were still obtained during cleaning, but aren't sufficiently accurate for the detailed monitoring procedure. Only follow-up monitoring photos of the substrate condition are available, which were taken on June 22, 2020.

Figure 3.4 shows the locations of the underwater photos taken on June 22, 2020 relative to the area cleaned in May. A total of seven photos were taken within a 6 m^2 area located near the center portion of the cleaned area, which are considered most likely to depict substrate that was cleaned during the operation (as opposed to photos taken along the edges of the cleaned area, which carry greater uncertainty as to whether they were fully cleaned or not). These photos show that the substrate on June 22 was generally composed of coarse gravel and cobble with a low to moderate degree of embeddedness and infilling with sand (Figure 3.5).

A photo transect was also completed on June 22 to further highlight potential differences in substrate composition created by the cleaning operation (Figure 3.4); Figure 3.6 shows the photos taken along this transect from onshore to offshore, with the cleaned area being located 15 m from the bank. These photos show that there was a greater proportion of sand contained within the substrate on both sides of the cleaned area, with a comparatively small amount of fine sediment within the treatment area.

Although the lines of evidence suggest that the condition of the cleaned substrate was at least partially maintained over the monitoring period, it is important to recognize the spatial variability in substrate composition at the Lower Patch site, where deposition of sand often occurs in discrete locations (e.g. behind larger cobbles), producing large differences in substrate composition across small spatial scales. Furthermore, cleaned gravel was not uniformly distributed across the area due to limitations of the cleaning methodology (Section 3.2.2), which resulted in some areas containing a greater proportion of sand and fine gravel than others; due to these caveats, the results of the change detection (without accurate post-operation monitoring sites) should be interpreted with a degree of uncertainty.

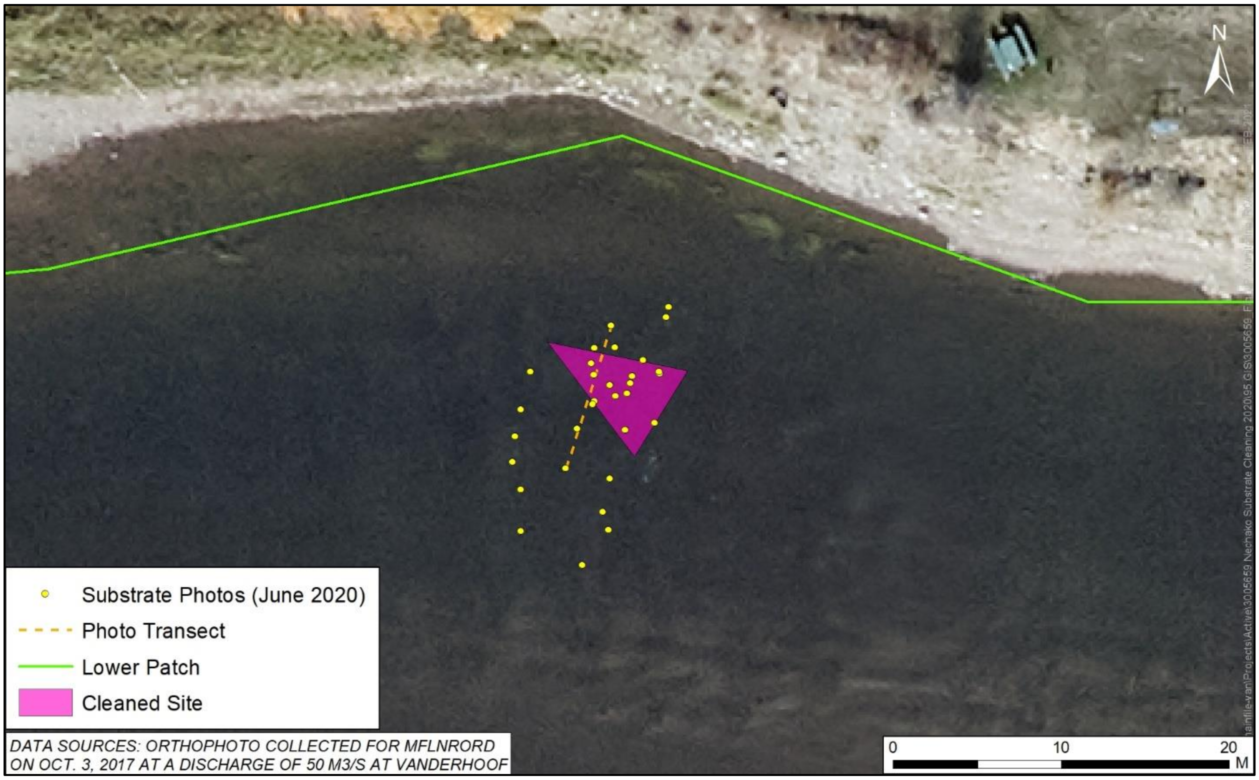

Figure 3.4 Cleaned site on the Lower Patch with locations of underwater photos taken to monitor the condition of the substrate on June 22, 2020.

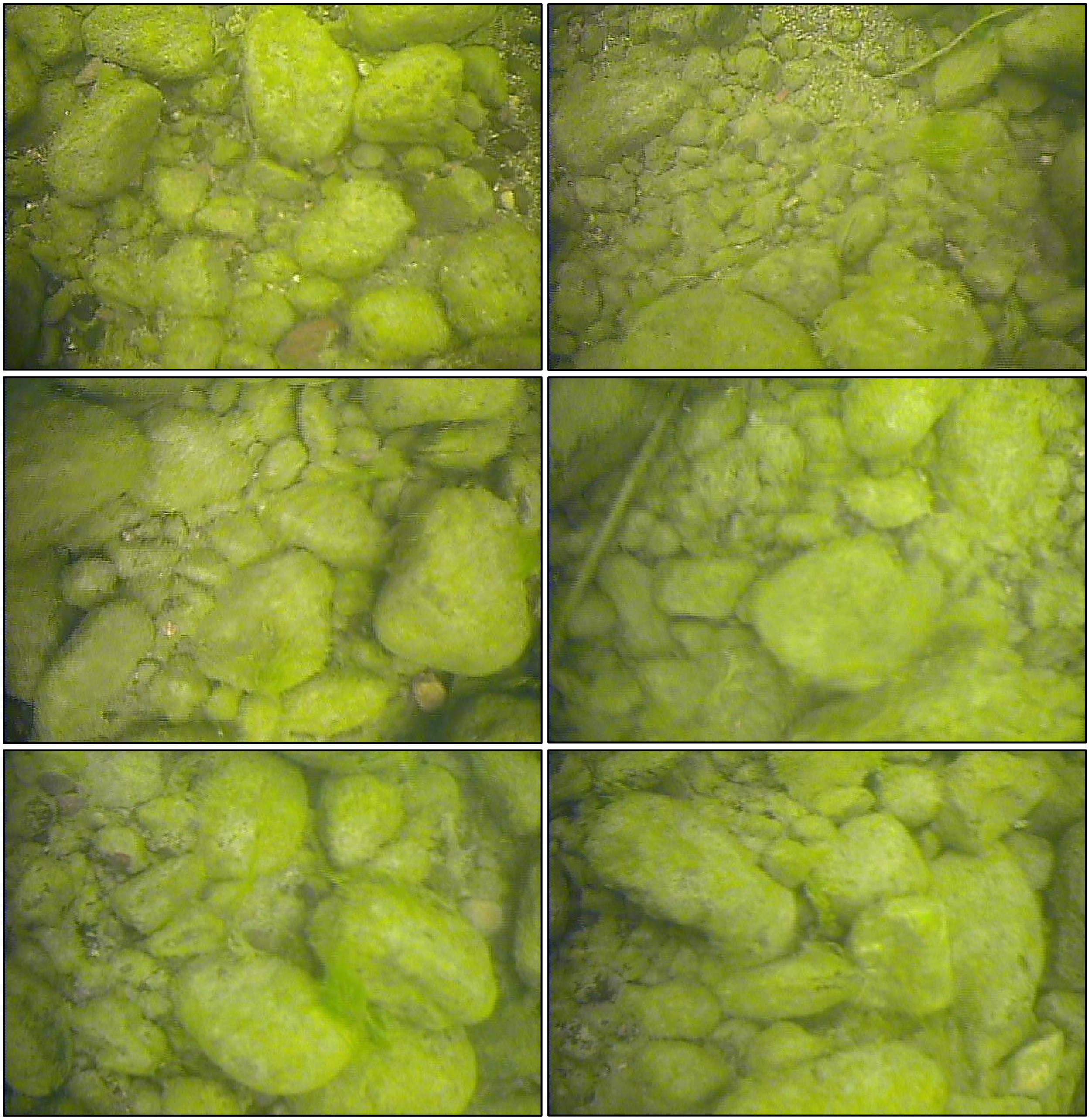

Figure 3.5 Substrate photos taken within cleaned area on Lower Patch on June 22, 2020.

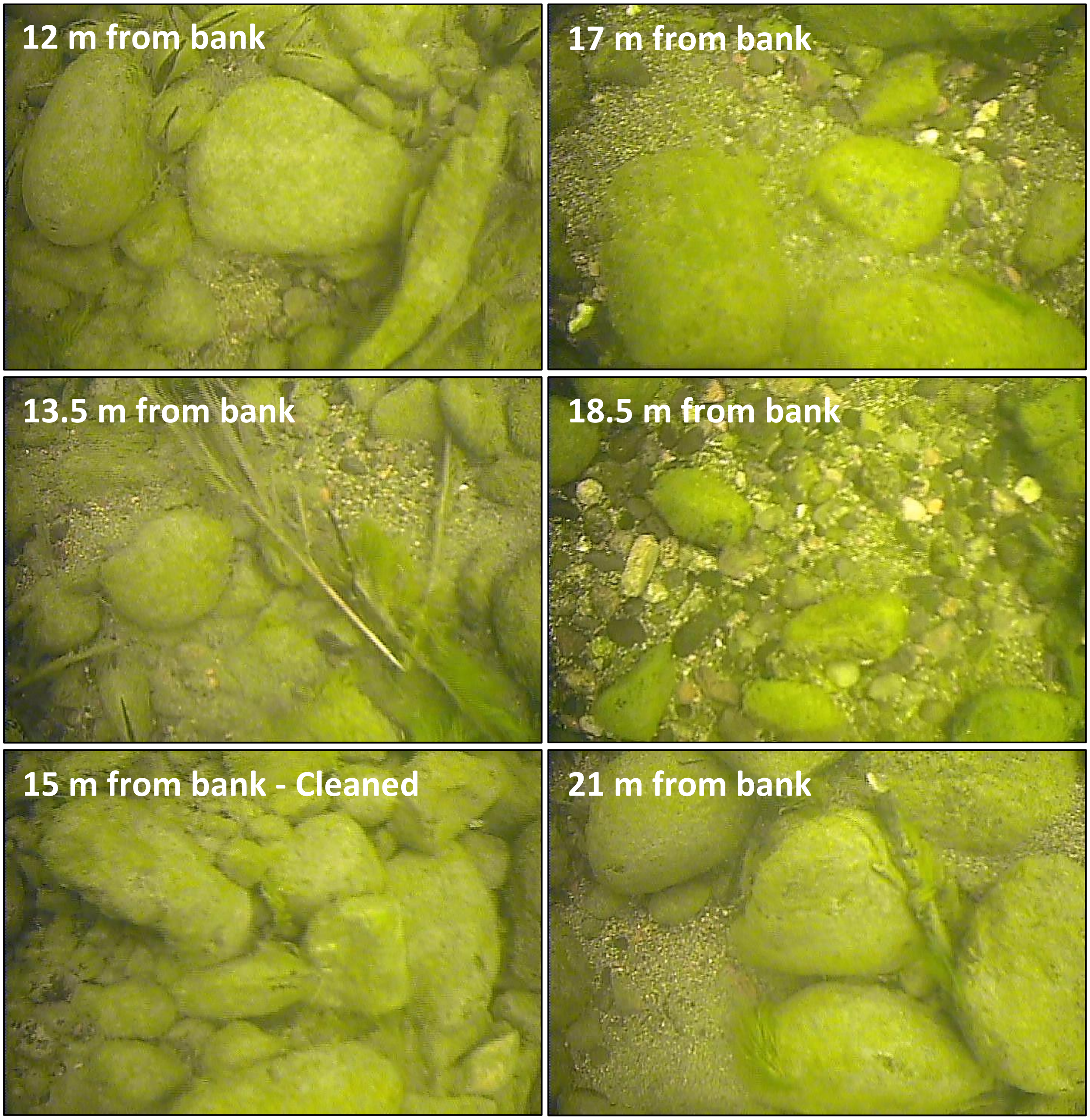

Figure 3.6 **Substrate photos taken along a transect crossing the cleaned area of the Lower Patch on June 22, 2020.**

3.3.2 Lower Site

Substrate monitoring photos were taken at 5 specific locations within the Lower Site treatment area (Figure 3.7). Photo comparisons of the substrate during the pre- and post-spawning period are provided below (Photo 3.13 – Photo 3.17); however, it is important to note that the scale in the May and June images is not the same, since, in May, the camera mount settled deeper within the newly cleaned deposits of loose gravel, thus magnifying the appearance of the gravels.

Firstly, it is important to note that the growth of macrophytes within the entire area rendered detailed observations of the underlying substrate difficult. That said, the condition of the cleaned substrate at Sites 1, 2 and 3 appears to have been somewhat maintained over the monitoring period, as the gravels still protrude above the bed and are not embedded in sand; this is particularly the case at Site 3, where a pocket of clean gravel is clearly visible which closely resembles the cleaned substrate. Sites 4 and 5 appear to have undergone greater siltation over this period, as the follow-up imagery taken in late-June shows a general cover of grey material, which is assumed to be very fine sediment. These two sites are located nearer to the bank, where siltation may be greater due to lower flow velocities, further exacerbated by the macrophytes which can reduce near-bed velocity and promote sediment retention.

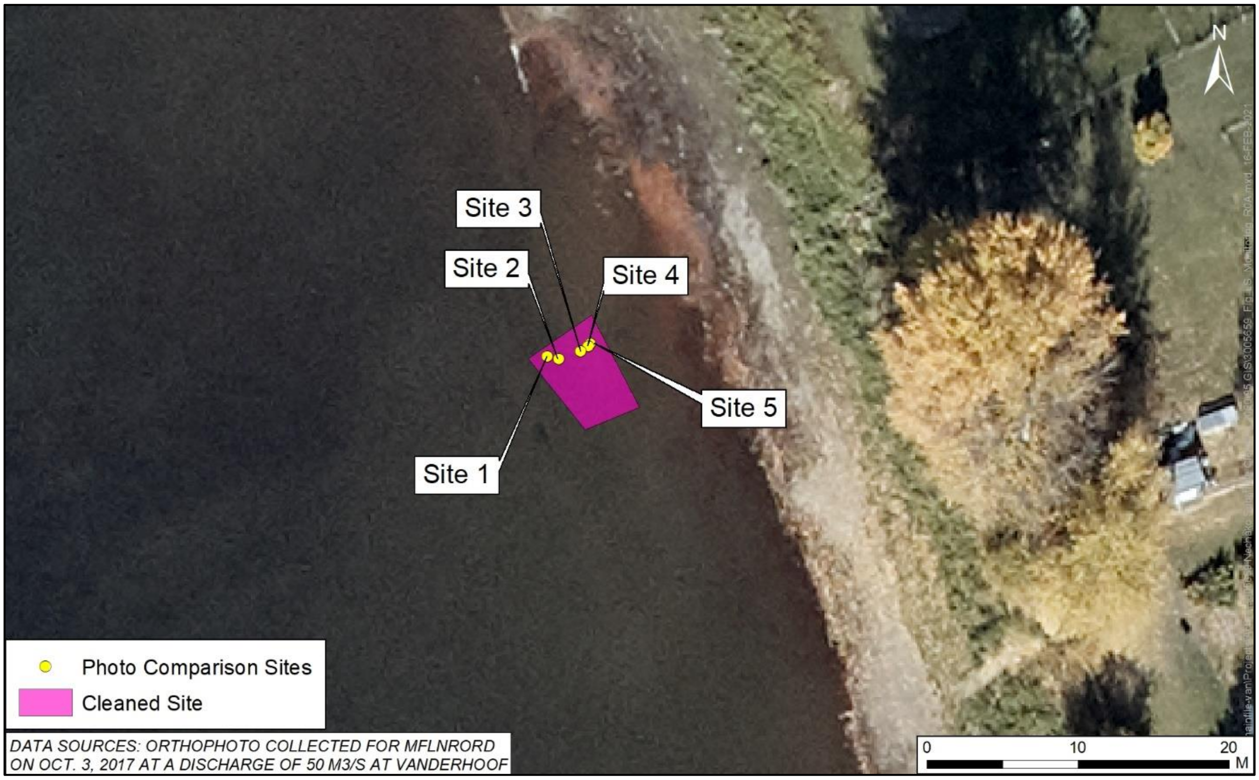

Figure 3.7 Substrate monitoring sites within the Lower Site treatment area where underwater imagery was collected immediately after cleaning on May 7, 2020 and on June 22, 2020.

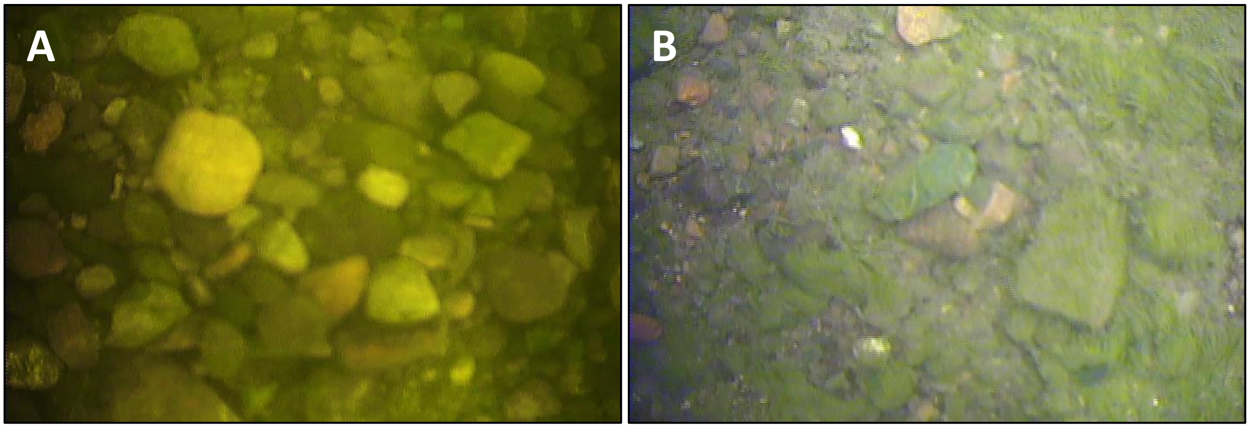

Photo 3.13 Substrate comparison at Site 1; A) May 7, 2020, B) June 22, 2020.

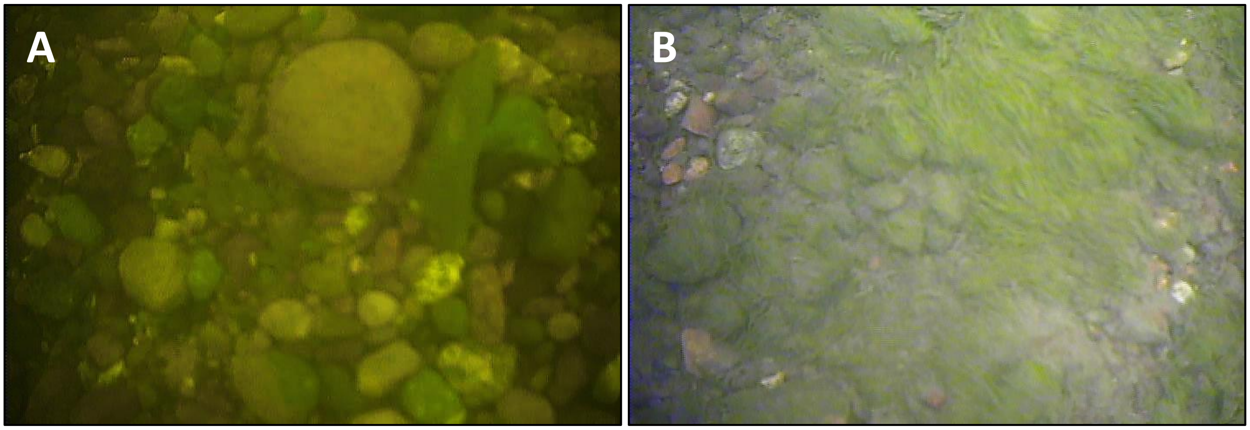

Photo 3.14 Substrate comparison at Site 2; A) May 7, 2020, B) June 22, 2020.

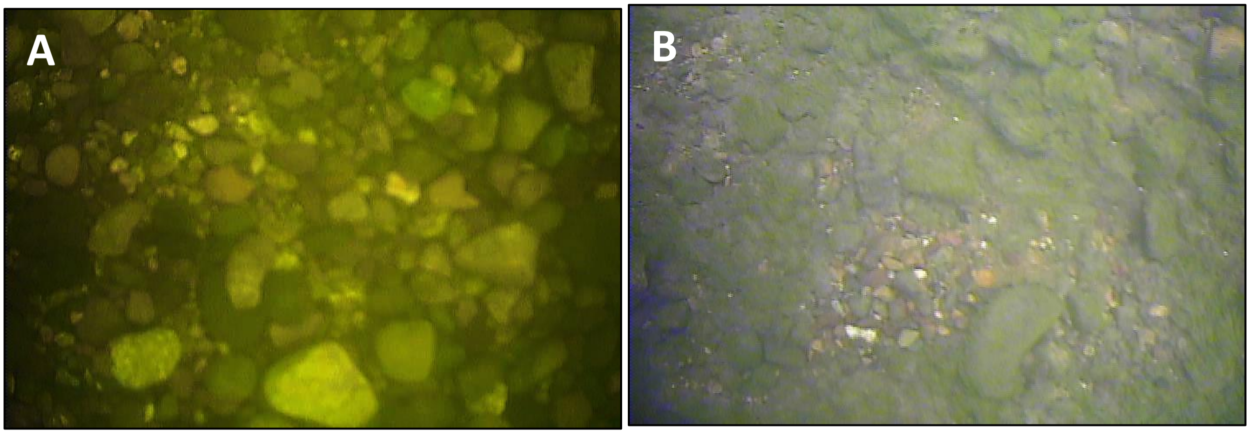

Photo 3.15 Substrate comparison at Site 3; A) May 7, 2020, B) June 22, 2020.

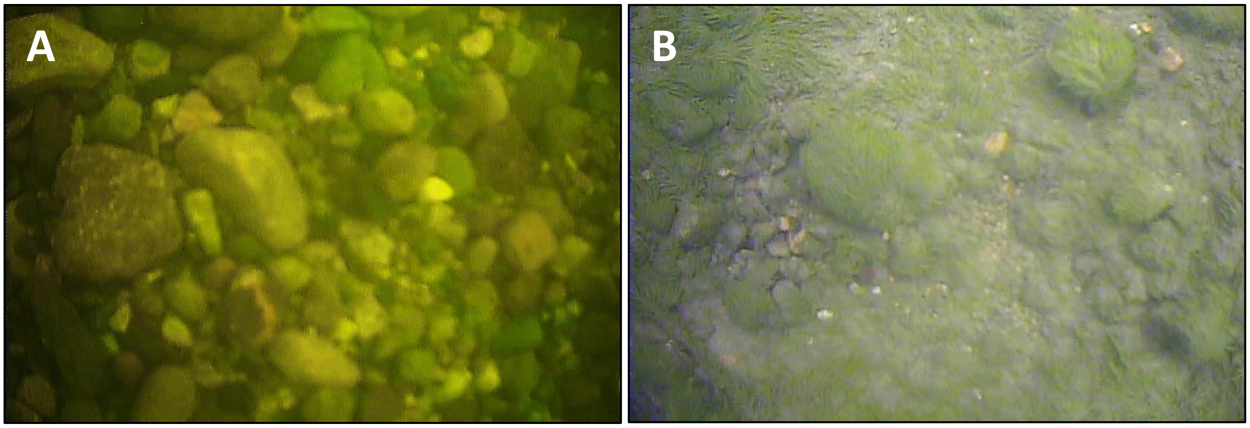

Photo 3.16 Substrate comparison at Site 4; A) May 7, 2020, B) June 22, 2020.

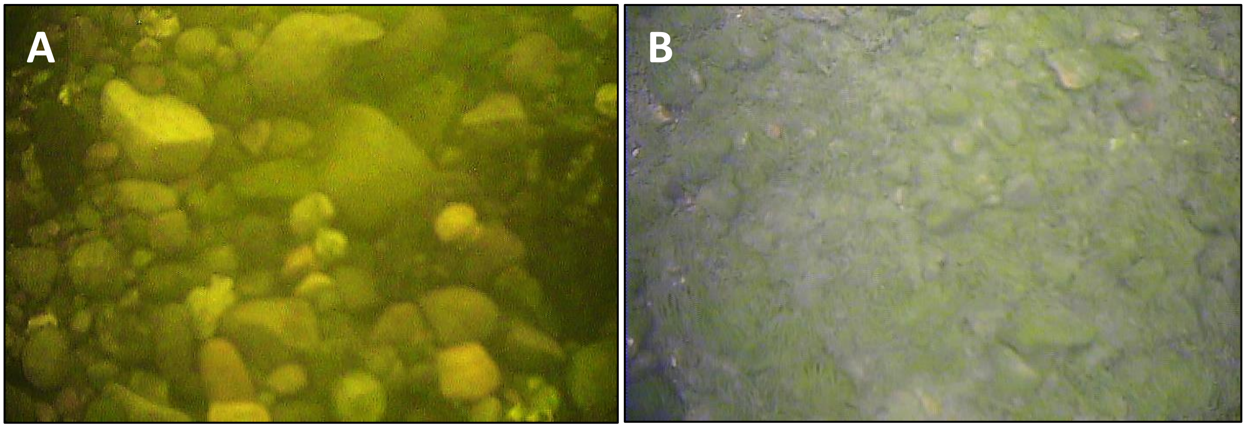

Photo 3.17 Substrate comparison at Site 5; A) May 7, 2020, B) June 22, 2020.

3.4 Sediment traps

The final locations of the four sediment traps embedded within the spawning reach are shown on Figure 3.8. All traps were found to contain a considerable amount of sediment when retrieved on June 22, 2020, with Traps 1 and 2 containing the greatest amounts (Figure 3.9). The amount contained in Trap 1 is likely to represent the maximum amount of sediment which could be collected by the traps, which is estimated to be approximately 55 kg based on the volume of the sampling bag and the typical mass density of dry sand. Although Trap 2 contained less sediment by weight, it is likely that the sampler was also 100% full (or nearly so), as some sediment loss may have occurred upon retrieval or due to local turbulence and near-bed hydraulics. Interestingly, the least amount of sediment was captured at Trap 3, which was located approximately 140 m directly upstream of the Lower Site cleaning area (both the cleaning area and Trap 3 were located approximately 10-15 m offshore from the north bank) (Figure 3.8).

The following paragraph describes the sediment contained within each sampler; however, it is important to note that a sieve analysis was not done with the sediment, and therefore descriptions are mostly qualitative.

The composition of the sediment contained within Trap 1 was uniform medium to coarse sand with almost no pebbles or gravels. In comparison, the sediment within Trap 2 contained more organic matter (wood), and consisted primarily of fine to coarse sand with trace granules (up to 3-5 mm), and only a few single gravels (~18 mm). Interestingly, the sediment collected by Trap 3 was noticeably finer than that collected at the other locations, as it was almost entirely composed of fine sand and silt with a relatively limited amount of coarse sand and no pebbles or gravels. Finally, the sediment within Trap 4 was almost entirely sand with no gravel, similar to Trap 1.

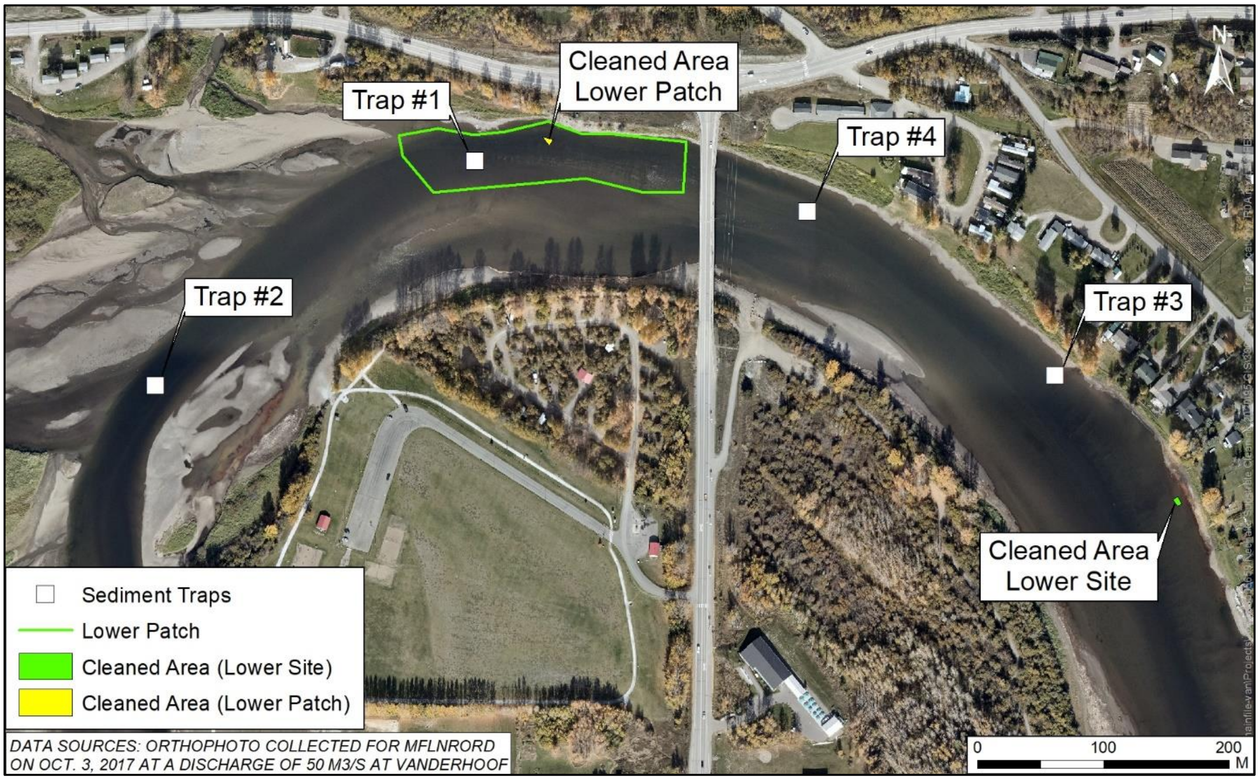

Figure 3.8 Final locations of the four sediment traps embedded within the spawning reach in 2020.

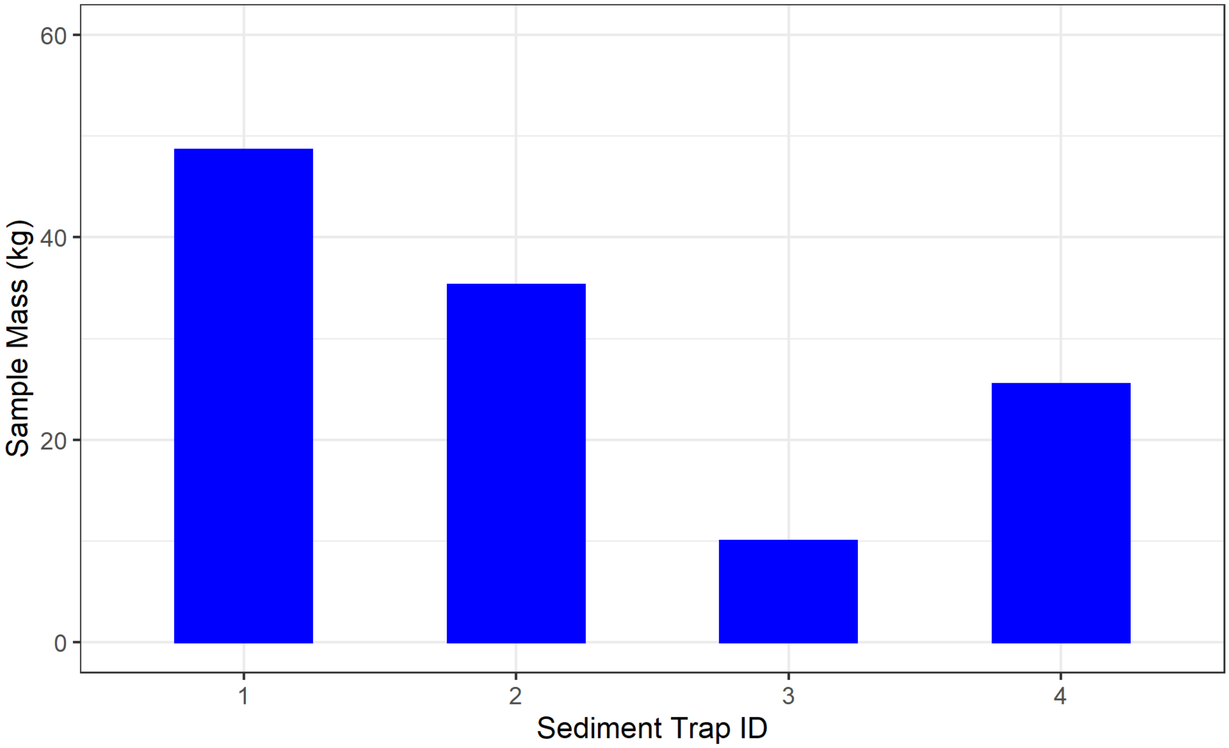

Figure 3.9 **Dry weight of sediment contained within the four sediment traps installed in 2020.**

4 ANALYSIS AND INTERPRETATION

4.1 Feasibility of using divers to restore spawning substrate

4.1.1 General limitations

There were several general limitations associated with using a diver-operated procedure to restore the quality of spawning substrate. Firstly, the divers are limited to areas which have a relatively low flow velocity, generally below 1.0 m/s. Although the divers were still able to perform some tasks in areas where the velocity was slightly above this threshold (1.0-1.5 m/s), the production rate, quality of the work and feasibility of the operation declined rapidly once velocity approached and exceeded 1.0 m/s. Under these higher velocity conditions, the diver and equipment (e.g. hydraulic jet, dredge, etc.) had to be tied off to additional anchoring systems, essentially eliminating the ability of the diver to move laterally. These conditions would restrict the progression of the work to a thin swatch oriented in a downstream direction, after which it would be necessary to reposition the anchors, diver and equipment laterally.

The second limitation is the production rate achieved using diver-operated machinery, especially in conditions which approach their operational feasibility (e.g. high velocity, low visibility, etc.). The maximum production rate achieved using the hydraulic jet ranged from 8-14 m^2/hour once on-site, while the production rate achieved using a suction dredge was slow enough to render the project infeasible given the allotted time and budget. It is important to note that these production rates represent the operational time required for hydraulic jetting (e.g. lowering jet hoses, changing divers, etc.) once on-site, but do not include mobilization to site, installation of anchoring systems, etc., which may considerably reduce the amount of time remaining for the diver to work on the bottom in a given day. The relatively slow production rates should be expected to limit the scale of future operations to small and moderate areas, or should be expected to generate very high costs to cover larger areas. That said, these techniques may still be suitable if the intent of the project is to restore the quality of the substrate within a small area to a high quality.

The third main limitation is the overall degree of effectiveness of the techniques, especially if the goal of the operation is to remove fines at-depth. As discussed in greater detail below, hydraulic jetting was found to be the only technique capable of mobilizing the existing substrates at-depth; however, the resulting quality of the cleaned substrate was not consistent across the treatment area due to the progressive downstream accumulation of fine sediment with increasing area. The use of a sediment removal method applied in combination with the jetting may (partially) resolve this issue, however it would be expected to drastically reduce production rates, while increasing logistics and cost.

The final limitation is related to the biological benefits of the restoration, given the operational constraints described above. Biological benefits may be marginal because the restored sites are relatively small and limited to areas with lower flow velocity, which may or may not correspond to spawning locations. In addition, although the cleaned areas on the Lower Patch and Lower Site appeared to be partially maintained over time (Section 3.3), this outcome is highly dependant on location, as the quality of the substrate would not be maintained in spawning areas exposed to high sediment transport.

Acknowledging these limitations, substrate cleaning using a diver-operated procedure may still represent a feasible solution for certain applications, as these methods were shown to successfully create clean gravel deposits in local areas. For example, these techniques may be useful if the intent of the work is to produce high quality substrate immediately prior to the spawning period at targeted locations, or for specific applications which require intensive, detailed cleaning of small areas.

4.1.2 Suction dredging

The use of suction dredging was found to be only partially effective at removing surficial fine sediment, and largely incapable of removing fines at-depth from within the substrate. The wide grainsize distribution of the existing substrate proved to be very problematic for this technique, as grains would become clogged in the dredge regardless of screen size. The effectiveness of suction dredging did increase by combining it with mechanical disturbance; however, much of the improvement was attributed to the mechanical disturbance itself, as opposed to increased effectiveness of the suction dredge. In fact, the suction dredge would only capture a portion of the sediment brought into suspension, while the rest either re-settled rapidly or dispersed downstream as a plume.

Overall, the very slow production rate achieved with this technique limits its application to small-scale restoration projects. Additional factors which limit size of the potential treatment area include the large anchoring system that is required, the limited mobility of the diver due to excessive drag on hoses and discharge lines, and the increasing safety concern associated with multiple anchoring systems and hoses. An effective application of this technique is likely limited to sites that have a low flow velocity (< 1 m/s) and a relatively uniform grainsize distribution (i.e. sand-bedded).

4.1.3 Hydraulic jetting

Hydraulic jetting successfully restored the quality of interstitial habitat within local areas by creating a relatively thick deposit of loose, cleaned gravels. This was achieved because the jet continuously mixed the surface and subsurface material, which progressively winnows fine sediment from the mixture as sands and silts are brought into suspension and transported downstream, leaving only the coarser grains in-place. However, this sorting process highlights a key limitation of the method; the resulting substrate composition is highly dependant on the amount of coarse gravels and cobbles contained within the pre-existing substrate. In this sense, to create ideal substrate, it is necessary to have a relatively high proportion of suitable grainsizes within the existing mixture. This method may therefore be best applied to areas with good quality spawning substrate that has become infilled, rather than to improve the quality of habitat where the native substrate may not contain the required grainsize distribution.

As previously mentioned, the production rate achieved with hydraulic jetting was approximately 8-14 m^2 per hour once on-site. This production rate is expected to restrict the application of hydraulic jetting to small- and moderately-sized areas, as the maximum estimated production rate is 40-50 m^2 per day depending on-site conditions. If this method is to be applied over consecutive days in an attempt to clean larger areas, it may be required to use it in combination with a method of sediment removal to overcome some of the limitations of hydraulic jetting, most notably that the quality of the restored substate generally decreases with area due to an increasing accumulation of fine sediment downstream. However, caution should be applied when planning on operation dependant on sediment removal given the limitations encountered with suction dredging (Section 3.1.1), and much higher costs and slower production rates should be expected.

4.2 Substrate quality during the spawning period

Immediately prior to the spawning period (May 6, 2020), the substrate on the Middle Patch was observed to be generally composed of clean cobbles and gravels, with a limited amount of surficial sand deposited between the coarser grains (Photo 3.2). This observation is consistent with previous studies (NHC, 2012, 2013, 2014) finding that only a limited amount of infilling has occurred on the spawning pad since placement in 2011. Although some spatial variability was observed, where certain areas had up to moderate amounts of surficial sand cover, the general condition of the substrate appeared to be relatively coarse with clean interstitial voids between the top layer of grains (to a depth of one or two grains thick).

The substrate on the northwestern portion of the Lower Patch consisted of a mix of large cobbles and gravels, generally infilled with sand. However, the amount of surficial sand did vary across the area, and several sites were found to have a coarse cobble substrate protruding above the bed with only a minor amount of sand infill (Photo 4.1). These observations show that, while there may not be extensive areas of high quality substrate, local areas do appear (from the surface) to provide a coarse substrate with interstitial voids. That said, the quality of the habitat provided by these large, protruding cobbles may be limited despite the lack of surficial sand due to other reasons (e.g. not enough interstitial spaces, voids are too large for larvae to maintain their position due to turbulent fluctuations, etc.). In comparison, the cleaned substrate is expected to have provided high quality interstitial habitat during the spawning period due to the loose mixture of cobble- and gravel-sized particles (Figure 3.1).

The pre-existing substrate at the Lower Site cleaning area was predominantly composed of small to large gravels with granules and scattered cobbles (Photo 3.6). Similar to the Lower Patch, the degree of embeddedness and amount of surficial fines was found to vary spatially, where some areas were found to have a substrate composed predominately gravels and granules with minor surficial sand. Although the cleaned site contained a lesser proportion of cobbles compared to the Lower Patch, the cleaned substrate is expected to have provided high quality larval habitat during the spawning period in the form of small- to medium-sized interstitial voids found throughout the loose gravel deposit to a depth of up to several grains thick (Section 3.2.3).

Overall, the cleaned substrate would be expected to have supported larval survival during the subsequent spawning period, yet these areas are very small and may not correspond to precise spawning locations in a given year. Similarly, while the condition of the substrate at the Middle Pad appears to provide relatively suitable larval habitat (up to one or two grains thick), the substrate may have a limited biological benefit if spawning is limited at that site. Apart from the cleaned areas on the Lower Patch and Lower Site, only local areas appear to provide a coarse gravel and cobble substrate with only a minor amount of sand infill, yet the quality of the habitat in these areas may be limited especially at-depth if an underlying sandy gravel matrix is present below the surficial grains. Interstitial voids below the surface layer of grains are important for larval survival, as experiments have shown that larvae may not be retained within the velocity refuge created by the boundary layer or pore spaces between surficial (embedded) grains (McAdam, 2011).

Photo 4.1 Existing substrate observed on the Lower Patch showing large rounded cobbles which may not provide suitable interstitial habitat due to the large size of the voids.

4.3 Sediment transport within the spawning reach

The sediment traps successfully provided an indication of the magnitude and type of sediment transport at four locations within the study reach (Figure 3.8). The sediment trap containing the greatest amount of sediment (Figure 3.9) was located on the Lower Patch, which was expected given the results of previous bedload sampling studies (NHC, 2016a, 2018). Trap 2 was intended to be placed upstream of where sediment is input from the island complex, in an area where coarse substrate has been observed previously (NHC, 2018); however, given the relatively large amount of sediment collected by Trap 2, it is likely that the trap was not installed far enough upstream to avoid inputs from the island complex. In comparison, the sediment transport rates sampled downstream of the bridge were much lower, especially at Trap 3, located approximately 140 m upstream of the Lower Site cleaning area. The fact that this sediment trap was only approximately 20-25% full suggests that this location was only exposed to a minimal amount of bedload transport, especially given the relatively small size of the sampler (approx. 0.05 m^3) and duration that it was in place (7 weeks). That said, the area around Trap 3 appears to be subject to greater siltation and deposition of suspended sediment comparted to the other sites, as further discussed below.

A trend of downstream fining was observed in the sediment collected by the traps; however, as previously mentioned, it is important to note that these results are based on qualitative observation only, as a sieve analysis was not completed for this study. The only trap containing a noticeable (albeit still extremely small) proportion of granules (up to 3-5 mm) and small gravels (~18 mm) was Trap 2, located immediately downstream of the island complex. Moving downstream, both the trap on the Lower Patch and the one just downstream of the bridge contained almost entirely uniform medium to coarse sand, while the downstream-most trap (Trap 3) contained a much finer sediment mixture composed almost entirely of fine sand and silt, with a relatively limited amount of coarse sand and no pebbles or gravels.

The very fine sediment contained within Trap 3 most likely represents fine sediment which settled out of suspension within very low velocity zones along the bank, rather than sediment transported in contact with the river bed (i.e. sand bedload). These findings are supported by the results of the underwater imagery and previous sampling (NHC, 2020), which suggest that most of the sand bedload is swept towards the inside of the channel bend, with a comparatively limited amount of bedload transported along the outer bend. As such, the area around Trap 3 and the Lower Site cleaning area are less likely to be exposed to frequent or high intensity bedload transport, yet remain subject to siltation.

4.4 Future considerations

The results of this study support findings from previous work (NHC, 2018, 2020), which show that localized areas along the northern portion of the channel downstream of the bridge appear to have a substrate that is composed primarily of pebbles and gravels with a relatively low proportion of surficial sand (Figure 4.1) and interspersed cobbles, potentially deposited through ice-rafting processes. Based on underwater images collected since 2012 (Figure 4.2 – Figure 4.6), the substrate in this area appears to have remained relatively coarse and unchanged over the past decade, suggesting that the area is not frequently exposed to high sand bedload transport, as most of the bedload sediment is concentrated towards the center of the channel and along the inside point bar (NHC, 2020).

Although the areas shown on Figure 4.1 may be less susceptible to infilling with sand, underwater imagery and sediment sampling suggest that the area is subject to siltation, especially within approximately 20-25 m of the bank. The degree of siltation appears to increase with proximity to the bank, likely due to irregularities in the bank geometry which create eddies and low-velocity zones that cause fine sediment to settle out of suspension. This information may be taken into consideration when siting future restoration work, including substrate cleaning or the placement of additional spawning substrates.

As shown on Figure 4.1, 2019 egg detection data provided by the NWSCC shows that detections occurred primarily along the center of the channel where the substrate is considered non-conducive to larval survival. Further investigation may be warranted to determine whether some viable eggs drift and deposit closer to the north bank where the substrate appears to be of better quality, or whether this is due to the absence of data (i.e. fewer egg mats placed in these areas). We recognize that some areas exist where the substrate is composed primarily of coarse gravel and cobble with limited surficial sand and that these areas might potentially support (at least some) larval survival. However, these are small and local in extent and may not correspond to spawning locations in a given year, and the overall quality of the interstitial habitat may be limited at-depth due to embeddedness and/or an underlying layer of sandy gravel. Future studies may be conducted to investigate innovative sampling methodologies that provide a more quantitative evaluation of biological habitat quality based on specific larval requirements (e.g. substrate composition below the surficial layer of grains).

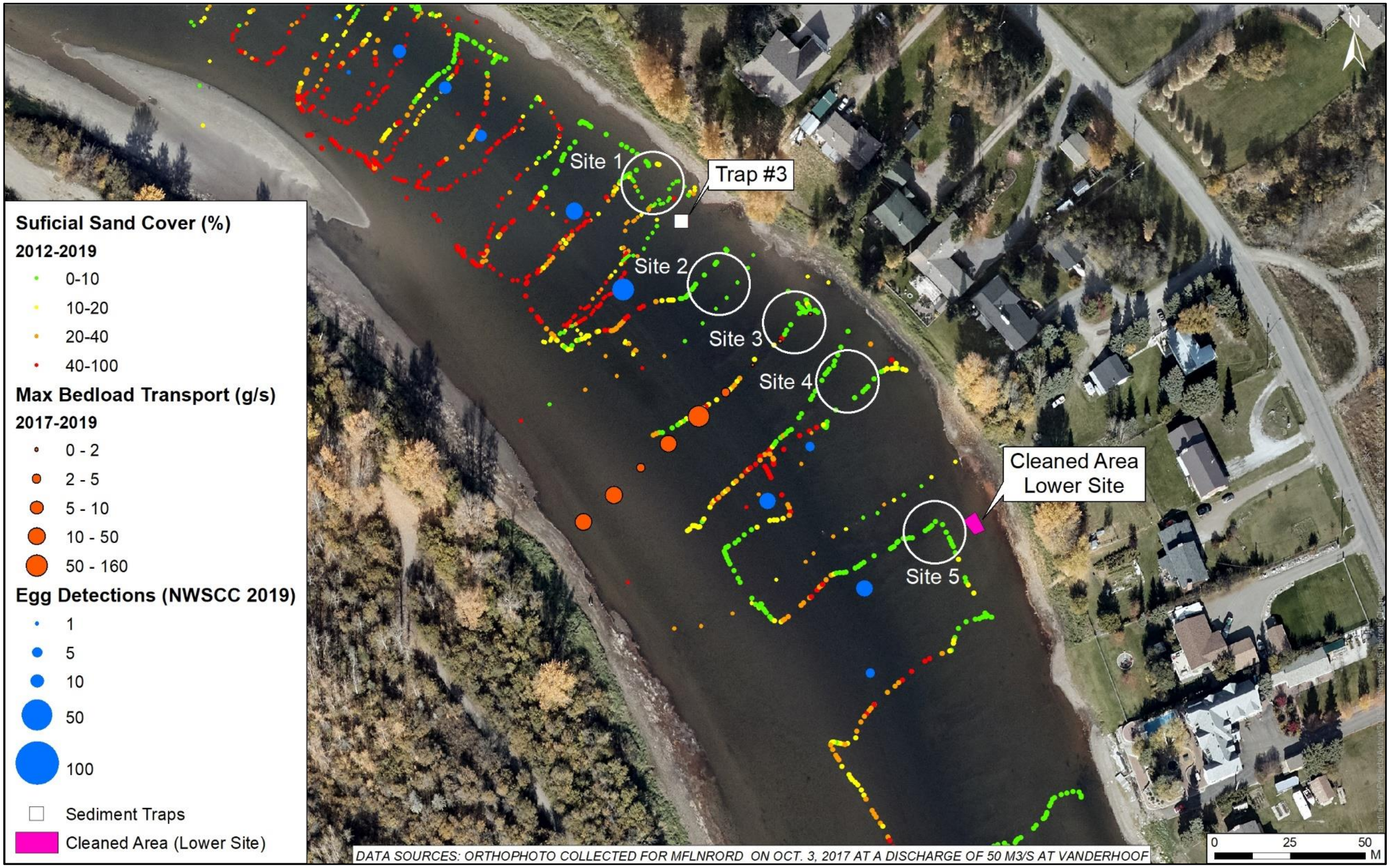

Figure 4.1 Overview map showing areas with minimal surficial sand which do not appear to be frequently exposed to bedload transport.

Figure 4.2 Comparison of substrate photos at "Site 1" labelled on Figure 4.1.

Figure 4.3 Comparison of substrate photos at "Site 2" labelled on Figure 4.1.

Figure 4.4 Substrate photos at “Site 3” labelled on Figure 4.1.

Figure 4.5 Substrate photos at “Site 4” labelled on Figure 4.1.

Figure 4.6 Comparison of substrate photos at “Site 5” labelled on Figure 4.1.

5 CONCLUSION

This study investigated the feasibility and performance of different diver-operated substrate restoration techniques on the Nechako River. Of the methods used, hydraulic jetting was found to be the most productive and effective, while suction dredging was found to be relatively ineffective due to operational issues which could not be resolved with the equipment at-hand. Hydraulic jetting was successful in creating relatively thick deposits of loose, clean gravel at both the Lower Patch and Lower Site locations prior to the onset of spawning; however, the amount of area cleaned at each location was relatively small (20-25 m^2 and 30-35 m^2, respectively). The results of this study show that diver-operated techniques may be applied to restore the quality of infilled substrate over small to moderate areas, but that the effectiveness and feasibility of the operations decrease with area, especially in challenging hydraulic conditions. These findings, along with the results of sediment sampling and underwater imagery, may be used to inform the siting and planning of future restoration works.

6 CLOSURE

We appreciate the opportunity to work with you on this project. Please do not hesitate to contact André Zimmermann (azimmermann@nhcweb.com), Barry Chilibeck (bchilibeck@nhcweb.com) or Simon Gauthier-Fauteux (sgauthierfauteux@nhcweb.com) by email or telephone (604 980 6011) if you would like to discuss any aspect of this report.

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