Morphological and Habitat Classification of the Lower Fraser River Gravel-Bed Reach: Confirmation and Testing

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by

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Executive Summary

This report summarises efforts to identify habitat units with accuracy from low-level air photographs and oblique photographs of gravel bars in lower Fraser River. Previously, systematic sampling over three years identified habitat units and described their physical and ecological characteristics at 12 "reference" sites in the aggrading sub-reach. The current work reversed the order of activities in order to test the ability to classify habitats consistently without detailed morphological and ecological information about the sites in hand. The work had three components.

First, a confirmation exercise involved habitat classification by photographs followed by ground surveys of two sites that had no prior sampling but that occurred within the aggrading sub-reach. Second, a testing exercise involved habitat classification by photographs followed by ground surveys of three sites that had no prior sampling and that occurred in upstream sub-reaches that were stable or mildly degrading. Each exercise was carried out in March with low-level air photographs (1:12,000) and repeated in August/September with oblique photographs taken from a height of 1000 m above the ground. Third, fish sampling in August/September 2001 was used to compare observed habitat-species associations at upstream test sites with expected associations based on sampling at the 12 reference sites between 1999 and 2001.

Habitat mapping from air photographs showed a high level of fidelity with ground surveys. Between 85% and 93% of units were identified correctly at all sites combined, which translated into between 87% and 98% of the total bar length being classified accurately. The expected number of habitat units matched the total number observed at confirmation sites, however, photo-based mapping predicted a higher number of units than were observed at two of three test sites.

Mapping from oblique photographs accurately predicted the number of habitat units at both confirmation and test sites. In this regard they surpassed air photographs, which tended to over-estimate the number of habitat units (i.e. habitat complexity) at test sites. Between 85% and 95% of units were identified correctly from oblique photographs at all sites combined.

Both the physical and ecological characteristics of habitat units at test and confirmation sites matched observations made at the 12 reference sites. Low sample size left comparisons of some habitat types inconclusive, however, a reasonable level of similarity was detected among the site groups for most parameters considered.

These results indicate that habitat units can be delineated reliably from low-level air photographs and oblique photographs. The techniques are somewhat complementary but each could be used alone to systematically identify habitat units at sites within the gravel reach. Because identification accuracy was less than 100% at all sites, some degree of ground truthing is recommended for future habitat typing exercises. The intensity of ground truthing will depend on the objectives of the project.

Oblique photographs have the advantage of being inexpensive and easily obtained. In approximately 1 hour and flying at an elevation of 1000 m above ground, one can take a complete set of photographs for analysis. A major disadvantage to oblique photographs, however, is distortion and the inability to measure lengths of habitat features accurately. Recommendations are made for taking high-quality oblique photographs from a plane.

Table of Contents

List of Tables

List of Figures

Cover: Middle Queens Bar, 20 August 2001, from 750 m altitude. View to the southwest: river flow is from left to right. Photo taken during a flight to obtain habitat information using oblique air photographs.

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1.0 Introduction

1.1 Background

Classification frameworks are useful tools for resource management and scientific research as they enable the ordering, comparison, synthesis, and inventory of biophysical data. A strictly geophysical classification for river channels was proposed by Kellerhals et al. (1976) and later modified for large rivers by Kellerhals and Church (1989). Other classifications have attempted to assign ecological attributes (i.e. fish use) to particular channel features commonly found in small streams (Bisson et al. 1982, Hawkins et al. 1993). The linkage between morphological channel features and ecological attributes is important for any river classification to be useful as a tool in fish habitat management. Establishing this link, however, can require considerable sampling effort and few habitat studies have endeavoured to achieve this goal. The morphological habitat classification recently developed for lower Fraser River (Church et al. 2000) makes a significant contribution towards this goal for large, gravel-bed rivers.

The two highest levels of the hierarchical habitat classification were applied to the entire gravel reach between Mission and Hope. The third level, which classified habitat types around gravel bars, was derived from field sampling at twelve sites between Chilliwack Mountain and Herrling Island. This stretch of the gravel reach is aggrading (persistently subject to sediment deposition) whereas reaches upstream of Herrling Island are either stable or mildly degrading (subject to sediment loss/erosion) (Church et al. 2000, Church et al. 2001). For the habitat classification to be useful as a research and management tool, it must be applicable to the entire gravel reach. As well, it must be capable of being used in a time-efficient and cost-effective manner. This report summarises efforts (i) to test the applicability of the habitat classification at additional sites between Hope and Mission and (ii) to examine the accuracy of identifying habitat units from air photographs as an inexpensive and time-efficient means of monitoring fish habitat along the gravel reach.

1.2 Statement of Purpose

We present results from an exercise to test our ability to identify habitat units with accuracy from low-level air photographs of gravel bars in lower Fraser River. Up to fourteen habitat types may be found around the perimeter of gravel bars and along channel banks. These habitat types are morphologically distinct and most support different assemblages of fish species. The ability to identify habitat types accurately from air photographs would provide a means of systematically monitoring fish habitat along the gravel reach in a cost-effective manner.

An earlier phase of work at the Department of Geography, University of British Columbia, developed a habitat classification that linked morpho-sedimentary characteristics of the gravel reach, as determined by air photo interpretation and ground surveys, with ecological attributes as determined by fish sampling. Data collection over three years (1999 - 2001) focused on 12 "reference sites" between Chilliwack Mountain and Herrling Island (Figure 1). Habitat types were delineated at these sites based on morphological characteristics and patterns of habitat use by *rearing juvenile* fish, both resident and anadromous, occupying the gravel reach. The basis for focusing attention on juveniles is that the ability of the river to nurture juvenile fish best summarizes its capacity to produce fish. This report summarises recent work that reversed the order of activities in order to test the ability to classify habitats consistently without detailed morphological or ecological information about the sites in hand. The work had two research components.

First, a confirmation exercise involved habitat classification by air photo analysis followed with ground truthing by field surveys of two pool-bar-riffle units that had no prior systematic sampling but that occurred between Chilliwack Mountain and Herrling Island. Follow-up fish sampling at these sites tested for agreement between observed habitat-species associations from sampling at these unfamiliar sites and expected habitat-species associations based on sampling between 1999 and 2001 at the 12 reference sites.

Second, a testing exercise involved habitat classification by air photo analysis followed with ground truthing by field surveys at three sites upstream of Herrling Island that had no prior sampling. Each of these sites was located within a stretch of river that is mildly degrading, based on sediment budget calculations from Church et al. 2001. Subsequent fish sampling at these sites allowed for comparison between observed habitat-species associations and expected habitat-species associations based on sampling at the 12 reference sites between 1999 and 2001.

The confirmation and testing exercises were conducted simultaneously for logistical reasons in March and August/September 2001. River discharge on March 7 was approximately 600 m^3/s and stereo air photographs were flown at a nominal scale of 1:12,000. Discharge was 3300 m^3/s on August 20 and 1600 m^3/s on September 20 when oblique photographs were taken from a fixed-wing airplane at a height of 750 - 1000 m above the ground.

Several questions related to the exercise are addressed in this report:

1. At what scale of air and oblique photography can habitat units be delineated reliably?
2. Can the habitat classification for a particular gravel bar be updated by air photo interpretation alone or are field surveys also necessary?
3. Are the physical characteristics of habitat types in upstream reaches similar to those of habitat types in the aggradational reach?
4. Is the assemblage of fish occupying a given habitat unit in upstream reaches similar to the fish assemblage in the same habitat type of the aggradational reach?
5. Can the habitat classification be applied by photograph interpretation to the whole gravel reach or only certain sub-reaches?

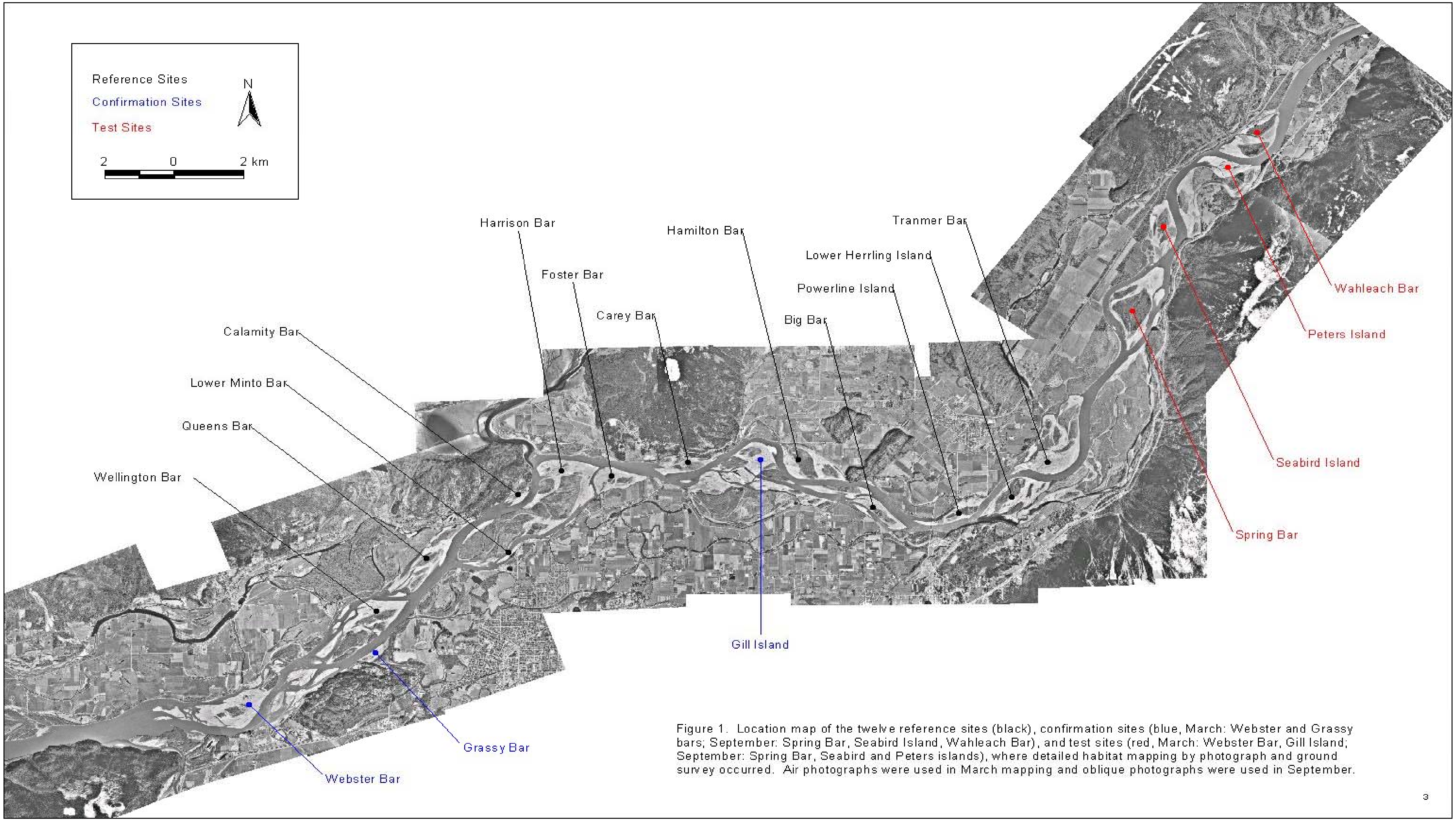


Figure 1. Location map of the twelve reference sites (black), confirmation sites (blue, March: Webster and Grassy bars; September: Spring Bar, Seabird Island, Wahleach Bar), and test sites (red, March: Webster Bar, Gill Island; September: Spring Bar, Seabird and Peters islands), where detailed habitat mapping by photograph and ground survey occurred. Air photographs were used in March mapping and oblique photographs were used in September.

2.0 Classification Overview

The hierarchical classification of Church et al. (2000) is summarised briefly below as background information. Refer to the original document for further details.

2.1 Level One – Reach Scale Classification

The gradient of Fraser River declines steadily through the gravel reach as a consequence of long-continued deposition of the gravel material as the river approaches the end of its course (Figure 2). Consequently, the competence of the river (the ability to transport sediment of a given size) also declines, and there is a downstream decline in the size of material comprising the bed and banks of the river. This declining competence determines the wandering morphology of the channel as the river is forced to flow around its own deposits.

Within the gravel reach, variations in morphological style are discernible, governed by the variation in reach gradient and the rate of sediment exchange and net aggradation. Trends in river gradient, observed morphology, and sediment transport have been collated in 5 sub-reaches of distinguishable morphological character (Table 1). Differences between sub-reaches lend them a distinctive distribution of habitats (though not individually unique habitats), which probably influences the fish assemblages dominantly found in each sub-reach. The characteristics of these reaches will remain unchanged for many decades in view of the cumulatively very large volume of resident sediment that will have to be moved to effect a definitive change in each sub-reach; hence these sub-reaches are suitable for strategic management planning within the gravel-bed reach.

2.2 Level Two – Pool-Bar-Riffle Classification

Within each sub-reach, the river is organised into a sequence of pool-bar-riffle units. These units correspond with the characteristic step-length for gravel displacement, once mobilised, in the river. Such units are characteristic of the organisation of all gravel-transporting channels. The average unit length along the river is 2.6 km, for a total of 31 units recognised along the study reach.

Typically, a unit consists of a riffle, superimposed bar, and adjacent/downstream pool (Figure 3). Some units are more complex; sometimes more than one unit is identified on a single, extended riffle; and sometimes the riffle is entirely coincident with the bar and is not separately identified. Around each unit, a variety of habitat types may be found that are replicated from unit to unit, changing in relative frequency as one moves from sub-reach to sub-reach along the river. The size of pool-bar-riffle units, and the fact that they are the largest identifiable units within which the full range of habitat types may be found, makes them suitable for operational management along the river, and appropriate as planning units for scientific studies of river sedimentation and ecology.

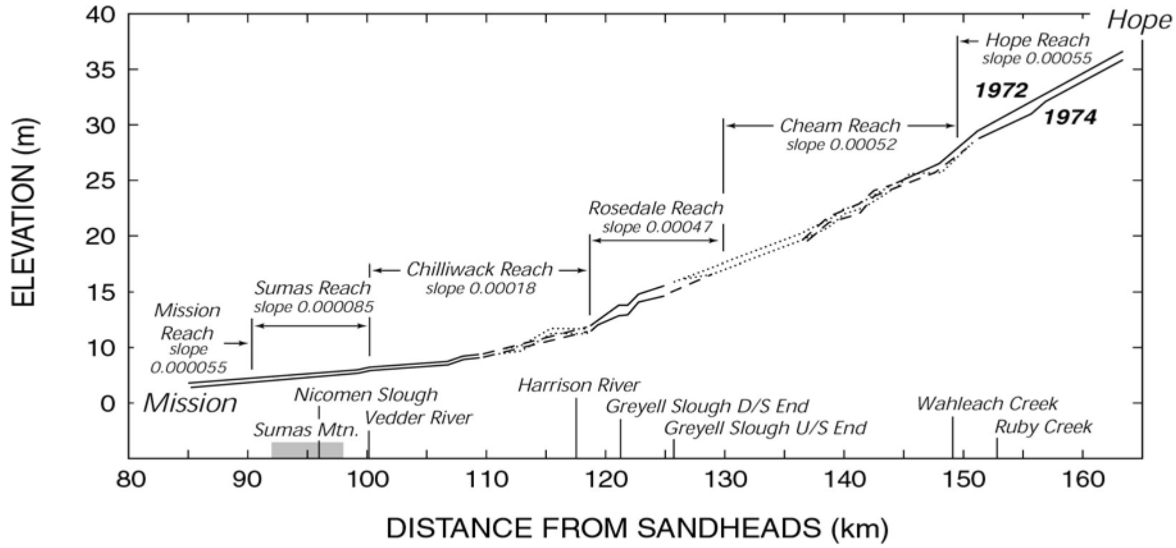


Figure 2. Water surface profile of the gravel reach, Hope to Mission, Fraser River (from McLean et al. 1999). The five sub-reaches corresponding to Level One of the hierarchical habitat classification of Church et al. (2000) are indicated. 1972 and 1974 indicate the years of survey. Solid/dashed/dotted lines indicate the density of supporting data. Dotted lines also indicate significant variation of water level between the two banks.

Table 1. Characteristics of the five morphologically homogeneous sub-reaches identified in Level One of the Habitat Classification of Fraser River gravel reach. Information in *italics* is estimated only (Church et al. 2000).

Name	Downstream Limit	River km	Mean Gradient	Mean Grain Size (mm)	Discharge at MAF (m^3s^{-1})[1]	Mean Gravel Transport (tonnes a^{-1})[2]	Aggradation Tendency	Major Features
Hope	Wahleach Cr.	149-165	0.00055		8766	*400 000*	*stable*	single-thread cobble-gravel channel with stable lateral bars
Cheam	Rosedale-Agassiz Bridge	130-149	0.00052	50	8766	400 000	mild degradation	major islands with surrounding bars; single dominant channel
Rosedale	Harrison R.	118-130	0.00047	40	8766	250 000	strong aggradation	island-bar complexes; channel commonly divided; laterally unstable
Chilliwack	Vedder R.	100-118	0.00018	26	9790	20 000	strong aggradation	channel bars with subordinate islands
Sumas mainly	Matsqui Bend	89-100	0.000085	16 - sand	9790	0	*degrading*	single-thread, gravel-sand transition; bars submerged

1. Based on gauges at Hope (first three reaches) and Mission (last two reaches). MAF = mean annual flood.
2. Transport is mean for the period 1952-1999, estimated at the downstream end of the reach.

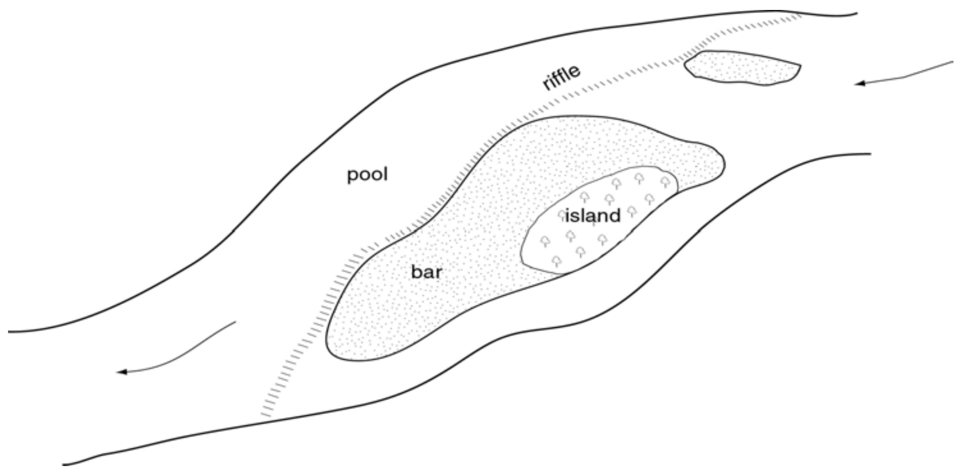


Figure 3. A schematic of a typical pool-bar-riffle unit in the gravel reach of Fraser River.

2.3 Level Three – Habitat Classification

Within pool-bar-riffle units, the finest level of classification identifies three *channel* types and fourteen *habitat* types (12 actual and 2 hypothetical) on the basis of morphological and hydraulic differences. Recognising and defining habitat types along the gravel reach of Fraser River began as an iterative process, using a combination of both air photograph interpretation and field surveys. Air photographs were examined initially to identify morphologically homogeneous areas around bars. Fish sampling served to validate and refine the boundaries of these habitats and identify spatial differences in the distribution of species. Together, physical characteristics and empirically derived ecological patterns formed the basis for the classification system.

River habitats were first classified according to *channel type* (Table 2). This level of classification distinguished seasonally active channels (summer) from perennial channels (main and side) and recognised differences in channel size.

Table 2. Level *III* of the habitat classification: three channel types associated with pool-bar-riffle units in the gravel reach of Fraser River.

CHANNEL TYPE	DESCRIPTION
Main	Channel conveys flow throughout year and includes the thalweg. Bed material consists mostly of clean gravels, containing a low proportion of fine sediment. The surface material is subject to bed load transport during freshet.
Side	Channel conveys flow during freshet but has little or no flow in winter. Wetted habitats at the upper and lower end can persist year-round. Bed material contains a variable amount of fine sediment. Minor bed load transport during freshet.
Summer	Channel is seasonally inundated during freshet only and is often oriented diagonal to the main channel and intersecting the bar top. Bed material contains a high proportion of fine sediment. Fine gravel may be transported; heavy sand load.

Fourteen *habitat types* (Table 3) are recognised as physically and ecologically distinct in the gravel reach. All habitats have a likelihood of occurring in each type of channel and at each site. The habitats differ with respect to morphological, sedimentary, and hydraulic characteristics and, consequently, they tend to host different assemblages of fish species. A sketch illustration of several commonly occurring habitat types is included for clarification (Figure 4). The thalweg was deliberately omitted because sampling limitations made it impossible to determine whether it represents rearing habitat for juvenile fishes.

Table 3. Level *III* of the habitat classification; fourteen habitat types associated with pool-bar-riffle units. Habitat abbreviations are given in parentheses. Habitat types in *italics* are hypothetical only because they have not been sampled.

HABITAT TYPE	DEFINITION
Bar Head (BH)	Upstream end of a gravel bar. Surface substrate is characteristically coarse and flow velocity is usually high (erosional) but can be a back eddy (depositional).
Bar Tail (BT)	Downstream end of a gravel bar, usually with moderate flow velocity. The habitat is often depositional and surface substrate consists of smaller cobbles and gravels.
Bar Edge (BE)	Any length of bar edge not occurring at the head or tail of a bar that is oriented parallel to the flow and subject to constant and consistent flow forces. A range of velocities and substrate types is possible. Riparian influence is variable.
Riffle (RI)	High-gradient area of shallow, fast water flowing over well-sorted substrate that often has granular structures and is stable. The flow is rough.
Eddy Pool (EP)	Area bounded by fast, rough water that creates a back eddy in the lee of the flow. Common on the inside edge of riffles and at the upstream end of some bar head habitats. Bank slope is invariably steep and the substrate is usually embedded cobble.
Open Nook (ON)	Shallow indentation along a bar edge of reduced velocity and variable substrate that is openly connected to the channel with no sedimentary barrier (unlike channel nook). An ephemeral habitat that often disappears with a relatively small change in water level.
Channel Nook (CN)	Dead-end channel or narrow embayment of standing water and concave geometry. Substrate material usually consists of sand/silt and embedded gravel.
Bay (BA)	Semi-enclosed area with no flow velocity and fine bed material (sand/silt). Occurring on the lee side of large sediment accretions that are deposited in the shape of a crescent-dune.
Cut Bank (CB)	Eroding bank of fine sediment that is steeply sloped or vertical. Dense riparian vegetation is often present. Large woody debris is common and flow conditions are variable.
Rock Bank (RB)	Natural rock bank, possibly with openings and cracks, that is invariably steep. The water is deep immediately offshore and currents are either fast or form a back eddy.
Artificial Bank (RP)	Bank is invariably steep and consisting of riprap or rubble rock that may have significant openings within its structure. The water is usually deep and fast immediately offshore.
Open Water (OP)	Open area with no direct influence from bank or bar edge features or riparian vegetation. Velocity and substrate characteristics are variable.
Bar Top (BT)	*Bar top surface inundated only during high flow with reduced velocity and shallow water depth relative to open water and the thalweg. Substrate is variable.*
Vegetation (VG)	*Area of flooded island and bank vegetation where velocity is reduced and substrate is relatively fine. Only submerged at high flow.*

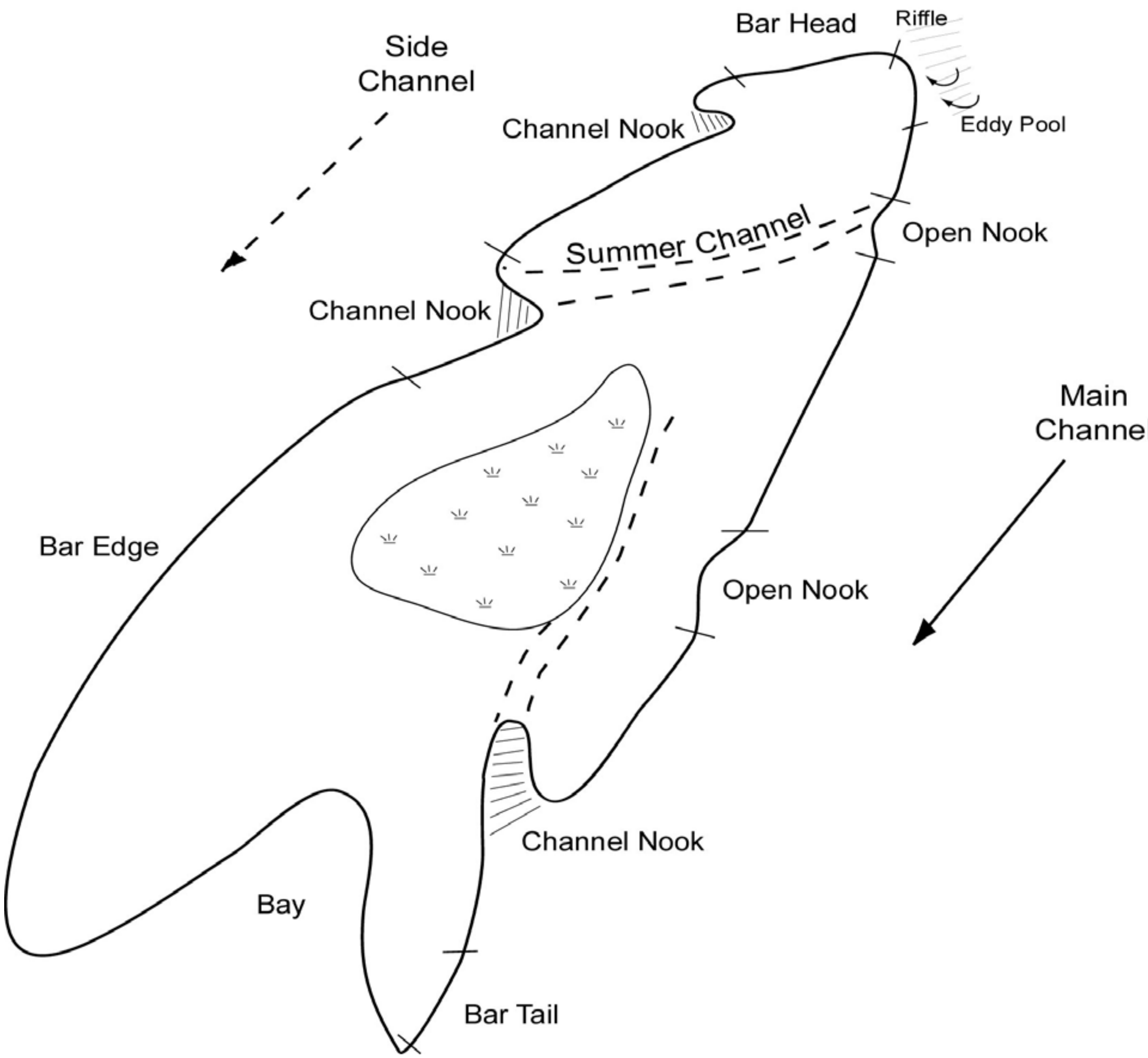


Figure 4. Sketch illustrating the three channel types and several common habitat types in the gravel reach of Fraser River.

3.0 Methods

3.1 Data Gathering – Habitat Mapping

Large-scale (1:12,000) air photographs of the gravel reach were flown at low water conditions on March 7, 2001. From these photos, two sites (Webster Bar and Grassy Bar) were selected between Chilliwack Mountain and Herrling Island for the *confirmation* exercise (Figure 1). Three sites upstream of Herrling Island were selected for the *testing* exercise: Spring Bar, Seabird Island, and Wahleach Island. First, habitat units were classified from air photographs of the sites based on the classification of Church et al. (2000). A technician with expertise in air photo interpretation and large river geomorphology was assigned this duty. The technician had never before visited the sites. Second, a ground survey of each site was conducted by walking around the bar perimeter and delineating all morphologically distinct habitat units. Ground surveys were carried out at a discharge similar to that of the photography, on March 26 (confirmation sites) and March 29 (test sites), and the ground crew was not permitted to consult the habitat maps previously created from photographs. Map pairs generated from air photographs and ground surveys at each site were then digitised and examined in a GIS (ArcView) to determine habitat unit lengths (meters) and to compare habitat typing by the two methods.

Habitat typing for the confirmation and testing exercises was repeated in summer 2001 using oblique photographs. The purpose was two-fold: to test the habitat identification technique at a higher water level and to test the technique with photographs that are more easily obtained and less expensive than stereo air photos. Oblique photographs were taken from a fixed-wing aircraft flown approximately 750 m above the ground on August 20, 2001. A Pentax instant camera with zoom lens (35-90 mm) was used but photo quality for some sites was poor because the automatic shutter speed was too slow for the flight speed and light conditions. A second flight occurred on September 20 at a height of 1000 m above the ground. Photographs were taken using a SLR-Pentax camera (35-200 mm lens) with the shutter speed manually set at <1/250 second. The resulting photographs were of superior quality. Sites examined for the *confirmation* exercise were Webster Bar and upper Gill Island (September) and sites assessed for the *testing* exercise were Spring Bar, Seabird Island, and Peters Island (August).

For a given site, both oblique overview photos (35-50 mm) and a series of detailed photographs (50-200 mm) were taken, the latter covering the entire site area. Overview photos were useful for orienting the technician as well as highlighting general channel and bar features. Detailed site photos were arranged together as a site mosaic that was most appropriate for examining morphological and habitat features. Habitat units around each site were identified from these multi-photo mosaics by a trained technician and ground surveys followed shortly thereafter. Habitat mapping covered only the portion of any given site for which sharp and reasonably undistorted photographs were available; hence, the entire bar area was not examined at all sites.

3.2 Data Gathering – Fish Sampling

Habitat typing in August/September was supplemented with fish sampling to test for agreement between the habitat-species associations observed at unfamiliar sites and expected habitat-species associations based on summer sampling of the 12 reference sites between 1999 and 2001.

Fish sampling was conducted only in August/September because, in comparison to March, juvenile fish are more reliably captured near-shore in summer months.

Habitat-species associations were examined by collecting juvenile fish within delineated habitat units using a beach seine net (12.5 m x 2 m) with a mesh size of 19 mm. Various capture techniques (minnow trapping, gill netting, electro-shocking) had been tested previously and beach seining provided the most reliable and consistent catch data as well as being the most versatile method for different habitat types. Its major limitation was that sampling extended only to a depth of approximately 1.2 m, the maximum depth one can safely work in chest waders.

Once collected, all fish were identified to species and counted. A minimum of 15 fishes representing each species in the haul were measured for fork length (mm) and weighed (g). Twenty-four species of fish have been identified during the study (see Appendix A), including 10 salmonid species, white sturgeon (red-listed in British Columbia) and 4 blue-listed species (mountain sucker, coastal cutthroat trout, bull trout, and Dolly Varden).

Observations and measurements of the physical characteristics of habitat units were made at all beach seine sites. Water velocity and depth were measured at nine points within the seine area using a wading rod and Marsh-McBirney velocity meter. The surface sediment was visually classified for degree of embeddedness and percent representation by major grain size classes. The slope angle of the bar edge was estimated and the presence and type of nearby vegetation were noted. Water temperature at the mid-point in the seine area was measured as well.

3.3 Data Analysis

3.3.1 Habitat Mapping From Photographs

Testing for agreement between *predicted* habitat units (mapped from air photos) and *observed* habitat units (mapped from ground surveys) was carried out by comparing habitat type <u>length</u> (meters). Percent agreement between predicted (P) and observed (O) lengths was calculated as the sum of the absolute difference between measured lengths for each habitat type divided by twice the total bar length (L): $(1 - [\sum|P-O| / 2*L])*100$. Multiplying total length by 2 was because a misclassification will be counted twice. Discrepancies in the boundaries and lengths of units are best examined by this method where, for instance, the number and position of habitat units agree between maps but the lengths of the units are unequal (Figure 5). This method was used only for March habitat maps because oblique photos have severe distortion and habitat unit lengths cannot be measured accurately.

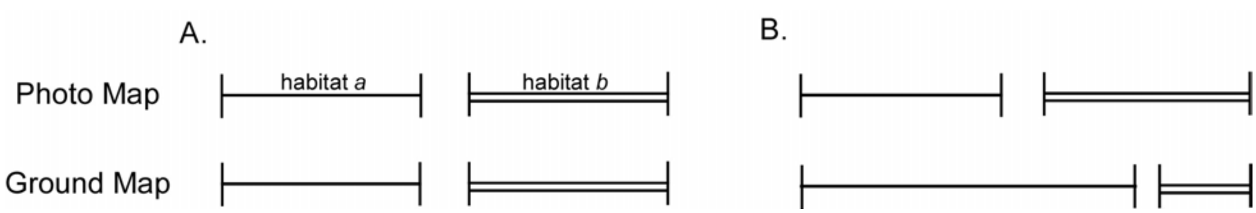


Figure 5. Hypothetical discrepancy in habitat unit lengths between the photo-based map and ground-survey map. (A) Total count and length of each habitat type is equal; (B) Total count of each habitat type is equal but lengths differ.

A second method for oblique photographs was used based on total counts of habitat units to compare habitat maps from photos and ground surveys. Agreement between the predicted and observed counts was calculated as the sum of the % correct, weighted by the number of units, for each habitat type and divided by the total number of observed units. The method was applied both to August/September oblique photographs and March air photographs for comparative purposes. The count-based method was useful for identifying cases where habitat units are completely overlooked (Figure 6a) and for cases where each unit is detected but assigned the wrong habitat classification (Figure 6b). The method also served to determine if photographs generally predicted greater or less morphological detail than actually existed based on the total number of units observed (Figure 6a).

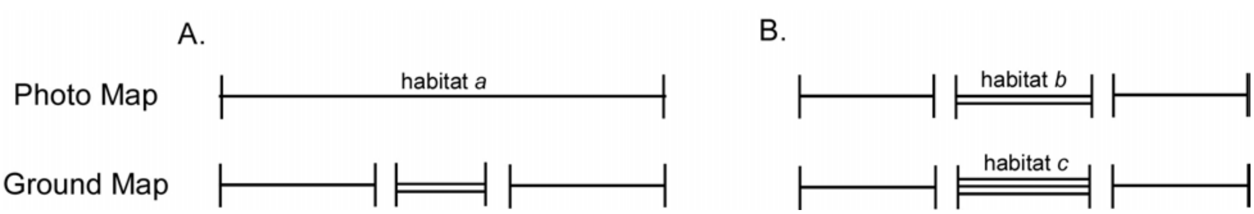


Figure 6. Hypothetical discrepancy in habitat unit counts between the photo-based map and ground-survey map. (A) Habitat type *b* is missed, a portion of habitat *a* is mis-identified, and the total count of habitats *a* and *b* differs; (B) The count and total length of habitat *a* are equal between maps and one unit is mis-identified as habitat *b* rather than habitat *c*.

3.3.2 Comparing Habitat Characteristics Between Reference and Test Sites

A question of interest was whether physical and ecological characteristics of habitat units at unfamiliar sites fell within the range of values observed at reference sites? Stated alternatively, were observations made between 1999 and 2001 at the 12 reference sites in the aggrading reach representative of conditions found at other sites within the gravel reach? Box and whisker plots were chosen to address this question because they are a simple and effective visual representation of dispersion in a data set. Lower and upper boundaries of the box represent the 25th and 75th percentiles, whiskers correspond to the 10th and 90th percentiles, and the median (50th percentile) is marked within the box.

Box and whisker plots by habitat type were constructed based on data from the 12 reference sites in summer months between 1999 and 2001. Because confirmation and test sites were sampled only in 2001, reference site data from 2001 first were examined separately to ensure similarity with previous years. No significant differences were noted; hence the 3-year data set was used to maximize sample size. Box and whisker plots were made for various physical characteristics and fish-related parameters. Measurements made at the confirmation and test sites were then compared to the box plots to determine if they fell within or outside the quartile range (25th to 75th percentile) observed at reference sites.

4.0 Habitat Identification From Stereo Photos

4.1 Confirmation Exercise Results

Habitat maps of Grassy Bar based on air photographs (Figure 7a) and a ground survey (Figure 7b) from March 2001 illustrate the site's simple bar configuration with a side channel that remains wet year-round. A total of 21 habitat units were identified based on photographs and 23 units were observed by ground survey (Table 4). An eddy pool located at the upstream end of the bar and an open nook found midway along the side channel were missed by photo-mapping, and each was relatively short in length (9 m and 21 m, respectively). The number of bar edge units mapped by photo and ground survey matched, however, the boundaries of several differed and two bar edge units were more fragmented in reality, consisting of bar edge as well as cut bank, eddy pool, and open nook units. Average unit length around Grassy Bar was 121 m and the difference in total bar length as mapped by air photograph (2789 m) and ground survey (2778 m) resulted from slight discrepancies in the boundaries of habitat units when digitised. Weighted mapping agreement by unit count was 87% and agreement by unit length was 94.3%; hence, more than 94% of the perimeter of Grassy Bar was mapped accurately.

Table 4. Comparison of habitat mapping at Grassy Bar in March 2001 based on air photographs and a ground survey. See **Table 3** for habitat type abbreviations.

Habitat Type	Unit Length (m)			Unit Count				
	Photo	Ground	P - G	# units - photo[a]	# units ground[b]	# units misID[c]	correct ID[d]	% correct[e]
Bay	0	0	-	0	0	-	-	-
Bar Edge	1871	1708	163	7	7	3	CB, EP, ON	100
Bar Head	119	119	0	1	1	0	-	100
Bar Tail	229	332	-103	2	2	0	-	100
Cut Bank	265	284	-19	2	2	1	BT	50
Channel Nook	28	28	0	1	1	0	-	100
Eddy Pool	69	78	-9	2	2	1	ON	50
Open Nook	186	207	-21	6	6	1	BT	83
Riffle	5	5	0	1	1	0	-	100
Riprap	17	17	0	1	1	0	-	100
Total	2789	2778	11	21	23	6	-	weighted mean = 87

a = # habitat units identified from photographs; b = # habitat units identified by ground survey; c = # units assigned the given habitat type but whose actual habitat classification differed; d = correct habitat type of mis-identified units; e = % of units observed by ground survey that were mapped correctly from photographs.

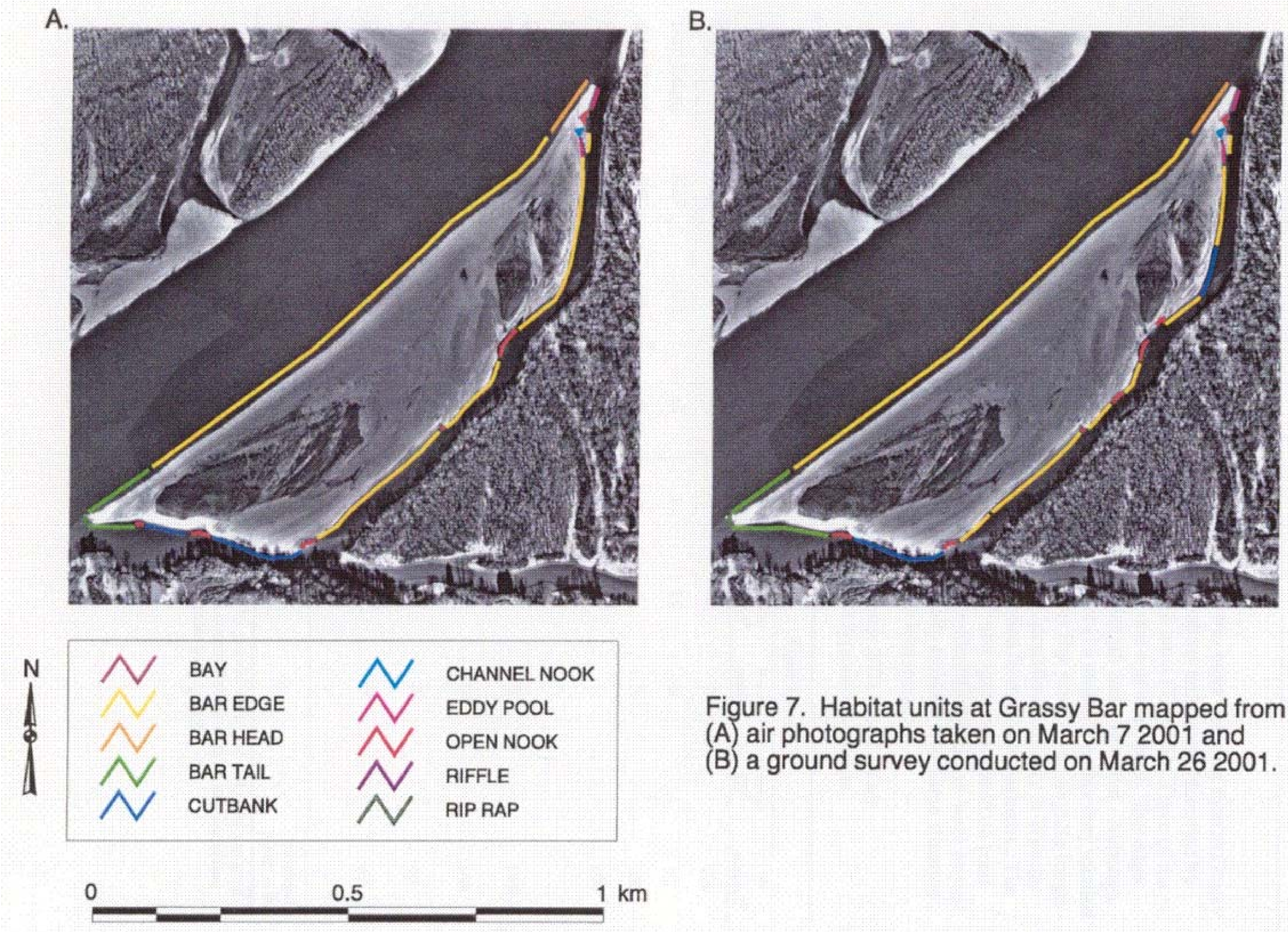


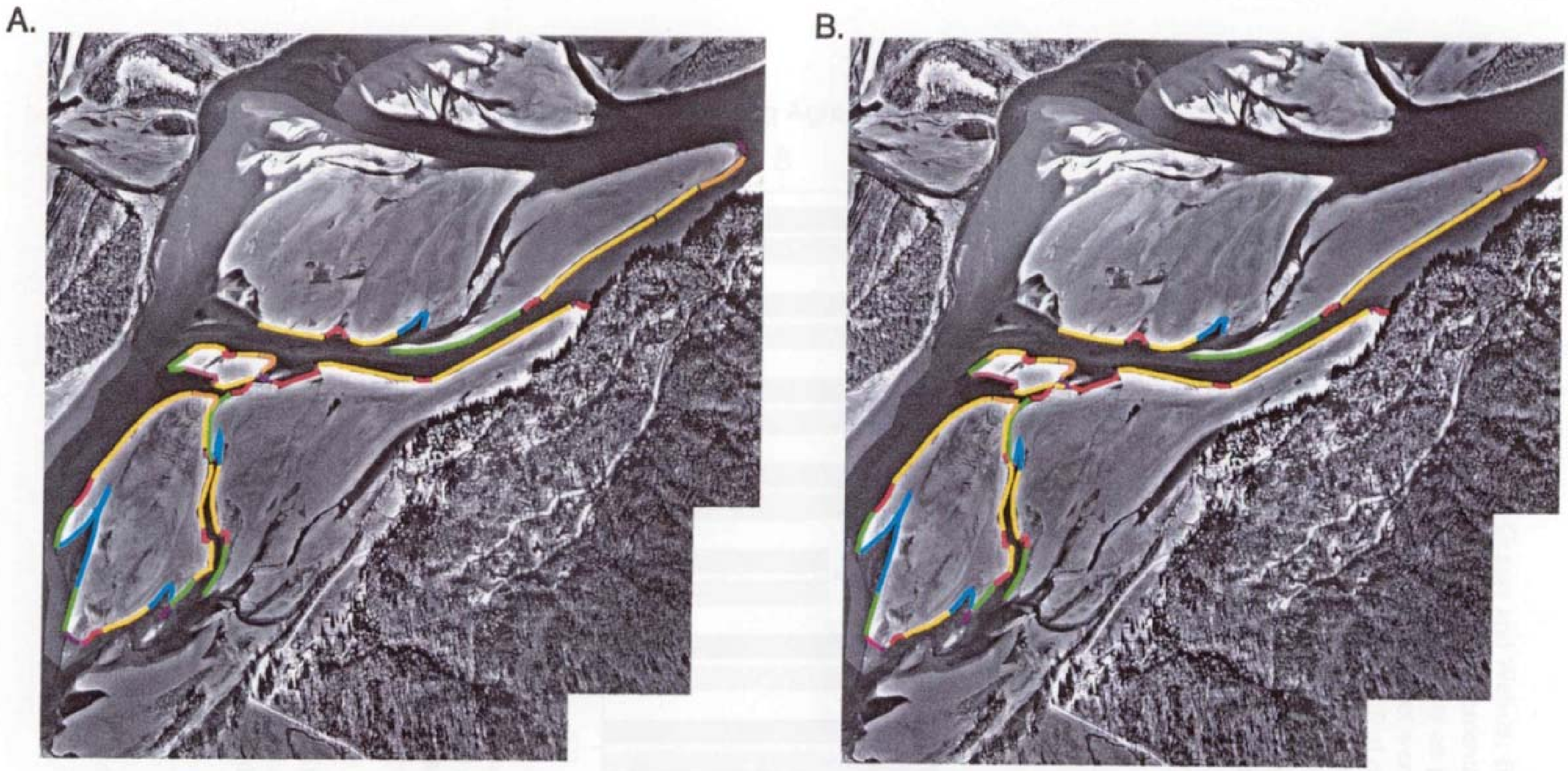
Figure 7. Habitat units at Grassy Bar mapped from (A) air photographs taken on March 7 2001 and (B) a ground survey conducted on March 26 2001.

The bar configuration and channel pattern around Webster Bar was more complex than at Grassy Bar and surface vegetation was lacking (Figure 8). A total of 53 habitat units were identified by ground survey whereas mapping by air photograph delineated 48 units (Table 5). Three of the five missed units were short riffles, one was an open nook, and one was a bar edge. Bar edge habitat was the most common habitat type represented by total length and unit count. Although open nooks were the second most common habitat type by count (13 units), together they totalled only 891 m of bar length. Average habitat unit length at Webster Bar was 142 m, slightly longer than at Grassy Bar. Several short riffle units (5 and 16 m) were identified correctly at Webster Bar, indicating that even small habitat features can be distinguished from air photographs. The mapping agreement based on the total number of units was 90% and agreement based on total bar length was very high as well, 98.4%. That no units were mis-identified and five were missed indicates that less detail was observed in photographs than actually existed. The same situation occurred at Grassy Bar and roughly the same proportion of units was missed.

Table 5. Comparison of habitat mapping at Webster Bar in March 2001 based on air photographs and a ground survey. See **Table 3** for habitat type abbreviations.

Habitat Type	Unit Length (m)			Unit Count				
	Photo	Ground	P - G	# units - photo[a]	# units ground[b]	# units misID[c]	correct ID[d]	% correct[e]
Bay	133	179	-46	1	1	0	-	100
Bar Edge	3425	3411	14	14	15	0	-	93
Bar Head	405	405	0	3	3	0	-	100
Bar Tail	1374	1312	62	7	7	0	-	100
Cut Bank	0	0	-	0	0	-	-	-
Channel Nook	1097	1084	13	4	4	0	-	100
Eddy Pool	27	56	-29	1	1	0	-	100
Open Nook	842	891	-49	12	13	0	-	92
Riffle	206	188	18	6	9	0	-	67
Riprap	0	0	-	0	0	-	-	-
Total	7509	7526	-17	48	53	0	-	weighted mean = 90

a = # habitat units identified from photographs; b = # habitat units identified by ground survey; c = # units assigned the specified habitat type but whose actual habitat classification differed; d = correct habitat type of mis-identified units; e = % of units observed by ground survey that were mapped correctly from photographs.



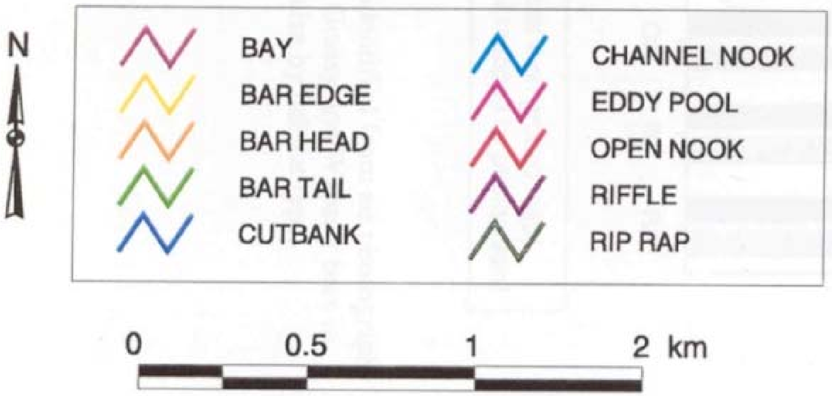


Figure 8. Habitat units at Webster Bar mapped from (A) air photographs taken on March 7 2001 and (B) a ground survey conducted on March 26 2001.

Weighted average mapping agreement for Grassy and Webster Bars averaged 93.4% and 90.5%, based on unit lengths and unit counts, respectively. The percentage of units identified correctly at the confirmation sites (# correctly identified / total # units on ground map) was 89.3% (Figure 9). This value was not weighted by number of units. Cut banks were missed 50% of the time, however, the sample size was low (n=2) and the mis-identified cut bank was classified as a steep bar edge. The identification accuracy was 91.7%, which considers the proportion of units identified correctly without regard for those habitat units missed by photograph mapping. For sites like Grassy and Webster bars where photo-based habitat mapping under-estimates the total number of units, the former statistic (% identified correctly) is more informative because it accounts for actual units missed from photographs.

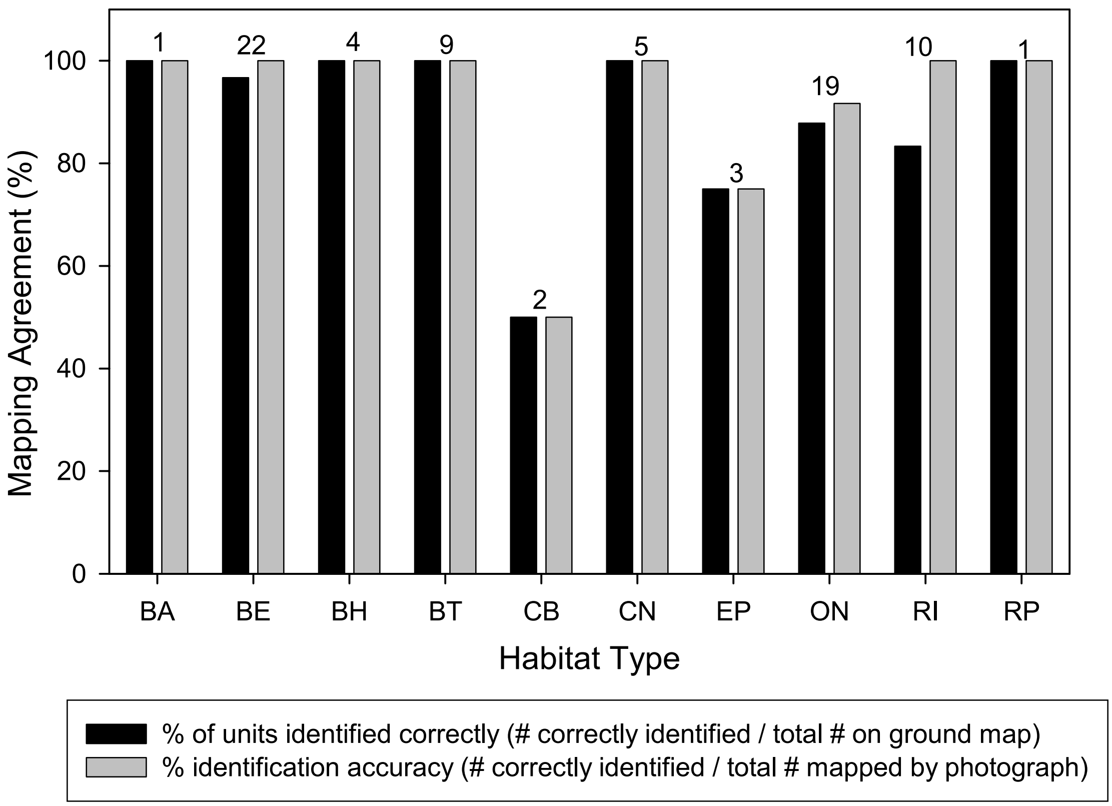


Figure 9. Mapping agreement (%) of habitat types between units identified from air photograph and habitat units identified by follow-up ground surveys at Grassy and Webster bars in March 2001. Numbers above the bars indicate the sample size by habitat type.

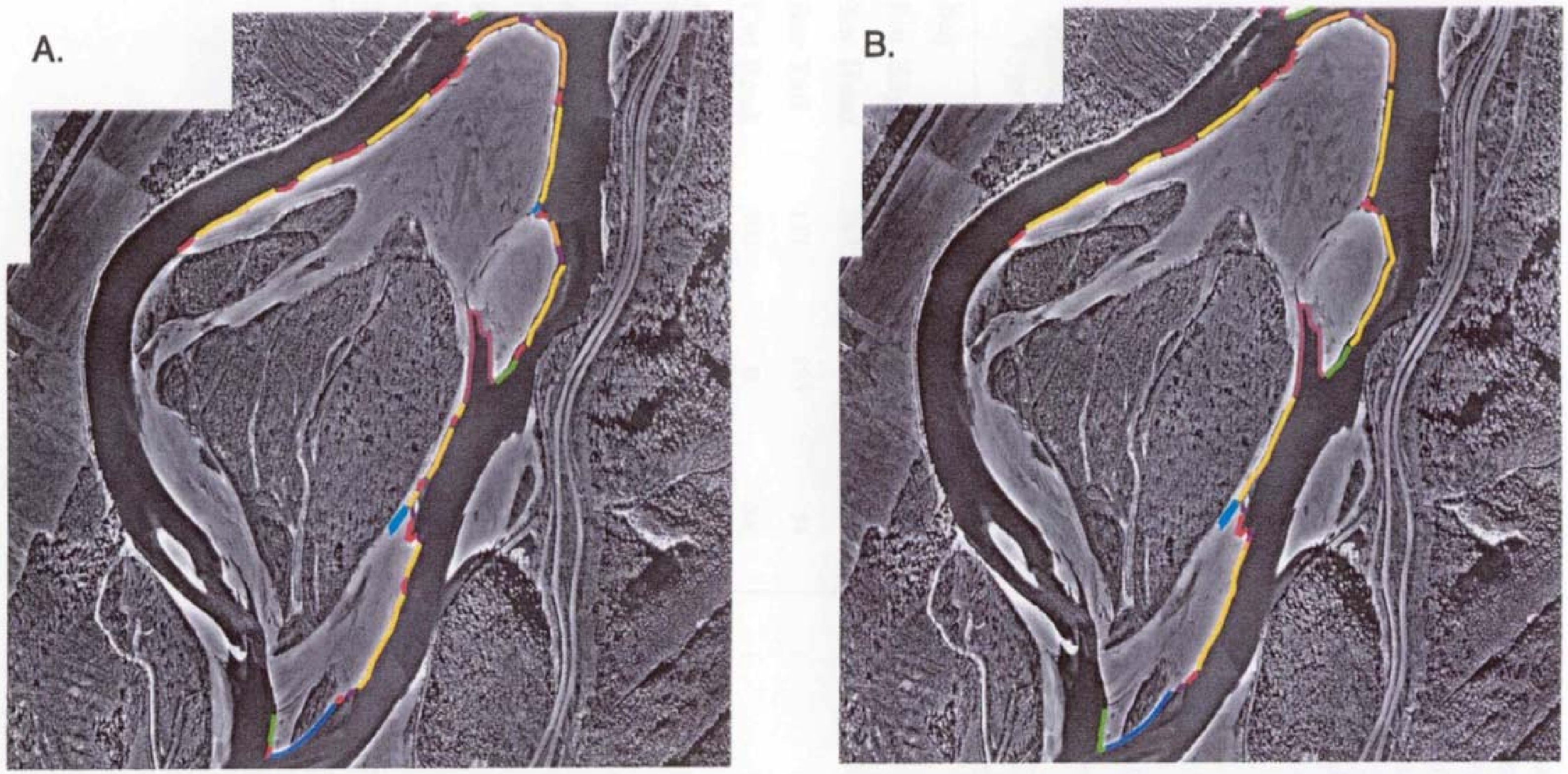
4.2 Testing Exercise Results

Spring Bar was the most downstream of the three test sites and its side channel flowing parallel to the main channel is wet throughout the year. Substantially fewer habitat units were observed by ground survey (28) than were predicted based on photo mapping (38). Despite this large discrepancy, the proportion of ground-surveyed units mapped correctly from photographs was 93%. Mapping agreement based on total bar length was high as well (92.5%), implying that the false units identified from photographs were short in length. The main channel bar flank, in particular, was less fragmented with longer individual habitat units than expected. The occurrence of open nooks was substantially over-estimated, with five nook-like features seen from photographs actually providing no reduction in water depth or velocity. Only two habitat units were totally mis-identified (one bar head and eddy pool) whereas at least some portion of the remaining 26 habitat units mapped around Spring Bar were identified correctly by photograph. Average unit length at Spring Bar was 209 m/unit, which is notably longer than at Webster and Grassy bars.

Table 6. Comparison of habitat mapping at Spring Bar in March 2001 based on air photographs and a ground survey. See **Table 3** for habitat type abbreviations.

Habitat Type	Unit Length (m)			Unit Count				
	Photo	Ground	P - G	# units - photo[a]	# units ground[b]	# units misID[c]	correct ID[d]	% correct[e]
Bay	705	705	0	1	1	0	-	100
Bar Edge	2427	2750	-323	10	7	3	BH, EP	100
Bar Head	654	593	61	3	3	1	BE	67
Bar Tail	237	333	-96	2	2	0	-	100
Cut Bank	347	347	0	1	1	0	-	100
Channel Nook	268	229	39	2	1	1	ON	100
Eddy Pool	0	21	-21	0	1	0	-	0
Open Nook	1022	752	270	14	8	6	4xBE 2xBT	100
Riffle	198	133	65	5	4	1	BE	100
Riprap	0	0	-	0	0	-	-	-
Total	5858	5863	-5	38	28	12	-	weighted mean = 93

a = # habitat units identified from photographs; b = # habitat units identified by ground survey; c = # units assigned the specified habitat type but whose actual habitat classification differed; d = correct habitat type of mis-identified units; e = % of units observed by ground survey that were mapped correctly from photographs.



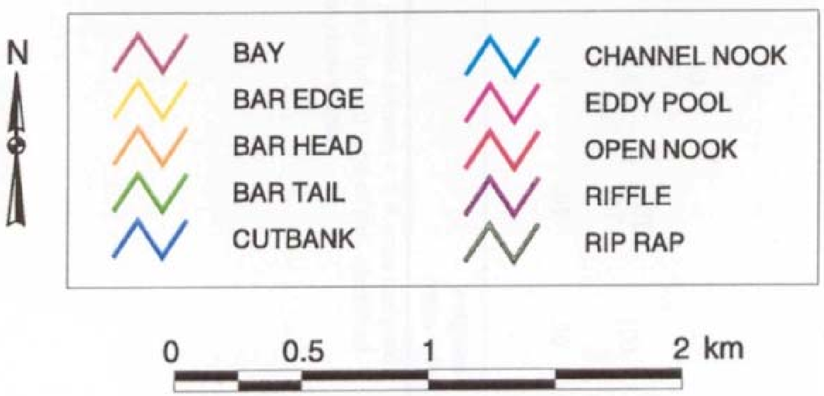


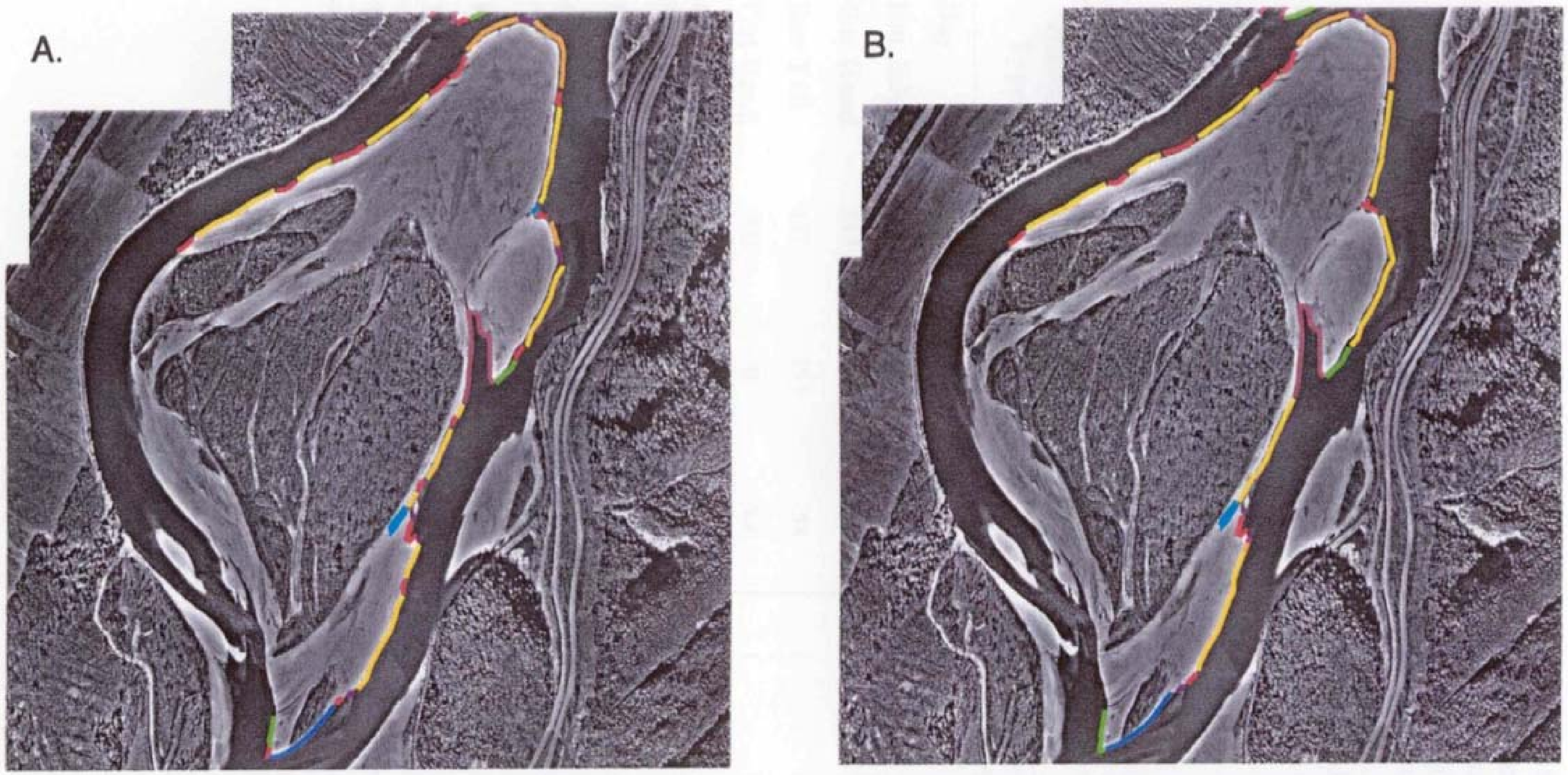
Figure 10. Habitat units at Spring Bar mapped from (A) air photographs taken on March 7 2001 and (B) a ground survey conducted on March 29 2001.

Seabird Island in March 2001 had little wetted side channel habitat and the main channel bar flank consisted of a small number of relatively long habitat units. Average unit length was 362 m and several habitat types were not represented, namely cut banks, channel nooks, eddy pools and rip rap. As at Spring Bar, the occurrence of open nooks was over-estimated because 3 apparent nook-like features offered no reduction in water depth and velocity for fishes. Whereas 90% of the total number of units were identified correctly, 87.2% of the total bar length was delineated correctly with respect to habitat type. A substantial length of cut bank habitat (300 m) was mis-identified as steep bar edge habitat and the length of open nook habitat was over-estimated by more than a factor of two.

Table 7. Comparison of habitat mapping at Seabird Island in March 2001 based on air photographs and a ground survey. See **Table 3** for habitat type abbreviations.

Habitat Type	Unit Length (m)			Unit Count				
	Photo	Ground	P - G	# units - photo[a]	# units ground[b]	# units misID[c]	correct ID[d]	% correct[e]
Bay	886	886	0	1	1	0	-	100
Bar Edge	1736	2154	-418	3	3	0	-	100
Bar Head	213	213	0	1	1	0	-	100
Bar Tail	137	193	-54	1	1	0	-	100
Cut Bank	300	0	300	1	0	1	BE	0
Channel Nook	0	0	-	0	0	0	-	-
Eddy Pool	0	0	-	0	0	0	-	-
Open Nook	260	125	135	5	2	3	2xBE BT	100
Riffle	74	52	22	2	2	1	BE	50
Riprap	0	0	-	0	0	0	-	-
Total	3605	3623	-18	14	10	5	-	weighted mean = 90

a = # habitat units identified from photographs; b = # habitat units identified by ground survey; c = # units assigned the specified habitat type but whose actual habitat classification differed; d = correct habitat type of mis-identified units; e = % of units observed by ground survey that were mapped correctly from photographs.



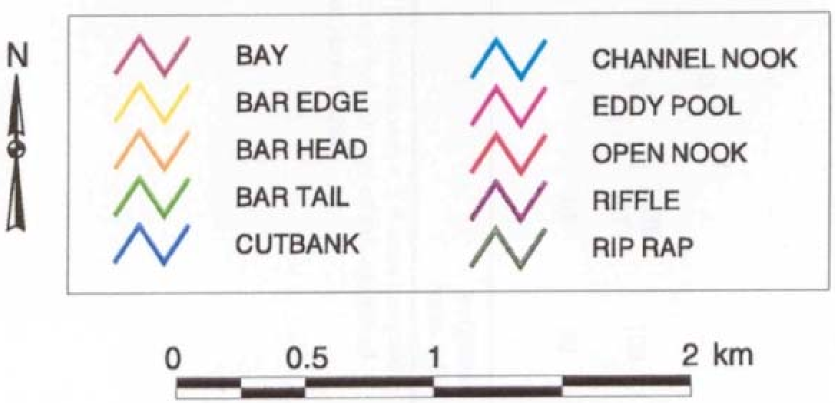


Figure 10. Habitat units at Spring Bar mapped from (A) air photographs taken on March 7 2001 and (B) a ground survey conducted on March 29 2001.

Side channel habitat at the most upstream of the three test sites, Wahleach Bar, was limited during winter months to a channel nook at the upstream end and a narrow bay at the downstream end. Unlike Spring and Seabird sites, the number of habitat units identified by ground survey (13) was similar to the total units mapped by photograph (12). Wahleach Bar had the longest average unit length of the sites (383 m) and all habitat types were represented except cut banks and eddy pools. A short riffle and area of rip rap at the upstream end were missed by photo-mapping and perceived as part of the bar head unit. At the most downstream end, an open nook predicted from photographs was in actuality part of the bar tail unit. Eleven of thirteen habitat units were mapped correctly (85%) from air photographs and because the missed units were short in length, mapping agreement based on total bar length was high, 97.9%.

Table 8. Comparison of habitat mapping at Wahleach Bar in March 2001 based on air photographs and a ground survey. See **Table 3** for habitat type abbreviations.

Habitat Type	Unit Length (m)			Unit Count				
	Photo	Ground	P - G	# units - photo[a]	# units ground[b]	# units misID[c]	correct ID[d]	% correct[e]
Bay	1680	1680	0	1	1	0	-	100
Bar Edge	2428	2417	11	3	3	0	-	100
Bar Head	146	131	15	2	2	0	-	100
Bar Tail	323	392	-69	1	1	0	-	100
Cut Bank	0	0	0	0	0	-	-	-
Channel Nook	226	226	0	2	2	0	-	100
Eddy Pool	0	0	0	0	0	-	-	-
Open Nook	187	106	81	3	2	1	BT	100
Riffle	0	15	-15	0	1	0	-	0
Riprap	0	17	-17	0	1	0	-	0
Total	4990	4984	6	12	13	1	-	weighted mean = 85

a = # habitat units identified from photographs; b = # habitat units identified by ground survey; c = # units assigned the specified habitat type but whose actual habitat classification differed; d = correct habitat type of mis-identified units; e = % of units observed by ground survey that were mapped correctly from photographs.

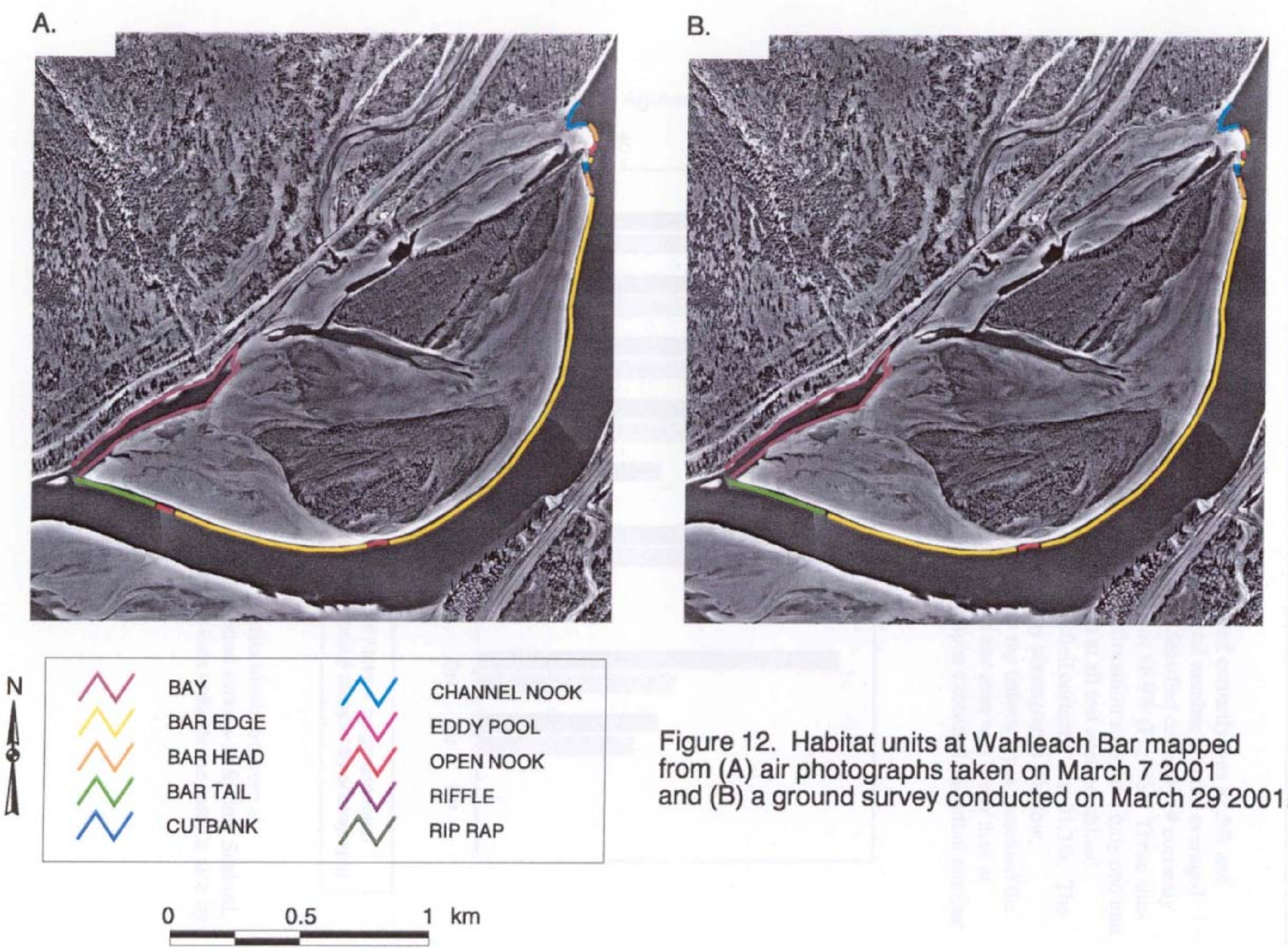


Figure 12. Habitat units at Wahleach Bar mapped from (A) air photographs taken on March 7 2001 and (B) a ground survey conducted on March 29 2001.

At test sites, the weighted average length of bar perimeter mapped correctly was 92.5% and mapping agreement based on unit counts and weighted by the total number of units averaged 89.3%. In contrast, the non-weighted average number of units identified correctly (# correctly identified / total # units on ground map) at upstream test sites was 68.9% (Figure 13). These sites had fewer habitat units per bar (17 versus 38 on average for confirmation sites) and only one unit of cut bank, eddy pool, and rip rap habitat types was represented at all test sites combined. Excluding the three rare habitat types, the percent of units identified correctly was 91.3%. The identification accuracy (# correctly identified / total # mapped by photograph) was low, averaging 58.5%. Again excluding eddy pool, cut bank, and rip rap habitat types increased the identification accuracy to 78.8%. The identification accuracy at test sites was lower than at confirmation sites because the total units mapped from photographs exceeded the actual number by 24% on average.

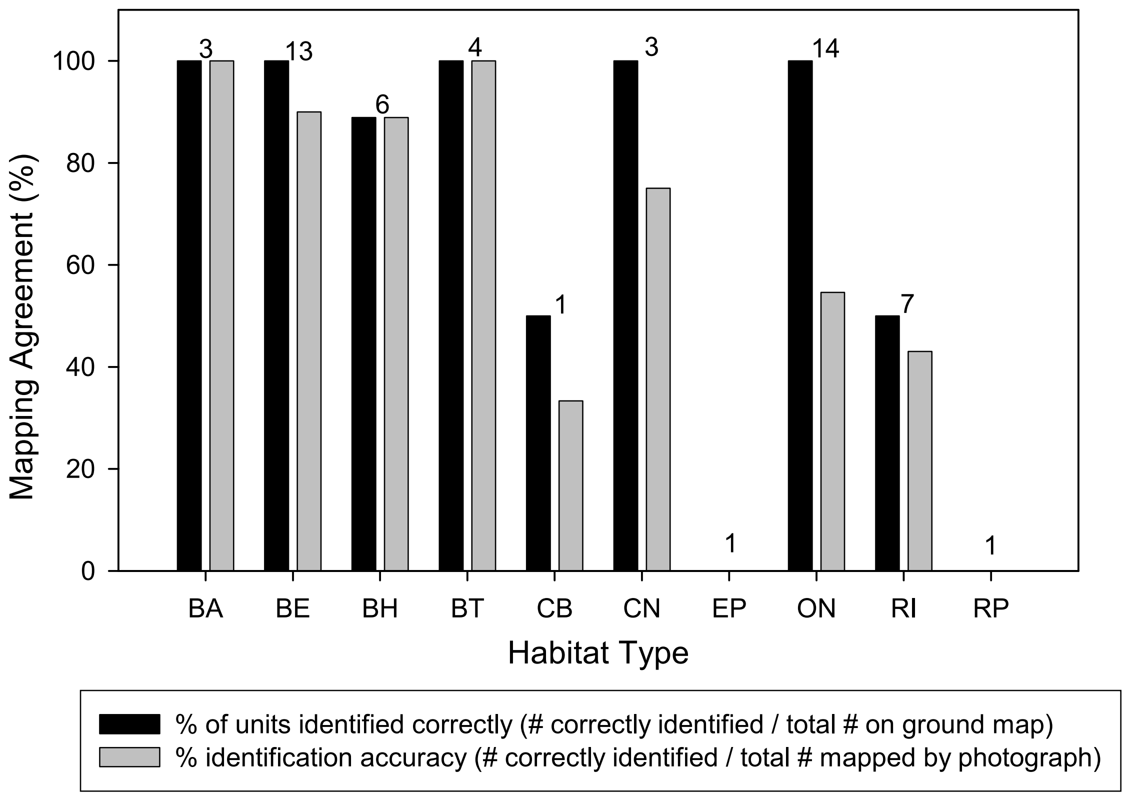


Figure 13. Mapping agreement (%) of habitat types between units identified from air photograph and habitat units identified by follow-up ground surveys at Spring, Seabird, and Wahleach bars in March 2001. Numbers above the bars indicate the sample size by habitat type.

A common error at test sites was to predict open nook habitats from photographs when in fact the features provided no reduction in water depth and velocity. Each of the upstream sites often had relatively steep bar edge habitat with high water velocity where nook-like features were observed. This error never occurred at confirmation sites. Another distinction was that upstream test sites had fewer habitats per unit bar length, with each habitat being on average more than twice the length of downstream sites. This difference in unit size matches general observations from upstream sites of the bars having a simpler bar configuration stabilized to a large degree by mature island vegetation. As well, upstream sites had larger substrate on average, which would be moved less frequently to form locally irregular topography and detailed morphological units. Such differences conformed to expectations from Level One of the habitat classification, that large-scale differences between sub-reaches of the gravel reach with respect to sediment transport rate, grain size, and channel gradient will lend each sub-reach a distinctive frequency and distribution of habitat units.

Despite morphological differences between sub-reaches, habitat mapping from air photographs, as measured by total length or total units of habitat classified, showed a high level of fidelity at both the downstream confirmation sites and upstream test sites (Table 9). The shortest units identified correctly at confirmation sites were 5-20 m in length. At test sites where the average unit length was more than double that of confirmation sites, the shortest units were 20-40 m. These values indicate a practical limit of resolution for habitat mapping from air photographs of 20 m.

Table 9. Percent agreement between photo-based habitat mapping and ground surveys at two downstream confirmation sites and three upstream test sites in the gravel reach of Fraser River. Values are weighted by the total bar length or total number of habitat units.

Measurement Unit	Confirmation Sites		Test Sites		
	Grassy	**Webster**	**Spring**	**Seabird**	**Wahleach**
Length (m)	94	98	93	87	98
Count (#)	87	90	93	90	85

5.0 Habitat Identification From Oblique Photos

Air photographs taken at a vertical angle provide a single and undistorted perspective of a site. In contrast, oblique photographs are taken at varying angles and provide a range of perspectives for any given site. It is important when habitat mapping to consult multiple oblique photographs depicting the same area from various angles and focal lengths to ensure that unavoidable distortion does not mask real habitat features. Distortion also poses the risk of exaggerating habitat features where, for instance, an irregular bar edge is perceived as an open nook.

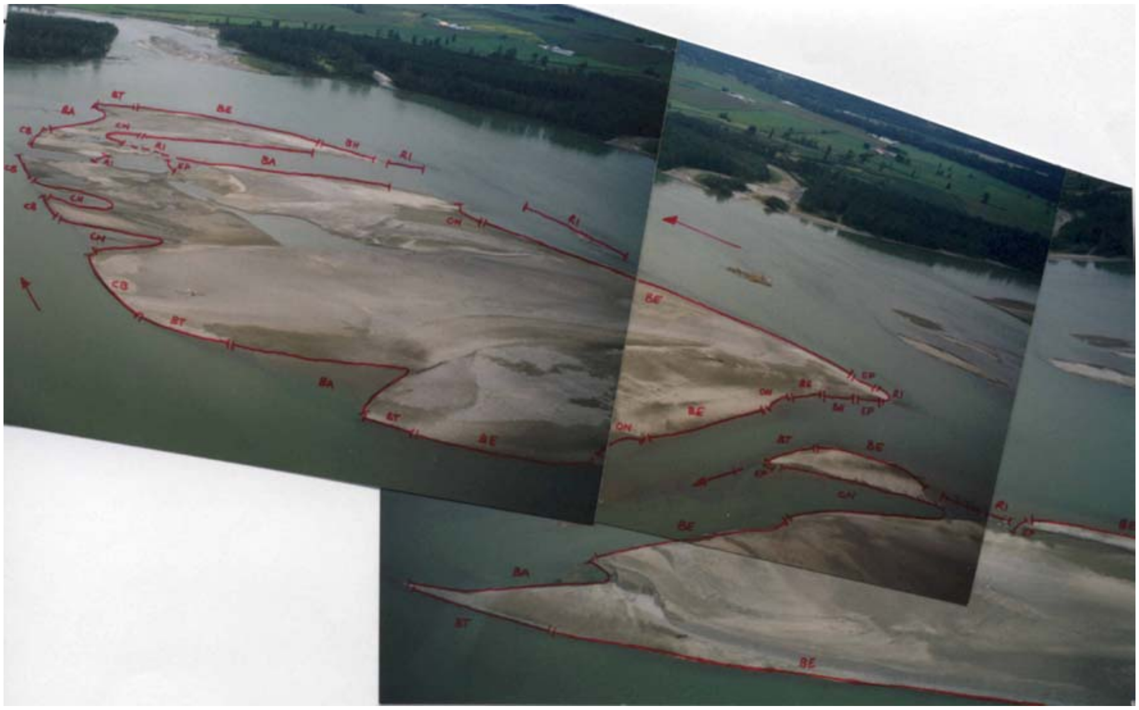
For our exercise, habitat mapping covered only the portion of any given site for which sharp and reasonably undistorted photographs were available. Hence, the total number of units counted at a site does not reflect habitat complexity around the bar perimeter. For the most part, overview photos depicting a substantial portion of each site are included in the report to demonstrate the mapping technique and resulting information. These photos, however, have substantial distortion and were not relied on for habitat mapping.

5.1 Confirmation Exercise Results

A total of 50 habitat units were mapped at Webster Bar based on oblique photographs (Figure 14). The same number was delineated by ground survey, however, 8 units were mis-identified by photo-mapping (Table 10). Two riffles and one eddy pool were missed, and these habitat units were consistently associated together at seven locations around Webster Bar. The frequency of riffle and eddy pool units was higher at Webster Bar than at any other site and one eddy pool was mistakenly mapped from photographs as bar head habitat. An example of photograph distortion impairing habitat mapping was seen with a large open-nook midway along the bar being mistaken for a bay. There was generally good matching between the habitat maps based on unit counts (85%) considering the overall complexity of the site.

The inner core of Gill Island was mostly dry by September 20 2001 when oblique photographs were taken and the outer bar perimeter was relatively simple, consisting of ten habitat units (Figure 15). Several habitat types were not observed, namely bar head, channel nook, eddy pool and rip rap (Table 10). A series of open nooks along the downstream edge were mapped correctly, however, a bar edge unit was mistaken for bar tail habitat. In total, nine of ten habitat units were identified correctly from oblique photographs, corresponding to a weighted mean of 90%.

A.



B.

Figure 14. An example of habitat unit mapping of Webster Bar from (A) oblique photographs taken on September 20 2001 (red) and (B) a follow-up ground survey conducted on September 21 2001 (black).

A.

B.

Figure 15. An example of habitat unit mapping of upper Gill Island from (A) oblique photographs taken on September 20 2001 (red) and (B) a follow-up ground survey conducted on September 24 2001 (black).

Table 10. Comparison of mapping from oblique photographs and a follow-up ground survey based on the total count of habitat units at Webster Bar and Gill Island in September 2001. See **Table 3** for habitat type abbreviations.

Habitat Type	Webster Bar					Gill Island				
	# units -photo[a]	# units ground[b]	# units misID[c]	correct ID[d]	% correct[e]	# units -photo	# units - ground	# units misID[c]	correct ID[d]	% correct[e]
Bay	4	3	1	ON	100	0	0	-	-	-
Bar Edge	9	10	1	CN	90	3	4	0	-	75
Bar Head	4	2	2	BE, EP	100	0	0	0	-	-
Bar Tail	5	4	1	BE	100	1	0	1	BE	-
Cut Bank	4	4	0	-	100	2	2	0	-	100
Channel Nook	4	5	0	-	80	0	0	-	-	-
Eddy Pool	6	7	1	BH	71	0	0	-	-	-
Open Nook	5	4	2	RI/EP, BE	75	3	3	0	-	100
Riffle	7	9	0	ON	75	1	1	0	-	100
Riprap	0	0	-	-	-	0	0	-	-	-
Total	48	48	8	-	weighted mean = 85	10	10	1	-	weighted mean = 90

a = # habitat units identified from photographs; b = # habitat units identified by ground survey; c = # units assigned the specified habitat type but whose actual habitat classification differed; d = correct habitat type of mis-identified units; e = % of units observed by ground survey that were mapped correctly from photographs.

The proportion of units identified correctly at Webster Bar and Gill Island averaged 89.4% (Figure 16), basically an identical value to the mapping agreement by air photograph at the confirmation sites in March (89.3%). These values were not weighted for the total number of habitat units. Only eddy pools were identified correctly less than 80% of the time. The identification accuracy for confirmation sites averaged 80.1%, which considers the proportion of units identified correctly without regard for those habitat units missed by photograph mapping. Both bar head and tail habitat types had 50% or less identification accuracy but the low accuracy at Gill Island (0%, n=1) heavily weighted the average.

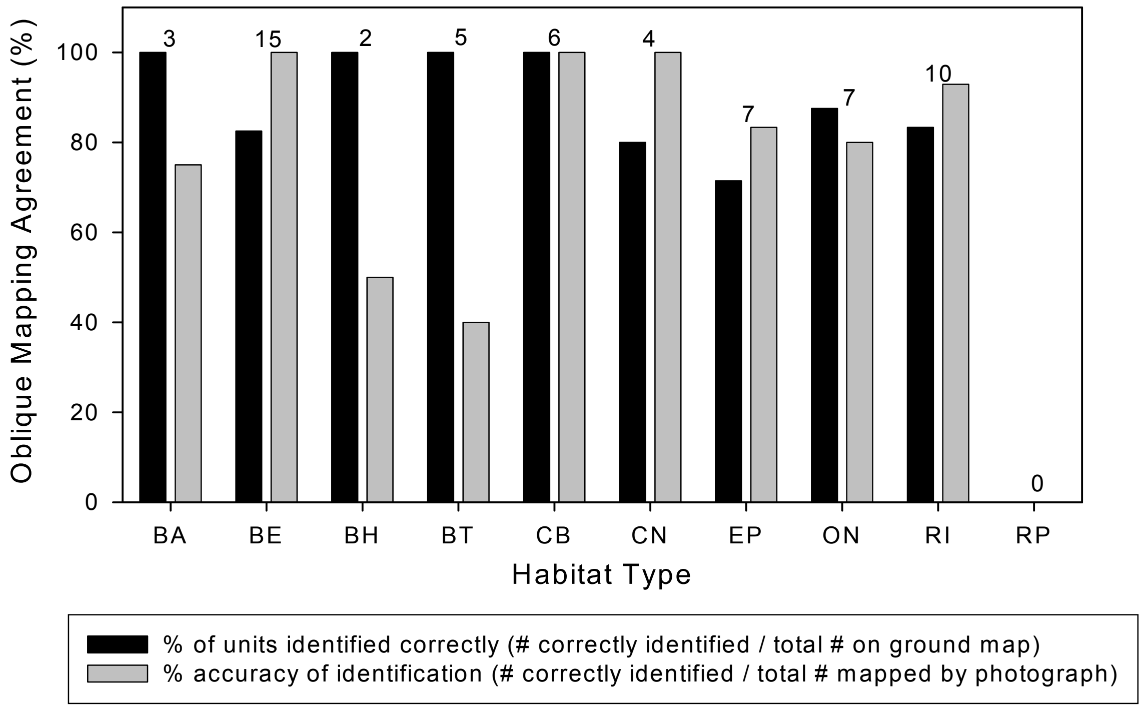


Figure 16. Mapping agreement (%) of habitat types between units identified from oblique photograph and habitat units identified by follow-up ground surveys at Webster Bar and Gill Island September 2001. Numbers above the bars indicate the sample size by habitat type.

5.2 Testing Exercise Results

A total of 33 habitat units were delineated by ground survey at Spring Bar, with bar edge habitat being the most common type represented (Figure 17). Open nooks were also abundant (n=8), however, two were missed and classified as channel nooks while 2 features perceived to be open nooks were extended bar edge habitat (Table 11). The single cut bank at Spring Bar was mistaken from photographs as a steep bar edge and one of three bar head units was mistaken to be an eddy pool. In total, 88% of units observed by ground survey were mapped correctly from oblique photographs of Spring Bar.

The majority of habitat units (89%) mapped around Seabird Island were identified correctly (Figure 18). Of the 18 units identified by ground survey, one eddy pool was missed and a bar head unit was mistaken to be an eddy pool (Table 11). No cut banks, open nooks, or rip rap were mapped at Seabird Island.

Peters Island had the highest proportion of habitat units identified correctly (95%), with only one riffle missed out of 42 units and two units (bar head and bar edge) mis-identified as open nooks (Table 11). Bar edge habitat was the most frequently represented and eddy pools were unusually common as well.

A.

B.

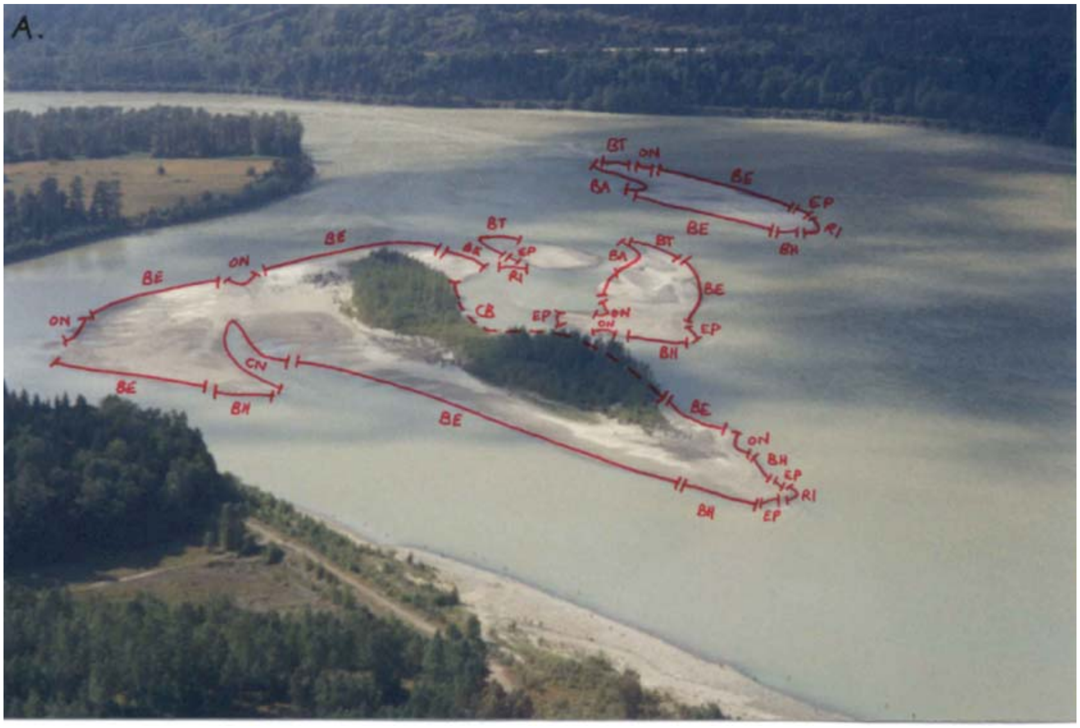
Figure 17. An example of habitat unit mapping at Spring Bar from (A) oblique photographs taken on August 20 2001 (red) and (B) a follow-up ground survey conducted on August 24 2001 (black).

A.

B.

Figure 18. An example of habitat unit mapping at Seabird Island from (A) oblique photographs taken on August 20 2001 (red) and (B) a follow-up ground survey conducted on August 24 2001 (black).

A.



B.

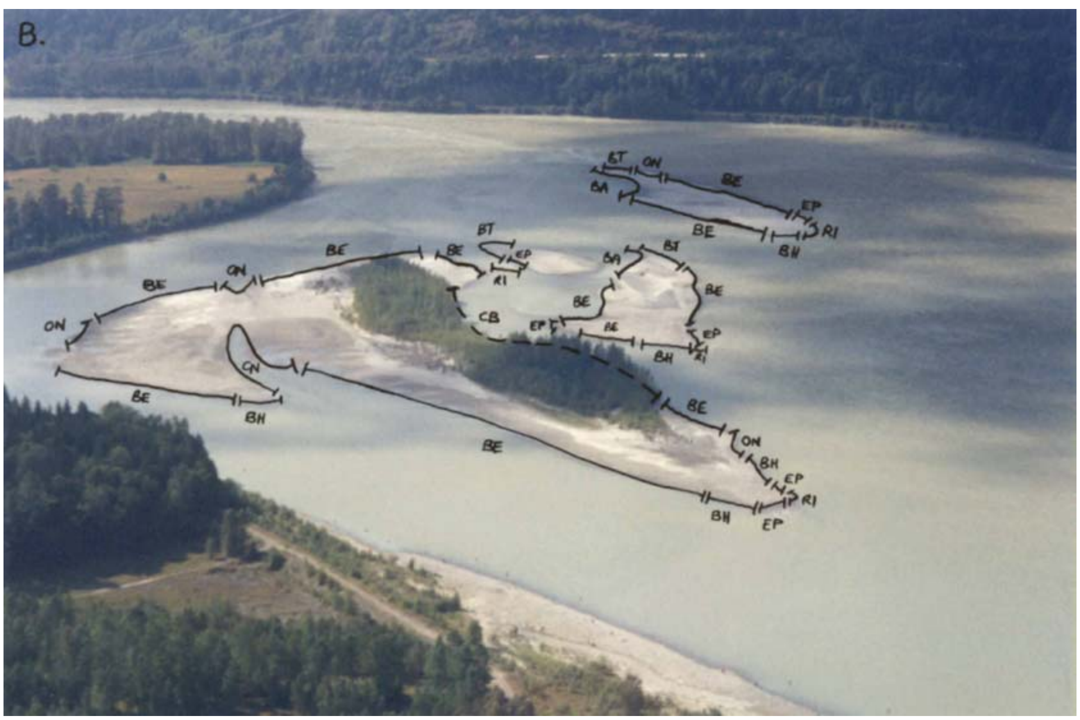


Figure 19. An example of habitat unit mapping at Peters Island from (A) oblique photographs taken on August 20 2001 (red) and (B) a follow-up ground survey conducted on August 25 2001 (black).

Table 11. Comparison of mapping from oblique photographs and a follow-up ground survey based on the total count of habitat units at the three upstream test sites in September 2001. See **Table 3** for habitat type abbreviations.

Habitat Type	Spring Bar					Seabird Island					Peters Island				
	# units -photo[a]	# units ground[b]	# units misID[c]	correct ID[d]	% correct[e]	# units -photo	# units ground	# units misID	correct ID	% correct	# units -photo	# units ground	# units misID	correct ID	% correct
Bay	0	0	-	-	-	2	2	0	-	100	2	2	0	-	100
Bar Edge	13	12	1	CB	100	5	5	0	-	100	12	13	0	-	92
Bar Head	2	3	0	-	67	2	3	0	-	67	6	6	0	-	100
Bar Tail	2	2	0	-	100	2	2	0	-	100	3	3	0	-	100
Cut Bank	0	1	0	-	0	0	0	0	-	-	1	1	0	-	100
Channel Nook	4	1	3	3xON	100	3	3	0	-	100	2	2	0	-	100
Eddy Pool	5	4	1	BH	100	1	1	1	BH	0	7	7	0	-	100
Open Nook	10	8	2	2xBE	75	0	0	-	-	-	6	4	2	BE BH	100
Riffle	3	3	0	-	100	2	2	0	-	100	3	4	0	-	75
Riprap	0	0	-	-	-	0	0	-	-	-	0	0	-	-	-
Total	39	34	7	-	weighted mean = 88	17	18	1	-	weighted mean = 89	42	42	2	-	weighted mean = 95

a = # habitat units identified from photographs; b = # habitat units identified by ground survey; c = # units assigned the specified habitat type but whose actual habitat classification differed; d = correct habitat type of mis-identified units; e = % of units observed by ground survey that were mapped correctly from photographs.

The proportion of units identified correctly at upstream test sites was 86.9% (Figure 20), substantially higher than the mapping agreement by air photograph at test sites in March (68.9%). Cut banks were missed 50% of the time, however, the sample size was low (n=2) and the mis-identified cut bank was classified as a steep bar edge. The identification accuracy was 82.9%, which considers the proportion of units identified correctly without regard for those habitat units missed by photograph mapping. Cut banks, eddy pools, and open nooks each had less than 70% identification accuracy despite the latter two habitat types having a reasonable large sample size (n=12).

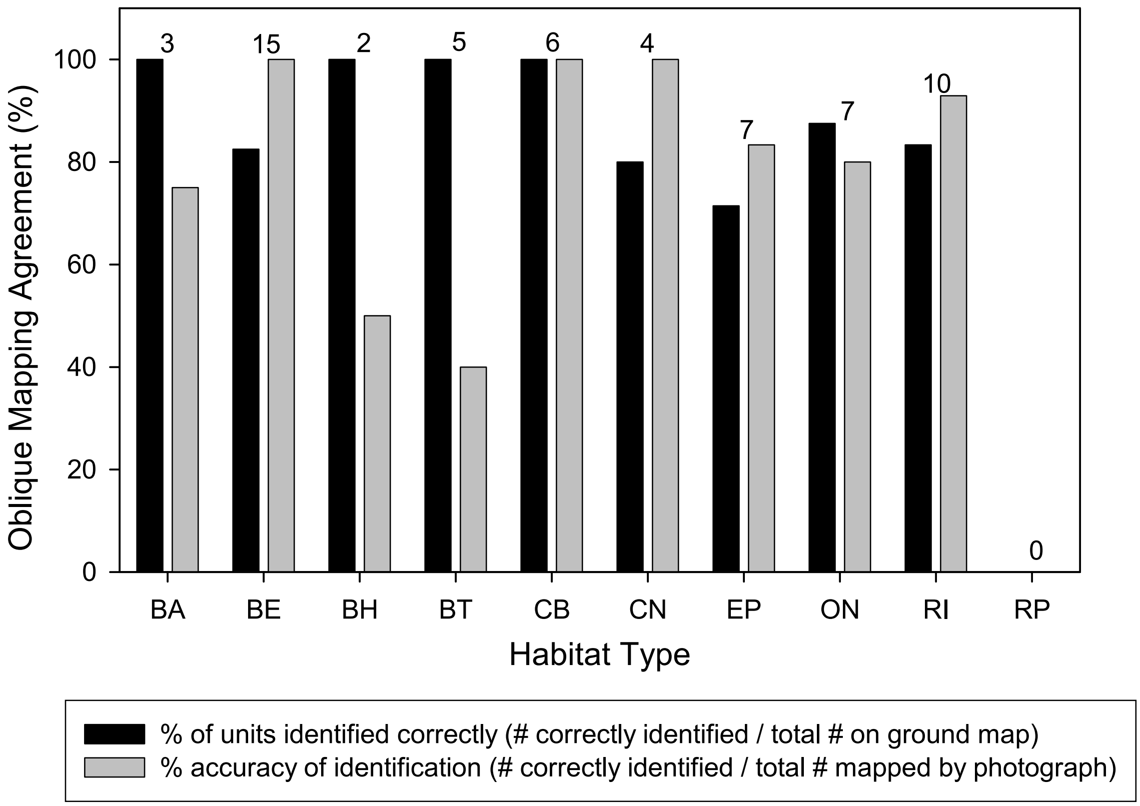


Figure 20. Mapping agreement (%) of habitat types between units identified from oblique photograph and units identified by follow-up ground surveys at Spring, Seabird, and Peters bars in September 2001. Numbers above the bars indicate the sample size by habitat type.

Table 12 summarises the agreement between photo-based and ground-based habitat maps obtained from the two photograph types, air and oblique. These values refer to mapping accuracy based on unit counts only because unit lengths were not measured from oblique photographs. There was a high level of mapping fidelity from both photo types based on the proportion of units identified correctly. The difference between photo types was insignificant for both site groups as well.

Table 12. Mapping agreement based on unit counts for each site type and each type of photograph from which habitat units were identified prior to ground survey. These values are non-weighted averages. Values for test sites in parentheses exclude cut bank, eddy pool and rip rap habitat types, which had a sample size of 1.

Photograph Type	Confirmation Sites (downstream)		Test Sites (upstream)	
	% correct ID	% ID accuracy	% correct ID	% ID accuracy
Air (March)	89	92	69 (91)	59 (79)
Oblique (Sept)	89	80	87	83

Other general differences between the photo types were noted. The pattern of over-estimating open nooks at upstream sites was less problematic with oblique photos than with air photographs. Over-rating habitat complexity, by identifying more habitat features than actually existed, was less of a problem with oblique photographs as well. The mapping agreement between vertical and oblique photographs was comparable for both test and confirmation sites when under-represented habitat types were excluded. However, there is concern for rare habitat units being mis-identified by photograph mapping. The general similarity between the total number of units predicted by photograph and the actual number mapped by ground survey implied that habitat features were depicted with reasonable clarity but that the correct classification of habitat units was occasionally problematic.

Classification errors were not systematic for most habitat types (e.g. all mis-identified open nooks were not actually channel nooks). One exception was bar head and eddy pool units being confused at both Spring and Seabird sites. This mistake was not surprising because the habitats most often occur at the same position around a bar and it is mostly hydraulic conditions that distinguish the two units. Errors in classification will be most consequential if the correct habitat type has significantly different ecological attributes than the predicted habitat type. This issue extends beyond the scope of this report but in many cases herein, the mistaken habitat type shared a relatively high degree of ecological similarity with the correct habitat (e.g. a bar head confused with an eddy pool). Other cases would represent a more substantial error, for instance a series of open nooks being mistaken as an extended length of bar edge habitat.

6.0 Physical Characteristics of Habitat Types

Several physical attributes (bank angle, average water depth, average and maximum velocity) and substrate characteristics (% sand/silt, % gravel, % cobble) were selected to compare habitat conditions between reference sites and the confirmation/test sites. The parameters are recognised as important determinants of habitat suitability for fish (e.g. Peterson and Rabeni 2001) and were measured consistently at all beach seine sites over the 3-year sampling period. Only August/September sampling data were included in the analysis.

Box and whisker plots were used to address the question of whether the physical attributes of habitat units at confirmation and test sites fell within the range of values observed at reference sites. If the median value for a given parameter measured at the confirmation and test sites fell within the box-range (25th and 75th percentiles) observed at the reference sites, then the site groups were similar. If, however, the median value fell outside the quartile range of the reference sites, then the site groups differed. For those habitat types with a low sample size at confirmation (BA, BT, CN, RI) and test (BA, RI) sites, the comparison with reference site conditions was less conclusive. Habitat types missing from the list (e.g. cut bank, rip rap) were not sampled at the sites. The number of beach seines conducted for each site group by habitat type is provided in Table 13 for reference. Box and whisker plots of confirmation and test sites are included in appendices B and C, respectively.

Table 13. Number of beach seine sets conducted in various habitat types during summer months at references sites (1999-2001) and confirmation/test sites (2001 only).

Site Group	BE	BH	BT	CN	EP	ON	BA	RI
Reference	205	92	83	49	44	59	39	4
Confirmation	12	8	0	1	2	2	1	0
Test	16	5	2	4	10	4	1	2

Bar edge habitat units at reference sites were highly variable with respect to bank angle, water depth, and mean and maximum velocity (Figure 21). Bottom substrate had a low proportion of fine sediment (sand/silt) and variable amounts of gravel and cobble. Bar edge units at downstream confirmation sites were similar to reference sites with respect to median velocity (mean and maximum), but median water depth and bank angle were higher. Characteristics of bar edge habitat at test sites fell within the expected range for bank angle, water depth and velocity, and the proportions of grain size classes (cobble, gravel, sand/silt) observed in bar edge units were similar for all site groups.

Bar head habitat units at reference sites were similar to bar edge units in that a wide range of physical conditions were observed. Bar head units tended to have higher water velocity and a larger proportion of cobble-sized bed material. Units at confirmation sites had a steeper bank angle and were deeper than reference sites but like bar edge units, had velocity conditions that were within the acceptable quartile range. The opposite pattern was observed with bar head units at test sites, which had a similar bank angle and depth as reference sites but whose water velocity exceeded the range observed at reference sites. Substrate characteristics of bar head units at both confirmation and test sites were similar to reference sites.

Bar tail habitat units were similar to both bar edge and bar head units with respect to bank angle, depth and velocity. The only notable difference was that bar tail units had a higher proportion of gravel and lower proportion of cobble-sized bottom sediment. No beach seining of bar tail units occurred at confirmation sites and only two sets were conducted at test sites. Nevertheless, the physical characteristics of upstream bar tail habitat based on the two sets were similar to reference sites with respect to all measured parameters.

C*hannel nook* habitat at reference sites showed variable bank angle and water depth, however, water velocity measurements were tightly concentrated around the median of 0 cm/s. They had a high proportion of fine sediment (sand/silt) and relatively little cobble-sized material. The one confirmation site sample was similar to reference sites for all measured parameters. Test sites were similar as well except for bank angle, which exceeded the reference site range.

Wide variability in physical attributes (Figure 21) and substrate characteristics (Figure 22) was observed in *eddy pool* habitat units at reference sites. Bank angle was steeper than other habitat types and the proportion of cobble sediment was generally low. Confirmation sites had higher median bank angle and depth than reference sites, but lower water velocity. Substrate texture was coarser, with higher proportions of gravel and cobble, but values fell within the reference range. Water velocity at test sites exceeded the reference range for eddy pool units, and test sites had a significantly higher proportion of cobble-sized sediment.

Open nooks at reference sites were generally characterized as having a low bank angle, shallow depth, and low water velocity. Substrate texture was variable but contained a relatively high proportion of fine sediment. The two open nooks examined at the confirmation sites had higher than expected velocity but other parameters including substrate texture were similar. Upstream test sites were very similar to reference sites except that they had a lower proportion of fine sediment and a significantly higher proportion of cobble.

Water velocity in *bays* was consistently 0 cm/s at reference sites, although bank angle and water depth were variable. Bottom sediment was invariably fine, containing a high proportion of sand/silt and no material >16 mm. Physical characteristics of the one sampled bay at Webster Bar fell within the expected range but substrate was coarser, with less sand/silt and more gravel than expected. Only one bay was examined at a test site, Peters Island, and its physical and sediment characteristics fell within the expected range based on reference sites.

Riffles were habitually difficult for beach seining and sample size for all site groups was low. Velocity was higher than in all other habitat types and water depth and bank angle were generally low. Substrate texture consisted of a relatively clean mix of gravel and cobble material. No riffles at confirmation sites were sampled and only two were examined at test sites (Spring Bar, Peters Island). These riffle units had a steeper bank angle and were deeper than reference sites but velocity conditions were similar. A higher than expected proportion of sand/silt was observed and gravel material was less common.

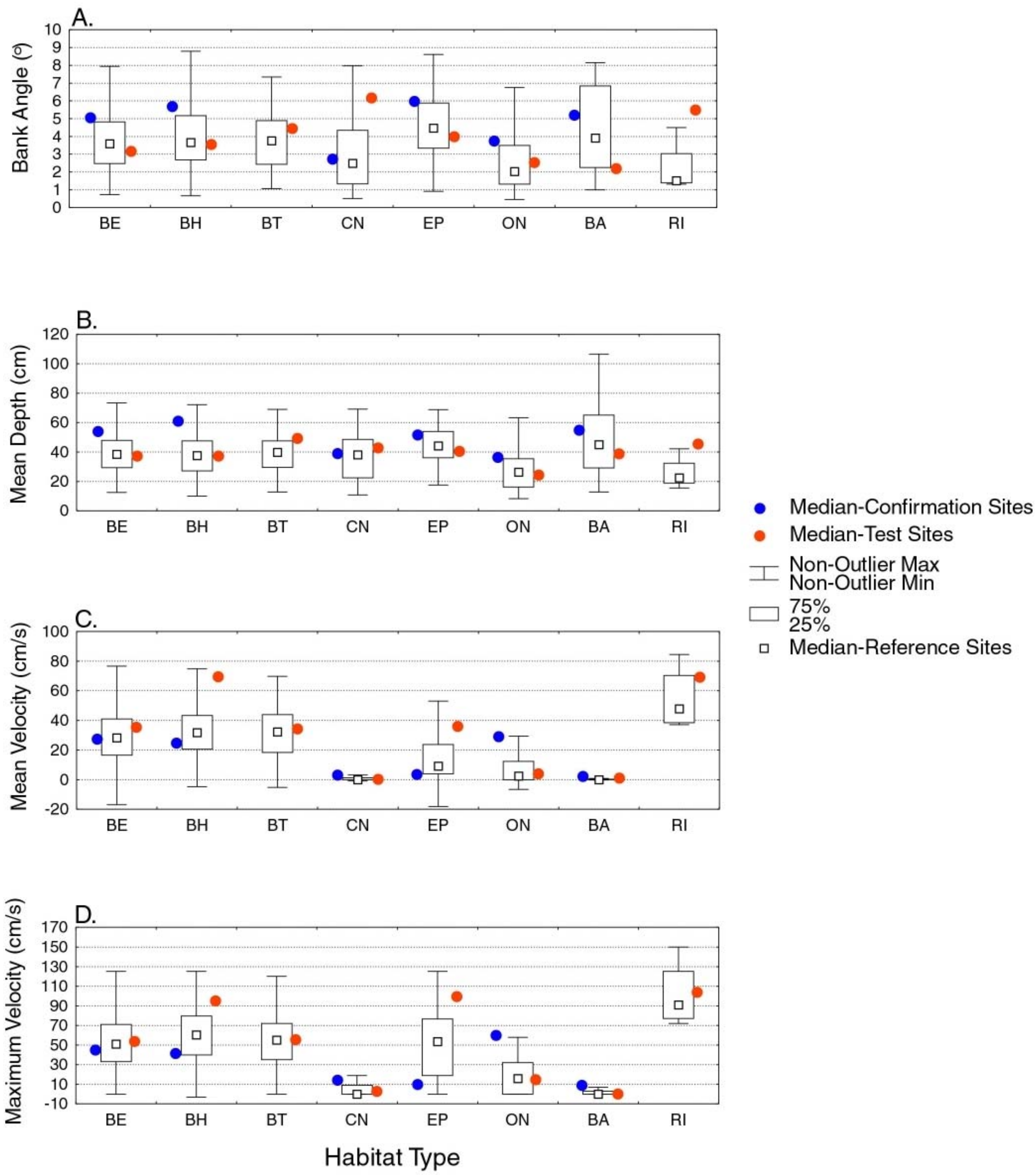


Figure 21. Physical characteristics of reference sites (bank angle, water depth, and velocity) measured in summer months (1999-2001) in comparison with measurements made at downstream confirmation sites and upstream test sites (summer 2001 only).

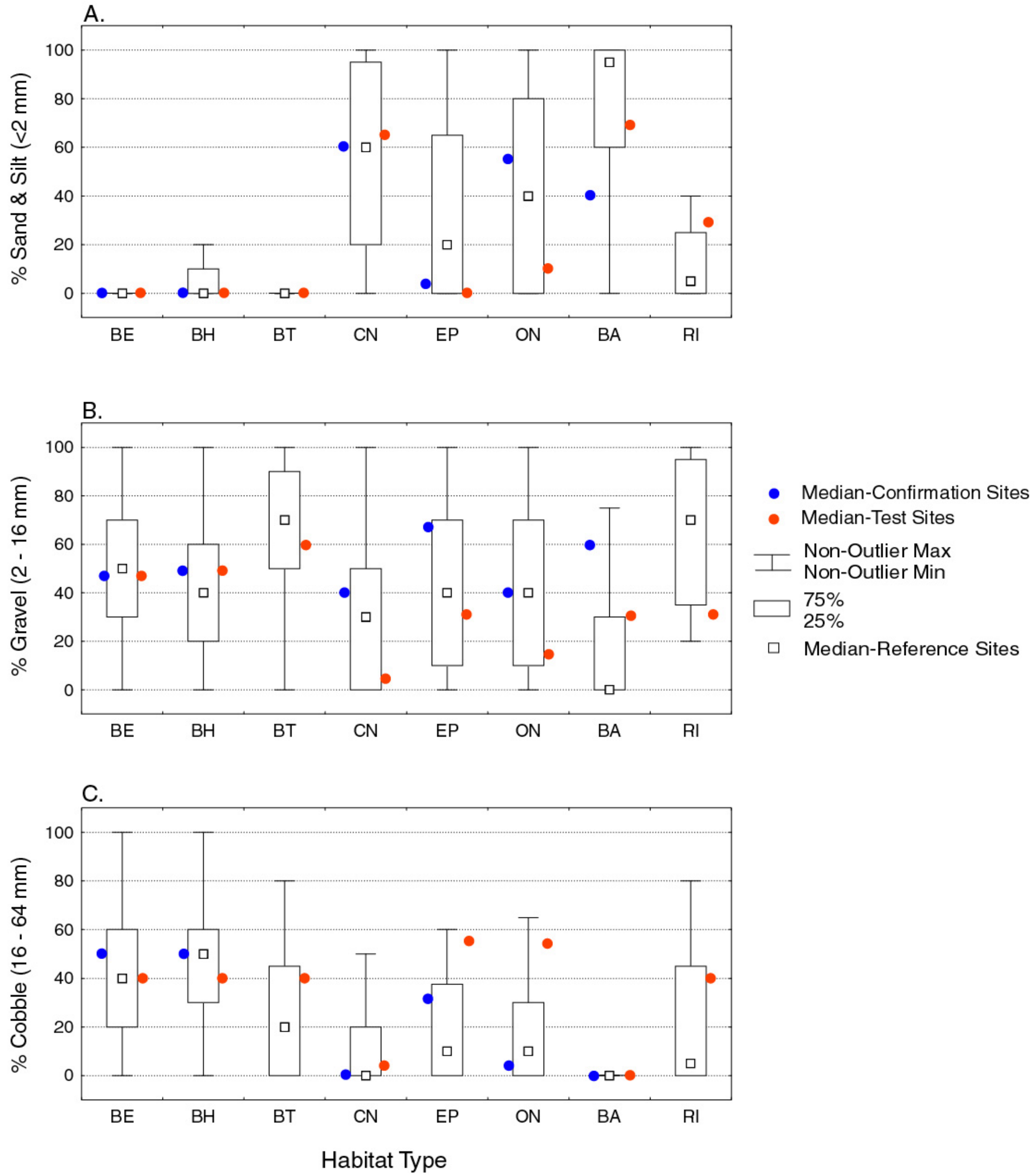


Figure 22. Substrate characteristics of reference sites (% cobble, gravel and sand/silt) measured in summer months (1999-2001) in comparison with measurements made at downstream confirmation sites and upstream test sites (summer 2001 only).

7.0 Ecological Characteristics Of Habitat Types

7.1 Comparison Of Confirmation and Test Sites to Reference Sites

Preliminary data presented in Church et al. (2000) showed that the association of various fish species differed among habitat types and that total fish density (all species) varied among habitat types as well. These patterns were seen consistently in all years of sampling at the 12 reference sites. The following analysis examines if these patterns were observed at confirmation and test sites. Comparisons in six species-specific densities, total density, and % salmonid species between reference sites and confirmation/test sites are presented in Figure 23 and 24. The six fish species were chosen on the basis of large sample size and contrasting patterns of habitat use.

Total density and the density of non-salmonid species were moderate to low in *bar edge* habitat units at reference sites as well as at confirmation and test sites. The proportion of salmonid species and juvenile chinook salmon density was relatively high and all site groups had similar median values.

Bar head habitat units were similar to bar edge units both in terms of density of fish and the proportion of salmonid species in beach seine hauls. Confirmation and test sites fell within the expected range based on catch data from reference sites as well.

Total density in *bar tail* habitats was slightly higher than for bar edge and bar head units and densities of redside shiner, mountain sucker and leopard dace were higher as well. The proportion of salmonids and chinook salmon density were each lower. Test sites exceeded the expected range for chinook salmon density and the % salmonid species, but were otherwise similar to reference sites based on densities of other fish species.

The one *channel nook* sampled at Webster Bar had significantly higher densities of juvenile largescale sucker and longnose dace, and total density fell outside the expected range based on reference sites. Catch data from channel nooks at test sites were similar to reference sites.

The two *eddy pools* sampled at confirmation sites had lower than expected density and all species-specific densities except largescale sucker and longnose dace fell below the range observed at reference sites. In contrast, test sites had a reasonable sample size (n=10) and the % salmonid species and all species' density except leopard dace fell within the expected range.

Total density in *open nooks* at reference sites was highly variable and both confirmation and test sites fell within the expected range. Densities of all fish species were within the expected range as well, except for chinook salmon, whose density was significantly higher at test sites. The proportion of salmonid species at test sites was high, but fell within the expected range.

Bays had low fish density and the proportion of salmonid species in beach seine hauls was expected to be low based on sampling at reference sites. However, the one beach seine at Peters Island collected a high proportion of salmonids, mostly cutthroat trout. The low sample size (n=1) for bays at test/ confirmation sites makes comparisons with reference sites less rigorous.

Riffles were sampled only at test sites and total density, as well as the density of most species, was lower than observed at reference sites. The one exception was longnose dace, whose density at test sites slightly exceeded the reference quartile range. The proportion of salmonids was high and matched with reference site observations, but these fish were mainly cutthroat trout and chinook salmon density was lower than expected.

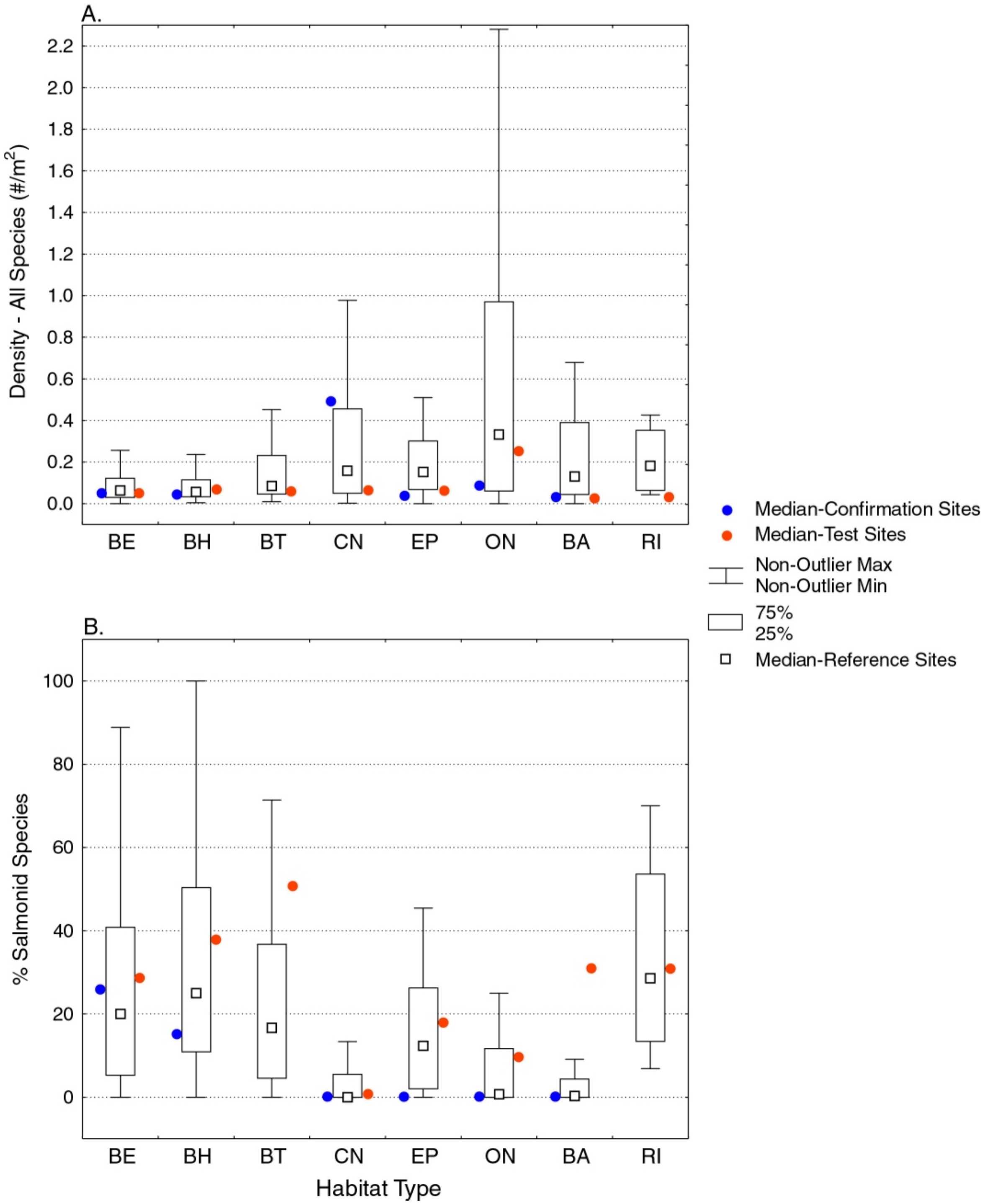


Figure 23. Total fish density (all species) and the percent salmonid species in beach seine hauls at reference sites in summer months (1999-2001) compared with measurements made at downstream confirmation sites and upstream test sites (summer 2001 only).

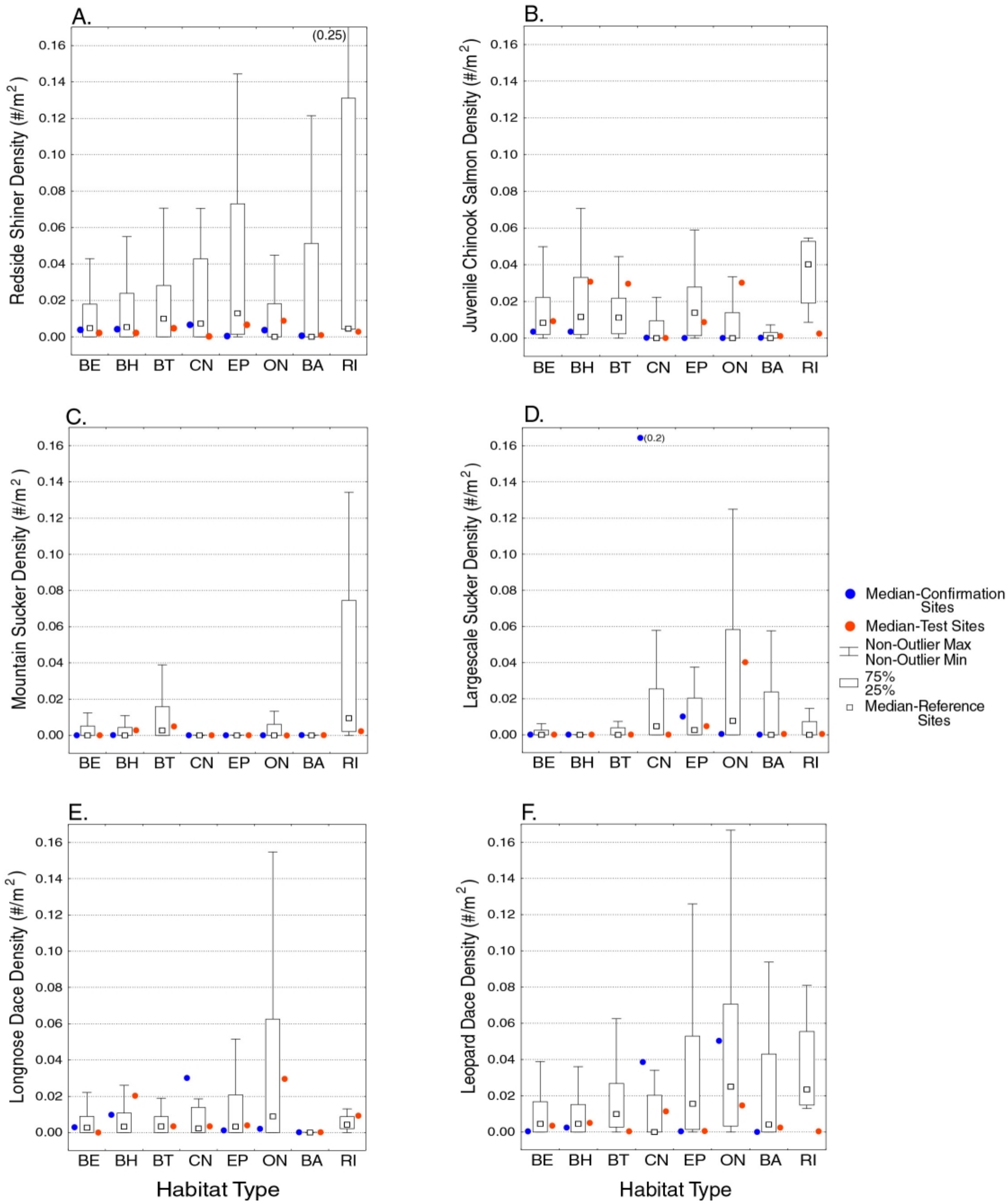


Figure 24. Species-specific density in habitat types at reference sites in summer months (1999-2001) compared with densities at downstream confirmation sites and upstream test sites (summer 2001 only).

7.2 Fish-Species Habitat Type Associations

Consistent with findings of Church et al. (2000), open nooks had the highest but also the most variable fish density of all habitat types. Both species of dace as well as largescale sucker were found in relatively high densities whereas redside shiner were only rarely found in open nook units. Bar tails had higher total density than either bar edge or bar head habitats and redside shiner, mountain sucker and leopard dace were particularly common. At test sites more so than reference sites, bar tails had a high proportion of salmonid species. In fact, several habitat types had a higher than expected proportion of salmonid species at test sites: bar edge, bar head, bar tail, eddy pool, open nook and bay. Of these, only bar tails and bays had proportions higher than the quartile range of reference sites.

Redside shiner were ubiquitous in all habitat types and at most sites along the gravel reach. The most notable habitat associations were with eddy pool and riffle units, and these habitats often were spatially associated with one another at a given site. Juvenile chinook salmon were common in all habitat types with reasonable flow, and density was positively related to mean velocity. As for redside shiner, the association of chinook salmon with both eddy pool and riffle habitats was not surprising given their usual proximity to one another at a site.

Mountain sucker showed the greatest degree of habitat specialization, having negligible density in all habitat types except bar tail, open nook, and riffle. These habitats had predominantly gravel-sized bottom sediment (2-16 mm), a low proportion of sand/silt, and high water velocity. Largescale sucker were associated mostly with slow-velocity habitat types, namely channel nooks, eddy pools, open nook and bays, which are more depositional in nature and have finer bed material.

Leopard dace at confirmation sites were found to use nook habitats, both open and channel types, to a greater extent than expected. The median density at test sites was higher than for other habitat types as well, indicating a preference by leopard dace for nook habitats. Eddy pools had a particularly high and variable density of leopard dace but only at reference sites. Longnose dace had the strongest association with open nooks but less so with channel nooks, probably because of their low velocity conditions. Longnose dace are adapted to moderate-flowing, coarse substrate environments and open nooks may be suitable for young juveniles in particular because of their moderate velocity. More elaborate statistical exercises would test this perceived association more rigorously.

8.0 Discussion and Recommendations

Habitat units were identified with a high level of accuracy by air and oblique photographs at five sites along the gravel reach in March and August/September 2001. No sites achieved 100% identification accuracy but the number of units identified correctly was consistently high, ranging between 85% and 93%. In terms of bar length, between 87% and 98% of the total perimeter length of sites was identified correctly. The practical limit of resolution for habitat unit classification was estimated to be 20 m from both air and oblique photographs.

From air photographs, the expected number of units generally matched the total number observed by ground survey at confirmation sites within the aggrading reach. The degree of habitat complexity predicted around these bars therefore agreed with the actual level of complexity. Average unit length was approximately 120 m at Grassy and Webster bars and mapping by air photographs mis-identified only 6 of 76 habitat units at the two sites combined. In terms of bar length, 94.3% and 98.4% of the total perimeter length was mapped correctly at Grassy and Webster bars, respectively.

Habitat mapping from air photographs of test sites identified a larger number of units than were actually observed at two of the three sites: Spring Bar and Seabird Island. At both sites, the number of open nooks was over-estimated and the nook-like bar features provided no reduction in velocity or water depth compared to the adjacent bar area. The mis-identification of bar edge habitat as open nooks may be consequential because open nooks consistently host higher densities of juvenile fish. A relatively high number of units were mis-identified at Spring Bar overall (12 of 28) but the false units were short and 92.5% of the total perimeter of Spring Bar was mapped correctly. Average unit length at test sites was more than double that of downstream confirmation sites. This difference matches with expectations of the habitat classification (Level One) that large-scale differences with respect to sediment transport rate and channel gradient lend each sub-reach a distinctive frequency and distribution of habitat units.

Oblique photographs are an inexpensive and readily accessible means of acquiring a photographic record of the gravel reach. In approximately 1 hour and flying at an elevation of 1000 m above the ground, one can take a complete set of photographs for analysis. A major disadvantage of oblique photographs, however, is distortion and the inability to measure lengths of habitat features accurately.

Habitat mapping of Webster Bar and Gill Island from oblique photographs in September accurately predicted the number of units around each bar. In this regard, oblique photographs surpassed air photographs. The number of mis-identified units was relatively high at Webster Bar (8 of 48) but low at Gill Island (1 of 10). Errors in identification did not show any systematic pattern.

Test site mapping from oblique photographs in August had a relatively low number of mis-identified units at each of the three sites. Additionally, the number of units predicted generally matched the number observed based on follow-up ground surveys. This is in contrast to the over-estimation of habitat complexity made by mapping of air photographs at test sites. The problem of mis-identifying bar edge habitat as open nooks was problematic with oblique photographs, but to a much lesser degree than with air photographs.

Both the physical and ecological characteristics of habitat units in the upstream test reach matched observations made at 12 reference sites in the confirmation reach. Low sample size left comparisons of some habitat types inconclusive, however, a reasonable level of similarity was detected among the site groups for most parameters considered.

Based on these results, we believe that habitat units can be delineated reliably both by low-level air photography and/or oblique photographs. The photo-techniques are somewhat complementary in that the methods of analysis provide slightly different information, however, each could be used alone to systematically identify habitat units at sites within the gravel reach. Because the accuracy of identification was less than 100% at all sites using both photographic methods, some degree of ground truthing is recommended for future habitat typing exercises. Ground truthing would involve ground surveys of a randomly selected sub-set of habitat units identified by photographic mapping. For technicians unfamiliar with the gravel reach of Fraser River, ground truthing should be relatively intensive until a reasonably high level of confidence is achieved.

The following are recommendations for taking oblique photographs from a plane:

- use a SLR-camera with zoom and manual settings
- set shutter speed for <1/250 second, adjusting for light conditions
- take photos through an open window whenever possible because windows can cause glare
- use 400 ASA film
- take photographs in bright and sunny conditions
- conduct the ground survey soon after the photos are taken (within three days during summer months when water levels fluctuate and within 1-2 weeks during winter months)
- take the photographs from as near-vertical an angle as possible to minimize distortion
- take overview photographs (35-50 mm) along the entire reach as well as detailed site photographs (70-200 mm) that together capture all the habitat features of a site from various angles

We recognise several additional tasks that would further improve habitat mapping capabilities for the gravel reach. These tasks include a:

- statistical study of the physical similarity of site types to improve our understanding of the consequences of mis-classifications;
- statistical study of species-site associations to improve inferences made about the consequences of changing habitat availability along the gravel reach;
- statistical study to determine whether systematic longitudinal gradients of habitat type and fish community exist (following Level One of the classification).

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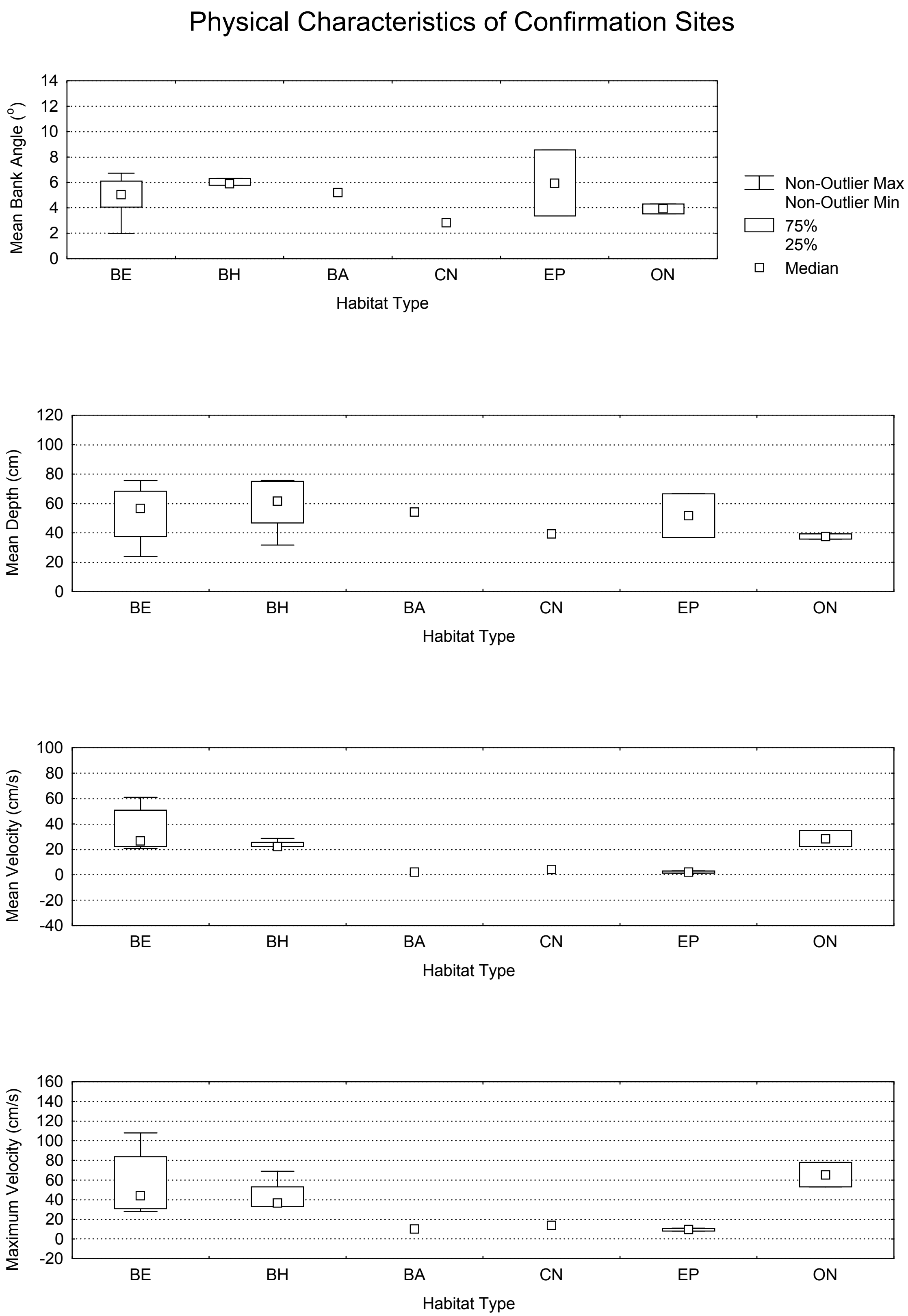
Appendix A. Fish species collected in the gravel reach of Fraser River, July 1999 to September 2001.

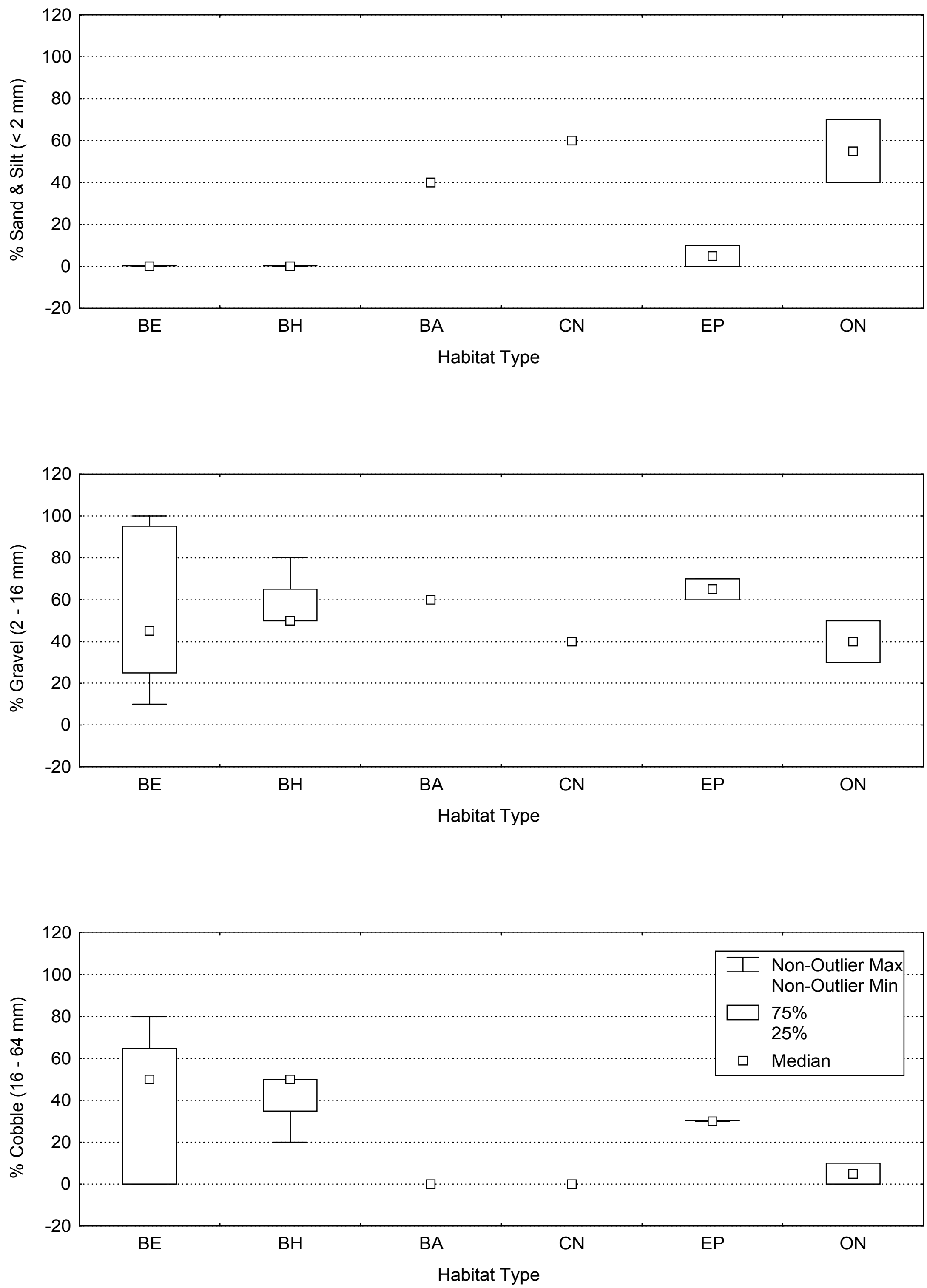
Family	Species	Common Name
Petromyzonidae	*Lampetra species*	Lamprey (unidentified species)
Acipenseridae	*Acipenser transmontanus*	White sturgeon[R]
Salmonidae	*Prosopium williamsoni*	Mountain whitefish
	Salvelinus confluentus	Bull trout[B]
	S. malma	Dolly Varden[B]
	Oncorhynchus clarki	Cutthroat trout[B]
	O. gairdneri	Rainbow trout
	O. gorbuscha	Pink salmon
	O. keta	Chum salmon
	O. kisutch	Coho salmon
	O. nerka	Sockeye salmon
	O. tshawytscha	Chinook salmon
Cyprinidae	*Hybognathus hankinsoni*	Brassy minnow
	Mylocheilus caurinus	Peamouth
	Ptychocheilus oregonensis	Northern pikeminnow
	Rhinichthys cataractae	Longnose dace
	R. falcatus	Leopard dace
	Richardsonius balteatus	Redside shiner
Catostomidae	*Catostomus columbianus*	Bridgelip sucker
	C. macrocheilus	Largescale sucker
	C. platyrhynchus	Mountain sucker[B]
Gasterosteidae	*Gasterosteus aculeatus*	Threespine stickleback
	G. aculeatus trachurus	Marine stickleback
Cottidae	*Cottus aleuticus*	Coastrange sculpin
	C. asper	Prickly sculpin

B: blue-listed
R: red-listed

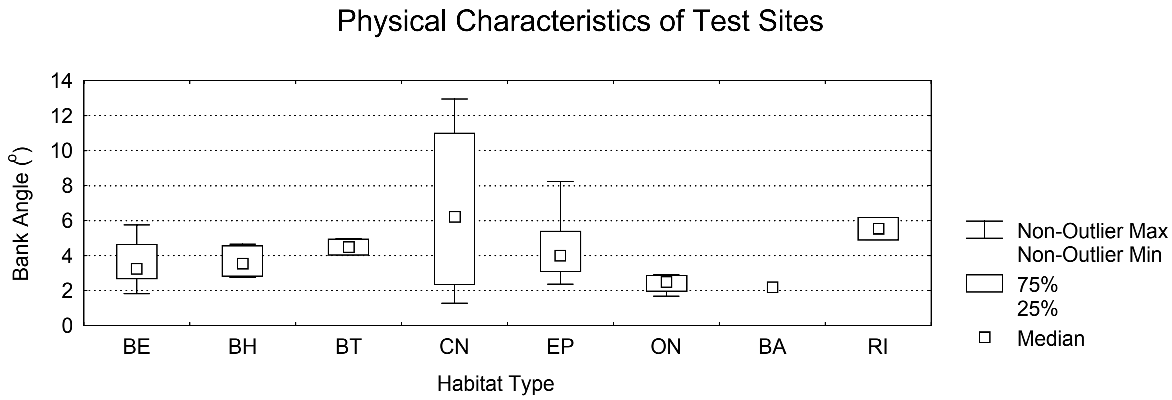
Appendix B. Box and whisker plots for four physical attributes (bank angle, average water depth, average and maximum velocity) and three substrate characteristics (% sand/silt, % gravel, % cobble) measured at confirmation sites (Webster Bar, Gill Island) in August and September 2001.

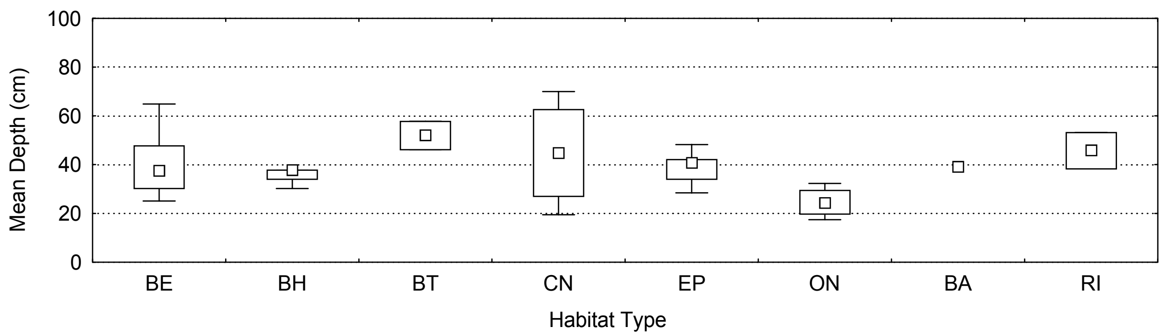

Physical Characteristics of Confirmation Sites
Mean Bank Angle (°)
14
12
10
8
6
4
2
0
BE
BH
BA
CN
EP
ON
Habitat Type
Non-Outlier Max
Non-Outlier Min
75%
25%
Median
Mean Depth (cm)
120
100
80
60
40
20
0
BE
BH
BA
CN
EP
ON
Habitat Type
Mean Velocity (cm/s)
100
80
60
40
20
0
-20
-40
BE
BH
BA
CN
EP
ON
Habitat Type
Maximum Velocity (cm/s)
160
140
120
100
80
60
40
20
0
-20
BE
BH
BA
CN
EP
ON
Habitat Type

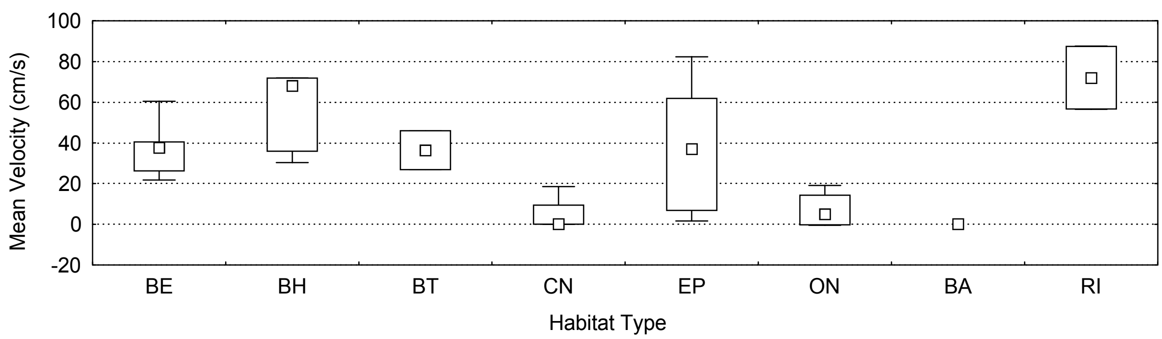
Substrate Characteristics of Confirmation Sites

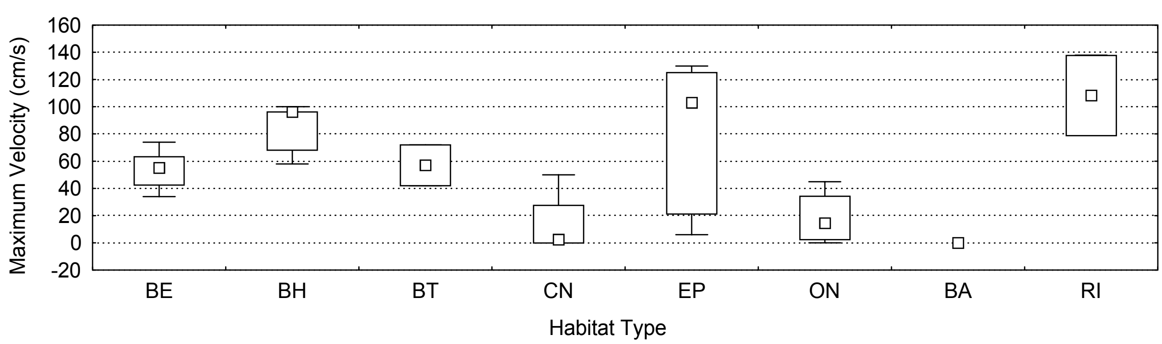


Appendix C. Box and whisker plots for four physical attributes (bank angle, average water depth, average and maximum velocity) and three substrate characteristics (% sand/silt, % gravel, % cobble) measured at test sites (Spring Bar, Seabird Island, Peters Island) in August and September 2001.

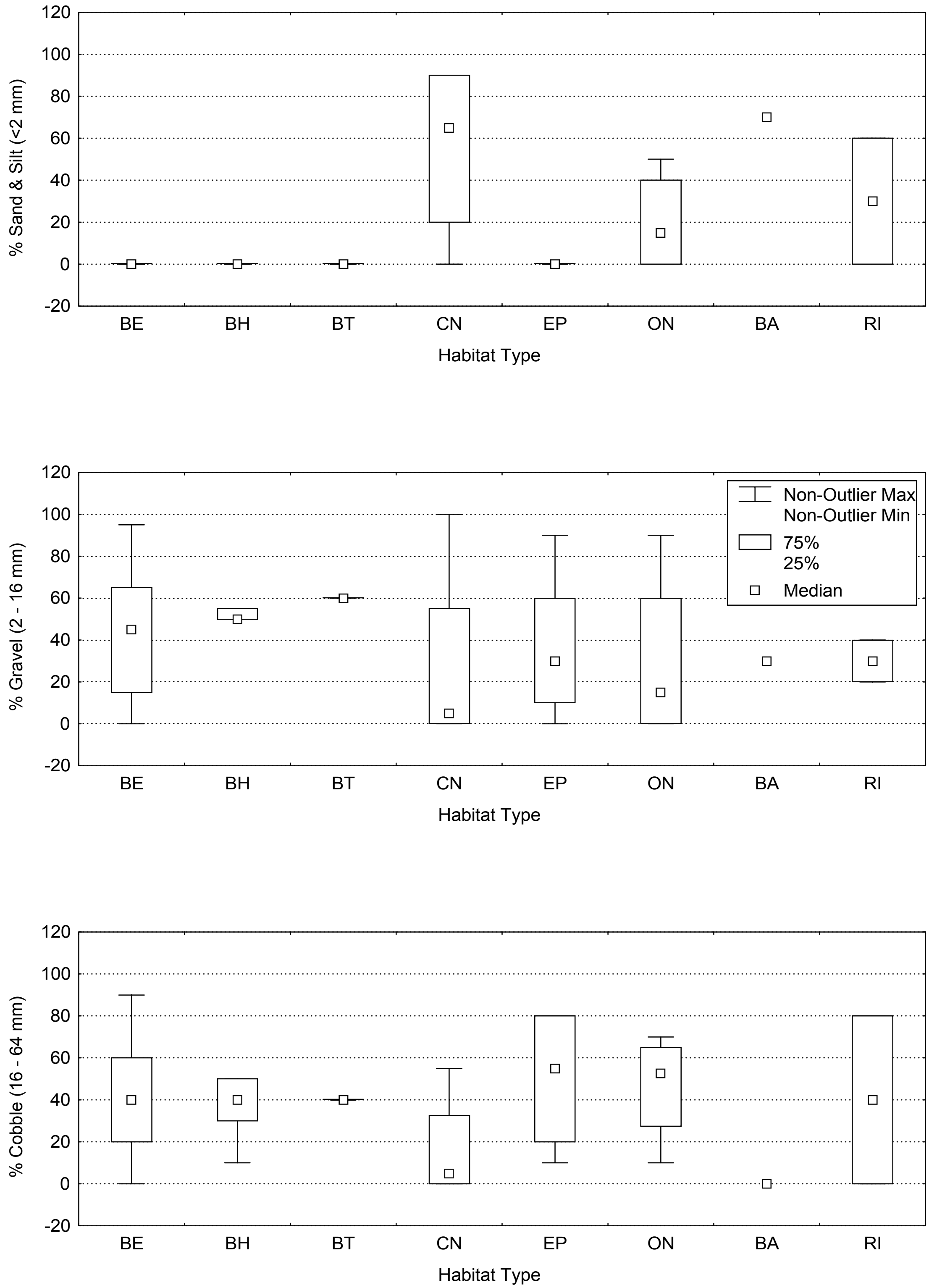

Physical Characteristics of Test Sites
14
12
10
8
6
4
2
0
Bank Angle (°)
BE
BH
BT
CN
EP
ON
BA
RI
Habitat Type
Non-Outlier Max
Non-Outlier Min
75%
25%
Median


100
80
60
40
20
0
Mean Depth (cm)
BE
BH
BT
CN
EP
ON
BA
RI
Habitat Type


100
80
60
40
20
0
-20
Mean Velocity (cm/s)
BE
BH
BT
CN
EP
ON
BA
RI
Habitat Type

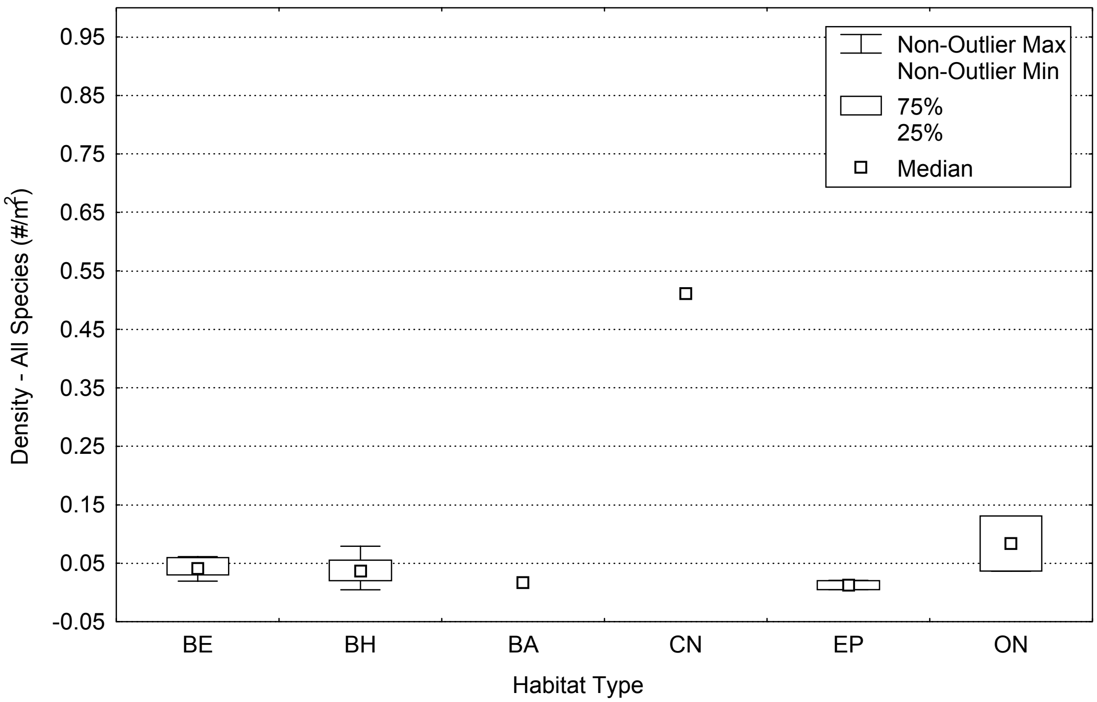

160
140
120
100
80
60
40
20
0
-20
Maximum Velocity (cm/s)
BE
BH
BT
CN
EP
ON
BA
RI
Habitat Type

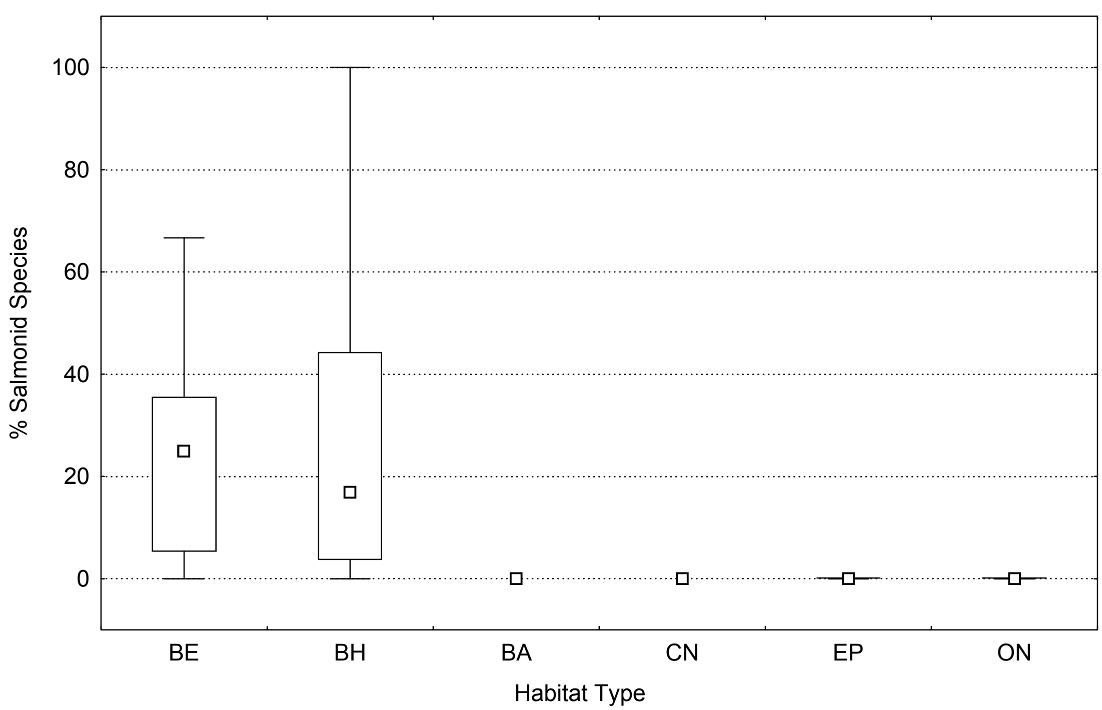
Substrate Characteristics of Test Sites



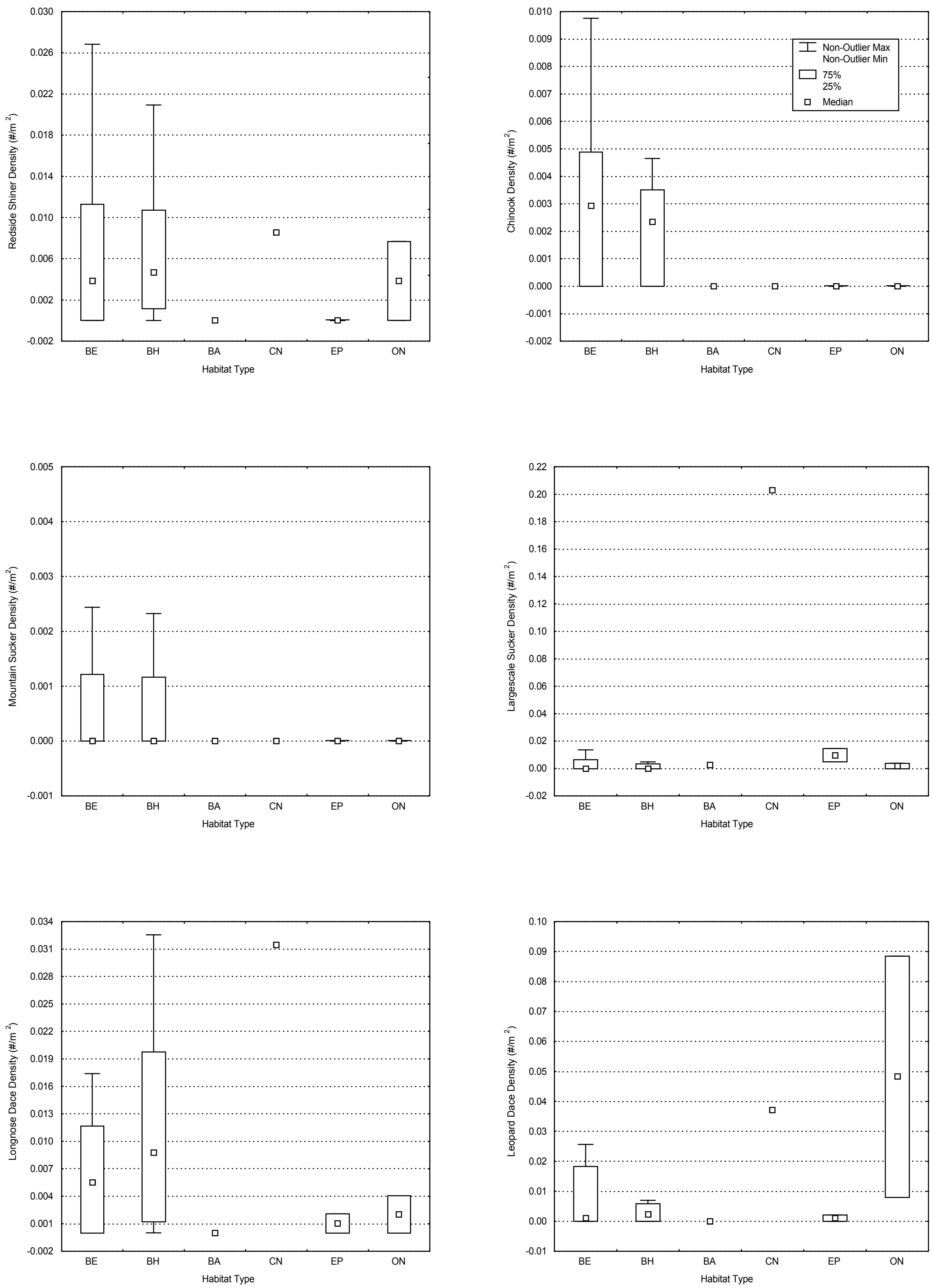
Appendix D. Box and whisker plots for total fish density and the percent salmonid species collected in beach seine sets at confirmation sites (Webster Bar, Gill Island) in August and September 2001.

Total Density and % Salmonids at Confirmation Sites



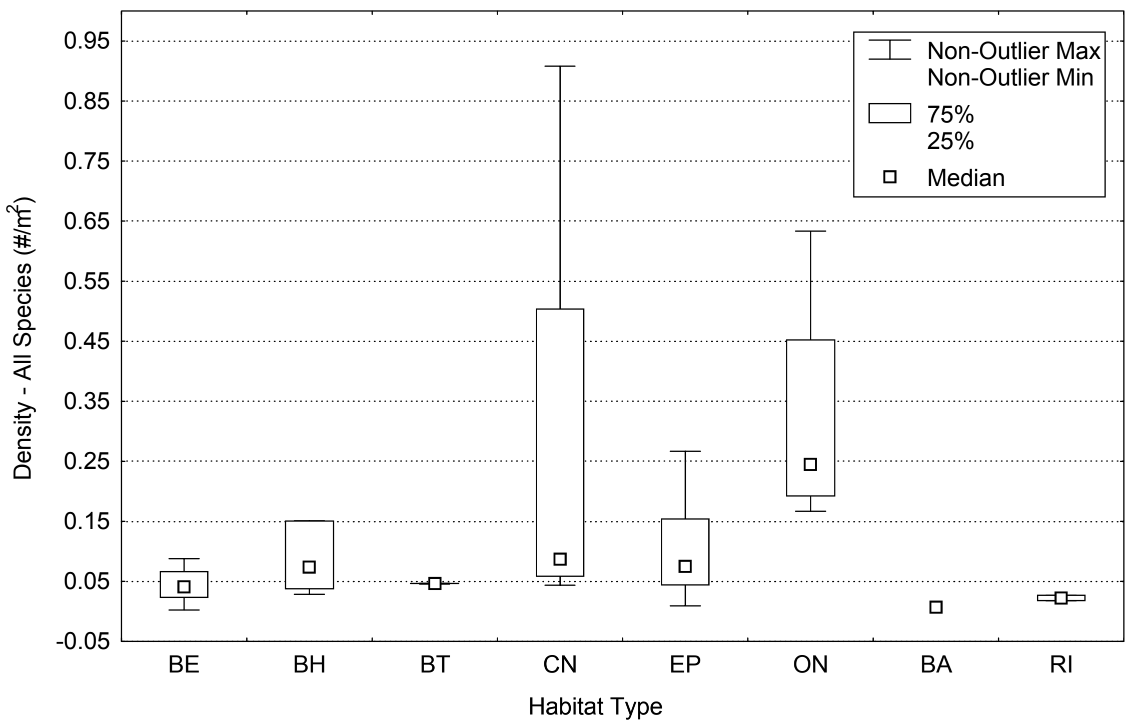


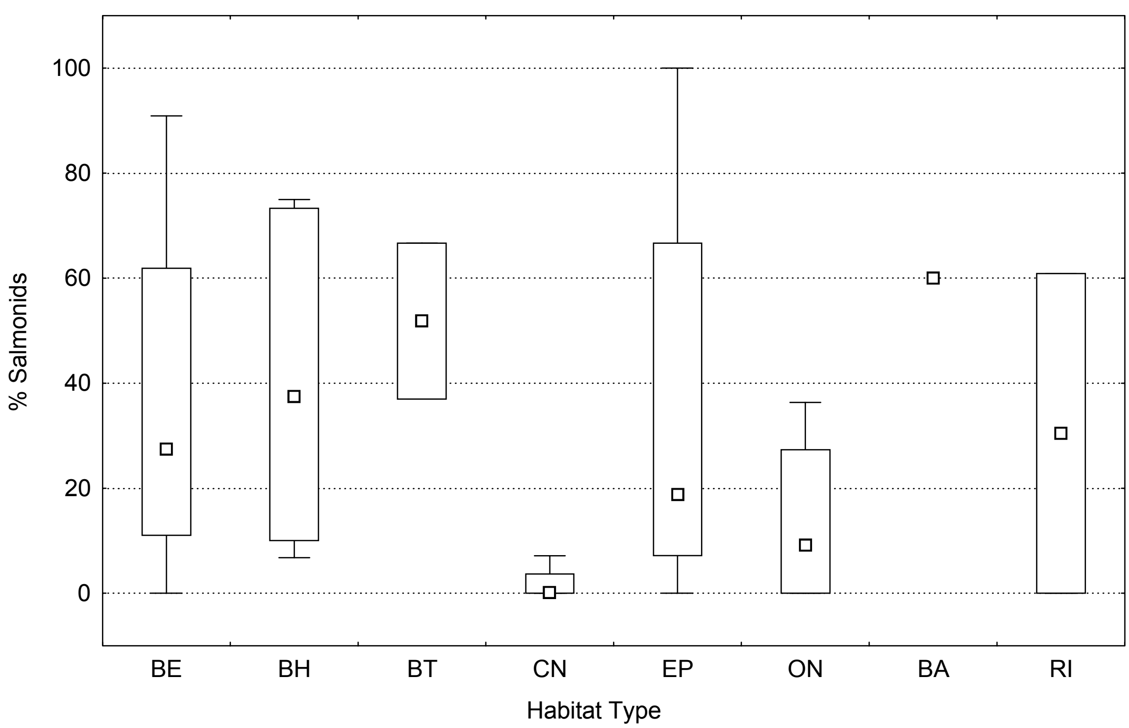
Fish Density By Habitat Type at Confirmation Sites



Appendix E. Box and whisker plots for total fish density and the percent salmonid species collected in beach seine sets at test sites (Spring Bar, Seabird Island, Peters Island) in August and September 2001.

Total Density and % Salmonids at Test Sites





Fish Density by Habitat Type at Test Sites