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Reconstructing the Highwood River's Holocene palaeoecology: Assessment of organic-rich alluvial samples collected following the 2013 flood event

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ABSTRACT

Periodic flood events are normal for rivers. These events sometimes deposit sediments that trap biological remains that can be used to reconstruct the local environment. Following the 2013 flooding of the Highwood River, southwestern Alberta, 24 organic-rich palaeoenvironmental samples were collected from the river's banks at 14 localities. These contained a variety of mollusc and botanical remains (macrofossils). Subsamples were processed and used to reconstruct the palaeoecology of the riparian zone throughout the bulk of the Holocene. Site-by-site variability was noted across the samples, indicating several depositional environments, including flood plains, barforms, backwater channels, and splays. Each environmental setting yielded varying assemblages of terrestrial, emergent and aquatic plants, as well as terrestrial snails and aquatic molluscs. Data synthesis generated a detectable signal of climatic change throughout the Holocene. The general trend shows a progression from drier conditions in the early Holocene towards relatively moist conditions today. This study is the first detailed examination of near-river palaeoenvironmental conditions in southern Alberta.

KEYWORDS

palaeoenvironmental, macrofossil, mollusc, seed, riparian, Highwood River, flood, vegetation, Holocene, Alberta

1. Introduction

Floods ravaged much of southwestern Alberta in 2013, causing considerable damage to riverbanks and infrastructure. Following this flooding, the Archaeological Survey of Alberta directed assessments of the impact on heritage resources along major rivers. As part of this program, a team from Stantec Consulting Ltd. conducted a Historical Resources Impact Assessment (HRIA) along a section of the Highwood River under permit number 14-077, reported in Bohach and Frampton (2015). Through the HRIA, the consultants collected bulk sediment samples containing organic remains. The intent was to use these samples for Holocene palaeoenvironmental reconstruction to provide an ecological context for the archaeological findings. This paper briefly summarizes our work on analyzing these samples and provides preliminary reconstructions of palaeoenvironments near the Highwood River during the Holocene. We had two objectives: 1) to document the macrofossil record from fluvial settings along the Highwood River, and 2) to investigate whether it was possible to detect a meaningful palaeoclimatic signal from such disparate sites. We conducted this research at the Quaternary Environments Laboratory, Royal Alberta Museum.

2. Site locations and inferred flood record

The study area is located along the Highwood River, from the Highwood's confluence with the Bow River and upstream for a linear distance of about 40 kilometres (Figure 1). The most down-stream site's catchment area is almost 4,000 square kilometres; whereas the upstream-most site had a catchment area of about half that. It is reasonable to assume that the watershed characteristics across the area at large are about equal. Because of this, it follows that on average about twice the volume of water flows past the downstream-most point than does the upstream-most site. Moreover, because the watershed has not drastically altered in size or topography since deglaciation, we can assume that this was the case throughout the Holocene.

We assessed river morphology at the sample locations. This included measuring the bank-full width (defined as the width at the break in slope between the river channel and the floodplain) from pre-flood aerial photography and estimated the volume of water (instantaneous discharge) required for the stream to reach bankfull flow at those locations. We also produced a flood return interval curve for the Highwood River based on data from Environment and Climate Change Canada (ECCC)'s Highwood River hydrometric station below the Little Bow Canal (Station 05BL004; Figure 2). This curve was generated with return intervals calculated using the standard formula (Kochel and Baker 1982) and third order polynomial regression.

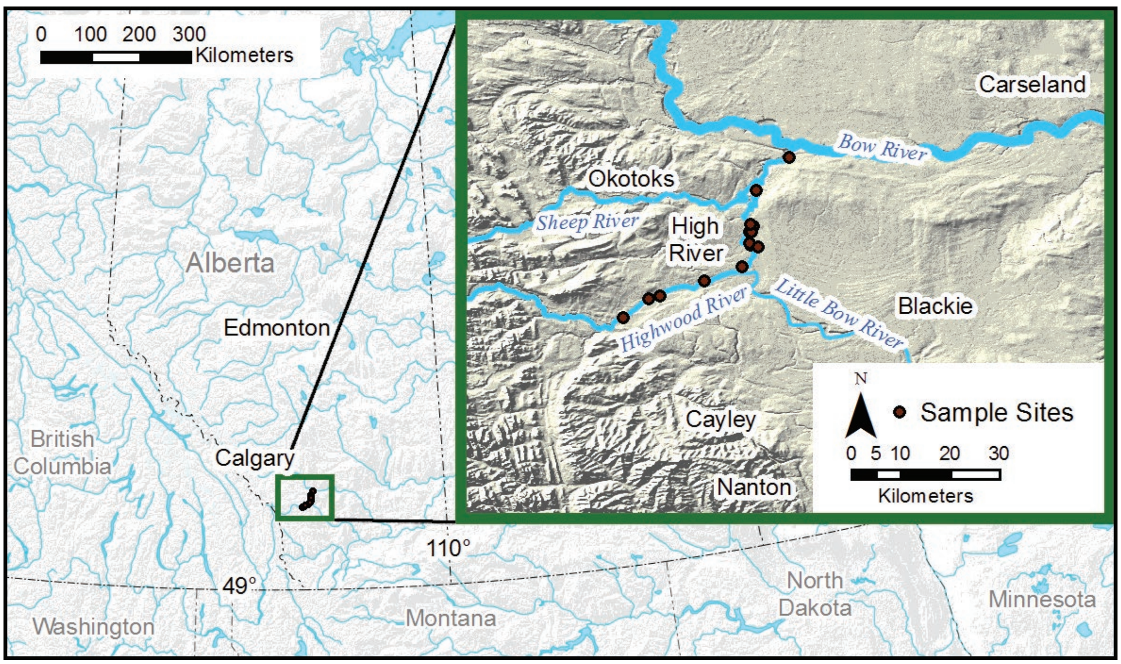

Figure 1. Study location map with notable hydrological and municipality locations labeled.

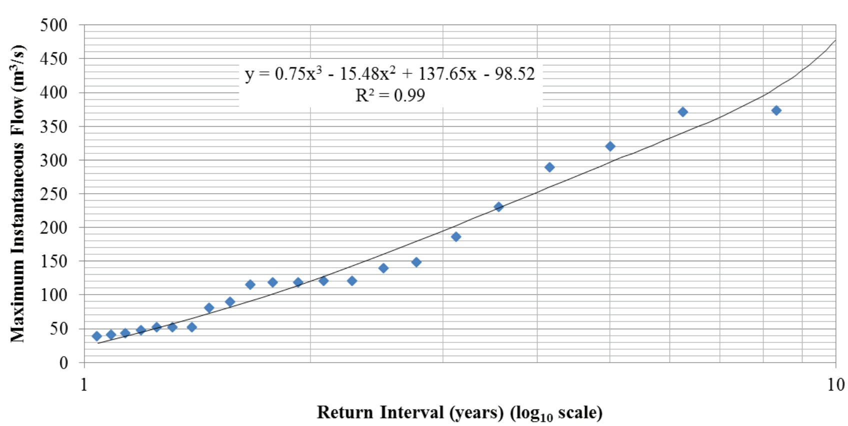

Figure 2. Third order polynomial discharge return interval curve for the Highwood River, below the Little Bow River, for intervals less than ten years. Note: 2013 flood data point not shown. At the Bow River this event was ca. 1:40 year event, well beyond the ten year range shown.

The stretch of the Highwood where this study took place is within the normal range for overbank event return intervals , averaging 1.8 years between all the sample locations (where the typical range is between 1.5 and 2.0 years [Dunne and Leopold 1978; Leopold 1994]).

Hydrology in the Saskatchewan River basin (which includes the Highwood River) has been observed as being nonstationary when analyzed at shorter timescales (e.g., 30 years), but at longer intervals (200 years or longer), hydrological responses appear to be stationary (Razavi et al. 2015). Additionally, the average climate varied only mildly throughout the Holocene to modern (Razavi et al. 2015). Precipitation calculated from global circulation modelling (GCM) for modern, mid-Holocene, and the last glacial maximum indicates that the Highwood basin's average annual precipitation throughout the Holocene was not more than 22 percent less than modern, and for most of this period, was not more than 10 percent less than modern (data from National Center for Atmospheric Research/University Corporation for Atmpspheric Research's Community Climate System Model (CCSM) 4.0 model, downscaled to 5 arc-minutes using WorldClim v.1.4 baseline data). Therefore, we can reasonably extrapolate the modern bank-full event return rate, indicating that overbank events and their associated floodplain deposits probably occurred, on average, at least once per year in about 55 percent of years in the Holocene.

3. Methods

3.1. Field collection and pre-processing

Palaeontologists Lisa Bohach and Emily Frampton of Stantec Consulting Ltd. conducted the field collection in October 2014. They found each locality either by foot traverse or by boat (detailed field methods are available in Bohach and Frampton 2015). The sampled layers were of two mains types: shellbeds (with aquatic/terrestrial molluscs) and vegetation mats (containing preserved plant macrofossils, such as seeds, twigs, moss, and foliage). In total, 24 samples were collected from 14 localities along the Highwood. All bulk samples, each weighing at least one kilogram, and surface-collected mollusc specimens were transported to Stantec's laboratory where they gradually dried. Mollusc specimens and bulk samples were then transferred to the Royal Alberta Museum for further processing and analysis. Age estimations were formulated using relative stratigraphic position and geomorphic relationships.

3.2. Sample processing

We conducted all further processing of the palaeoenvironmental samples at the Royal Alberta Museum's Quaternary Environments Laboratory from November 2015 to January 2016. We processed the samples according to standard palaeoenvironmental procedures, using essentially the same method described by Beaudoin (2007), with only slight modifications to suit this study's clay and organic-rich samples.

We processed 100 millilitres (measured by displacement) of each sample, first allowing the material to soak in tap water at ca. 3 degrees Celsius until most clasts were dispersed, then we wet-screened the material through a sieve stack. We conducted this fractionation in order to consolidate the macroremains while removing the majority of fines (particles less than 90 μm), facilitating the sorting of macrofossils. The complete wet-screening methodology is detailed in the final report to the Archaeological Survey of Alberta Culture and Tourism (Bolton 2016).

3.3. Sorting and identification

We sorted the contents of each fraction under a dissecting microscope at 7.5 to 112.5-times magnification with an auxiliary "cool light" illuminator. Each sample was systematically scanned and all macroremains removed with fine forceps. Recovered macroremains included mollusc shells, seeds, fruits, achenes, conifer needles, identifiable leaves, twigs and their parts. Sizable or clearly identifiable insect remains, coarse (> 3.35 mm) wood and charcoal , and other unique specimens were also separated.

Relative abundance was noted for very numerous and miscellaneous macroremains (e.g., ostracod valves, bryophytes, mollusc and leaf fragments, insect parts, fungal sclerotia, rootlets) as well as inorganic elements (e.g., sediment clasts, rocks and mineral matter, concretions). We removed and vialled mollusc shell fragments and moss fragments separately. Remaining residue was air-dried for storage.

We estimated the relative abundance of the residue material found in each fraction of the samples using a four-class system. The classes applied were "abundant", "common", "frequent", and "rare". After sorting an entire fraction and completion of residue analysis, the sorted materials were identified, counted, and vialled for storage.

3.4. Identification

Each sorted entity was identified to the lowest possible taxonomic level, using a variety of published sources (Table 1), especially Montgomery (1977), Clarke (1981) and

Table 1. Major references consulted for identifications of macroremains in this study.

Macroremains Identified	Source Title	Author and Year
Plant remains (seeds, leaves; vascular plants)	Flora of Alberta	Moss 1983
Plant remains (seeds, leaves, stems; vascular plants and bryophytes)	Flora of North America	Flora of North America Editorial Committee 1993+
Seeds	Seeds and Fruits of Plants of Eastern Canada and Northeastern United States	Montgomery 1977
Tree remains (seeds, leaves, twigs, flower/cone parts)	Trees in Canada	Farrar 1995
Aquatic molluscs	The Freshwater Molluscs of Canada	Clarke 1981
Terrestrial molluscs	Land Snails of British Columbia	Forsyth 2004
Terrestrial molluscs	How to Know the Eastern Land Snails	Burch 1962
Terrestrial molluscs	Land Snails and Slugs of the Mid-Atlantic and Northeastern United States	Hotopp et al. 2013
Terrestrial molluscs	A Guide to the Land Snails and Slugs of Montana	Hendricks 2012

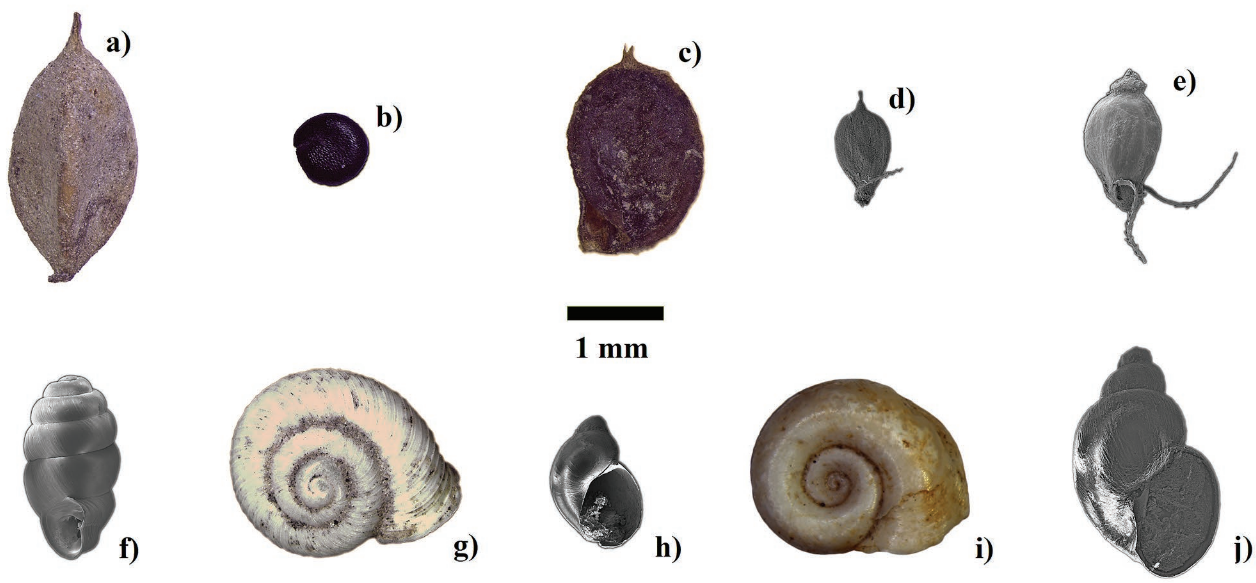

Figure 3. Microphotographs of major macrofossil taxa: a) *Carex* sp. (LM); b) *Chenopodium* sp. (LM); c) *Corispermum* sp. (LM); d) *Scirpus* sp. (SEM); e) *Eleocharis* sp. (SEM); f) *Vertigo* sp. (SEM); g) *Vallonia* sp. (LM); h) *Succineidae* sp. (SEM); i) *Gyraulus* sp. (LM); j) *Fossaria* sp. (SEM).

Forsyth (2004). Whenever possible, identifications were supported by consultation with the Seed and Macrofossil Reference Collections of the Royal Alberta Museum. Dr. Richard Caners (Alberta Biodiversity Monitoring Institute) assisted with identification of the moss taxa. We recorded the numbers in each distinct taxonomic entity in each fraction, before vialling for permanent storage. Figure 3 presents light microscope (LM) and scanning electron microscope (SEM) images of select taxa. These taxa are generally representative of the faunal and floral diversity observed across the samples and proved to be suitable indicators of palaeoclimate.

4. Results

The following summary highlights the main features of four representative samples from the 24-sample set.

4.1. Late Pleistocene to early Holocene (locality L47)

As well as being potentially the oldest of the sampled sites, this sample is set apart from all others because it contained molluscs assigned to the group *Promenetus umbilicatellus*/ *Gyraulus parvus*. *P. umbilicatellus* has specific habitat requirements, occurring only in intermittent wet areas, such as vernal pools, marshes, and the flooded margins of intermittent streams (Clarke 1981:190). However, *G. parvus* can live in both permanent and temporarily wet areas. Despite differences in preferred habitat hydrological regime, both species live in dense aquatic vegetation.

The presence of organic residues supports the notion that this site was occupied by dense vegetation. About 30 percent of all residue material from this site was vegetative debris. Though the sample contained no plant seeds or fruits, we consider that the site was directly occupied by abundant vegetation, or was a trap for fluvially transported vegetation and the molluscs that lived in association with it.

Additionally, the presence of juvenile and adult *Fossaria* (another aquatic snail) indicates that the site was located within flooding distance from a perennially wet feature such as the Highwood River, a tributary, or an oxbow lake. Aside from *F. parva*, an amphibious species, *Fossaria* are chiefly aquatic, rarely venturing further than the moist banks and shorelines which surround their aquatic habitats. The occurrence of wetland habitat-preferring land snails, juvenile and adult Succineids, also supports the near-water location of this site.

Finally, since the sedimentary context is chiefly clay, with evidence of short intervals of soil development in the adjacent profile, it follows that this layer was deposited as one of several overbank flood events. It is likely that a stronger-than-normal meltwater freshet, potentially combined with a rainfall event, dislodged aquatic molluscs from their normal habitats and carried them to the fringe of floodwaters where they were deposited along with land snails (e.g., juvenile *Euconulus fulvus*). These snails were probably carried down-slope (descending the river corridor or transported overland) by the same event. The marked shell damage we observed on the mollusc remains indicates the magnitude of the flood's hydraulic energy. Broken shells were the only elements more abundant than vegetative debris in this sample.

4.2. Early to mid-Holocene (locality L20)

Represented by two distinct fossiliferous strata, L20 illustrates the capacity for marked change within a small area, and during a presumed relatively small time span. It included indicators of both a mesic dry-land site dominated by land snails and a moist littoral or riparian wetland. The particular samples from the L20 locality included a shell-rich vegetation mat, and sediment collected from around a piece of buried wood. Both samples were collected from below a tephra layer (probably the Mazama Tephra of age ~7700 cal yr BP; Egan et al. 2015).

Aside from vegetative debris, the vegetation mat contained evidence of a diverse assemblage of land snails, mostly of flattened heliciform varieties, including *Discus* sp. We also found Succineids and *Vertigo modesta*, a pupilliform land snail at this site. All these snails are common in leaf-litter of hardwood and mixedwood forests. The presence of Succineidae points to nearby wet habitats. The evidence suggests that this specific site was located on a low-lying terrace that, though somewhat removed from the water table, was still inundated by river waters during peak-flow events.

The sample associated with the wood included a variety of wet area indicators, including the preserved seeds and fruits of members of the sedge family, Cyperaceae, including *Carex*. *Chenopodium* seeds, and the fruits of pondweeds, *Potamogeton*, were also encountered. Of these three genera, *Chenopodium* (goosefoot) is probably the most tolerant of fluctuating hydrologic conditions. Goosefoots are characteristic of disturbed environments, growing in a wide range of dry to moist environments, from open to wooded areas (Moss 1983 : 240-244). Accordingly, plants of this genus are well suited to colonize disturbed and periodically flooded riparian areas. *Carex* species grow in similarly diverse habitats, ranging from dry uplands to bogs and marshes, but most species prefer moist sites (Moss 1983: 120-156). *Potamogeton* species, on the other hand, are strictly aquatic plants that normally grow in the littoral zone of waterbodies (Moss 1983: 53-58). In this context, they indicate a backwater environment, such as a flooded meander scar or abandoned channel. Because of the hydrophilic characteristics of the vegetation noted at this site, it was likely located relatively close to the river when the layer was deposited.

Although we do not know the precise temporal relationship between the two samples from L20, what is clear is that within a small area there is capacity for marked environmental variability based on hydrological site conditions. Here, one sample showed the signs of a relatively dry, wooded site, while the other preserved evidence of the nearby river and associated riparian zone. Despite the difference in local hydrology, subsequent flood events inundated both layers, eventually burying them in alluvium.

4.3. Late Holocene (locality L8)

The L8 locality contained a variety of macroremains that suggested the presence of a nearby wooded riparian area as well as at least local periodic disturbances. We found the land snail, cf. *Punctum minutissimum*, known for preferring alkaline forest floors (Hotopp et al. 2013), in this sample. We also detected the land snails *Discus whitneyi* and *Vallonia gracilicosta*, signifying that the surrounding environment was probably rich with leaf-litter. Also in this sample were seeds of multiple *Chenopodium* species, strawberry (*Fragaria vesca*), and a variety of wetland sedge species (e.g., *Eleocharis palustris*, *Trichophorum* cf. *clintonii*, and *Trichophorum* cf. *pumilum*). Although these macroremains could have been transported from other localities before and/or during flooding, they show that nearby sites offered requisite habitat characteristics for a diversity of plant life, including moist riparian shrub-lands and woods, as well as more open meadows and forest glades. Evidence of aquatic taxa, probably washed directly from the Highwood River, included the shells of aquatic snails (*Gyraulus parvus* / *circumstriatus*) and pea clams (*Pisidium* sp.), as well as the preserved oogonia of charophytes (macrophytic green algae).

Evidence from this sample's assemblage suggests that the landform at the time of deposition was a portion of the active floodplain near the river. A sandy layer, this deposit may be a preserved sand bar. However, based on its stratigraphic, biological and sedimentary contexts, we postulate that it was a splay that occurred just beyond the channel corridor. The sediment was clearly deposited in a riparian terrestrial environment which showed no sign of consistent near-water table rooting (i.e., we found no root channel redox concentrations, which were common at other localities).

We favour the splay mode of deposition, because it is a typical result of upstream channel avulsion , and can explain the thick (ca. 35 cm) sand deposit as well as the presence of chiefly terrestrial taxa, with select aquatic taxa also preserved. Because the underlying sediment is chiefly sand, yet the vast majority of mineral matter in the sample was finer than 90 micrometres, deposition probably occurred immediately following the splay, as the finer sediments and light and floating debris settled and the water receded. We suggest that minor depressions also formed following the dramatic sedimentation event, where, as water retreated, fluvially and overland-transported remains accumulated in the lens comprising this sample. This type of debris concentration occurred at several other localities as well.

	Fossaria	Gyraulus parvus / cirumstriatus	Eleocharis	Carex	Scirpus	Chenopodium	Corispermum	Succineidae	Discus and Vallonia	Vertigo
Late Holocene	9%	78%	33%	100%	100%	100%	100%	39%	40%	0%
Late Holocene (veg mat)	100%	100%	100%	100%	100%	100%	100%	75%	100%	33%
Mid-to late Holocene	100%	10%	100%	0%	0%	30%	0%	100%	34%	100%
Mid-Holocene	22%	100%	0%	0%	0%	0%	0%	7%	0%	0%
Early to mid-Holocene	81%	0%	0%	0%	0%	0%	0%	81%	100%	26%
Early to mid-Holocene (veg mat)	0%	0%	0%	9%	0%	19%	0%	100%	0%	100%
Late Pleistocene to early Holocene	56%	0%	0%	0%	0%	0%	0%	59%	0%	0%

Figure 4. "Percent of most" of indicator taxa, arranged by habitat preference from wettest (L) to driest (R). Deposit type: shellbeds = blue, vegetation mats = yellow; 100% = most of a taxon from a deposit type was in that age class.

5. Synthesis and analysis

To assess the relative changes of the landscape over time and space, we used key taxa as indicators of ecological status as a whole. We relativized the average of counts from all samples of these indicator taxa within each age group and site type (vegetation mat or shellbed) by computing the percent of the maximum average for each taxon (Figure 4). By analyzing the data this way, we ensured that each taxon, age class, and site type got its own scale while total results were still comparable (zero to 100 percent of the maximum in that class). The indicator taxa included the sums of the following molluscs: *Fossaria*, *Gyraulus*, *Succineidae*, *Discus* and *Vallonia*, and *Vertigo* spp. (including adults and juveniles). Likewise, we used the sum of plant remains of *Eleocharis*, *Carex*, *Scirpus* (also counting those taxa previously assigned to *Scirpus*, including *Schoenoplectus* and *Trichophorum* spp.), *Chenopodium*, and *Corispermum* seeds/achenes to summarize the flora.

Because *Fossaria* snails occur in the very earliest-classed sample (L47), their obligate habitat characteristics must also be present at this time. This means that ponds, pools, or other environments with permanent or temporary water and the associated submersed aquatic vegetation were necessarily present during late Pleistocene to early Holocene times at the site of deposition or somewhere up-slope (terrestrially located or a site upstream), presumably nearby.

By the mid-Holocene, densely vegetated vernal pools, which are some of the best habitat for *Gyraulus*, formed in the near-river floodplains adjacent to the Highwood River. These pools could have arisen in the depressions following uprooting of vegetation, in abandoned channel sections, old chutes, as well as in surface flow-controlled hollows. Accordingly, depressional deposits were found at five sites from the mid-Holocene or later. Other sites may have resulted from similar processes, although their stratigraphy alone is not sufficient evidence.

However, the early Holocene environments near the Highwood River also appear to have possessed somewhat more open characteristics than later intervals, including potentially disturbed sites (i.e., with less dense canopy cover), demonstrated by *Chenopodium* occurrence. Additionally, various terrestrial snails, including *Vertigo* spp. and *Succineidae*, occurred during this interval with a relatively high density at several sites.

Mid-to late and late Holocene sites showed an increase in forest-dwelling land snails (e.g., *Discus* and *Vallonia* spp.) and riparian plants (e.g., *Scirpus*, *Carex*, and *Eleocharis* spp.). This is suggestive of the onset of overall moister conditions, particularly those that were suitable for the colonization of mixed-wood and coniferous dominant forests throughout much of the river valley. Spruce (*Picea* sp.) needle occurrence also increased during this time, further supporting this interpretation.

The occurrence of sandy disturbed site-specific taxa, including bugseed (*Corispermum* sp.), and a site interpreted as a splay from late Holocene samples indicates that the fluvial geomorphology of the Highwood River was not entirely quiescent. We believe that sometime during the late Holocene at least one sizable avulsion event occurred, perhaps following flooding conditions similar to those in 2013. In turn, this mobilized a great deal of sediment, reworked some barforms and banks, and created new habitats for colonizer species to invade (e.g., *Chenopodium* and *Corispermum* spp.).

Overall, despite variability in depositional environments, the consistent image of the Highwood River's riparian area throughout the Holocene is one of constant dynamism. Following the recession of ice sheets in the area, the landscape was ready for an influx of terrestrial colonizers as well as select riverine and wet-area-specific taxa. As the landscape, river's geomorphology, and the communities that resided along the valley adjusted to the new conditions, a continual adaptation in response to climatic changes occurred. The ranges of near-river organisms changed as a result of increasingly moist and relatively stable conditions. Vegetation communities matured to the conifer-mixed-wood forest amidst grass and parkland habitats we see today.

Despite site-specific succession and other variability, we note that none of the taxa identified in this study are from habitats very different from those found in the region today. There is no evidence of wholesale vegetation change or range extensions of specific taxa. All taxa found here are consistent with present environmental conditions and are found at similar present-day sites in southern Alberta.

6. Conclusion

The samples collected from the banks of the Highwood River following the 2013 floods revealed an array of important palaeoecological data. Each locality relayed a unique depositional history and abiotic image of the landscape. More importantly, we were able to detect a meaningful ecological signal, reflecting a climate signal over time. The general trend was from dry-area tolerant species to increasingly moist-preferring taxa, until the assemblages became very similar to those of the present landscape.

Much future work remains to unify the dynamic ecology and geomorphology of fluvial sites to create a comprehensive palaeoenvironmental interpretation through both space and time. Continuing research, particularly at other fluvial sites, will contribute to the growing knowledge of microsite and landscape dynamics that have worked to shape the ecology and physical characteristics of the river valleys of southern Alberta throughout the last 12,000 years.

7. Acknowledgments

We thank Alberta Culture and Tourism and the Archaeological Survey for providing the funding necessary to complete this project. Thanks also to Dr. Richard Caners for identification of moss fragments and Dr. Lisa Bohach and Emily Frampton from Stantec Consulting Ltd. for conducting the field component of this project and providing insight into the field methods.

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