Examination of nontraditional materials for microvertebrate fossil screenwashing

BROOKE K. HAIAR

The Cifelli Lab at the University of Oklahoma, USA, both championed and systematized the use of nested screenboxes for sediment processing in the effort to isolate microvertebrate fossil remains. These particular methods have become the standard of the industry and are capable of winnowing thousands of kilograms of matrix down to quantities that can be reasonably picked through by hand. Other methods for screenwashing using non-traditional materials have been suggested, including nylon mesh bags and paint sieves. In this brief report, the efficacy of both of those newer materials is systemically analyzed and the pros and cons of all three methods are discussed.

The collection and underwater washing (henceforth referred to as screenwashing) of fossil-bearing matrix has long been a practice used in vertebrate paleontology to recover the smaller remains of larger organisms, or the remains of smaller organisms which are often overlooked in quarry work due to their size (Blob and Badgley 2008; Foster and Heckert 2011). Hibbard (1949) championed the idea of deeper investigation of rock matrix for the presence of microvertebrates. He described the screenwashing methods of the time, specifically for unconsolidated Cenozoic-aged material, using both wet and dry methods. McKenna (1962) described the construction of wooden boxes with window screen bottoms, designed for washing matrix in a field setting which was a predecessor to the process described by Cifelli et al. (1996). Rixon (1976) went into great detail on how to separate matrix using stacked sieves and a flowing water source. A sifting machine was created by Ward (1981) which created a more systematic approach to sieving for microvertebrates, but involved a bulky and costly setup. The Cifelli Lab at the University of Oklahoma, USA, pioneered the systematic use of nested screenwashing boxes and the mass processing of large quantities of matrix to recover the often-overlooked smaller fossil components of previously well-sampled vertebrate localities, specifically in consolidated materials. Cifelli et al. (1996) provided the paleontology community with explicit instructions on how to make nested screenwashing boxes that produced two size-classes of matrix, once reduced, as well as the process for an initial wash with water, and secondary washes with kerosene or heavy liquid (e.g., zinc bromide) separation. Wilborn (2009), a Cifelli Lab graduate, furthered this study by systematically analyzing the use of hydrogen peroxide as a secondary wash fluid, which proved to be a safe and more cost-effective way of reducing matrix, especially those matrices composed of swelling clays. Hydrogen peroxide also proved to reduce matrix as efficiently as, or more efficiently than, kerosene in almost all cases.

The traditional screenwashing process is spelled out in detail in Cifelli et al. (1996), but a review is provided below. Two wooden boxes are constructed, one with an 18 mesh (standard window screen, with 1 mm openings) and another with 30 mesh (0.6 mm openings). The coarse mesh and fine mesh boxes are nested inside of each other. Matrix is added to the interior-most box and the set is soaked in water overnight. Large metal or plastic tanks (often on the order of 150 gallon/600 liter, and typically referred to as stock or cattle tanks) are used to hold upwards of 16 screenboxes at a time for soaking. After soaking overnight, the boxes are gently agitated to disaggregate the soaked matrix and allow non-fossiliferous particles to pass through the mesh. The agitation consists of shaking the boxes laterally, while underwater, to move the matrix over the screens. The screenboxes are then separated and laid out to dry, preferably on an elevated surface to permit air flow-through (such as propped against dimensional lumber) and/or on sheet metal to increase the solar reflectivity and speed drying. Since Cifelli et al. (1996) there have been variations in sizes of boxes and coarseness of mesh used in different labs, but the general setup remains the same (Miller 1989; Heckert 2004; Bhat 2017).

One of the more challenging aspects of this traditional screenwashing process is having the space available to wash and dry the screenboxes. Both the washing in the cattle tanks and the drying of the separated boxes have a large footprint. There are often thousands of pounds/kilograms of matrix that need to be screenwashed in order to sufficiently sample a locality. The space needed for a setup to wash any large quantity of matrix is prohibitive at many smaller institutions. Another drawback to this method is that the cost of making the screenboxes themselves can be quite high relative to the budget of some institutions. More recent forays into screenwashing techniques have posited using different materials to contain the matrix to be washed, such as commercially available paint sieves (Avrahami et al. 2015) and kitchen sieves (Araujo et al. 2011). Another often discussed, but not systematically examined, containment method is the use of nylon sacks created from nylon mesh (Grady 1979). This paper discusses smaller-scale alternatives to the traditional screenbox washing technique uti-
lizing 5-gallon/20-liter buckets for soaking, a comparison of
paint sieves and nylon mesh bags for screening of material, and
the use of a fume hood for drying. The aim here is not to di-
rectly compare these methods to traditional screenwashing but
to evaluate their overall efficacy in reducing matrix. I also dis-
cuss their merits and drawbacks as viable alternatives for bulk
processing and microvertebrate recovery at smaller institutions
with space or budget constraints, and for use in the field.

Material and methods

Traditional screenwashing.—Traditional screenboxes consist
of two boxes nested together. There is a smaller box with a
coarse mesh, which fits inside a larger box with a finer mesh.
Variations in sizes of boxes exist and are dependent on the user.
Cifelli et al. (1996) reports constructing boxes of dimensions
14″ × 12.5″ (36 cm × 31.8 cm) in size, with a depth of 7.12″ (18
cm) for the larger box. The smaller box is 12″ × 10.5″ (30 cm
× 26.7 cm), with a depth of 7.12″ (18 cm). A large metal tank,
typically referred to as a cattle tank, is suggested as a way to
wash up to 16 screenboxes at a time (Cifelli et al. 1996). A tank
of this size is difficult to house indoors and is typically placed
outside. Access to water and the ability to drain the sediment
from the cattle tanks is necessary, and both must be imme-
diately adjacent to the tank location. In the field this can be
accomplished with a nearby river or stream, when available, as
long as safety precautions are made for sudden changes in dis-
charge rate. A pump system can also be used to fill and empty
tanks adjacent to nearby water sources. Screenwashing of this
type done in an indoor lab setting requires the space for the
cattle tanks, a water source, and a place for periodic disposal
of the sediment that settles in the bottom of the cattle tanks.
There also needs to be a separate space available for drying the
separated screenboxes. To remove the reduced matrix from the
nested screenboxes, typically a large piece of fabric is laid out
and the boxes are emptied onto it. The boxes are then struck
to make sure any material stuck in the mesh is removed. This
is repeated for each screen size. Care is needed before using
the boxes for a different collection locality as some material
can become stick in the mesh; the mesh needs to be carefully
brushed to prevent any accidental contamination.

Paint sieves.—Paint sieves (or paint strainers) are readily avail-
able materials from any paint or hardware store. These bags
are made of nylon and come in 5-gallon (20-liter) bucket sizes. A
quick search at an online store shows them to be about 1 US
dollar apiece, so they are cheap and disposable. The standard
mesh size of the paint sieves results in one size component of
the reduced matrix, with a hole approximately 0.16 mm in
diameter (Avrahami et al. 2015), which is equivalent to 100
mesh size. After filling with matrix, the bags can be cinched
closed with twine or nylon rope, then submerged in water and
soaked overnight. Once soaked, the material needs to be agi-
tated. This is done by lifting the bag in and out of the water for
approximately a minute, then breaking up any mud layers on
the bottom of the bag by gently pushing against the bottom of
the bag by hand, and finally a repeat of lifting in and out of the
water for another minute. Reduction is complete when the bag
appears to no lose any more appreciable mass. Removal of the
material from the paint sieves is much simpler than for screen-
boxes as there is only one size component to consider. The
dried material can simply be poured into a container. Material
can become stuck in the mesh, and gentle brushing of the out-
side of the sieve with fingers can remove most visible material.
Since the paint sieves are disposable there is no need to clean
them to prevent cross-contamination between localities.

Nylon mesh bags.—Rolls of nylon fabric are available from a
variety of netting suppliers online and potentially locally, as
well. Most stores have a variety of mesh sizes. For this exper-
iment an attempt was made to replicate the screenbox sizes of
30 and 18 mesh. The 18 mesh results in a hole 1 mm in diam-
eter; the 30 mesh is 0.6 mm. Netting in 1 mm and 0.5 mm sizes
was purchased, which resulted in slightly smaller mesh open-
ings than the original 30 of the screenboxes. The 1 mm fabric
was cut into 30″ (75 cm) diameter circles, and the 30 mesh/0.5
mm was cut into 36″ (90 cm) diameter circles. The resultant
materials were laid out on top of one another (coarser mesh
fabric on top) and a standard amount of weighed matrix was
added. Both circles were then cinched closed with nylon rope
and soaked overnight. The agitation method was the same as
that for the paint sieves with the exception that the inner-most
bag was the one with mud buildup that needed to be broken up.
The nested nylon bags produced two sizes of material which
were kept separate in order to speed picking. Once dried, the
bags were untied and the inner bag was lifted out. The inner
bag was gently shaken to remove any material from sticking to
the bottom of it. One edge of the bag was then released from
the gathered nylon and put into the receiving container. The
consolidated material was then poured in. The process was
repeated for the outer bag. As with the paint sieves, material
could become stick and gentle brushing of the outside of the
bag with fingers removed the material.

Both the paint sieves and the nylon mesh bags were soaked
in 5-gallon (20-liter) buckets. The space available for this proj-
ect allowed for nine buckets to be used at a time. The nylon
rope used to cinch the bags shut was looped around a wooden
brace in order to suspend the bags and prevent contact with
sediment at the bottom of the bucket (Fig. 1). After soaking,
the bags were agitated gently (described above). The bags were
then placed on an elevated dish drying rack in a fume hood
for drying. This particular hood was not connected to a ven-
tilation system as venting of the air is not required, only the
flow-through circulation to dry the matrix. This allowed the
reduced matrix to be dried in no more than 8 hours. For this
experiment, the reduced matrix was weighed for both the paint
sieves and the nylon bags in order to determine percent mass
reduction. The nylon bags resulted in two size fractions of
washed concentrate. The end masses of the fine and coarse
fractions were weighed separately, added together, then sub-
tracted from the original mass.

Matrix material.—The matrix used for this experiment was
from the Morrison Formation, an Upper Jurassic terrestrial
deposit. It was collected from the Two Sisters 2 Quarry, a vertebrate locality in northern Wyoming, USA, excavated by the Virginia Museum of Natural History (Martinsville, USA) and the University of Lynchburg (Lynchburg, USA) (Wilborn 2006; Haiar and Porter 2016). This particular quarry is located in the lower part of the formation, approximately 15 m above the contact with the underlying Sundance Formation. The Morrison Formation varies greatly in thickness but composite sections from Wilborn (2008) propose a total thickness of 53–63 m in this region. While no official member names have been assigned to the Morrison Formation in this area, the quarry is located in Unit 1 of Ostrom’s (1970) stratigraphic system, in the Upper Jurassic. The lithology is a sandy siltstone with calcite cement and swelling bentonitic clay. The matrix used for this experiment was collected during the excavation of large dinosaur fossils. Any rock removed during excavation was collected and processed for microvertebrate fossils.

Results

There were 13,799 g of matrix processed over 48 replicate samples using the paint sieve method. The average percent mass reduction for samples processed using paint sieves was 74.79 % (Table 1). The nested nylon mesh bags had an average reduction rate of 84.35 % over 19 replicate samples and a starting total mass of 9991 g (Table 2). Figure 2 illustrates the comparison in reduced matrix between the two methods.

Discussion

In order for the proposed screenwashing materials to be considered viable alternatives to nested screenboxes they needed to produce significant reduction in the original matrix. There is

<table>
<thead>
<tr>
<th>Original mass</th>
<th>End mass</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>298.84</td>
<td>69.69</td>
<td>76.68</td>
</tr>
<tr>
<td>267.24</td>
<td>79.45</td>
<td>70.27</td>
</tr>
<tr>
<td>285.94</td>
<td>100.22</td>
<td>64.95</td>
</tr>
<tr>
<td>262.70</td>
<td>85.23</td>
<td>67.56</td>
</tr>
<tr>
<td>298.73</td>
<td>53.36</td>
<td>82.14</td>
</tr>
<tr>
<td>298.68</td>
<td>64.06</td>
<td>78.55</td>
</tr>
<tr>
<td>296.53</td>
<td>55.44</td>
<td>81.30</td>
</tr>
<tr>
<td>297.64</td>
<td>55.70</td>
<td>81.29</td>
</tr>
<tr>
<td>285.20</td>
<td>53.52</td>
<td>81.23</td>
</tr>
<tr>
<td>294.62</td>
<td>61.65</td>
<td>79.07</td>
</tr>
<tr>
<td>299.11</td>
<td>60.04</td>
<td>79.93</td>
</tr>
<tr>
<td>299.64</td>
<td>50.64</td>
<td>83.10</td>
</tr>
<tr>
<td>300.01</td>
<td>58.14</td>
<td>80.62</td>
</tr>
<tr>
<td>297.48</td>
<td>59.50</td>
<td>80.00</td>
</tr>
<tr>
<td>297.29</td>
<td>55.99</td>
<td>81.17</td>
</tr>
<tr>
<td>299.25</td>
<td>56.64</td>
<td>81.07</td>
</tr>
<tr>
<td>295.59</td>
<td>68.77</td>
<td>76.73</td>
</tr>
<tr>
<td>281.29</td>
<td>107.38</td>
<td>61.83</td>
</tr>
<tr>
<td>243.37</td>
<td>189.35</td>
<td>22.20</td>
</tr>
<tr>
<td>272.51</td>
<td>62.77</td>
<td>76.97</td>
</tr>
<tr>
<td>299.69</td>
<td>95.08</td>
<td>68.27</td>
</tr>
<tr>
<td>249.38</td>
<td>71.72</td>
<td>71.24</td>
</tr>
<tr>
<td>273.47</td>
<td>97.72</td>
<td>64.27</td>
</tr>
<tr>
<td>277.59</td>
<td>79.74</td>
<td>71.27</td>
</tr>
<tr>
<td>245.52</td>
<td>96.48</td>
<td>60.70</td>
</tr>
<tr>
<td>260.32</td>
<td>77.22</td>
<td>70.34</td>
</tr>
<tr>
<td>254.50</td>
<td>71.14</td>
<td>72.05</td>
</tr>
<tr>
<td>280.20</td>
<td>78.53</td>
<td>71.97</td>
</tr>
<tr>
<td>278.96</td>
<td>98.98</td>
<td>64.52</td>
</tr>
<tr>
<td>296.27</td>
<td>87.33</td>
<td>70.52</td>
</tr>
<tr>
<td>288.82</td>
<td>83.19</td>
<td>71.20</td>
</tr>
<tr>
<td>297.33</td>
<td>89.23</td>
<td>69.99</td>
</tr>
<tr>
<td>286.64</td>
<td>83.97</td>
<td>70.71</td>
</tr>
<tr>
<td>294.23</td>
<td>81.95</td>
<td>72.15</td>
</tr>
<tr>
<td>297.00</td>
<td>73.47</td>
<td>75.26</td>
</tr>
<tr>
<td>296.02</td>
<td>86.58</td>
<td>70.75</td>
</tr>
<tr>
<td>296.25</td>
<td>62.75</td>
<td>78.82</td>
</tr>
<tr>
<td>288.23</td>
<td>57.63</td>
<td>80.01</td>
</tr>
<tr>
<td>288.94</td>
<td>49.89</td>
<td>82.73</td>
</tr>
<tr>
<td>294.79</td>
<td>48.37</td>
<td>83.59</td>
</tr>
<tr>
<td>298.97</td>
<td>50.29</td>
<td>83.18</td>
</tr>
<tr>
<td>298.55</td>
<td>52.54</td>
<td>82.40</td>
</tr>
<tr>
<td>299.71</td>
<td>42.28</td>
<td>85.89</td>
</tr>
<tr>
<td>299.10</td>
<td>56.54</td>
<td>81.10</td>
</tr>
<tr>
<td>299.45</td>
<td>53.27</td>
<td>82.21</td>
</tr>
<tr>
<td>297.57</td>
<td>53.38</td>
<td>82.06</td>
</tr>
<tr>
<td>299.06</td>
<td>49.37</td>
<td>83.49</td>
</tr>
<tr>
<td>291.26</td>
<td>50.76</td>
<td>82.57</td>
</tr>
</tbody>
</table>
approximately 10 kg of original matrix was washed using the nylon bags. 15 kg of original matrix was processed using the paint sieve method, and a fossil vertebrate locality in northern Wyoming, USA. Approximately terrestrial deposit. This material was collected from the Two Sisters 2 Quarry located in the lower part of the Morrison Formation, Upper Jurassic, in northern Wyoming, USA. Bentonitic clay collected from the Morrison Formation, an Upper Jurassic terrestrial deposit. This material was collected from the Two Sisters 2 Quarry, a fossil vertebrate locality in northern Wyoming, USA. Approximately 15 kg of original matrix was washed using the paint sieve method, and approximately 10 kg of original matrix was washed using the nylon bags. A benefit to traditional screenwashing is the volume of matrix that can be processed at one time. Using 5-gallon (20-liter) buckets for soaking matrix, either with nylon bags or paint sieves, drastically reduces the footprint needed for a screenwashing setup. It potentially slows down the rate of washing since one can only use so many buckets at a time, whereas the traditional, larger setup allows for processing in bulk at greater speeds. But if the space is not available, the buckets seem a feasible alternative.

<table>
<thead>
<tr>
<th>Original mass</th>
<th>Fine mass</th>
<th>Coarse mass</th>
<th>Total mass remaining</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>269.8</td>
<td>3.8</td>
<td>27.7</td>
<td>31.5</td>
<td>88.32</td>
</tr>
<tr>
<td>548.7</td>
<td>4.4</td>
<td>64.6</td>
<td>69.0</td>
<td>87.42</td>
</tr>
<tr>
<td>460.0</td>
<td>3.6</td>
<td>54.3</td>
<td>57.9</td>
<td>87.41</td>
</tr>
<tr>
<td>635.9</td>
<td>7.4</td>
<td>121.4</td>
<td>128.8</td>
<td>79.75</td>
</tr>
<tr>
<td>445.9</td>
<td>12.7</td>
<td>78.7</td>
<td>91.4</td>
<td>79.50</td>
</tr>
<tr>
<td>451.0</td>
<td>10.9</td>
<td>59.8</td>
<td>70.7</td>
<td>84.32</td>
</tr>
<tr>
<td>487.0</td>
<td>10.7</td>
<td>72.5</td>
<td>83.2</td>
<td>82.92</td>
</tr>
<tr>
<td>543.6</td>
<td>21.6</td>
<td>73.7</td>
<td>95.3</td>
<td>82.47</td>
</tr>
<tr>
<td>611.2</td>
<td>19.5</td>
<td>95.2</td>
<td>114.7</td>
<td>81.23</td>
</tr>
<tr>
<td>613.9</td>
<td>10.3</td>
<td>80.9</td>
<td>91.2</td>
<td>85.14</td>
</tr>
<tr>
<td>589.5</td>
<td>17.7</td>
<td>71.7</td>
<td>89.4</td>
<td>84.83</td>
</tr>
<tr>
<td>477.0</td>
<td>14.3</td>
<td>21.5</td>
<td>35.8</td>
<td>92.49</td>
</tr>
<tr>
<td>398.6</td>
<td>9.2</td>
<td>37.6</td>
<td>46.8</td>
<td>88.26</td>
</tr>
<tr>
<td>510.0</td>
<td>12.5</td>
<td>37.4</td>
<td>49.9</td>
<td>90.22</td>
</tr>
<tr>
<td>447.4</td>
<td>10.6</td>
<td>56.4</td>
<td>67.0</td>
<td>85.02</td>
</tr>
<tr>
<td>572.0</td>
<td>7.9</td>
<td>46.9</td>
<td>54.8</td>
<td>90.42</td>
</tr>
<tr>
<td>600.9</td>
<td>23.3</td>
<td>142.3</td>
<td>165.6</td>
<td>74.94</td>
</tr>
<tr>
<td>604.9</td>
<td>12.2</td>
<td>72.6</td>
<td>84.8</td>
<td>85.98</td>
</tr>
<tr>
<td>664.6</td>
<td>26.0</td>
<td>160.8</td>
<td>186.8</td>
<td>71.89</td>
</tr>
</tbody>
</table>

Table 2. Results from screenwashing using nylon mesh bags. Matrix masses (Fine and Coarse fractions) were added together, then subtracted from the original. All measurements are in grams.

<table>
<thead>
<tr>
<th>Mass</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>84.35%</td>
<td></td>
</tr>
<tr>
<td>74.79%</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. Comparison of mass reduction between the nylon mesh bags and the paint sieves. The numbers reported are averages from all samples. The original matrix lithology was a sandy siltstone with calcite cement and swelling bentonitic clay collected from the Morrison Formation, an Upper Jurassic terrestrial deposit. This material was collected from the Two Sisters 2 Quarry, a fossil vertebrate locality in northern Wyoming, USA. Approximately 15 kg of original matrix was washed using the nylon bags. A benefit to traditional screenwashing is the volume of matrix that can be processed at one time. Using 5-gallon (20-liter) buckets for soaking matrix, either with nylon bags or paint sieves, drastically reduces the footprint needed for a screenwashing setup. It potentially slows down the rate of washing since one can only use so many buckets at a time, whereas the traditional, larger setup allows for processing in bulk at greater speeds. But if the space is not available, the buckets seem a feasible alternative.

A benefit to traditional screenwashing is the volume of matrix that can be processed at one time. Using 5-gallon (20-liter) buckets means the volume of material that can be washed is determined by the space available for buckets. However, when used for testing localities for viability, soaking the bags in their own individual buckets will prevent cross-contamination and
allow multiple sites to be run simultaneously. The drying time
of the wet matrix is also going to be higher in the paint sieves
and nylon mesh bags than if the boxes were laid out in the sun
simply due to the smaller surface area of the condensed matrix
exposed to the air in the bags. In the field, I would suggest the
bags be opened to allow for more surface area to be exposed
to the air and speed drying time. A workaround for a lab setup
used in this study was to place the wet samples on an elevated
dish drying rack in a surplus fume hood. The hood was placed
in the research area but did not need to be connected to the
building’s air flow. The samples dried overnight, a speed simi-
lar to that of traditional screenboxes, depending on climate.
Any fume hood could be used in such a manner to increase the
speed of drying.

Conclusions

Traditional screenwashing using nested boxes, large containers
for soaking, and spread out areas for drying allows for large
quantities of matrix to be reduced in a short time. However,
there is significant cost associated with the materials needed,
including nylon mesh fabric cut into bags, or the use of paint sieves, could allow those at smaller institutions
to process matrix samples for microvertebrates without a
significant cost or space investment. The nylon mesh bags appear
to be the best at replicating the results achieved with traditional
screenwashing, reducing the matrix by 84.35 %, and are highly
recommended.

Acknowledgements.—Thanks to Rachel Cooke and Marina Reid
(both University of Lynchburg, USA) for help in processing matrix.
Suggestions and comments from Brian Davis (University of Louis-
ville, USA), Laura Henry-Stone (University of Lynchburg, USA), An-
drew B. Heckert (Appalachian State University, Boone, USA), Haviv
Avrahami (North Carolina State University, Raleigh, USA), and Kyle
Davies (Oklahoma Museum of Natural History, Norman, USA) were
very helpful in creation of the manuscript and are much appreciated.
Appreciation is extended to John Foster (Utah Field House of Natural
History, Vernal, USA) and an anonymous reviewer for comments and
revisions. A special thanks to my festschrift co-editors, Brian Davis and
Matt Wedel (Western University of Health Sciences, Pomona, USA).
And thanks go to Richard Cifelli (University of Oklahoma, Norman,
USA) for inspiration. Funding for this project was made available by
the Schewel Student-Faculty Endowed Research Grant.

References


Avrahami, H.V., Heckert, A.B., and Martin, L. 2015. Comparison of nested
sieves, traditional screen boxes, and paint sieves for the recovery of
microvertebrate fossils. Journal of Vertebrate Paleontology 35 (Sup-
plement): 81–82.

Bhat, M. 2017. Techniques for systematic collection and processing of ver-
tebrate microfossils from their host mudrocks: a case study from the
Upper Triassic Tiki Formation of India. Journal Geological Society of
India 89: 369–374.

In: R. Rogers, D. Eberth, and A. Fiorillo (eds.), Bonebeds: Genesis,
Analysis, and Paleobiological Significance, 333–396. University of

associated techniques for the recovery of microvertebrate fossils. In:
R.L. Cifelli (ed.), Techniques for recovery and preparation of mi-
crovertebrate fossils. Oklahoma Geological Survey Special Publica-
tion 94-4: 1–24.

Eberth, D., Rogers, R., and Fiorillo, A. 2008. A practical approach to the
study of bonebeds. In: R. Rogers, D.Eberth, and A. Fiorillo (eds.), Bone-
University of Chicago Press, Chicago.

Foster, J. and Heckert, A.B. 2011. Ichthyoliths and other microvertebrate
remains from the Morrison Formation (Upper Jurassic) of northeast-
ern Wyoming: A screen-washed sample indicates a significant aquatic
component to the fauna. Palaeogeography, Palaeoclimatology, Palaeo-
ecology 305: 264–279.

Grady, F.V.H. 1979. Some new approaches to microvertebrate collecting and

Haiar, B. and Porter, K. 2016. Overall body size as an indicator of ontoge-
etic stage in sauropod dinosaurs. Journal of Vertebrate Paleontology
36 (Supplement): 148.

Heckert, A.B. 2004. Late Triassic microvertebrates from the lower Chinle
Group (Otsischalkian–Adamanian: Carnian), southwestern USA. New

Hibbard, C. 1949. Techniques of collecting microvertebrate fossils. Uni-
mversity of Michigan Contributions from the Museum of Paleontology
8: 7–19.

McKenna, M. 1962. Collecting small fossils by washing and screening.
Curator 5: 221–235.

Miller, B. 1989. Screen-washing unconsolidated sediments for small macro-
Palatechniques. The Palaeontological Society Special Publications 4:
260–263.

Ostrom, J. 1970. Stratigraphy and paleontology of the Cloverly Formation
(Lower Cretaceous) of the Bighorn Basin Area, Wyoming and Mon-

Rixon, A. 1976. Fossil Animal Remains: Their Preparation and Conserva-


Wilborn, B. 2006. Microvertebrate assemblage from a Dinosaur Quarry in
the lower Morrison Formation, Bighorn Basin, Wyoming. Journal of
Vertebrate Paleontology 26 (Supplement): 138–139.

Wilborn, B. 2008. Paleoecology and Stratigraphy of the Morrison and Clo-
Dissertation, University of Oklahoma, Norman.

Wilborn, B. 2009. The use of hydrogen peroxide (H₂O₂) in secondary pro-
cessing of matrix for microvertebrate recovery. Journal of Vertebrate
Paleontology 29 (3): 976–978.

Brooke K. Haiar [haiar@lynchburg.edu], University of Lynchburg, 1501 Lakeside Dr., Lynchburg, VA 24501, USA.

Received 12 October 2021, accepted 7 February 2022, available online 30 March 2022.

Copyright © 2022 B. Haiar. This is an open-access article distributed under the terms of the Creative Commons Attribution License (for details please see http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.