

1 **Pre-print of published version**  
2

3 **Reference:**

4 Nijland, W., Coops, N.C., Coogan, S.C.P., Bater, C.W., Wulder, M.A., Nielsen, S.E., McDermid, G.,  
5 Stenhouse, G.B. (2012), Vegetation phenology can be captured with digital repeat photography and  
6 linked to variability of root nutrition in *Hedysarum alpinum*. Applied Vegetation Science. doi:  
7 10.1111/avsc.12000

8 **DOI**

9 <http://dx.doi.org/10.1111/avsc.12000> (published online: 24 SEP 2012).

10 **Disclaimer:**

11 The PDF document is a copy of the final version of this manuscript that was  
12 subsequently accepted by the journal for publication. The paper has been through  
13 peer review, but it has not been subject to any additional copy-editing or journal  
14 specific formatting (so will look different from the final version of record, which  
15 may be accessed following the DOI above depending on your access situation).

16  
17 **Vegetation phenology can be captured with digital repeat**  
18 **photography and linked to variability of root nutrition in *Hedysarum***  
19 ***alpinum***  
20

21 Wiebe Nijland\*

22 Faculty of Forest Resources Management,  
23 University of British Columbia, 2424 Main Mall, Vancouver, BC, V6T 1Z4, Canada.

24  
25 Nicholas C. Coops

26 Faculty of Forest Resources Management,  
27 University of British Columbia, 2424 Main Mall, Vancouver, BC, V6T 1Z4, Canada.

28  
29 Sean C.P. Coogan

30 Department of Renewable Resources,  
31 University of Alberta, 751 General Services Building, Edmonton, AB, T6G 2H1, Canada

32  
33 Christopher W. Bater

34 Faculty of Forest Resources Management,  
35 University of British Columbia, 2424 Main Mall, Vancouver, BC, V6T 1Z4, Canada.

36  
37 Michael A. Wulder

38 Canadian Forest Service (Pacific Forestry Centre), Natural Resources Canada, 506 West Burnside  
39 Road, Victoria, BC, V8Z 1M5, Canada  
40

41 Scott E. Nielsen,  
42 Department of Renewable Resources,  
43 University of Alberta, 751 General Services Building, Edmonton, AB, T6G 2H1, Canada

44  
45 Greg McDermid,  
46 Foothills Facility for Remote Sensing and GIScience,  
47 Department of Geography, University of Calgary, 2500 University Drive, NW, Calgary, Alberta, T2N  
48 1N4, Canada

49  
50 Gordon B. Stenhouse  
51 Foothills Research Institute, Hinton, Alberta, T7V 1X6, Canada

52  
53 \* corresponding author:  
54 Phone: +1 (604) 827 4429, Fax :+1 (604) 822 9106  
55 email: irss.ubc@wiebenijland.nl

56

## 57 **ABSTRACT**

58 Question: Can repeat (time-lapse) photography be used to detect the phenological development of a  
59 forest stand, and linked to temporal patterns in root nutrition for *Hedysarum alpinum* (alpine  
60 sweetvetch) an important grizzly bear food species?

61 Location: The eastern foothills and front ranges of the Rocky Mountains in Alberta, Canada. The area  
62 contains a diverse mix of mature and young forest, wetlands, and alpine habitats

63 Methods: We deployed six automated cameras at three locations to acquire daily photographs at the  
64 plant and forest stand scales. Plot locations were also visited on a bi-weekly basis to record the  
65 phenological stage of *H.alpinum* and other target plant species, as well as to collect a root sample for  
66 determining crude protein content.

67 Results: Repeat photography and image analysis successfully detected all key phenological events  
68 (i.e., green-up, flowering, senescence). Given the relation between phenology and root nutrition, we  
69 illustrate how camera data can be used to predict the spatial and temporal distribution and quality of a  
70 key wildlife resource.

71 Conclusions: Repeat photography provides a cost effective method for monitoring vegetation  
72 development, food availability, and nutritional quality at a forest stand scale. Since wildlife responds to  
73 the availability and quality of their food resources, detailed information on changes in resource  
74 availability helps with land use management decisions and furthers our understanding of grizzly bear  
75 feeding ecology and habitat selection.

76

77 **1. INTRODUCTION**

78 Seasonal changes in vegetation phenology are critical drivers of food availability and quality for a wide  
79 variety of animal species. Food availability affects large-scale movements in migratory species such  
80 as caribou (Festa-Bianchet et al., 2011; Sharma et al., 2009), as well as the seasonal foraging habits  
81 of species within their home ranges (Nielsen et al., 2003; 2010). This is the case for grizzly bears  
82 (*Ursus arctos*), which are considered generalists with diverse diets that change during the course of  
83 the year. Individual bears may travel large distances to locate high quality food sources (Rogers,  
84 1987) with a diet comprised of seasonally abundant and nutrient rich food (Hamer and Herrero, 1987;  
85 Hamer et al., 1991; Craighead et al., 1995; McLellan and Hovey, 1995; Munro et al., 2006). Within  
86 their remaining range in western Canada, grizzly bears have three distinct foraging seasons:  
87 hypophagia, early hyperphagia, and late hyperphagia (Nielsen et al., 2006). During hypophagia,  
88 grizzly bears feed on the roots of *Hedysarum* spp. (sweetvetch) and other early herbaceous material.  
89 During early hyperphagia, their diet extends to green herbaceous material such as *Heracleum lanatum*  
90 (cow-parsnip) and *Equisetum* spp. (horsetail), while in the later season berries such as *Shepherdia*  
91 *canadensis* (buffalo berry) and *Vaccinium* spp. (huckleberry, blueberry and lingonberry) make up the  
92 majority of their diet. As fruit consumption declines in the fall, grizzly bears once again dig for  
93 sweetvetch roots (Nielsen, 2005; Nielsen et al., 2006; Munro et al., 2006; Nielsen et al., 2010). While  
94 animal matter and insects are an important food resource for grizzly bears during spring and early  
95 summer, the wide variety of vegetable matter, including roots, forbs and fruit, makes up the majority of  
96 their diet from late June through to early October. The amount of animal matter consumed by grizzly  
97 bears can also vary by season (moose and other ungulate calves), distribution and abundance (Munro  
98 et al.2006).

99 In previous work (Bater et al., 2011a,b; Coops et al., 2012) the role of digital cameras in monitoring  
100 vegetation phenology across a range in grizzly bear habitats of Alberta has been demonstrated.  
101 Camera images provide an alternative to traditional assessment of phenology that rely on field  
102 observations, often by seasonal workers, volunteers and amateur naturalists, who record discrete  
103 events such as flowering, leaf emergence, and other characteristics depending on observation goals  
104 and site location (Crimmins et al., 2008; Studer et al., 2007). While these observations are a valuable  
105 source of information, they are limited in spatial coverage, are often based on varying methodologies  
106 and conducted by many observers with different training and skill levels resulting in data  
107 inconsistencies. Repeat photography using ground based cameras (i.e., near sensing (Jongschaap  
108 and Booij. 2004)) to monitor vegetation phenology allows for very fine temporal sampling (e.g., at daily  
109 or hourly intervals) in a consistent and cost-effective manner. In fact, near sensing of vegetation  
110 phenology is dramatically increasing in popularity across a diverse range of disciplines including,  
111 agriculture (Purcell, 2000; Karcher and Richardson, 2003; Zerger et al., 2010), plant ecology (Ide and

112 Oguma, 2010; Graham et al., 2010; Kurc and Benton, 2010) and forestry (Ahrends et al., 2008; Polgar  
113 and Primack, 2011; Sonnentag et al., 2012). However, many of these studies focus on either linking  
114 distributed cameras into networks to follow phenological development at national or continental scales  
115 (Jacobs et al., 2009; Graham et al., 2010; Ide and Oguma, 2010) or observations of a single plant or  
116 plot (Karcher and Richardson, 2003; Sonnentag et al., 2012).

117 By mounting camera systems on towers, trees or platforms, data can be acquired at an intermediate  
118 scale of observation, providing a link between field-based observation methods and satellite derived  
119 estimates (Hufkens et al., 2012). Bater et al.(2011b) confirmed that spectral indices derived from these  
120 camera systems relate significantly to field observations of both the green-up and senescence of  
121 vegetation. with mean absolute differences in residuals between the predicted and observed dates of  
122 green-up and length of growing season reported as four days and six days, respectively. These  
123 measures of vegetation phenology from ground-based cameras also significantly relate to satellite-  
124 derived measures of greenness (Coops et al., 2012).

125 Despite the demonstrated capacity to monitor vegetation phenology remotely, changes in vegetation  
126 greenness detected by cameras do not necessarily directly correspond to other factors affecting use of  
127 those resources such as nutrient quality. For example, in the case of grizzly bears the nutritional  
128 content of *Hedysarum alpinum* (alpine sweetvetch) roots varies significantly throughout the growing  
129 season, with its highest nutritional concentration occurring prior to and during the initial green-up  
130 phase (Hamer et al., 1991; Coogan et al., 2012). Once the above ground biomass component of  
131 *H.alpinum* has reached its peak, corresponding to the mid-point of the growing season, the nutritional  
132 value of the roots substantially decreases when compared to the initial green-up earlier in the season  
133 or senescence in the fall (Coogan et al., 2012). As a result there is a need to link remote sensing  
134 derived observations of greenness to not only vegetation activity, but also to the nutritional value of the  
135 above and below ground components of the vegetation.

136 The main objectives of this study are twofold. First, examine changes in vegetation phenology of key  
137 individual plant species critical to grizzly bear diet using very high spatial resolution digital camera  
138 data. Changes in vegetation phenology (spectral greenness) for individual plants were examined over  
139 a full growing season and compared to phenophase observations of the above ground vegetation  
140 component, as well as to the nutritional content of the below ground roots. The second objective of the  
141 study is to demonstrate if individual species-based models, such as *H.alpinum*, can be scaled up  
142 using stand scale digital camera observations. If these relationships exist, then the distribution and  
143 timing of forage availability can be predicted at broader scales.

## 144 2. METHODS

145 *2.1 Study Area*

146 The focus of this study was the foothills in western Alberta, Canada. The area contains a diverse mix  
147 of mature and young forest, wetlands, and alpine habitats. Three sample sites were located near the  
148 towns of Robb and Cadomin, Alberta (53.2°N; 117.0°W) in order to observe the range of phenological  
149 changes and growing season conditions across known grizzly bear habitat. At each site a pair of  
150 cameras were installed with different fields of view (see camera setup section below), one camera  
151 focused on individual plants (plant scale), while the second camera focused on the forest stand (stand  
152 scale). Details on the sites, their vegetation composition, and location are summarized in Table 1.

153

154 **Table 1:** Characteristics of the camera plot locations

155

<b>Plot</b>	<b>Coordinates [UTM 11N]</b>	<b>Elevation [m]</b>	<b>Vegetation Type</b>
Drinnan Creek	N5894401 ; E465076	1356	Spruce and pine forest
Folding Mountain	N5900474 ; E447823	1139	Spruce forest
Cardinal Divide	N5860769 ; E483439	2025	Alpine meadow

156

157 *2.2 Digital Camera Setup*

158 Six standard commercially available digital camera systems manufactured by Harbortronics (Gig  
159 Harbor, Washington, USA) were installed at the three sites. The camera systems include a Pentax  
160 K100D digital SLR camera mated to an intervalometer. The camera was sealed in a fiberglass case  
161 with a solar panel and lithium ion battery to provide power. At each of the three plots, one camera was  
162 mounted three metres above the ground on a tall and dominant tree and pointed north (as described  
163 in Bater et al., 2011a) with images capturing conditions of the forest stand (Figure 1, right). A second  
164 camera was mounted close to the first camera, but with a reduced field of view (approximately 5 x 5  
165 m) in order to monitor a small number of individual plants (Figure 1, left), hereafter referred to as the  
166 plant scale. To minimize directional effects caused by solar movements, all cameras acquired five  
167 images per day between noon and 13:00 local time at regular intervals. Digital images were archived  
168 as full resolution JPEG files (3008 x 2008 pixels) and ancillary data included a time stamp for easy  
169 reference of date of acquisition.

170



171

172 **Figure 1:** Example images at the plant scale (left) and forest stand scale (right) taken at the Cardinal  
173 Divide site near Cadomin, Alberta. Both images taken at 15 July 2010.

174

### 175 2.3 Field validation, phenophase codes and root nutrition data

176 Two sets of imagery acquired at the three sites provided a range of homogenous understory and  
177 overstorey species-specific regions of interest, observable on the digital camera imagery. All sites  
178 were visited weekly between April and October 2010 to record the phenophase codes (Table 2) of the  
179 vegetation following the practices of Dierschke (1972). In the further analyses we use summarized  
180 phenological scale with pre-leaf: Vegetative  $\leq 4$ , leaf: Vegetative  $\geq 5$ , flower: Reproductive  $\geq 6$ , seed:  
181 Reproductive  $\geq 10$ , and dormant: Vegetative  $\geq 9$  (Table 2). The green-up, flower, and senescence  
182 dates are defined as the first occurrence of leaf, flower and dormant respectively. Observable species  
183 included *Hedysarum alpinum* (alpine sweetvetch), *Shepherdia canadensis* (buffalo berry), *Lathyrus*  
184 *ochroleucus* (cream pea), *Vaccinium vitis-idaea* (lingonberry), *Arctostaphylos uva-ursi* (Bearberry),  
185 and *Dryas octopetala* (mountain avens). In addition to the phenophase observations *H. alpinum* plants  
186 just outside of the observable images were also sampled for nutritional content. In total, 66 samples  
187 were collected and analysed for crude protein content following the procedures described in Coogan  
188 et al. (2012). All protein measurements were normalized as a fraction of the total dry matter. To allow  
189 comparisons between the camera information, phenology data, and root protein data, root samples  
190 were grouped into five phenological stages (pre-leaf, leaf, flower, seed, and dormant).

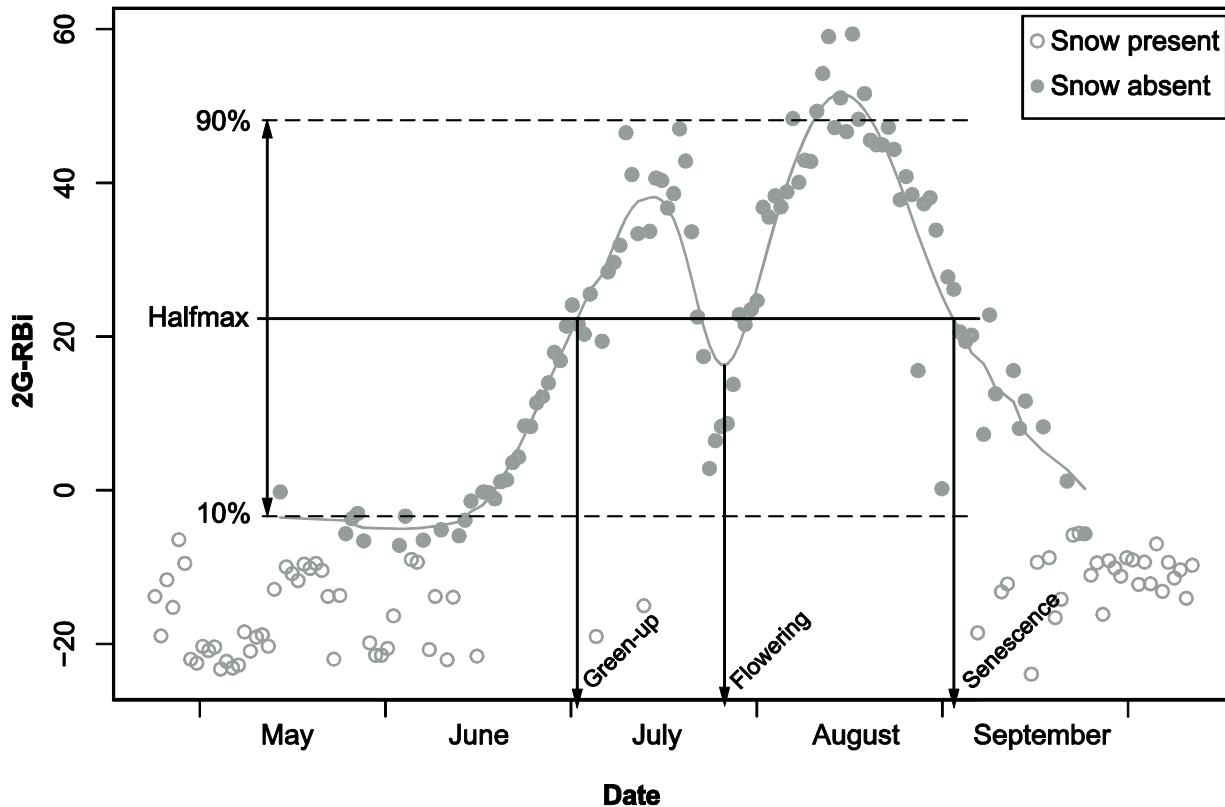
191

192

<u>Vegetative</u>	<u>Reproductive</u>
0. Closed bud	0. Without blossom buds
1. Green leaf out but not unfolded	1. Blossom buds recognizable
2. Green leaf out, start of unfolding	2. Blossom buds strongly swollen
3. Leaf unfolding up to 25%	3. Shortly before flowering
4. Leaf unfolding up to 50%	4. Beginning bloom
5. Leaf unfolding up to 75%	5. Up to 25% in blossom
6. Full leaf unfolding	6. Up to 50% in blossom
7. Stem / first leaves fading	7. Full bloom
8. Yellowing up to 50%	8. Fading
9. Yellowing over 50%	9. Completely faded
10. Dead	10. Bearing green fruit
	11. Bearing ripe fruit
	12. Bearing overripe fruit
	13. Fruit or seed dispersal

194

195



196

197 **Figure 2:** Seasonal metrics calculated from the 2G-RBi time-series from each pixel.

#### 198 *2.4 Image Analysis:*

199 As discussed in Bater et al (2011a), a number of approaches exist to extract phenological information  
200 from a time series of remotely sensed spectral data. Information on key dates, such as green-up and  
201 senescence, has precedence in the literature (e.g. Waring et al., 2006). In our case, to extract the  
202 phenological response from the image sequences, the five images collected each day were averaged  
203 into a single daily scene to reduce the effects of differential exposure and shading in the images.  
204 These daily averages were then filtered a 4 x 4 mean kernel to reduce data volumes and the effects  
205 plant parts moving in the time between images caused by plant growth or more notably wind.  
206 In order to extract a single spectral index indicative for vegetation activity from the blue, green and red  
207 spectral channels we calculated the 2G-RB index (Richardson et al., 2007), hereafter noted as 2G-  
208 RBi. The 2G-RBi compares the green channel of the RGB image to the red and blue channels to  
209 derive excess greenness corrected for illumination differences:

$$210 \quad 2G\_RB_i = 2\mu_G - (\mu_R + \mu_B), \quad [1]$$

211 where  $\mu_G$ ,  $\mu_R$  and  $\mu_B$  are the camera observed brightness values (image DN) in the green, red and  
212 blue channels, respectively. All images where snow was present in the scene were removed from  
213 further analysis and a smoothing spline with rigidity of 2/3 was fitted to the 2G-RBi data for each pixel  
214 similar to that of Richardson et al. (2009). Key dates from the fitted spline were then extracted  
215 including date of green-up, end of season, and flowering of the *H.alpinum* (Figure 2). To do so, green-  
216 up was defined as the first date the greenness was higher than that pixels robust halfmax (90<sup>th</sup>  
217 percentile – 10<sup>th</sup> percentile / 2); senescence was defined as the last date the greenness was higher  
218 than that pixels robust halfmax. The robust halfmax was chosen above a standard halfmax or inflexion  
219 point to account for the greater amount of scattering present in the by-pixel data as opposed to  
220 analysis of averages over larger pre-defined areas. The halfmax is commonly used to detect the dates  
221 of start of season in camera (Richardson et al., 2009, Bater et al., 2011a), or satellite based phenology  
222 detection (Schwartz et al., 2002) Flowering of *H.alpinum* was detected as a local minimum in the  
223 greenness curve between the green-up date and the end of season. This minimum is caused by the  
224 pink flowers of *H.alpinum* that have a negative 2G-RBi.

#### 225 *2.5 Landscape forage quality*

226 Based on the derived relationship between phenological development and root protein content of  
227 *H.alpinum* we inferred the nutritional value available in the stand as derived from a time-series of the  
228 stand scale photographs. The clearly outstanding colour of the pink *H.alpinum* flowers allows for  
229 detection of this species over the stand, as the flowers have a negative greenness value. The

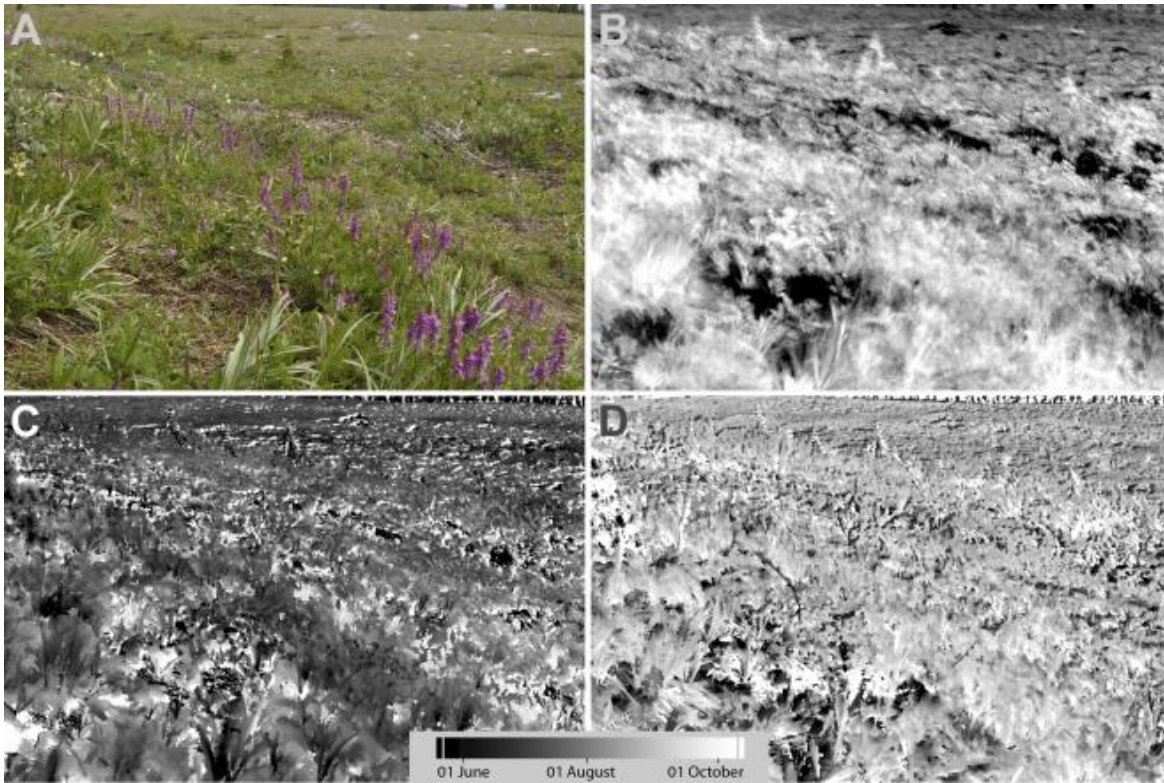


230 detected flowers are buffered in a 25 pixel radius excluding any bare areas to create a mask of  
231 *H.alpinum* plants. The area within this mask was used to derive the phenological development of  
232 *H.alpinum* through the growing season and the dates of green-up, flowering, and senescence for this  
233 species. The phenological events for *H.alpinum* as detected by the camera system is linked to  
234 underground root nutrition by the temporal relation between root crude protein content and  
235 aboveground phenology (Coogan et al., 2012). Repeat photography provides information on both the  
236 location of the species of interest (*H.alpinum*) and the timing of phenological events. The combination  
237 of the development and location provides insight in the availability of high quality forage on a  
238 landscape scale.

### 239 **3. RESULTS**

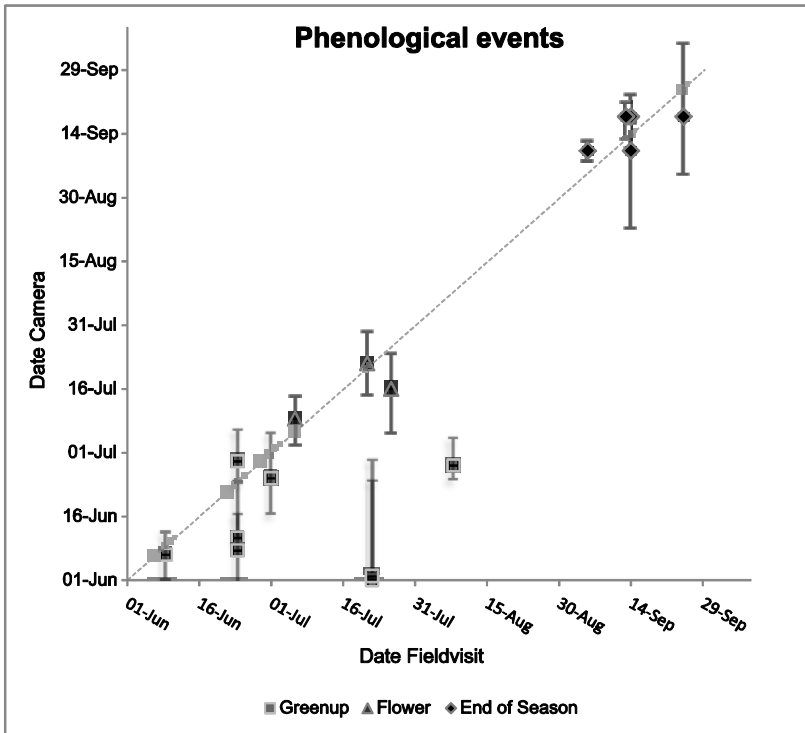
240 Approximately 850 images were obtained from each camera covering the period from mid-April to mid-  
241 October. Figure 3(A) provides an example of a typical field of view at the plant scale during flowering  
242 of *H.alpinum*. The image clearly shows the leaf structure and flowers of the plant. The 2G-RBi image  
243 is shown in Figure 3(B) with white areas indicative of very green vegetation and darker areas showing  
244 non-vegetated scene components. The derived start and end of growing season images are shown in  
245 Figure 3(C) and (D) respectively.

246 Camera-derived dates of phenological events and the field observed dates are strongly correlated ( $r^2$   
247 = 0.89,  $p < 0.01$ ,  $N=16$ ), except for evergreen ericaceae shrubs (e.g., *V. vitis-idea*, *A. uva-ursi*) which  
248 did not exhibit easily detectable changes in phenology or greenness and show up as clear outliers  
249 below the 1:1 line (Figure 4). The relationship between the field measured phenophase and the  
250 protein content of *H.alpinum* is shown in Figure 5, and demonstrates the reduction in protein content  
251 while plants are actively growing. The pre-leaf phenological stage had the highest nutritional value  
252 while the flower and seed phenophases had the lowest nutritional values. Also apparent is the high  
253 nutritional load of the below ground component when the species are dormant, and the variability of  
254 root protein across the 3 sites.



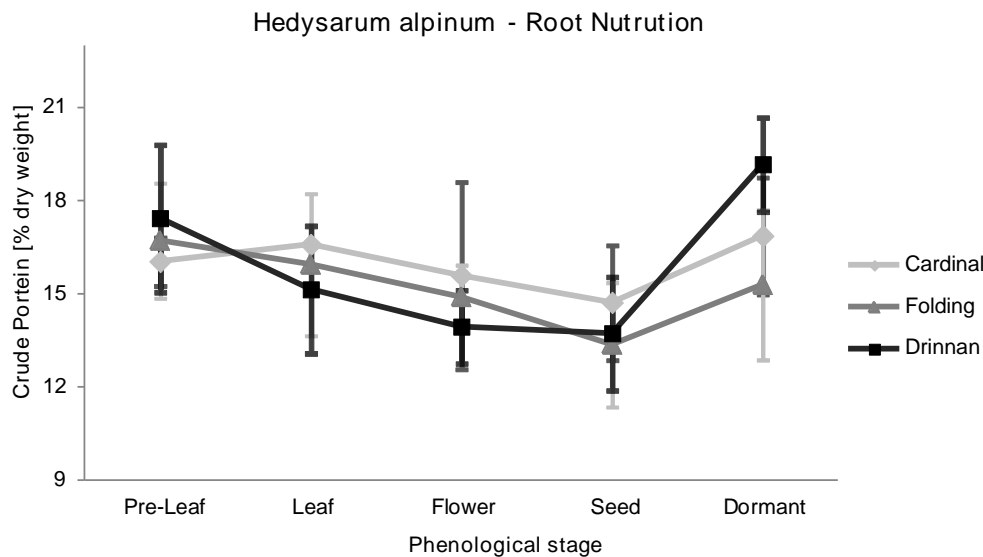
255

256 **Figure 3:** Examples of phenology camera data, A) RGB image, B) 2G-RB index image, C) Green-up,  
 257 D) Senescence.



258

259 **Figure 4:** Dates of major phenological events as observed in the field and as derived from the camera  
 260 spectral response ( $R^2 = 0.89$ ,  $p < 0.01$ ,  $n=16$ ), whiskers show the first and third quartiles for the  
 261 camera derived dates, the dashed line represents 1:1.  
 262



263  
 264 **Figure 5:** Average crude protein content of *H. alpinum* roots sampled in three locations in west-central  
 265 Alberta, Canada in different phenological stages. Error bars are 1 standard error above and below the  
 266 mean. Based on data from Coogan et al. (2012).  
 267

### 268 3.1 Landscape forage quality

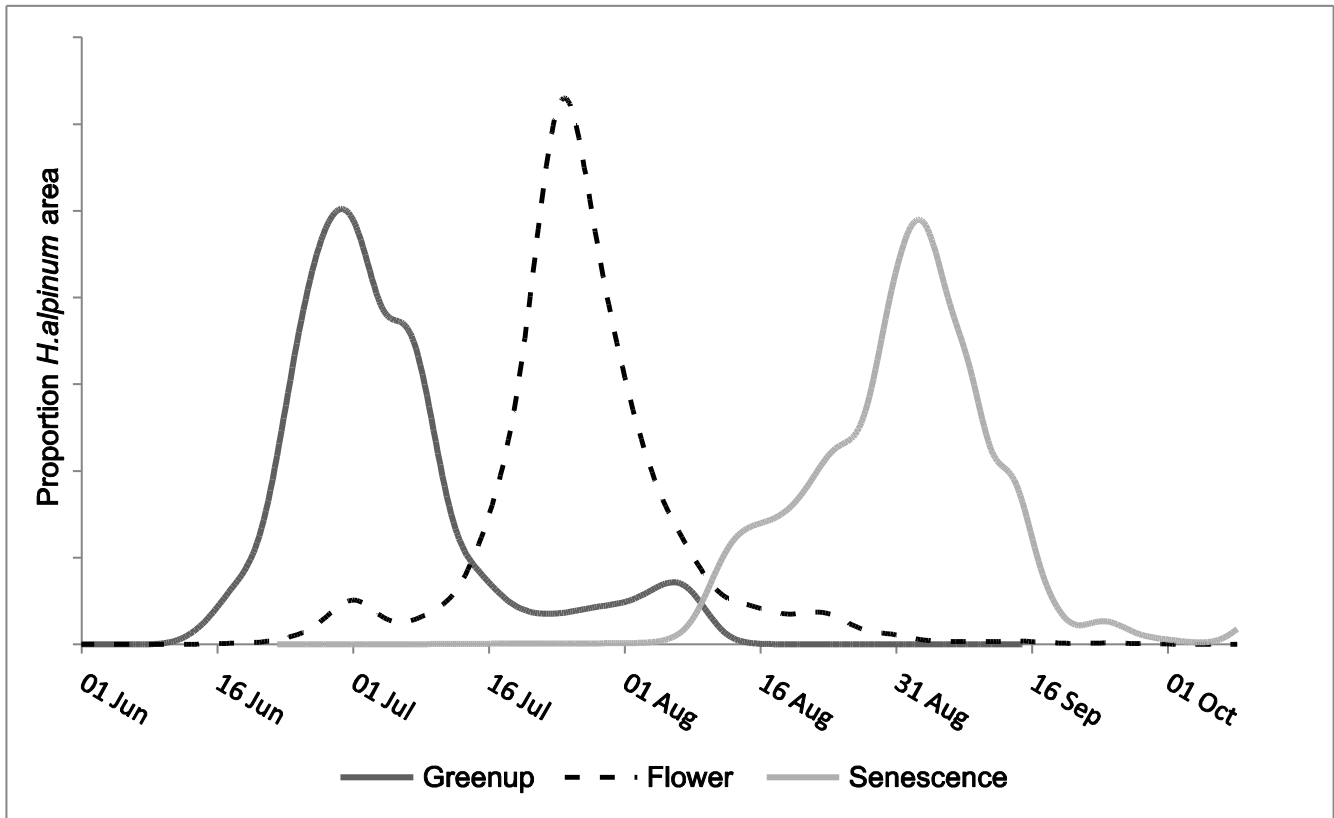
269 Based on a time series of images at the forest stand scale, we detected both the spatial distribution  
 270 and phenological development of *H. alpinum*. Figure 6 shows a forest stand scale photograph at the  
 271 Cardinal divide site with areas marked in pink representing the area of *H. alpinum* plants. The temporal  
 272 patterns of major phenological events in the cells containing *H. alpinum* are shown in Figure 7. Green-  
 273 up starts halfway through June with the peak of growth two weeks later. Flowering lasts approximately  
 274 three weeks, between mid-July and the first part of August. The decline of greenness starts around  
 275 mid-August with all aboveground components senesced by mid-September.



276

277 **Figure 6:** Spatial pattern of presence of *H.alpinum*, masked in pink for the stand scale image  
278 collection at Cardinal Divide near Cadomin, Alberta.

279



280

281 **Figure 7:** Histograms of Green-up, Flowering, and Senescence for *H.alpinum* from the Cardinal Divide  
 282 stand scale camera perspective.

283

#### 4. DISCUSSION

284 While broad scale patterns in phenology can provide an overall assessment of available food  
 285 resources and inter-annual changes in forest productivity, a key limitation of working at this scale is  
 286 the inability to detect subtle or species specific phenological events which occur at the temporal and  
 287 spatial scale at which animals perceive their environment and are critical for food modelling (Nielsen et  
 288 al., 2003; 2010). In this paper we use two sets of cameras configured to capture imagery at the plant-  
 289 and forest stand scale. This paired design allowed the precise timing of initial leaf unfolding and the  
 290 development of fruits to be observed and subsequently linked to the nutritional value of the  
 291 belowground food resource. Placing cameras in close proximity to plants offers the advantage of  
 292 continuous data and possibly reduced frequency of field visits for collection of phenological data  
 293 (phenophase monitoring). This study confirms that ground-based cameras can be employed to  
 294 simultaneously monitor phenology of multiple plant species within the image footprint, and that images  
 295 capturing different scales can be linked with landscape assessments of vegetation nutrition. The  
 296 phenological development of *H.alpinum* indicates that high protein roots were available before the  
 297 start of July and again after the end of August (Coogan et al., 2012). This pattern corresponds well



298 with root consumption patterns as observed in grizzly bear feces (Munro et al., 2006) and GPS  
299 telemetry data on habitat selection (Coogan et al., 2012) which show most root consumption in late  
300 April to June, and resuming from August to October.

301 From a wildlife management and monitoring point of view, we believe it is the linking of figures 5 and 7  
302 in this work which provide the greatest insights. Whilst there is considerable variability around the root  
303 nutritional value at the sampled sites (initial high nutritional value, followed by a reduction at flowering  
304 and seed, and an increase again at dormancy), the pattern of nutritional status throughout the season  
305 is similar to many understory species. Most of these species allocate greater resources above ground  
306 for reproduction at certain times of the year, thereby reducing resources below ground and at other  
307 times, with few above ground resources to support at pre-leaf and dormant stages, the below ground  
308 component of the vegetation gains comparatively more resources and thus nutrient content. This  
309 pattern of below ground nutrient availability is the inverse of the camera observable greenness, and  
310 thus the link is an inverse one for forest managers. The portion of the scene shown in Figure 7 at each  
311 of the key, above ground phenological phases, can essentially be inversely multiplied by the nutritional  
312 value in Figure 5 to provide a landscape estimate of the nutrient carrying load of this specific  
313 vegetation type for wildlife. In this example at Cardinal divide, nutritional availability for food is highest  
314 between June 1st - July 1st (before maximum green-up) and after August 15th (during senescence).  
315 The capacity to provide explicit dates of when these maximum nutritional load events occur across the  
316 landscape is of significant benefit to managers as it provides key time periods when bear activity in  
317 these areas is most likely, or conversely least likely, to occur due to root forage quality and availability.  
318 While other food sources, and management activities, will of course also impact bear movements and  
319 locations, this information provides one key perspective on the overall bear landscape. Multiple  
320 cameras, at multiple sites, characterising the key bioclimatic zones across the region would, when  
321 combined, provide a region-wide bear forage availability map which could be updated in real time and  
322 provide an immediate perspective on the nutritional load for the bears within this area.

323 For the stand scale detection of forage availability, improvements can be made to the current camera  
324 setup. Because the cameras have a highly oblique view, only part of the image frame can be used for  
325 a reliable detection of phenological development in individual species. In areas far from the camera  
326 position, the spatial resolution is reduced. The potential to install the cameras with a field of view  
327 closer to nadir would decrease perspective issues as well as potentially provide better separation  
328 between taller and adjacent lower vegetation. However, such a setup would require a higher mounting  
329 point for the cameras and possibly installation on a mast or structure other than a tree which would  
330 increase deployment costs and reduce the area observed.

331 As this study demonstrates, unique challenges remain for detecting phenological events in evergreen  
332 species. Evergreen species show a less pronounced response in camera measured greenness and  
333 are therefore not reliably identified by the current system. An improved detection of the phenology of  
334 evergreen species may be provided by a modified camera system that detects changes in near  
335 infrared reflection which is known to be highly sensitive to changes in vegetation activity.

## 336 **5. CONCLUSIONS**

337 In this paper we describe a system and approach to detect the phenological development of individual  
338 plant species from daily camera images at both a plant and forest stand scale. The phenological  
339 development of certain species is closely linked with the nutritional value of above and belowground  
340 parts of these plants, and therefore the availability of high quality forage for grizzly bear. The use of  
341 repeat photography provides a cost effective way to assess vegetation development and food  
342 availability at a forest stand scale, improving information availability for management of bear habitat  
343 and as a tool for increasing our understanding of grizzly bear feeding ecology.

## 344 **ACKNOWLEDGEMENTS**

345 Sam Coggins (University of British Columbia) and David Laskin (University of Calgary) were members  
346 of the deployment team. Andrew Richardson (Harvard University) and Scott Ollinger (University of  
347 New Hampshire) provided initial advice and enthusiasm for the network plans. Funding for this  
348 research was generously provided by the Grizzly Bear Program of the Foothills Research Institute  
349 located in Hinton, Alberta, Canada, with additional information available at: [www.foothillsri.ca](http://www.foothillsri.ca).

350

## 351 **REFERENCES**

- 352 Ahrends, H.E., Brügger, R., Stöckli, R., Schenk, J., Michna, P., Jeanneret, F., Wanner, H., Eugster, W., 2008.  
353 Quantitative phenological observations of a mixed beech forest in northern Switzerland with digital  
354 photography. *Journal of Geophysical Research* 113, 1–11.
- 355 Bater, C., Coops, N.C., Wulder, M.A., Hilker, T., Nielsen, S., McDermid, G., Stenhouse, G.B., 2011a. Using digital  
356 time-lapse cameras to monitor species-specific understorey and overstorey phenology in support of wildlife  
357 habitat assessment. *Environmental Monitoring and Assessment* 180, 1-13.
- 358 Bater, C., Coops, N.C., Wulder, M.A., Nielsen, S.E., McDermid, G., Stenhouse, G.B., 2011b. Design and  
359 installation of a camera network across an elevation gradient for habitat assessment. *Instrumentation Science  
360 & Technology* 39, 231-247.
- 361 Coogan, S.C.P., Nielsen, S.E., Stenhouse, G.B., 2012. Spatial and Temporal Heterogeneity Creates a “Brown  
362 Tide” in Root Phenology and Nutrition. *ISRN Ecology* 2012, 618257.

363 Coops, N.C., Hilker, T., Bater, C., Wulder, M.A., Nielsen, S.E., McDermid, G., Stenhouse, G.B., 2012. Linking  
364 ground-based to satellite-derived phenological metrics in support of habitat assessment. *Remote Sensing*  
365 *Letters* 3, 191-200.

366 Craighead, J.J., Sumner, J.S., 1995. The grizzly bears of Yellowstone.

367 Crimmins, T.M., Crimmins, M. a., David Bertelsen, C., 2009. Flowering range changes across an elevation  
368 gradient in response to warming summer temperatures. *Global Change Biology* 15, 1141–1152.

369 Dierschke, H., 1972. On the recording and presentation of phenological phenomena in plant communities.  
370 English translation of: Zur Aufnahme und Darstellung phänologischer Erscheinungen in Pflanzengesellschaften.  
371 Translated by R.E. Wessell and S.S. Talbot. 1970 International Symposium for Vegetation Science., The Hague.

372 Festa-Bianchet, M., Ray, J., Boutin, S., Côté, S., Gunn, A., 2011. Conservation of caribou (*Rangifer tarandus*) in  
373 Canada: an uncertain future. *Canadian Journal of Zoology* 89, 419–434.

374 Graham, E.A., Riordan, E.C., Yuen, E.M., Estrin, D., Rundel, P.W., 2010. Public Internet-connected cameras used  
375 as a cross-continental ground-based plant phenology monitoring system. *Global Change Biology*.

376 Hamer, D., Herrero, S., 1987. Grizzly bear food and habitat in the front ranges of Banff National Park, Alberta,  
377 in: Zager, P. (Ed.), *Proceedings of 7th International Conference on Bear Research and Management*.  
378 International Association of Bear Research and Management, Williamsburg, Va, U.S.A and Plityice Lakes,  
379 Yugoslavia, February and March 1986., pp. 199–213.

380 Hamer, D., Herrero, S., Brady, K., 1991. Food and habitat used by Grizzly Bears, *Ursus arctos*, along the  
381 Continental Divide in Waterton Lakes National Park, Alberta. *Canadian Field Naturalist* 105, 325-329.

382 Hufkens, K., Friedl, M., Sonnentag, O., Braswell, B.H., Milliman, T., Richardson, A.D., 2012. Linking near-surface  
383 and satellite remote sensing measurements of deciduous broadleaf forest phenology. *Remote Sensing of*  
384 *Environment* 117, 307-321.

385 Ide, R., Oguma, H., 2010. Use of digital cameras for phenological observations. *Ecological Informatics* 5, 339-  
386 347.

387 Jacobs, N., Burgin, W., Fridrich, N., Abrams, A., Miskell, K., Braswell, B., Richardson, A.D., Pless, R., 2009. The  
388 Global Network of Outdoor Webcams: Properties and Applications, in: *Networks*. ACM International  
389 Conference on Advances in Geographic Information Systems, Seattle, WA, pp. 111-120.

390 Jongschaap, R.E.E., Booij, R., 2004. Spectral measurements at different spatial scales in potato: relating leaf,  
391 plant and canopy nitrogen status. *International Journal of Applied Earth Observation and Geoinformation* 5,  
392 205–218.

393 Karcher, D.E., Richardson, M.D., 2003. Quantifying turfgrass color using digital image analysis. *Crop Science*  
394 943-951.

395 Kurc, S. a., Benton, L.M., 2010. Digital image-derived greenness links deep soil moisture to carbon uptake in a  
396 creosotebush-dominated shrubland. *Journal of Arid Environments* 74, 585–594.

397 McLellan, B.N., Hovey, F.W., 1995. The diet of grizzly bears in the Flathead River drainage of southeastern  
398 British Columbia. *Journal of Zoology/Revue Canadienne de*.

399 Munro, R.H.M., Nielsen, S., Price, M.H., Stenhouse, G.B., Boyce, M., 2006. Seasonal and Diel Patterns of Grizzly  
400 Bear Diet and Activity in West-Central Alberta. *Journal of Mammalogy* 87, 1112-1121.

401 Nielsen, S., 2005. Habitat Ecology, Conservation, and Projected Population Viability of Grizzly Bears (*Ursus*  
402 *arctos* L.) in West-Central Alberta, Canada. *Habitat*.

403 Nielsen, S., Boyce, M., Stenhouse, G.B., Munro, R.H.M., 2003. Development and testing of phenologically  
404 driven grizzly bear habitat models. *Ecoscience* 10, 1–10.



405 Nielsen, S., McDermid, G., Stenhouse, G.B., Boyce, M., 2010. Dynamic wildlife habitat models: Seasonal foods  
406 and mortality risk predict occupancy-abundance and habitat selection in grizzly bears. *Biological Conservation*  
407 143, 1623-1634.

408 Nielsen, S., Stenhouse, G.B., Boyce, M., 2006. A habitat-based framework for grizzly bear conservation in  
409 Alberta. *Biological Conservation* 130, 217–229.

410 Polgar, C. a, Primack, R.B., 2011. Leaf-out phenology of temperate woody plants: from trees to ecosystems. *The*  
411 *New phytologist* 191, 926-41.

412 Purcell, L.C.C., 2000. Soybean canopy coverage and light interception measurements using digital imagery.  
413 *Crop Science* 40, 834-837.

414 Richardson, A.D., Braswell, B.H., Hollinger, D.Y., Jenkins, J.P., Ollinger, S.V., 2009. Near-surface remote sensing  
415 of spatial and temporal variation in canopy phenology. *Ecological Applications* 19, 1417-1428.

416 Richardson, A.D., Jenkins, J.P., Braswell, B.H., Hollinger, D.Y., Ollinger, S.V., Smith, M.L., 2007. Use of digital  
417 webcam images to track spring green-up in a deciduous broadleaf forest. *Oecologia* 152, 323–334.

418 Rogers, L.N., 1987. Effects of food supply and kinship on social behavior, movements, and population growth of  
419 black bears in northeastern Minnesota. *Wildlife Monographs* 51, 1-72.

420 Sharma, S., Couturier, S., Côté, S.D., Cote, S.D., 2009. Impacts of climate change on the seasonal distribution of  
421 migratory caribou. *Global Change Biology* 15, 2549–2562.

422 Sonnentag, O., Hufkens, K., Teshera-Sterne, C., Young, A.M., Friedl, M., Braswell, B.H., Milliman, T., O’Keefe, J.,  
423 Richardson, A.D., 2012. Digital repeat photography for phenological research in forest ecosystems. *Agricultural*  
424 *and Forest Meteorology* 152, 159-177.

425 Schwartz, M.D., Reed, B.C., White, M.A., 2002. Assessing satellite-derived start-of-season measures in the  
426 conterminous USA. *International Journal of Climatology* 22, 1793–1805.

427 Studer, S., Stöckli, R., Appenzeller, C., Vidale, P.L., 2007. A comparative study of satellite and ground-based  
428 phenology. *International Journal of Biometeorology* 51, 405–414.

429 Waring, R.H., Coops, N.C., Fan, W., Nightingale, J.M., 2006. MODIS enhanced vegetation index predicts tree  
430 species richness across forested ecoregions in the contiguous U.S.A. *Remote Sensing of Environment* 103, 218-  
431 226.

432 Zerger, a., Viscarra Rossel, R. a., Swain, D.L., Wark, T., Handcock, R.N., Doerr, V. a. J., Bishop-Hurley, G.J., Doerr,  
433 E.D., Gibbons, P.G., Lobsey, C., 2010. Environmental sensor networks for vegetation, animal and soil sciences.  
434 *International Journal of Applied Earth Observation and Geoinformation* 12, 303-316.  
435