Big dairy data to disentangle the effect of geo-environmental, physiological and morphological factors on milk production of mountain-pastured Braunvieh cows

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1
2
1. Summary

3 The transhumance system, which consists in moving animals to high mountain pastures during summer,
4 plays a considerable role in preserving both local biodiversity and traditions, as well as protecting against
5 natural hazard. In cows, particularly, milk production is observed to decline as a response to food shortage
6 and climatic stress, leading to atypical lactation curves that are barely described by current lactation
7 models. Here, we relied on five million monthly milk records from over 200,000 Braunvieh and Original
8 Braunvieh cows to devise a new model accounting for transhumance, and test the influence of
9 environmental, physiological, and morphological factors on cattle productivity. Counter to expectations,
10 environmental conditions in the mountain showed a globally limited impact on milk production during
11 transhumance, with cows in favourable conditions producing only 10% less compared to cows living in
12 adverse conditions, and with precipitation in spring and altitude revealing to be the most production-
13 affecting variables. Conversely, physiological factors as lactation number and pregnancy stage presented
14 an important impact over the whole lactation cycle with 20% difference in milk production, and may
15 therefore alter the way animals respond to transhumance. Finally, the considered morphological factors
16 (cow height and foot angle) presented a smaller impact during the whole lactation cycle (10% difference in
17 milk production). The present findings can help farmers to establish sustainable strategies for alleviating
18 the negative effects of transhumance on productivity and preserving this important livestock practice.
19
20
2. Introduction

21
22 Transhumance, which consists in moving livestock to high mountain pastures in the summer months,
23 provides both ecological and socio-cultural services to the human populations living in the mountainous
24 regions of many European countries[1–3]. Indeed, transhumance-annexed grazing sustains and preserves
25 endemic plant communities [4], feed local cattle to produce traditional alpine cheese, and attract many
26 tourism-related activities [5]. Further, it counteracts land abandonment in mountain areas and therefore
27 contributes preserving landscape against scrubs growth and vegetation encroachment [6], as well as natural

28 hazards such as avalanches [7] and wild fires [5]. The term "alping" (a translation of the German word
29 "Alpung" or its French equivalent "montée à alpage") will be used here to describe the approximately 100
30 days that dairy cattle spend on alpine pastures during the summer months. Similarly, animals brought to
31 mountain pastures will be referred to as "alped" cows, and the alpine summer pastures will be called
32 "alps".
33
34 Despite such ecological and social benefits, the surface dedicated to alping decreases each year (~2400 ha
35 per year [8]), and a questionnaire-based study revealed in 2010 that one third of the participating breeders
36 intend to probably abandon the transhumance practice in the following decades. In summer 2018, 107'000
37 dairy cows were alped in Switzerland during approximately 100 days [9]. A steep drop in milk production
38 is observed during this period, which hampered the evaluation of lactation curves through standard models
39 that assume a linear decrease in production [10] after the maximum milk yield is reached (i.e. ~100 days
40 after calving) [11]. Among the explanations proposed to interpret such a detrimental effect on productivity
41 are the food deficit intake due to the meagre grassland as found in high alpine pastures, as well as the need
42 to tackle environmental stress due to new and sometimes harsh habitat conditions [12]. On the other hand,
43 milk composition is known to change during alping [13,14] and results in the production of highly valuable
44 milk products such as butter and alp cheese.
45
46 Milk production and quality is notoriously affected by a wide variety of environmental factors, including
47 calving season, vegetation types composing animals' diet [15–18]. Environmental temperature is also
48 known to directly affect cattle productivity because of heat [17] or cold [19] stress. Furthermore milk
49 quality and production of alped cows are expected to be indirectly affected by global warming, as forage
50 quality and biomass productivity of alpine sites are likely to decrease with increasing temperature and
51 decreasing precipitation [20,21].
52
53 Despite the existence of huge databases storing monthly milk records for several European cattle breeds,
54 no effort has been produced so far (at least to our knowledge) to exploit such an information and
55 understand the ways alping affects milk productivity [22]. Indeed, most of the existing literature focuses on
56 small experiments (with sample size <100) mainly restricted to compare two groups of animals in different
57 environmental conditions, so as to investigate the potential effects of altitude [23], vegetation type [23,24],
58 supplemental feeding [25,26], calving season [27] or breed [12,27,28]. Furthermore, no adaptation of
59 general model of lactation curves [11] have been proposed to account for alping, which hinders a
60 straightforward comparison of lactation curves for alped cow. Last but not least, the overall impact of
61 environmental factors and global warming on milk production during alping is also still unknown.
62
63 For these reasons, a better understanding and characterisation of the impacts of transhumance on milk
64 production and the way production is influenced by environmental factors is needed. To fill this gap, we
65 relied on over five million monthly test-day milk records collected between 2000 and 2015 from more than
66 200,000 Braunvieh cows, a local Swiss cattle breed well adapted to the alpine pastures. Then, we used this
67 information to: 1) devise a new mathematical model to fit lactation during alping; and 2) investigate the
68 influence of environment on milk production, together with the effect of physiological and morphological
69 factors on milk production during alping. This can be achieved thanks to biogeoinformatics which takes
70 advantage of geo-referenced animal data in order to link biological and environmental information with the
71 help of advanced informatics tools [29].
72

3. Data

74
75 *Milk records and animal information*
76 Milk records from all alped Braunvieh cows were provided for the period 2000-2015 by the Braunvieh
77 Schweiz AG breeding association. Importantly, a direct comparison with non-alped cows was impossible
78 due to data unavailability, but milk measurements of alped cows entailing records from both the lowland
79 farm and the alp, enabled the estimation of milk production in both situations. The full dataset is composed
80 of 5,681,498 test day records (methods A4 and AT4 according to ICAR-Guidelines [30]), including
81 616,081 lactations derived from a total of 245,313 cows. In line with national and international rules, milk
82 records are taken approximately on a monthly basis, with the first record taken between the 5th and 42nd day

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83   after calving. Each test day record included information on the following traits: Milk (kg), Fat (kg and %),
84   Protein (kg and %), somatic cell count (1000 cells/ml), but our study specifically focused on milk
85   production in terms of quantity (milk yield). Out of the total number of records, 1,481,387 were taken in
86   the alps, whose altitude were systematically stored in the database, while their precise location were
87   documented in 95% of the cases (Fig. 1). The first record in the alp is usually taken within the first four
88   days after arrival, and is followed by three more records in the alp to encompass the entire alping period
89   (typically 100 days). Moreover, to morphologically describe animals, linear type description and
90   classification of cows are scored during the first lactation of all cows of the database. In our study we
91   considered the body height at withers and the scores (1-9) for foot angle. In addition, insemination data for
92   each lactation (date, sire's name) are also available.

93

94   A stringent data quality control procedure was applied prior to analysis to remove: 1) incomplete years
95   (which resulted in removing beginning of 2000 as well as end of 2015 due to missing lactation records); 2)
96   cows with average interval between first and last insemination longer than 100 days (as computed over the
97   first three lactations); 3) cows that had their first calf while being younger than two years, or older than
98   four years; 4) cows belonging to breeds different from the Braunvieh or Original Braunvieh; 5) cows with
99   parents other than Braunvieh or Original Braunvieh; 6) lactations shorter than 270 days; 7) lactations with
100   calving interval shorter than 290 days; 8) lactations with alps below 1100 meters above sea level (masl) or
101   above 2600 masl; 9) lactations with calving happening between March and August; 10) lactations from
102   cows that had already calved more than nine times; 11) lactations with the first record taken after the 42nd
103   day after calving; 12) lactations with records taken before calving; 13) records taken before the 5th day and
104   after the 500th day after calving; 14) the second alping season (i.e. final part of lactation curves) from
105   animals that are alped twice in the same lactation. After filtering, we obtained a final dataset composed of
106   3,527,138 records over 371,696 lactations from 175,474 cows.

107

108   *Factors influencing milk characteristics*
109   Milk characteristics are known to be influenced by different factors. Meaningful predictor variables were
110   then selected according to literature review, by assuming the same factors to be relevant in both lowland
111   and mountain conditions. As a result, climatic and environmental indices [19,31] were taken into account
112   together with physiological (lactation number, pregnancy stage [32,33]) and morphological factors (Table
113   1).

114

115   *Climatic data*
116   Climate has been observed to influence milk production [34]. Consequently, maximum and mean
117   temperature [23] as well as daily rainfall [24] were extracted from the meteoswiss Grid-Data products
118   database. This dataset is derived by interpolation of records from several weather stations across
119   Switzerland, and consists of 2km-resolution raster files (1km-resolution from the year 2014 and on).
120   Further, daily average wind speed and relative humidity were obtained from respectively 440 and 495
121   meteoswiss weather stations. We then interpolated these values between stations to obtain a continuous
122   representation of the variables, with a squared inverse-distance weighting (IDW) [35] within a maximum
123   distance of 50 km.

124

125   On the basis of such environmental data, the Temperature Humidity Index (THI) and Cold Stress Index
126   (CSI) were computed following Bryant et al. [19], in particular::

127

128    $$THI = 0.8T + \left(RH/100 \cdot (T - 14.4) \right) + 46.4 \qquad (1)$$

129

130   with *T* being maximum daily temperature [°C] and *RH* the relative humidity [%], and

131

132    $$CSI = \left(11.7 + (3.1 \cdot WS^{0.5}) \right) \cdot (40 - T) + 481 + 418 \cdot \left(1 - e^{-0.04 \cdot rain} \right) \qquad (2)$$

133
134 with *WS* being the wind speed [m/s], *T* the mean daily temperature [°C] and *rain* precipitation [mm]. These
135 indices were computed over a 3- and 30-day period to account for short/long heat waves/cold spells,
136 respectively.
137
138 *Digital Elevation Model*
139 Due to the coarse spatial resolution of temperature data (2-km), a correction of -0.45°C/100m (i.e. the
140 observed temperature gradient in the dataset) was applied to account for local variation in temperature due
141 to topography. This correction was achieved using both the Digital Elevation Model DHM25 dataset
142 produced by swisstopo [36] and the recorded altitude of the alp available in the dataset. The digital model
143 DHM25 is a tridimensional representation of the earth's surface in Switzerland, as based on the elevation
144 data from the Swiss National Map 1:25,000 (NM25). A symmetric 25-m grid matrix model is then
145 interpolated starting from the digitized contour lines and spot heights from NM25. Comparisons among
146 control points shows an average accuracy of the produced model of 2-3 m for the pre-Alps and Alps,
147 respectively.
148
149
150 *Biogeographical Region*
151 The Federal Office for Environment (FOEN) divided Switzerland into six biogeographical regions [37],
152 obtained using fauna and flora data and aggregating areas with common species. Species distributions
153 being strongly related to the relief, these regions reflect in fact the topography of the country. Most of the
154 alps hosting Braunvieh cows appear to be located in the Northern and Eastern Alps biogeographical
155 regions. More rainfall occur in the Northern Alps when compared to the Eastern side (Fig. 1), because the
156 mountain chain act as a barrier to precipitations coming from the West and North [38].
157

4. Methods

159
160 *Lactation curve modelling*
161 A lactation curve is usually estimated from one single cow with repeated observations along a lactation
162 cycle and with records taken on a daily/weekly basis [11]. Here, test-day milk records were collected
163 monthly, making the individual-based estimates of lactation impossible because of the small number of
164 observations with regards to the number of parameters to estimate, particularly when describing a complex
165 curve like the one of alped cows. Therefore, we analysed several animals at a time by taking the average
166 milk production for a given Day In Milk (DIM, or number of days after calving). Records from cows
167 remaining at the lowland farm during the alping season (between the 15th of May and the 31st of August)
168 were excluded from this average computation, while only cows at the lowland farm were considered in the
169 average outside this time frame. Moreover, cows were grouped according to their calving month. Finally,
170 when fitting the curve, each averaged milk yield was weighted according to the number of observations on
171 that day.
172
173 Several models have been proposed to describe lactation curves [39], with the Wood, Wilmink, Ali-
174 Schaeffer (AS) and Legendre polynomial formulations being the most popular [40]. Among these
175 mathematical formulations, Wilmink proposes a linear equation that is retained in the present work given
176 its inherent simplicity and good performance [40]. This model is written as:
177
178 $$Y_t = a + b \cdot e^{-k \cdot t} + c \cdot t \qquad\qquad (3)$$
179
180 where Y_t is the observed variable (milk yield), t is the DIM, and a, b, c and k are the parameters to
181 estimate. However, k is usually set to 0.1 to make this equation linear [40].
182
183 Here, we introduce additional terms to Eq. 3 in order to explicitly account for the transhumance effect.
184 Particularly, alping has been observed to severely affect milk production, with alped animals showing a
185 steeper linear decrease than before alping (Fig. 2). Further, alped cows usually experience a small yet rapid
186 boost shortly after their return to the lowland farm, followed by a softer decline in milk production.
187 Tacking these observations into account, we then propose to adapt Eq. 3 as follows:

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189
$$Y_t = a + b \cdot e^{-k \cdot t} + c \cdot t + d \cdot max(0, t - t_1) + f \cdot max(0, ceiling\ (t - t_2)/305) + g \cdot max(0, t - t_2)$$
190 (4)
191
192 Where t_1 is the DIM at which the cow is alped, and t_2 is the DIM at which the cow is brought back to the
193 lowland farm. Importantly, the expression $d*max(0,t-t_1)$ is the expected linear decrease during alping, so
194 that the d-parameter reflects the effect of alping. The $f*max(0,ceiling(t-t_2)/305$ captures the expected boost
195 in production after alping and $g*max(0,t-t_2)$ represents the linear decrease in milk yield after alping; in the
196 latter arguments, the max() term ensures the model to be only affected during and after alping respectively,
197 while the ceiling expression (i.e. round to the upper integer) constructs a binary operator (0/1) to recreate
198 the instantaneous boost after the return to the lowland farm. In our case, t_1 and t_2 were determined
199 independently for each calving month. The proposed equation only works for a standard lactation period of
200 305 days.
201
202 The d-parameter enables the estimation of the loss in milk yield associated with alping over a given period
203 of time. Indeed, the amount of milk lost during alping for a period of x days can be approximated with
204
205 $$Y_{loss} = \frac{d \cdot x^2}{2}$$ (5)
206
207 However, it is essential that the model fits well the beginning of the curve for this equation to work, which
208 can be achieved by artificially increasing the weight of point measurements before the transhumance.
209 Thus, weights before alping were multiplied by 100 when investigating the d-parameter depending on the
210 calving month (Fig. 2 and 3). Furthermore, as older cows tend to calf later in the season, thereby creating a
211 correlation between lactation number and calving month, the impact of alping according to the calving
212 month is entangled with lactation number. Therefore, when examining milk production and the impact of
213 alping for each calving month, only cows in their first lactation are considered (Fig. 3).
214
215 Ordinary linear regression models were then computed in R using the lm() function of the stats package
216 [41] to estimate parameters in Eq. 4.
217
218 *Measuring the effect of influencing factors*
219 For sake of interpretation, all influencing factors (i.e., explanatory variables) were grouped into
220 environmental, physiological and morphological categories (Tab. 1). The effect of influencing factors was
221 tested by comparing milk records produced in conditions as dissimilar as possible. Importantly, since the
222 low number of measurements per animal imposed the use of averages, effect determination was not
223 possible through classical regression models. Consequently, groups were created according to the first and
224 third tertile of the distributions, in order to include animals from the most contrasted situations
225 (environmental, physiological and morphological) while retaining enough observations to guarantee a
226 sufficient statistical power. Since productivity is known to be optimized with mild weather conditions [34],
227 exceptions were made for THI and CSI where the second and the third tertiles were used as the two
228 contrast groups instead of the first and third tertile.
229
230 Group membership was assessed through the creation of a dummy variable assuming the value of 1 if
231 belonging to the group considered, 0 otherwise. Then, the impact of influencing factors was computed by
232 adding an interaction term to Eq. 4 that allows chosen parameters to vary as a function of the group. The
233 here defined environmental variables affect milk production during the alping stay only. Accordingly,
234 lactation curves were modelled only until the end of the alping season (meaning the f and g parameters not
235 to be estimated), with the sole d-parameter varying as a function of the group. In contrast, physiological
236 and morphological factors influence the whole lactation cycle, so that all terms of Eq. 4 (coefficients a, b,
237 c, d, f and g) are allowed to vary as a function of the group.

238
239 Within-group production was estimated both at the lowland farm and in the alps for physiological and
240 morphological factors or during alping season only for environmental factors, by integrating the area under
241 the lactation curve. The between-group difference was then assessed by computing the percentage of the
242 difference in milk production with respect to the reference group, this group being arbitrarily chosen as the
243 one with the highest milk production during alping. The difference in the d-parameter (Δd) between the
244 two groups is then also displayed to show how differently the concerned groups were impacted by alping.
245 As the response differs according to the calving months, results were computed for each calving month
246 separately and the months of September and February were chosen as representative of autumn and winter
247 calving, respectively.
248
249 *Significance testing*
250 Log-likelihood ratio tests were performed to investigate both the impact of adding the parameters d, f and g
251 to the Wilmink model, and of the considered influencing factors. When testing the addition of parameters
252 d, f and g to the Wilmink equation, Eq. 3 and 4 were considered as null and alternative models,
253 respectively; when testing the influencing factors, the null model was constructed by removing the
254 interaction between the dummy variable group and the parameters of Eq. 4.
255
256 The resulting G-score test-statistics were then converted into p-values, which were further corrected for
257 multiple testing by means of the Bonferroni's approach [42]. G-scores were evaluated using the lrtest()
258 function from the lmtest R-package [43].
259

5. Results

261
262 *Lactation curve modelling*
263 Overall, the proposed equation fit both the drop in milk production due to alping and the tail of the
264 lactation curve, as illustrated here for the calving months of September and February (Fig. 2). In particular,
265 the terms added to the Wilmink equation (Eq. 4) significantly increase the full model performance (p-
266 value$<10^{-16}$). In the case of autumn calving (Fig. 1a), the proposed equation fits the entire lactation cycle.
267 For winter calving (Fig. 2b), the beginning and the end of the transhumance season appear to be the most
268 challenging periods to be fitted because of a non-linear slope. The use of Eq. 5 can be illustrated with the
269 autumn calving, with a d-parameter of -0.08, which is translated by a loss of 144 kg over 60 days.
270
271 Total milk production and milk production during alping is reported for the calving months of September
272 and February (Fig. 3). For the sake of comparison among months, only cows in their first lactation are
273 considered in this graph, as lactation number and calving month are correlated. Cows calving in autumn
274 produce on average 6033 kg during their first lactation, among which 1320 kg are produced in the alp. In
275 contrast, total milk production turns out to be lower for cows calving in winter (5155 kg during their first
276 lactation), while milk production during alping is increased (1755 kg). The d-parameters for the two
277 calving seasons being markedly different (-0.08 and -0.02 for autumn and winter calving respectively)
278 indicates that productivity is more impacted by alping when calving occurs in autumn than when occurring
279 in winter.
280
281 *Effect of influencing factors*
282 The significance of the interaction between the group variable and the d-parameter is reported (Sup. Mat.
283 S1). Hereunder, only factors with at least one calving month having a significant Δd (i.e. a significantly
284 different impact of alping between the two contrast groups) are presented.
285
286 Among environmental conditions, THI, spring precipitation, biogeography and altitude turned out to show
287 a significant effect on milk production during alping (Fig. 4a-l). Particularly, precipitation in spring and the
288 biogeographical region showed the most important difference on milk production during alping, followed
289 by altitude and altitude difference. Further, calving period appears to interact with environmental
290 conditions, with bigger differences between groups being present in autumn.
291

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292 The effect of environmental factors are small compared to those of physiological factors, where the biggest
293 effect is found for pregnancy stage for winter calving with a difference in milk production during alping of
294 20%. Although third and higher lactation cows produce more milk during the whole lactation cycle
295 including alping (Fig. 4m), they also appear to be more impacted by alping than the first lactation cows as
296 highlighted by negative Δd-values (Fig. 4o). The influence of pregnancy stage appears to affect milk
297 production during alping, especially for cows calving in autumn (Fig 4p and 4r). Further, higher cows
298 and/or with steeper foot angle produce more milk both before and during alping than lower ones with
299 gentle foot angle (Fig. 4s, t, v, w). However, alping appears to negatively impact such cows, especially
300 higher ones (Fig. 4u and 4x).
301
302

303 # Discussion
304
305 *The importance of calving season*
306 The proposed model succeeded in quantifying the impact of alping on milk production by assuming a
307 Wilmink pattern for cows experiencing the same conditions (Fig.2; [40]). As expected, total milk
308 production resulted globally higher for cows with alping occurring at the end of the lactation, since the
309 drop in production happens later in the cycle. Anyway, winter calving might still be financially attractive
310 for farmers since milk produced in the alps will have a higher economic value on the market and
311 productivity will be higher during alping (Fig. 3).
312
313 Calving season also influences the way an animal is prompt to respond to environmental stress, with a
314 greater impact of transhumance (i.e. greater d-parameter in absolute value) for cows calving in autumn and
315 therefore alping at the end of their lactation cycle. Increased feed intake is known to have distinct effects
316 on milk production depending on the lactation stage [44], and from what we observe it appears that milk
317 production at the end of the lactation cycle is more sensitive to environmental changes. Similarly, when
318 studying the effect of the considered factors, we showed that the between-group difference in milk
319 production during alping is almost always greater for autumn calving.
320
321 *Effect of the environment and climate change*
322 Climate change requires species to adapt quickly to new and extreme climatic conditions [45]. In this
323 context, cattle survival and annexed services for humans are threatened because of the low adaptive
324 potential observed for industrial breeds [46]. In Switzerland, climatic conditions are becoming hotter and
325 dryer [47], which exhorts to better understand the effects of climate on cattle welfare and production both
326 at farms and during transhumance. Here, we observe a sensible negative effect of precipitation in spring
327 (Fig 4e-f), probably because of their influence on forage growth [31]. Interestingly, heat waves (which are
328 known to highly affect cattle productivity [48]) were found to have minimal impact on milk production
329 during alping, probably because temperatures at high altitude rarely reach problematic thresholds.
330 Similarly, cold spells seem to have an almost negligible influence (Sup. Mat. S1). The observed effect of
331 biogeographical regions on production can be explained by the difference in spring precipitation between
332 such regions (158mm/month versus 98mm/month for the Northern flank and the Eastern part,
333 respectively). Altitude confirmed its effect on productivity [23], being intrinsically connected with climatic
334 conditions and vegetation type.
335
336 *Effect of physiological and morphological factors*
337 Lactation number has long been known to strongly influence milk production [49], and this also holds for
338 milk production during alping (Fig 4m-o). Even more important, pregnancy stage was found to have a
339 significant impact on milk production during alping, especially when calving occurs in autumn (Fig. 4p-r).
340 In order to optimize milk yield, cows are generally inseminated a few months after calving, to reach a time
341 span of one year between lactation cycles, implying pregnancy stage not to be considered in lactation
342 models to avoid strong collinearity with calving season [15,16]. However, correlation among these

343 variables was not extreme in the present case (r^2=0.8), most likely because of unsuccessful inseminations
344 leading some cows to delay pregnancy. These results must be interpreted with care, as cows with an early
345 pregnancy are prone to fertility problems

347 Many recent research effort focused on increasing yield in cattle, leading to augmented cattle size [50] but
348 disregarding important side-effects such as the loss of adaptive traits through genetic erosion [51]. This
349 phenomenon might become deleterious for transhumance. For instance, despite showing higher productive
350 performances even at alping, higher cow appear to be more impacted when moved to high mountain
351 pastures (Fig. 4s-u). As for foot angler, steep angle is associated with a smaller risk of developing hoof
352 diseases [52]. Cows with steeper foot angle were observed to produce more milk both in lowland farm and
353 during alping, but this factor appears to be have limited on the d-parameter (Fig. 4v-x).

355 *Limitations*
356 Traditionally, lactation modelling is performed on an individual basis, and usually relies on daily or weekly
357 milk records [53]. Here, we based our work on a database composed of monthly milk records, which
358 required the transformation of the data into daily averages over thousands of cows to avoid over-
359 parameterisation in the model. This averaging might have diluted the strength of the effect we investigated.

361 Moreover, the proposed approach still misses validation, which could be achieved by relying on individual
362 observations recorded daily or weekly and belonging to different breeds from the one used here.

364 Next, the amount of observations among calving months was not constant in the dataset, which possibly
365 made the estimates from the winter months less robust. Further, a hidden age effect – as older cows tend to
366 calf later in the season– could have biased the observed differences in milk productions among groups.

368 Last but not least, the model does not explicitly take into account cow feeding during alping, which is
369 likely to affect milk production [24]. Indeed, the use of concentrate feeding varies among alps and among
370 cows of the same alp. Particularly, differences in milk yield with different calving season could be globally
371 influenced by varying concentrates feeding, with cows at an early stage in the lactation cycle – and thus
372 producing a substantial amount of milk – potentially receiving more concentrates.

6. Conclusion

377 Transhumance is a traditional farming practice which supports the preservation of both agricultural
378 biodiversity and the socio-cultural heritage of human communities. Nevertheless, a loss in productivity is
379 typically linked with alped livestock, which might discourage farmers from pursuing transhumance and
380 poses its beneficial side-effects on ecosystems under threat. Here, we combined biological, geo-
381 environmental and computer science tools to better understand the influence of environmental,
382 physiological and morphological factors on milk productivity during transhumance. We relied on high
383 resolution meteorological data and five millions georeferenced monthly milk records as collected from
384 over 200,000 Braunvieh cows in Switzerland. We show that both environmental and morphological factors
385 have limited influence on animal production, with dry conditions in spring being nevertheless the most
386 affecting environmental factor. This evidence suggests that animal production during transhumance might
387 become even more insecure in future years due to climate change, and stress therefore the urgency of
388 devising strategies to protect this practice. On the other hand, physiological factors such as lactation
389 number, pregnancy stage have strong impact on milk production during the whole lactation cycle.

Ethical Statement
No ethical statement to declare.

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397
398 **Funding Statement**
399
400
401 **Data Accessibility**
402 The data was provided from the Braunvieh-CH association, under the explicit conditions that it will not be shared nor used for
403 other studies. However, a partial dataset is available with the average milk production during alping from 20000 cows, together
404 with lactation information (calving date, lactation number) and environmental data at the location of alping. Cows were chosen
405 randomly, with equal number of animals per year, lactation number and calving month. Furthermore, researchers interested in
406 performing studies on these data may contact directly the association (see contact information homepage.braunvieh.ch).
407 The code used for this article is available at https://github.com/SolangeD/lactModel
408
409 **Competing Interests**
410 We have no competing interests.
411
412 **Authors' Contributions**
413 SD performed most of the analyses with the help of AB. CF and SJ supervised the work. SD wrote the first draft of the article and
414 all authors contributed in improving this draft.
415
416
417

418 # References

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5. Authors. Year. Title. *Abbreviated Journal title* **Volume**, page range. (doi)

6. Authors. Year. Title. *Abbreviated Journal title* **Volume**, page range. (doi)

Tables

Table 1

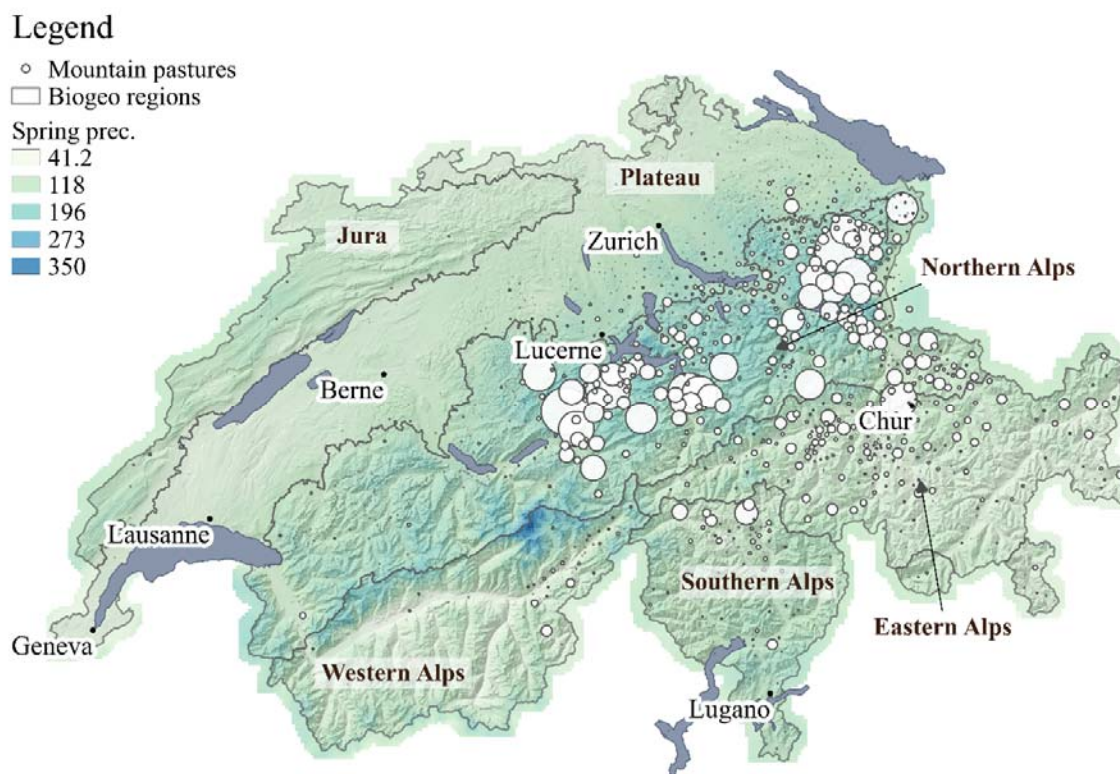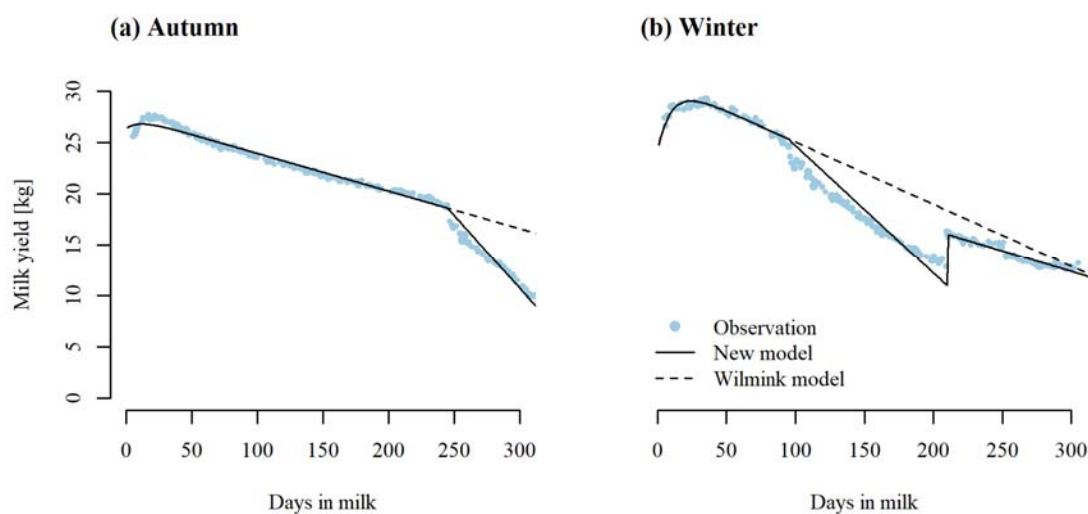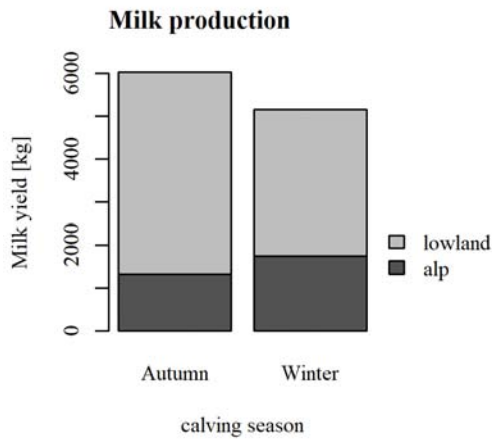|	Name	Description	Group cut-off
Environmental	Temperature Humidity Index (3 days)	Climatic index based on temperature and humidity, averaged over 3 days before milk record at the alp. See section on climatic data	59.4-65.4 / >65.4
	Temperature Humidity Index (30 days)	Climatic index based on temperature and humidity, averaged over 30 days before milk record at the alp. See section on climatic data.	59.6-63.1 / >63.1
	Cold Stress Index (3 days)	Climatic index based on temperature, wind speed and precipitation, averaged over 3 days before milk record at the alp. See section on climatic data.	960.1-1045.9 / >1045.9
	Cold Stress Index (30 days)	Climatic index based on temperature, wind speed and precipitation, averaged over 30 days before milk record at the alp. See section on climatic data.	997-1042.9 / >1042.9
	Spring precipitation	Average monthly precipitation [mm] between April and July; computed for each year, at the location of each alp.	<120.6 / >155.3
	Biogeographical region	Only regions with sufficient sample size were retained, and therefore two categorical variables were created. See section on biogeographical regions. .	North Alp / East Alp
	Altitude	Altitude [m] of the highest alp during the lactation cycle	<1600 / >1900
	Altitude difference	Difference in altitude between the highest alp and the lowland farm.	<641 / >1021
	Aspect 100m	Aspect of the alp (North/South facing) as based on 100m-resolution DEM.	300-60 / 120-240
	Aspect 1km	Aspect of the alp (North/South facing) as based on 1km-resolution DEM.	300-60 / 120-240
Physiological	Lactation number	Number of lactations the cow experienced since birth (correlated with animal age).	1st lact / ≥3rd lact
	Pregnancy stage	Pregnancy stage [days] at the beginning of alping.	<73 days / >153 days
Morphological	Height of animal	Height at withers [cm]	<139 / >143
	Foot angle	A note between 1 and 9 (with 9 being the steepest).	<4 / >6

Figures

Legend

- ○ Mountain pastures
- ▢ Biogeo regions

Spring prec.
- 41.2
- 118
- 196
- 273
- 350

Plateau

Jura

Zurich

Northern Alps

Lucerne

Berne

Chur

Lausanne

Southern Alps

Geneva

Eastern Alps

Western Alps

Lugano

Fig. 1

(a) Autumn

(b) Winter

- ● Observation
- —— New model
- --- Wilmink model

Milk yield [kg]

Days in milk

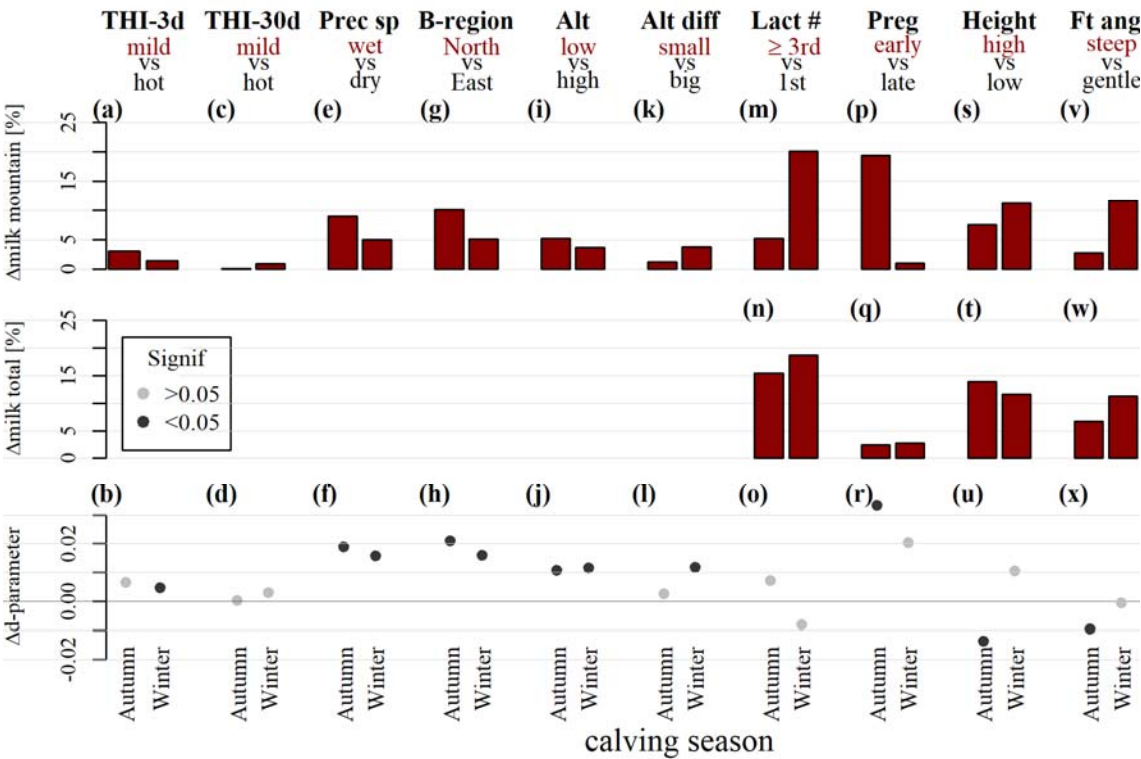Days in milk

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Figure 3

Figure 4

Figure and table captions

Table 1: List of factors included in the present study with supposed influence on lactation during alping. Factor-specific cut-off values are reported in the last column. These values are used to assess factor-specific effects on lactation (see Methods for an exhaustive explanation).

Figure 1: Geographic location of the alps hosting Braunvieh cows (white circles), with average monthly precipitation in mm between April and July 2015 in the background (chosen as example year). Frontiers of biogeographical regions are also reported. The size of the circles is proportional to the number of milk records taken at a given alp. The majority of the alps hosting Braunvieh cows are located in Northern and in the Eastern Alps biogeographical regions.

Figure 2: Lactation curves as derived from the proposed model (full line) and the Wilmink model (dashed line) for cows that calved in September (a) and February (b). The Wilmink model was fitted using points from the beginning of the curve only, i.e. before alping. . Each dot represents the average of milk records per day. When t>245 (a) and between 95 and 210 (b), records from the alp only are used to calculate the average, whilst records from the lowland farm only are included for the remaining time frame.

Figure 3: Milk production during alping (black) and from the lowland farm (grey) is reported for autumn and winter calving, as represented by the months of September and February, respectively. Only cows in their first lactation are considered here.

Figure 4: The effect of influencing factors is tested by investigating the difference in productivity between two groups of animals coming from contrasted conditions (first and third tertiles, except for THI where second and third tertile are chosen). Each factor is here reported in a separate column. At the top of each column, the factor name as well as the contrasted groups are reported; the group with highest milk yield during alping is chosen as the reference group, highlighted in red. In each barplot, the first bar shows the result for autumn calving, and the second for winter calving. The between-group difference in milk production during alping is displayed in the top panel, the between-group difference in milk production during the whole lactation in the intermediate panel, the change in the d-parameter at the bottom. The Δd-parameter indicates how the reference group is impacted by alping compared to the other group, with positive values meaning lower negative impact (see Eq. 4). Significant Δd values are plotted in black, while grey indicates non-significance. Environmental factors affects production during alping only, making a comparison of the whole milk production redundant (which is why no graph is present in the intermediate panel of the concerned variables). To facilitate the understanding of this graph, the example of lactation (Lact #) is detailed here, where we refer to cows in their third or higher lactation as third lactation cows: third lactation cows produce 5% more milk during alping than first lactation cows when calving in autumn and even 20% more when calving in winter (m). When considering the whole lactation, third lactation cows produce 15% more milk than first lactation cows when calving in autumn and 19% when calving in winter (n). Third lactation cows calving in autumn are slightly less negatively impacted by alping (positive Δd) than first lactation cows; an inverse behaviour is observed for winter calving, although both relationships are not significant (o). THI: Temperature Humidity Index, as averaged over 3 (THI-3d) or 30 (THI-30d) days. Prec sp: precipitation in spring. B-region: biogeographical region. Alt (diff): (difference in) altitude, lact #: lactation number, Preg: pregnancy stage, height: height at withers and ft ang: foot angle.